BUILDING RESEARCH AND DOCUMENTATION

CONTRIBUTIONS AND DISCUSSIONS AT THE FIRST CIB CONGRESS, ROTTERDAM, 1959, EDITED BY THE INTERNATIONAL COUNCIL FOR BUILDING RESEARCH, STUDIES AND DOCUMENTATION - CIB

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ELSEVIER PUBLISHING COMPANY

1961 AMSTERDAM - LONDON - NEW YORK - PRINCETON

Library of Congress Catalog Card Number 61-14941

With 278 figures and 46 tables

PRINTED IN THE NETHERLANDS BY

N.V. DRUKKERIJ D. REIDEL, DORDRECHT

Preface

The present book contains selected chapters on ten different subjects that were included in the programme of the first Congress of CIB, held in September 1959 in Rotterdam, the Netherlands.

The reports that were presented in advance to the participants in that Congress are all included in this book together with concise accounts of the discussions at the Congress.

The accomplishment of the editorial task by the General Secretariat of CIB has been greatly facilitated by the valuable assistance of staff of the British Building Research Station and by the extensive collaboration of the staff of Bouwcentrum, the Netherlands.

Thanks may also be expressed to the publisher of the present book whose cooperative efforts have been an indispensable element in its completion.

J. DE GEUS
General Secretary of CIB.

Rotterdam, July 1961

Introduction

J. VAN ETTINGER,
President of the first CIB Congress

In 1959 it fell to me, as President of the International Council for Building Research, Studies and Documentation – CIB, to preside at the first Congress of this organization held at Rotterdam.

It is now my great pleasure to introduce this book which may be considered a direct result of the said Congress; a great pleasure because I am of the opinion that the 44 reports which constituted the basis of the Congress and on which the contents of this book are also based can be a valuable contribution to the aim which concerns us all, either consciously or unconsciously, the aim to achieve a habitable world.

Although it is not possible to calculate in an exact way the building consequences, involved in the assumption that the world must be habitable for everybody e.g. in the year 2000, it seems nevertheless important to fix the order of magnitude in order to throw light on the scope of the task to be accomplished. Calculations, based on certain estimates, I have made earlier have brought me to the conclusion that of the 1958 stock of 500 million dwellings only 100 million need not be replaced before the year 2000, when the need will have grown out to 1100 million dwellings. This leaves us with the task to build 1000 million dwellings before the year 2000. (From "Towards a Habitable World" by J. van Ettinger, published by Elsevier Publishing Company, Amsterdam, 1960.)

Obviously a balanced development of our human society cannot be achieved by building dwellings alone, but there is a vast additional task with regard to the construction of other buildings, such as schools, hospitals, churches, factories, etc., as well as in the domain of what might be termed as public works and services. The total volume of building required can in terms of money be estimated at 2.5 times the required house-building.

BUILDING RESEARCH

To achieve this aim means a lot of building research, a rational transmission of knowledge on the basis of objective, practical and active building documentation. In these respects considerable arrears must be made up; it is remarkable to note what a small proportion of building output is devoted to building research. Whereas in the aircraft industry for instance up to 10 per cent and in the pharmaceutical industry up to 5 per cent of production is devoted to research and development, in the sphere of planning, building, housing and civil engineering this figure lies between 0.1 and 0.2 per cent in some countries, and in many countries it is even lower or non-existent. In these figures no allowance is made, of course, for what is being done in industry in the way of research with respect to specific materials that benefit building and other branches of industry.

If we consider it reasonable that in building and civil engineering 1 per cent of the production should be spent on research and development, the capacity of research, documentation and development will, expressed in terms of money, have to grow from 100 million dollars which is roughly the amount now spent on this work, to 1.500 million dollars in 1999 *,

* 1% building capacity in 1999 equals 3.000 million dollars if the gross investments in building and civil engineering are estimated to be 300 milliard dollars in that year. Assuming that 50 per cent of this amount would be spent in industry, 1500 million would correspond to the 100 million dollars mentioned above.

an increase of fifteen times in a few generations. Especially in the first ten years, this increase will have to be very fast to enable the rapidly increasing building capacity to be used to maximum effect.

Apart from the basic problems, research for planning, building and civil engineering can be subdivided into three categories. The first category, which at the same time determines the manner in which the other problems are tackled, relates to functional research. This should be taken as the starting point if it is desired to direct building research to the ultimate aim: improvement of the functioning of our society on behalf of the individual, the family and the community. Here we are not interested primarily in the buildings as such, but rather in the way in which they function. In this connection the notions "function" and "functioning" should be interpreted in their widest sense.

The second category that can be distinguished relates to technical research into the best possible technical realisation of the functional requirements to be fulfilled by buildings. The technical realisation itself involves a number of small- and largescale organisation problems, *i.e.* management problems, which constitute the third category. All these three are interdependent.

BUILDING DEVELOPMENT

There is little sense in research work as such if it is not followed by a direct or indirect improvement of the product to which the research relates. This is particularly difficult in the building industry, where so much uncoordinated activity takes place and unity can only be sought prior to production (with the principal) and after production (in the finished product).

Many buildings are prototypes, which as a rule are not followed up with series production. There is no continuity in the development.

With complicated production problems no improvement of any kind can be obtained quickly without systematic development work.

Systematic development work at the same time prevents the research work being split up into a number of small subjects, which on the face of it would not appear to be interrelated. Systematic development work therefore leads to unity in research activities. There is never full value from extensive development work, however, unless standardisation, mass production and repetition are accepted. It is only in this way that a well thought out development cycle can be achieved, which can lead to rational production and a high living value of our buildings.

TRANSMISSION OF BUILDING KNOWLEDGE

There is an important matter, however, which must not be overlooked, *viz.* transmission of knowledge. Without transmission of knowledge rapid development is impossible, because the right knowledge and experience cannot then find their way to the right place at the right time. In our present-day world with its increasing differentiation and specialisation, transmission of knowledge is becoming more and more a factor of importance. Without exaggeration, the development of an efficient system of transmission of knowledge is one of the most important basic problems of our time, inseparably bound up with research and development.

Essentially, transmission of knowledge means bridging the gap between science and practice.

Already in the national sphere this is a many-sided problem because it implies overcoming all kinds of resistance and leading the constantly increasing flood of knowledge into proper channels.

In the international sphere the additional difficulty is that of overcoming differences in language and behaviour between nations and differences in behaviour and mode of expression between groups. The conclusion has been reached in CIB that realisation of international transmission of knowledge involves as main elements:

a) Unity in presentation:
   methodology, standardisation of formats, references, classification, filing and other documentation techniques;
b) Machinery for organisation:
   a network of information centres working in close cooperation;
c) Media
   publications as media for the transmission.

The CIB and especially its former Documentation Section have always paid special attention to the problems of efficient transmission of knowledge.

It is for this very reason that I was very happy at the success of the first CIB Congress, during which the results of many years' intensive research work was presented publicly, thus making its start on the road called transmission of knowledge. It is for the same reason that I introduce this book to you with much pleasure.

May the knowledge of so many, collected here with so much care, find its way to practice, in order that it may bear fruit thousandfold.

Rotterdam, May 1961

Contents

SUBJECT 2. DESIGN AND CALCULATION OF CONSTRUCTIONS: SAFETY FACTORS

SUBJECT 3. DIMENSIONING ON THE BUILDING SITE, TOLERANCES AND DIMENSION CONTROL

SUBJECT 5. MASS HOUSING IN RAPIDLY DEVELOPING TROPICAL AND SUBTROPICAL AREAS

SUBJECT 7. FUNDAMENTAL ASPECTS OF TRANSMISSION OF KNOWLEDGE

SUBJECT 9. INDUSTRIALIZATION OF BUILDING

SUBJECT 10. OPERATIONS RESEARCH

Subject 1

SOCIOLOGICAL AND FUNCTIONAL ASPECTS OF HOUSING DESIGN

UDC 301 : 721.001 : 728

MAIN REPORTS

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The sociology of housing: research methods and future perspectives

UDC 301: 721.001: 728

P. CHOMBART DE LAUWE

"Maître de Recherches", National Centre for Scientific Research (France)

INTRODUCTION

Until recently we badly gauged the effects of the industrial revolution on the transformation of housing and the consequent changes of social life. Houses expressed, through the ages, the relation between nature and society; towns reflected the functions of the social groups and their relations.

In modern times architects and planners are no longer faced only by harmonious arrangement of clear functions. Cities became monsters, housing shortages disorganised social life. Replanning, decentralisation, new towns in deserts and enormous housing programmes became everyday tasks. The pressing nature of problems suggested only technical solutions to be important. But psychological disturbances in new houses, poorly defined or new requirements and disquiet about distant consequences of plans drawn up hastily necessitated a different approach. Other forms of research asserted themselves. Not the use of material to serve man, but man himself tends to be overlooked. Before we house him, we must know him.

This necessity to solve urgent problems and to forecast the future by study in advance united architects, engineers and sociologists into one team. What are the results, what problems are left?

We recently published a study on the birth and development of sociology in housing [1] and apologise for not referring to many other works on which information may be obtained from the CSTB [2] pamphlets.

We merely recall the first contact between experts at the 1956 CIB Conference in Paris and the second meeting in London, parallel to the efforts of the Housing Committee and of the European Bureau of the U.N. Technical Assistance Administration.

The 1958 study cycle at Sèvres, organised with the French Ministry of Health, is such an example [3].

Considerable documentation also resulted from the work of related organisations [4]. We regret that our documentation on various countries, in particular Eastern European, is incomplete but this gap may be filled at this Congress. With this knowledge and the experiments our team followed closely, we try to define sociology of housing, to determine main subjects and methods and to give some examples of results, in order to see prospects in this almost virgin field.

In this report we shall not list all the work but spotlight some basic problems to stimulate a discussion.

THE THEMES OF RESEARCH

Repeatedly we urged towards simultaneous study of housing as an integral part of social life

[1] *Famille et Habitation*, Volume I (Sciences Humaines et Conception de l'Habitation), Works of the Social Ethnology Group, Paris, published by the CNRS, 1959.
[2] *Informations Internationales*, in Cahiers du CSTB since 1956, particularly Nos. 27 and 29.
[3] European Study Cycle on the social aspects of housing, United Nations, Geneva, 1958.
[4] Housing Committee of the IUFO Brussels.

and of internal social life of the family or families in housing [1]. Defining the civilisation of the occupants and the town plan must precede plans of dwellings and, furthermore, studying the needs of households, their behaviour and their relations to the interior of dwellings must precede the town plan.

Study of functions is only one aspect of sociology of housing. First needs and aspirations, family groups, neighbourhoods, relations, structures in relation to economic and demographic evolution, etc., must be studied. Through such studies the determination of quantitative and qualitative needs, forecasts, programmes, standards of floor space, types and groups of houses, collective facilities, integral wholes, etc., becomes possible.

These three major groups of research themes can be:

1. housing and the family,
2. from the "small neighbourhood" to the "integral whole",
3. housing in society, the town and the region.

HOUSING AND THE FAMILY

French architects and engineers with whom we discussed interior layout insist on separating functions in space, taking either day and night (Prieur), parents and children (Wogenscki) or private and communal life (Pingusson) as the main division, but all trying, as Le Corbusier stated, to interrelate these.

Their remarks confirm, though only partly, the conclusions of our investigations into behaviour and wishes of families in new housing.

Knowledge of needs

On the one hand we mentioned insufficient knowledge of the requirements the functions must satisfy. They still are inadequately inventorised, poorly analysed and badly graded. Their variations according to social categories and regions are largely ignored.

On the other hand, the analysis of the notion of "function" through the history of functionalism, the comparative studies in various cultures and the recent investigations in many different types of housing, emphasize a dangerous ambiguity. The word is given too restrictive a meaning and too technical a sense, which suppress the entire freedom of the individual, as if we were housing rabbits or mice and not human beings.

A family's house is not an ordinary mechanism. It forms a coherent whole, a structure which should express the structure of the family and allow the latter to live in harmony, making allowance not only for the function of each member at any moment but also for the role which he plays in relation to the other members. The possibilities of communication between persons must be respected. It is not simply a matter of being logical, practical or utilitarian.

Though functionalism opened up new vistas, too narrow functionalism can lead to technically perfect housing which, however, does not suit the human temperament.

Detailed research on floor space per person, for instance, has taught us that improvement of interior layouts only allows a minimal reduction of standards of dwelling occupancy. For a particular civilisation the needs of space and its appropriation cannot be limited whilst trying to satisfy other needs.

Numerous authors attempted to inventorise the arising needs of housing and to show the effects if these needs were not satisfied (Abrams and Dean, Kennedy, Brockman). Some (Kennedy) make an interesting analysis of the needs of the husband, wife, children, grandparents and domestic servants, but only deal with well-off families, the only ones for whom suitable housing can be provided today. Others (Abrams and Dean) deal with families of every income group and the necessity of constant adaptation to new requirements and structures, stressing the consequences of depressions, changes of residence, class conflict, etc., but their study should be completed by the work of architects, taking their remarks into account.

[1] *cf. Habitation et Vie sociale* in Cahiers du CSTB 1956, Vol. 27, and also *Famille et Habitation (op. cit.)*, Introduction and Chapter II.

Others (the work of the Norwegian group described by Brockman) gave remarkable descriptions of family behaviour but did not study its motivations deeply enough.

Others confine themselves to polls on needs we shall criticise below from the viewpoint of methodology. In any case we have enough studies to attempt a useful synthesis. Various bodies in different countries do this. We do it in France together with the "Centre Scientifique et Technique du Bâtiment".

Living standards and economic problems

An excellent starting point for the study of housing needs for families is to observe how they organise their space in relation to the planning of their time and budget. The interrelation of these problems is one reason why it is difficult to get families with different ways of life to live in the same group of dwellings. We have shown that, according to salary, profession and the role of the head of the family in the production process, monthly or daily rhythms of expenditure vary considerably.

Simultaneously the place of housing expenditure and the importance attached to it vary. How can housing programmes be planned in advance if the financial means of families and the importance of housing to them are unknown?

Lack of understanding between specialists is often caused by lack of knowledge of the consequences of variations in living standard. It is trite to state that if you are hungry and warm the need for housing is less imperative. But it is difficult to evaluate this need in each country. Therefore, simultaneous general and detailed study of the economic situation is needed.

The cultural aspect and aspirations

The variation in needs is also due to difference in types of culture, in the guiding images to which the population is attached and the trends of thought behind the conception of housing. That is why we stressed the necessity of ethnological research and of the history of ideas.

If this is already important for industrialised regions, what pitfalls beset the unwary who draw up housing programmes for countries described as economically underdeveloped! What will be the evolution of the Moslem or the coloured family in tall blocks of flats? Must one disregard the psychological, emotional and spiritual needs linked to roles and structures? Would allowance for these retard necessary changes? What shocks are caused by lack of adaptation of these people to their new houses? These questions would impel us to start from entirely new bases.

Instead of studying frustrations and conflicts due to failure to satisfy elementary needs, instead of attaching too much importance to subconscious sexual instincts to explain behaviour, we might give real priority to the above-mentioned frustrations of lack of hope and absence of anything to live for, which in wealthy countries unbalance many people more certainly than emotional frustration in infancy.

The merit of certain architects, such as Le Corbusier, is to present over-all views which can doubtless be criticised but are, nevertheless, a call to new life. We have not only to study the needs of people or their temporary wishes, translated by curt and inaccurate answers to hasty questionnaires: we must study what they live for. Disillusioned young people have started revolutions for no reason at all. If they took part in collective work and felt themselves part and parcel of their town, if they had the opportunity of self-expression and creation in their own homes, would they still turn to revolution?

Here we return to the freedom of families and individuals. We were glad to see our efforts here reinforced not only by the architects with whom we published interviews, but also by doctors, such as Dr. Hazemann, who recently dealt at length with the subject in a series of articles [1].

However, for us it is not a question of freeing man in his home from the physical and mental

[1] R. H. HAZEMANN, La Liberté concrète, condition de la Santé physique et mentale, *Rev. hyg. et méd. sociale*, VII, 1 (1959) 34–35.

ills lying in wait for him. We must envisage a freer life in a more constructive, a more dynamic sense. Architects and sociologists wishing to work together should bear that in mind before they start.

FROM THE SMALL NEIGHBOURHOOD TO THE INTEGRAL WHOLE

We can envisage a free life only by studying families in a larger framework than the home and by defining steadily increasing entities, such as groups of dwellings, neighbourhoods, districts and towns. However, we do not favour over-rigid definition of categories on the basis of personal ideas and beliefs as more exact studies show the errors of plans that overlook these needs of regrouping.

Households in the primary group of the neighbourhood

There is no shortage of works by sociologists on the "primary" or "elementary" groups. However, it is surprising that town planners defining a neighbourhood unit sometimes indicate a small number of households and sometimes a group of 10,000 dwellings.

Both in rural and urban areas, groups of households have tended to form at local level. The urban equivalent of the hamlet and its internal tensions is the world of the staircase or landing. However, we note enormous differences which do not depend on civilisation – the phenomenon is universal for villages, but depends on social class in urban environment. Is the "neighbourhood" a lower-class need? Are the classes that free themselves of it and that create other tensions in their relations with both the outside world and relations better off?

It seems with a view to this freeing themselves that solutions allowing families themselves to choose the neighbours they would prefer in a fairly large unit would be the best. But what are the best of these solutions? We cannot believe that detached or semi-detached houses give more freedom in urban centres than properly designed blocks of flats with generous landings [1]. The few investigations into this subject only allow us to state that more research is possible and profitable here.

From village to district

The dimensions of a larger living unit might appear easier to define. In rural life villages – for instance, in France – rarely exceed 1500 inhabitants without becoming small towns. The small urban residential districts studied in working-class areas of large agglomerations such as Paris varied from 800 to 2000 inhabitants.

In France the plans of the Ministry of Construction provide for units of 200 to 300 households, districts of 800 to 1200 households, "arrondissements" (roughly equivalent to wards) of 1500 to 2500 households and towns of 10,000 households [1]. But the programmes do not make allowance for the variation in needs from one social class to another. On the other hand, which of the above units should contain the main collective facilities? To answer this question a deeper knowledge of the needs is required.

What needs have to be satisfied by these provisions? What is the structure of a unit? How do relations tend to establish themselves between families, and between families and single persons? What are the relations between the various generations? What is the pyramid of optimum ages? What are the relations established between the different social classes? What groups appear spontaneously? What organised groups are to be expected? Have the plans for housing groups an answer to all the social needs that underlie these questions? Only methodical investigations and experimental studies can give the right solutions. In this case, too, these studies can be relatively rapid if the researchers have the necessary means at their disposal.

The integral whole and the gateway to a new civilisation

All these problems recur on a much greater scale with the regrouping of residential districts

[1] See on this matter the criticism which follows of polls which claim to show that a house is always widely preferred to a flat.

in the new integral wholes. Between the satellite towns as in Britain or the huge projects integrated into conurbations carried out in other countries and recently in France, industrial society has not yet found a suitable urban framework.

Since the Charter of Athens, in which town planners defined the functions of an urban whole (living, moving about, working, cultivating the body and the mind), research has been continued, and today's problem of the facilities of the integral whole demonstrates the extent to which the awareness of a harmonious social life has developed. In recent works of the French Ministry of Construction [1] we are presented with a plan of facilities comprising educational and cultural, commercial, social and health facilities, green areas, parking and sports grounds.

In other countries extensive studies have likewise been made of the requirements at various levels in the urban whole. I have in mind in particular the remarkable Dutch works, and the British, Swedish, German, Polish and other studies on which we possess documentation. It has everywhere been found that social life in new residential districts is impossible if the collective facilities are not very widely developed.

In particular it may be observed that a valid comparison between individual houses and blocks of flats cannot be made as long as collective facilities have not been provided in a sufficiently complete and exact manner.

But we believe that the essential aim in all these studies, however remarkable, is to link the analysis of the particular needs of a certain sector to the over-all conception of the housing project that has to express the existing social structure and, still more, the social structures tending to appear. To give only one example: it will be clear that the provision of commercial facilities is linked to that of cultural facilities. The analyses made so far on old towns show the extent to which the commercial and the cultural centres of attraction tend to intermingle. But the commercial centres should not dictate the introduction of cultural centres, as often happens in an unplanned town. On the contrary, planning must allow the introduction of commercial centres to facilitate the development plans of cultural activities. An exact conception of the importance of this problem would require a series of examples in a given town, which would lead us too far.

HOUSING IN SOCIETY: THE TOWN AND REGION

With a view to the foregoing, we think that dwellings and housing cannot be studied without bearing in mind a definition of the town in the regional whole and the entire community. Hence architects, engineers and builders who have to house people of different social classes which coexist in the same urban framework, must study the most general works on town planning and territorial planning, making allowance for economic and demographic problems. Forecasts and calculations of population development, industrial production and evolution of consumer demand must guide town planners, since without these no valid housing programmes can be made.

But the town cannot be seen solely in this light. Transformation of social structures and development of mutual relations between social groups must be studied parallel with economic and demographic studies. To this end, research into disintegration of old structures and deterioration of behaviour, caused by and resulting in housing shortages, is indispensable. Work on juvenile delinquency, infantile psychiatry, criminology, development of mental ills, etc., must coincide with study of lack of vitality of social groups and the resulting absence of ties between individuals. An inventory of residential districts requiring transformation and the preceding research are impossible without previous study.

Finally, it is necessary to seek behind these social changes the part played by trends of thought, ideologies, views of life, different systems of value and cultural patterns followed by those who have to live in the towns. By bearing in mind historical studies and comparisons

[1] The review *Urbanisme*, Nos. 62 and 63, 1959.

between civilisations in an age when cultural contacts between the various people of the world occupy a similar place, we must make this effort of comprehension to solve technical problems in a valid manner. We shall come back a little later to the subject of respecting the liberty of the individual and of human groups in our civilisation.

THE METHODS

We cannot discuss every approach to the foregoing themes. We shall, therefore, concentrate on housing proper and neighbourhood units, *i.e.* Subject 1 and part of Subject 2.

In every form of research the procedure is, progressively, to define in an increasingly exact fashion criteria whose variations can be discerned. The analysis of the variables makes it possible in particular to determine thresholds which will give indications of the measures to be taken by the builders. On the other hand, the study of functions and structures and the study of the behaviour pattern of the users and its motivation will allow us to define the needs and the aspirations with which urban housing and towns must comply.

The extent of the problems prevents the exclusive use of methods peculiar to one branch of science. The study of social life in housing is the result of teamwork by specialists from various branches. On the other hand, if the aim is to achieve precise applications in the shortest possible time, we shall see that fundamental research has, nevertheless, to occupy a major position in the interests of successive applications.

PUBLIC OPINION POLLS

In the first investigations into housing, sociologists set out chiefly to find the opinions of the occupants. Useful information has been collected in this way, but nowadays these mass polls appear inadequate, for the persons questioned reply without being adequately aware of the information required in answer to the problems being put to them. For instance, the preference for a house, noted in various countries, has no significance as long as the users do not know what they can expect from flats. In a recent inquiry we found that a large number of persons who had previously expressed the desire to have a house had, in fact, been happy in a flat. Their true needs, which they were unable to formulate clearly, were, in fact, satisfied in a manner they did not expect. It is nonetheless true that many families prefer a house, but the figures of public opinion polls cannot always be directly used. Now that the construction of large blocks of flats is imperative in many towns, it is essential to review these methods of observation seriously.

We think it necessary that nowadays the opinion of the population at large, of whom a representative sample was taken (10,000–20,000 households, in national inquiries), be supplemented by experimental research into limited sets of subjects chosen in particular housing groups. These few subjects are then studied more deeply, the conditions under which they are observed being supervised more and more precisely. Such research has been conducted in Britain, Holland, France, Germany, the Scandinavian countries, etc.

More and more it is proving necessary to follow the households studied for longer periods and possibly to make experiments by observing the same households before rehousing, just after rehousing and two or three years later. The construction of groups of dwellings based on the results of investigations is the best method of arriving at an exact check. The Norwegian work in this respect is among the most advanced research.

THE ESTIMATION OF NEEDS

Careful study of the way of life, behaviour and attitude of households is a first means to estimate their needs. Questionnaires taking into account the situation in which the households are observed should be used and that situation must be described extensively. Thus a series of variables to be related to variables of behaviour and attitudes is collected.

The term "situation" denotes the place occupied in professional life, in the financial scale, the social classes, the ethnic and age groups, etc. Living standards and way of life vary according to cultural influences and material conditions.

Behavioural patterns and attitudes of households vary considerably with the above variables. Behaviour towards children, food, neighbourhood, etc., is linked with ways of use of the dwelling and also with attitude to society and life.

Sufficiently extensive questionnaires requiring "yes" or "no" as answers and allowing elaborate replies by interested parties, and scales permitting precise classification of subjects must be used simultaneously. For example, for households who want their meals in the kitchen the needs architects must satisfy cannot be determined without exact observation of social life during the privileged moments of these meals. The significance of a meal varies from country to country and from one social class to another in one country, but it is easy to establish types of households corresponding to types of situations and to base housing programmes on these observations.

In this research a privileged part must be given to the study of the relations between the planning of time and the utilisation of space, to those of economic behaviour (place of housing in the family budget and consumption habits) and to those of the social parts played by the various members of the family and of the transformations of family structure and relations.

The observation of families selected at random in the housing groups must be supplemented by research into pathological cases. The study of the deterioration of behaviour linked to material housing problems has enabled us largely to determine thresholds of floor space and occupancy below which one cannot go without almost certainly exposing the occupants to serious disturbances.

Taking these various elements into account, we can list the needs mentioned above and we can try to see at what moment and in what way the satisfaction of the occupants manifests itself. Beyond the pathological threshold we can then determine the equally important thresholds of satisfaction.

Finally, it is also possible to study the aspirations of households, but this can never simply be a matter of asking questions about wishes regarding facilities. Many questions, often seeming irrelevant, enable investigators to find out the aspirations of households that they cannot always express clearly.

THE DYNAMIC AND EXPERIMENTAL STUDY

A valid study of the many complex variables requires a call upon the notion of "social environment". Behaviour and attitudes of individuals or groups are related to all elements of the social environment in which they exist. Often relations are established between variables of behaviour and of environment which do not correspond to the questions asked. Choice of adequate variables requires a general table that often is drawn up with difficulty. Such a table permits the choice of variables to be isolated and regrouped. For example, the variable of floor space per person or number of inhabitants per room can be isolated with certain accuracy and related to another: the degree of satisfaction. But the latter may have a stronger tie to the variable of soundproofing (see p. 10).

Individuals in their environment cannot be studied without observation of their past experience and the influence of earlier environments.

The subjects observed cannot be situated in a material three-dimensional space but must be located in a multi-dimensional social space. Simultaneous allowance must be made for the position of subjects in the dwelling or group of dwellings and for social differences separating them in terms of their prejudices, degrees of comprehension and possibilities of communication. Different ways of life may separate households living closely together materially. Nevertheless, layouts of houses and rooms influence social relations and communications. Builders should think of the channels of communication and the changes due to their plans. Though with certain reservations, the technique of group dynamics can be used for these sociometric ecology studies. So far this research has led to the creation of artificial groups and the establishment of communications. In our case the usual environment and the relations of daily life are the major factors.

Thus active participation of the households observed, posing problems of introduction and contacts, is required. This becomes even more complex in the experimentation proper, but subjects may be much more cooperative if they understand the endeavours of architects and sociologists to be of direct use to them and to the entire population.

THE ETHICAL ASPECT

If it is impossible to work effectively without winning the confidence of the households concerned, the sociologists assume certain responsibilities in respect to them. It would be dangerous to ask households to help produce solutions contrary to their aspirations. It is possible that the economic interests of the builders are inconsistent with those of the users. The sociologists must, therefore, contribute towards better understanding between the two groups. The only correct method is to communicate the results of research to the two parties simultaneously. We have already had an opportunity to convince builders of the necessity of these measures. We do not think they have regretted it.

Another moral problem arises. To what extent do we have the right to make experiments? In fact, every new construction is an experiment and the systematic studies that we must make can even allow experiments in a more favourable sense. However, it is impossible to use the results of the investigations to facilitate the implementation of a political or social reform of which the population is not aware and which may run against their aspirations. There is thus a duty to inform the public so that town planning is envisaged as having the maximum possible participation of all classes and of representatives of every group and trend.

EXAMPLES OF RESULTS

What results can henceforth be obtained from the work done? The accounts given by various countries in published works and articles show very different examples, but almost everywhere the interest aroused by research has impelled architects, engineers and builders to use certain data from the investigations of the researchers. The papers which are to be read at this congress will give a more exact idea of the possibilities of practical utilisation.

For our part, we should merely like to take a few very limited examples relating to various studies we have undertaken in recent years.

DETERMINATION OF THE FLOOR-SPACE THRESHOLD

We have urged the importance of determining thresholds for various indices. On the matter of occupancy (floor space per person or number of residents per room) several cross-check investigations have allowed us provisionally to suggest two floor-space thresholds which can be utilised only in a country like France. These thresholds should be revised for other areas, but the principle of determination may remain the same.

Relations between parents and children

From a preliminary series of investigations we found that certain forms of behaviour of parents towards children vary significantly according to the floor space available. We found that in houses that are too small the tension between mother and children in particular became critical beyond a certain occupancy threshold.

Infantile psychiatry

Research carried out later by Mrs. Chombart de Lauwe shows that misbehaviour of children becomes much more frequent beyond a certain occupancy threshold.

In terms of these two sets of research, we have estimated that there was a critical threshold of about 8 square metres per person or 2.3 residents per room.

Despite various remarks on this matter, we do not believe that a better layout of the ground plan or facilities can change the critical threshold very much, but investigations made to date have not yet been very numerous, so that we merely put forward these figures as a working hypothesis requiring checking.

The thresholds of satisfaction

In other investigations among families in old dwellings or new groups of housing, we noticed that the degree of satisfaction varied very significantly, as might be expected, with the floor space per person and that the curves of satisfaction displayed an abrupt change beyond a certain threshold. We think that we can now locate this threshold at approx. 14 to 16 square metres per person. But, as for the preceding threshold, studies must be continued to arrive at greater precision.

This second threshold probably varies a little more according to the layout of the ground plans and the arrangement of rooms than the preceding threshold. However, cross-checking of these remarks with other observations of attitudes and motivations leads us to believe that the need for space and for adaptation of space must be considered and that a reduction of the standards of floor space in exchange for a rearrangement of rooms may have grave psychological and sociological consequences. To furnish all the proof required it would be necessary to resume research into the need for independence felt by the individual and groups of persons inside the dwelling, the need for rest and relaxation, for external social relations, etc., as we began to conduct in groups of new dwellings.

Search for optima

It seems that there are not only lower but also upper thresholds in a particular civilisation and country, although up to now we have few elements to support this hypothesis. We have merely found that in overspacious dwellings corresponding to the standard of living of very well-to-do families, the social distances between the members of the family were influenced by the material distances and that the emotional development of children was affected very badly.

Consequently, a comparison of these lower and upper thresholds should facilitate the search for the optima to determine the programmes. These optima would probably vary in a quite distinct fashion not only from one country to another, but from one social class to another in the same country.

SOME OTHER ESSENTIALS

During our inquiries we noted that among the needs that we brought to the fore certain other essentials are now called for in construction. Of these, we may cite the following:

Soundproofing

During comparative research embracing three groups of new housing, we found that, as mentioned above, the degree of satisfaction varied radically when the dwellings were soundproofed or not. Looking at it from another angle, we found, as in many other investigations, that noise had catastrophic effects not only on nervous fatigue but also on social relations between families and within one family.

It was possible to analyse the importance of noises in the dwelling, those coming from the flat above being by far the most important in one of the housing projects, those of the pipes in another, followed closely by those of the flat below, of the lifts and of the staircases shared by the flats. In the only really soundproofed project there were only occasional complaints about pipes and lifts. The whole social life of the project had been transformed and, a special point, one of the main objections to communal housing was now removed.

Collective facilities

During the last few years in France and other countries, observations have been made on the absolute necessity of developing collective facilities in groups of housing and integral wholes. In the course of inquiries carried on for some years we, as well as other observers (*cf.* the studies of Houist, Dayre, etc.), continually stress the grave dangers of bringing together large numbers of families in groups of housing without giving them certain indispensable means.

In particular, we accentuated the necessity of crèches, day nurseries for children, premises for young people, sports fields, playgrounds, guided activities, etc. And, of course, with greater reason, the traditional facilities from the commercial point of view and from the angle of the social services, etc., must be provided.

Collective needs can, just as individual needs in houses, be graded by precise sociological studies. The above-mentioned programmes of the Ministry of Construction fortunately include much more collective provisions than formerly.

The observations cited seem to have been taken into account. Nevertheless, much remains to be done to specify the organisational consequences in social life of the use of these facilities. For example, real efforts to study assistance for the formation of groups and expansion of cultural activities of young people have been made. But who are they, how do they form groups spontaneously, how do their needs vary with social class, what do they think and expect of life? We know we are badly informed here. May the studies made by our team member Jenny soon bring us food for thought here! It would be a pity if facilities for young people merely projected the ideas of older generations on today's youth, which could itself have made a real contribution.

Supervision and education of children

Facilities for young people being important, those for supervision and education of children below the age of 14 are even more important. In all the housing estates and groups of dwellings in which we made investigations the same problem was raised by most families. If unobtrusive supervision and educational care, which should lead to creation of specialist posts for adequately trained staff, are not taken into consideration, veritable catastrophes threaten to occur. The presence of a single child who misbehaves may then result in the misbehaviour of many others. The result is a systematic distrust by families which cannot be overcome as long as educationists will not give them the necessary guarantees. Conversely, if supervision and education are sufficiently well conceived, we believe that the children may benefit widely from the easier contacts establishing themselves in the groups of dwellings and that their emotional and social development will be better than if they were isolated.

SOME TRENDS

Other essentials could be indicated. Meanwhile, we may point out a number of trends which could make it possible progressively to specify measures as important as the preceding ones.

Liberation from the neighbourhood

The possibility of establishing social relations with neighbours is a considerable advantage provided that the freest possible choice of these relations can be made.

So far the only solution that appeared to us to give satisfaction to the residents of communal housing projects was the interior street as conceived, for instance, by Le Corbusier. The possibility of having the front doors of 50 dwellings open on the same street automatically eliminates quarrels between residents of the same landing, whilst at the same time rendering possible elective relations between quite a large group of neighbours.

But these neighbourhood problems require a much deeper study, such as we started in our last investigation.

We are re-encountering many problems raised by research workers in other countries. It would seem that the layout of flats inside blocks should really be influenced by the results of this work.

Housing and family budget

From quite a different point of view housing programmes must make allowance for family means in order to determine the assistance the State must give to households in social classes which cannot entirely meet the cost of accommodation. We thus return to the study of thresholds in connection with another subject. If we analyse family budgets and define with close precision the various parts of the item "housing", we find that below a certain income threshold families cannot devote a sufficient part of that income to housing. The system of housing allocation practised in France must be developed further, otherwise dwellings built for less well-to-do families will be occupied by others. However, all the remarks made at the end of investigations seem to have been studied sufficiently by the authorities, since steps have recently been taken to exclude certain income groups from housing built with the aid of State grants. But continuation of study for estimating needs and corresponding assistance is difficult, as work on family budgets and consumption units has to start again at the beginning for certain aspects. We have already provisionally determined a series of thresholds, but it would be necessary to resume this research by using new scales of consumption units, since the present (the Oxford scale and others) no longer appear to be valid.

Housing, food and social life

In various investigations we have studied the role of food in social life of the family. In France the meal is, in particular for working-class families, the essential moment of social family life. The place of the meal is, therefore, fundamental. As investigations of recent years show, most families dislike the kitchen as an integral part of the living-room and they often build a partition to make a kitchen to take their meals. A small separate kitchen (kitchenette) may be envisaged if meals can be eaten in the living-room. But the solution requires material conditions above a certain income threshold and certain cultural trends.

Recently, kitchens with a dining recess have been proposed. This certainly corresponds to a psycho-sociological need, but the transformation of family life in a rapid social evolution requires, with such plans, to facilitate simultaneously the change from eating in kitchens to eating in living-rooms. Thus the enlarged kitchen should be so close to the living-room that changing would not require great effort.

Here we share the opinion of certain architects whose preoccupation we have noted to be that of anticipating requirements. For there is an educational aspect of internal arrangement which must remain of prime importance. But we urge that education be based on observations so that families have more awareness of their own aspirations and are given means of satisfying these aspirations.

WIDER PROBLEMS

These few examples – unfortunately too few, and described too briefly – illustrate the necessity for a general stock-taking of requirements. The work we started in this direction should be compared with similar work in other regions or countries, so as to make it possible to spotlight the needs common to various societies and the special needs corresponding to certain cultural trends.

The satisfaction of these needs may lead to functions being determined more precisely. We again stress the value of general studies, not only from the psychological and sociological angle, but also on the basis of historical data and ethnology. The points of similarity which we have recently found in the history of functionalism since the 17th century, in the study of functions in various civilisations and in the study of functions in old and new dwellings in France gives us a greater awareness of the underlying and often badly expressed hypotheses which form a guidance in the conceiving of plans. The concepts of needs, functions and structures require to be discussed. The exchange of ideas which we have had with a group of architects allows us to see a little more clearly into this field.

The investigations which we have recently conducted in the form of interviews with France's leading architects could be extended to other countries to bring about a better understanding and to bring to the fore the definitions on which it would be possible to reach agreement.

CONCLUSION

At the end of this report we return to the problem posed at the beginning. On the one hand, it is possible to stipulate the fundamental needs and the aspirations of the population with which the architects, engineers and town planners must comply and, on the other hand, the major obstacles are being defined with increasing clarity. The fundamental question that continues to be raised is that of the freedom of the family and the individual in social life. Housing can play a vital part in this field.

We have spoken elsewhere of liberation rather than of freedom, as the very definition of freedom could provoke long discussions and, on occasion, lead to a greater lack of understanding instead of possibilities of coming closer together. Moreover, the idea of a progressive liberation of man from the shackles that impede him in social life may be a very certain guide for town planners who wish to benefit humanity.

The point at issue is, therefore, to free man from his fetters rather than to impose upon him an idea of liberty which may be peculiar to one civilisation or another, to one religion or another or to one ideology or another.

We have stressed the necessity of working in this way and the need for extensive research to obtain a general picture rather than special local applications. We believe that basic research, detached from any obligations or contacts, is the only possibility of arriving at this broad picture.

Finally, we should like to conclude by emphasizing the necessity of defining the moral conditions in which this research can take place and by returning to the problems of ethics which we posed earlier. A code of ethics must be drawn up for town planners and the representatives of the social sciences. This would be one of the tasks to be solved in collaboration by teams consisting of both researchers and technicians working to draw up plans.

A practical example of a functional study of housing

UDC 721.001 : 728 (492)

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Household Council, Advisor to Bouwcentrum (the Netherlands)

In the Netherlands, where by early 1959 650.000 dwellings had been built since the Second World War, the quantitative aspect of housing was of primary importance, but to prevent the creation of vast numbers of rapidly depreciating dwellings the quality also required due attention. Therefore in 1953, at the initiative of Bouwcentrum and of the Netherlands Household Council, the study of the functional principles of housing was initiated under the auspices of a Study Council that embraces numerous authorities and institutions interested in housing and domestic efficiency.

ORGANISATION OF THE STUDY

The study is guided and its results are assessed and sanctioned by the Study Council "Functional Principles of the Dwelling", in which are represented:

Netherlands Household Council,
Roman Catholic Institute of Housing,
Foundation "Good Housing",
Study Group "Efficient House Construction",
Bond of Netherlands Architects (BNA),
Bouwcentrum,
Ratiobouw,
Netherlands Institute for Housing and Town Planning,
National Housing Council,
Agricultural Domestic Science Department of the Agricultural University,
Research Institute for Public Health T.N.O.

A central study group is, as executive and coordinating body, responsible for the practical execution of the study and for each of the seven subjects of study mentioned below a separate sub-committee was created.

The task of these sub-committees of experts is primarily to formulate essential requirements for the various functions of housing. Repeated discussions on the notion "essential requirements" resulted in the following definition:

"By 'essential requirements' is understood requirements which are essential for a harmonious development of the family and the individual and the fulfilment of which is, in principle, regarded by the majority of Dutch people as an essential condition for achieving an acceptable standard of living and housing from the material, moral, cultural and social points of view." This definition leaves ample room for different interpretation but was found sufficiently clear, since emphasis was laid on "constants" – generally applicable requirements – rather than on regional or social "variables".

The complicated organisation with independently operating sub-committees that should not embark on different roads necessitated a clearly defined starting point for the study. The difficulties encountered initially in this respect were overcome by the establishment of a special team responsible for compiling reports.

Apart from formulating essential requirements the sub-committees had to collect as much information as possible from literature. Thus the experience of, for example, Cornell University and of Hemmens Forskningsinstitut in Stockholm was used. Finally the sub-committees individually conducted investigations.

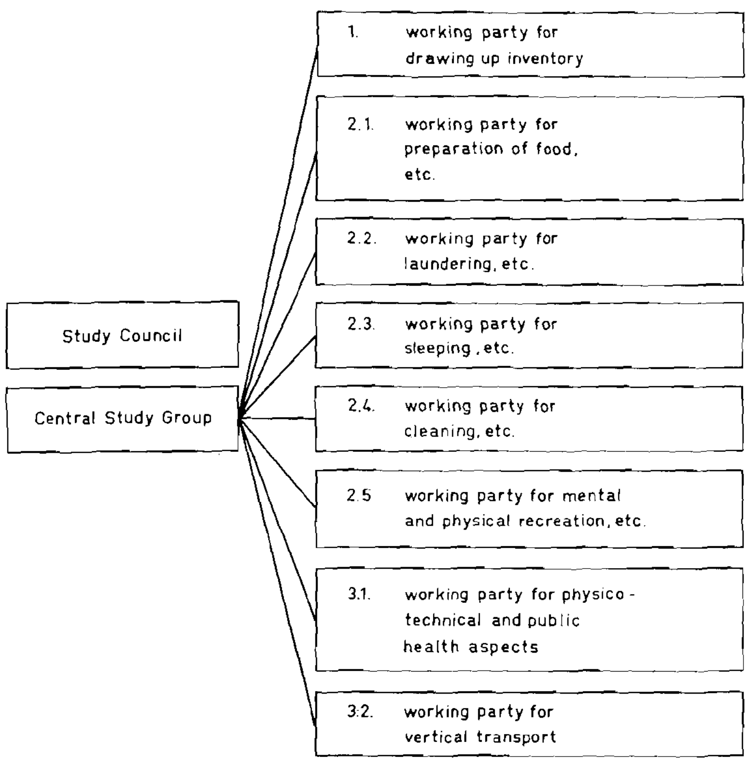
This organisation might appear to be unwieldy, but in the course of the study it became clear that close collaboration between experts from widely different spheres was necessary.

THE INVESTIGATION

The functional studies were not entirely exhaustive nor have they been completed as yet: for example, in the field of job analysis and time and motion study it has not been fully comprehensive.

It was based on ordinary daily actions and movements of housewives acting as test persons.

ORGANISATION SCHEME



Objections can be raised against this method, but in practice one does not meet only "ideal" housewives performing "ideal" actions and movements. Adaptation of layout and equipment of a dwelling to ideal actions and movements would probably necessitate an instruction booklet or physical training in order to perform these ideal actions.

However, application of job analysis to housing would allow a great deal of improvement.

The investigation was carried out as follows. First the desiderata and complaints of the housewives were ascertained by a general preliminary inquiry in 1954.

It became evident from this tentative inquiry that the problem of storage in the dwelling is of great importance. Therefore, an inquiry was conducted among 2000 housewives in 1955 to obtain exact information on the inventory of Dutch dwellings, which could be used as a starting point for determining the storage space and the essential furniture required in the dwelling.

The inquiry was carried out with five existing inquiry groups of 400 housewives of the Household Council of the Netherlands, which had already been used for this type of work. All the national women's organisations engaged in furthering the welfare of women in the domestic sphere are represented in the Household Council of the Netherlands, which aims at:

(a) The promotion, in the general interests, of efficient housekeeping;

(b) The representation and safeguarding of consumers' interests and home interests with government institutions, scientific institutions, trade and industry.

More than 500,000 families are thus related to the Household Council.

In 1953 the Household Council undertook the formation of inquiry groups to be able to test the opinions of Dutch housewives. The Netherlands Foundation for Statistics furnished the basic information required for the composition of the inquiry groups. By means of advertisements in the journals of women's associations and announcements on the radio it was possible to enlist the cooperation of a large number of Dutch housewives. Thus five inquiry groups each of 400 housewives were formed. Each group represented as closely as possible the characteristic features of Dutch households of two or more persons and the groups had to reflect four aspects of the Dutch people:

(a) Distribution according to province and size of municipality;

(b) Size of family;

(c) Religion of the members of the family;

(d) Profession or occupation of the members of the family (indication of the social status).

The extent to which the inquiry groups are representative of the Dutch people must be commented upon.

The groups were composed on a basis of voluntary participation, which implies that the more active housewives were represented foremost. This, however, may have had a favourable effect on the quality of the answers to questionnaires and it was an advantage that use was made of the opinions of these more conscientious housewives.

The inquiry was conducted by correspondence.

It proved necessary to subdivide the inventory into groups of articles. For this purpose the division into subjects of study discussed (p. 20) later in this report, was observed as much as possible.

The bureau of the Household Council, in collaboration with the Central Study Group and the appropriate sub-committees, compiled a questionnaire for each inquiry group, stating a series of articles associated with the subject of study. As the inquiry groups were practically identical in size and composition, it was possible to obtain from each group information about part of the inventory.

A single questionnaire was submitted to two different inquiry groups, thus providing an opportunity to check the results of the groups against each other.

EXAMPLE

Parts of a questionnaire used for the inquiry to establish the inventory of dwellings in the Netherlands

Explanatory notes to the questions concerning the kitchen inventory.
Please read this explanation carefully before filling in the questionnaire.

COMPLETING THE QUESTIONNAIRE

You will find quite a number of articles in the list which you probably do not possess at all. We should be glad if you would mention those articles which you have to store and not the articles which you should like to possess. We are probably causing you a little trouble with the pans, etc., but in order to give us the right idea about the space required to store these utensils we must ask you to measure the diameter of your largest pans and to fill in the number of a certain size in the relevant column.

If you possess any articles not mentioned in the list, please state these articles in the blank space provided for this purpose.

KITCHEN INVENTORY

1. *Pans*	*Diameter*	*Number*
	12 cm	......
	14 cm	......
	16 cm	......
	18 cm	......
	etc.	......

The same for frying pans, pressure cookers, etc.

2. *Crockery and Glassware*	*Number*
beakers	......
sweet dishes	......
butter dishes	......
bread plate	......
soup plates	......
dessert plates	......
floating bowls	......
glasses (beer, long drinks, wine, etc.)	......
butter knives	......
fruit knives	......
fruit forks	......
cake forks	......
cheese knives	......
spoons (small, large)	......
tea spoons	......
others	......

3. *Misc. Kitchenware*	
potato basket	......
washing-up bowl	......
fudge mould	......
bread board	......
toaster	......
kitchen knives	......
kitchen spoons	......
kitchen forks	......
cake tin	......
scales	......

This information was used to determine the spatial requirements, both the storage space and the space required for use being considered.

The method adopted with regard to the space required for use of the articles is in itself quite simple. First of all it was ascertained what actions must be performed when carrying out a certain duty and which of those is characteristic of the space requirements. A test person then performed this action against a background from which dimensions could be read off and the action was finally recorded photographically. To ensure that the results would be to some extent representative, it was established to what extent the space requirements were affected by different working methods and ways of moving. To this end some of the actions were performed by different test persons. If substantial deviations were found, photographs were made of more than one test person. On the whole, however, it was sufficient to photograph test persons of (for the Netherlands) average height (Figs. 1 and 2).

In principle, the same method was used for determining required dimensions of storage space. The results of the inventory inquiry revealed what had to be stored, but this information had to be supplemented and corrected, as the composition of this inventory was characteristic of the year 1955.

Apart from the nature of the articles to be stored, it had to be ascertained where they had to be stored. Hence, allowance had to be made for the place where the articles were used most, how often they were used and for the possibility of providing combined storage space for different articles. As it is impossible to lay down hard and fast rules for the way a housewife should use her storage space, an effort has been made to provide an arrangement with a high

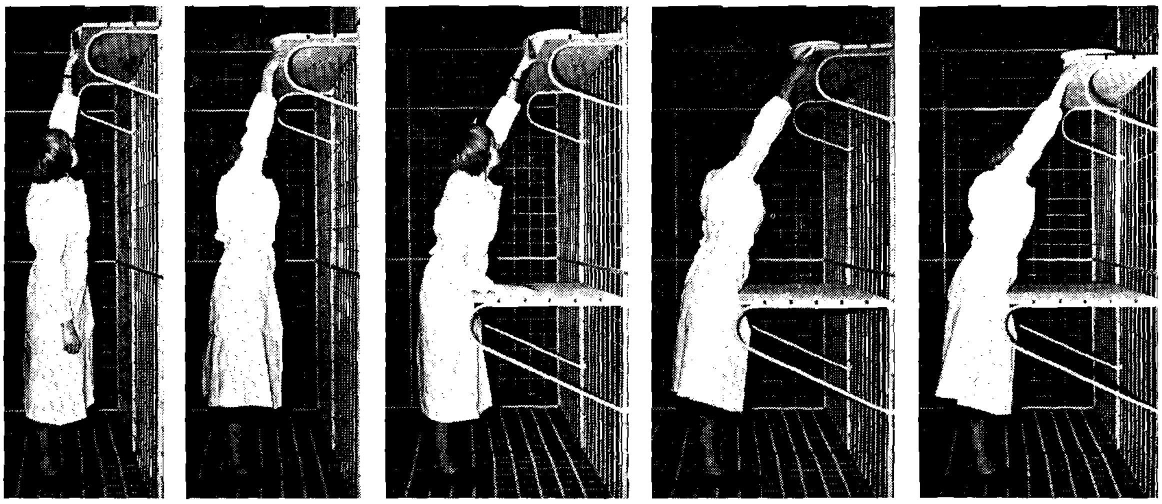


Fig. 1. Photographs of a test person to determine reaching height.

Fig. 2. Photograph for the determination of the space required for using a washing machine.

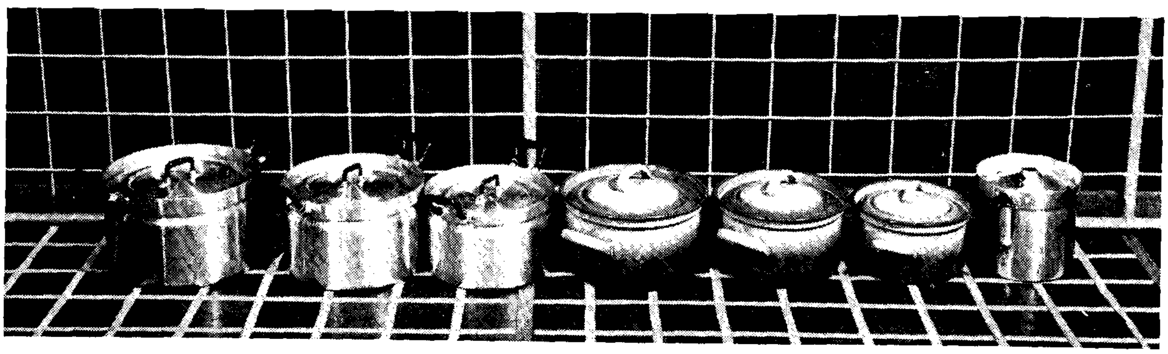


Fig. 3. Photograph for the determination of the length of storage space required for six pans and a milk boiler.

degree of flexibility, which can be achieved by adopting standard dimensions whenever possible. Photographs were made of the articles to be stored together in a single storage space, from which the required dimensions of the storage space could be read off (Fig. 3).

This method of measuring relates solely to the elements, but it was also necessary to establish the spatial consequences of combinations of elements. To this end a number of combined arrangements were set up, among others, of kitchens and of laundering equipment, an effort being made to achieve the most efficient "production line".

These arrangements also allowed overlapping of work space, circulation space, etc., to be determined. The investigation was not extended beyond this combination of elements into certain arrangements. No floor plans of the rooms were drawn.

PRODUCTION LINE FOR PREPARATION OF FOOD, COOKING AND EATING

Diagram of actions

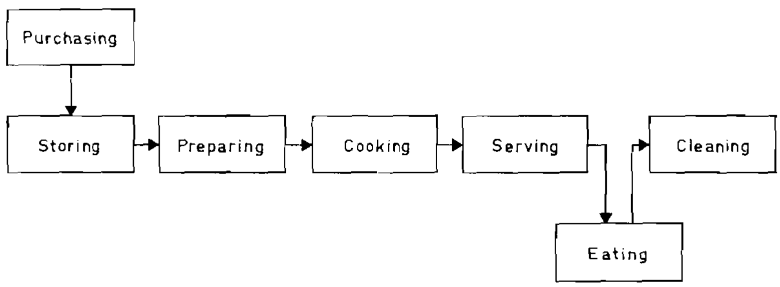
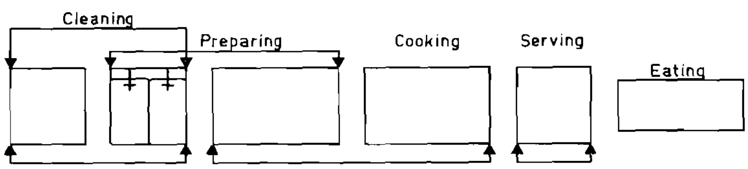


Diagram of actions and requirements

Actions



Requirements

Water Detergents Refuse disposal	Water Provisions Equipment Pans	Crockery Provisions Equipment	Crockery Cutlery

AIDS

In the preceding section reference was made to the photographing of actions, articles, etc. This method was adopted partly for practical reasons and partly with the object of producing convincing material. There is nothing new in measuring the space required for various pieces of furniture and apparatus, which is clearly illustrated by the well-known standard work "Bauentwurfslehre" by Neufert. Nor is there anything new in the photographing of a housewife working at the drainboard. However, a more convincing result is undoubtedly obtained by photographing a housewife at the drainboard in such a way that the dimensions can be read from the background and the floor than by making an artist's drawing of a woman at the drainboard with the dimensions written in or by photographing her without indication of dimensions.

The aids used for photographing are very simple, *viz.* an L-shaped rack with one side of 2 m and one of 3 m and with a height of 2.40 m, divided into 10 cm squares, a number of floor slabs divided into squares and further a number of shelves likewise divided into squares and of different sizes, which can be mounted against the rack and are adjustable in height.

DIVISION INTO SUBJECTS OF STUDY

As the functions in a dwelling are highly divergent, the study has been divided up into a number of subjects, which together form a series with a certain relationship. Purchasing of food, storage of provisions, preparation of food, cooking, boiling, etc., serving, eating, washing-up, and storage of left-overs constitute, for example, a series. The subjects heating, lighting, ventilation, sun protection, etc., exhibit a certain relationship. The study is divided into the following subjects:

1. preparation of food, cooking, eating;
2. washing, drying, ironing, mending;
3. sleeping, dressing, personal hygiene, baby care and nursing the sick in the home;
4. cleaning and maintenance, with respect to choice of materials and finish of floors, walls and ceilings;
5. housing requirements with respect to mental and physical recreation and activities;
6. physico-technical and sanitary requirements;
7. vertical transport.

Final reports on the first five subjects are available in English and in Dutch. The study of another subject has been completed but the results have not yet been published, while work is still in progress on the last subject, *viz.* vertical transport in the home.

The subjects of study more or less overlap one another. The purchasing of foodstuffs suggests the tradesman's problem in multistorey buildings and thus the problem of vertical transport. Eating usually takes place at a table which can also be used for sewing, mending and playing games. If the bedroom is heated, it can also be used for study, etc.

The reports have not been confined to concrete data but also contain an account of the backgrounds involved, so as to provide insight into the "process" referred to earlier. The object is that the architect can thus make a proper choice from the various solutions.

SOME RESULTS OF THE STUDY

DIMENSIONS FOR A VARIETY OF PURPOSES

The reports contain dimensions for the storage space required in a dwelling – indeed a novelty – dimensions and arrangements for laundering and kitchen equipment, dimensions for the height of cupboard shelves in connection with accessibility, dimensions of the space required in front of a bed to be able to make it and sweep underneath it, working heights for drainboard, sink and kitchen cooker, dimensions for the arrangement of furniture in living-room and bedroom, data concerning the desirable location of rooms with respect to one another, etc.

Example

Part of a guide with dimensions for elements of the kitchen.

Drainboard with a double sink:

Length double sink		65 cm
drainboard between sink and cooking apparatus		100 cm
drainboard on the other side		60 cm
	total	225 cm

General data on storage space:

Height of shelves for articles:

(a) not required very often	max.	185 cm
(b) often required	max.	170 cm
Distance between underside of cabinets and work surface of drainboard	min.	35 cm
Depth of cabinets above drainboard		30 cm

etc.

BACKGROUNDS

The reports also contain the backgrounds involved. This can be illustrated with the following passage from the report on "Housing Requirements with respect to mental and physical recreation and activities", in which the point is raised that each member of the family should have a room of his own:

> When discussing the requirements for activity and recreation of each member of the family it was found that, in addition to the common living space, the infant, the school-going child and the adolescent, as well as the husband and in some cases also the wife, should have a domain of their own, thus in many cases a room of their own.
>
> For the younger children a shared room is more acceptable than for the older children, who can hardly do without a room of their own. Hence, it is a first requirement for the habitability of the dwelling that the bedrooms should also be suitable for dwelling purposes. This implies that a not too expensive intermittent heating is indispensable.
>
> To provide efficient solutions for this will prove to be one of the most serious problems. A further investigation will have to be carried out to establish the most suitable form of heating for this purpose: central heating, gas heating, etc. For very large families it will not be necessary to provide a separate room for each member of the family in view of the greater flexibility which a family of this type presents.

This passage shows that the results of this study are not made to measure. It is not sufficient just to copy the data furnished. They must be interpreted in the right way and an effort must be made to find new combinations and the required degree of flexibility, like at the exhibition "Everyman's home of tomorrow", in which a group of young architects under the direction of W. van Tijen have realised the requirements and desiderata presented by the results of the study as far as possible.

In this flat a clear distinction has been made between bedrooms and living-rooms, an attempt hitherto only made in the single-family house (living-rooms on the ground floor and bedrooms on the floor above). This advantage of the single-family house has now also been introduced for flats. The multi-purpose room,which is commonly provided in many countries and has more than proved its value, has been realised in this dwelling in the form of a play corridor. Together with the children's bedrooms this space is a children's domain with many possibilities, while, moreover, it provides excellent insulation between the living-room and the kitchen on the one hand, and the children's bedroom on the other.

Another point in this connection is that in the reports on the study it is recommended that an effort should be made to reduce the noise level in the dwelling both by the application of sound-absorbing materials and by a proper arrangement of the rooms (*e.g.* no bedrooms next to a common staircase).

In a way the design of "Everyman's home of tomorrow" can be regarded as one of the results of the study. However, it should only be regarded as a typical idea and it is not yet a prototype to be put into production (Fig. 4).

Another result of the way in which the study was organised is to bring the housewife into the picture in a very early stage, even before the architect starts on his design. Information becomes available on the point of view of the user of the dwelling, even though this does not provide anything definite about the desiderata of the individual future occupant.

CONTINUATION AND PERSPECTIVES

A milestone has been reached with the publication of the reports and with the realisation of the results of the study in "Everyman's home of tomorrow", but the end of the road has certainly not yet been reached. In fact, it is open to question whether there is an end to this road at all. The great mobility of our society and the rapid progress in engineering alone make it necessary to revise and supplement the reports frequently. There are yet a number of other aspects which necessitate continuation of the study.

The results of the study should find their way into building practice not only as regards the

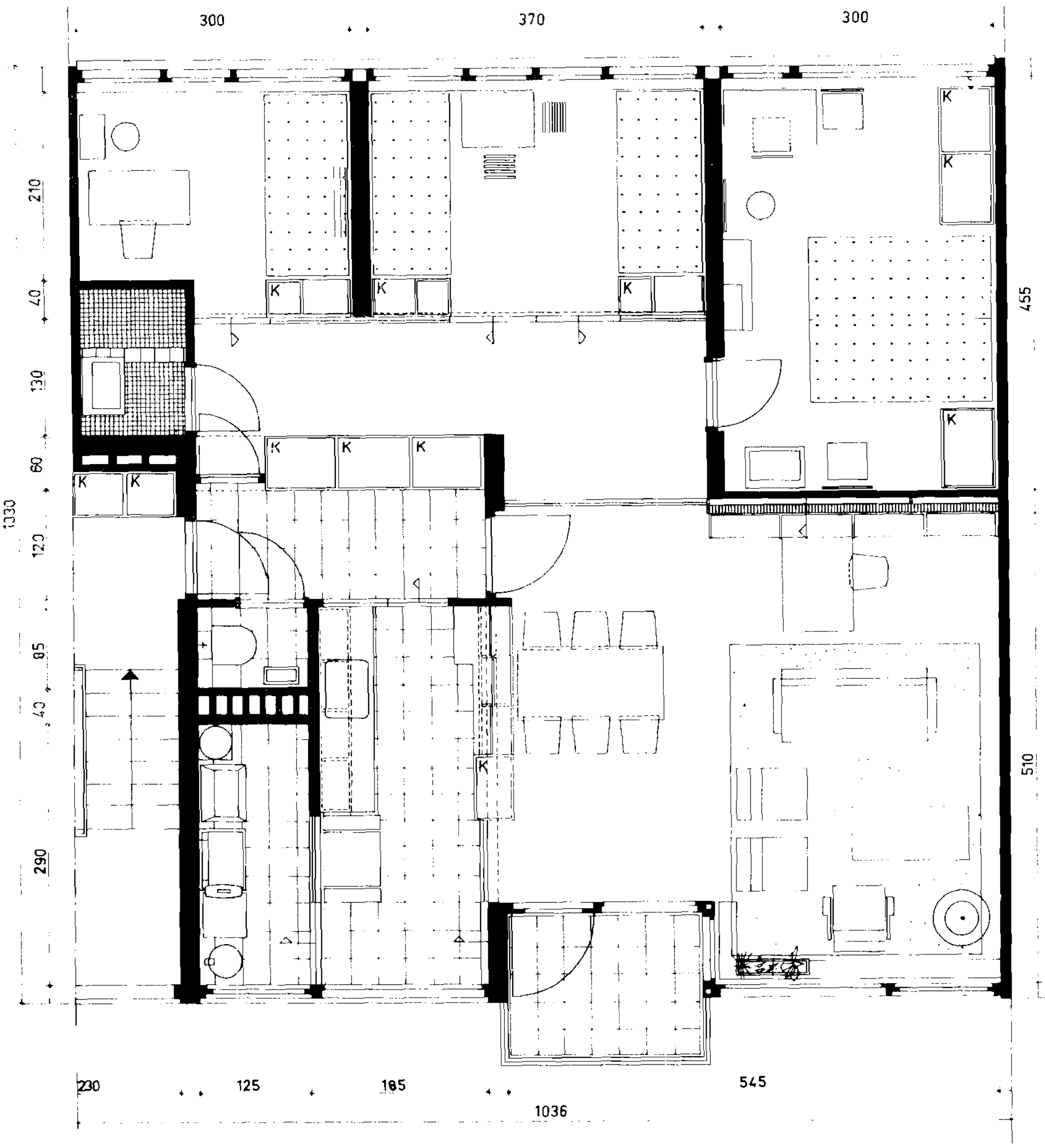


Fig. 4. "Everyman's home of tomorrow".

dimensions of the kitchen equipment or of the laundering facilities, but especially as regards the "backgrounds". It will be necessary, therefore, to develop a prototype of "Everyman's home of tomorrow", of which the costs permit large-scale realisation on behalf of low-cost housing.

The standard of "Everyman's Home" could not be obtained on a large scale even now. The thousands of premium dwellings produced in the Netherlands could well be "Everyman's Homes" as regards area and finish without involving any difficulties from the financial point of view. For the broader sections of the population, however, they are still too expensive. Considering the development of low-cost housing in recent decades, there is no doubt that in the near future there will be a general demand backed by the necessary funds for a dwelling of the "Everyman's Home" type. The present dwellings with a total floor space of from 70 to 90 m^2 at a price of Dfl 20,000 indicate that we are no longer so very far removed from the standard "Everyman's Home", which has a floor space of approx. 100 m^2. This will certainly necessitate budget changes, but I believe that the need for efficient housing will be so generally felt that people will be prepared to make the necessary sacrifices. Apart from developing a prototype, it will be necessary to devote closer attention to numerous other problems. It is essential that the insight should be both deepened and widened. Some attempts in this direction have already been made. A study is being made, for example, of the dimensions and layout of cupboards, deepening the basic knowledge of storage space hitherto acquired. The widening of the scope of the study is illustrated by the work recently taken in hand on the development of housing accommodation for independent persons. So far the study has been confined to dwellings for the family.

WOMEN'S ADVISORY COMMITTEES

The idea of bringing the housewife, thus the user of the dwelling, into the picture is quite a new feature for functional studies. That this is certainly not the only way in which the Dutch housewife can exercise her influence in the sphere of house building, since "Women's Advisory Committees for House Building" have been set up in a number of Dutch municipalities. The task of these committees is to assess house-building plans from the point of view of the housewife, to suggest improvements and, in some cases, to institute inquiries into and make a study of, for example, the establishment of central laundry facilities in a new neighbourhood.

In some towns such committees were set up on the initiative of lady members of the town council, by a federation of women's associations or by the mayor and councillors of the municipality concerned. The methods adopted by the committees for the performance of their task also vary from town to town. Generally, the procedure followed is that the women's advisory committees receive municipal house-building plans for low-rent or premium-built housing or similar plans of building societies for assessment and subsequent discussion with the architect concerned or with a technical official. It is no doubt very desirable that the members of the various advisory committees should perform their task as expertly as possible and it is expected that the study "Functional Principles of the Dwelling" will also constitute a valuable contribution in this respect. It is satisfactory to note that study days have been organised for the women's advisory committees at which the functional studies and the design of "Everyman's home of tomorrow" are explained and that it is intended to organise more meetings of this type in the future.

ARCHITECTURE AND FUNCTIONAL STUDIES

In conclusion, it will be worth while to devote some attention to a point which has been the subject of numerous discussions: namely, the relationship between architecture and functionalism.

In the Netherlands the functional study has been applied for a number of specific reasons. The labour market, the shortage of materials and, in fact, the whole of the economic and social life made it essential in the postwar years for the government to play a very active part in house building.

The efforts of the government were not confined to increasing the production of houses to the fullest possible extent. The quality also had to be of an acceptable standard.

Qualitative requirements were combined with the financing schemes and the licensing policy, but these requirements are based on a kind of general opinion of what is and what is not acceptable, which is not exactly an objective yardstick. Therefore, the requirements were subject to a fair amount of fluctuation and were adapted to circumstances and to the pessimistic or optimistic expectations of the moment. The architect was confronted with different "standards" all the time and in each individual case he had to make allowance for different regulations. Functional studies of the dwelling give the "standards" a steadier character. This does not in any way imply that the studies must immediately be raised to the level of standards. In various respects the level indicated as desirable is at present still too high for the Netherlands, although not entirely unattainable. The functional studies, however, indicate a level which can be used to test the level indicated by the authorities and to draw attention to the points which require improvement.

We have touched on the subject of the practical policy of Dutch housing. It is worth while to revert to a fundamental aspect of the problem. The architect is expected to have insight into the "processes", *i.e.* the actions, functions, etc., which will ultimately have to be performed in the building. As a dwelling is a place where it should be possible to cook and eat, bring up children, receive visitors, sleep, study, listen to the radio, watch television and nurse the sick, this "process" of living in a dwelling is more complicated than would appear at first sight.

Mr. H. B. J. Witte, former Minister of Housing and Building of the Netherlands, once said: "The building of a dwelling is still regarded too much as a fairly simple matter, of which the problematics can be intuitively sensed by any architect and any principal. We have certainly not yet advanced that far. The dwelling is an extremely complicated mechanism. It is at once a hotel, a restaurant, a church, a café, a place of recreation, a workshop, a laundry, a children's playground, a study, etc. It is very difficult to establish a harmonious relationship between all these things."

In view of the importance of all these varying functions it is essential that they should be performed in a proper manner. The layout of the dwelling should not determine what functions can or cannot be performed and it should not be left to the occupants to adapt themselves to the dwellings as well as possible. The object of the functional studies is to turn this state of affairs the other way round.

The first thing to be done is to formulate the requirements of the family and the individual members of the family and only then can the layout of the dwelling be laid down on the strength of these requirements. Therefore, the functional studies give the architect insight into the process and provide him with fundamental data for his design.

The sociological aspects of the location of housing projects

UDC 301 : 728 : 011.22

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As this report may serve both as a contribution for the CIB Congress and as a basis for a study by the "Conseil Supérieur" of the "Institut National du Logement" of Belgium, its title might, in line with the latter study, better read: Introduction to the study on standard specifications and norms of location of living quarters, dwellings, etc.

Since this study may lead to legislation, not only social but also human and economic aspects must be scrutinised, and the variety of interwoven factors can hardly be dealt with separately.

The author, not being a sociologist, will gladly leave it to that profession to judge the importance of his findings. He takes the viewpoint of the town planner and thus the study corresponds with the particular mission of his Institute to help prepare laws that fix location standards.

This report presents general thoughts, studies existing conditions, develops a synthesis, derives principles, and concludes with a programme aimed at their application.

LOCATION OF DWELLINGS

The problem of developing housing projects is as many-sided and as interesting as the functions such development is based upon. Towns were built to meet military, administrative, religious, cultural and commercial needs. Smaller concentrations were based on needs of land cultivation. Sometimes sites were even selected by chance.

The rhythm in the composition of townships is that of fortune and misfortune, of epidemics and cataclysms, of whims and caprices of men. There is no balance between the needs of the population and their satisfaction, since these needs develop with civilisation itself and with technical progress. If the latter slows down a balance may be struck by accepting a certain amount of mediocrity.

But the advent of the machine upset everything. The various forms of exchange soared with the invention of railways, telegraph, telephone, automobiles, planes, radio, TV, etc., and civilization obtained an entirely new substructure.

Also the military world changed. Dispersion of units superseded concentration and towns with a military function lost their *raison d'être*.

The complexity of life compelled States to take an interest in many problems and the political and administrative functions of towns changed accordingly.

Also the cultural and educational function changed. Separate university towns are no longer created. Institutes of learning are scattered over a wide area in line with the tendency toward democratization of learning.

The creation of commercial concentrations today is seldom based solely on the commercial functions. Fairs are being organised everywhere since modern transport brings both goods and customers, and old traditional markets become less important. This scattering over a wide area is also found in the religious sector.

The machine entirely changed the agricultural sector and introduced a great exodus of people.

Simultaneously with these changes the character of the town itself altered. The industrial function largely dominates the other functions and has led to great agglomerations. Furthermore, there is the rapid increase in population, mainly owing to better therapeutics and food and to better transport facilities. The latter get an ever increasingly important role in modern life. It is, therefore, important to find out how these changes influenced the distribution of the population and the location of living quarters.

The creation of industrial agglomerations has long been determined almost solely by the richness in minerals of the chosen site. The railways, waterways and roads are then introduced to serve the supply of non-local materials and the transport of products and workers. Subsequently, the excellent communications attract small and medium-sized industries. Soon workers from far away must be called upon and an extra impetus is given to the rural exodus. The agglomeration must then make place for what may be termed generic functions and the development takes place in a haphazard and unpredictable fashion. There is no plan behind it but the will of speculative operators.

Housing projects and their location are also subject to these fortuitous factors. Lack of space, high density of construction, neglect of hygienic aspects and overcrowding reign supreme. Work is abundant and the employer is forced for better or for worse to provide shelter for the proletarian population. The "spontaneous" economy of the location of minerals subordinates everything.

Ad. Puissant has given us a gripping account of the agglomerations caused by industry and has taken Charleroi as an example:

"On the steep side of the Sambre river lies Charleroi, stronghold of industry. It is surrounded by a hilly countryside, with charming villages. This district has a very rich subsoil, especially in coal. So much for the land itself.

Now take a considerable number of factories, small, medium-sized and large, take some old spoilbanks covered with bushes, only very recently ploughed through by steel constructions on which dump trucks move to and fro, take the railway lines with all their special sections used by the industry and a number of level crossings which are always closed, take lots of small houses, one piled on top of the other, and some large houses with neglected, shabby gardens, take some large highways with trams running on them and a large number of narrow and crooked streets, steep and very poorly paved, add some canals to it, some rivers and a few chapels, stir it all well, throw it on the piece of land I mentioned earlier, add some smoke, dust, thunder and lightning and there you have it: the Charleroi region. . . ."

But the days when the selection of a site for the industry was only determined by richness of mineral resources are now behind us. Nowadays entirely new factors play a role. Even "natural" products and extractive industries do not escape this phenomenon. Have we not witnessed the disappearance of the vines from the Meuse Valley when easier transport allowed import of French wines? Consider the abandoned iron mines of the Ardennes. When minerals began to be treated with coke and blast furnaces set up near the coal mines started to use minerals from abroad that were found to be cheaper, the Belgian minerals were no longer required.

The coal mines of the Hainault region have been threatened ever since coal was found in Limburg, where exploitation was cheaper and where the poorer, originally agricultural population is less "particular". The creation of the European Coal and Steel Community changed the requirements for exploitation of coal and steel.

Agricultural industries, located near to the sources in the past, now have wide scope as a result of better transport. Distilleries, breweries, millers and oil factories disappeared from the countryside and gigantic plants in built-up areas replaced them.

Heavy industries are extremely mobile. With the change from wood to coke the metallurgical industry of the Ardennes moved to the Sambre and Meuse coal districts. The glass industry went from the Ardennes to the Hainault area. The terra cotta industry, initially tied up to earth and forest, then to earth and coal, can now afford to be elsewhere if a main waterway is near, as is proved by the Boom brick industry and by the refractory material industry at Hemixem. The manufacturing and processing industries follow the heavy industry wherever it may go and they may either be scattered widely or concentrated in large towns. Location of industries now depends largely on the will of man, provided that certain geographical requirements are met. It appears that there were no rules or regulations and that "chance" played a predominant role.

That is why Belgium, like other countries, has a highly industrialised capital that provides an important consumption market, that lies in the centre of a road system concentrated on the capital and that includes facilities for transport of a labour force at rates well below cost price.

We may conclude that the era of industrialisation has known two great epochs: that of the concentration of the industry on sites where raw materials were available, when man came to the place of employment, and that of industrial concentration totally free from any rule or regulation, without any consideration of human requirements and needs. In both cases it was the economic function which was the decisive factor in determining urbanisation.

PRESENT-DAY CONDITIONS

The analysis of the situation thus created in the towns will be carried out along the lines of the main components of urbanisation, which are, according to the Charter of Athens, dwelling, work, recreation (off hours) and circulation. And, in addition, education and enlightenment.

LIVING QUARTERS

The sites selected for agglomerations do not always meet the minimum requirements. Often an industrial establishment and a housing project are jammed together in a narrow valley which industry renders unsuitable to inhabit. This is the case with the Liège industrial agglomeration, which crowds the Meuse valley. Often the marshy nature of certain regions, such as the valley of the lower Haine, is accentuated by the exploitation of coal mines. This equally applies to the coal basins of the Province of Limburg and certain Ruhr districts. In other cases, the sites selected for building housing projects do not meet the necessary requirements of geography, orientation, hydrology, etc. Industrial plants nearly always coexist with living quarters, and this is why conditions in those areas are bound to be insalubrious. Sizes of towns seldom result from human decision, but instead from a bundle of forces which are either beyond human control or with which man has no wish to interfere.

This explains how monstrous urban concentrations with millions of inhabitants came into being, hotbeds for all sorts of sociological problems: running of public services at prohibitive cost, undue slowness and operational cost of urban transport, abnormally low birth rate, juvenile delinquency, increase of neurophysiological accidents, etc. These agglomerations develop at the expense of the rural areas, which suffer from the very reverse evils, *i.e.* from underpopulation which, in turn, is the reason of insufficient public facilities, in particular with regard to cultural aspects, leisure time and transport facilities.

It is for the sociologists to gauge the drawbacks just mentioned and to provide town planners and town builders with such norms for urban and rural population as may appear justified in the circumstances.

As a rule, density of living quarters in urban districts is excessive. This, of course, opens the way to evils such as physical insalubrity, moral and physical diseases, lack of urban equipment and, consequently, of social contacts. It is also up to the sociologists to set norms and standards for urban density.

In this connection it must be pointed out that insufficient density of living quarters should also be avoided. In cases such as these, rational public facilities are barred owing to prohibitive cost; hence human contacts will be too scarce to create a community. Another aspect not to be overlooked regards the integration of immigrants into a homogeneous community. R. Duocastella studies the phenomenon of adaptation of a population immigrated into the city of

Mataro, Spain [1]. He stresses in particular the regrouping of immigrants district by district and even street by street, according to their geographical origins; this, of course, adversely affects adaptation.

Similar facts have been ascertained in various towns of the Borinage coal-mining district, where Flemish miners have settled. In this connection, the power of a certain population to assimilate populations immigrating from other regions or other countries should be assessed. In Belgium, this problem is comparatively urgent owing to the large-scale immigration of foreign labour into the various Belgian coal-mining districts. Here is yet another task for the sociologist.

Particularly where localisation of living quarters is being considered, the fact should be stressed that, since these dwellings are built with a view to providing shelter for many decades to come, their natural force of inertia strongly withstands both the desirable intrinsic adaptations and the practical application of new techniques to newly constructed houses; this applies to the general adoption and practice of such new techniques, to the geography and equipment of such modern living quarters, and finally to the use of new materials.

Assuming a constant density of population in the course of time and a 100-year expected life-time of dwellings, 50% of the population would have to live in houses of at least 50 years of age, whilst 75% would be put up in living quarters of more than 25 years of age; in other words, in houses constructed by the previous generations. In the light of these facts, the delayed adaptation of dwellings to new needs and particularly to new possibilities, is obvious.

The overwhelming majority of houses is uncomfortable for want of essential and elementary equipment and facilities. The general census of the Kingdom at December 31, 1947, reveals that only 7% of the dwellings in Belgium are equipped with a bathroom.

The common system of building houses closely bordering roads and streets is a source of considerable inconveniences and complaints owing to noise, dust and traffic dangers. Not infrequently, entire blocks of houses are of such narrow construction that insalubrity is completely irretrievable.

Public facilities are ill-distributed, owing to the circumstance that urbanisation was entirely left to the initiative of speculators. Consequently, communications between residential areas and other town districts are insufficient and, moreover, dangerous, owing to unavoidable crossings of main roads, highways, etc.

Lastly, apart from a very considerable number of uncomfortable buildings which might be described as "pre-insalubrious", there are further large numbers of badly insalubrious houses that should be evacuated and demolished. The number of these may be rated at 200,000, *i.e.* approximately 6% of the Belgian total. As a rule, these slum dwellings are agglomerated in rows or blocks.

LABOUR AND THE RELATIONS BETWEEN LABOUR AND LIVING QUARTERS

Mostly the place of employment is either too near to, or too far from the worker's home. The inconveniences due to distance stand to reason. Nonetheless, it should be worth while for sociologists to examine the consequences on the morality and careers of children by a prolonged absence from home of the head of the family.

The importance of the distance between living quarters and place of employment is emphasized in the following statistical tables, which mainly refer to the situation of miners.

(1) According to the census of 1947, Table I shows for the Borinage district, town by town, the origin of workers, the site where the town's inhabitants are employed and the number of workers travelling more than one hour to reach their work.

(2) Table II shows for the mining areas Borinage, Centre, Charleroi, Liège and Campine, the origin of miners employed in the colleries at June 30, 1953 [2].

(3) Table III shows, for all miners working in Belgium, the distance between place of

[1] *Population*, January, 1957.

[2] Particulars taken from the documentary records of the Office National du Placement et du Chômage.

employment and living quarters in each coal-mining district. These data were compiled as a result of an investigation carried out in 1958 by means of an inquiry supervised by the Institut National de Statistique (National Board for Statistics), acting on instructions of the European Coal and Steel Community (C.E.C.A.).

(4) Table IV, from the same source of information, shows the details of distances in terms of time between the place of employment and the living quarters for all miners working in Belgium.

(5) Table V, also from the same source of information, shows how often miners working in Belgium return home in average.

(6) Table VI, published by the European Coal and Steel Community (C.E.C.A.), shows travelling times of more than one hour performed by miners and workers in the iron industry of the affiliated nations (1958 census).

(7) According to the 1947 census, Table VII shows the origin of the working population in the Brussels urban and suburban districts.

TABLE I

AREA OF THE "BORINAGE": MIGRATION OF WORKING PERSONS (1947 CENSUS)

	Persons working in the municipality			*Persons living in the municipality*			
Municipalities	*Total coming from elsewhere*	*Coming from the "Borinage" (included in column 1)*	*Coming from outside the "Borinage" and travelling at least one hour*	*Working in or outside the municipality but in the "Borinage"*	*Working outside the "Borinage" (total)*	*In France*	*Working outside the "Borinage" and travelling at least one hour (included in column 5)*
	1	*2*	*3*	*4*	*5*	*6*	*7*
Baudour	2260	1883	80	2126	59	6	50
Bernissart	123	8	53	983	54	—	2
Boussu	2135	1851	193	4642	197	107	172
Ciply	80	77	2	275	12	4	6
Cuesmes	3523	3052	167	4038	244	34	215
Dour	1065	1027	31	4165	145	151	137
Elouges	394	385	7	1657	27	262	9
Eugies	470	460	9	923	31	33	31
Flénu	143	128	11	2919	5	14	59
Frameries	1868	1705	163	4508	266	186	193
Ghlin	219	137	59	2365	143	5	113
Harchies	707	277	145	1267	55	9	9
Harmignies	427	341	16	437	32	—	5
Hautrage	1319	747	338	1345	53	3	19
Hensies	2585	1199	413	1271	15	135	11
Hernu	1333	1162	108	3991	133	29	17
Hyon	443	423	17	860	90	3	11
Jemappes	2407	2221	137	4917	290	27	29
La Bouverie	1093	1053	38	3165	123	50	38
Mons	7577	5974	617	9263	828	33	573
Nimy	1382	1231	56	1340	96	1	7
Pâturages	962	920	42	3618	128	15	24
Quaregnon	2006	1732	201	6569	366	21	301
Quiévrain	298	278	7	1450	57	803	53
St-Ghislain	2113	1767	113	1531	77	12	8
Tertre	2825	1708	274	1857	25	—	7
Thulin	106	92	6	783	45	116	6
Warquignies	116	99	17	336	10	8	10
Wasmes	1639	1535	71	5524	189	25	10
Wasmuël	389	376	1	1339	64	—	4
Total	42,007	33,848	3392	79,464	3859	2092	2129

TABLE II

GEOGRAPHICAL DISTRIBUTION OF BELGIAN LABOUR IN COAL MINE INDUSTRIES (SITUATION AT 30-6-1953)

Borough of residence	*Areas* *Borinage*	*Centre*	*Charleroi*	*Liège*	*Campine*
Antwerp	1	—	10	2	187
Malines	—	—	49	2	195
Turnhout	—	—	17	260	3529
Brussels	23	226	140	10	42
Louvain	2	7	177	445	1312
Nivelles	1	22	226	3	—
Brugge	—	3	4	—	10
Courtrai	840	10	1	—	5
Dixmude	7	—	—	—	1
Furnes	1	1	—	—	3
Ostend	2	—	2	—	4
Roulers	158	3	1	—	8
Thielt	13	1	1	—	9
Ypres	219	103	—	—	21
Ghent	73	183	19	1	24
Alost	129	728	38	1	6
Audenarde	945	97	11	—	21
Eerlo	—	10	—	—	7
St. Nicolas	—	1	4	—	12
Termonde	—	6	12	—	8
Mons	10680	500	13	—	1
Ath	1616	33	1	—	—
Charleroi	3	1741	14176	2	2
Soignies	258	3995	37	—	—
Thuin	8	2145	1623	1	—
Tournai	1239	11	1	—	—
Liège	1	—	1	9535	7
Huy	—	1	7	202	—
Verviers	—	—	—	988	2
Waremme	—	1	3	444	10
Namur	—	—	2483	38	—
Dinant	—	—	19	2	—
Philippeville	—	—	102	—	—
Hasselt	—	—	—	462	14381
Maseyck	—	—	—	37	5954
Tongres	1	—	1	1350	3506
Bastogne	—	—	—	1	—
Marche	—	—	—	7	—
Virton	—	—	1	—	—

TABLE III

DISTANCE IN KM BETWEEN PLACE OF WORK AND RESIDENCE FOR MINE WORKERS IN BELGIUM

(Investigation by means of inquiry undertaken by the High Authority of the European Coal and Steel Community in 1958)

Area	*—5 km*	*5—10 km*	*10—30 km*	*30—50 km*	*50—100 km*	*100 km +*	*Total*
Campine	473	167	275	77	64	21	1077
Liège	462	88	64	46	41	3	704
Charleroi	626	213	77	17	27	6	966
Centre	323	111	36	10	17	5	502
Borinage	362	126	40	18	52	6	604
Total: Mine industries	2246 (58.3%)	705 (18.3%)	492 (12.8%)	168 (4.4%)	201 (5.2%)	41 (1.6%)	3853

TABLE IV

DISTANCE IN TIME BETWEEN PLACE OF WORK AND RESIDENCE FOR MINE WORKERS IN BELGIUM

(Investigation by means of inquiry undertaken in 1958 by the High Authority of the European Coal and Steel Community)

Area	*Nationality*	*-15'*	*15-30'*	*30-45'*	*45-60'*	*1-1½ h*	*1½-2 h*	*2 h +*	*Total*
Campine	Total	460	262	140	75	66	43	31	1077
	Belgian	225	235	138	71	55	30	17	771
	Italian	121	11	—	—	—	—	—	132
	Others	114	16	2	4	11	13	14	174
Liège	Total	352	161	65	40	45	25	16	704
	Belgian	118	64	38	29	30	19	8	306
	Italian	158	59	17	4	3	—	—	241
	Others	76	38	10	7	12	6	8	157
Charleroi	Total	416	319	99	34	64	22	12	966
	Belgian	150	137	55	23	32	17	9	423
	Italian	182	127	30	8	21	4	1	373
	Others	84	55	14	3	11	1	2	170
Centre	Total	240	175	40	16	8	9	14	502
	Belgian	93	86	23	6	7	7	14	236
	Italian	106	73	15	6	1	1	—	202
	Others	41	16	2	4	—	1	—	64
Borinage	Total	312	170	29	8	23	28	34	604
	Belgian	113	80	21	4	21	27	33	299
	Italian	128	56	5	3	—	—	—	192
	Others	71	34	3	1	2	1	1	113
	Total	1780 (46.2%)	1087 (28.2%)	373 (9.7%)	173 (4.5%)	206 (5.3%)	127 (3.3%)	107 (2.8%)	3853
	Belgian	699	602	275	133	145	100	81	2035
	Italian	695	326	67	21	25	5	1	1140
	Others	386	159	31	19	36	22	25	678

From these statistical tables it appears that movements of workers to and from the places of employment are extremely considerable. Some of these people have to face incredibly long, strenuous and expensive trips to reach their place of employment.

These facts are due to industrial concentration, and are particularly striking where workers and employees in the Brussels urban and suburban districts are concerned. No doubt the reasons in this particular case have their origin in the industrial concentration being of more recent date in this area, as a result of which workers and employees had no opportunity of settling down in living quarters close to their places of employment. It is, moreover, not unlikely that the high cost of houses, flats, etc., available for sale or to let is sufficient reason to these people to keep on living in their own district, where lower housing charges compensate for the cost and inconveniences resulting from the unavoidable trip to and from work. These lower charges are accounted for by the decreasing demand for living quarters in rural areas, due to the rural exodus. Whilst employment is transferred to other regions, the perennial character of real estate causes rentals and purchase prices to decline to ensure continuity of occupation.

Whilst trips between the industrial agglomeration and the hinterland are considerable, those made within the geographical limits of the industrial centre are far from being negligible, the less so as the agglomeration comprises large numbers of inhabitants. Studies have revealed the serious character of this travelling problem, reaching the conclusion that a decrease of population in these centres is imperative.

The sociologist faces the task of finding and establishing limits to the density of population and to areas of urban agglomerations which should not be exceeded. The town planner will

TABLE V

FREQUENCY OF RETURN TO THE FAMILY OF MINE WORKERS IN BELGIUM

(Investigation by means of inquiry undertaken by the High Authority for the European Coal and Steel Community in 1958)

Area	*Nationality*	*Private households*					
		Every day	*Once per week*	*Once per fortnight*	*Monthly or irregularly*	*In holidays*	*Total*
Campine	Total	976	—	—	1	28	1005
	Belgian	767	—	—	1	1	769
	Italian	87	—	—	—	15	102
	Others	122	—	—	—	12	134
Liège	Total	591	—	—	6	44	642
	Belgian	306	—	—	—	—	306
	Italian	167	—	—	6	37	210
	Others	118	—	—	—	7	125
Charleroi	Total	749	1	1	3	113	876
	Belgian	416	1	1	—	1	419
	Italian	244	—	—	2	86	336
	Others	89	—	—	1	26	121
Centre	Total	404	—	—	—	43	447
	Belgian	236	—	—	—	—	236
	Italian	125	—	—	—	40	165
	Others	43	—	—	—	3	45
Borinage	Total	499	1	—	—	41	542
	Belgian	299	—	—	—	—	299
	Italian	132	1	—	—	24	157
	Others	68	—	—	—	17	85
	Total	3219 (91.7%)	2	1	10	269 (7.7%)	3512
Coal mine industries							
	Belgian	2024	1	1	1	2	2029
	Italian	755	1	—	8	202	970
	Others	440	—	—	1	65	506

have to suggest appropriate means of action with a view to confining or to reducing industrial centres to these limits.

CULTURAL AND RECREATIONAL ASPECTS

Considered from the cultural and recreational angle, the deficiency of built-up areas is particularly striking in rural districts. The exodus to which these districts are subjected is not an improvement.

The situation is particularly serious for schooling, whatever the level. Conditions for primary education are unfavourable owing to the shortage of pupils. Secondary schools are difficult to enter.

The "Institut National du Logement" has delimited the areas covered by the activities of evening schools for technical tuition. From this map it appears that vast areas have insufficient means of communication with these institutes.

Movements in the field of culture are equally scarce and unsatisfactory in rural districts. Lack of equipment is the barrier that impedes progress in this field. The same applies to sporting facilities. General use of TV receivers is no more than an insufficient expedient, the cultural value of which is very questionable and even far from harmless.

Generally speaking, recreational equipment and possibilities in most cities are insufficient. City-development due to private enterprise remained free from any municipal control.

TABLE VI

NUMBER OF WORKERS OF THE COUNTRIES OF THE EUROPEAN COAL AND STEEL COMMUNITY WHO LIVE AT A TRAVELLING DISTANCE OF MORE THAN ONE HOUR FROM THEIR PLACE OF WORK.

(Investigation by means of inquiry undertaken in 1958 by the High Authority of the European Coal and Steel Community)

Countries	*Coal-mine industries* × *1000*	*Steel-producing industries* × *1000*
Germany	23.7 of 551.1 *i.e.* 4.3%	12.5 of 276.6 *i.e.* 4.5%
Belgium	17.7 of 154.2 *i.e.* 11.5%	6.9 of 51.5 *i.e.* 13.4%
France	7.2 of 209.2 *i.e.* 3.5%	6.1 of 164.2 *i.e.* 3.7%
Italy	0.5 of 5.6 *i.e.* 8.9%	4.7 of 53.4 *i.e.* 8.8%
Luxemburg		1.8 of 20 *i.e.* 9%
The Netherlands	2.5 of 55.6 *i.e.* 4.5%	1.4 of 7.9 *i.e.* 17.8%

TABLE VII

WORKING POPULATION IN THE BRUSSELS AGGLOMERATION ACCORDING TO ORIGINAL BOROUGHS (1947 CENSUS)

Original borough	*Number*	*Original borough*	*Number*
Antwerp	5110	Mons	1702
Malines	6292	Soignies	3994
Turnhout	692	Thuin	559
		Tournai	743
Brussels [1]	48213		
Louvain	12030	Huy	292
Nivelles	12121	Liège	1655
		Verviers	357
Brugge	1175	Waremme	742
Dixmude	143		
Ypres	214	Hasselt	690
Courtrai	570	Maaseik	183
Ostend	491	Tongres	256
Roulers	246		
Thielt	245	Arlon	136
Furnes	151	Bastogne	67
		Marche-en-Famenne	147
Alost	18809	Neufchâteau	186
Termonde	6674	Virton	114
Eckloo	146		
Ghent	2665	Dinant	431
Audenarde	1504	Namur	2026
St. Nicolas	467	Philippeville	166
Ath	1087	Total	136,652
Charleroi	3161		

[1] Population living in the borough of Brussels outside the agglomeration of Brussels.

Municipal authorities proved incapable of compelling speculative operators to provide sufficient green areas and free ground for recreational purposes. No interference has come from government officials; indeed, legislation up to 1945 was silent in matters of territorial development.

Whilst municipalities did in fact impose on contractors the obligation of constructing roads and sewers, they have on only rare occasions shown some interest in matters of collective property in the cultural, social and recreational fields. They have neglected this problem by sheer ignorance, whilst, on the other hand, the absence of any legislation on town planning was the cause of similar carelessness at government level. In consequence of this situation, conditions of recreational facilities in industrial centres are deplorable. The Charleroi district contains 36 hectares of public parks for a population of 450,000, which means approximately 1 sq. yd. per inhabitant. The situation in other agglomerations is hardly better, if at all.

As regards the recreational centres, leisure time organisation calls for the creation of adequate equipment.

Both the authorities and private enterprise have an important task to fulfill in this field. They should undertake to organise the creation of social centres for relaxation, recreation and cultural development in all districts of comparatively sufficient importance. These centres should be erected in the immediate vicinity of the agglomerations, in preserved parks easily accessible to the public; any such parks should become municipal trust properties. Any urban agglomerations which still have this kind of natural resources on their outskirts – this applies in particular to the forests of the Charleroi and Liège districts – should make it a point of duty to prevent speculators from being a constant menace to these natural riches, the perennial character of which should be ensured, initially by way of decree and at a later stage by converting it into municipal trust property.

TRAFFIC

At the time of horse-powered traction, there was no real objection to the building of houses closely alongside traffic roads. Nowadays things are quite different. Streets and roads are a nuisance to inhabitants. Fast and dense car traffic is a source of many inconveniences of safety, hygiene and comfort. Hygienists are engaged in measuring the ill-effect of traffic noise and exhaust gas air pollution on the human organism. Conclusions will have to be drawn from these investigations with a view to establishing the standards of distance to be kept up between main traffic roads and living quarters alongside these. The main road, taken as a basis for the location of a group of dwellings, should not cause any nuisance to the residents. It should be kept fully apart from these living quarters without, however, being too distant for easy transport at the lowest possible cost. This is a matter of appropriate proportions, which the town planner knows best how to define.

CONCLUSIONS

The situation of living quarters briefly described here and considered on its intrinsic merits and its relations to work, to cultural and recreational equipment and to traffic roads, may be synthesized as follows:

(1) The absence of any rules and regulations in matters of industrial location is noted, hence the impossibility to coordinate the economic development of a district and the location of living quarters.

(2) The site of certain urban concentrations does not meet the material requirements of location.

(3) Living quarters suffer from the close vicinity of industry.

(4) Towns and industrial centres are overcrowded whilst rural districts are underpopulated.

(5) Density of living quarters is often too high, sometimes too low.

(6) Public facilities are ill-distributed.

(7) Ancient town planning and the age of houses are the main causes of discomfort in many living quarters.

(8) The number of insalubrious living quarters is considerable.

(9) Long and strenuous trips to and from work are inflicted on a considerable number of workers.

(10) Cultural and recreational facilities are inadequate, particularly in rural districts.

(11) Recreational facilities in cities are insufficient where green areas and free ground, popular relaxation centres and accessible municipal reserves are concerned.

(12) Traffic causes serious inconveniences, whether from the angles of safety, hygiene or comfort.

The sociological response to the situation of living quarters has been disclosed and explained in the course of the preceding paragraphs. Studies, investigations and research are to be carried out by sociologists, and this work should be done in association with the studies of norms and standards for the location of living quarters.

LOCATION OF LIVING QUARTERS

The principles that should be applied with a view to laying down norms and standards for the location of living quarters are founded on the hypothesis that the economic development and demographic evolution of a certain area are closely associated and interwoven; hence, the location of living quarters calls for the regulation of industrial location.

DRAFT OF PRINCIPLES

(1) Industrial location shall not be chosen haphazardly, but shall instead be subjected to rules and regulations commanding the development of the national territory, conditional on the demographic needs of each individual district, on the needs for employment of the population and on the necessity to use the existing living quarters. In this connection, these various factors shall be investigated on a long-term basis.[1]

(2) Fluidity of labour shall be ensured by adequate means of transport interconnecting the residential areas with the industrial sites.

(3) The right to work shall be coupled with the freedom of choice, materializing as a result of plurality of industries in each region.

(4) Care shall be taken that the critical point of urban congestion never be exceeded.

(5) The rural population, *i.e.* the population living on the produce of agriculture and associated enterprises, shall be mixed – to the extent of the needs for providing common facilities – with an urban population to be employed in carefully selected rural-urban centres.

(6) The national scheme for development lays down the importance and the evolution of population in each district, the volume and the employment, the means of transport, the collective equipment of national and regional interest and the reserved natural sites and parks.

(7) Each region shall be provided with a scheme for development defining the network of communications and the zoning conditional on the general instructions held in the national scheme.

(8) Each municipality shall adopt the scheme for development laid down for the area under its control, particularly in respect of the insalubrious districts to be restored to sound living conditions, of the districts to be rebuilt or to be newly created.

WORKING PLAN AND PRACTICAL APPLICATION OF PROGRAMMES

The Institut National du Logement (National Housing Board) suggests the following working plan for the study of these problems.

(1) Elaborate study of the existing situation, particularly with regard to the following subjects: (a) Relations between employment and living quarters, per district; frequency of trips to and from work, distances, duration and cost of these: influence of this travelling on the worker's productivity; how does the absence from home of the head of family affect the family life? (b) Relations between living quarters and secondary, high and technical schools. (c) Needs for work in areas with under-employment.

(2) Study of maximum sizes of the great urban centres: population, surface areas, density. Criteria of congestion and overcrowding.

(3) Study of the minimum distribution of rural population, both in quantity and in density.

[1] In the October, 1951, issue of *Population*, R. Ziegel proposes the setting at European level of the rules commanding industrial settlement and population.

(4) Study of criteria to be enforced on creating new urban concentrations: figures of population, origin of this population, time schedule, collective equipment and community spirit.

(5) Study of criteria to be applied in matters of receptivity of inhabited built-up areas where immigration and distribution of industrial population are concerned.

(6) Establishing of norms for industrial location and for the location of living quarters; application of these standards to the study of building programmes.

(7) Study of the legislation to be proposed in connection with the national scheme for development and town planning.

(8) Propositions dealing with the rules and regulations commanding industrial location as scheduled by the national scheme for development and town planning, with the methods of application of these rules, and with the administrative machinery best suited to achieve this industrial location; propositions concerning interdictions, assistance provided by the State and obligations.

(9) Propositions dealing with the materializing of building programmes, whether carried out by private enterprise or by public enterprise, dealing also with the kind of organisation capable of carrying out these programmes and, finally, with the policy to be adopted in matters of land and real estate.

(10) Study of urban renewal: methods for material and sociological investigations, propositions concerning financial assistance granted by the State to municipalities carrying out their own restoring and renovation. Problems of re-designing the structures of satellite cities and neighbouring units will be studied with a particular view to living quarters.

Housing design based on furniture and functional studies

UDC 721.011.2

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Housing represents a considerable amount of society's amassed investments. Therefore it is of great importance that the most is made of the means which are at its disposal. In recent years a lot of work has been done on rationalization of the building industry, a matter often simply regarded as a technological one or, in other words, a problem of how to use more economic materials and constructions and time-saving work methods. The fact that rationalization or increase of productivity is not only a question of rational production methods is largely ignored. It seems to be forgotten that productivity, roughly speaking, is the usable value of the product in proportion to the productive power spent. A higher productivity may just as well be gained by increasing the usable value of the product as by decreasing the contribution of productive power. In the case of housing this line of thought needs careful investigation. It is necessary to establish whether or not the usable value of the dwelling is as high as we can at present make it, and also if we can show ways of increasing the value of the dwelling without having to increase the contribution of productive power or introduce more materials, more working hours, or increase the area of the dwelling. The main task of housing research must be to ascertain the factors which decide the usable value of the dwelling and through investigations to decide on those proposals which ensure a high usable value. Research work should be carried out continuously in order to ensure that recommendations and other design data correspond to the changes in conditions and in this way do not discourage development.

The work in recent years on housing research at the Danish National Institute of Building Research has been aimed at establishing a practical useful tool for the designing architects. By means of this tool the designers can avoid a great number of the many mistakes and omissions which are found even in the latest schemes through some preliminary studies of plan types. This work has been mainly concerned with the plan solutions of the dwelling whereas research into practical detail solutions – the housewife's gadgets as well as more sociological research into the cultural pattern of certain layers of populations – has been purposely avoided.

This choice of subject was partly due to two factors. Firstly, the problem of planning of the dwelling was the most important at the time and, secondly, these investigations were expected quickly to give results suitable for publication. By research into what is demanded of dwellings it has been found that there are some elementary and quite general demands which should be fulfilled by all normal family dwellings. These demands can fairly easily be stipulated as standards to be used by the designers. First of all, space must be allowed for the normal functions: the members of the family must be able to sleep, work, eat, wash, etc. Also the dwelling must be planned so that each individual has the opportunity of being with other members of the family and of being alone.

In order to satisfy the above-mentioned functions, the dwelling must be planned with ample space for furniture and installations, including space for the use of these things.

The usable value of the dwelling cannot be measured by its size alone, because the dimensions and planning of each room determine to a great extent the possibilities of furnishing. Room area alone is not sufficient. It must be possible to use it conveniently. The lengths of the walls, the position of windows and doors are critical to the efficiency of the dwelling and must, therefore, be determined on the basis of standards for the position of furniture. The basis for setting standards of furnishing is laid in the following way. First, by investigations into dwelling an exact knowledge is acquired of what type of furniture the tenants possess, the size of each article and how each piece of furniture is placed and used. Secondly, this knowledge is compared with the demand of space for each article of furniture, based on its function, and an analysis of the furniture on the market. Standards for furnishing do not aim to dictate how to place the furniture in a certain dwelling, but make sure that there are one or more ways of placing the most common types of furniture.

Inquiries into the use of the dwelling have shown that one type of dwelling is used in several different ways, not only when the families are composed differently, but also when they are, broadly speaking, the same in number, sex and age. For example, the same type of room may by different families be used for parents, for children or for dining. It is, therefore, very important that the standards for the furnishing of each room of the dwelling are worked out in a way to allow for several different types of furnishing. In this way there is a better chance of satisfying the present and the future families' demands during the often very long span of life of the building. This demand for the possibility of changing furniture in certain rooms, when needed, creates a certain relationship of dimensions of a range of furniture, furniture groups and free areas desirable. A coordination of dimensions and the required floor areas of furniture – possibly by deciding on a furniture module or certain preferred dimensions of furniture items and groups of items – will not necessarily have to be tied to the building module. For instance, different wall thicknesses will cause the room dimensions to be non-modular.

To comply with the demands of the furnishing of individual rooms is not sufficient to ensure an appropriate utilization of the dwelling. The wrong interrelationship of rooms will

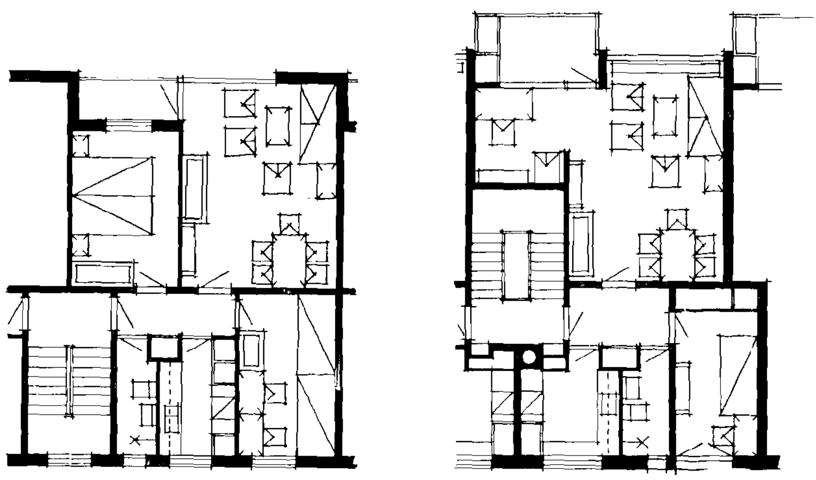

Fig. 1. Two flats from housing estates built recently in Copenhagen. Both flats have an area of 74 m^2, including balcony, and therefore the building force for each is approximately the same. However, there is a considerable difference in the usable value obtained with the requirements of an ordinary family in view. The flat on the left has three rooms, all with access from the entrance lobby, and may be furnished with four beds. The flat on the right has only two rooms and only one possible bed position, not counting the living-room. Thus the efficiency of the flat on the left is essentially higher, both in area and cost.

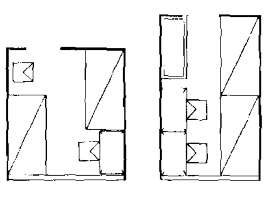

Fig. 2. Two children's bedrooms each of 10 m^2. The room on the right has dimensions enabling the beds to be placed end to end and is, therefore, the more useful.

often result in the dwelling's use being unsuitable to the particular demands of the occupants. This has been demonstrated by investigations of dwellings with different layouts. The investigations have been aimed mainly at comparing two types of plan: one in which the entrance lobby gives access to all rooms, and the other in which one or more rooms have their only access through the living-room. It is found that the usable value is far greater in the first case. Amongst other advantages the direct access to the room from the lobby gives greater freedom of choice in different uses of the room. Proposals for the access conditions of a dwelling must, therefore, first of all make the demand that all habitable rooms in normal types of dwelling should be entered from the entrance lobby or its adjacent passage. In particular, no bedroom

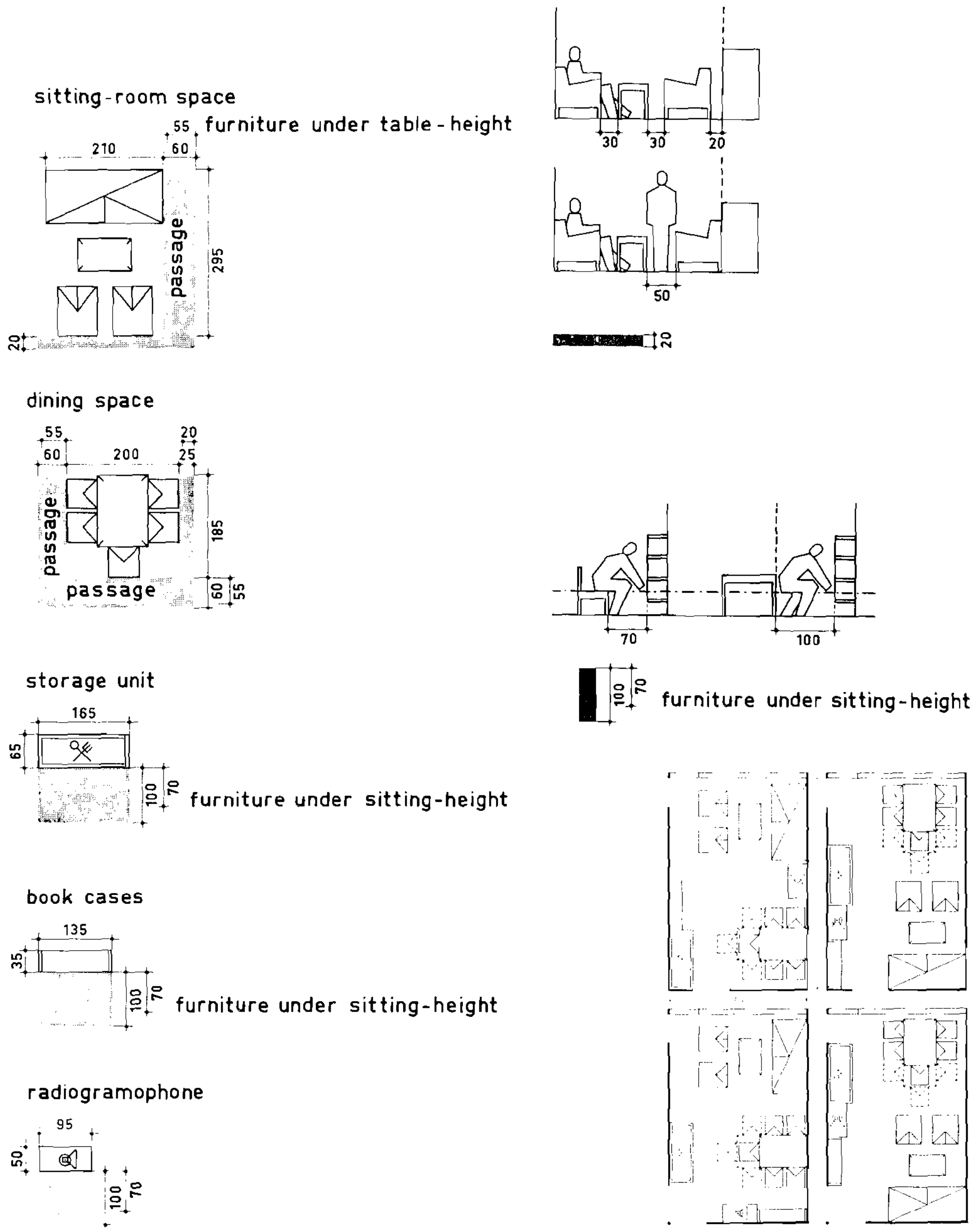

Fig. 3. Examples of proposed furnishing arrangements. On the right the group of furniture the living-room must contain is shown. The dotted squares beside the furniture indicate the areas necessary for passage in the room and for using the pieces of furniture. On the left the principle for establishing the operative areas is illustrated. The lower sketches show a sitting-room dimensioned to accommodate the various groups of furniture and, at the same time, enabling more than one possible position for each piece.

must give the only access to another habitable room. Nor should the living-room give the only access to another habitable room, as the peace in the room is disturbed and the use of the adjacent rooms restricted. The demands are of special importance in dwellings with only a few rooms.

It is evident that such demands on the access conditions of the dwelling must eliminate certain plans as unsuitable. Demands of furnishing also cause a reduction of possible solutions. This condition, however, gives a distinct perspective to work with the usable value of the

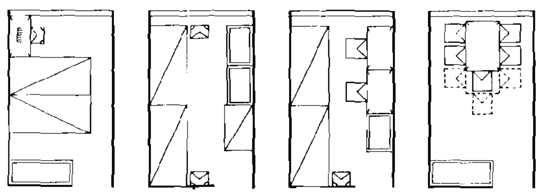

Fig. 4. Bedroom dimensioned with a special view to flexibility. As shown, the room may be used by parents, parents and a baby, two children or as a dining-room.

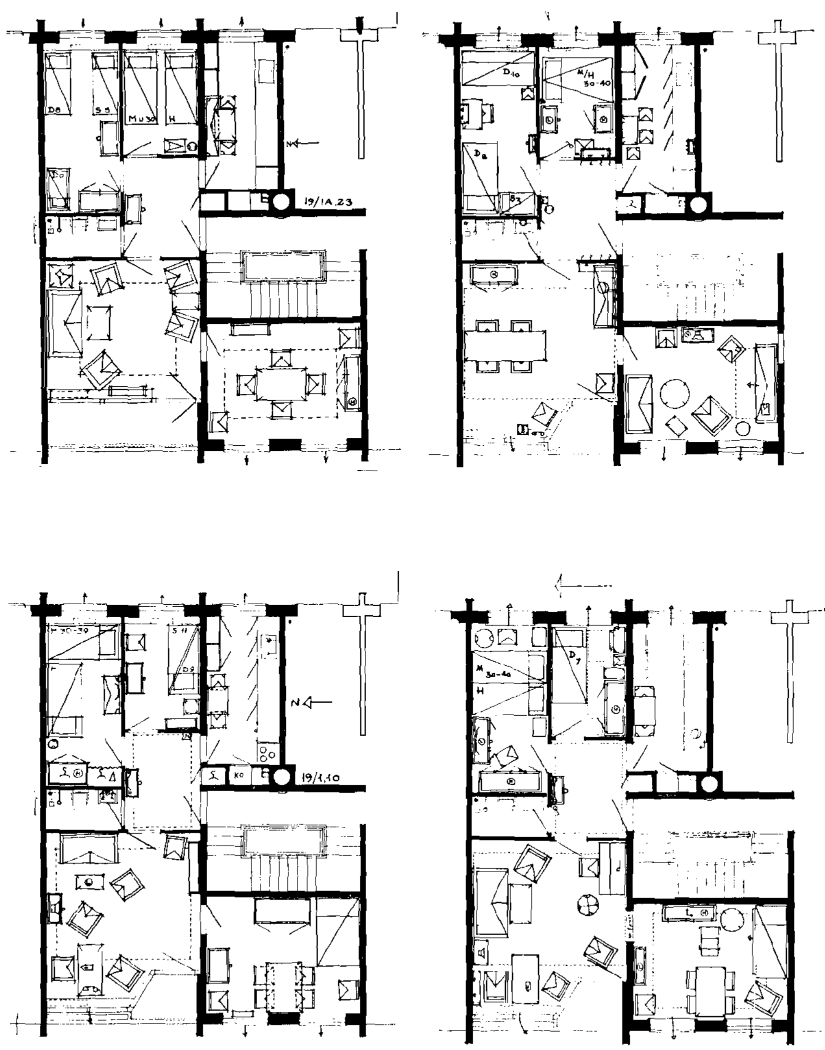

Fig. 5. Four examples from a housing survey in Copenhagen. The way the inhabitants have used the accommodation shows that the plans contained some grave errors. Firstly, the living-room will not contain the necessary furniture and, secondly, the largest bedroom, undoubtedly intended as the parents' bedroom, has access only from the living-room. The consequence of this is that most families use the largest bedroom as a living-room, usually as dining-room, and the two remaining small bedrooms are overcrowded with beds. Note specially the positions of the double beds. They have been adopted regardless of inconvenience in daily use. This can be regarded as a sign of the necessity to provide space for this type of furniture.

dwelling in view. The dwellings designed today vary from scheme to scheme and are, therefore, as a whole not suitable for industrial production. When certain standards for the dwelling have been stipulated through investigation it may be permissible to decrease the present freedom and lay down a few models or standard solutions. These will – apart from complying with the most important demands of the dwelling – be far more suitable for a rational production than the present dwellings. Comparative investigation into what is being built has shown that a great deal of plans and details is often repeated with relatively small variations. Almost identical requirements have given rise to a sort of voluntary "type-plan" making. These "type solutions" cannot all be of the same quality and the multitude of small variations makes difficult the possibility of a technical rationalization of the building industry. Research in the usable value of the dwelling can, therefore, not only lead to a greater efficiency but also create the basis of a more rational and, possibly, industrial production.

Discussion

THE STUDY OF VARIOUS TYPES OF FAMILY

INVESTIGATION

More and more it is realized that the decisions on programming, design and equipment of dwellings influence directly the social and individual life of their occupants. Today's growing large-scale production of dwellings increases the architect's need for assistance by sociologists to aid in the understanding of the needs of man in modern society.

The rapporteur Mr. P. CHOMBART DE LAUWE (France), referring to sociological work in this field in various countries, considers such work far from easy. Each family member has his own social role and family life should be understood in this sense. The analysis of family structure instead of the functional study should be our basis.

It is not bad to live, as we do, in a period of transition if only we stay aware of this fact. Simple public opinion polls seldom result in unbiassed information, which can only be acquired by the application of complicated investigation techniques. There is always the risk of a too narrow-minded judgment based exclusively on the terms of reference of the research worker, architect and housing authority.

Inquiries should, according Miss VAN RANDEN (the Netherlands), not be restricted to one but embrace all members of the family. The advice of the main user, the housewife, favoured by the rapporteur Mrs. J. MEIHUIZEN (the Netherlands) is, as Mrs. DE VESTEL (Belgium) says, undoubtedly useful, but involves the difficulty of obtaining advice from non-specialists.

Mr. FROMMES (Luxemburg) warns against the fallacies of inadequate questionnaires. The man in the street can neither read drawings nor sufficiently understand scale models. Cataloguing Man on the basis of investigation of his needs and maintaining the categories thus established too rigidly may, as says Mrs. DE VESTEL, exclude every conception of progress and liberty. Dr. KUMINEK (Poland) states that observation at one moment only is also inadequate. His organization studies the family before it moves into the new dwelling, after the move and again after two years.

Our changing society makes it necessary, according to Mr. BASART (the Netherlands), to consider sociology as a normative science and sociological research as a continuous process.

It is not important to have in every dwelling rooms indicated by their primary functions, says Prof. BAYLON (Yugoslavia), but there should be all those spaces and arrangements that correspond with all indispensable social, hygienic and functional activities. In this sense Prof. BAYLON is preparing an exhaustive general scheme.

TASK, ROLE AND TRAINING OF THE SOCIOLOGIST

What is the scope of the task of the sociologist? The rapporteur Mr. CHOMBART DE LAUWE sees as tasks the investigation into satisfaction of users and into their motivation, the determination of critical thresholds and the harmonization of needs.

Architects should see the sociologist as a member of the team and not use him to rationalize their own prejudices.

Mr. BARETS (France) finds that teams often lead to a compromise of opinions and wonders who should lead the team. The role of the sociologist is predominant in the very initial stage of the study of a dwelling project and great care is required not to act on behalf of preconceived ideas of often middle-class research workers. Mr. CHOMBART DE LAUWE concludes that the training of sociologists must embrace both fundamental and practical aspects to avoid either too theoretical an approach or an approach in the sphere of "small business".

WHY INTERNATIONAL COOPERATION?

Sociological research cannot, as technical research often can, procure a kind of universal law. Results are applicable under unique conditions that differ widely from area to area. What, then, is the use of international talks? Why do specialists favour intensified mutual contact? Can, as asks Mrs. DE VESTEL, a valuable common method of investigation, applicable everywhere, be elaborated?

The conclusion is, states Dr. KUMINEK, that different methods are applicable in all modern countries and the rapporteur Mr. CHOMBART DE LAUWE sees a common solution in the determination of thresholds of satisfaction which may greatly differ from area to area, but which allows the same method of investigation. Intensified exchange of experience is a first step.

COMMON TERMINOLOGY

Mrs. DE VESTEL and Mr. FROMMES stress the need in this respect for a common multilingual terminology of social concepts.

STUDY OF SPECIAL CASES

Mr. FROMMES indicates the abundant possibilities in the study of pathological cases, though the rapporteur Mr. CHOMBART DE LAUWE warns against oversimplification. Better surroundings do not automatically reduce tension.

Mrs. DE VESTEL asks for attention to the needs of rural populations migrating to urban areas. Lack of open spaces and inadequate technical provisions may inflict great harm.

FLEXIBILITY OF DESIGN

FREE CHOICE

Dwellings must, as states the rapporteur Mrs. MEIHUIZEN, serve several generations and Mrs. DE VESTEL adds that flexibility in design is required to permit adaptation to the changing needs in our age of progress.

Mr. SCAILLON (Belgium) wonders whether man should adapt himself to his house or the house should be adapted to man. The rapporteur Mr. CHOMBART DE LAUWE prefers the first principle though great care not to eliminate existing values, such as spontaneous help to neighbours, is required.

The rapporteurs Mr. CHOMBART DE LAUWE and Mr. C. CRAPPE (Belgium) prefer to house families in big cities in flats rather than moving them to the outskirts. Is not social life almost entirely absent in cities like Los Angeles?

STANDARDIZATION

Mr. TURIN (E.C.E. of the United Nations) emphasizes that the existing variety in designs is mainly a variety in details, and classification according to a limited number of standard types of dwelling seems quite possible. A reasonable variety of types according to family types and at reasonable prices seems well within reach. The Chairman, Mr. ARCTANDER, thinks that sociological and functional studies may well serve the purpose of standardization.

MATTERS RELATING TO DESIGN

OPEN AIR SPACES

The rapporteur Mrs. MEIHUIZEN emphasizes the need for spaces where children and housewives can freely develop themselves, and Mrs. DE VESTEL makes it clear that the role of exterior space is just as important as that of interior space.

SOUND INSULATION

Both Mr. BASART and Mr. FROMMES consider further study of soundproofing indispensable. The worst nuisance comes from sounds from neighbours, the next from street sounds, the last from sounds inside the house, but all three are serious nuisances, according Mr. CHOMBART DE LAUWE.

FURTHER NATIONAL INFORMATION

CZECHOSLOVAKIA

Mr. HRŮZA indicates the approach in long-term planning. The first step is evaluation of existing dwellings and determination of conditions for development and of users' needs. The latter are examined by discussions between architects and users, by inquiries with the help of trade unions, etc. The next step is the preparation of experimental projects, *e.g.* by architectural competitions. The following phase is elaboration of standards, obligatory over a certain period, by teams embracing various disciplines. The last phase is preparation of concrete mass projects with the fullest possible industrialization. The work is in full development and good experiences are already available.

UNITED KINGDOM

Dr. WEST, fearing that the complexity of problems suggested by Mr. CHOMBART DE LAUWE might discourage young investigators, underlines that first a few major factors to be studied should be selected.

His organization studies users' needs by means of teams; it consists of some 20 members, representing various disciplines so that different outlooks and appropriate presentation of the results achieved can be made. Housing by local authorities is studied by field surveys before and after occupation and by field and laboratory experiments with full-scale models. The aim is not to replace the architect but to provide comprehensive, reliable and unbiassed data. The team wishes to speak for the inarticulate typical client of the local authorities. In recent years research has been carried out over a wide field – acceptability of sizes, shapes, heating systems, etc. – so that standards for good housing, though never static, can better be recommended.

U.S.S.R.

Mr. BOGOMOLOV indicates how thorough long-term planning of quantitative and qualitative aspects in an over-all planning of production is envisaged.

In housing it is striven to gain a conception as a whole with due attention to community requirements. Different categories of families are taken into account, standardization is pursued and industrial production is developed.

At least 15% of the available area is used for green spaces in each project. Special provisions are made for special categories, such as the single, the aged, etc.

THE NETHERLANDS

A paper in English on "The housing problem and the integration of the disciplines concerned" by Mr. BASART and Miss LINDGREEN is made available to interested specialists.

Subject 2

DESIGN AND CALCULATION OF CONSTRUCTIONS: SAFETY FACTORS

UDC 624.04.5

MAIN REPORTS

E. TORROJA
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ADDITIONAL REPORTS

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Design and calculation of construction: safety factors

UDC 624.04.5

E. TORROJA

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A few years ago a working group was set up within the C.I.B. to study advisable imposed loads in buildings. A report on this was presented about a year ago, and consequently this subject has been included in the discussions of the current Congress.

Almost as soon as Professor Rinaldi initiated his investigations it was realised that it was pointless to study imposed loads without at the same time considering the question of safety factors. It was also realised that all this was related, in turn, to the strength of materials. This subject really goes beyond the scope of activities of the C.I.B., and belongs more properly to other organisations of an international character, such as the European Concrete Committee. This committee concerned itself actively with these matters in the field of reinforced concrete structures.

Consequently, a joint committee was formed between the two organisations (their findings are presented in a separate report), consisting of Messrs. Rinaldi, Rüsch, Mazure, Esquillan, Thomas and myself.

The ideas previously elaborated by Levi, Prat and Freudenthal, among others, proved most useful, as well as the statistical information collected by Paez and applied to a statistical and mathematical study of the problem. All this prior work constituted the starting basis of the investigation.

Having marshalled all these facts, the Joint Committee rapidly reached the agreement that, it not being possible to reduce to nil the probability of collapse, it is advisable to relate the optimum estimated probability of collapse to the minimum generalised cost of construction, *i.e.* the sum of the cost of the structure and the product of the probability of collapse multiplied by the cost of construction, plus the estimated damage in the event of collapse. However, the application of this principle leads to highly complicated calculations, which are most inconvenient in practical application.

The probability of collapse is a function of a set of other probabilities, *e.g.* that the loads may surpass the design estimate, that the strength or characteristic limiting values of the materials may be smaller than anticipated, that the assumptions in the calculations do not exactly correspond with the facts (both as regards the divergence between the theoretical hypothesis underlying these calculations and the true rheological behaviour of the materials, and because actual calculation errors may be included in these calculations) and, finally, because workmanship is always liable to imperfections which are difficult to avoid in view of the complex nature of the human element and material factors involved.

The fact that many of the statistical laws describing these phenomena do not have a Gaussian distribution or even a symmetrical one, enormously complicates the study of the combined probabilities. Levi's idea of employing logarithmic laws certainly simplifies the problem and even without resorting to this technique satisfactory results can be reached, as Paez has shown, though at the cost of much greater complexity. But the Committee decided that in any case it was better, if only provisionally, to obtain design laws which should be as simple as possible, without attempting suddenly to propose exceedingly revolutionary methods.

Hence the proposal of the Joint Committee was limited to the following: firstly, to establish certain, simply formulated criteria defining the design imposed loads and, secondly, the limiting strength properties of the materials. These formulations should take account of the greater or smaller deviations which, in each particular case, the various types of loads or materials may exhibit.

The type of formula adopted and discussed in the Report of the Joint Committee is of the form $CM\,(1 \pm \delta)$, where C is a safety factor, M is the corresponding mean value and δ the coefficient of variation. This formula differs from that proposed by other authors, who have suggested an expression of the form $M(1 \pm k\delta)$.

The Joint Committee provisionally adopted the first of these two formulae, not only because it is simpler than the more general one, given by $M(1 \pm k\delta)$, but also because they feel that this second formula does not express other facts, in addition to the actual deviation of the phenomenon (either the load or the strength of the material), which are at least as important. These other facts are, for example, the inaccuracy in placing the reinforcement within concrete, errors in the alignment and geometry of structural parts, variations in stiffness of foundations and the possibility of other accidents, which are either unforeseen or unsatisfactorily anticipated due to weather circumstances or to accidents which cannot be estimated, etc. All these possible sources of error can best be covered by a factor C, which multiplies the whole expression.

These are matters of opinion, and such opinions are more likely to differ than to coincide. But there is a necessity of more compelling power than personal views which makes it necessary to adopt a single solution. I do not think that it is for the members of this Congress or that this is the right moment or circumstance to embark upon a detailed technical discussion, which would easily become very lengthy and which might even lead to friction when the large number of possible opinions exponentially decreases the probability of reaching agreement.

The proposal of the Joint Committee merely seeks to solve the problem in relation to the limiting strength of the material. Besides this, as mentioned in the Gvozdev, Streletsky and Tahl report, there remain other questions to consider before the dimensions of any structure can be fixed. Such questions include the limiting conditions for cracks in concrete (which are acceptable only within certain limitations), maximum permissible deformation, etc. There is also the possibility of introducing a third multiplying factor – or a corrector of the two proposed by the Joint Committee – to modulate the range of the above sources of weakness in terms of the uses and functional circumstances of the particular structure that is being considered. But it is difficult to envisage a statistical and mathematical means of arriving objectively at specific values for this kind of problem. Whether it is done in one manner or another, it is certainly necessary to establish values to provide guidance in practice: values that should incorporate the largest possible amount of information and thought on the subject.

The delegates from Eastern Europe were not present until after the work of the Joint Committee had been completed and summarised in the report compiled by this Congress. Consequently, among the papers submitted to the Congress there are new and important reports of these delegations but none from Western Europe. Such reports include the following:

(a) *Research on the concrete strength theory*, by O. Y. Berg. A new theory of failure is presented, applicable to stone materials and founded on the cleavage effect in heterogeneous materials, such as concrete.

(b) *Shear strength of reinforced concrete elements*, by M. S. Borishansky. This presents the theory and formulae utilized in U.S.S.R. for the calculation of beams submitted to the combined action of bending moments and shear forces. It is one of the most interesting contributions to this subject, which so greatly engrosses specialists in all parts of the world.

(c) *Investigations into the rigidity and the opening up of cracks in reinforced concrete bending members*, by V. I. Murashev. This paper summarizes the work of this well-known specialist on the subject of calculating the deflections to be expected in beams under bending. This is a particularly important problem at present with the increasing use of high-tensile steels, which lead to much larger stresses and hence also larger deformations than in the case of normal quality steels. In many cases the minimum dimensions of a structural part may therefore be fixed by the permissible maximum deflections rather than by questions of strength.

(d) *Computing shells by the method of critical equilibrium*, by A. R. Rzhanitsin, presents an original method of fixing the limiting loads to be supported by a shell. In a way it can be regarded as a praiseworthy attempt to generalise the methods of lines of failure, due to Professor Johanssen. This subject has also been investigated in Great Britain by Professor Baker. If this can be experimentally supported, it would represent a most important simplification of the complex theories which are currently used to analyse the strength of these structural forms.

In the field of metal structures, the following should be mentioned:

(e) *An investigation into the actual conditions of work and the limit states of steel skeletons of industrial buildings*, by E. I. Belenya. This paper discovers the appreciable differences which are experimentally observed between the strength of this type of structure and the theoretically calculated results which are obtained currently on the basis of existing hypotheses. Related to this problem, and independently of the material, there is the problem of the redistribution of moments in statically determinate structures. Both matters are dealt with in this paper.

(f) [1] *Redistribution des moments dans les poutres continues d'après la théorie des déformations limites*, by M. Tichy. This paper demonstrates the practical difficulties involved in calculations when taking into account the real, non-linear, stress-strain diagrams of materials.

(g) [1] *Zufällig veränderliche Nachgiebigkeit bei den Durchlaufträgern und Rahmenkonstruktionen*, by M. Tichy and M. Vorlicek. This introduces, for the first time as far as I am aware, the concept of statistical variability in the flexibility indices along beams, such as they may arise in practice.

In the field of prestressed concrete only one paper was submitted:

(h) [1] *Vorschriften für die Bruchmomentbemessung der Spannbetonquerschnitte*, by J. Krohov. This work crudely indicates the unjustified difference in criterion, as applied on the one hand to the own-weight and, on the other, to the imposed loads, in accordance with present-day requirements of the specifications of the various countries.

I have left to the last, because of its importance, the following report, of a general character:

(i) *Present state and current problems of structural design*, by A. A. Gvozdev, N. S. Streletsky and K. E. Tahl. This paper constitutes a first-class general exposition of the current situation of the combined set of problems comprising the basic calculations of structures: not only concrete and steel structures, but also stone, brick and timber structures. It provides guidance for research workers in the immediate future. The present brief commentary on this paper, for whose proper judgment and comment I lack the necessary time and capacity, shows the enormous quantity of problems – perhaps problems of detail, but nonetheless very important – which arise when it is attempted to advance from the general principles to the practical applications of calculating methods applicable to each type of structure and each kind of constructional medium. The volume of problems is so great and it requires such a varied measure of specialization that this is not the proper place to tackle them, nor is it the function of the C.I.B. to attempt the encompass the whole field. This field is at present distributed among many associations and organisations, both national and international.

Making recommendations on the values of specific imposed loads for the various types of construction projects seems to be a typical form of activity of the C.I.B., and it would not appear that what it does in this direction could interfere with or molest other organisations. As an international organisation specially created to deal with problems connected specifically with housing, and covering an enormous variety of facets – human, social, technical and legal – it has the authority and, in a sense, the responsibility to deal with these questions, and its activity in that well-defined field should be well received by all.

Having made recommendations on the conditions for minimum safe strength and for the imposed loads that should be applicable to housing it would be important for the C.I.B. to occupy itself also, through its own working groups, with the setting up of specifications for

[1] Papers (f), (g) and (h) not included in this book.

other types of buildings (hospitals, schools, public halls, etc.). On the other hand, I believe that it is the mission and responsibility of other organisations specific to each type of problem (and whose existence in large numbers evidently proves the complexity of the field and the multiplicity of its specialised aspects) to deal with the very complex detail of calculation methods as they are applicable to metal, reinforced concrete, prestressed concrete and other structures. The International Association for Bridge and Structural Engineering, the Soil Mechanics Association, the organisation dealing with shell structures and those dealing with welding and with applied mechanics, the European Committee for Concrete, The International Union of Laboratories for Testing Building Materials and many others are occupying themselves actively with these matters. They share these activities in a friendly cooperation and noble competition.

The C.I.B. has full confidence in these organisations, and can continue to collaborate with them, as it has done up to the present (with the C.E.B.), considering those problems whose social purpose demands that it seeks the aid of other technologies.

Furthermore, the contributions submitted to this Committee show an agreement of opinion on the development of the principles and systems based on limit design in preference to the classical idea of permissible stresses. There is also agreement on the fundamental criteria that safety should be calculated by probability or statistical mathematical theory. Hence I feel that the results of this meeting could be well summarized as follows.

CONCLUSIONS

1. The normal imposed load of persons and furniture for housing may be fixed at 150 kg/m^2.

2. The proposal of the Joint C.I.B.-C.E.B. Committee may serve as a starting point for the calculation of concrete and steel structures of ordinary buildings.

3. It would be important to complete an investigation whereby a third factor of safety could be determined. This would be a correction factor applicable to cases of structures exposed to weathering, or special kinds of structural parts of various types.

4. To define the appropriate permissible limits of states of fissuration in reinforced and prestressed concrete and for fixing the maximum allowable deflections, it would be important to recommend to the pertinent organisations and, especially, the European Concrete Committee and the International Federation for Prestressing, that the necessary studies be undertaken. The C.I.B., for its part, would offer what collaboration these organisations might require of it, considering that the C.I.B. is specialised in the functional problems of housing.

5. It would be advantageous if the C.I.B. were to organise a working group whose object would be to determine the bases for calculation and safety applicable to stone and brick structures and to timber structures. These are of the greatest importance in building. The C.I.B. should seek the aid, in this event, of specialised bodies which are occupied with problems related to these materials.

6. It is also proposed to set up a working group to investigate the imposed loads which are appropriate to such types of buildings as hospitals, schools and public halls.

The present state and current problems of structural design

UDC 624.04

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It is generally believed that the theoretical foundation of practical methods of structural design rests on structural mechanics in a broad sense, including the statics and dynamics of systems that are composed of beams and trusses, the theory of elasticity, the theory of plasticity and other branches dealing with the influence of forces on bodies subject to deformation.

In making the calculations it is necessary, of course, to proceed from the nature and values of mechanical actions upon structures and to define the numerical limits of usefulness of the building materials (*e.g.* strengths and design unit) appropriately to their qualities and service conditions.

The economic aspect of the durability problem is of primary importance. Therefore, it would be reasonable to take into account not only the mechanical but also the physical and chemical influences of environment upon the structures.

In reality, the development of the above-mentioned branches of knowledge is not taking place in a well-balanced way, and the practical design of structures is somewhat one-sided. The structural mechanics of elastic media and elastic systems has developed into an extensive subject possessing a rich literature. The method of taking non-elastic phenomena is being developed, but the practical requirements are far from being satisfied. Little attention has been given to the study of mechanical actions upon structures. Much has remained unchanged for decades due to established tradition. Though the investigations of materials are sometimes rather extensive, what is known about them is sometimes inadequate and the form is inconvenient from the point of view of the structural design. Moreover, durability is almost completely ignored in practical design.

Structural mechanics grew and developed in response to practical requirements. In the course of this progress, however, its more studied branches became independent subjects whose theoretical significance has been increasingly predominant over their practical application. As a theoretical subject, structural mechanics is to a great extent detached from the real materials and studies instead ideally elastic or plastic bodies, etc. This made it possible to obtain results of a very broad significance (elasticity, for example, is a property inherent in any material) but at the same time gave them a specific quality. Also the abstracting from the whole structure of flat units or other units and considering those independently led to idealised substitutes for the real structures. Though the latter are convenient due to their easy observability, they give an inadequate reflection of the actual state of affairs. The development of structural mechanics along these lines was perfectly legitimate and, at the same time, fruitful for the progress of design work and construction in general: the critical analysis and choice of design solutions employed by the structural engineer, the broad variety of structural designs in modern construction, as well as the evolution and appearance of new structural forms, are largely due to the successes of structural mechanics in its theoretical aspect, which has greatly broadened the designer's horizon.

The principal aim of structural mechanics is the determination of stress and strain conditions under the action of given factors in every particular point and at any particular moment of investigated schemes and in dynamic problems.

True, in structural mechanics there are works betraying a synthetical trend, which makes it possible to search for design schemes conforming to the combination of requirements set in advance.

The creation by Professor I. M. Rabinovich of a broad range of trusses serves as a distinct illustration of the fruitfulness of such investigations. There are still very few reports of investigation of the synthetic trend in structural mechanics, perhaps because of the great diversity of requirements for structures and the possibility of meeting them by various types of construction.

Practical computation demands that structural mechanics should have certain methods of estimating non-elastic deformations, such as the plastic creep of wood, the creep and plasticity of steel, mortars and concrete, the formation and growth of cracks in stone, concrete and reinforced concrete structures and other phenomena characteristic of various materials.

Indeed, the influence of these factors on the state of structures can, as shown by experience, be very important, whereas calculation based on classical methods, either underestimating these factors or disregarding them altogether, frequently proves in actual fact to be a very rough approximation to reality, notwithstanding their apparent harmony and accuracy.

The elastic characteristics of materials are the same in principle, but different materials have their own peculiar ways of deviation from elasticity. This has put great obstacles in the way of creating more advanced theories which, according to the above, must be numerous and mostly non-linear. Practice makes it imperative, however, to introduce basic amendments which take into account the deficiency of the simplified designs employed. This would lead us to the consideration of complex spatial systems and evaluation of interactions of numerous and often heterogeneous construction elements and the structure foundations. To have all these requirements satisfied would seriously overburden structural mechanics and deprive it of those simplifications and schematization of various phenomena which ensured its successful development in the past. Several ways can be outlined, however, which can facilitate the solution of the task.

In contrast to the calculation of elastic systems, which ordinarily makes it possible to determine the stress and strain conditions at any stage of loading, a special method of limiting equilibrium is being developed. This method does not permit the prediction of deformations and frequently fails to detect the state of stress in any part of the structure. Nevertheless, it helps to ascertain the conditions of the advent of limiting equilibrium; for instance, to find the load intensity putting the structure into this state.

The sphere of application of the limiting equilibrium method, discovered at the time of Coulomb (1773), became increasingly narrow throughout the 19th century in view of the successful development of the theory of elastic system calculation. It was only used in connection with determining earth pressure. Its florescence came with the successes of the theory of plasticity.

The method of limit equilibrium includes the equalisation of bending moments in steel continuous beams used in a number of countries, in particular in USSR, and also the calculation of cross sections of beams working statically at the plastic stage. It usually takes into consideration only stresses normal to the principal cross sections, though the effect of more complex stress conditions on the plastic strain development may be substantial. The USSR building code considers this fact and includes the normal (σ_x) and tangential (τ_x) stresses in the calculation. The method of taking into account the stresses σ_y is also worked out. For short beams the stresses τ_{xy} and σ_y may and should be taken into consideration.

When the method of limit equilibrium is used for the strength calculations of reinforced sections, then the stress throughout the compressed zone may be taken to be equal to the yield-point stress. Theoretical and experimental investigations show that the error introduced by eccentric tension and bending when the calculation is based on this simplified method is negligible. The method has been accepted in the USSR and allowed in the USA and also in the other countries for the ultimate strength calculation. In the Soviet Union this method is used also for the design of structural members resisting eccentric loads if the reinforcement on one side of the section reaches the yield-point stress, and also for masonry constructions subjected to vertical loads applied with an eccentricity between 0.225 and 0.35 of the cross section depth.

Since the 1930s a number of works have been written, including remarkable investigations by K. W. Johanson, on the calculation of the load-carrying capacity of concrete slabs, whence the limit equilibrium method was extended to new fields. More clear grounding of the limit equilibrium method was contained in principles for which the first valid proof, to our knowledge, was suggested by A. A. Gvozdev in 1936. Considering the properties of materials themselves the use of the limit equilibrium method for statically indeterminate systems might be more suitable for steel constructions. However, it was more effective for reinforced concrete and prestressed concrete structures.

Actually, the carrying capacity of a steel construction is often restricted by the loss of stability. Besides this, the growth of plastic deformations of steel leads to large residual displacements hindering the use of the structure. The definition of allowable residual deformations would solve the problems of the ranges with which plastic deformations of steel constructions may be used. Therefore this definition should be considered to be of great current importance.

In reinforced concrete, statically indeterminate structures, the appearance of extreme deformations before the exhaustion of their bearing capacity is possible but less likely. Therefore, the design of many systems that are composed of beams, columns and slabs may be made in the ultimate stage by using the limit equilibrium method. In the USSR, in particular, this method has been adapted from the calculation of reinforced concrete slabs supported on four sides, plates, beams and frames. In systems that are composed of beams and columns the redistribution of stresses is allowed. However, in this case not only the conditions of equilibrium should be satisfied but also the value of the stresses defining the cross section dimensions should be not less than 70% of the stresses computed for the elastic system.

At the present time the application of the limit equilibrium method to shell design is attracting much attention. The report *Calculation of shells by the limit equilibrium method* submitted to the Congress by A. R. Rzhanitsin supports this statement.

It is, of course, possible to use other ways to overcome difficulties in estimating the interaction of various parts of the structure and the foundation and in taking a fuller account of the properties of materials. In case the problems become too cumbersome for analytical solution, computing machines and model investigation must be applied. The task of practical calculation is to determine the most expedient dimensions of the structure and its individual conventional elements or to examine the designs for the economy and purpose of the structure, but not the detection of the stress state. Using all achievements of various branches of structural mechanics, the practical design draws on other sources too. Even though structural mechanics is based on experiment, it tries to derive a small number of initial propositions and to deduce from these any further conclusions.

Meanwhile, experimental investigations yield empirical data which can be used with great success for the solution of more specific problems. There is no good reason to renounce them. Therefore, semi-empirical methods retain a prominent place in practical computation.

The application of different theories based on the idealization of real conditions may be not always and completely appreciated in the theoretical way. The application of theories is often controlled on an experimental basis and the range of application is established in the form of empirical relations also in an experimental way. This is especially true of the design of elastic systems, the limit equilibrium method and other theories used in the structural calculations.

The difficult problem of shear resistance in reinforced concrete structures attracts the attention of many research workers at present. The requirement for the reinforcement to resist completely the tensile stress diagram is in contradiction with experimental data and for a long time it has been relaxed in various ways by the codes of many countries. The method adopted in the USSR is explained in a paper submitted to the Congress by M. S. Borishansky. Equilibrium conditions are set out for part of a beam separated by an oblique cross section; only one part of the transverse force resisted by the concrete compression area would be difficult to determine in advance.

Experimental data and an empirical formula are, therefore, used to fill the gap. Though this formula probably does not take account of all influencing factors, it helps to achieve a much better conformity between computation results and experimental data than could be made with the help of the "classical" theory.

As a rule, the stiffness of reinforced concrete structures was not in the past checked by calculation. It was considered adequate to use rules establishing the required depth of cross section in different parts of the span. While in the past this was acceptable, today the calculation of deflection in reinforced concrete structures has become indispensable for a number of reasons. The prevailing use of prefabricated structural members leads to frequent use of one-span beams or slabs without end restraint. The construction height is often deliberately reduced in order to decrease the weight of assembled elements, but the principal reason for reduction in stiffness is the application of high-strength steel in ordinary reinforced concrete, which is subjected to larger stresses, leading to larger elongations of reinforcement than in the case of the steel that was formerly used.

The calculation of the stiffness of reinforced concrete slabs and beams regarded as homogeneous elastic elements led, as was established long ago, to grave underestimation of the actual deflection if the construction had cracks. Therefore, it was necessary to work out a better design method which would take account of several peculiarities of reinforced concrete, including the influence of sustained loads at the deflection increment.

The paper submitted to the Congress by V. I. Murashev studies the stiffness of reinforced concrete beams with vertical cracks in their tension areas. Certain factors are introduced here by the author which can undoubtedly exert considerable influence on the deflection value. These are:

The influence of the concrete between the cracks in the tension area on the elongation of the reinforcement;

The presence, in the compression area of concrete, not only of elastic deformations but also of creep and plastic strains.

The significance of these circumstances depends on the particular kind of reinforcement, percentage of reinforcement, the value of reinforcement stress in the areas of cracks and other factors. Speculation alone is not an adequate basis for their estimation, which is, therefore, carried out with the aid of empirical data. There is a series of works by other authors devoted to the appreciation of the same factors, particularly Doctor S. Soretz's report, recently submitted to the European Concrete Committee. In all works on the stiffness of cracked reinforced concrete empirical parameters play a substantial role.

The design of masonry, concrete and reinforced concrete members subjected to compression with a relative small eccentricity is a typical example of using the empirical relations. One group of research workers (especially Prof. H. Rush) takes the curved stress–strain relations found for some concretes at different rates of deformation, held constant during the test, at an artificially fixed neutral axis. These curves help to compose the graphs for reinforced eccentrically compressed members which may be used in designing. Directly from testing eccentrically compressed members of masonry, concrete and reinforced concrete, research workers in the USSR, USA and in other countries came to conclusion that for the definite range of eccentricity the linear law of load–moment relation is well confirmed at reaching the limit of bearing capacity. In other words, the moment of the ultimate force relative to some axis in the considered section is constant and independent of the eccentricity (as long as this eccentricity does not exceed definite limits). In the Soviet Union a large number of reinforced concrete columns and also masonry and concrete pillars have been tested.

According to the designing code the moment axis noted above in masonry and concrete members coincides with the more weakly stressed section edge. In reinforced members the axis goes through the reinforcement close to this edge. According to the American data the axis goes closer to the centre of the section. This small divergence is probably explained by the difference in the process of preparing and testing specimens. The relations noted above are accepted in codes of the USSR, USA, England, Sweden and other countries. It seems that the simple relations are more convenient in practice even though they are established empirically. The investigations such as Prof. Rush's work mentioned above may give valuable data on which to base these relations or to make them more precise. For example, they may be used in order to determine the effect of sustained axial load in relation to which the ultimate moment should be calculated.

A typical example of a problem in which empirical values play a large role is the question of the width of crack openings in reinforced concrete constructions, which is worked out intensively in some countries, including the USSR.

An example of a different sort is provided in the paper by E. I. Belenya, whose experimental study of connections between structural elements and even whole steel structures of industrial buildings has revealed substantial difference between the actual and theoretical strength, the latter being estimated on the basis of generally accepted and largely conventional design schemes. As a result of this work certain corrections have been worked out. Even though they do not claim to be absolutely accurate these amendments are helpful in designing economical structures of uniform strength.

Some eminent engineers are reluctant to use empirical relations for designing in the belief that this would prevent the structural engineer from exercising a logical control over computation technique and complicate theoretical training in construction. In practice, however, the final formulae can be equally obscure, whatever their origin, if no effort has been made to trace their derivation from the basic propositions of theory or to examine the empirical data they result from. But both practical engineers and students show a good grasp and confidence in these formulae if they have made a conscious study of their experimental and theoretical substantiation.

Determination of loads and other external actions acting on the structures in most cases goes beyond the boundaries of structural mechanics. This is the task for aerodynamics, hydrodynamics, structural heat engineering and other disciplines. Determination of these actions, especially loads, is rarely based on theoretical propositions but it is merely a result of observations. The question of actions on structures has never, on the whole, been the subject of broad systematic investigation. Characteristics assumed in practical calculation too often lack adequate substantiation and may carry big errors.

The pressure of loose substances on the walls of silo towers had a theory of its own, and the formulae employed for the computation of these pressures were still believed valid both theoretically and experimentally in the mid thirties. Cases of unsatisfactory service of silo towers were usually ascribed exclusively to bad construction work. However, extensive investigations conducted by Tahktamyshev on grain silo towers in the city of Baku in 1938 and 1939 proved that the former conception of the pressure exerted by loose substances on the walls was inadequate and overoptimistic. They discovered that excess of actual pressures over those computed, especially towards the middle of the tower's height when releasing the substance, as well as the unevenness of pressure distribution along the perimeter in the silo horizontal sections, were so great that they could explain the unsatisfactory service of even those structures that had not been so very poorly built. In 1943, the French engineers M. and A. Reimbert obtained similar results concerning the pressure of the loose substances on the bottom and the walls of silo towers.

After investigations by American and Soviet scientists in recent years, former conceptions of the value and distribution of seismic forces have substantially changed. Important research has been carried out in the Soviet Union into wind pressure on highly flexible structures and rather extensive observations are currently under way with regard to snow loads. The loads on dwellings and public utility buildings differ substantially in various countries, which is not, of course, a reflection of actual differences in the use of these structures but just a tribute to tradition. Nor is there sufficient clarity about the choice of load values resulting from industrial equipment. On the whole, progress in the question of the values of external actions to be taken into account in structural design can by no means be regarded as satisfactory.

There is an increasing number of investigations of construction materials, which is very useful both to the improvement of the technology of their manufacture and to the correct selection of materials appropriate to their application, and also to a clearer understanding of their behaviour in construction. Big gaps, however, are still to be found in the theory dealing with the strength of metals, concrete, brickwork and wood. Indeed, steel is regarded in computations as an elastic–plastic material, whereas it often proves to be brittle in rupture under conditions we cannot foresee with sufficient clarity.

Considerable progress has been made in the Soviet Union by Onishchik and his school in the question of strength of masonry. The establishment of the fact that in a column subjected to compression individual stones are exposed to bending and shear has been very helpful in understanding the importance of the absolute size of the stone and the reasons why masonry of bricks possessing equal resistance to compression and cemented with the same mortar may so substantially differ in strength. The correct understanding of the role of joints in brickwork has to led to the development of new and better methods of brick-laying (vibration).

Great significance for the elaboration of the theory of concrete strength will probably attach to the establishment of a certain limit in the load-bearing capacity, for example, in compression, defined by a significant increase in transverse deformation. The investigations of this problem have been described in a paper presented by O. Y. Berg. By developing his own views he was able to forecast a more favourable relation between endurance and ultimate strength for high-strength concretes, which was then corroborated experimentally. It remains to be learned why certain grades of concrete (of low strength), after being loaded up to the above-mentioned threshold of behaviour, are relatively better adapted for carrying further loads than high-strength grades of concrete.

There is still much that remains obscure in the question of strain development and rupture conditions for concrete in tension. Investigations carried out in different parts of the world during the last years in this field have yielded a considerable amount of new data.

An adequate theory of concrete strength should be linked with the theory of its deformations, linear and non-linear creep and plasticity, to which extensive analytical and experimental studies have been devoted in the USA, USSR, and other European Countries. It can be expected that with the advancement of the theory of concrete strength, a number of empirical relations used in computation at the present time will be better substantiated.

Design problems become much clearer as soon as the structure's fitness for utilization is under consideration. Indeed, unsuitable structures have no practical value. The purpose of computation, therefore, should be to determine the dimensions of the construction (or to check them) in order to avoid conditions under which the fitness of the structure for utilization might become exhausted.

The criteria of limiting conditions themselves frequently lie beyond conceptions of structural mechanics. Strength criteria, for instance, fall within the competence of the science of materials; the limiting deformations of the structure of industrial buildings are determined by peculiarities of the technological process occurring, and the deformation of buildings and structures intended for housing people (primarily, apartment and public utility houses) by the convenience of people, etc.

It is possible, as a matter of principle, to imagine a wide range of conditions where the structure no longer meets certain functional requirements. According to Soviet standards, these conditions bear the name of limit conditions and the whole variety of them has been reduced to three main groups. The first limit condition is characterized by the loss of load-carrying capacity or the appearance of permanent deformations which make the further utilization of the structure either impossible or inexpedient.

The second limit condition is distinguished by deformations of inadmissible value (even if elastic) and the excessive vibration of the structure. The third limit condition occurs with the appearance and expansion of cracks which preclude the further utilization of the structure. This condition primarily concerns reinforced concrete and masonry structures.

Let us examine now in more detail the first limit state. Since the values of limit residual deflections are not yet specified a stress limitation serves as their substitute. This is especially true for steel constructions. The destruction of masonry piers and reinforced concrete columns or the stability loss of steel constructions is a typical case of exhaustion of the carrying capacity. From the theoretical point of view Shanley's revision of the Engesser-Karman-Yasinsky conception of the loss of stability of columns undoubtedly deserves full attention because it reflects more correctly the actual phenomena.

From the practical point of view the main aim is the unification of design methods. Although stability problems have been studied in detail both by theoretical and experimental methods, different countries have adopted different design methods which can be explained only by tradition. This relates to the design of centrally or eccentrically led, plain or latticed struts. Meanwhile this divergence complicates international comparison of design data. That is why the unification of computation methods is very urgent.

In practice, loss of stability is always connected with exhaustion of carrying capacity, the latter occurring in the plastic range. Therefore it is logical to take plastic strains into consideration in the stability study, as provided for in the USSR building code. The same remains true for the much less developed study of beam stability. Here, too, practical design methods are at variance. The influence of eccentric loading on beam stability is important. This question has not up to now been reflected in practical design, although it has theoretically been sufficiently studied in design specifications without inconvenience.

The intricate stress state of the beam web receives due consideration in the USSR building code, where three stress components (σ_x, σ_y and τ_{xy}) are examined, and also in German design standards, which consider two stress components (σ_x and τ_{xy}). The great effect of this complex stress state leads us to recommend similar solutions for other countries.

Computations based on structural mechanics methods give no answer to the question of the degree of reliability of the designed structure, *i.e.* about the margin of safety against the arrival of one or another limit condition. If a construction unit is loaded till breakdown it becomes possible to reveal directly the ultimate load, which depends on the actual dimensions and form of the unit and also on the properties of the material employed. In design work, however, the actual strength values of materials of the future structure are still unknown because of their possible scatter.

The possible load value is also not exactly certain for the same reason. There is, sometimes, no reliable information on a number of other circumstances relating to the future life of the structure. All this makes it imperative to proceed in computation from the "worst" possible suppositions regarding possible overload, reduction in the strength of materials, etc. It is self-evident that this important aspect of designing "reliable" structures is not a product of structural mechanics or simply supplements it.

As is well known, the former approach to providing reliability consisted of the comparison of design and available stresses. This approach has a fault because it assumes tacitly the proportional increase of stress with the load. In fact, this proportionality is broken by non-elastic deformation as a result of the different probabilities of increase of different types of load.

In the ultimate load method, which had been used for some years in the Soviet Union for the design of reinforced concrete and masonry constructions and as now recommended in some countries for the design of reinforced and, especially, prestressed constructions, the ultimate strength of the section is made equal to the force obtained by multiplying the loads (dead load, live load, wind load, etc.) by different coefficients.

This approach seems somewhat unilateral as it does not take sufficiently into account the variability of different materials.

In the Soviet Union, for instance, in checking the reliability of a structure according to the first limit state, the biggest load possible during the utilization period is compared to the least value of load-carrying capacity which is determined taking into account the possible reduction in the strength of materials due to the scatter of their properties.

Coefficients taking account of possible overload and possible reduction in the strength of materials as compared with their normal (determined by standards) values have been accordingly named coefficients of overloading and material homogeneity coefficients. It is apparent that the former are by nature in most cases bigger than unity, while the latter are less than unity. Naturally, not all of the circumstances influencing the safety of structures can be taken into account by the above-mentioned two groups of coefficients.

Therefore, the design should take account of a third coefficient, which has been named coefficient of behaviour conditions. Thus, the general appearance of the design formula according to the method of limit conditions will be

$$N \leqslant m \Phi$$

where N is the effort from the biggest possible load;

Φ the least value of load-carrying capacity;

m the coefficient of behaviour conditions.

To determine overload coefficient values for the loads whose variability is of statistically chance character is in itself a statistical problem; the same refers to the coefficient of homogeneity of materials.

The combination of various types of loads acting on the structure belongs to the same range of problems.

As the first and simplest solution, it is customary in the USSR to base the "calculation strength" of materials on the possibility of their deviation by three standards from the mean statistical values, with the theoretical probability of encountering lower values equal to approximately 1/1000. The "design loads" were chosen in such a manner that the probability of their being exceeded should be equal to the same figure. In order to simplify the system of design coefficients, the factor of behaviour conditions was in the majority of cases taken as equal to one, and when necessary being given greater or smaller values.

There are other suggestions for the choice of design coefficients. Prof. Torroja, for instance, has suggested that the coefficients of load increment and strength reduction should be based on the deviation from the mean value by one standard, whereas other necessary security factors should be taken into account by introducing additional multipliers. Apparently, the selection of a system of coefficients is not a matter of principle, but it is important to avoid complications detrimental to practical design. More essential from the viewpoint of principle is the method adopted to substantiate the values of the factors of safety obtained by introducing certain design coefficients.

There are numbers of suggestions on this matter from Messrs. R. Levy and M. Prot of France, Mr. A. M. Freudenthal of the United States, Prof. Verzbicki of Poland and Prof. Rzhanitsin of the Soviet Union, who propose that numerical values of design coefficients (or safety factors) should be determined by the statistical method, proceeding from a certain *a priori* value of guarantee against the arrival of a limit condition.

To be able to assess the general reliability of the structure by the statistical method, it is necessary that all aspects in the utilization of the structure should be known and examined, be available for computation and represent statistically chance values. In practice, however, these conditions are by no means fulfilled. Therefore, it should be considered at the present level of knowledge that statistical methods can be fruitfully used for determining danger values of a number of design factors, such as the least design strength of materials, the greatest design load, etc., as well as for evaluating the relative degree of danger presented by combinations of unfavourable factors in the service of structures.

At the same time, when determining the absolute values of security factors introduced in the design, it is the experience accumulated in designing, construction and maintenance that is primarily used in order to secure reliability and economy of the structure.

In this kind of approach, special importance attaches to the collection and analysis of data relating to cases of damage or complete destruction of structures.

Unfortunately, no systematic work is carried out on these problems.

On the whole, the renunciation of the so-called "classical" design methods of calculation based on the laws of resistance of elastic materials, consideration of the "exploitation"stage in the service of the structure and the use of allowable stress, has brought forth results of great practical and theoretical importance. A definite though not very big economy has been obtained in steel structures by taking account of plastic deformations.

Substantial savings have been obtained in reinforced concrete structures by reducing, and sometimes eliminating altogether, the use of compression reinforcement in flexural members, and also by saving web reinforcement (bent-up bars, stirrups). There was a considerable cut in material expenditure for eccentrically compressed members of reinforced concrete and masonry.

Only the renunciation of the "classical" design methods has made it possible to build up a theory of deflections for reinforced concrete beams producing results agreeing well with experimental data. The limit states method has logically led to a unification of design of reinforced and prestressed concrete structures, due regard still being given to peculiarities resulting from the properties of the structures and of the materials used. The renunciation of the "classical" methods has made it possible to avoid certain errors that followed from them and to tackle design problems which did not yield to the old methods, which stated expressly or by implication that loads lead to the proportional increment of all stresses. A separate consideration of different design coefficients improves connections among designing, construction and operation of buildings and structures. For example, account in the calculation of possible reduction in the strength of materials can be linked with the statistical approach to evaluating the quality of materials at plants and construction sites.

A method has been developed in the USSR for checking the strength of concrete used in the manufacturing of precast units and in larger projects. As an experiment, this method has been included in standard technical rules. By this method, two indices are used to determine concrete strength: one is the mean value and the other the value of strength deviation of individual samples. The value of permissible reduction in the strength of individual samples had been established in relation to the number of tests.

The statistical method for evaluating the results of tests of mass-produced reinforced concrete units has been recommended by Soviet standard technical rules.

A comparative study of design standards functioning in different countries has revealed that the safety factors used in the USSR for reinforced concrete, masonry and steel structures are in most cases lower than abroad. At the same time, it has been proved by experience that structures designed according to Soviet standards are, on the whole, perfectly reliable. Individual defects in these structures result for the most part from violations of construction rules or maintenance requirements.

Nonetheless, it is certainly desirable, and in some cases even necessary, that there should be further research to improve and specify individual design factors.

Structural design methods were discussed at a joint meeting held in Moscow in December, 1958, by a Commission of the International Council for Building Research, Studies and Documentation and the USSR Academy of Construction and Architecture. This Conference pointed out the interest presented by the method of limit state design both in the theoretical aspect and from the viewpoint of its economic prospects. It recognized the necessity to take account, in appropriate cases, of the actual properties of materials (not elasticity alone, but also plasticity, creep, crack formation, etc.) and recommended the application of the calculus of probability for finding a number of design parameters. Besides that, the conference outlined for the coming period an urgent programme of research into the following five problems:

1. Factors acting upon structures.
2. Load-carrying capacity of structures.
3. Crack resistance of structures.
4. Deflections of structures.
5. Statically indeterminate systems beyond the limit of elasticity.

Each of these problems consists of several parts, to a large extent independent, which in turn represent extensive and often little-investigated branches of knowledge.

The fulfilment of this programme would give a fresh impetus to the further improvement of calculation and design methods, and to the construction of structures reliable in service and economical at the same time. Structural engineers of all countries, therefore, have an equal interest in this programme.

International cooperation is indispensable in view of the great scope of the programme, as was specially noted by the Moscow Conference.

It is desirable that the Design Commission of the International Council for Building Research, Studies and Documentation should undertake to promote this cooperation.

The following steps in this direction are suggested:

1. The establishment of contacts with international and national organizations dealing with structural design.
2. The forwarding to these organizations of the above-mentioned draft programme of research (amended if necessary) so that the members of organizations engaged in research on some of the problems on the programme and desirous of taking part in this international cooperation could inform the commission about it.
3. The information of scientists and scientific research organizations which have established contact with the commission regarding similar research conducted by other scientists, and help in the organization of scientific contacts. Conferences on particular problems should be organized if necessary.
4. The discussion of all tangible results of research carried out in accordance with the plan.

Ensuring full freedom of research for all individual participants, this cooperation would unquestionably accelerate and enlarge scientific studies, and bring the viewpoints of specialists in different countries closer together.

Research on the concrete strength theory

UDC 624.04 : 624.012.4

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INTRODUCTION

The presence of the combined states of stress is characteristic of the majority of concrete structures. The calculation of the strength of concrete under the action of combined stresses is possible on the basis of any theory of failure. In the native literature as well as in that abroad the results of many experimental and theoretical researches of failure of concrete and of other materials that have a different compressive and tensile strength under combined state of stress are described.

Extensive study was accomplished by Ros and Eichinger [1], Richart, Brandtzaeg and Brown [2], Gvozdev [3], Rosnowski, Perederij, etc. Measurements in most of the experiments were limited to the determination of the largest loading the specimen sustained by the combined state of stress. Sometimes concrete and lateral reinforcement strains were measured.

The theoretical study of strength of materials under the action of combined stress was accomplished by two principal processes: (1) the creation of the general mathematical theory of strength of materials which have different compressive and tensile strength, and (2) the analytical generalization of investigation results of the physical effects in the material.

So far the theory of brittle failure of solids has not been sufficiently developed [1, 5]. The theory proposed by Mohr is used for the analysis of failure under these conditions [6]. However, this theory does not include the physical effects which determine the failure. Some authors [1] conclude that Mohr's theory in many cases proves to be quite useless.

Different suggestions that concerned the mathematical interpretation of the failure criteria were made to amend the theory proposed by Mohr. Philonenko-Boroditsch [7] applied in his work a wide generalization of Mohr's theory and proposed to value the approaching of the ultimate state by means of an ultimate surface plotted by him in a system of coordinate axes (σ_1, σ_2, σ_3), where σ_1, σ_2, σ_3 are principal normal stresses. Using the equations of Philonenko-Boroditsch as a base, it is possible to deduce the criterion of plasticity proposed by Mises-Hencky and the other criteria of failure that were proposed earlier.

Gvozdev [3] has developed the method of analysis of the strength of reinforced concrete structures by triaxial states of stress. This method has been accepted for the USSR standards of design. To determine the coefficient of the effectiveness of side pressure, Gvozdev has given the theoretical solution based on the analysis of ultimate plastic flow of the thin-walled pipe filled with concrete under uniaxial compression and internal pressure.

The determination of the coefficient of the effectiveness of the side pressure, considering the reduced thickness of the pipe wall, has also been exposed by Lipatoff [8].

When studying biaxial states of stress, Bressler and Pister [9] have introduced the linear relation between the octahedric shearing stress and the first invariant of the stress tensor. This relation was determined empirically when analyzing the empirical data of testing of the hollow concrete cylinder under varying combinations of torsion and compression. Blakey and Beresford [10] have proposed a similar equation governing the fracture of concrete that differs only by some coefficients.

The above-mentioned general theoretical solutions improve to some degree the equations of the Mohr theory. However, the contradictions which are observed sometimes when evaluating the empirical data, and the deviation of the empirical data from the theoretical, cannot be analyzed at the present state of the theory. As before, the mathematical generalizations do not give a good representation of the physical phenomena determining the failure of materials. Therefore the other trend of the development of the theory is interesting when examining the strength of concrete and other materials that have different compressive and tensile strengths.

The first premise of this trend that this paper deals with is the formulation of a failure criterion based on the physical process of cleavage or shear failure under the action of combined stresses.

PHYSICAL BASES OF STRENGTH AND DEFORMATIONS OF CONCRETE

When analyzing the failure of concrete only the final phase of the phenomenon, *i.e.* the state of the specimen after the failure, is considered. The state of the specimen before failure remains unconsidered. All the existing theories of failure are based on the critical notion of the criterion of failure, on reaching of which the material instantly fails.

Many tests revealed the facts of influence of different microdestructions of the texture of material on the final failure. Bridgman [11] observed changes of volume of specimens of marble, talc, diabase and other materials that were subjected to unconfined compression tests. At a definite stage of loading an increasing volume of solid was occurring instead of a diminution, which does not agree with the principles of the physics of solids. Bridgman supposed that the increasing volume is the result of the disturbance of solid continuity and of the developing of a cleavage process. Gvozdev [3] suggested that different microdestructions causing the failure of the specimen are the result of non-uniformity in the texture of concrete.

This author first proved in 1950 [12], followed by other authors, that the brittle failure of concrete under unconfined compression tests of specimens in the shape of prisms begins when irreversible cracks appear along the direction of the effective force. The appearance of microcracks under the stresses R_{cr} long before the attainment of the ultimate strength of the specimen R_{pr} (prism strength) is revealed by means of microscopy and microphotography. It is possible to determine the limit R_{cr} according to the curve presenting the coefficient of the transverse strain [8]

$$\nu = \frac{\Delta\varepsilon_2}{\Delta\varepsilon_1}$$

where $\Delta\varepsilon_2$ is the increment of the value of transverse strain at a definite stage of loading;
$\Delta\varepsilon_1$ the increment of the value of longitudinal deformation at a definite stage of loading.

The value ν when the stresses increase to R_{cr} attains the maximum possible theoretical value for the solid ($\nu = 0.5$) and then exceeds it, which is possible only as a result of rupture of the material.

The foregoing data are corroborated in a number of researches which were carried out by different methods. The experiments of Jones [13, 14] were accomplished by means of ultrasonic apparatus. L'Hermite [15] observed the appearance of microcracks by means of a sensitive sound apparatus which registered the sound impulses at the moment of cracking. Both methods were applied to experiments by Rüsch [16]. Blakey and Beresford [10] observed the same effect under tensometric measurement of the transverse and longitudinal strains.

The readings of apparatus obtained by different methods of discovering microcracks in concrete when loading on the specimen is changing, are shown schematically on conditional scales on Fig. 1.

The border of microcracks formation R_{cr} corresponds to the initial stage of the process of overcoming cleavage strength of concrete R_{cl} in the direction normal to the direction of axial compressive loading.

At reaching the boundary R_{cr}, cleavage strength of the transverse direction is overcome only on certain elementary planes. The reason for the final failure of the specimen is the successive rupture of concrete which develops in a direction longitudinal to the compressive stress. The possibility of tensile stresses appearing on the planes normal to direction of unconfined compression is proved theoretically in the works of Volkoff[17].

The classic theories of strength deny the presence of stresses on these planes. The average tensile stresses in the transverse direction are considered to increase from values approaching zero to R_{cl} when the stress is changing from R_{cr} to R_{pr}; the state when cleavage of concrete is overcome over the entire longitudinal section of specimen corresponds to the stage of failure. Therefore the process of the development of microdestructions is the physical basis of strength of material under compression.

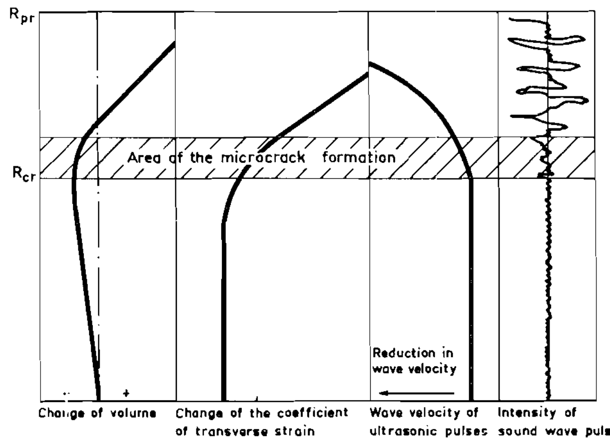

Fig. 1. Conditional scales of readings obtained by various methods for discovering microcracks in concrete.

In some institutes of the USSR Academy of Science, investigations[18, 19] were carried out on small specimens of different materials with careful observation and registration of the process arising on the surface of specimen. These studies have led to the conclusion that if the microcracks caused by the local overcoming of the cleavage strength were formed at the initial loading on the specimen, then the carrying of the load – without it being increased – over prolonged periods results in failure of the specimen.

The failure arises because of gradual development of microcracks that occurs in the large surface of failure. Therefore the process of appearance and development of microcracks is determinant for the long-time strength of material.

The researches[8] made by the author have revealed that the strength of concrete under the action of repeated load depends also on the volume of initial microdestruction of the material.

The level of the formation of microcracks is variable[8] and depends on the value of the absolute strength, as may be seen on the diagram of Fig. 2, *i.e.* the value

$$\frac{R_{cr}}{R_{pr}}$$

increases with the increase of $R_{pr}\varphi$.

The data of the experiments have a definite similarity concerning the position of the limit of the formation of microcracks in the specimens of different materials, which evidently proves the presence of certain general laws.

The analysis of microphenomena in concrete helps to explain certain laws of concrete straining under load.

The plastic deformations examined in the theory of plasticity are results of micro-disturbances of continuity that are following the shearing stresses, as with metals. One of the essential features of microcrack formation in metals is the possibility of their closing. The absolute dimensions of microcracks up to the moment of failure of plastic materials amount to microns and to parts of microns. The microcracks developing in concrete under compression have other features.

The microcracks caused by stresses R_{cr} are irreversible ones; their development is characterized by the appearance of the coefficient of transverse strain of concrete, the value of which exceeds $\nu = 0.5$.

In contradistinction to plastic strains (of the first type) of metals, the non-elastic strains

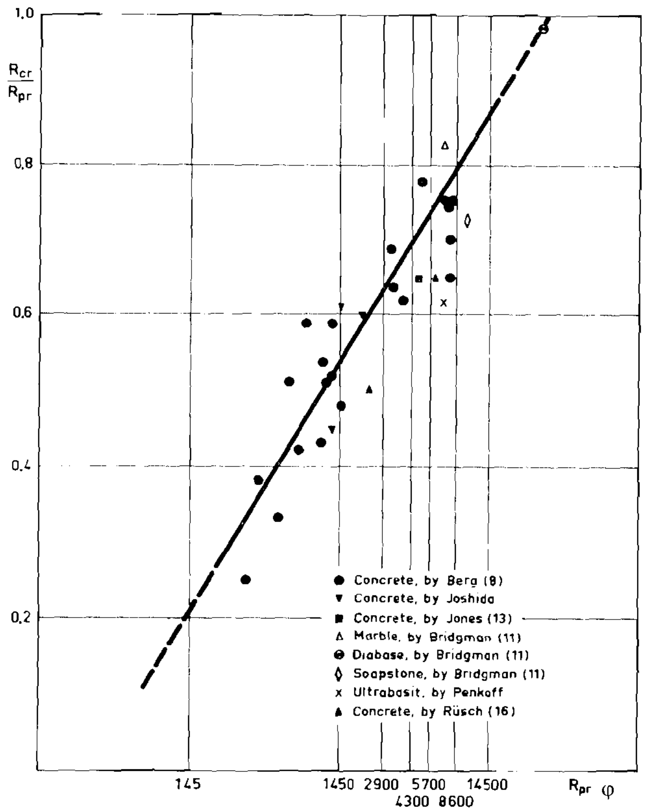

Fig. 2. Dependence of the level of formation of microcracks on the value of the absolute strength of the material.

which are accompanied by irreversible cracking at brittle failure must be called conditionally "plastic deformations of the second type". The opinion that it is necessary to distinguish plastic strains developing in concrete and those developing in metals is supported by L'Hermite [15], Cowan [20] and Mehmel [21].

The law of change of strains caused by stresses in concrete $\sigma = f(\varepsilon)$ is expressed in the compression diagram [20, 22]. The general shape of this diagram is presented on Fig. 3. The full strain may consist of elementary strains of the following types:

1. The elastic strains with the linear stress–strain relation.
2. The creep strains with the non-linear strain–time and linear stress–strain relations.
3. Plastic strains of the "second type", which have non-linear stress–strain and strain–time relations.
4. "Pseudo-plastic" strains, which have combined non-linear stress–strain and strain–

time relations when the large surfaces of failure are forming and the specimen collapses.

Plastic strains of the second type are of the greatest practical importance for the evaluation of strength at unconfined compression because they directly cause the failure that appears already at pseudo-plastic strains.

The side pressure at the triaxial state of stress considerably changes the process of the development of plastic strains of the second type, which prevent the development of longitudinal microcracks. Therefore the values of the longitudinal and transverse strains which can be sustained by the specimen increase immeasurably as compared with uncombined deformation.

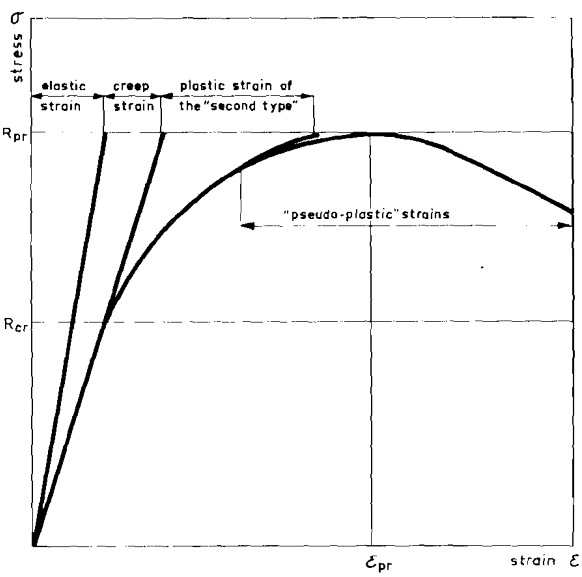

Fig. 3. Compression diagram for the law of change of strains caused by stresses.

EQUATIONS OF CONCRETE STRENGTH THEORY

The brittle failure of material at unconfined compression ($\sigma_2 = \sigma_3 = 0$), as it was shown, is a result of cleavage failure. The development of irreversible microcracks, the disturbance of the continuity of solid and its failure because of breaking, which is directed along the active force (Fig. 4a), occur when the stresses increase from R_{cr} to R_{pr}. This combined process is plotted on Fig. 4b. The energy spent for the successive failure of the specimen under microcrack formation is equivalent, according to the diagram, to the energy that is required for overcoming cleavage strength in the transverse direction over the whole section of the specimen. Therefore, if the side pressure (Fig. 4c), the value of which is equal to cleavage strength R_{cl} of material, is applied in the process of unconfined compression of the specimen (when the stresses R_{cr} are attained), the energy required for microcrack formation will be absorbed by the energy of forces caused by compressive stresses $\sigma_2 = \sigma_3 = R_{cl}$.

The first microcracks would arise only under compressive stresses $\sigma_1 = R_{pr}$.

It is possible to assume, as the first approximation, that for the failure of a concrete specimen under the action of combined stresses, the stress σ_1 must be raised over the value R_{pr} by the quantity within which under the unconfined compression the cleavage strength over the whole longitudinal section of the specimen is overcome, *i.e.* by the stage

$$R_{pr} - R_{cr} = KR_{pr}$$

where

$$K = 1 - \frac{R_{cr}}{R_{pr}}$$

R_{cr}/R_{pr} must be taken from the diagram on Fig. 2.

If the value of side pressure differs from R_{cl}, the value of the strength is increased proportionally to the value

$$n_3 = \frac{\sigma_3}{R_{cl}}$$

i.e. it is taken that the absolute value of the principal stresses does not influence the process of failure. This influence can evidently become quite appreciable under stresses (σ_1, σ_2, σ_3) of great values.

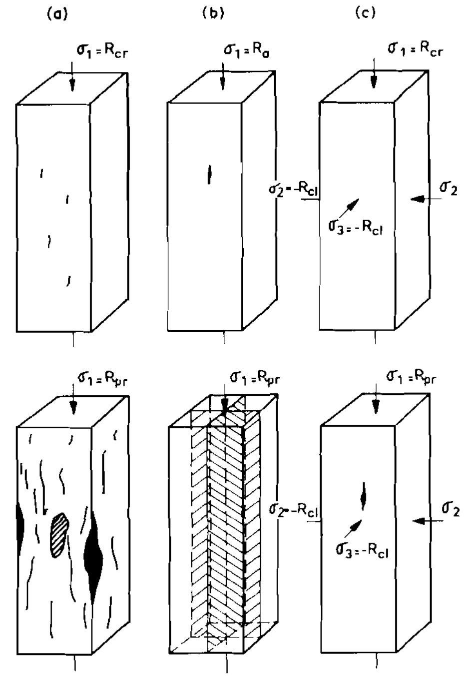

Fig. 4. Development of microcracks. (See text.)

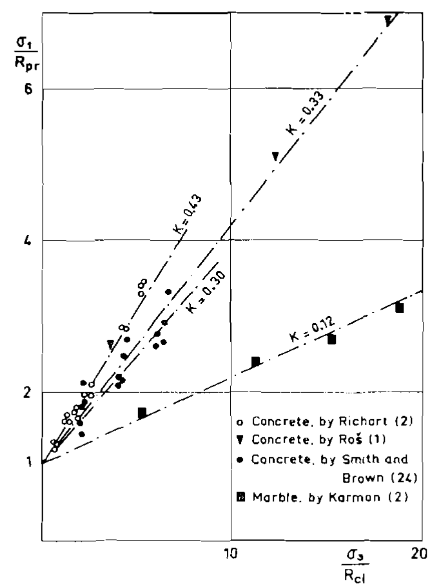

Fig. 5. Results of experiments for the determination of strength at the triaxial state of stress.

The equation of strength of the triaxial state of stress will have the following shape based on the hypothesis that was formulated above

$$\frac{\sigma_1}{R_{pr}} = 1 + K n_3 \qquad (1)$$

where all symbols are the same as above. This equation is plotted in the coordinate system

$$\frac{\sigma_1}{R_{pr}}, \quad \frac{\sigma_3}{R_{cl}}$$

as a family of curves, the inclination of which depends on the strength of the material (on the coefficient K).

The values R_{cl} and R_{pr} for concrete, according to USSR Design Standards, and the average values of the coefficient

$$\frac{R_{cr}}{R_{pr}}$$

taken from the diagram of Fig. 2, are given in Table I for the application of equation (1).

The equation can be generalized if one substitutes σ_1 and R_{pr} by the average full stress P_{av} as the average characteristic of the triaxial state of stress. It is possible to derive the

TABLE I

Grade of concrete R_{cube}	*100*	*200*	*300*	*400*	*500*	*600*
Compressive strength of prism R_{pr}	80	145	210	280	350	420
Axial tensile strength (cleavage strength) R_{ct}	10	16	21	25	28	30
R_{cr}/R_{pr}	0.50	0.58	0.63	0.69	0.72	0.74
K	0.50	0.42	0.37	0.31	0.28	0.26

Units are kg/cm^2.

average full stress if the average of all possible full stresses that appear on the elementary planes which are situated on the surface Ω of the infinitesimal sphere containing the given point will be considered as suggested by Novoziloff[23], who gave the solution for the average shearing stress.

It is possible to determine the value of the average full stress from the equation

$$P_{av}^2 = \frac{1}{\Omega}\int P_f^2 \, d\Omega \tag{2}$$

where P_f is the full stress at a given point and determined from equations of the theory of elasticity.

It should be noted that the basic hypothesis of the classic theory of elasticity about the continuity of the medium is not realized when the value of concrete stresses is more than R_{cr}. However, it is possible to present conditionally the non-uniform medium as the homogeneous one when the average characteristics are used.

Solution of equation (2) in the spheric coordinates for the value of full stress at the triaxial state of stress gives the expression

$$P_{av}^{III} = \frac{\sqrt{3}}{3}\sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2} \tag{3}$$

Hence for the biaxial state of stress ($\sigma_3 = 0$)

$$P_{av}^{II} = \frac{\sqrt{3}}{3}\sqrt{\sigma_1^2 + \sigma_2^2} \tag{4}$$

and for the unconfined compression ($\sigma_2 = \sigma_3 = 0$)

$$P_{av}^{I} = \frac{\sqrt{3}}{3}\sigma_1 \tag{5}$$

It is possible to modify equation (1) for the general case of stress conditions ($\sigma_1 > \sigma_2 > \sigma_3$), proceeding from equations (3) and (5), as follows

$$\frac{P_{av}^{III}}{P_{av}^{I}} = \frac{\sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2}}{R_{pr}} = 1 + Kn_3 \tag{6}$$

and after the transformation

$$\frac{\sigma_1}{R_{pr}} = \sqrt{1 + 2Kn_3 + K^2 n_3^2 - \frac{n_2^2}{c^2} - \frac{n_3^2}{c^2}} \tag{7}$$

where $n_2 = \frac{\sigma_2}{R_{ct}}, \quad c = \frac{R_{pr}}{R_{ct}}$

The curves from equation (7) are plotted and the results of experiments for the determination of the strength at the triaxial state of stress are given on Fig. 5 in view of comparison of theoretical and experimental data. The data of experiments which were carried out by Richart[2] on concrete, on cement mortar by Smith and Brown[24], and on marble by Karman[1] were used for plotting the curves. The value $R_{cl} = 650\varphi$ is taken for marble.

The theoretical curves conform to the experiments. The greatest scatter of individual experimental data in comparison with the theoretical curve attains 27%. This scatter can not be considered excessive if one takes into account that in the absence of some characteristics the data were taken according to average normative figures.

It is possible to use the linear equation of strength, suggested as a first approximation, for the analytical evaluation of the brittle failure of concrete and other materials which have different values of both tensile and compressive strength when they work under the combined states of stress. The initial parameters, R_{pr}, R_{cr}, R_{cl}, are determined from pure-compression and pure-tension tests.

It is possible at great pressures (when the overcoming of the cleavage strength in the transverse direction is impossible) to attain states of plasticity (plastic strains of the first type) if the value of shearing stress is a considerably great one. The limit of the transition from the brittle state to the plastic one requires additional study.

It is also possible to study the conditions of the appearance of brittle failure at the biaxial state of stress by the general equation (6). Under the biaxial state of stress, when both the stresses σ_1 and σ_2 are compressive, failure can occur only in the axial direction σ_3, where side pressure is absent.

Substituting in equation (6) $\sigma_3 = 0$ one may obtain the equation of failure for this case in the following shape

$$\frac{\sigma_1^2 + \sigma_2^2}{R_{pr}^2} = 1$$

or (8)

$$\frac{\sigma_1^2}{R_{pr}} = \sqrt{1 - \frac{n_2^2}{c^2}}$$

The examination of equation (8) is different because of the scanty experimental data. The decrease of strength according to equation (8) is not revealed by means of some experiments[2, 25].

There is a sufficient number of experiments for the other biaxial state of stress, when σ_1 is the compressive stress, $\sigma_2 = 0$ and $\sigma_3 = -\sigma_3$ is the tensile stress. Failure of the specimen must occur in this case because of the overcoming of the cleavage strength in the direction of the tension σ_3.

It is possible to transform equation (6) for this state of stress to the next one

$$\frac{\sqrt{\sigma_1^2 + \sigma_3^2}}{R_{pr}} = 1 - Kn_3 \tag{9}$$

or, neglecting

$$\frac{\sigma_3^2}{R_{pr}^2}$$

because of its small value

$$\frac{\sigma_1}{R_{pr}} = 1 - Kn_3 \tag{10}$$

It is necessary for the comparison of results obtained from equation (10) and the data of experiments to make the value of the coefficient K, depicted on the diagram of Fig. 2 (uniaxial compression), the more precise one. A lowering of the limit R_{cr}, *i.e.* the increasing of K under tensile stresses σ_3 in the direction normal to the direction of the action σ_1, should be expected. The whole range of stresses from 0 to R_{cl} determines the overcoming of the cleavage strength under the tensile stress only, and therefore in this case $K = 1$. Thus it may be considered that the data of the experiments in the coordinate system

$$\frac{\sigma_1}{R_{pr}}, \quad \frac{\sigma_3}{R_{cl}}$$

should be situated in the region limited by the value taken from the compression tests and by $K = 1$. The law of change under these conditions has not been studied and remains unknown.

A number of experimental data has been examined on specimens of cement-sand mortar by Smith [26] and of concrete by Veriguin [27] and McHenry [28], and for the biaxial state of stress when σ_1 is the compression and σ_3 is the tension (Fig. 6), in order to compare these data and the theoretical curve plotted according to equation (10). The results of gypsum tests by Davidenkoff [29] and of cast iron tests by Grassi and Cornet [30] and Coffin [31], which reveal similar laws, are presented on the same diagram.

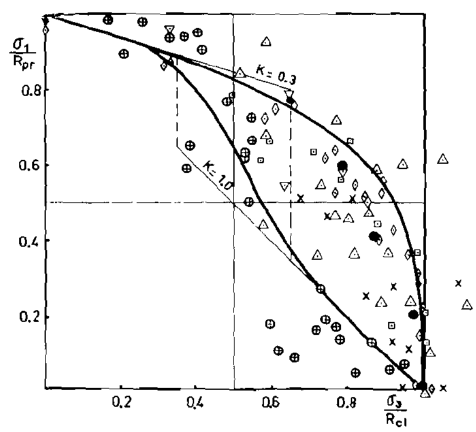

Fig. 6. Experimental data on the biaxial state of stress.

It is possible to plot two extreme positions on the theoretical curve on the basis of equation (10) depending on the law of change of the coefficient K. Both the curves are shown on Fig. 6. The law of change K taken for both the curves (K_1 and K_2), depending on n_3, is given in Table II. The value $K = 0.3$ for the principal compression is taken according to Table I and corresponds to the average strength of the specimens tested in the above-mentioned experiments for the given biaxial state of stress. For cast iron this value is somewhat lower.

TABLE II

n_3	0.1–0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
K_1	0.3	0.5	0.7	0.9	1.0	1.0	1.0	1.0
K_2	0.3	0.33	0.35	0.38	0.4	0.45	0.5	1.0

Data of the tests are grouped in the region of these curves.

CONCLUSION

The notions about the nature of brittle failure in the principal compression conditions of concrete suggested in this paper show that consideration of the most simple laws of the overcoming of the cleavage strength which were discovered has great importance for the evaluation of concrete strength and its strains.

The equations of strength, suggested as the first approximation, based on the assumption about the linear relations should be considered. In spite of this, these equations correspond to the test data.

A more detailed study of these laws would undoubtedly be interesting. It should be necessary at the same time to accumulate data about the limit of microcrack formation in different materials under different test conditions.

REFERENCES

[1] M. Ros and A. Eichinger, *Versuche zur Klärung der Frage der Bruchgefahr*, Zurich, 1928.
[2] F. Richart, A. Branzaeg and R. Brown, *Univ. Illinois Bull.*, 4 (1929) 190.
[3] A. A. Gvozdev, *Analysis of Carrying Capacity of Structures according to the Method of Ultimate Equilibrium*, Moscow, 1949.
[4] V. D. Kousnezoff, *Physics of Solids*, Vol. II, Tomsk, 1941.
[5] A. Nadaï, *Theory of Flow and Fracture of Solids*, 1950.
[6] O. Mohr, *Abhandlungen aus dem Gebiete der technischen Mechanik*, Berlin, 1914.
[7] M. M. Philonenko-Boroditsch, *Engineers' Collection, USSR*, Vol. 19, 1954.
[8] O. Y. Berg and A. F. Lipatoff, *Proc. All-Union Research Inst. of Transport Construct., USSR*, Vol. 19, Moscow, 1956.
[9] B. Bresler and K. Pister, *Proc. Am. Soc. Civil Engrs.*, 81 (1955) 674.
[10] F. Blakey and F. Beresford, *Tensile Strains in Concrete*, Melbourne, 1955.
[11] P. W. Bridgeman, *J. Appl. Phys.*, 20 (1949) 12.
[12] O. Y. Berg, *Vestnik Akad. Nauk SSSR*, 70 (1950) 4.
[13] R. Jones, *Brit. J. Appl. Phys.*, (1952) 7.
[14] R. Jones and E. Gateield, *Road Research Tech. Papers*, (1955) 34.
[15] R. L'hermite, *Idées actuelles sur la technologie du béton*, Paris, 1955.
[16] H. Rüsch, *Zement, Kalk, Gips*, Vol. 1, 1959.
[17] S. D. Volkoff, *J. Tech. Phys., USSR*, Vol. 24, part 12, 1954.
[18] C. H. Jourkoff and B. N. Narsulaeff, *J. Tech. Phys., USSR*, Vol. 23, part 10, 1953.
[19] V. R. Reguel, *J. Tech. Phys., USSR*, Vol. 26, part 2, 1956.
[20] H. Cowan, *Engineering*, 171 (1952) 4518.
[21] A. Mehmel, *Beton- u. Stahlbetonbau*, (1956) 5.
[22] H. Hadley, *Civil Eng.*, 20 (1950) 4.
[23] V. V. Novoziloff, *Appl. Math. and Mechanics, USSR*. Vol. 16, part 5, 1952.
[24] F. Smith and R. Brown, *Univ. Washington Bull.*, No. 106, 1941.
[25] E. Reinus, *Betong*, 40 (1955) 1.
[26] G. Smith, *J. Am. Concrete Inst.*, 25 (1953) 2.
[27] K. P. Verigin, *Beton i Zhelezobeton, USSR*. (Concrete and reinforced concrete), (1956) 2.
[28] D. McHenry and J. Karni, *J. Am. Concrete Inst.*, 29 (1958) 10.
[29] N. N. Davidenkoff, *Vestnik Akad. Nauk SSSR*, 99 (1954) 1.
[30] R. Grassi and J. Cornet, *J. Appl. Mechanics*, 16 (1949) 2.
[31] R. Coffin, *J. Appl. Mechanics*, 17 (1950) 3.

An investigation into the actual conditions of work and the limit states of steel skeletons of industrial buildings

UDC 624.04 : 624.014.2

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Investigations that have been conducted and operating experience show that the actual stresses in structural members of skeletons of industrial buildings are usually very different from those calculated, with the result that the structures turn out to be of unequal strength at different points; sometimes the safety factors are insufficient, but more often they are excessive. The difference between the actual and the calculated stresses can be explained by two fundamental circumstances:

1. A lack of correspondence between the idealized system and the actual behaviour of the structure.
2. A lack of correspondence between the actual value and the nature of the loadings on the one hand, and the design values on the other.

This paper is concerned with a study of the work of structures under prescribed loadings.

The design charts normally used for the steel skeletons of industrial buildings are only approximations to the actual conditions of work of the skeleton, conditions which are distinguished by the joint work of different structural members, linked up into a unified spatial structural system together with the substructures and deformable foundation.

A common method of simplifying calculations is to divide the spatial system of the skeleton frame into separate flat structural members without proper account of their actual interrelationships. However, even these separate flat structural members are calculated according to approximate schemes. These simplifications in calculations are due not so much to the desire to make the calculating process easier as to the fact that the problems have not been developed and that there are too few studies of the influence of different factors on the work of the structure to serve as a basis that might be used to develop designing procedures (acceptable in practice) which would account for all these factors.

The behaviour of complex statically indeterminate systems beyond the limits of elasticity has not been studied in sufficient detail. This makes it difficult to determine, by calculation, the limit states of such structures. For this reason, in the majority of cases of practical designing the limit design stresses in rods of statically indeterminate systems and their displacements are determined from the elastic stage, which leads to a discrepancy between these values and the actual values.

Although there is a large number of researches on the limit state of frame systems, this problem is hardly at all developed due to its complexity. Up to the present time, there has been no investigation that could be called exhaustive with regard to combination frames in which the work of the frame (compressed-bent) members is combined with that of statically indeterminate trusses.

The present paper includes the results of investigations into the actual distribution of stresses and deformations in transverse frames of the steel skeletons of single-storey industrial buildings for different types of static loads. The study considers both elastic and elastic-plastic stages of the structure. The study is of an experimental-theoretical nature, the basis being the assumption that the experimental part is the most reliable in enabling one to uncover the physical essence of the phenomena under study.

The experimental studies were first carried out with models of individual assemblies and flat structural members which permitted varying the conditions of work of the structures;

the data obtained were verified and amended during tests of a two-span experimental skeleton, under conditions sufficiently close to natural size, and also under natural scale conditions on skeleton frames of industrial buildings.

In this investigation, the principal factors affecting the behaviour of frames were determined and on this basis practical procedures were worked out to account for these factors in designing. Amended design schemes of combination frames of this type have been obtained in which allowance is made for the structural peculiarities of lattice girders and their connections with columns, for elastic and elastic-plastic deformability of joints of lattice girders and columns, and for the interaction between the steel structure of frames and the substructures and their foundation.

Ordinary design schemes do not take into account the peculiarities of interconnection of lattice girders and columns in the two cross sections at the level of the lower and upper flanges of the girder. In design schemes the girder is taken as continuous, connected to the columns at one point at the level of the lower flange (Fig. 1b). This is not in accord with the actual conditions of work of the frames. In the design scheme proposed on the basis of this investigation, account is taken of the method of joining the girder and columns in two sections in height and of the eccentricity in transmitting the vertical reaction of the girder onto the column (Fig. 1b).

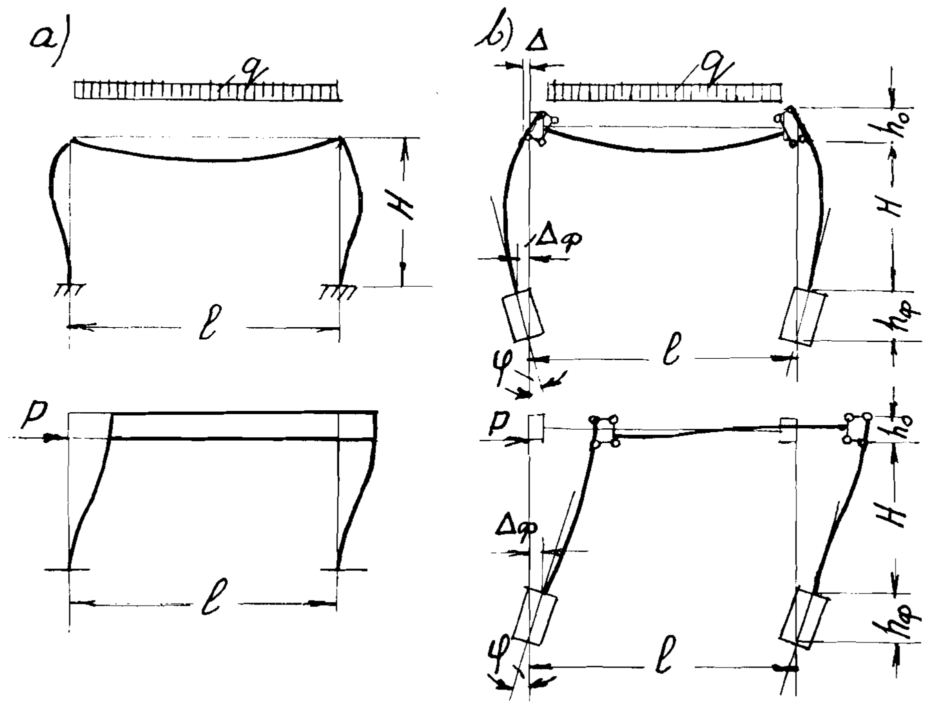

Fig. 1. Frame deformation under load: (a) According to accepted design schemes; (b) According to proposed design schemes.

In selecting girder sections of single-storey frames of industrial buildings, the unloading effect of support moments is frequently disregarded, *i.e.* the advantages of the frame system are not utilized. As tests of an experimental skeleton frame and natural-scale tests have shown, the rods of lattice girder frames in such designing are found to be of unequal strength: the flanges have surplus safety factors, while the lattice members frequently have insufficient safety factors. The unloading effect of support moments is ignored chiefly because of the lack of sufficiently reliable procedures for determining their values. Joints between girders and columns are regarded either as absolutely rigid or as pinned; in the latter case the structural solution of the attachment is usually distinguished by light-weight sections of connecting members.

As theoretical and experimental studies on models and the experimental frame have shown, in lightened connections (which ordinarily are taken as the pinned type) there appear moments that comprise up to 60–70% of the values of the moments in the case of rigid connection. At the same time, "rigid" joints yield noticeably.

The load-deformation characteristics of the connection of the upper flange to the column obtained from experimental studies of models may be replaced (with an accuracy sufficient for practical purposes) by three straight lengths that simulate the three stages: elastic, elastic-plastic and plastic (Fig. 2).

Deformability curve of flange connection in the function of stress

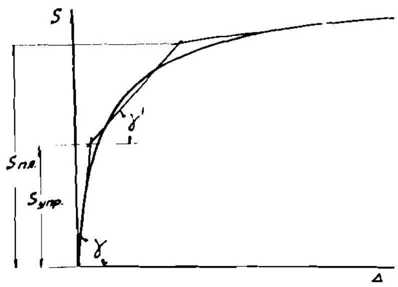

Fig. 2. Substitution of a curvilinear work diagram of a flange connection by a broken diagram, and establishing the design parameters of the connection.

On the basis of a transformation of experimental properties of joints into broken linear diagrams, parameters have been obtained which are necessary for designing frames which characterize the properties of the joints (c is the pliability of the joint in the elastic stage, c_l the pliability of the joint in the elastic-plastic stage, S_y the limit value of stress in the elastic stage of the work, and S_n is the limit value of stress in the elastic-plastic stage of the work). The values of these parameters are given in the form of graphs in the function of geometrical characteristics of joints (Fig. 3). Knowing the characteristics of joints, one can calculate the frame with any number of joints working in the elastic-plastic stage.

If we are given (for structural reasons) the geometrical characteristics of joints, it is possible, by utilizing the graphs, to determine their physical parameters and to design the frame, and by selecting the proper geometrical characteristics it is possible to regulate the distribution of stresses in the frame and its behaviour.

A graphical-analytical method has been worked out to determine the moment in a frame joint functioning in the elastic-plastic stage. This method permits a rapid analysis of the dependence of the magnitude of the moment on the deformability of joints when the load on the frame increases.

Fig. 4 shows the results of a determination by means of the graph-analytical method of the moment on a middle support of a two-span frame for two design variants of connecting the upper girder flange to a column.

A correct evaluation of the magnitudes of support moments of lattice girders permits the reduction of the cross section of girder flanges and a more reliable determination of the stresses in lattice members. This latter circumstance is especially important since the cause of some failures of trusses has been the loss of stability by medium cross stays of the trusses, the stresses in which are mainly dependent on the support moments.

The supposition taken in the designing on rigid connection with columns at the level of the top of the substructures does not accord with the actual conditions of work of the frames, since the substructures move under load. Due to movements of the substructures of the column, in the foundation there occurs not only a turning but also a horizontal displacement (Fig. 1b).

The proposed design scheme of a frame with columns fixed in absolutely rigid substructures standing on elastic semispace has been verified experimentally both on a model and on an experimental framework and in natural-scale tests, and may serve as a good basis for designing frames with account taken of their interaction with substructures and the foundation.

As a rule, when taking into consideration the deformability of the substructure foundation, the design values of the moments in the columns and at the level of the foot of the substructures diminish. Hence it is possible to lighten the weight of the columns and

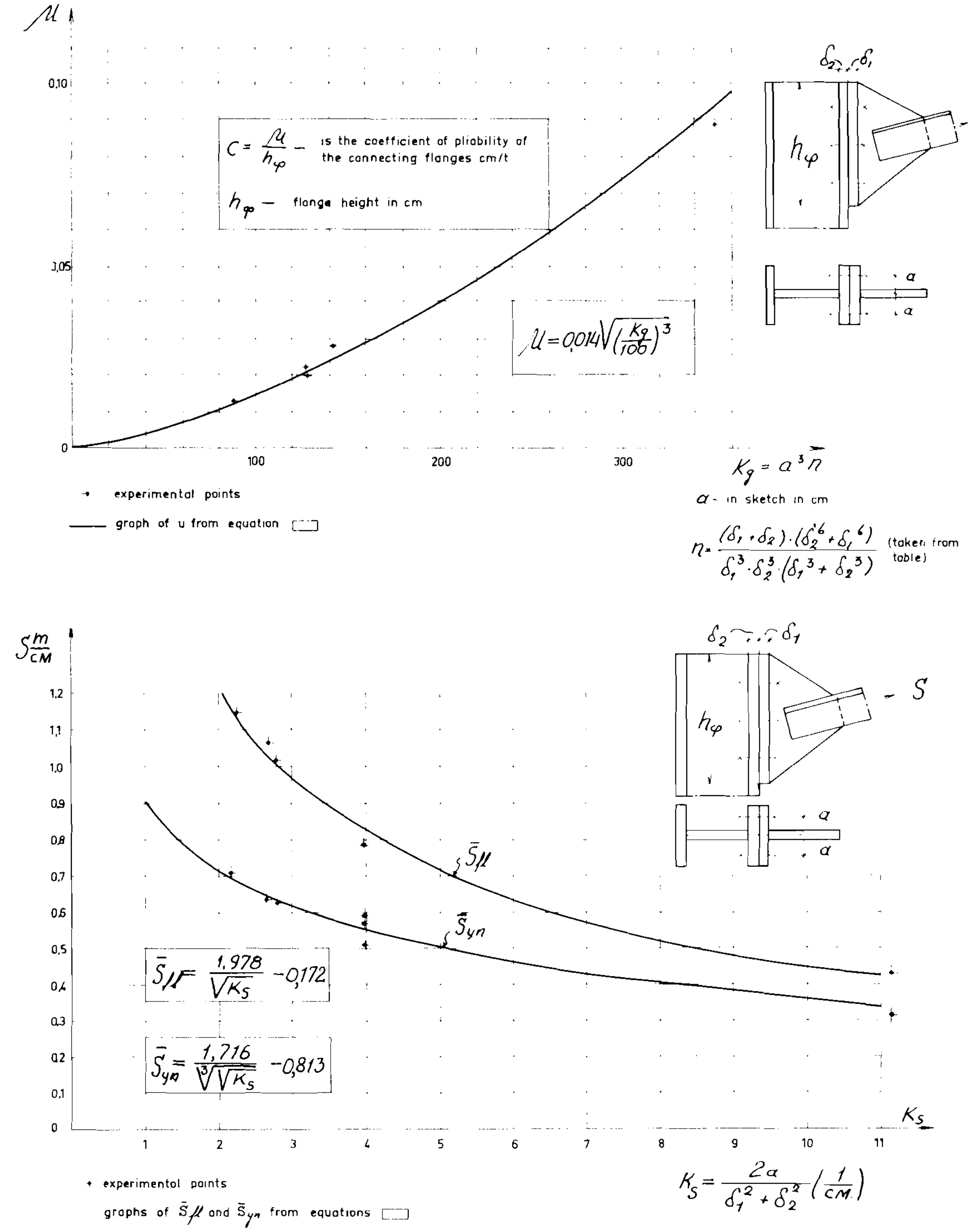

Fig. 3. Graphs of design parameters of flange connection.

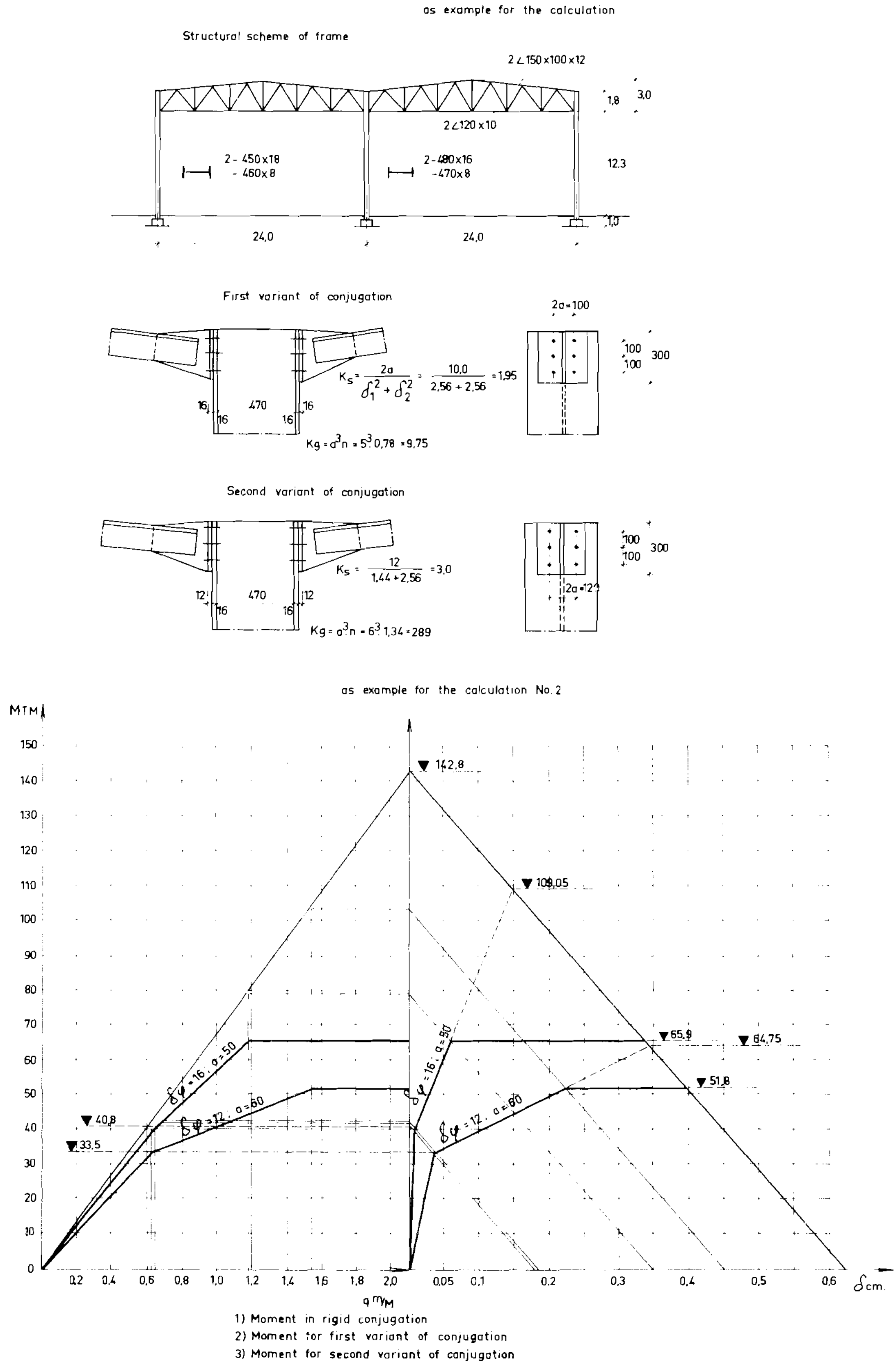

Fig. 4. Illustration of determination of moments on a middle support of a two-span frame by the graph-analytical method.

anchoring bracing and to reduce the volume of the substructures. Tests of a two-span frame in an experimental frame showed that when the girder was given a vertical load, the deformability of the foundation of the substructures reduced the moments on the base level of the column by 20%, and on the level of the foot of the substructures by 25% as compared to moments in rigid fastening.

At the same time, the deformability of the substructures of the foundation considerably increases the horizontal displacements of the frames – a phenomenon that must be accounted for, especially in buildings with heavy-duty crane operation.

For elementary frame schemes and their loadings, we have obtained formulae for transition from moments calculated without account taken of deformability of the foundation of the substructures to moments with account of this deformability. Using these formulae, graphs have been constructed that characterize the influence of deformability of the foundation of the substructures (Fig. 5). The influence of the deformability of the foundation of the substructures depends not only on the characteristics of the ground, but also on the sizes of the substructures and, to a large extent, on the rigidity of the columns.

In frames with columns of different rigidity and with various strengths of the substructures, there occurs a redistribution of moments towards an increase in their values in columns with stronger substructures, even if the columns themselves are less rigid.

In testing a two-span experimental frame by horizontal loading, a deformability of the substructures of the foundation and a varying degree of anchoring of the columns due to unequal strength of the substructures became apparent (Fig. 6). At the foundation of the extreme column, which rested on a very rigid substructure, the moment increased two-fold, in the foundation of the other extreme column the increase was 27%, and in the foundation of the most rigid middle column the moment diminished by 75%. At the girder level, the horizontal displacements of the frame increased three-fold as compared with displacements in the case of fixed columns.

Observations of displacements of substructures due to concentrated crane loads in operating shops have shown that even in the case of compact clay ground with a modulus of deformation from 2000 to 4500 kg/cm^2 the substructures are displaced, and these displacements alter the values of moments in the foundations of the columns from 10 to 40%.

Studies of the stressed state of continuous stepped columns working with eccentric loads have shown that the strength design of columns (according to the two-term formula) insufficiently reflects the actual stress state of the columns. Due to initial eccentricities in the columns and also due to local and general flexures, stresses in the transverse section of the column do not follow the law of plane sections: moments appear in the columns in a plane perpendicular to the principal deflection, and bending-twisting bimoments occur which produce overloading of the extreme fibres of the column flanges.

The non-uniformity of distribution of stresses in the column flanges, discovered in tests of models of columns and experimental frameworks, is characterized by the magnitude of the coefficient of edge overstress (the ratio of maximum edge stress to the mean stress in the column flange), the mean statistical value of which was (in the tests that were conducted) ψ 1.24; in individual cases, the values of ψ reach 2.9 and more. As a statistical analysis of the test results has shown, the most favourable type of loading (from the standpoint of edge overstress of the flanges) is non-central loading of the columns by vertical crane loads. When the frame columns are mainly under a bending load, the mean value and the root-mean-square deflection of the value of the coefficient of edge overstress are at a minimum.

Non-uniform distribution of stresses in the column flanges determines the earlier (as compared with design suppositions) transition of columns from elastic work to elastic-plastic work.

Frame tests with various types of loading and subsequent analysis of results have shown what factors produce the most essential effect on the distribution of stresses and deformations for a particular type of loading.

Characteristic of turning of substructure

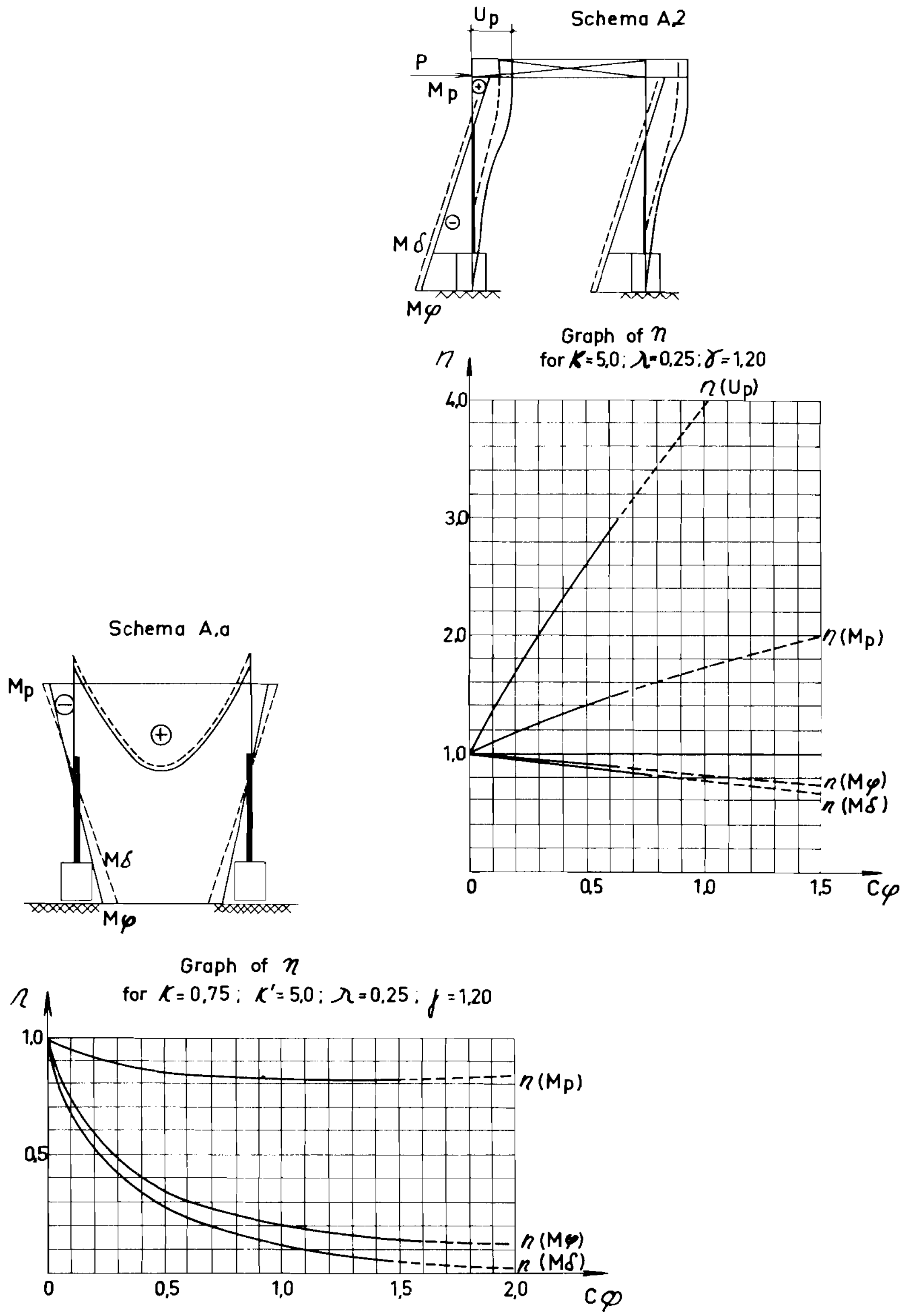

Fig. 5. The influence of deformability of the foundation of the substructures on the functioning of the frame.

When the frame girder is given a vertical load, close coincidence of design stresses and actual stresses may be obtained only when the properties of the joints (the pliability of fastening the upper-zone girder to the columns included) and deformation of the foundation of the substructures are taken into account. Of greatest importance here are correct estimates of the peculiarities of the girder-column joints.

When the frames are loaded with vertical crane or horizontal loadings, it is of greatest importance in design to consider the deformability of the foundation of the substructures. This calculation is particularly important for a correct determination of the magnitude of horizontal displacement of the frames. Such a calculation is permissible only for determining the stresses in the branches of columns, as it reduces stresses in the lattice by 20–30%. Taking this into consideration and also the fact that single angles of the lattice undergo unsymmetrical deformations, it is expedient in selecting cross sections of rods in the lattice to introduce a coefficient of work conditions, $m = 0.5$–0.75.

These tests, made up to destruction of the frames of the experimental framework, and an analysis of the results have made it possible to expose certain peculiarities in the transition to the limit state of flat single-storey combination frames of steel frameworks in industrial buildings.

In the case of frame overloading with horizontal or vertical loadings (noncentrally applied to the columns) the frames exhibited excessive deformation before they lost the capacity to take on further loads.

Under the action of these loadings, the limit state was, as a rule, attained (by a six times statically indeterminate frame) at a moment close to transition of the structure from elastic to the elastic-plastic stage of work and, at least, with the attainment of ductility at one point.

The attainment (by a many times statically indeterminate frame) of the limit state in carrying capacity before that in deformation, is due to the loss (by one of the frame rods) of stability and the instantaneously subsequent failure (due to redistribution of stresses) of one or several extra connections, which converts the overloaded member of the frame (truss, column) into a changing system (mechanism). If one of the members of the frame, which directly takes on the increasing load, loses its carrying capacity, the remaining members of the frame that are carrying other types of loads can retain the carrying capacity. However, the limit state of the frame for carrying capacity of that particular type of load is achieved.

The attainment by statically indeterminate frames with two spans and more of a limit state in carrying capacity by means of successive failure of all extra connections, is possible only in the case of a specially selected combination of loadings that could hardly ever occur under actual conditions.

The loss of the carrying capacity of the frame occurs before the limit state in deformations when the lattice girder (truss) is given a vertical load. In this case, the loss of stability of one of the compressed girder rods leads to instantaneous transformation of the girder into a mechanism due to redistribution of the stresses and a simultaneous failure of several extra connections.

A column can likewise instantaneously lose its carrying capacity when acted upon by a noncentrally applied vertical load. If in the most stressed cross section there occurs a loss of local stability of the members of the cross section, as a result of which the carrying capacity of the section is radically diminished, the stresses are redistributed to other sections, which can likewise attain their limit carrying capacity under that load, and the column as a whole will lose its capacity.

Investigations have established the following peculiarities in the work of a frame in the elastic-plastic stage, an account of which is necessary to obtain a sufficiently close picture of the actual behaviour of the structure by means of calculation.

1. When the frame passes from the elastic to the elastic-plastic stage of work, the linear

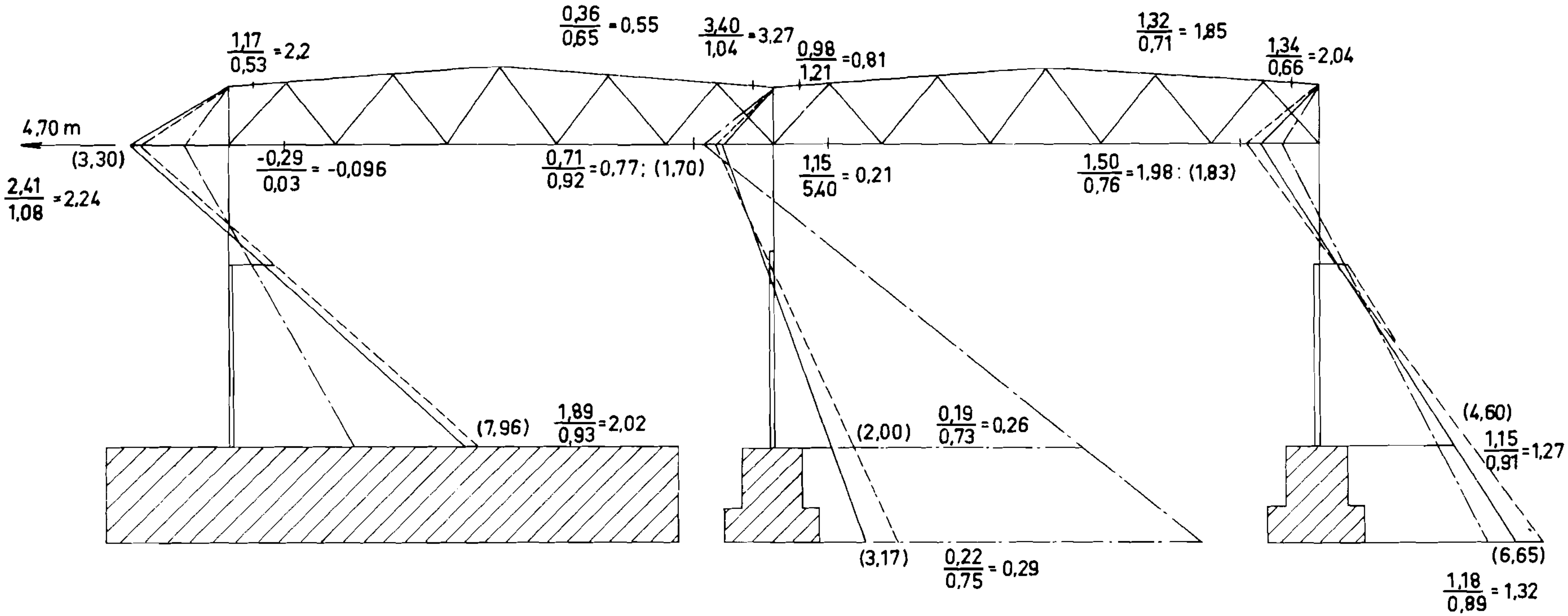

Fig. 6. The influence of deformability of the foundation of substructures according to the results of tests of an experimental frame under horizontal loading. —— for experimental data, – – – – for calculations with account taken of the deformability of the foundation of the substructures (scheme No. 1), — - — for calculations disregarding deformability of the foundation of the substructures. In parentheses are given the experimental values of moments in mm. The fractions are the structural corrections: in the numerator for design scheme No. 2; in the denominator for design scheme No. 1.

relationships of displacements and stresses due to the load are disrupted, this being due to the following causes:

(a) The development of plastic deformations of the foundation of the substructures.

(b) The development of bending deformations in compressed members (*e.g.* column lattices) both before the members lose stability due to the presence of initial eccentricities, and after the loss (by the members) of local and general stability.

(c) The development of plastic deformations in the most stressed cross sections and joints of the structure.

2. When a frame is acted upon by horizontal loadings, which produce considerable moments at the level of the foot of the substructures, the frame loses its carrying capacity, not only as a result of the formation of plastic hinges at the most stressed sections of the columns, but also as a result of a loss of resistance of the substructures to angular displacements, and this loss of resistance may, conventionally, be considered as the formation of plastic hinges at the level of the foot of the substructures (Fig. 7).

3. The formation of plastic hinges in welded columns of I-type cross section with ratios (ordinarily used in practical designing) of the thickness of the flanges and webs to their widths of

$$\frac{\delta_n}{b_n} = \frac{1}{20} - \frac{1}{30} \qquad \frac{\delta_\omega}{h_\omega} = \frac{1}{50} - \frac{1}{110}$$

is accompanied by loss of local stability of the compressed flange and part of the web.

Cross sections with members which have lost local stability in the formation of a plastic hinge have a reduced carrying capacity as compared with the still elastic parts of the member. As the general deformations of the structure develop, local deformations in the cross section increase and the carrying capacity of the member decreases in accord with the diminishing carrying capacity of the cross section. Therefore, the principle of constant moment in a plastic hinge

$$\frac{dM}{d\varphi} = 0$$

which is involved in all frame calculations when account is taken of plastic deformations, is not observed in frames of thin-walled members, and cannot be accepted unreservedly in calculations.

4. When frame members are fastened to prevent the loss of general stability and when their main function is bending, the frame loses its carrying capacity as a result of successive formation of plastic hinges before the transition of the structure into a mechanism. However, in frames with ordinary thin-walled members, the collapse load is attained with the appearance of $n + 1$ plastic hinges (n is the degree of static indeterminateness of the frames), as is considered in generally accepted design theory with account taken of the development of plastic deformations, but before it.

In cross sections which rapidly develop plastic hinges, the carrying capacity is reduced owing to loss of local stability and a redistribution occurs of loading on the other members; as a result, a number of plastic hinges appears at a constant value of loading and the load reaches its limit value when the structure has not yet attained a full mechanism of plastic hinges.

The steel framework of industrial buildings is a complex structural assembly which functions as a three-dimensional system when loaded. The three-dimensional functioning of the framework is most effectively manifested during the operation of crane loads, which load directly only part of the members of the framework, when, due to the interconnection of the system, the entire framework begins to function, and the work of the directly loaded members of the frames is eased. When crane loadings are acting from bridge cranes moving

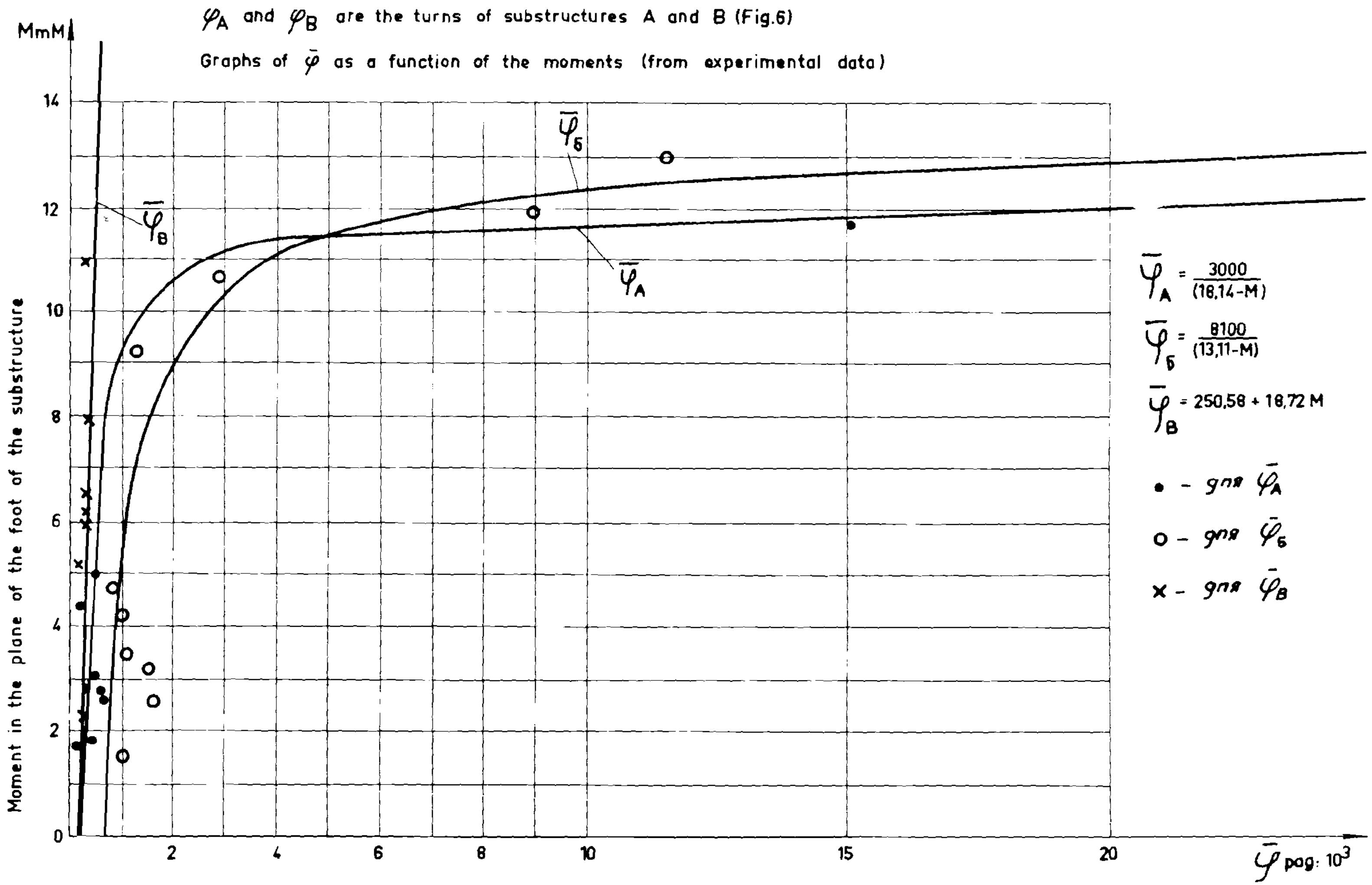

Fig. 7. Characteristics of the turning of substructures of an experimental frame as a function of the magnitude of the moments at the level of the foot of the substructures.

along rails fastened to columns, the three-dimensional function is ensured by longitudinal members rigid in the horizontal plane (longitudinal horizontal connections, rigid roofing, braking beams, etc.).

In the case of intra-shop transportation suspended from ceiling structures, three-dimensional functioning may be ensured by longitudinal vertical connections inserted continuously between the latticed girders of the frames.

The theoretical investigation includes general methodology of frame designing with account taken of the three-dimensional function and special methodology for designing various structural systems of framework (framework with a single longitudinal connection, framework with multiple-span frames of identical height in all spans under the action of crane loading on the columns, and framework with overhead transport in case of one and two longitudinal connections). Graphs have been developed to simplify practical calculations.

Designing frames for three-dimensional functioning reduces to calculating a flat frame to the action of crane loadings and elastic resistance of connections or covering.

In buildings with low rigidity or short-lived roofing, frames (asbestos plywood, corrugated steel, tile, Eternit, etc.) should be designed with account of elastic resistances of connections, which reduce horizontal displacements of the frame being designed.

For the design system one may take a block of seven or five frames with a disadvantageous location of crane loading for the middle frame, which is taken as the design frame.

In the presence of connections situated in a single level, the elastic resistance may be determined from

$$R_4 = S_4 a_{red} \tag{1}$$

where S_4 is the horizontal reaction in the fastening of columns at the level of connections from the crane loading on the middle frame of the design block.

The quantity a_{red} (reduced coefficient) is determined from

$$a_{red} = a_{44} + \xi_1 a_{34} + \xi_2 a_{24} + \xi_3 a_{14} \tag{2}$$

in which the coefficients a are taken from graphs (Fig. 8) of the function of geometric characteristics of frames, while the coefficients ξ characterize the ratio of the magnitude of crane loading on the frames contiguous to the one being designed, to the magnitude of the crane loading on the frame being designed, and are computed from the ordinates of the lines of influence.

In buildings with the same column height in all spans, displacement of the frame in the three-dimensional block at the level of connections is determined from

$$\Delta = \Delta_f (1 - a_{red}) \tag{3}$$

where Δ_f is the displacement of the flat frame at the connection level, due to the action of crane loadings.

In buildings with rigid and durable roofing (reinforced concrete assembled plates, etc.), it is advisable to design frames with account taken of the identical displacement of all frames of the block at the roofing level. The magnitude of frame displacement at the roofing level in this case is determined from

$$\Delta = \frac{\Delta'_{fl}}{n} \tag{4}$$

where Δ'_{fl} is the displacement of the flat frame at the connection level due to the integrated crane loading acting on the block; n is the number of frames in the block, not exceeding 10.

In buildings with overhead transport of a lifting capacity of 5 tons and more it is desirable to design the roof of the building with continuous vertical braces, which ensure the three-dimensional functioning of the trusses.

Calculation of the three-dimensional functioning of frameworks leads to a convergence

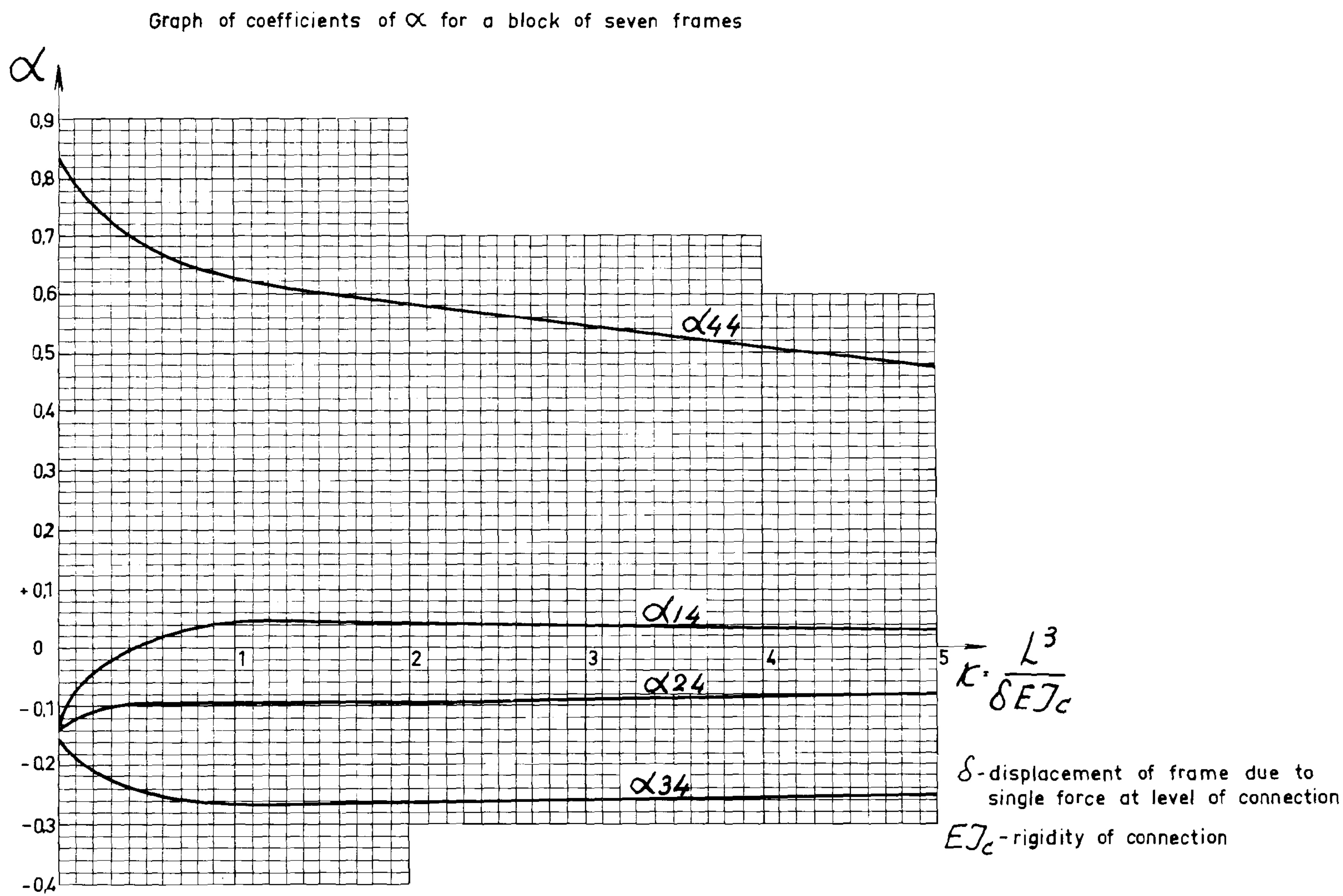

Fig. 8. Coefficient graphs α.

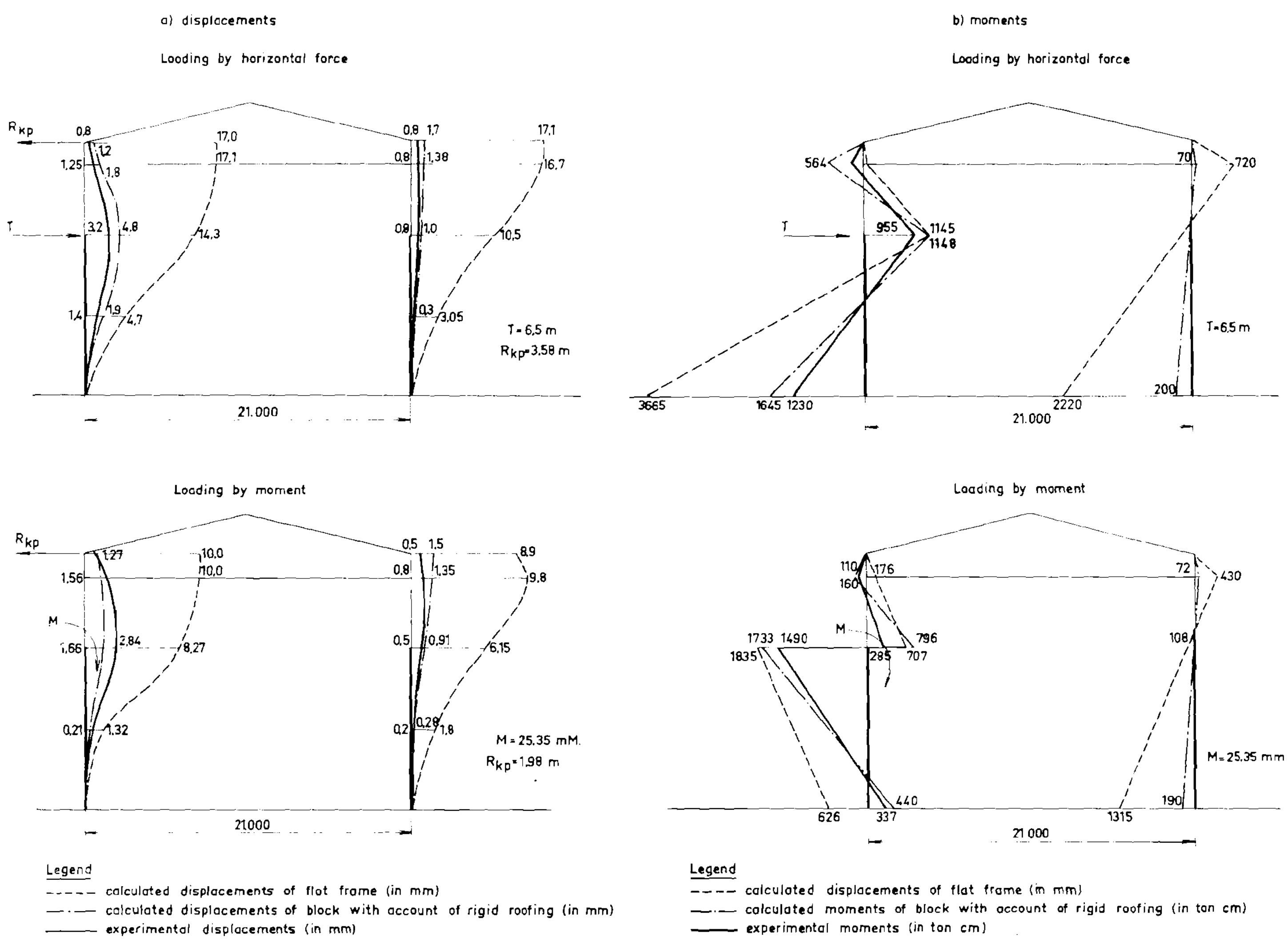

Fig. 9. The results of natural-scale frame tests.

of the calculated values of stresses and deformations of the frames with the actual values, to a correct distribution of material in the structure and, as a rule, to a reduction in the design stresses and, consequently, to a reduction in the weight of the structures.

In individual cases - mainly for the upper branches of columns and cross sections at the level of the foot of the substructures - disregard for three-dimensional functioning leads to a depression of calculated values of moment and, consequently, a reduction in the actual values of the safety factor (Fig. 9).

Reduction in the values of the moments due to three-dimensional functioning under conditions of testing the experimental frame reached 74%, while under conditions of testing natural-scale structures it reached 67% on a loaded column and 90% on an unloaded column. The design values of the moments due to the sum of all loads acting on the frames diminished to 75% in the designs that were carried out. The reduction of frame displacement in the three-dimensional block with respect to displacements of the flat frame, is as much as 10-fold and more.

An increase in the number of connections – horizontal under the action of bridge cranes and vertical under the action of overhead transport – as a rule considerably increases the effectiveness of three-dimensional functioning. To ensure effectiveness of three-dimensional functioning it is usually sufficient to consider only two horizontal connections and a vertical one.

The placing of transverse connections at the ends of the block is advisable to ensure joint functioning of the two extreme frames of the block when crane loadings are applied to them.

The influence of braking beams on three-dimensional functioning is slight and, as a rule, in practical designing it may be disregarded.

Calculation of three-dimensional functioning of transverse frames produces the greatest effect in frames of great height, when the distances between the columns are small and when the columns are of slight rigidity.

Frame calculation with account taken of three-dimensional functioning should be carried out when designing new buildings and, in addition, the results of this study may be utilized in solving problems of strengthening structures in connection with increasing loadings, both for travelling cranes and overhead transport.

Shear strength of reinforced concrete elements

UDC 624.075.3 : 624.012.45

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The problem of the shear strength of reinforced concrete beams and slabs subjected to the action of transverse forces is one of the most complicated in the theory of reinforced concrete. Although research in this field was started already in the last century and is being continued to this day, it has so far yielded no conclusive results. The great interest in this question arises from the incomplete explanation provided by the "classical" theory and by the well-known divergencies which are observed between experimental data and the results of computations based on this theory.

In reinforced concrete members subjected to simple bending (combined action of bending moments and/or transverse forces) the bearing capacity, the formation and the opening of cracks must be determined. Due to limited space only the first of these problems will be dealt with in this paper.

At the Institute of Concrete and Reinforced Concrete of the USSR Academy of Building and Architecture the author has, under the direction of Prof. A. A. Gvozdev, carried out extensive investigations on reinforced concrete beams subjected to the action of transverse forces. On the basis of the results obtained an ultimate strength design method, described hereunder, was elaborated.

Considering the behaviour of a flexural reinforced concrete member under load it may be noted that even in beams with relatively small span, cracks normal to the axis of the beam are the first to appear. As the load increases, some of these cracks develop in a direction slanting towards the middle of the span. In the subsequent stages of loading still more shallow sloping cracks appear, which sometimes cross the already formed vertical cracks.

If such slanting cracks appear in sections subjected to large bending moments they originate in the tension zone and gradually propagate towards the compression zone. However, when the bending moments are small, the slanting cracks first appear near the neutral axis and gradually spread out, both up and down. With further increases in loading these cracks develop gradually and open up; it must be noted that they open more widely than the vertical tension cracks. In a schematic representation of the state of a beam before failure, it may be considered that the diagonal crack divides, as it were, the beam in two parts, connected with each other in the compression zone by the concrete above the crack and in the tension zone by the longitudinal reinforcement of stirrups and bent-up bars which cross the crack. When the load is increased still further, the resistance of the reinforcement crossing the diagonal crack may be overcome and in this case both parts of the beam will rotate reciprocally around a common hinge in the compression zone. This causes a further opening of the crack and a reduction in the height of the compression zone leading to its failure, a very similar compression failure occurring above a vertical tension crack.

In the presence of strong and well-bonded longitudinal reinforcement, which resists the reciprocal rotation of both parts of the beam, the concrete fails under the combined action of compression and shear. This usually starts in the compression zone above the crack. When the compression zone is strong, as in T-beams, rupture may start in the web, in the general direction of the principal compressive stress.

Based upon these two possible schemes of rupture two ultimate conditions of equilibrium must be considered; the disturbance of either one of the two may be the cause of destruction:

1. The moment of the external forces relative to the centroid of the compression zone above the diagonal crack must be smaller than the moment, which may be taken up by the main reinforcement of stirrups and bent-up bars

$$M_e \leqslant f_s\sigma_s Z_s + \sum f_v\sigma_v Z_v + \sum f_b\sigma_b Z_b \tag{1}$$

2. The external transverse force must be smaller than the combined ultimate strength of the concrete, the bent-up bars and the stirrups

$$Q_e \leqslant Q_c + \sum f_v\sigma_v + \sum f_b\sigma_b \cos\varphi \tag{2}$$

A third condition of equilibrium determines the height of the compression zone and the magnitude of the lever arm entering the first inequality. The factors entering this inequality are illustrated in Fig. 1, and will be considered in detail below.

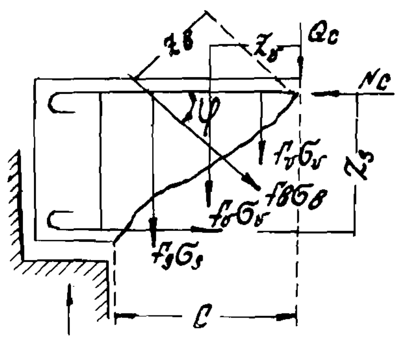

Fig. 1. Factors determining the ultimate conditions of equilibrium.

In working out the above-mentioned inequalities a series of assumptions were made, some of which may lead to certain errors. In particular, it was admitted that both the longitudinal and the transverse reinforcement are able to resist only pure tension and do not resist shear. A number of authors have expressed the opinion that longitudinal reinforcement is capable of resisting shear. It is, however, impossible to agree fully with this opinion. In the case of diagonal crack developing in close proximity of the support, the main reinforcement working in shear may, perhaps, perceptibly partake in resisting a transverse loading, working as a dowel. However, if the crack occurs even at a relatively small distance from the support, such an occurrence is hardly possible, since the reinforcement will bend and tear off the concrete cover.

It was also assumed that the yield stresses will be reached simultaneously both by the concrete and by the entire transverse reinforcement. In reality, however, this may not be the case as the ultimate conditions occur in succession, which may lead to some error to be accounted for by the introduction of corrective factors.

Let us analyse in greater detail the factors which enter inequalities (1) and (2). M_e and Q_e are the moment and the shear acting in and along the inclined cross sections. They differ from those used in the design of normal cross sections due to the fact that in determining them it is necessary to consider whether the load is applied above or below the inclined cross section, thereby determining whether these forces should be regarded as right-hand or left-hand ones (Fig. 2).

$f_s\sigma_s$, the internal force acting in the main reinforcement when bond is sufficient, may be taken equal to the internal force at yield stress. When bond is sufficient it should be taken as the equivalent of the force which will cause the reinforcement to be pulled out. The values of $f_v\sigma_v$ and $f_b\sigma_b$ may be considered equal to the internal forces at yield stress.

The ultimate shear Q_c taken up by the concrete should be studied in greater detail. In order to determine the values of Q_c 75 beams were tested by the author in 1937. These were single-span, simply-supported and cantilever beams. Portions of all of these beams were devoid of web reinforcement either on the entire length between the support and the load or on a part of it. In the latter case these portions were either close to the support, near the load or on both sides of the inflexion point.

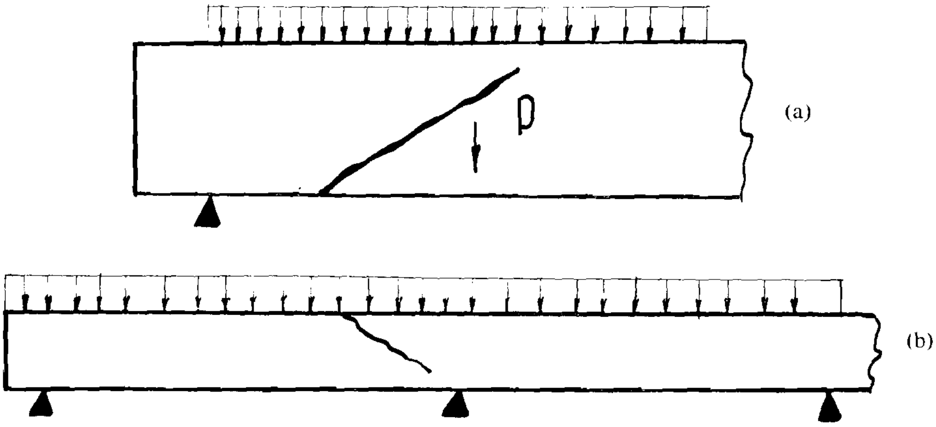

Fig. 2. Application of forces. Force P in (a) is applied below the inclined section and should be considered as a force acting on the right side of the beam. A uniformly distributed load within the inclined section must also be considered as a force acting on the right side of the beam.

These tests made it clear that the value of the ultimate shear taken up by the concrete depends mainly on the size of the beam cross section, the cube strength of concrete and the angle of inclination of the diagonal crack. On the basis of these tests an empirical formula was proposed for the determination of the value of the shear which can be resisted by the concrete, taking into account the factors mentioned above

$$Q_c = K \cdot bh_0R_b \tan a = \frac{Kbh_0^2R_b}{c} \tag{3}$$

where c is the projection of the beam axis of the diagonal crack along which failure occurred and K is a factor which in the first approximation may be taken as constant and equal to 0.15.

The concrete in the zone of the diagonal crack is in a state of complex stress, and in the absence of a sufficiently developed theory of the strength of concrete it is difficult to provide theoretical proof of this expression. It is clear that Q_c must depend on the size of the cross section and on the cube strength of concrete, but the influence of the slope a of the crack is less evident. However, their interdependence may be shown by the following simple reasoning: Q_c is the sum of the components normal to the axis of the element of the principal compressive stresses, whose direction is reflected by the slope of diagonal cracks. The steeper these cracks, the steeper will be the direction of the principal compressive stresses and the greater their vertical component and, therefore, also the value Q_c.

These tests show also that even when the reinforcement is securely bonded with the concrete various kinds of failure remain possible. When the distance between the load and the support is small and also when stirrups are closely spaced, failure of concrete in compression in the direction of the principal compressive stresses causes the destruction of the beam. This kind of destruction is characterized by the fact that shortly before rupture a series of shallow, sometimes fan-shaped cracks appears in the compression zone at the end of the diagonal crack. Simultaneously, numbers of oblique cracks open at various levels side by side with the main cracks. Then scaling begins and the concrete is crushed both in the compression zone and at various levels in the proximity of the diagonal crack, as well as in the tension zone near the support.

When the distance between the support and the load is small, the principal compressive stresses are directed parallel to the line connecting the centre of the support with the load point, thus forming, as it were, a compressed brace. In this case the diagonal cracks, as a rule, are also parallel to that line. The smaller the distance between the support and load and, therefore, the steeper the brace formed, the greater is the vertical component Q_c.

When the distance between the support and the load is large and when the web reinforcement is relatively weak, destruction is caused by shear of the compression zone along a line which is the continuation of the diagonal crack. It is easy to show that in this case the value of Q_c will depend on the slope of the crack. Indeed, compressive forces normal to the plane of shear substantially increase shear strength and therefore the sharper the slope of the crack, the smaller will be the component of normal stresses acting in a direction perpendic-

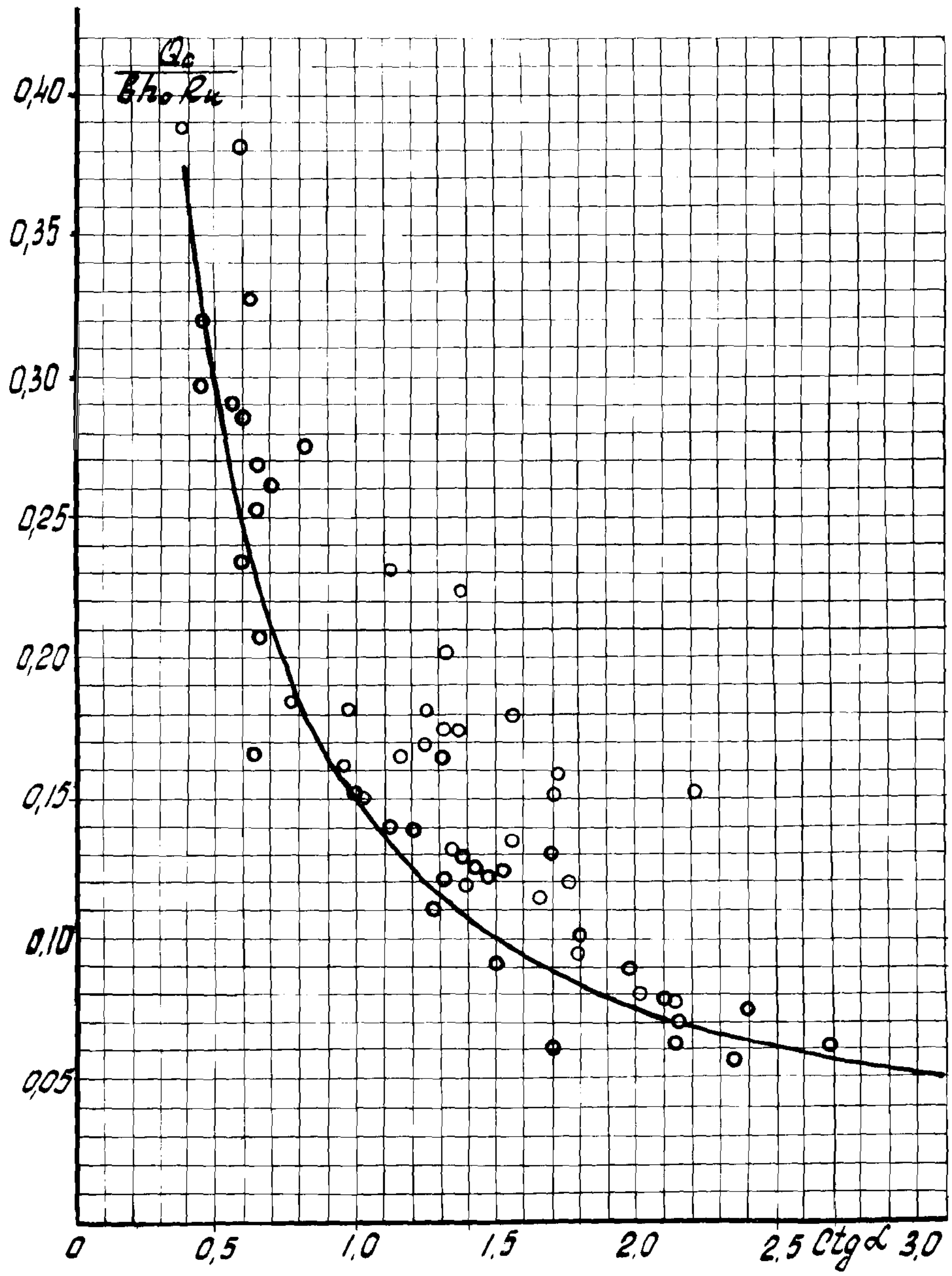

Fig. 3. A curve illustrating the dependence of $Q_c/b\ h_o\ R_b$ on the cotangent of the crack inclination angle.

ular to the plane of shear and, consequently, the smaller will be the resistance to shear expressed by Q_c.

It must be noted that in testing beams carrying two concentrated loads another type of failure was evidenced, in which the diagonal crack crossed the section situated under the load well below the neutral axis and, entering the zone of pure bending, went through it almost horizontally. Cracks formed at both ends of the beam and joined up, thus leading to a formation resembling a tied arc. Although the reinforcement remained well anchored in the sound parts of the beam, local breaking of the bars from the concrete and the disturbance of bond caused the destruction of the compressed concrete midway between the loads at stresses in the reinforcement which were well below its yield point. Despite the different character of failure the ultimate shear strength of these beams coincided well with that computed by the above formula, disregarding a certain unavoidable scatter.

In Fig. 3 values of the cotangent of the crack slope (the ratio of the horizontal projection of the crack to the effective beam height) are plotted along the horizontal axis, while those of

$$\frac{Q_{c\,ult}}{bh_0R_b}$$

are plotted along the vertical axis.

The curve represents the ultimate shear strength, computed from equation (3), and the dots represent actual test values. All the dots fall fairly close to the curve, although a considerable scatter is observed.

If we assume that the diagonal crack crosses the entire length of the section between the support and load, then the expression for Q_c will coincide with the one derived from the University of Illinois tests, which assumes that the value of the moment of the transverse load remains constant for a beam of a given cross section reinforcement and strength of concrete, regardless of the distance between the load and support. However, if the portion of the span between support and load is provided with web reinforcement, then, as tests show, failure will occur along a much steeper crack and at a higher load. In this case the moment of the transverse force will no longer remain constant.

The value of the factor K in equation (3) may be considered constant only in the first approximation. It depends on a series of factors, *e.g.* percentage of reinforcement, cube strength of concrete. Tests carried out recently have shown that when the distance between the support and load is small the value depends upon the size of the bearing plates through which both the load and the reaction of the support are transmitted.

The influence of these factors may partly explain the scatter of test results apparent in Fig. 3. However, their effect is not very large, and for the sake of simplicity it was decided to neglect them, assuming $K = 0.15$.

Some investigators have noted that, all other conditions being equal, the ultimate shear strength depends on the area of the tensile reinforcement. In our tests, in order to avoid failure in bending due to the yielding of reinforcement, the beams, as a rule, were over-reinforced; under-reinforced beams failed through the yielding of the tensile bars and, therefore, the effect of the variation of the longitudinal reinforcement was small. It may also be pointed out that in the University of Illinois tests the increase of the main reinforcement area had an effect on the ultimate shear strength of the beams only in the absence of web reinforcement, whereas in beams with such reinforcement the increase of longitudinal reinforcement area had no effect on the ultimate load. This question requires additional investigation. In order that the area of reinforcement could be varied within comparatively wide limits without fear of bending failure, it seems advisable to use high tensile steel.

The formula proposed for the computation of Q_c, as well as any other empirical formulae, have a limited field of application within which they remain true. It is impossible to admit that in the case of a vertical crack Q_c will become equal to infinity. In our tests the ratio of h/c reached 2.5, and even then a sufficiently good agreement with formula (3) was still observed.

For checking the method of computations proposed, besides the 75 beams mentioned above, more than 60 beams were tested with web reinforcement along their entire length. These were single-span, simply-supported beams and beams cantilevering at one or both ends. These beams were tested with one or two concentrated loads in the span and on the cantilevers; in other cases a larger number of equally spaced concentrated loads were applied.

Some of the beams were reinforced with stirrups, others with bent-up bars and several with both stirrups and bent-up bars. Besides this an analysis was carried out of test data on beams failing in shear and described in the literature. Altogether more than 200 beams were analysed.

All the data thus collected are in good agreement with the results of theoretical computations. A frequency distribution curve for test data deviations from calculated values is presented in Fig. 4. The average deviation is equal to + 1.5 %, whilst the standard deviation is 16.2 %.

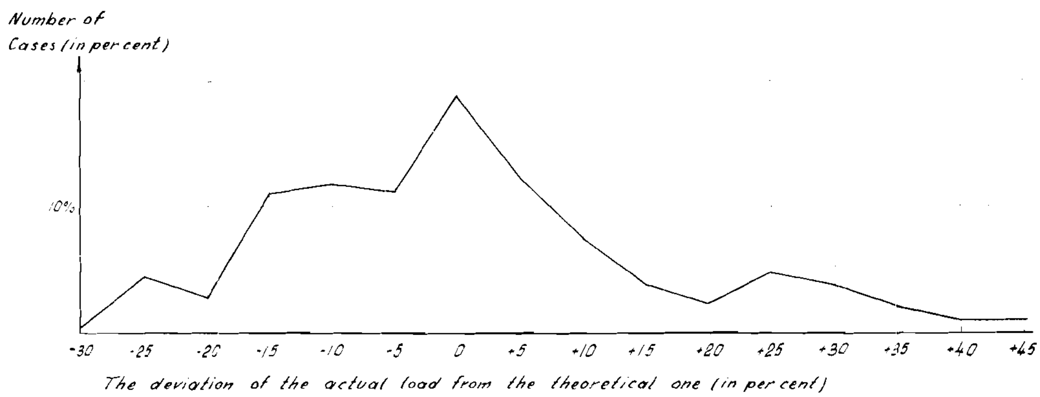

Fig. 4. Frequency distribution for test data deviations from calculated values (for 203 beams).

The use of the fundamental inequalities for design purposes would be laborious, mainly because the slope of the most dangerous cracks is unknown and therefore the strength would have to be checked along several oblique directions. However, it has been found possible to elaborate a set of formulae based on equations (1) and (2) and to establish certain design rules which, substantially simplifying the computations, secure automatically the fulfilment of these equations for any cross section. Hereunder we present the development of the expression used for the computation of the stirrup area, based on equation (2).

Consider a beam subjected to a combination of concentrated and uniformly distributed loads. The shear diagram will in this case consist of several trapezoidal portions as shown in Fig. 5. Assume that the load is applied at the upper edge of the crack. If we consider the stirrups to be uniformly and continuously distributed along the whole portion of the beam under consideration, then for the inclined cross section beginning in the tension zone at a distance x_2 and reaching the compressed face at a distance x_1 from the support, equation (2) may be written in the form

$$Q_0 - px_1 \leqslant \frac{0.15\, bh_0^2 R_b}{x_1 - x_2} + q(x_1 - x_2) \tag{2a}$$

where Q_0 is the shear force at the support;

$Q_0 - px_1$ is the shear force acting in the inclined cross section under consideration, ending at the point x_1;

$x_1 - x_2 = c$ is the projection of the diagonal crack;

q is the intensity of stress which can be resisted by the stirrups per unit length of the beam

$$q_v = \frac{f_v \sigma_v}{e}$$

p being the intensity of the uniformly distributed load.

Equation (2a) may further be transformed as follows

$$Q_0 \leqslant \frac{0.15\, bh_0^2 R_b}{c} + (q_v + p)c + px_2 \tag{2b}$$

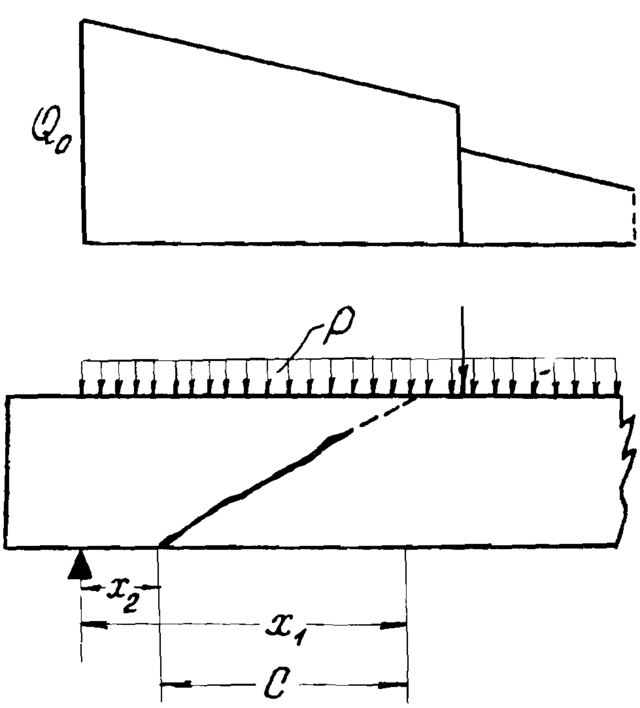

Fig. 5. Shear diagram of a beam subjected to a combination of concentrated and uniformly distributed loads.

Assuming that x_2 remains constant and is known, the slope of the crack may be found for which the right-hand portion of expression (2b) reaches its minimum, which may be done by equating to zero its first derivative by c

$$-\frac{0.15\, bh_0^2 R_b}{c^2} + p + q_v = 0 \tag{4}$$

from which

$$c = \sqrt{\frac{0.15\, bh_0^2 R_b}{p + q_v}} \tag{5}$$

Substituting this value in equation (2b) and taking $x_2 = 0$, which leads to the minimum of Q_0, we obtain:

$$Q_0 = 2\sqrt{0.15\, bh_0^2 R_b (q_v + p)} \tag{6}$$

from which

$$q_v = \frac{Q_0^2}{0.6\, bh_0^2 R_b} - p \tag{7}$$

Equation (6) shows that when stirrups are provided and when the distance from support to load is greater than the length c obtained from expression (5), the ultimate shear force is independent of this distance. In analysing the University of Illinois tests the authors had observed that for beams provided with stirrups the ultimate shear did not depend on the length of the "shear span", as it did for elements with no web reinforcement.

Using equation (7) the required area of stirrups may be determined. When bent-up bars are spaced fairly widely apart, then for any given stirrup area, the required area of these bars can be determined by the following expression

$$f_b \sigma_b \sin \varphi = Q_0 - 2\sqrt{0.15\, b h_0^2 R_b (q_r + p)} \qquad (8)$$

The area of bent-up bars and stirrups obtained by equations (7) and (8) ensures the fulfilment of expression (2) for any slope of the diagonal crack.

In most cases no checking of flexural strength of the inclined cross sections is required. Provided that the main tensile reinforcement is reliably anchored at the supports, is neither interrupted nor bent up, and that the downward load is applied to the upper face of the beam, equation (1) is automatically fulfilled and, therefore, the flexural strength of the beam in the inclined cross sections remains ensured as long as the strength of the normal cross sections is not exceeded.

It can be easily shown that in the presence of bent-up bars the flexural strength of any inclined cross section will be provided for if the normal cross sections at the bends are sufficiently strong and if the distance between the bend located in the tension zone and the normal cross section where the bar becomes fully stressed is not less than 0.5 h_0.

Even in cases where the main reinforcing bars are terminated in the tension zone, checking of the flexural strength of inclined sections by means of expression (1) may usually be avoided, provided the bar is extended sufficiently far beyond the section where it is really required. The length of this extension is determined by the condition that stirrups and bent-up bars crossing any oblique cross section situated beyond the end of the cut-off bar should fully compensate the strength of this bar.

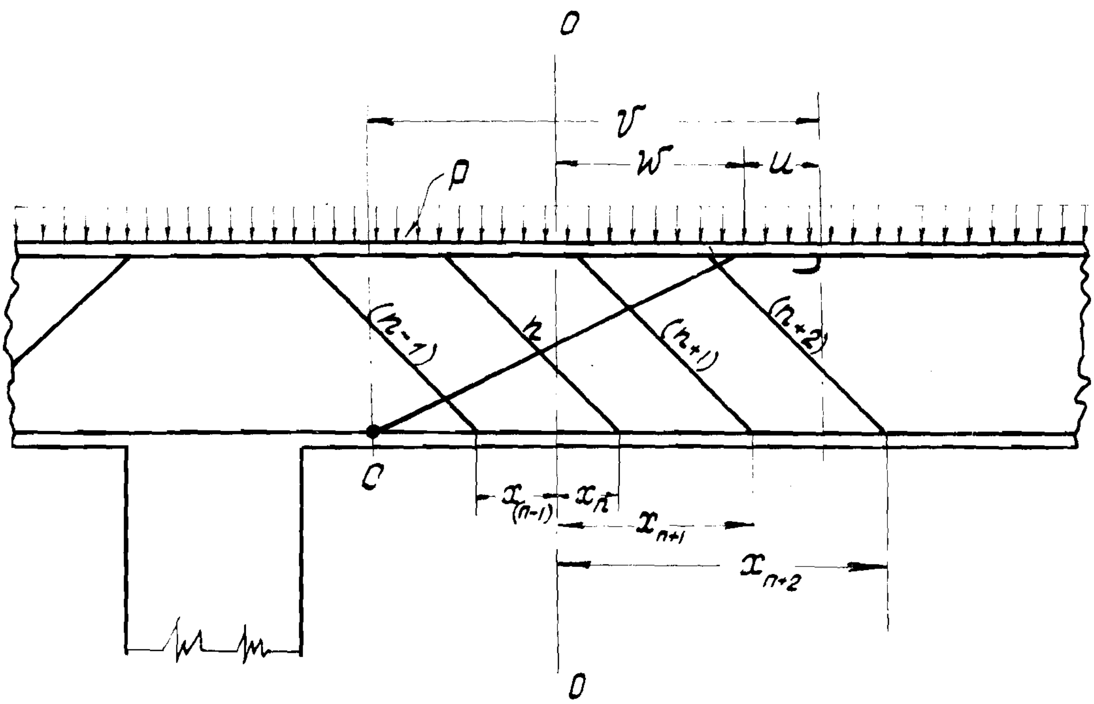

Fig. 6. Determination of distance at which negative moment reinforcement over intermediate supports may be terminated in continuous beams.

The distance w at which negative moment reinforcement over intermediate supports may be terminated in continuous beams may be determined as follows (see Fig. 6):

Let 0–0 be a vertical cross section at which one of the reinforcing bars becomes superfluous, and where theoretically this bar could be cut off. Taking into account the danger of failure along an oblique cross section, the bar should be extended for a length $w + u$ beyond the cross section 0–0, where u is the length needed for anchoring the bar. The length w should be chosen in such a manner that for any inclined cross section beginning at a distance u from the end of the bar the strength should remain ensured.

The most dangerous cross section will be the one where the difference between the moment of the external forces and that of the internal forces acting in the reinforcement crossing this section, reaches a minimum. Let v be the horizontal projection of this cross section. By equating to zero the first derivative by v of the aforesaid difference of moments it can be shown that the most dangerous cross section will be the one where the vertical component of the outside forces is equal to the sum of the vertical components of the internal forces acting in bent-up bars and stirrups crossing this section. In this case we have

$$Q_1 = \sum_k^m Q_b^i + q_e v$$

from which (9)

$$v = \frac{Q_1 - \sum_k^m Q_b^i}{q_e}$$

where Q_1 is the shearing force in the vertical cross section 1–1, located at a distance w from the point of the theoretical bar end towards the middle of the span;

$$\sum_k^m Q_b^i$$

denotes the sum of the vertical components of ultimate strength of the bent-up bars crossing the inclined cross section under consideration and

q_e is the ultimate strength of stirrups per unit of beam length.

The moment of the external forces in the most dangerous cross section under consideration, *i.e.* the moment about point c of the external forces lying to one side of this section, is equal to

$$M_e = M_1 + Q_1 v \qquad (10)$$

where M_1 is the moment of external forces in the vertical cross section 1–1, $Q_1 = Q_0 - pw$ and

$$M_1 = M_0 - Q_0 w + \frac{pw^2}{2}$$

M_0 and Q_0 being respectively the moment and the shear in the vertical cross section 0–0.

By substituting these values in equations (9) and (10) we obtain

$$v = \frac{Q_0 - pw - \sum_k^m Q_b^i}{q_e} \qquad (11)$$

$$M_e = M_0 + Q_0(v - w) - pw\left(v - \frac{w}{2}\right) \qquad (12)$$

The condition ensuring flexural strength in the inclined cross section may be written as

$$M_e \leqslant f_s\sigma_s Z_s + \frac{q_v v^2}{2} + \sum_k^m Q_b^i(v - w + x_i) \tag{13}$$

where $f_s\sigma_s$ is the ultimate strength of the uninterrupted tensile reinforcement, crossing the section under consideration,

Z_s is the lever arm of this reinforcement,

Q_b^i the vertical projection of the internal force taken up by the bent-up bars, and

x_i the horizontal distance from the bend in the compression zone to the vertical cross section 0–0.

Since M_0 is the moment at the point of the theoretical end of the longitudinal bar, it is equal to the sum of ultimate moments resisted by the uninterrupted reinforcement and of the ultimate strength moment of the bent-up bar crossing section 0–0, *i.e.* $M_0 = f_s\sigma_s Z_s + Q_b^n x_n$. Then the condition of strength may be rewritten as

$$M_e \leqslant M_0 + \frac{q_v v^2}{2} + \sum_k^{n-1} Q_b^i(v - w + x_i) + Q_b^n(v - w) + \sum_{n+1}^m Q_b^i(v - w + x_i) \tag{14}$$

where k and m designate the first and last bent-up bar crossed by the diagonal crack. In order to obtain the value of the distance w from expression (14), by transformation and equating the left-hand part to the right-hand, we get

$$M_e = M_0 + \frac{q_v v^2}{2} + (v - w)\sum_k^m Q_b^i + \sum_{(-n)} Q_b^i x_i \tag{15}$$

Here $\sum_k^m$ covers all bent-up bars crossed by the inclined cross section, while $\sum_{(-n)}$ covers the same bars, except those designated $(-n)$ by (n), which cross 0–0.

Substituting M_e in equation (15) by its expression drawn from equation (12) and designating $\sum_{(-n)} Q_b^i x_i$ by $\tilde{M}$, we get

$$\left(Q_0 - \sum_k^m Q_b^i\right)(v - w) - pw\left(v - \frac{w}{2}\right) - \frac{q_v v^2}{2} - \tilde{M} = 0 \tag{16}$$

Eliminating v from equations (11) and (16) and designating $\left(Q_0 - \sum_k^m Q_b^i\right)$ through $\tilde{Q}$ we obtain, after transformation

$$\frac{(\tilde{Q} - pw)^2}{2q_v} - \tilde{Q}w + \frac{pw^2}{2} - \tilde{M} = 0$$

or

$$\frac{p}{2}\left(1 + \frac{p}{q_v}\right)w^2 - \tilde{Q}\left(1 + \frac{p}{q_v}\right)w + \frac{\tilde{Q}^2}{2q_v} - \tilde{M} = 0$$

$$w = \frac{\tilde{Q}}{p}\left(1 - \left[\frac{1 + \dfrac{2\tilde{M}p}{\tilde{Q}^2}}{1 + \dfrac{p}{q_v}}\right]^{\frac{1}{2}}\right)$$

Neglecting $\dfrac{2\tilde{M}p}{\tilde{Q}^2}$, which is small compared with 1, we get

$$w = \frac{\tilde{Q}}{p}\left[1 - \frac{1}{\left(1 + \frac{p}{q_v}\right)^{\frac{1}{2}}}\right] \leqslant \frac{\tilde{Q}}{p}\left[1 - \frac{1}{1 + \frac{p}{2q_v}}\right] \leqslant \frac{\tilde{Q}}{2q_v + p}$$

Substituting the value of $\tilde{Q}$, we finally obtain

$$w = \frac{Q_0 - \sum_k^m Q_b^i}{2q_v + p} \tag{17}$$

In order to check these formulae a series of beams 20 cm wide and 50 cm high, reinforced with six bars 25 mm in diameter, were tested. The beams were tested with one load at mid span and imitated a portion of a continuous beam between inflexion points of adjacent spans. Only two of these bars ran through the entire length of the beams, while the other four were cut off in the tension zone, the distance w where this was done being determined in accordance with expression (17). All beams failed at loads causing the yield of the main tensile reinforcement, mostly at mid span.

The design method presented above provides structures with the required bearing capacity, and in a number of cases makes it possible to reduce the web reinforcement. Its main advantage lies in the presentation of a clear picture of the phenomena which take place in a flexural reinforced concrete member under the action of transverse forces. It permits allowance to be made for such factors as the level of load application, which remains disregarded in the usual design methods. Besides, it renders possible the determination of stresses in the reinforcement near the supports (which is necessary for the evaluation of the bond length), enables the exact computation of the places where the main reinforcement may be cut off in the tension zone, and permits scientific design for elements of abruptly varying height, etc.

MEANING OF SYMBOLS

- M_e bending moment caused by external forces and acting in an inclined cross section.
- Q_e Shear caused by external forces and acting along an inclined cross section.
- Q_c Shear taken up by the concrete.
- $f_b\sigma_b \sin\varphi$ Shear taken up by a bent-up bar.
- R_b Ultimate flexural compressive stress of concrete, roughly equal to its cylinder strength.
- σ_s Ultimate stress in the main tensile reinforcement.
- σ_v Ultimate stress in the stirrups.
- σ_b Ultimate stress in the bent-up bars.
- f_s Area of the main tensile reinforcement.
- f_v Area of the stirrups.
- f_b Area of the bent-up bars.
- $q_v = \frac{f_v\sigma_v}{e}$ where e is the distance between stirrups.
- p intensity of the distributed load.

Other symbols used are explained in the text or in the appropriate illustrations.

Investigations into the rigidity and the opening up of cracks in reinforced concrete bending members

UDC 624.012.45 : 69.059.2

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Systematic investigations into the appearance and opening up of cracks and also into the rigidity of reinforced concrete bending members have been in progress in the U.S.S.R. since about 1937.

These studies are being conducted with members of various cross-sectional areas reinforced with different grades of steel, with different proportions of reinforcement and made of different grades of concrete. Most of the studies were carried out for structures with ordinary reinforcement and under short-term loading. However, during the last few years studies have been in progress dealing with the rigidity and with the opening up of cracks under long-term loading and with prestressed structures.

The opening up of cracks in the tensile zone of the concrete for working stresses in reinforcement of optimum periodic profile (deformed bar reinforcement, which ensures maximum bond with the concrete), $\sigma_a = 2500$ kg/cm^2, does not exceed crack opening in members with smooth round reinforcement at stresses of 1250–1300 kg/cm^2.

Thus the profile of the reinforcement produces a considerable effect on the opening up of cracks and also on the rigidity of the member, though to a smaller degree.

Deflections of beams with extra-high-strength reinforcement increase, under working loads, approximately in proportion to the increase in working stresses in this reinforcement.

It has been established that the deflection of beams must be checked when using periodic profile reinforcement of high-strength steels because in a number of cases the measured deflection of beams under working loads exceeded the allowable values even for short-term loading.

Our attempts to use the ordinary theory of elastic reinforced concrete used in Western Europe for calculating the rigidity of reinforced concrete beams have not met with success because beam deflection is essentially affected by plastic deformations in the compression zone of the concrete and also by the presence of cracks in the tensile zone of the concrete. At the same time, one must take into account the effect produced on beam deformation by the work of the concrete between cracks in tension. The first systematic investigations established relationships to the development of cracks and also for alterations in the rigidity of bending members, and in 1939 it was possible to formulate the principles of a theory for calculating the opening up of cracks and for rigidity; in the following years this theory was subjected to comprehensive experimental verification and refinement.

In 1952, this method of calculation was accepted by the Official Building Code for designing reinforced concrete structures in the U.S.S.R.

In developing the design theory we have introduced the concepts of the mean relative deformation of tensile reinforcement in concrete and the mean deformations of compressed concrete (Fig. 1) along the sections between cracks. The concept has been introduced of the modulus of elastic-plasticity of concrete E_δ^1, which is the ratio of stress in the compressed zone of concrete in a cross section with a crack to the total mean relative deformation, including the elastic and plastic parts (Fig. 2a).

The modulus of elastic-plasticity of concrete is expressed by means of the modulus of elasticity of concrete with the aid of the coefficient of plasticity of the concrete λ, which is equal to the ratio of the plastic part of the deformation to the total deformation or, in other words, by means of elastic deformations with the aid of the coefficient of elasticity ν, equal to the ratio of the elastic part of the deformation to the total deformation

$$E'_\delta = (1 - \lambda) E_\delta = \nu E_\delta \tag{1}$$

where E'_δ is the modulus of elasticity of concrete,

$$\lambda = f(\sigma_\delta, t, R \ldots)$$
$$\nu = f_1(\sigma_\delta, t, R \ldots) \tag{2}$$

Here σ_δ, t, R are the stress, time, and grade and type of concrete, respectively.

The concept has been introduced of the effective modulus of elasticity of the reinforcement in the concrete E_{ac}, equal to the ratio of the stress in the tensile reinforcement in the cross section with the crack to the mean relative deformation of the reinforcement (Fig. 2b). The effective modulus of elasticity of the reinforcement is expressed by means of the modulus of elasticity of the steel, *viz.*

$$E_{ac} = \frac{E_a}{\varphi} \tag{3}$$

where $\varphi = E_a/E_{ac}$ is the coefficient of completeness of the stress diagram in the reinforcement, which takes into account the effect of tensile concrete between cracks on the deformation of the reinforcement.

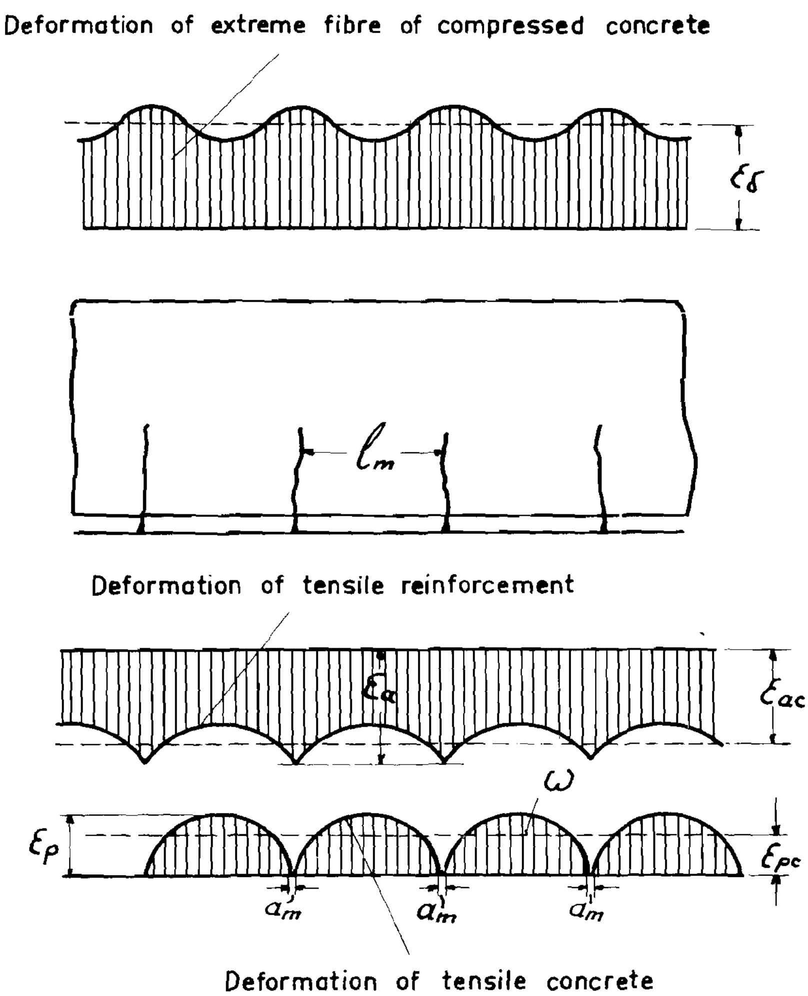


Fig. 1. Diagram of alterations in the relative deformations of tensile reinforcement and concrete along the member.

The coefficient φ is a function of the stress in the reinforcement, the time, the grade of concrete and the geometric parameters of the cross section.

$$\varphi = f(\sigma_a, t, R, \pi \ldots) = 1 - \omega x \frac{M_{\delta m}}{M} \tag{4}$$

where σ_a, t, R and π are, respectively, the stress in the tensile reinforcement in the cross section with the crack, the time of action of the load, the strength of the concrete and the geometrical parameters of the cross section;

$M_{\delta m}$ is the bending moment which the concrete undergoes at the appearance of the crack (Stage *Ia*);

M is the bending moment due to external action (the load and other actions);

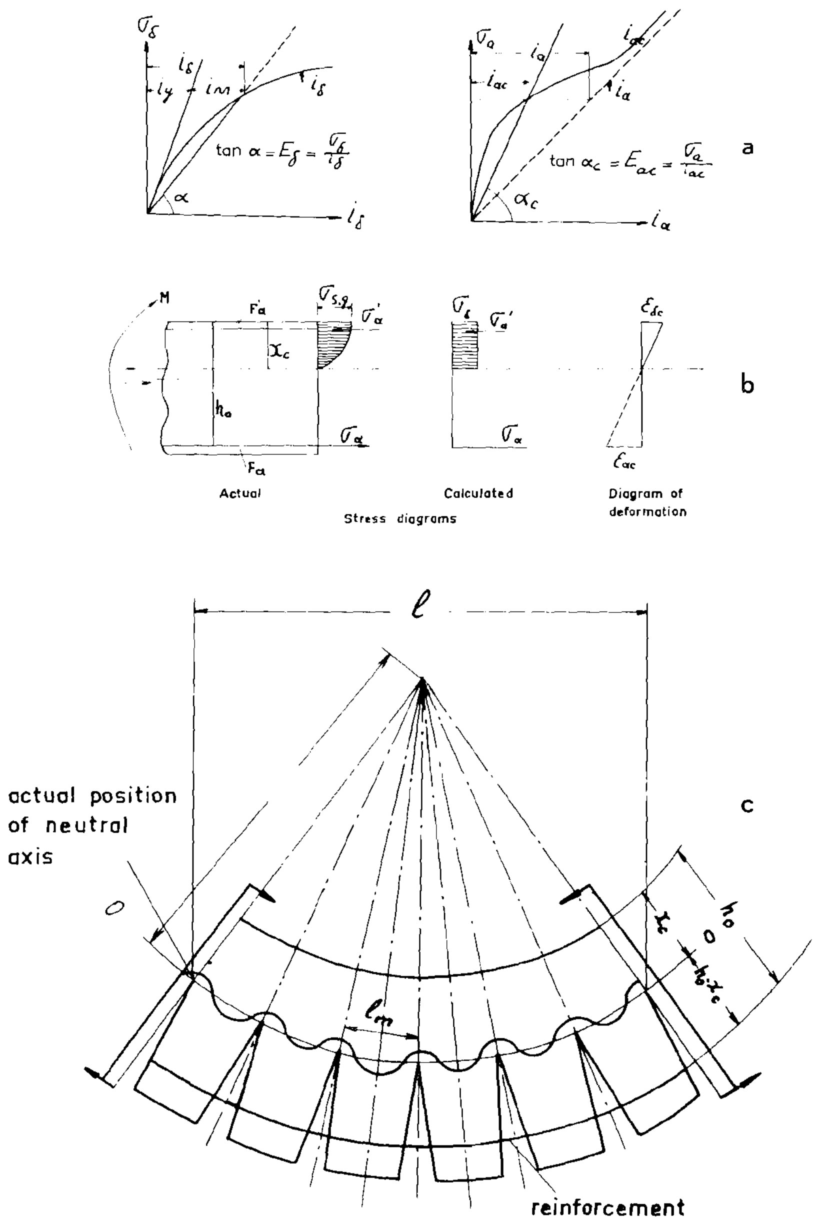


Fig. 2. Deformation of members during pure bending.

ω is the coefficient of completeness of the stress diagram in the tensile concrete over the distance lm (Fig. 1); and

x is the ratio of stress in the concrete halfway between cracks to the ultimate strength of the concrete in tension.

It is, furthermore, assumed that the mean relative deformations of the concrete and reinforcement vary linearly along the height of the cross section (Fig. 2c).

The mean height of the compressed zone x_c (Fig. 2c) in the general case is a function of the elastic-plastic properties of the materials, the geometric parameters of the cross section and the longitudinal force due to the external load and the prestressing of the member.

$$x_c = \varphi(E_\delta', E_{ac}, \pi, N) \tag{5}$$

where π denotes the geometric parameters of the cross section and N is the longitudinal force.

Given these prerequisites, the mean curvature of the axis of a member is expressed by the following equations

$$\frac{1}{\rho_c} = \frac{E_{ac}}{h_0 - x_c} = \frac{\sigma_a}{E_{ac}(h_0 - x_c)} = \frac{M_a}{E_{ac}W_a(h_0 - x_c)} = \frac{M_a}{B_a} \tag{6}$$

$$\frac{1}{\rho_c} = \frac{E_\delta}{x_c} = \frac{\sigma_\delta}{E_\delta' x_c} = \frac{M_c}{E_\delta' W_c x_c} = \frac{M_c}{B_c} \tag{7}$$

Here

$$B_a = E_{ac}W_a(h_0 - x_c) \tag{8}$$

is the rigidity of a reinforced concrete cross section with a composite stress diagram for the tensile zone;

$$B_c = E_\delta' W_c x_c \tag{9}$$

is the rigidity of the reinforced concrete cross section with a composite stress diagram for the compression zone;

W_a is the elastic-plastic section modulus for the tensile zone with a composite stress diagram;

W_c is the elastic-plastic section modulus for the compression zone with a composite stress diagram;

M_a is the moment of external forces relative to the centre of compression in the compression zone;

M_c is the moment of external forces relative to the centre of the tensile reinforcement.

In the general case, when a moment and longitudinal force arise in the cross section due to an external load, $M_a \neq M_c$, $B_a \neq B_c$, and $M_a/B_a \neq M_c/B_c$. In simple bending (in the absence of a longitudinal force) $M_a = M_c = M$ and $B_a = B_c$.

In the case of a simple bending (Fig. 2c)

$$\begin{aligned} W_a &= S_{a\delta} + S_{a\delta}' \\ W_c &= S_{\delta a} + S_{\delta a}' \end{aligned} \tag{10}$$

where $S_{a\delta}$ and $S_{a\delta}'$ are, respectively, the static moments of the tensile and compressive reinforcement relative to the centre of the compression zone of the concrete; and $S_{\delta a}$ and $S_{\delta a}'$ are, respectively, the static moments of the area of the compression zone of the concrete and the compressive reinforcement relative to the centre of the tensile reinforcement.

The height of the compression zone (taking the calculated stress diagram in the compression zone of concrete as rectangular) is determined from the equation

$$n'F_a \frac{h_0 - x_c}{x_c} - n'F_a' \frac{x_c - a'}{x_c} - F_\delta = 0 \tag{11}$$

F_δ is the area of the compression zone of concrete.

$$n' = \frac{E_{ac}}{E_\delta'} = \frac{E_a}{\varphi(1-\lambda)E} = \frac{n}{\varphi(1-\lambda)} = \frac{k}{\varphi\nu}$$

On the basis of experimental data, the product of $\varphi\nu$ may be taken as equal to 0.33–0.25. In the U.S.S.R. Building Code $\varphi\nu = 0.33$.

The mean width of cracks opening due to forces is determined from the equation

$$A_{mc} = \left(\frac{\sigma_a}{E_{ac}} - \omega\frac{\sigma_{\delta p}}{E_{\delta p}}\right) lm \tag{12}$$

or, neglecting the second term because of its smallness,

$$A_{mc} = \frac{\sigma_a}{E_{ac}} lm = \frac{M}{W_a E_{ac}} lm \tag{12a}$$

$$lm = \left(\frac{\sigma_{am}}{R_p} - R_p'\right) U \frac{R_p}{\omega'\tau} \tag{13}$$

where $\sigma_{am} = \frac{M_m^{11}}{W_a}$ is the stress in tensile reinforcement immediately after the appearance of cracks;

M_m^{11} is the bending moment due to external forces immediately after the appearance of cracks;

U is the ratio of the area of the reinforcement to its cross-sectional perimeter.

$$n_p' = E_a/E_{\delta p}'$$

where $E_{\delta p}'$ is the modulus of elastic-plastic concrete in tension, and is equal to $(1-\lambda_p)E_\delta$ (where $\lambda_p \cong 0.5$);

R_p is the ultimate strength of the concrete in tension;

τ is the bond stress of the reinforcement with the concrete;

ω' is the coefficient of the completeness of the reinforcement-concrete bond diagram.

For smooth reinforcement the ratio

$$\frac{R_p}{\omega'\tau}$$

may be taken as equal to unity, and for periodic profile reinforcement as 0.5–0.65.

A complete account of this theory for the calculation of the rigidity and opening up of cracks and its experimental substantiation is given in our monograph, published in 1950 in the U.S.S.R.,[1] and also in a number of other works that have appeared in recent years.

By way of illustration, Fig. 3 gives a comparison of measured deflections for beams tested by Bakh (Notebook No. 38 of the German Concrete Union) with the theoretical values

[1] V. I. MURASHEV, *Crack-proofness, rigidity and strength of reinforced concrete*, Mashstroiizdat, 1950.

calculated in accordance with the foregoing method (bottom graph), and using the first stage with a reduced modulus of elasticity of the concrete (0.625 E_δ, upper graph).

A second example is given in Fig. 4; a comparison of the measured relative values of depths of the compression zone $\xi = X_c/h_0$ and the calculated values determined from equation 11 for T-type and rectangular beams tested in 1958. As may be seen from the figures, after the formation of cracks the depth of the compression zone diminishes to a definite constant value that corresponds to the coefficient $\varphi\nu = 0.33$–0.25.

Fig. 5 presents an over-all graph for the ratio of the theoretical deflection to the experimental value for a series of beams tested in NIIZhB in 1957–58.[1] As may be seen from the graph, the coincidence of theoretical and experimental values for deflection in this series of experiments (and also in all the earlier series) is very satisfactory.

At present the investigation of rigidity and of opening of cracks has been completed in a large series of prestressed beams with different degrees of prestress. The results of these tests are still being analysed. To illustrate, Fig. 6 gives the curves of deflection of beams reinforced with periodic-profile steel with a yield point of 4500 kg/cm² without prestressing and with stress $\sigma_{ax} = 4050$ kg/cm² and 2800 kg/cm². The character of the deflection curves

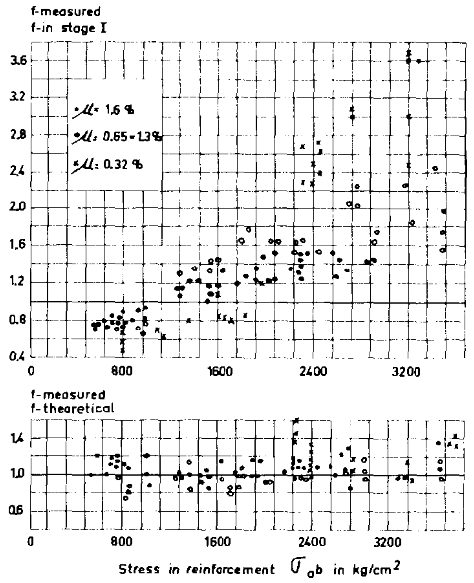
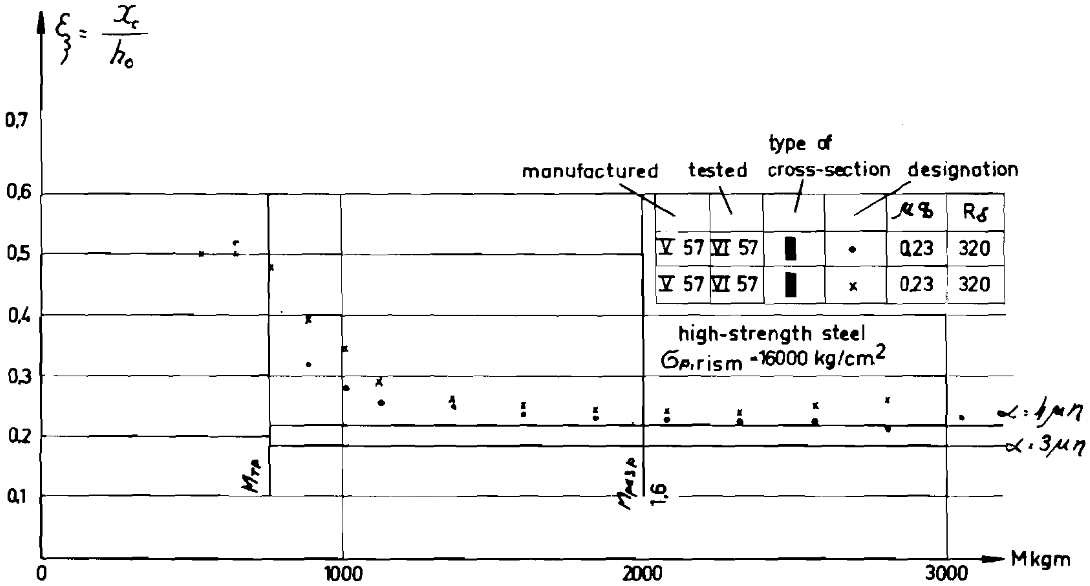


Fig. 3. Values of f(measured)/f(calculated) for rectangular beams tested by Bakh.

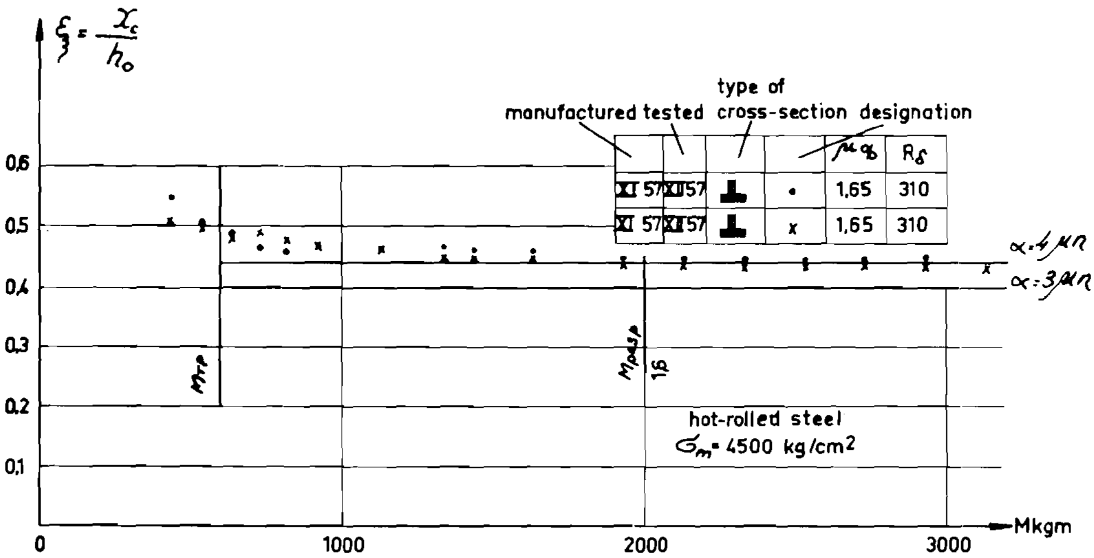
does not depend on the degree of prestressing, whereas the amount of deflection perceptibly diminishes with increasing prestressing, the result of an increase in the moment that produces the appearance of the cracks. Hence, the rigidity of prestressed reinforced concrete bending members is described by the same physical parameters and, as investigations have shown, should be calculated by the foregoing theory, taking into account the initial stresses in the concrete.

There is likewise no fundamental difference in the behaviour of ordinary and prestressed members under continued loading. The curves (Fig. 7) of the increase of deflection for beams with ordinary and prestressed reinforcement are identical in character, while the increment in deflection (in the case of continued loading) which occurs with increased prestressing, slightly diminishes. More detailed information about the behaviour of ordinary and prestressed beams under continued loading may be reported after a complete analysis of the experimental data.

[1] The tests were carried out by postgraduate student Yu. A. Suslov under the direction of the author.



Graph ξ for beams of rectangular cross section



Graph ξ for T-beams

Fig. 4. Comparison of measured relative values of depths of compression zone with calculated values for rectangular and T-beams.

$$f = \frac{M}{B} \cdot K$$

$$B = \frac{E_a}{\psi} \cdot F_a \cdot c \cdot h_o^2$$

$$\psi = 1 - 0{,}67 \frac{M_{\delta T}}{M}$$

Steel	Designation	μ %	R	Type
Cold-drawn wire σ_{np} = 17000	●	0,23	320	▨
	○	0,23	320	▨
	+	0,53	330	I
	Δ	0,53	330	I
	✱	0,55	230	⊥
	◑	0,55	230	⊥
Hot-drawn steel 4500 kg/cm²	□	0,80	300	▨
	■	0,80	300	▨
	x	1,52	260	I
	v	1,52	260	I
	⦶	1,65	310	⊥
	⊕	1,65	310	⊥

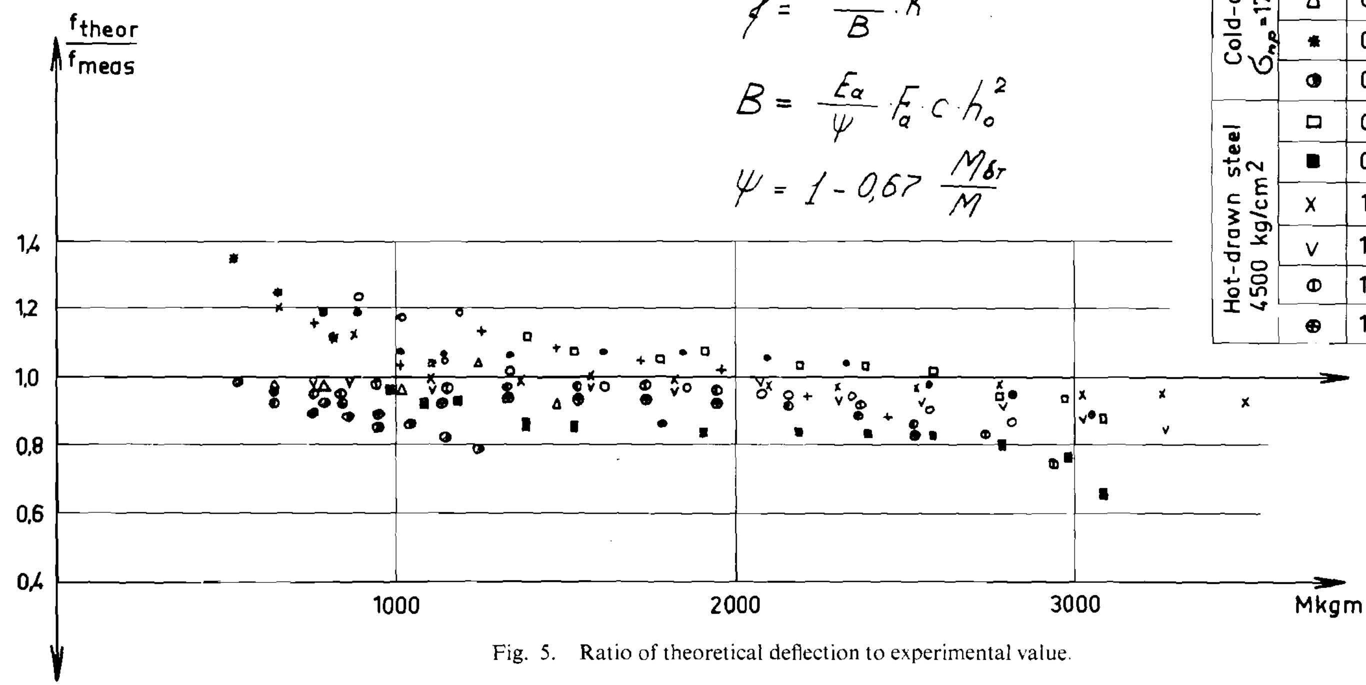


Fig. 5. Ratio of theoretical deflection to experimental value.

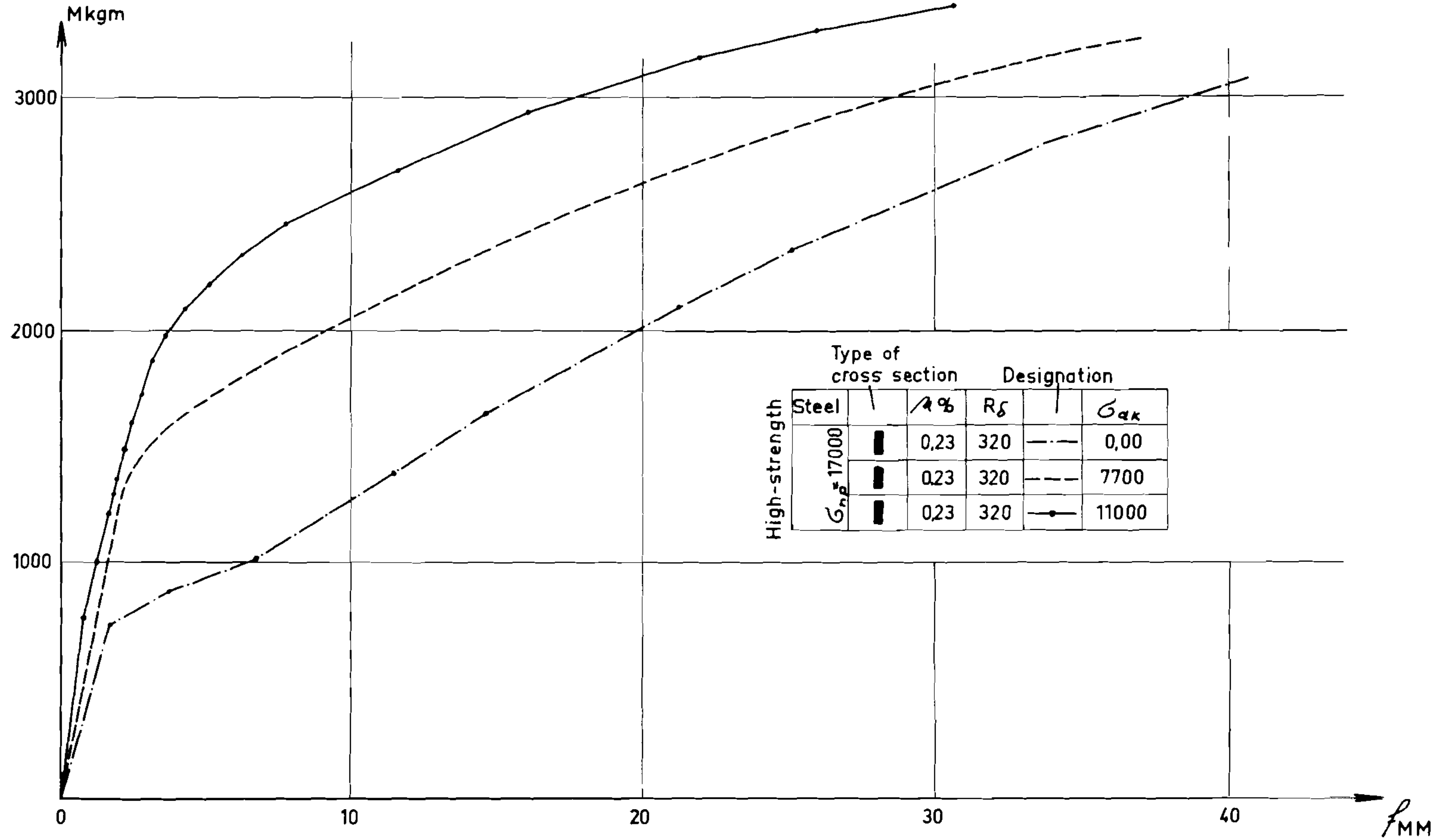
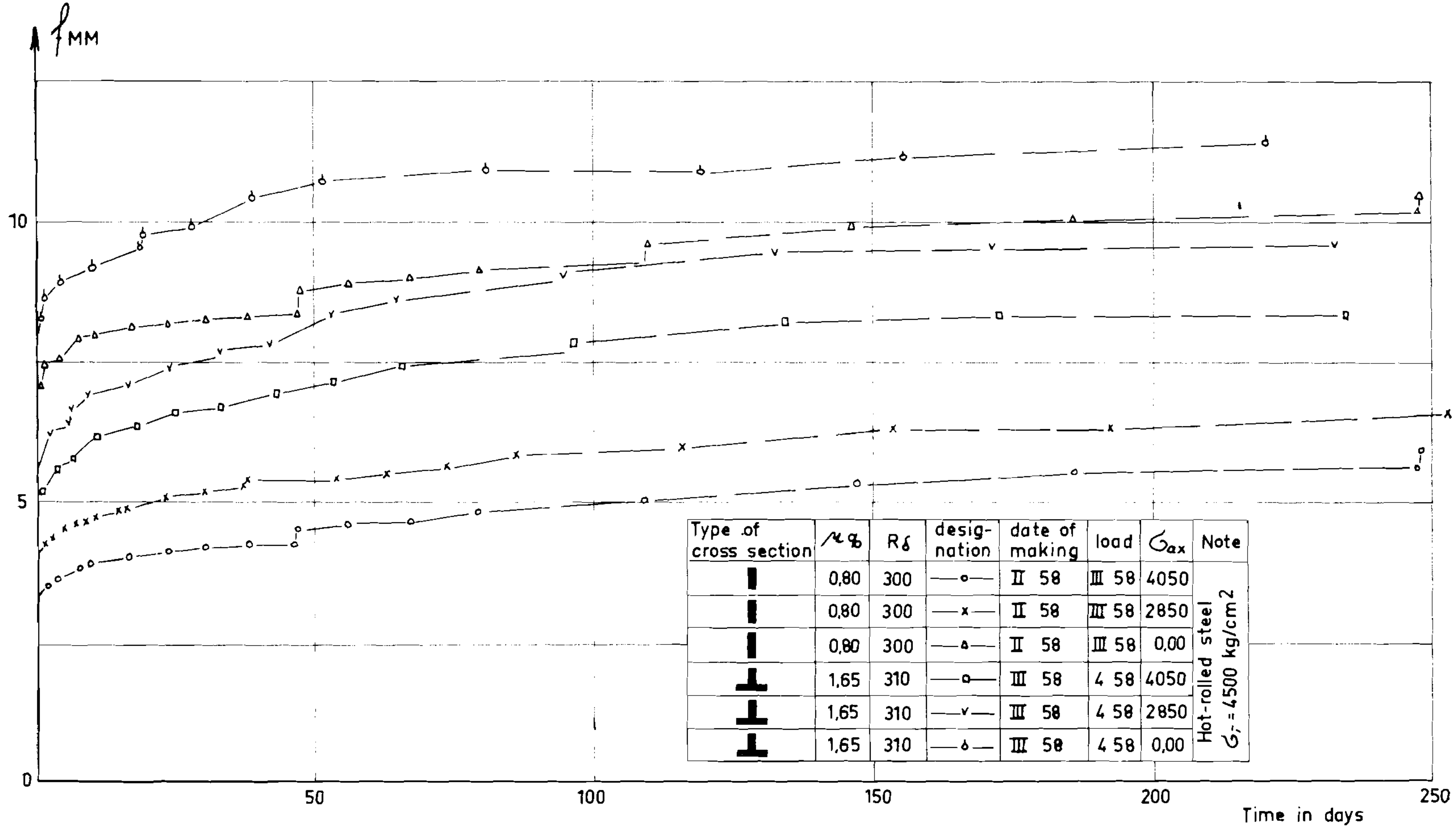


Fig. 6. Experimental deflections of rectangular string-concrete beams as a function of the degree of prestressing.



Type of cross section	μ %	Rδ	designation	date of making	load	σax	Note
▮	0,80	300	—o—	II 58	III 58	4050	Hot-rolled steel σT = 4500 kg/cm2
▮	0,80	300	—x—	II 58	III 58	2850	
▮	0,80	300	—Δ—	II 58	III 58	0,00	
┻	1,65	310	—□—	III 58	4 58	4050	
┻	1,65	310	—v—	III 58	4 58	2850	
┻	1,65	310	—δ—	III 58	4 58	0,00	

Fig. 7. Deflections of rectangular beams in time as a function of the degree of tension.

The theory elaborated above of calculating rigidity has permitted a large range of problems to be tackled, the solution of which had been prevented because of the absence of a correct understanding of the deformations in reinforced concrete. These include a large number of problems associated with the calculation of the forces and deformations caused by the action of temperature in reinforced concrete structures. To illustrate, we may take a rectangular or round plate acted upon by a temperature gradient in its plane from the centre to the periphery with tensile reinforcement along the boundary of the plate.

These problems also include various contact problems in which the stresses are proportional to the rigidity; dynamical problems; problems on the redistribution of stresses in statically indeterminate reinforced concrete structures and also problems of accounting for the influence of flexibility on the carrying capacity of columns, etc.

At present, investigations are in progress in these and other fields on the basis of these new conceptions of rigidity and the opening up of cracks in reinforced concrete. The elaborated theory, with allowance for inelastic deformations of concrete, is used also in a number of cases for the calculation of strength.

However, this problem requires special consideration.

Computing shells by the method of critical equilibrium

UDC 624.074.4

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The conventional method of computing shells by the methods of the applied theory of elasticity provides no information on the carrying capacity of the shell, unless the latter is made of a brittle material; apart from this, the method is too complicated for mass-scale application. Such deficiencies are not inherent in the calculation of shells based on their treatment as rigid-plastic systems, for which the carrying capacity can be determined comparatively simply by the kinematic method of critical equilibrium. The method is rather widely used in computing rod structures and metal and reinforced concrete plates. In recent years ways have been found of applying the critical equilibrium method to computing some kinds of shells, which constitutes the subject of this paper.

Computation of structures by the kinematic method of critical equilibrium was developed in the thirties in quite a general way by Professor A. A. Gvozdev, who deduced and substantiated the limit principle of the minimum of an external load, equilibrating the real form of collapse of a rigid- or elastic-plastic system. As a rule, the equations of equilibrium in the kinematic method are so formed that variation in the work of external and internal forces on the displacement equals zero. For linearly deformed systems, *i.e.* systems in which the arrangement of the work of the structure does not change in the course of deformation, the variation of work may be replaced by full work of the external and internal forces.

The main difficulty in computing shells by the critical equilibrium method lies in finding forms of collapse which are close to actual conditions and in calculating the work of inner forces on such forms of collapse. Deformations of a rigid-plastic shell in the stage of critical equilibrium may be both distributed continuously along its surface and concentrated along certain lines, which we shall henceforth term fracture lines. To calculate the work of the internal and external forces is a simpler task in the case of concentrated deformations, and to obtain an approximate solution it is, therefore, more feasible to assume concentrated deformations as forms of collapse. For a number of shells, use can be made of the methods of computation and the forms of collapse used in the theory of critical equilibrium of plates.

COMPUTING SHALLOW SHELLS

Let us imagine a form of collapse of a shallow shell, similar to that of a flat plate with a series of plastic hinges and a deflection surface in the form of a shallow polyhedral surface (Fig. 1). The cross section of the shell along every fracture line will be wholly plastic, the

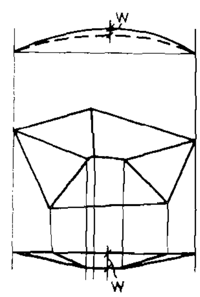

Fig. 1. Form of collapse of a shallow shell.

extension zone being separated from the compression zone by a neutral line coinciding with the common axis of rotation of the adjacent parts of the shell (Fig. 2). The critical bending moment should be determined in this case for the whole cross section of the shell along the fracture line. The magnitude of the critical moment M_T^i in the ith structural rib is expressed by the formula

$$M_T^i = S_i^+\sigma_T^+ + S_i^-\sigma_T^- \tag{1}$$

where S_i^+ and S_i^- are the static moments of the extended and compressed parts of the cross section of the shell about the neutral line, and σ_T^+ and σ_T^- are the yield limits of the material for extension and compression.

For a shallow shell of a constant thickness, the static moments S_i^+ and S_i^- may be assumed to equal the product of the thickness of shell δ and an area confined by the neutral line, the central line of the shell arc, and the verticals at the ends of the fracture line (Fig. 2).

Having assumed the form of collapse of the shell, it is possible to calculate the work of the internal and external forces on displacements of this form of collapse. By disregarding the elastic work of those parts of the shell which have not yielded, we obtain the following expression for the work of the internal forces

$$T = -\sum(S_i^+\sigma_T^+ + S_i^-\sigma_T^-)\varphi_i \tag{2}$$

Here φ_i denotes the angle of mutual rotation of the adjacent elements of the shell along the ith fracture line. Summation is carried out along all the fracture lines.

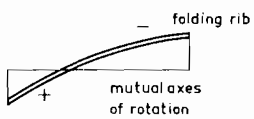

Fig. 2. Static moments for a shallow shell of constant thickness.

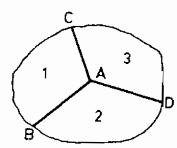

Fig. 3. Axes of rotation in a shallow shell. (See text.)

The work of the external forces is expressed as follows

$$V = \int_F qW\,\mathrm{d}F \tag{3}$$

where q is the vertical load applied to a unit area of the horizontal projection of the shell, and W denotes the vertical deflections of the shell, determined by the particular form of collapse. Integration is carried out over the whole area of the horizontal projection of the shell.

The actual form of collapse should satisfy the limit criterion

$$T + V = \max \tag{4}$$

To find this criterion, it is necessary to obtain not only a picture of the distribution of the fracture lines on the surface of the shell, but also the position of the common axes of rotation of the parts of the shell above the stationary horizontal plane of its support.

Suppose that only concentrated deformations of extension and compression take place along the lines of fracture of the shell in directions perpendicular to the fracture lines, and that there are no shear displacements either in the tangential plane of the shell or in the vertical plane which passes through the fracture line. Hence, the instantaneous axis of mutual rotation of two adjacent parts of the shell must be in a plane containing the fracture line of these two parts of the shell. In view of the low gradient of the shell, this plane may be considered vertical, and the instantaneous axis of rotation as coinciding in plan with the fracture line.

It is likewise easy to establish that all the common axes of rotation must intersect one another and lie in one plane. Indeed, if the rotation of elements 1 and 3 of the shell (Fig. 3) relative to element 2 take place about axes AB and AD, which do not intersect the vertical line A, then the movement of element 3 can be represented as the sum of the rotary movement about a new axis parallel to the initial one and intersecting axis AB on the vertical line A, and of a translational movement perpendicular to plane AD. This translational movement brings about displacements of elements 1 and 3 along plane AC, and the mutual movement of elements 1 and 3 will not represent simple rotation. Hence, the condition of absence of shear displacement along the fracture lines calls for an intersection of all the common axes of rotation of the elements located around a common point.

Moreover, the mutual rotations relative to the intersecting axes sum up as vectors directed along the axes of rotation and equal to the corresponding angle of rotation. Hence, the vector of mutual rotation of elements 1 and 3 is equal to the difference between the vectors of rotation of elements 1 and 3 relative to element 2. This means that all the three vectors of mutual rotation of elements 1, 2 and 3 lie in one plane. Examining in succession all the other elements and the axes of their rotation we find that all the axes of mutual rotation of the rigid elements of the shell should be in the same plane. Let us call it the plane of rotation axes. For a shell which is in a state of critical equilibrium the plane of rotation axes plays the role of a neutral layer, since the points of the fracture lines undergo no horizontal displacement on this plane.

As the position of the plane of rotation axes does not affect either the vertical displacements W or, consequently, the work of the vertical external load q, it should be obtained from the equation of minimum work of the internal forces

$$\sum = (S_i^+ \sigma_T^+ + S_i \sigma_T)\varphi = \min \tag{5}$$

If the plane of rotation axes is horizontal, which occurs, for example, in the presence of two vertical planes of shell symmetry, the position of the plane can be found in the following way: Let us plot in succession all cross sections of the shell along the given fracture lines, multiplying the horizontal scale of each cross section by the corresponding angle of rotation φ_i (Fig. 4), and intersect all these cross sections with a horizontal straight line, representing a vertical projection of the plane of rotation axes. By changing the position of the horizontal

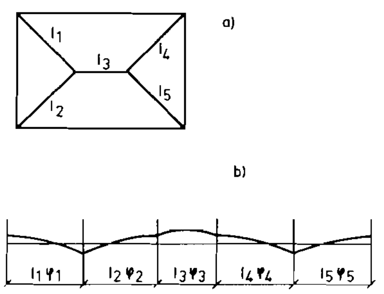

Fig. 4. Determination of position of horizontal plane rotation axes (see text).

straight line separating the compressed and extended parts of the cross sections of the shell, we obtain the equation of minimum work (5) in the form

$$\sum_{\text{lower}} (F_i \sigma_T + F_i^+ \sigma_T) = \sum_{\text{upper}} (F_i^- \sigma_T + F_i^+ \sigma_T^+) \tag{6}$$

where F_i^+ and F_i are the extended and compressed parts of the above-mentioned cross section along the ith fracture line, *i.e.* of the actual cross section with a horizontal scale multiplied by φ_i. Summation of the left-hand part of equation (6) is carried out for areas located below, and of the right-hand part for those above the plane of rotation axes.

Equation (6) follows from the well-known rule that the sums of absolute values of static moments of the upper and lower part of the cross section relative to the axis separating these parts of the cross section (the plastic moment of resistance) attain the minimum value if the areas of the upper and lower part of the above cross section are of equal magnitude.

The position of the plane of rotation axes, corresponding to equation (5), may be interpreted in a different way. Let us isolate a narrow strip $\varepsilon\varphi_i$ wide on the surface of the shell along all the fracture lines, where ε is some small factor, and φ_i is the mutual angle of rotation in the ith fracture line. On removing the material of the shell, which is outside the isolated strips, we obtain a rod model of the fracture lines (Fig. 5). The plane of rotation axes should divide the volume of the model into two parts, to satisfy the equation

$$\sum_{\text{lower}} (V_i^- \sigma_T^- + V_i^+ \sigma_T^+) = \sum_{\text{upper}} (V_i^- \sigma_T^- + V_i^+ \sigma_T^+) \tag{7}$$

where V_i^- and V_i^+ are the volumes of the rods corresponding to the ith fracture line and located below or above the plane of rotation axes respectively. The $-$ or $+$ index is applied here, depending on the sign of the deformations in the corresponding part of the fracture line.

If it is known that there is extension along all the fracture lines below the plane of rotation axes, and compression above (as in the case of a shell with edges free to move in horizontal directions), the volume of the rod model of the fracture lines should merely be divided by the plane of rotation axes in the ratio σ_T^+/σ_T^-.

The tilt of the plane of rotation axes in non-symmetrical shells can be determined by changing the angles of inclination of the plane. Such changes satisfy equation (5) when equality exists between the static moments of the upper and lower part of the fracture line

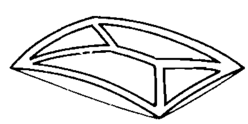

Fig. 5. Rod model of fracture lines in a shallow shell.

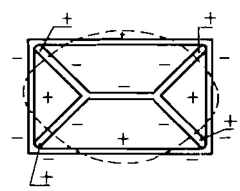

Fig. 6. Flat grid of fracture lines on the horizontal projection of a shell.

rod model, taken for two intersecting vertical planes. In this case the elements of the rod model related to the extended parts of the fracture lines should be multiplied by σ_T^+, and those related to the compressed parts of the fracture lines by σ_T^-. In other words, the centre of gravity of the part of the fracture line rod model which is above the plane of rotation axes (account being taken of the multiplication of the rod volumes by the corresponding yield stress) should be on the same vertical line as the centre of gravity, found in the same way, of the lower part of the rod model located under the plane of rotation axes.

The spatial rod model may be replaced by a flat grid of fracture lines on the horizontal projection of the shell. The width of the fracture lines on the grid is assumed to equal $\varepsilon\varphi_i\delta$, where δ is the thickness of the shell at the corresponding point of the fracture line. The line of intersection of the plane of rotation axes and the surface of the shell should divide the area of the fracture line grid in the same ratios as above (Fig. 6).

SHALLOW SHELL RECTANGULAR IN PLAN

Let us examine a shell of constant thickness with freely displacing edges, hinged along a rectangular contour. The pattern of fracture lines for such a shell may be considered as being similar to that of the plastic hinges in a rectangular plate hinged along the edges (Fig. 7). The plan of the spatial rod model of the shell fracture lines is shown in Fig. 8. In view of the constant thickness of the shell, the upper surface of the rods of this model may be examined instead of their volumes.

In the case of unit deflection at the points of intersection of lines E and F, the area of the surface of a diagonal rod in the model will be expressed by the formula

$$l_1\varphi_1 = \frac{a-c}{b} + \frac{b}{a-c} \tag{8}$$

and the area of the surface of the model's central longitudinal rod by

$$l_2\varphi_2 = \frac{4c}{b} \tag{9}$$

The total area of the upper surface of the model rods is equal to

$$4l_1\varphi_1 + l_2\varphi_2 = \frac{4}{b}\left(\frac{a^2 - ac + b^2}{a-c}\right) \tag{10}$$

This area should be divided by the plane of rotation axes into two parts: the extended and the compressed part, so that the whole extended area multiplied by σ_T^+ should equal the whole compressed part multiplied by σ_T^-. The boundary separating the extended part from the compressed one should coincide with the line of intersection of the surface of the shell and the plane of rotation axes. The length c of the central fracture line should be found from the equation of minimum critical load q determined from equation (4).

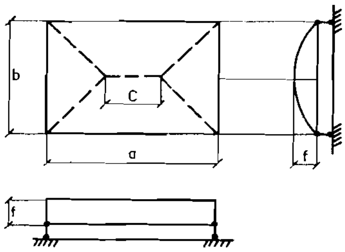

Fig. 7. Pattern of fracture lines for a rectangular shallow shell of constant thickness with freely displacing edges.

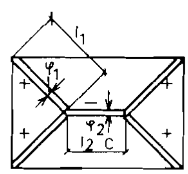

Fig. 8. Spatial rod model of fracture lines of the shell in Fig. 7.

A particularly simple computation can be made for a shallow cylindrical shell in which the longitudinal dimension a in plan markedly exceeds the transverse dimension b. The usual result in this case is that the surface of the compressed part of the fracture line model should be less than the surface of one central rod of the model, the plane of rotation axes is a tangent to the shell surface along the central fracture line, and the compressed part of the shell is disregarded in the formula defining the work of the internal forces. According to equation (2) we obtain

$$T = -4\sigma_T^+ S_i\varphi_i = -\tfrac{4}{3}f\delta\frac{(a-c)^2 + b^2}{a-c} \tag{11}$$

Here f is the rise of the shell surface, δ is its thickness and S_i is the static moment of the shell cross section along the diagonal fracture line, taken about the horizontal plane passing through the central fracture line. For a parabolic outline of the transverse cross section of the shell, the static moment equals $\frac{1}{3}f\delta l_1$ (Fig. 9).

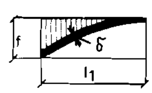

Fig. 9. Parabolic outline of the transverse cross section of a rectangular shallow shell. The static moment equals $\frac{1}{3}\ f\ \delta\ l_1$.

For other outlines of the shell transverse cross section, the above value of the statical moment may be assumed as an approximation since any transverse cross section in a shallow shell differs little from a parabola.

The work of an external load for a given form of collapse is found from equation (3). In the case of a uniformly distributed load

$$V = \frac{q}{6} b(2a + c) \tag{12}$$

From equation (4) we find that

$$q = \frac{8 f \delta \sigma_T^{+}}{b^2} \cdot \frac{(a - c)^2 + b^2}{(a - c)(2a + c)} \tag{13}$$

The minimum of this expression is obtained when

$$c = \frac{3a^2 + b^2 - b\sqrt{9a^2 + b^2}}{3a} \tag{14}$$

and is equal to

$$q = \frac{16}{3} \cdot \frac{\sigma_T^{+} \delta f}{ab} \left[\frac{b}{3a} + \sqrt{1 + \frac{b^2}{9a^2}} \right] \tag{15}$$

The condition that the diagonal fracture lines are wholly in the extended zone appears as follows

$$\frac{a}{b} > \sqrt{\frac{-2 + 3\varphi + \varphi\sqrt{9\varphi^2 - 8}}{6}} \tag{16}$$

where

$$\varphi = \frac{2\sigma_T^{+} + \sigma_T^{-}}{\sigma_T^{-}} \tag{17}$$

Formula (15) remains approximately valid even in the case when there is no inequality (16), since the inclusion of a part of the diagonal fracture lines in the compressed zone as a rule lowers the position of the plane of rotation axes quite insignificantly and changes the work of the internal forces T by only a few per cent.

Formula (15) may also be applied in an approximate way to shallow shells of double curvature, since the central fracture line in such shells is only slightly curved in the vertical plane and may be replaced by a rectilinear one. It is advisable in this case to replace the rise of the shell f in formula (15) by a somewhat smaller quantity equal to the distance from the plane of support of the corners of the shell to the centre of gravity of the central, compressed fracture line.

SHALLOW SYMMETRICAL ROTATION SHELL

A rotation shell may be considered as the limit of a shell polygonal in plan, with an infinite number of sides along the supporting contour. The form of collapse of a rotation shell under an axially symmetrical load will likewise be axially symmetrical with an infinite number of radial fracture lines, forming a continuous surface.

If the form of collapse of the shell results in a conical deflection surface, and the edges of the shell are capable of moving freely in horizontal radial directions, the plane of rotation axes will divide the meridional cross section of the shell into compression and extension in proportion to the yield limits. The base ring should be included in the meridional cross section of the shell if it is rigidly joined to the shell proper (Fig. 10).

If the edges of the shell are fastened to prevent horizontal displacements, one should take into account the possible formation of concentrated deformations along the line where the edges of the shell are fastened. The rod model of fracture lines for such a shell will consist of an annular rod running along the supporting contour, and of a countless number of meridional rods whose total width equals $m\Delta\varphi$, where m is the number of fracture lines and $\Delta\varphi$ is the angle of rotation in a meridional fracture line. Magnitude m tends towards infinity and $\Delta\varphi$ towards zero, while the product, as can easily be proved, tends towards $2\pi\varphi$, where φ is the angle in the annular fracture line. By dividing the width of the summed meridional fracture line and the length of the annular fracture line by 2π, we obtain the total cross section of all the fracture lines, shown in Fig. 11. The cross section should be

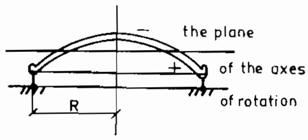

Fig. 10. Meridional cross section of a shell with its base ring rigidly joined to the main structure.

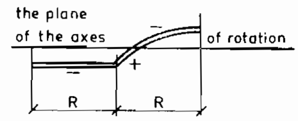

Fig. 11. Total cross section of all fracture lines in a shallow symmetrical rotation shell.

divided by a horizontal line, depicting the plane of rotation axes, into extended and compressed parts inversely proportional by area to the yield limits for compression and extension.

With a constant thickness of the shell, the horizontal line must pass through a point of the support of the meridional cross section, as shown in Fig. 12. In this case the shell will be

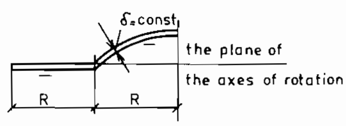

Fig. 12. Plane of rotation axes passing through a point of support of the meridional cross section (for constant shell thickness).

compressed in every direction, but the compression will be very small in the fracture line at the support as compared with tangential deformations of compression in the other parts of the shell. If the thickness of the shell at the supports exceeds that of its average thickness, the pattern of deformations will be similar, but bending deformations will appear in the support fracture line, *i.e.* tensile deformations at the top, and compression deformations at the bottom. If the thickness of the shell at the supports is less than the average thickness, the plane of rotation axes passes above the plane of the supports, and tangential tensile stresses arise in the lower part of the shell.

The work of the internal forces is determined by formula (2), which is as follows for the axes of a shell symmetrically supported along the contour

$$T = -2\pi\varphi(Rh\sigma_T a + S_R^+\sigma_T^+ + S_R\sigma_T) \tag{18}$$

Here φ is the angle of rotation in the annular fracture line running along the line of support of the shell, and a is the distance from the supporting plane to the plane of rotation axes, while S_R^+ and S_R are the statical moments of the extended and compressed parts of the meridional cross section (running from the centre of the shell), taken about the plane of rotation axes.

If the edge of the shell cannot be displaced in horizontal directions and the thickness of the shell at the supports is not less than its average thickness, then a equals half the thickness of the shell at the supports, and the whole shell is compressed. In this case

$$T = -2\pi\varphi\sigma_T\left(R\frac{h^2}{2} + S_R\right) \tag{19}$$

where h is the thickness of the shell at the supports and S_R is the statical moment of the whole meridional cross section about the plane of support of the shell.

If the edge of the shell can be freely displaced in a horizontal direction, the first factor in formula (18) should be deleted, and the statical moments S_R' and S_R should be determined relative to the plane dividing the area of the meridional cross section in the ratio $\sigma_T^- \sigma_T^+$.

The work of the external forces is found from formula (3), which provides the following equation for a conical form of collapse

$$V = 2\pi\varphi q_0 \int_0^R \eta r \, dr \tag{20}$$

where q_0 is the numerical factor determining the intensity of the load, and η is the distribution function of the load along radius r.

The collapse load is found from the condition $T + V = 0$.

In some cases a smaller load, as compared with the conical form of collapse, is provided by a form in which the deflection surface has the shape of a truncated cone (Fig. 13).

Let the equation of the shell surface in cylindrical coordinates (r, Z) appear as

$$Z = f\left(1 - \frac{2h}{R^n}\right) \tag{21}$$

Then, as shown by calculations, with a uniformly distributed load the form of collapse as a truncated cone results in a smaller load if $n < 2$.

With $n > 2$, the smallest limiting uniformly distributed load will correspond to the conical form of collapse of the central part alone of the shell limited by

$$R_2 = R \sqrt[n]{\frac{h}{f}} \cdot \frac{n + 1}{n(n - 2)} \tag{22}$$

where h is the thickness and f is the rise of the shell surface (Fig. 14).

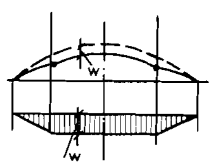

Fig. 13. Collapse load provided by a form in which the deflection surface is in the shape of a truncated cone.

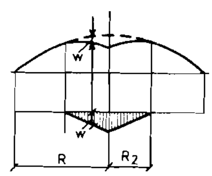

Fig. 14. Conical form of collapse of the central part of a shell.

CYLINDRICAL VAULT SHELL

Now let us consider an open cylindrical shell freely supported on its ends by two diaphragms (Fig. 15). With a sufficient thickness of the shell, the outline of its transverse cross section may be regarded as unvariable, and then the calculation of the shell reduces itself to computing the bending and limited torsion of a thin-walled girder.

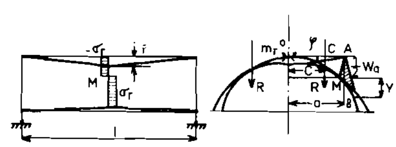

Fig. 15. Open cylindrical shell freely supported on its ends (see text).

If the shell is of small thickness, the outline of the cross section undergoes a deformation which can be approximated as follows at the stage of collapse: A plastic hinge is formed along the crown of the shell, and longitudinal deformations of elongation and compression appear concentrated along the central transverse cross section. Each half of the shell located on one side of the plastic hinge works in bending and torsion, like a thin-walled rod with an undeformed cross section. In the critical state, a bending-torsional plastic hinge is formed in the central cross section of this thin-walled rod.

Let the right-hand half of the central cross section of the shell turn by angle φ about the instantaneous centre of rotation A. Then the relative angle of twist of the central transverse cross section of half the shell equals $2\varphi/l$, where l is the span of the shell.

Reciprocal deplanation in the central cross section produces concentrated elongations

$$E = \frac{4\varphi}{l} W_{\mathrm{A}} \tag{23}$$

Here W_{A} is the sectorial coordinate of the point of the cross section under consideration, *i.e.* twice the sectorial area limited by the radii vectors drawn from pole A to the given point B on the profile and to some initial point M, and by the profile itself (Fig. 15).

Assuming that point O moves along a vertical line, we find that pole A is located on the same horizontal line as point O.

The sectorial coordinate W_{A} may be expressed as a function of the position of pole A by the formula

$$W_{\mathrm{A}} = W_{\mathrm{O}} + ay \tag{24}$$

where W_{O} is the sectorial coordinate plotted from pole O, y is the distance from the point under consideration to the horizontal axis passing through point M, and a is the distance from point O to the centre of rotation A.

The position of point M is determined from the condition under which the resultant of longitudinal stresses in the cross section equals zero. Since all stresses equal σ_T^+ or σ_T^- when in a critical state, point M should divide half the cross section of the shell in proportion to these values.

The expression for the work of the internal forces at the given displacement will have a term $-\varphi l m_T$ corresponding to the rotation of the longitudinal plastic hinge, where m_T is the limiting bending moment in the plastic hinge, and a term corresponding to longitudinal deformations of the central cross section

$$-\sigma_T^+ \int_+ E\,\mathrm{d}F + \sigma_T^- \int_- E\,\mathrm{d}F \tag{25}$$

In the first integral, integration is done over the extended part of the cross section, and in the second over the compressed part. Subsequently, in order to simplify matters, we shall amalgamate the two integrals, placing the yield limit under the integral sign and assuming that σ_T may have two meanings, depending on the sign of deformations. Then the general expression for the work of the internal forces, account being taken of expressions (24) and (25), may be written as

$$T = -\varphi l m_T - \frac{4f}{l}\left(\int \sigma_T y\,\mathrm{d}F + \frac{1}{a}\int \sigma_T W_0\,\mathrm{d}F\right) \tag{26}$$

Let the external load be distributed uniformly along the span of the shell, forming in each half of the transverse cross section a vertical resultant R which crosses the horizontal tangent of the cross section at point C (Fig. 15). The work of such a load at the given deformation is found by

$$V = Rfl\frac{a-c}{a} \tag{27}$$

Assuming the sum of expressions (26) and (27) to equal zero, we find

$$R = \frac{m_T}{a-c} + \frac{4}{l^2(a-c)}\left(a\int \sigma_T y\,\mathrm{d}F + \int \sigma_T W_0\,\mathrm{d}F\right) \tag{28}$$

Let us introduce into the analysis sectorial coordinates W_C with the pole at point C and with the previous initial point M. Then

$$W_O = W_C - cy \tag{29}$$

In this case expression (28) appears as

$$R = \frac{m_T}{a-c} + \frac{4}{l^2}\left[\int \sigma_T y \, dF - \frac{1}{a-c}\int \sigma_T W_C \, dF\right] \tag{30}$$

To obtain the minimum R, a must become infinite when

$$m_T > \frac{4}{l^2}\int \sigma_T W_C \, dF \tag{31}$$

or must have a minimum value if expression (31) is reversed. This minimum value is determined by the presence in the graph of W_A of not more than one change of sign in the half cross section. Hence, point A (Fig. 15) should coincide with point O_1 shown in Fig. 16 in accordance with the condition that the sectorial coordinates W_{O_1} of point M and of the extreme point O of the half cross section are both zero.

Thus, when expression (31) is observed, the shell is destroyed without a longitudinal hinge and, when the expression is not observed, the shell fails in the manner shown in Fig. 15, with the centre of rotation A at point O_1 determined according to Fig. 16. In this case the

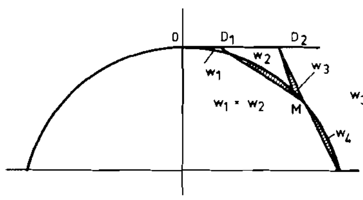

Fig. 16. Determination of the centre of rotation when a shell fails in the manner illustrated in Fig. 15.

graph of W_C must have a sign similar to that of the graph of W_O, which corresponds to the passage of the resultant external load on the half cross section of the shell through the line OO_1.

The case is different when the signs of W_C and W_O are opposite. The minimum R in formula (30) is then obtained in every case with $a \to \infty$, *i.e.* the shell should seemingly always collapse according to the girder variant. One should, however, take into account the possibility of negative angles of φ when the centre of the shell shifts upwards. In this case, the work of the plastic hinge will have an opposite sign and inequality (31), as the prerequisite for the girder variant of collapse, remains in force. When expression (31) is not observed, the half cross section should turn by some angle about point O_2 which is the extreme position of the pole of the sectorial areas A, whose graph changes its sign only once, *viz.* at point M. The second zero point of the graph of sectorial areas having a pole at O_2 coincides with the extreme lower point of the cross section (Fig. 16). This case corresponds to the passing of a resultant external load on the half cross section of the shell to the right of point O_2.

The case when the resultant of the external load on the half cross section of the shell passes through O_1O_2 is more complicated and requires a numerical comparison between the critical values of the loads for a girder variant of collapse and for rotations of the central plastic hinge in one direction or another.

Discussion

Following explanatory comment on the Congress reports by the main rapporteurs, Prof. E. TORROJA and Prof. A. A. GVOZDEV, several contributions to the discussion are made.

1. Prof. Dr. W. WIERZBICKI (Poland) submits the results of his own studies on the safety of reinforced concrete structures. The conception of safety presented in the reports of Prof. TORROJA and of Prof. GVOZDEV seems, in principle, not contrary to the conception of Prof. WIERZBICKI, as presented by him last year at the Moscow Symposium when he analysed the application of the semi-probability method for the study of safety of steel structures. Prof. WIERZBICKI now presented the results he had obtained using the same method applied to the safety of reinforced concrete constructions.

Let us consider as failure of a reinforced concrete column or beam the crushing of the concrete and the moment that the reinforcement bars have attained their yield strength. These phenomena occur, as numerous observations have shown, simultaneously. The stress in the concrete at the moment of crushing and the yield stress in the steel are therefore the two starting points to determine the bearing capacity of the construction. They are both variable quantities.

Fig. 1 gives a probability curve for the compressive strength R_b of the concrete. The shaded area Ω_b represents the probability Ω_b that the values R_b will be between the limit value R_{bg} and the maximum value of R_b. In other words, R_{bg} is the strength of the concrete, below which – with a probability Ω_b – the real strength of the concrete of a certain quality will not fall.

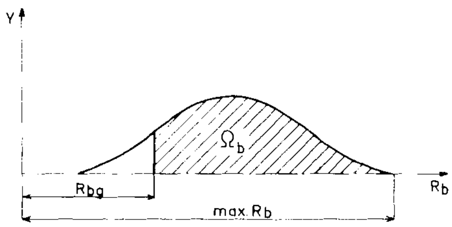

Fig. 1. Probability curve for the compressive strength values of concrete.

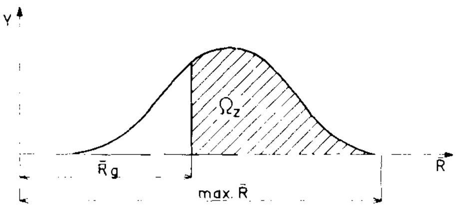

Fig. 2. Probability curve for the yield stress values of steel.

Fig. 2 gives a probability curve for the yield stress of the steel. We assume that this curve applies to yield of the steel for tension and for compression.

In this case the shaded area Ω_z represents the probability Ω_z that the values $\bar{R}$ will be between the limit value $\bar{R}_g$ and the maximum value of $\bar{R}$. This means that one can assume – with the probability Ω_z – that the yield stress of the reinforcing steel will not fall below the value $\bar{R}_g$.

In order that failure – in the sense of this discussion – of a column or beam should not occur, the following two independent conditions must be satisfied at the same time:

(a) The compressive strength of the concrete must be greater than the limit value R_{bg}, Ω_b being the probability of this fact.

(b) The yield stress of the reinforcing bars must be greater than the limit value $\bar{R}_g$, Ω_z being the probability of this fact.

Thus, in acccordance with the theorem of multiplication of probabilities, we may suppose, with a probability of $\Omega_b \cdot \Omega_z$, that failure will not take place if the strength of the concrete is not less than R_{bg} and the yield stress of the reinforcing steel is not less than $\bar{R}_g$.

Let p be the safety index, *i.e.* the probability that failure will not occur. We now have

$$\Omega_b \cdot \Omega_z = p \tag{1}$$

Since failure occurs when the stress in the concrete becomes greater than the compressive strength and, simultaneously, the stress in the steel passes the yield stress, it is not necessary to take different values for Ω_b and Ω_z, the more so as their equivalence assures a more exact readability of the probability curves. Consequently we find that

$$\Omega_b = \Omega_z = p^{\frac{1}{2}} \tag{2}$$

Let us now first consider axial compression of a symmetrically reinforced column. In these circumstances a value of the stress in the concrete at the strength limit R_{bg} and a value of the stress in the steel at the yield limit $\bar{R}_g$ correspond to a safety index p. The axial force in the column at failure is then given by

$$N_m = (A_b R_{bg} + A_z \bar{R}_g)x \tag{3}$$

where A_b is the area of concrete in the column section,
A_z the cross-sectional area of reinforcement,
x the reduction coefficient for buckling.

The axial force N_d permissible in the column cannot, however, be equal to the force N_n, in view of the factors that can reduce the failing load of the column, calculated according to formula (3).

We therefore compare the force N_d with the force N_n, reduced in an appropriate way. Assume

$$N_d = N_n(1 - \sum a_i^1) \tag{4}$$

where the coefficients a_i^1 indicate the limit decreases (in percentages) of the failing load N_n, due to the fact that the particular conditions of formula (3) have only been fulfilled incompletely, whereas $\sum a_i^1$ indicates the decrease (in percentage) of the failing load N_n, due to the fact that all these conditions have only partly been fulfilled. The coefficients a_i^1 are, generally, not variables of a statistical character. They are calculated according to the formulae of strength of materials and the theory of structures, *e.g.*

$a_1^1 = 0.04$ is the coefficient characterizing the decrease of the failing load due to errors in the dimensions of the concrete in the cross section of the column;

$a_2^1 = 0.03$ is the coefficient characterizing the decrease of the failing load due to errors in the dimensions of the transverse reinforcement bars.

The accepted method of plastic deformations allows us to consider the failure of a reinforced concrete column – consisting of crushing of the concrete and simultaneous yield of steel – as equivalent, in practice, to yield being exceeded in a transverse section of a steel column subjected to compression. As we have for the latter case assumed a safety index, $p = 0.8$, we can consider this index as appropriate for the case of a reinforced concrete column.

Let the safety index $p = 0.8$ be the starting point for our calculations. Using formula (2) we obtain the formula that characterizes the desired probability

$$\Omega_b = \Omega_z = 0.9 \tag{5}$$

These probabilities being found, the probability curves drawn for the concrete strengths in compression and for the steel stresses at yield, give the permissible load N_1 for the column.

Similar considerations can be applied to the case of a beam subjected to bending.

2. Dr. A. A. SORETZ (Austria), who is rapporteur for the European Concrete Committee on the subject of deformations, says that a subcommittee for deformations has been established by this Committee.

With regard to conclusion 4 of Prof. TORROJA's general report and to the report of Prof. BERG, Dr. SORETZ states that in some cases deflections become too big. Since this depends only on the materials, the matter should be studied by the committees for materials, but CIB should create a committee for deformations and deflections in housing.

Since April, 1959, the European Committee for Concrete has had a committee to study cracking.

Rules or theories for calculation in terms of stress are also needed and a translation from stresses to forces is required. Failure is often the result of excessive deformation rather than excessive force. Tensile failure of concrete is more a matter of strain capacity than of stress.

3. Mr. J. KUIPERS (the Netherlands) of the Stevin Laboratory at Delft, commenting on the general report by Prof. TORROJA, makes the following statement:

In several publications dealing with the safety of structures, statistical methods have been introduced. The aim of all these is to develop a method which makes it possible to evaluate the chance of failure or of unserviceability below a certain known value. This means that the chance of the load ("surcharge") S being greater than the strength ("resistance") R is below that value. Because S and R have a statistical distribution, the difference $(R - S)$ is also statistically distributed. One method for the chance of failure to be determined is the statistical index:

$$f_{st} = \frac{R_m - S_m}{(s_r^2 + s_s^2)^{\frac{1}{2}}} \tag{6}$$

where R_m and S_m are the mean values of the well-defined R and S (these are, for example, both dependent on the desired lifetime of the structure). Furthermore, s_r and s_s are the standard deviations of R and S respectively. This formula can be used for further developments; the statistical entities of interest in the problem are explicitly incorporated in the formula in the most suitable manner.

Generally, the designer needs a simpler formula. The best way is to use

either $\qquad R_m = nS_m$

or $\qquad R_m = n(G_m + kP_m) \qquad (7)$

For normal use the values of n and k can be prescribed in the different codes, while G and P are the dead load and the live load respectively. These two formulae resemble the old-fashioned safety factor formulae in form, but now n and k can be calculated with equation (6) for several values of f_{st}, s_s and s_r.

Doing so, we have defined

$$n = \frac{R_m}{G_m} \tag{8}$$

and then calculated n from

$$f_{st} = \frac{R_m - G_m}{(s_r^2 + s_g^2)^{\frac{1}{2}}} \tag{9}$$

In this way n is the "safety factor" when the dead load alone is working on a structure for which a chance of failure is accepted corresponding to a certain value of f_{st}.

The live load P is supposed to have a greater variance than G. Therefore the ratio

$$\frac{R_m}{G_m + P_m}$$

must have a value greater than

$$n = \frac{R_m}{G_m}$$

to achieve the same value of f_{st}. Therefore the factor k is introduced.

Formula (6) is most suitable in the case of normal distributions. It then provides an exact measure for the probability of failure. For other types of frequency-diagrams the value of f_{st} is to be considered as a rough indication for that probability.

As long as we do not know enough about the real distributions of the strength and of the loads – and it will be very difficult to obtain enough information about events that rarely occur – it is not possible to evaluate the risk with exactness, and if this were possible the chance of the unserviceability that can be accepted must be decided upon.

With the method described it becomes possible to estimate the value of the statistical index corresponding to current design specifications. It is necessary to assume values for the standard deviations in the loads. These can be estimated and they are presumed to be independent of the material used. The standard deviations of the strength are known in some cases or can also be estimated.

It appears that the statistical index has the following values:

Concrete	3.5–4.5
Steel	2.5–3
Timber	2.5–2.7

Although it is to be emphasized again that these values can not be translated into real chances of failure, they give a good idea of how different materials can be compared. Such a comparison is more trustworthy if the materials resemble each other more or less in behaviour or in the way they are used, and is of special interest when new materials or unusual structural methods are introduced. In that case it seems to be logical to choose a value of f_{st} for the new materials the same as for comparable materials used in comparable situations.

Summarizing, we think that the proposed method has the following advantages:

(a) Design rules, working loads, etc., for new materials can be set up in such a way that a safety is obtained which is comparable with that required for materials already used.

(b) The effect of a change in the working loads on the chance of unserviceability can easily be estimated.

(c) Factors affecting the safety can be incorporated in the formula in the most rational place. Some of them perhaps will affect the mean value of the strength or the standard deviation, while others may influence the load, etc.

(d) In unusual or extreme cases it is possible that the designer falls back on the basic formula to adapt it to the given circumstances.

(e) If in the future the probability distributions are proved to be log. normal or extreme-value distributions, formula (6) would have to be used in combination with a simple transformation of the variables. The basic idea of the method would remain the same.

The method which is proposed during the CIB meeting in Rotterdam tries to combine the advantages of statistics and of simplicity. The basic formula is

$$\frac{R_m(1 - \delta_r)}{C_m} = C_s S_m(1 + \delta_s)$$

which in this form is not a statistical formula, nor a very simple one. For general use, values for C_m and C_s can be prescribed.

As it does not seem reasonable to allow the designer to choose a value for the standard deviation in the load, also δ_s should be prescribed, and then the only variable left is δ_r, which can be calculated if tests have been carried out. However, a more direct method is to provide the designer with the formula

$$R_m = n_1 S_m(1 + s_s)$$

or, perhaps better, to use $R_m = n_2 S_m$, the contractor being required to make his concrete meet certain requirements with respect to R_m and δ_r.

In this way we are back again to formula (7), but without the possibility of making modifications on behalf of different properties of G and P.

From the report presented at the meeting it is clear that the coefficients C_s and C_m must have certain values, but it is not clear how these values are calculated. Comparable entities can be computed from formula (6). Calculating back from the values proposed for C_s and C_m for concrete it appears that the statistical index is about 3.5, which is comparable with the results obtained earlier, where it was calculated that this index varies between $f_{st} = 3.5$ and $f_{st} = 4.5$.

In conclusion, it seems that the proposed method has the following disadvantages:

(a) Although the most important statistical entities appear in the formula, they are partly incorporated in the C values.

(b) This means that for every new material these C values must be evaluated anew by a special committee.

(c) Since there is no direct connection between the proposed formula and the probability of failure, the designer cannot adapt the values of C to unusual cases on the basis of probability.

4. Prof. Dr. J. P. MAZURE (the Netherlands) reviews the tasks of CIB and of other organizations. CIB cannot compete with specialist organizations in their own field. Specialists' papers should be discussed at specialists' meetings. Hence CIB should concentrate on the study of loads and permissible deformations of structures.

However, apart from this there is the task of coordination of results obtained for several structural materials, the choice of which must be rational. Generally, safety factors must be chosen in a rational way, taking into account the properties of the materials. CIB could coordinate the study of deviations.

We can distinguish:

(a) Loads: being the same for all materials. The carrying capacity, however, depends on the nature of the materials.
(b) Actual dimensions and design dimensions, also after a prolonged period (corrosion).
(c) Reliability of materials: homogeneous or not.

It is necessary to formulate the safety factors for materials in a rational way in order to know what use can be made of them.

From p. 58 of the report of Prof. GVOZDEV, it can be stated that exact calculation of the probability of collapse is next to impossible. To gain a better insight, collection of a great number of data is urgently required. In practice, data become available only on big and spectacular failures, but never on small failures such as appearance of cracks, these being repaired rapidly before they become known to the "outside world". It is, however, important to collect all information on buildings near to failure, and to publish this.

5. Prof. A. W. HENDRY (United Kingdom) of the University of Liverpool, comments on the statistical approach to structural safety, referring to a series of tests on "identical" welded steel frames. He expresses agreement with the recommendations reported by Prof. TORROJA.

In doing so, however, he draws attention to two aspects of the matter which seem to be of some importance.

The first is the selection of suitable index parameters for the strength of the structure, such as yield point of steel or crushing strength of concrete. Some time ago he carried out a series of tests [1] on 22 nominally identical welded steel frames made by 11 manufacturers.

He found that the mean strength of the frames was 5.85 tons with a standard deviation of $\pm$ 0.44 tons whilst the mean yield stress of the material was 16.7 ton/sq. in. with a standard deviation of $\pm$ 0.82 ton/sq. in. Thus the standard deviation of the strength of the structure was about $\pm$ 7.5% whilst that of the material used was $\pm$ 4.9%. Although these tests were on a limited scale the results do serve to show that the probable variation in the strength of a structure is likely to be considerably greater than the variation in strength of the material used in its construction.

The second point he makes is that it seems to be essential to correlate the statistical approach with the actual behaviour of structures under load.

Thus two structures which have the same ultimate loads may have load deflection curves as indicated by A and B in Fig. 3. Suppose that these curves refer to structures of average strength and that the line PQ represents the mean maximum load applied to the structure when the load factor is 1.45. Then in the case of structure A the resulting plastic deformation

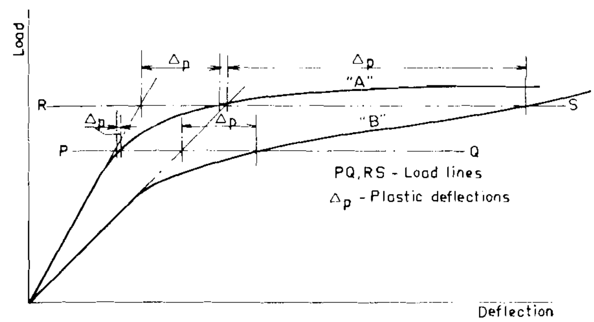

Fig. 3. Load deflection curves of two structures which have the same ultimate loads.

is negligible but in structure B it is larger, although perhaps not unmanageable. If, however, we assume that the curves refer to structures of strength, say, 28 % lower than average, the corresponding position of the load line would be RS; in this case the plastic deflection of structure B would assume collapse proportions.

If the standard variation of the strength of the structure was $\pm$ 7.5 % this could happen with a probability of 1 in 20,000. At the same time, if the standard deviation of the load was $\pm$ 5 % the probability of complete failure would be 1 in 10,000,000. These figures are, of course, purely illustrative but are intended to bring out the fact that a remote chance of complete collapse does not necessarily safeguard against the occurrence of embarrassingly large plastic deformations.

The formula suggested by Prof. Torroja, together with the values given for C_m, δ, etc., appear to imply a load factor (*i.e.* the ratio of strength of structure to working load) of 1.62 for steel structures. Although the latest version of B.S. 449 [2] avoids giving a load factor, it is of interest to note that the working stresses given in this code imply a load factor of 1.7 for simple beams. Before the suggested formula and numerical values could find their way into British practice it would, therefore, be necessary to explain the basis of the multipliers and standard deviations suggested in the Congress papers.

6. Prof. M. Cigánek (Czechoslovakia) presents a substantially illustrated contribution, the essence of which can be summarized as follows:

Following the collapse of a flat-slab roof of a reinforced concrete tank, loading tests were carried out on two similar structures. As a result of these tests, modifications were made to the design for the reconstruction of the collapsed roof. Further loading tests were made on the new roof. These indicated that:

(a) The dimensions and positions of openings in the slab have an important influence on the distribution of stress.

(b) Settlement of the supports and rotation of the column heads have a considerable effect on the magnitude of bending moments in the slab.

(c) The internal columns, which are usually designed for axial load, are often subjected to high bending moments, particularly during the stages of covering the tanks with earth.

(d) Columns and column heads which are circular in section have the most favourable influence on stress distribution, particularly during the changing loading conditions during construction.

7. Mr. Y. TSUBOI (Japan), referring to the difference between the American and the German method for computing flat slabs, gives a concise explanation on a maximum strain theory he has adopted in relation to the rupture of slabs.

8. Prof. KERKHOFS (Belgium) also discusses flat slabs.

The shape of the column heads influences the distribution of flexural moments, as also was shown in the lecture of Prof. CIGÁNEK. A circular shape has proved the most favorable.

We also know that the moments at the column heads are not equal to 0, although we still lack a proper method to compute those moments. However, one must have something to work with, even if it is not completely exact. Prof. KERKHOFS would be very pleased if someone could give him a quick method to determine the moments.

9. The rapporteur Prof. GVOZDEV describes research that has been done on the basis of the "lines-of-failure theory" of Johanssen and of the American Building Code. These methods, however, show differences in the reinforcement needed.

We must look for the rupture lines and try to find a solution on a theoretical basis. When rupture takes place near the column there is a difference from the theory of Johanssen. The effective lever arm is greater than the thickness of the slab. This explains the deflections that have been found. The theory of Johanssen is extended by taking the real thickness of the slab where the cracks appear, into account.

10. The rapporteurs Prof. TORROJA, Prof. MAZURE and Dr. SORETZ give further comments, partly in reply to Mr. KUIPERS' remarks (see 3 above) on the subject of safety factors. These comments can be summarized as follows:

(a) The values for the coefficients of variation of the strength of materials (δ_r) have already been established for some materials, *e.g.*

$$\delta_{steel} = 0.08$$
$$\delta_{concrete} = 0.16$$

(b) The quality of the materials, also with regard to δ_r, should be the responsibility of the producers and not of the builders. In the case of steel this is already a common situation. The manufacturers give a guarantee for the quality of their products. In some countries this is also done for concrete.

(c) Exceptions must be made for special structures, such as big dams, etc. Evaluations should be made specially for such structures.

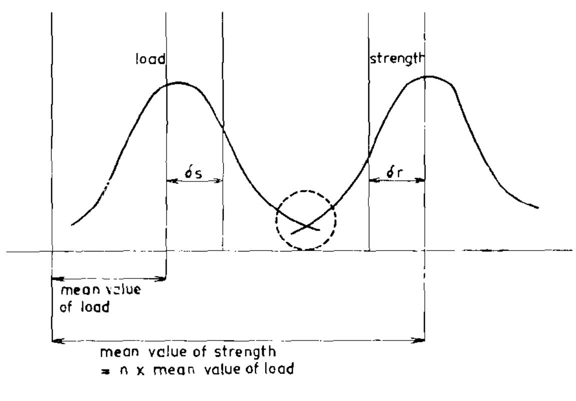

Fig. 4. Graph indicating the specific character of the problem of calculating the safety of structures.

(d) The values of the coefficient of variation of the loads (δ_s) can very well be deduced from statistical data. Obviously there will be a different δ for different kinds of loads.

(e) The classical thesis dealing with the safety of structures was that the strength should be n times the load. The problem is characterized by Fig. 4. To evaluate n in connection with an accepted small probability of failure, one has to know where and how the curves terminate (the encircled area in the figure). However, these curves are mostly not Gaussian. It will be practically impossible to obtain sufficient data to establish the ends of the curves. Hence Prof. TORROJA's theory is correct by taking only δ and introducing a multiplier.

11. Mr. M. TICHÝ and Mr. M. VORLIČEK (Czechoslovakia) made available a written contribution in German under the heading "Zufällig veränderliche Nachgiebigkeit bei den Durchlaufträgern und Rahmenkonstruktionen" (Incidental variations in the flexibility of continuous beams and frame structures), which can be summarized as follows:

For the calculation of continuous beams and statically indeterminate frame structures, the factor EI of the different elements – depending on the geometrical form of the cross section and the mechanical properties of the material – should be evaluated. In practice, however, no account is taken of the variability of these factors EI, due to incidental circumstances. The authors of the contribution describe the investigations they have carried out to determine the above-mentioned variability. In order to obtain an essential simplification, use was made of the flexibility factor

$$\frac{1}{EI}$$

instead of the factor EI. Furthermore, the data obtained have been introduced in formulae to calculate the relative deviations of the bending moments in some statistically indeterminate structures.

12. Mr. J. KRCHOV (Czechoslovakia) also made available a written contribution in German, headed "Vorschriften für die Bruchmomentbemessung der Spannbetonquerschnitte" (Prescriptions for measuring of yield moments in prestressed concrete cross sections). This contribution can be summarized as follows:

A survey is given of the formulae used in a number of countries for the calculation of the theoretical yield moment of a rectangular cross section with a single prestressed reinforcement. In case of a small percentage of reinforcement, the values of the yield moment found from the different formulae are well in accordance with one another. However, if a large percentage of reinforcement is used, big differences appear.

Furthermore, a general view is given on the safety factors that are required in the different countries for the design of prestressed concrete beams submitted to bending moments. Taking into account that the adopted calculation methods in the different countries lead to a divergency of results, the author indicates the necessity of obtaining an international unification of the prescriptions for computing prestressed concrete structures.

In concluding the exchange of views, the Chairman, Prof. V. I. OVSYANKIN, emphasises that further joint work to make building both safer and more economic is required and that mutual cooperation seems to be a condition for success.

Note. Not included in this book, though presented at the Congress, are:

(a) The resolutions of the 1958 CIB Symposium in Moscow.

(b) The report "Superimposed loads and safety factors", by the Chairman of the relevant CIB Working Commission. This report was published in No. 1–2, 1958, of the CIB Bulletin.

REFERENCES

1 A. W. HENDRY, *Civil Eng. and Public Works Rev.*, 45 (1950) 525.

2 A. W. HENDRY, *The Use of Structural Steel Building*, B.S. 449/1959, British Standards Institution, London.

Subject 3

DIMENSIONING ON THE BUILDING SITE, TOLERANCES AND DIMENSION CONTROL

UDC 389.6 : 526 : 69.05

MAIN REPORTS

G. CIRIBINI
Director of "Centro per la Ricerca Applicata sui Problemi della Edilizia Residenziale" (Italy)

A. R. VAN DEN BURG
Bureau of Consultants for Applied Statistics (the Netherlands)

ADDITIONAL REPORTS

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J. NOIRÉ
Geometrist (France)

S. JANICKI
Head of Building Department of "Polski Komitet Normalizcyjny" (Poland)

Introduction to the standardization of dimensioning on the building site, tolerances and dimension control

UDC 389.6 : 526 : 69.05

G. CIRIBINI

Director of the "Centro per la Ricerca Applicata sui Problemi della Edilizia Residenziale" (Italy)

INTRODUCTION

One of the problems in rationalizing and economizing the construction of a building is the question of facilitating and simplifying the process and operations involved in assembling factory-made elements with those produced on site.

The transfer of design dimensions to real building forces us to face the question of dimensional tolerances, which involves the question of accuracy in mounting the various elements and the question of dimensional variances inherent in the production technics of both factory and site. An analysis of the latter shows that there is also a certain, even predominant, influence on the accuracy of the dimensions of the method of transfer from the design to the building. It is, therefore, important to apply standardized methods and instruments for this transfer that permit an insight into the possible dimensional errors.

In the CIB Commission involved in the experimental dwelling construction programme of the High Authority for the European Coal and Steel Community, we made an endeavour to arrive at a standardized method that would have the merit of being applicable simultaneously in all countries of the latter organisation, irrespective of national circumstances and usual practices of the builders involved. In other words, we intentionally strived at comparability and, therefore, not necessarily at the most perfect, hence relatively costly, method, so that we could prescribe a standardized method for sites in different countries and of different firms.

THE METHOD

The method used includes three main elements:

1. General frame of reference.
2. Transfer of readings in the horizontal plane.
3. Transfer of readings in the vertical plane.

GENERAL FRAME OF REFERENCE

The bench marks and directions related to the local ordnance grid provide a starting point for the location of the building that is obligatory and reliable. Each element of the building is, from this basis, located in space by a triaxial coordination system, one axis vertical and two horizontal but not necessarily perpendicular, originating in the plane $Z = O$ of the unfinished surface of the first floor.

The choice of the horizontal axes is influenced by:

(a) The possibility of transfer in elevation.

(b) The planimetry of the building and the future location of its elements.

The first possibility is subject to the properties of the instrument, the altimetric characteristics of the structure and the nature of the zone surrounding it.

For the second point the distribution nature of the building leads to such a choice of horizontal axes that a minimum of dimensional variance of errors is secured.

A description of a classic method of arriving at couples of horizontal axes and of their transfer, in the case of a rectangular building of medium height surrounded by ample working zones, may permit us to analyse variants in special cases.

The origin of the system is materialised by intersecting two perpendicular main alignments 1A and 2A, determined by tacheometer and transferred to plane Z = O in a simple way, *e.g.* by stretching suitable impregnated lines (Fig. 1).

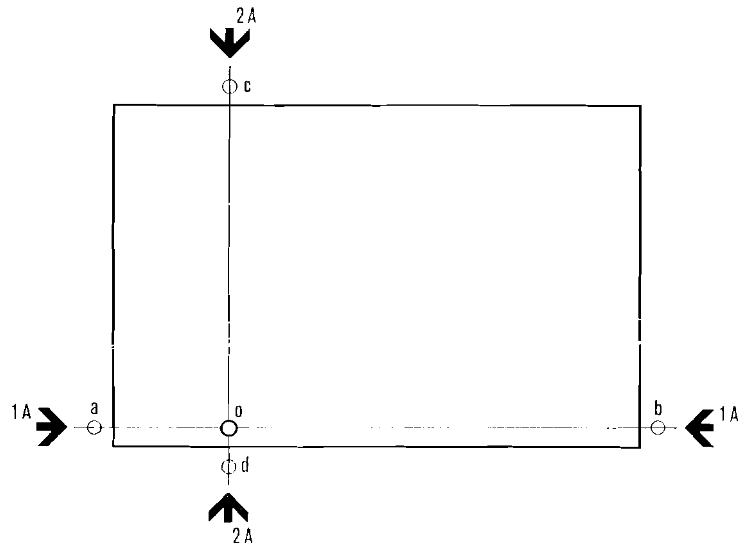

Fig. 1. System for arriving at couples of horizontal axes and of their transfer.

It is convenient to have these alignments coincide with the perimeter directions of bearing elements that recur in the various storeys.

To materialize these alignments two points must be identified with great precision since even a small error causes future errors that cannot easily be checked.

The origin O being materialised by linear measurement, a bench mark A is collimated in a determined position of the horizontal circle by the instrument in O and the azimuth L_A is read off. Next the telescope is transited to read

$$L_A + \frac{\pi}{2}$$

and approximately at C a horizontal staff of some decimeters is read. The operation is repeated in the conjugate position to read L_A' and

$$L_A' + \frac{\pi}{2}$$

the mean of the two readings on the horizontal staff thus indicating the direction of C. The error in the angle

$$\frac{\pi}{2}$$

being subject to the sensitivity of reading of the instrument, is accidental between $+ u$ and $- u$ and the operation should, therefore, be repeated for different positions, applying Bessel's rule, the average of all readings then being taken as the definite direction of C. Thus instrumental errors are practically eliminated and a point D can be located in the ideal axis CD in the same way, though materialising of D with the instrument in C by collimation to O is a more rapid method.

To prepare transfer in elevation we may materialize on each alignment two other points, now nearer to the structure. Both of these points are given a concrete bench mark, 1 meter high and exactly vertical. Thus it becomes possible to transfer the principal alignments in elevation by a simple and accurate process, though such a transfer can only be made on the unfinished upper surface of the first and higher floors. The substructure requires a different mode of operation, but the link with the superstructure is constituted by the reference axes in plane Z = O.

Thus we obtain two families of transfers affected by a different error propagation coefficient, one dependent on the precision of the tacheometer, the other on the precision of the plumb line. The transfer of the main alignment 1 A and 2 A to each storey by tacheometer makes the checking of vital readings independent of the position of the lower elements and its errors, this being a main advantage of the method. The transfer in elevation is illustrated in Fig. 2.

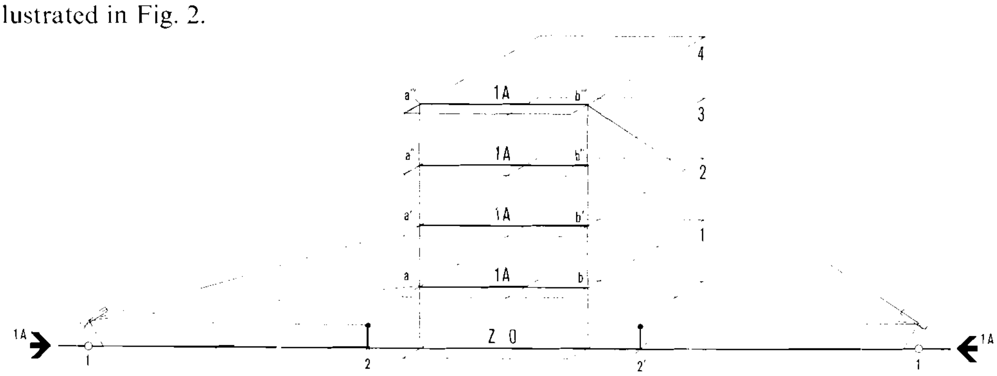

Fig. 2. Transfer in elevation.

The bench marks of each principal alignment indicated by staffs in 1,2, 1′ and 2′ must stay visible. 1 and 1′, where the instrument is stationed, should be at a distance from the building of about $2\frac{1}{2}$ times the height of the structure. The transfer in elevation to plane 1 and to the other planes can thus proceed, eliminating at the same time the influence of instrument errors (Bessel's rule). In this way we apply a method capable of different interpretations. We might, for example, immediately envisage oblique axes, in which case the only new complication is the limitation of variance in the angle of the intersecting alignments.

However, a real restriction imposed by our method lies in the necessity of having available the fixed points to set up the instrument. A different form of our method can often obviate this drawback. We may, as shown in Fig. 3, materialize oblique axes outside the building, thus profiting from a greater distance from the building together with a less extensive working zone. We then encounter, however, the disadvantage that an average divergence of 5 mm between the exterior perimeters of the wall plates and an angle B of 30° result already in a 9 mm variation between upper and lower references axes. Great exactitude of planimetric determination of wall plate perimeters is, therefore, a rarely fulfilled condition to this method.

Another procedure making it possible to eliminate several drawbacks, whilst theoretically adhering to the same principles, is the transfer in elevation of certain points as intersections of two directions (Fig. 3).

The tacheometer is set up at point X_1. Next the collimation is established of a point suitably chosen in the plane Z = O and this direction is transferred to the upper storey. Next, after collimation starting from X_2, the direction is transferred to the storey situated above. The intersection of the two directions thus transferred determines the point corresponding to A on the upper wall plate. It will be clear that the materialization of the two directions on the storeys situated at a greater elevation and the application of Bessel's rule – still required – for the transfer, require a study of small instruments capable of receiving the resultant direction of collimation for the storey under consideration.

The advantage of the method is the possibility of doing without any fixed point outside

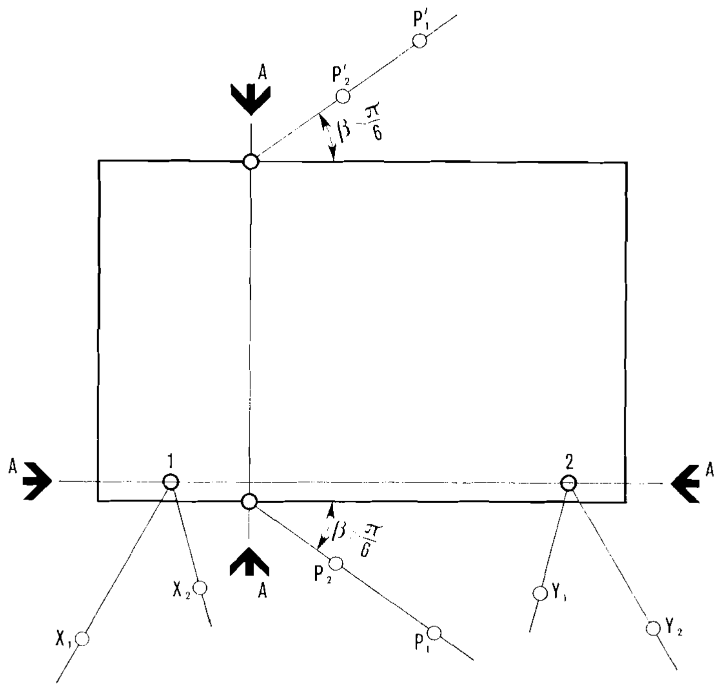

Fig. 3. Transfer in elevation of certain points as intersections of two directions.

the structure and of transferring all the points desired, making allowance for the limitations which will be recommended in the marking-out of different storeys. On the other hand, the impossibility of constant collimation (from the start of the work until completion of the structure) of the bench marks in the plane $Z = O$ forms a difficulty which is often very great.

Finally, transfer by optical instruments may be fully impossible, in which case the plumb line is used starting from precisely materialized bench marks and applying improvements to attain increased precision of the plumb line.

TRANSFER OF READINGS IN THE HORIZONTAL PLANE

Superstructure

Elements can be located on different storeys by linear measurement by a steel tape with claws (Fig. 4). One claw (Fig. 5) is locked in the desired position, the other (Fig. 6) at zero by its special handle. The tape can thus be used as divider, and marking-out errors practically coincide with reading errors, the scriber coinciding with the reading reference notch. The readings always being done in excess, their errors have the same sign and can be ignored as they are less than 1 mm.

Measuring tape and marking claws have a maximum interval of tolerance of

$$t = \left.\begin{matrix}0\\+0.5L\end{matrix}\right\}\text{ mm}$$

where L is the value of the total length of linear measurement in meters.

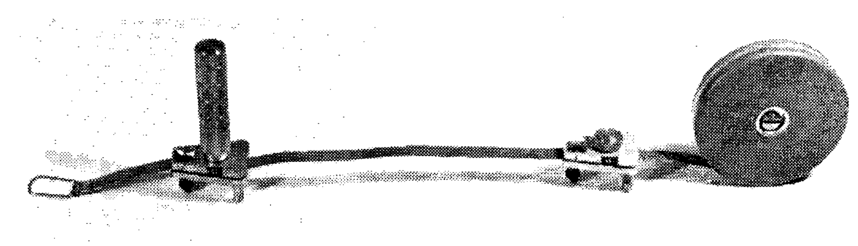

Fig. 4. Steel tape with claws used for linear measurement.

This formula makes allowance for calibration values and those deriving from the elastic elongation of the tape; it should be considered valid for an ambient temperature of 20° C.

For temperatures above or below this value, allowance will have to be made for the thermal expansion of the tape and a suitable correction made (positive or negative). This correction is given by the formula

$$\Delta l = \pm \lambda \Delta \vartheta L$$

where λ represents the coefficient of thermal expansion (12×10^{-6});

$\Delta\vartheta$ represents the difference in temperature between ambient temperature and the calibration temperature of the instrument, which is 20° C; and

L represents the total length of the linear measurement made in meters.

Readings transferred in this way differ from those of the working drawings since they depend on the chosen point of reference. It is, therefore, necessary to work out beforehand a detailed marking-out plan, giving an optimum sequence of operation with a view to the possible mean error, the time of transfer and the useful employment of operators.

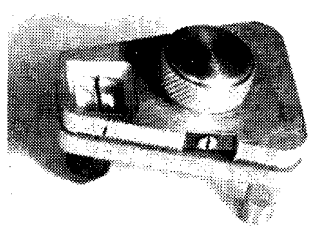

Fig. 5. One of the claws of the steel tape, to be locked in the desired position.

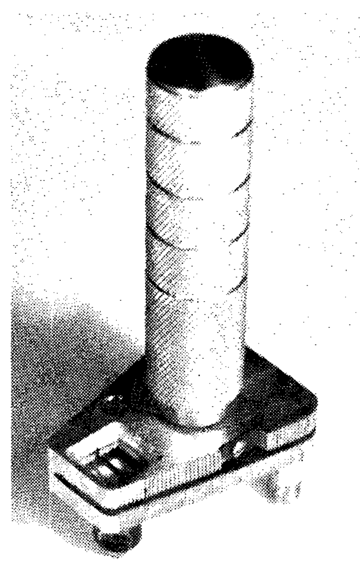

Fig. 6. One of the claws of the steel tape, to be locked at zero by a special handle.

Starting from the origin of the reference axes the position of the elements is transferred along a main alignment 1A (Fig. 7). To locate a second series of elements, parallel and at fixed distance, an arc a_1 with a radius equal to this distance is set out from the origin and an arc a_2 is set out from point 1, having a radius

$$k = \sqrt{\overline{OO'}^2 + \overline{O1}^2}$$

The intersection O′ of the arcs locates the first element of the second series.

This operation is repeated for the last element of the second series *(n′)* and the penultimate *(n − 1)* of the first. O′ and *n′* identify the alignment of the second series. A check can be made by checking, for example, that diagonals M and N (Fig. 7) are equal.

The method of intersecting arcs creates independence from the general frame of reference. It is applicable for transfer of readings of a maximum of 20 meters without the use of auxiliary main reference axes and, thus, several origins. Subdivision of the field of reference should, however, not be exaggerated so as not to depart from the idea to obtain, for each storey, a fairly reasonable interval of variation of measuring error. The use of several origins would, as is evident, introduce complex systematic errors at the limits of each reference zone.

To arrive at greater precision we might modify the claws so that marking out can be done by *chords* instead of arcs, with a measuring device not leaving it to the operator to determine the intersection of the latter. The claws may also be given a device to stabilize the determined points to avoid errors in the process of establishing bench marks.

In conclusion, it can be stated that the idea behind the checking of the marking-out is that the dimensional tolerance of spaces that have to satisfy certain constructional requirements and of spaces that are most important because of their determination by laborious measurements, is determined *a priori* and their mutual agreement is checked *a posteriori*

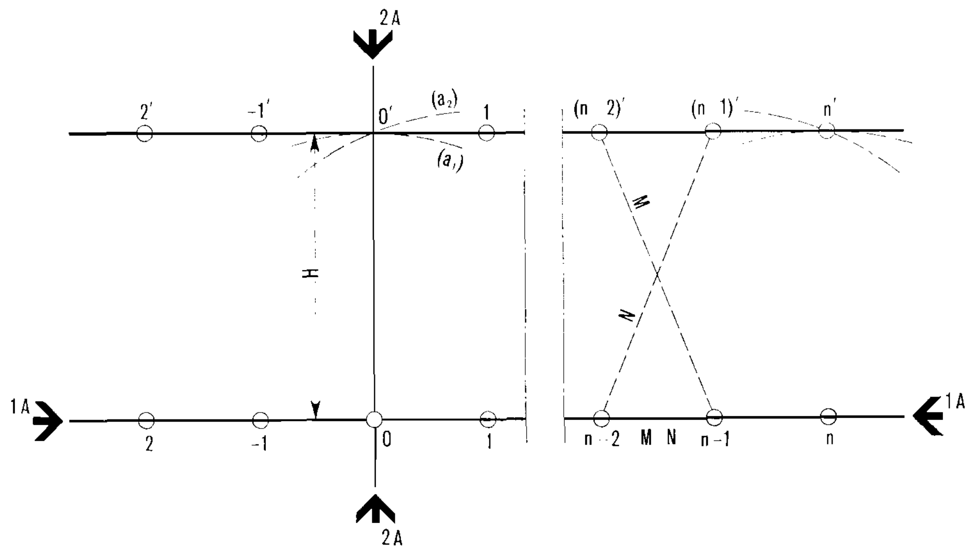

Fig. 7. Transferring the position of the elements, starting from the origin of the reference axes.

Substructure

We have spoken of contact between two families of operations. Let us briefly examine the traditional way to establish this contact. Trestles supported by stakes are firmly fixed on the ground and well squared boards are fastened to them in such a way that their upper edge is about horizontal and at a height differing less than one decimeter from one board to another.

Alignments for locating the bearing elements of the substructure can then be determined by couples of points on the upper edge of the boards and by stretched lines. A pair of these lines is made to coincide with the reference axes of the superstructure and all others take this pair as reference, thus establishing the desired contact. The points of intersection of the lines are transferred to the working plane by a plumb line. It is sufficient thus to transfer the two main alignments and then to proceed as for the superstructure.

TRANSFER OF READINGS IN THE VERTICAL PLANE

Here we may consider the two fundamental limitations separately. The first is the adherence to a determined reading of the project with the definition of the altimetric dimension of the building's cross section, *i.e.* regarding the building as a whole.

The second, on the other hand, involves the observation of a partial determined reading for each significant vertical interval, *i.e.* the altimetric details, and is fundamental for vertical adjustment of the heterogeneous elements.

The problem may be solved in its entirety by carefully materializing in relation to a bench mark situated outside the building, at a known key elevation, the level of the upper, unfinished surface of the substructure located at the highest negative elevation of the plan and then proceeding with the superimposed distances between the successive storeys by some suitable process, starting from the highest negative elevation. During construction of the building it will be possible to transfer the reading from storey to storey by means of a levelling instrument used altimetrically (Fig. 8).

A vertical levelling staff is installed, preferably at the elevation of the origin of the storey to which the transfers are being made. Several pendulum-type levelling staffs are also set up

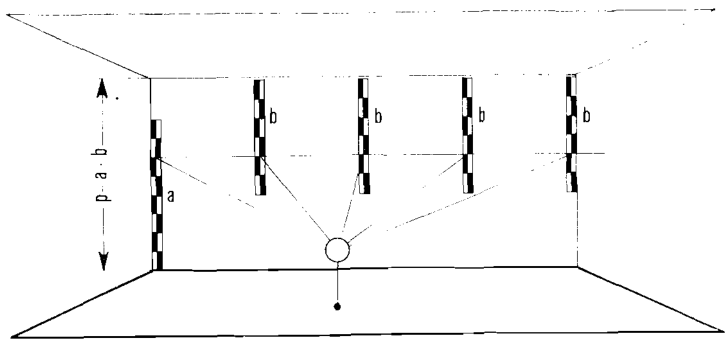

Fig. 8. Levelling instruments used altimetrically for transferring readings from storey to storey.

in a suitable position on the equipment of the upper storey. (In the case of reinforced concrete structures, the zero position of the latter can coincide with the underlying by means of a level.) The equipment on the storey will be at the desired elevation when the sum of the two readings made respectively on the vertical staff and on all the pendulum-type staffs coincides with the difference in thickness of the floor or, in the opposite case, with another elevation fixed beforehand. This latter value should, therefore, appear on the marking-out plans in a suitable position as key elevation.

The importance of choosing the point at which to set up the level should finally be noted, since from this point it must be possible to read either the vertical staff or the pendulum-type staffs.

Accuracy of measurement and tolerances in the building industry — A general introduction

UDC 621.753 : 69

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MEANING OF ACCURACY OF MEASUREMENTS

In everything that is manufactured there occur inaccuracies of measurement, which means that the actual dimensions of the manufactured product differ more or less from the dimensions indicated in the drawing or the specifications. If these deviations are considerable they will give rise to two types of damage. If, for example, the building materials or the transfer measurements for a house differ considerably from the prescribed dimensions, this will result in much extra work having to be done in the form of truing up during construction. The damage makes itself felt in extra working hours and consumption of material. The second type of damage arises when the house is in use. In some cases it is possible to express this damage directly in terms of money, if necessary repairs have to be effected owing to incorrect measurements, but the damage may also manifest itself in the form of inconvenience caused by, for example, a door which does not close well, or as an unesthetic result. It is, therefore, of considerable social importance to strive for greater accuracy of measurements, because this will make it possible not only to reduce building costs but also to produce dwellings of better quality.

A more remote but certainly tangible advantage of increasing the accuracy of measurements lies in the possibility which it offers to introduce new and more highly mechanised working methods, thus allowing a further degree of industrialization in the building industry to be reached.

This is a development which it has also been possible to undertake in other branches of industry. The automation in the metal industry would be unthinkable without attaining a certain degree of perfection in dimensioning. It is, therefore, important that all those who participate in the building industry should give serious consideration to the problem of measurement inaccuracy and to the possibilities of reducing it in an economically sound way.

WHAT IS INACCURACY?

Inaccuracy may be defined as the difference between the actual dimensions of a building material or element and the prescribed dimensions. As already said, deviations of this kind are inevitable. It is not possible to imagine any manufacturing process in which the measurements of all the manufactured products correspond exactly with their standard. As long as these deviations are small nobody will experience any inconvenience as a result of them. However, what is a small deviation? Here we are faced with the concept of tolerance. A tolerance is the permissible deviation from standard, *i.e.* a measurement deviation which is not so considerable as to cause difficulties while the product is used. As an example, reference may be made here to the measurement deviations of a door. It can be said that the measurement deviations of a door panel are not disturbing as long as the door opens and closes easily in the frame and as long as the clearance between door and frame is not so large or so oblique as to give rise to esthetic objections. How large a tolerance should be in any particular situation can only be determined experimentally. We can now formulate the following simple statements:

deviation $<$ tolerance $\rightarrow$ the measurement is correct
deviation $>$ tolerance $\rightarrow$ the measurement is incorrect

By introducing the concept of tolerance, it is possible to judge whether a deviation is permissible or not. The example given has already shown that there may be a certain subjective element in the concept of tolerance. What one person considers to be unwarranted from an esthetic point of view may still be regarded as satisfactory by another who is less critical. In the case of an expensive dwelling the tolerances would, for this reason, perhaps have to be smaller than in the case of a cheap dwelling. We should, however, not exaggerate the influence of this subjective element, as apart from the subjective esthetic requirements there are the purely functional requirements such as, in the case of a door, the fact that it should shut easily. Such requirements are purely objective. On account of these functional requirements it is necessary to ensure a certain degree of accuracy of measurements even with the cheapest products. If this degree of accuracy is not attained, it is possible to choose between delivering an inferior product and correcting the measurements by means of refashioning on the building site. The latter procedure is frequently chosen, with the consequence that during the construction of dwellings a very considerable amount of time is lost in adjusting the various elements so that they fit the structure.

MEASURES FOR IMPROVING DIMENSIONING

The foregoing clearly shows that an improvement of the dimensioning can be attained in two different ways. In fact, one can try on the one hand to reduce the variations occurring in the dimensions and, on the other hand, an attempt may be made to increase the tolerances, for if a larger tolerance can be obtained it will be possible for an initially unacceptable measurement deviation to be made permissible. Such an increase of the tolerances can be achieved essentially by making changes in the design. Thus there are, for example, various systems for the positioning of a beam. One system will allow more tolerance in the wall distance than the other method of positioning. By choosing a construction in which there is a considerable tolerance the number of cases presenting an inadmissible measurement deviation is reduced, thus ensuring a better quality of dimensioning. In some cases it is also possible to increase the tolerances by a proper choice of the sequence in which the various building operations are performed.

However, more important than increasing the tolerances are the ways in which the measurement deviations can be reduced. Essentially there are four ways of achieving this:

1. In designing the building material and/or the building it is possible to deal with the problem of measurement deviations by choosing a construction in which the possibility of errors or considerable deviations is reduced to a minimum. Thus it will be possible in many cases to choose between various building materials. One material (*e.g.* bricks) will present larger measurement variations than another (*e.g.* certain types of natural stone).

2. It is possible to try to make the manufacturing process more accurate by using better instruments which function with greater precision and by choosing better working methods. The transfer of measurements provides a clear example of this. By choosing a good system of transfer of measurements and by using reliable measuring instruments for this purpose a considerable improvement in the accuracy of measurements can be achieved, resulting not only in more accurate dimensions of the final product but also in a decrease of the number of interruptions during the subsequent stages of the construction work.

3. During the production of building materials and during the building operations considerable improvement can be achieved by an effective control. In this connection specific reference is made to systems of statistical quality control of dimensions, which are

applied very successfully in many branches of industry but which, unfortunately, have found little acceptance in building industry as yet. The literature dealing with this question is already so considerable that it seems unnecessary to give further details here.

4. Finally, the accuracy of measurements can be improved by means of a final inspection with rejection of defective items. This applies especially to building materials. Thus it is possible to remeasure the manufactured building materials and to reject the specimens that present an excessive deviation. To a limited degree this method can also be used during the actual construction work. Needless to say, this method is much more expensive than the method referred to under 3, because it is unquestionably better to manufacture good products initially than to produce defective products which have to be sorted out afterwards. On Fig. 1 a survey is presented of all the aforesaid measures for improving the quality of dimensioning. The diagram also indicates the consequences resulting from such improved dimensioning. In the first place it will reduce the amount of refashioning work having to be performed on the building site with all the economies resulting therefrom. Once this stage has been reached, it will be possible to adapt the building process to the new circumstances and to introduce further mechanization, if so desired. The latter could be called the industrialization of the building process.

PROGRAMME OF ACTION

To achieve the proposed improvements in dimensioning several measures will be necessary:

1. More insight will have to be gained into the economic consequences of the existing inaccuracies of measurements. In several countries studies have already been undertaken in which building materials and dwellings were examined for their dimensions. Within the framework of the second construction programme of the European Coal and Steel Community the "Institut für Bauforschung" at Hannover is making a study concerning the expenses involved in truing up doors and door frames. This is, of course, only a first step, as many other elements of buildings would still have to be studied.

2. As yet little is known about tolerances. It is true that many countries have standardization regulations for building materials in which tolerances are mentioned, but these tolerances are usually based rather on the degree of accuracy actually attained in the respective building material industry of the country concerned than on the functional fitting requirements which should be set. It would, therefore, be desirable to determine these tolerances objectively for the various building materials and elements of the building. A first step in this direction was taken by the Bouwcentrum at Rotterdam, which has – within the framework of the aforesaid second experimental construction programme of the European Coal and Steel Community – laid down tolerances for doors and door frames on the basis of requirements of practical use.

3. By combining the investigations referred to under 1 and 2 it is possible to gain an insight into the number of inadmissible measurement deviations occurring in practice in the various building materials and building elements, as well as into the resulting damage. On this basis a priority programme can be drawn up for the improvements to be effected.

4. On the basis of such a priority programme a propaganda campaign would have to be conducted among all interested parties, notably, the future proprietors, architects, contractors and manufacturers of building materials, with a view to arriving at an increased accuracy of measurements, especially with regard to such materials and elements as mentioned at the top of the priority list. The purchasers (*i.e.* for the buildings, the future proprietors and architects; and, for the building materials, the contractors) should – more than they have done so far – bring pressure to bear upon their suppliers in order to induce them to ensure greater accuracy of measurements. This pressure will have to be exerted purposefully and in such a way that the demand for greater accuracy is not formulated in a general and vague way but is specified in the form of tolerances and an inspection system.

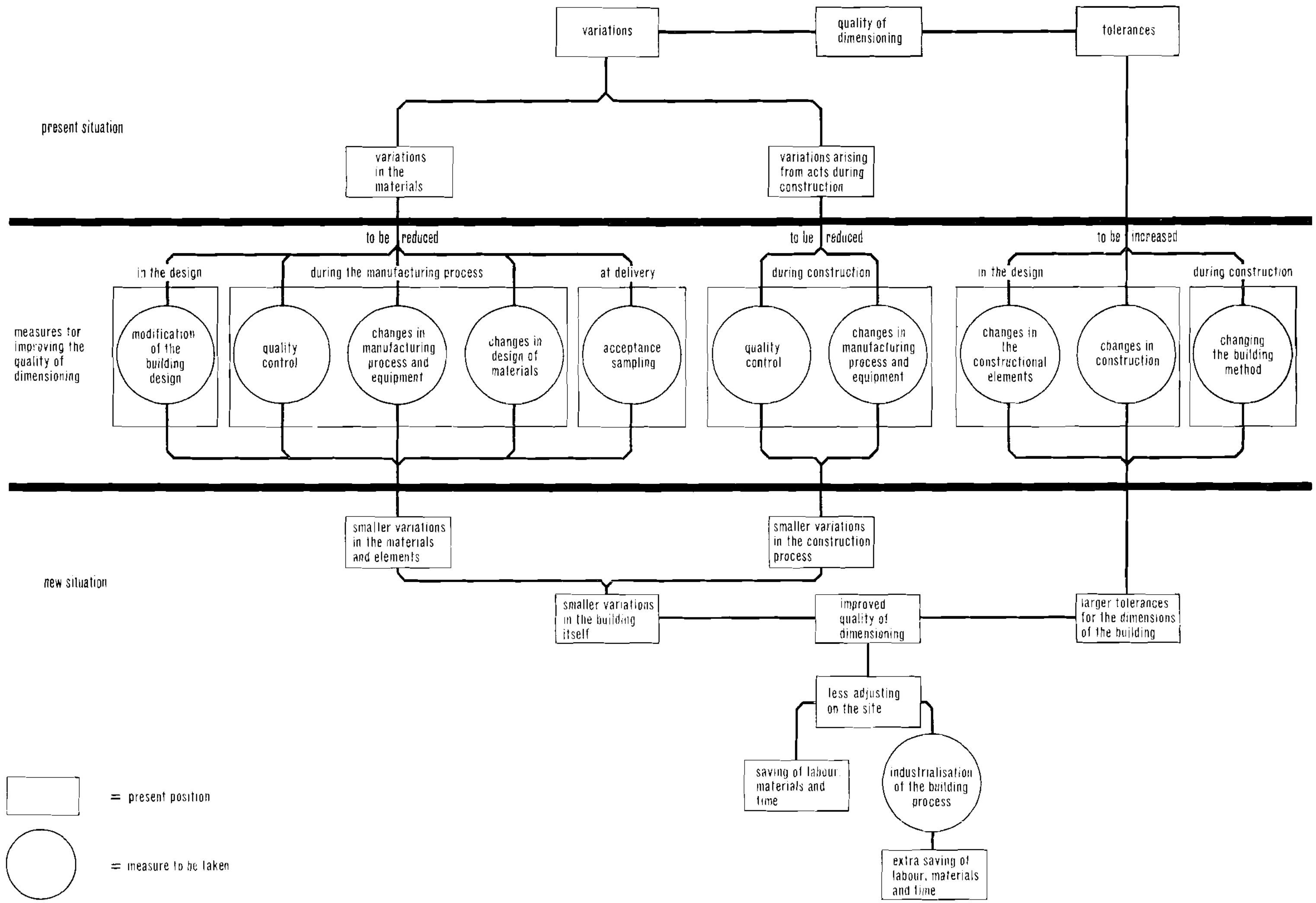

Fig. 1. Improving the quality of dimensioning in the construction of dwellings.

The suppliers will then automatically be induced to pay more attention to the question of accuracy of measurements.

5. Manufacturers of building materials and contractors will have to apply a system of statistical quality control to measurements, which will enable them to achieve in an inexpensive way a considerable increase in accuracy of measurements. In most countries of Western Europe there are specialized consultants who can help them in this respect.

6. For the building materials to be delivered a system of acceptance sampling will have to be formulated. Under such a system the accuracy of measurements is to be checked by the purchasers in accordance with specific inspection schemes which have been brought to the notice of the supplier beforehand. The best procedure is to incorporate such inspection regulations into the standards of the various countries. In this connection it will also be necessary to determine the consequences of the rejection of lots or parts of lots. In this field, too, there are specialized consultants in many countries.

7. All those involved in designing and selecting building materials and buildings will have to be aware, more than they have been so far, of the influence their decision has on the quality of the dimensioning.

REFERENCES

System of tolerances and fits in the building industry (French), International Organization for Standardization, Technical Committee ISO/TC 59, No. 50, Paris, 1957.

Research on the accuracy of measurements for some building materials (Dutch), Bouwcentrum, Rotterdam, 1959 (not for sale).

Indications for the transfer of measurements and dimensioning in house building (Dutch), Werkgroep Maatvoering van de Studiegroep Efficiënte Woningbouw (to be published).

Some observations on the statistical study of measurement tolerances in the field of house building and on the experimental determination of such tolerances on the building sites (French), Instituto di Edilizia del Politecnico di Milano, Milan, 1956.

G. Sacchi, *The problem of tolerances in the building industry* (French), Centro per la Ricerca Applicata sui Problemi dell' Edilizia Residenziale, Milan, 1957.

International comparison of inaccuracies of measurements in house building (Dutch, German, French, Italian), Bouwcentrum, Rotterdam, 1959.

Measurement deviations in house building (Dutch), Adviesbureau voor Toegepaste Statistiek, Rotterdam, 1956.

Directions for the implementation of the Second Experimental Housing Programme of the European Coal and Steel Community (French, German, Italian, Dutch).

Objective determination of tolerances for doors and door frames (French, German, Italian, Dutch), explanation relating to enclosure B3 of the previous report.

Accuracy of measurements and rationalization in the execution of building projects

UDC 389.1 : 65.011 :69

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The coordination of all dimensions of a building and of its elements on the basis of one and the same standard measurement has become an important condition for efficient building. It allows construction with different structural elements without the necessity of truing them up on the site. Mutually corresponding dimensions that are accurately transferred permit the use of prefabricated and large-size elements. They also permit more efficiency in traditional construction methods. Three examples may illustrate our point:

1. execution of masonry,
2. prefabrication and fitting of windows,
3. manufacturing of sanitary equipment.

MASONRY

Several countries have now adopted standardized brick sizes. These are large-size perforated bricks and tiles, hollow blocks of concrete and porous blocks of concrete. These types of blocks combine sufficient strength with more favourable thermal properties than the conventional type full bricks and tiles. The walls they are used for can, therefore, be less thick than usual.

Physiological tests have given us the proper weights, the best dimensional ratios and the most favourable working process. A bricklayer who used to build a 1 m^2 wall $36\frac{1}{2}$ cm thick with the conventional full bricks can now build a $2\frac{1}{2}$ to 4 m^2 wall 24 cm thick, but with the same thermal capacity, in the same time (Figs. 1 and 2).

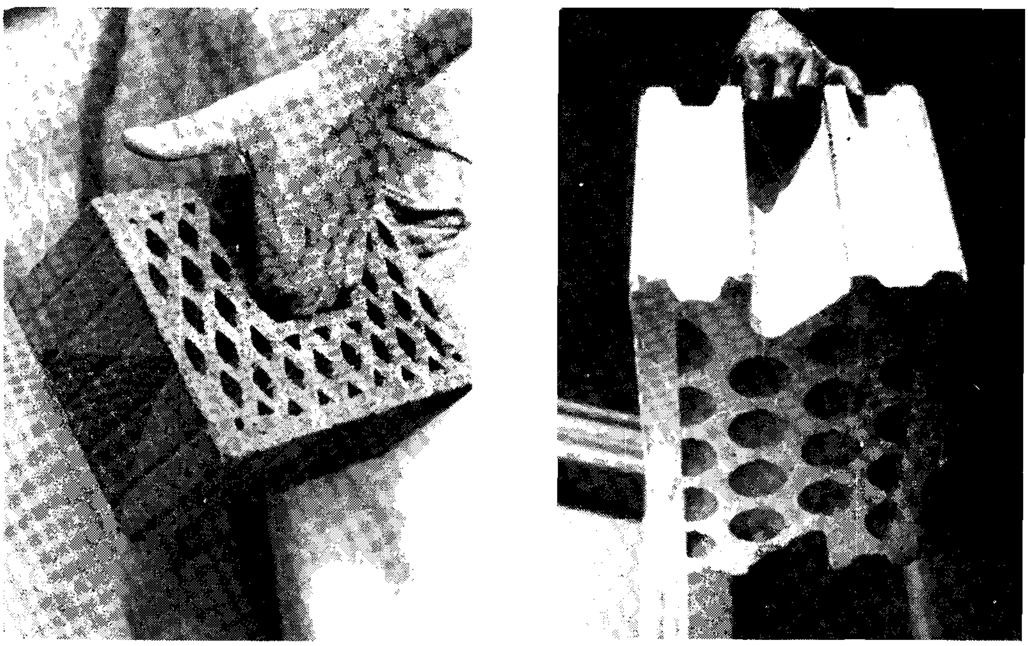

Fig. 1. Bricks and perforated blocks: more efficient building materials.

If the wall dimensions do not correspond with those of the tiles and bricks, bricks must be cut to size on the site. The larger the size of the brick, the more work the bricklayer has to do (Fig. 3).

In one case, where a building was erected using bricks whose sizes did not correspond, the bricklayers wasted more than one third of their time cutting the bricks to size. It took them

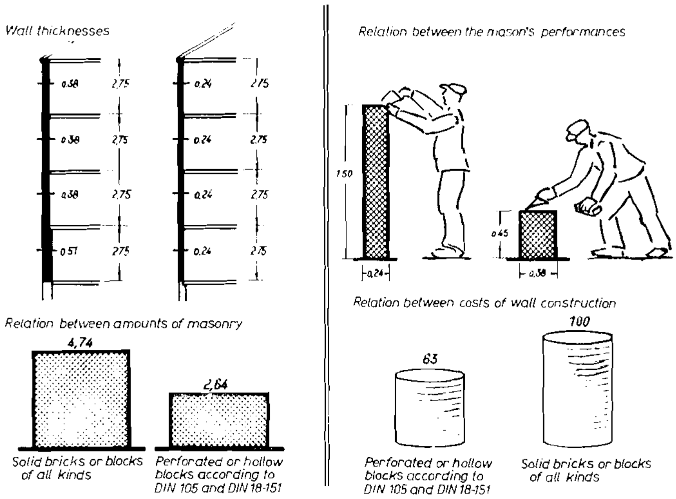

Fig. 2. The thickness and dimensions of walls built according to conventional and advanced masonry techniques. On the right, the work performance of the bricklayers and the building costs.

Type of brick or block	Solid brick (e.g. Mz. 150, Ks 150)	Perforated brick with groove for catching	Perforated brick with mortar groove on both sides	Threefold hollow block (e.g. porous burnt clay)	Hollow block of chalky material with grooves for catching	Twofold hollow block (e.g. natural pumice)
Format in mm	240 × 115; NF	113; 240 × 175; 2¼ NF	238; 240 × 240; 6 NF	238; 365 × 240; 9 NF	238; 370 × 240; 9 NF	238; 490 × 240; 12 NF
Additional bricks and blocks	-	HLst. 11/2 NF	HLst. 11/2 NF	4/6 St., 6/6 u. 4/6 A	4/6 St., 6/6 u. 4/6 A	4/8 St., 8/8 u. 4/8 A
Volume in cm³	1960 (100)	4 746 (242)	13709 (699)	20 849 (1064)	21134 (1078)	27 989 (1428)
Gross weight in kg/m³, at site	1971	1307	1033	1537	1104	1089
Weight of blocks in kg, at site	3.86 (100)	6.20 (161)	14.16 (367)	24.46 (634)	23.34 (605)	23.83 (617)
Thickness of walls in cm	36.5	24.0	24.0	24.0	24.0	24.0
Working method	Individually laid			Laid in rows		

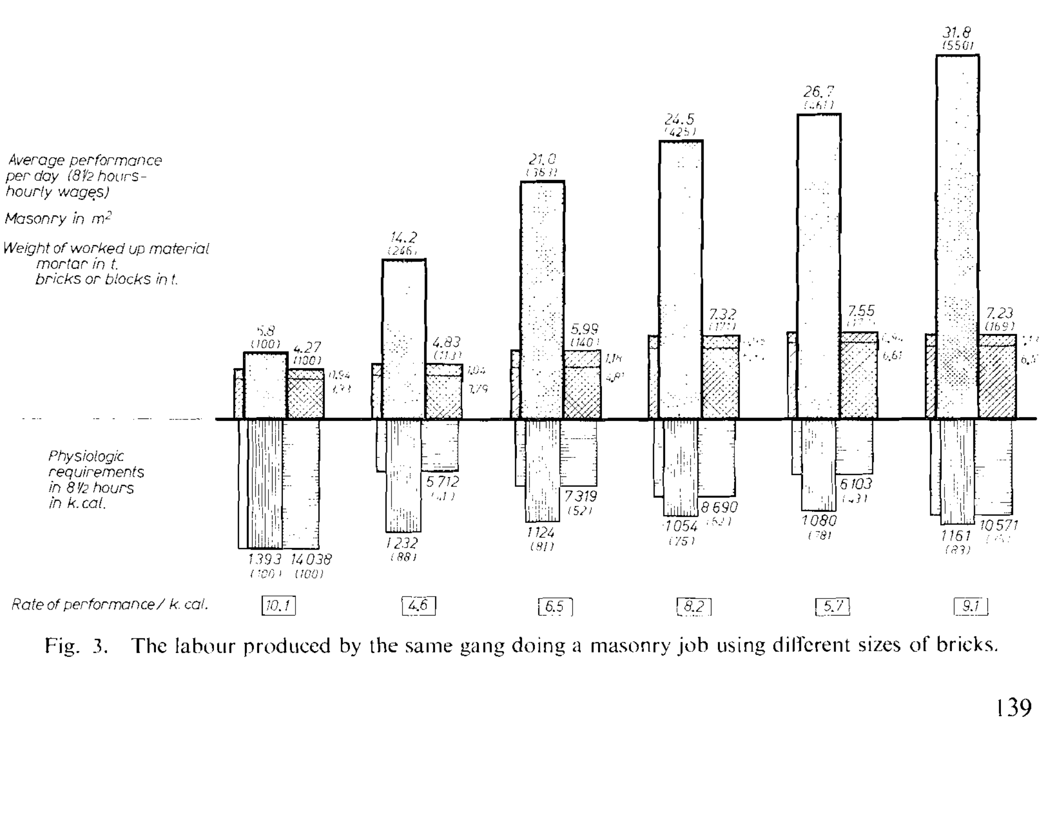

Fig. 3. The labour produced by the same gang doing a masonry job using different sizes of bricks.

150 hours to build a required wall surface, including the cutting of the bricks. At the same speed and power the job could have been done in only 100 hours if the dimensions of building and bricks had corresponded properly. This means that they could have built a 100 m^2 wall in the same time they used to build a 67 m^2 one on account of the hold-up.

The deviation between dimensions of buildings and bricks and the inaccurate conversion of these dimensions when building with large blocks may, therefore, cause excessive labour and inefficient building methods. Standardized, corresponding dimensions and measure-

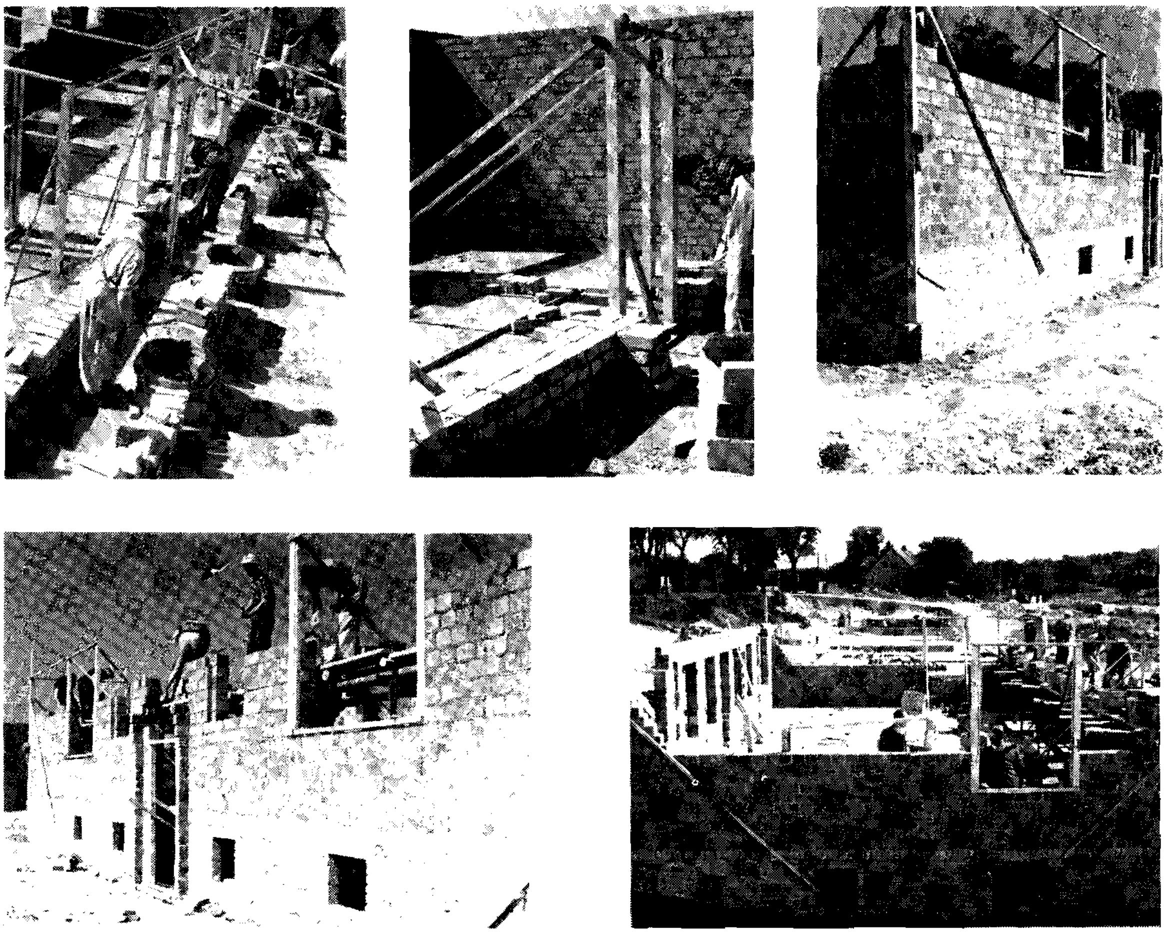

Fig. 4. Wooden window and door frames of the Dutch type being used in Germany.

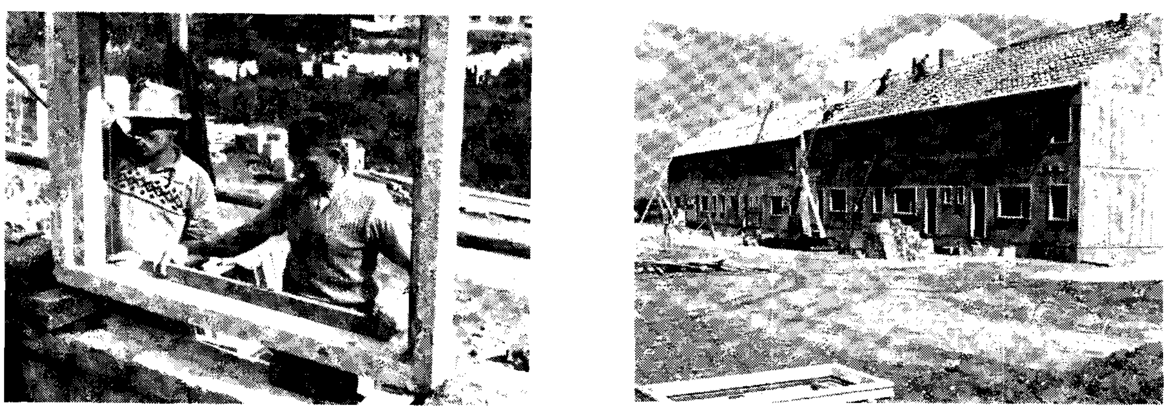

Fig. 5. Accurately dimensioned prefabricated concrete window frames.

ments of buildings and bricks, and the proper conversion of the dimensions, on the other hand, bring out to full advantage the new wall-building method that is highly efficient and advantageous and contributes considerably to fast and systematic brick laying.

WINDOWS

So far in several European countries it has been common practice to build openings for windows with the aid of plumb and level. With this system it often happens that the dimensions deviate 3–4 cm from the required dimensions.

The joiner in charge of window construction must take all dimensions on the site and construct the windows in accordance with the dimensions of the opening, which often vary in size. Furthermore, the windows must be constructed one by one and each window frame will, therefore, fit one particular opening only.

With these different dimensions it can occur that individual frames do not fit the openings. This is why windows are not provided with ironmongery, glass and painting until fitted in the openings. This work is done on the site under unfavourable conditions. This inefficient and time-consuming process is caused by openings made with inaccurate and divergent dimensions.

With the use of simple methods it is possible, however, that all openings have exactly the required dimensions. In Holland it is general practice to manufacture the sash frames in advance to standard size and fit them into the openings (Fig. 4).

In Germany concrete sash frames are used which are made in moulds and fitted in the wall afterwards (Fig. 5).

Recently, sheet steel frames prefabricated in the factory and fitted while the masonry is being done have also been used (Fig. 6).

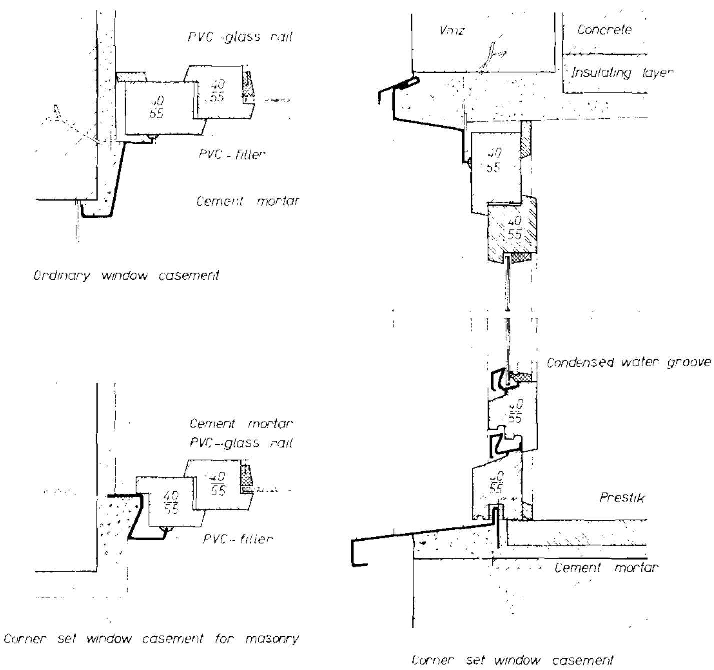

Fig. 6. Prefabricated steel frames for wooden window casings.

The same effect may also be achieved by giving the bricklayer template or full-size models. When there is no doubt that, owing to the method described above, the dimensions of the openings are exactly adhered to, the joiner may make all windows of the same size in one series in his workshop so that all windows will accurately fit the corresponding sashes. The windows will not have to be finished on site either. They can be provided with ironmongery and fitments, glass and paint in the workshop, which is more efficient, and work will proceed much faster when fully finished windows arrive to be fitted on the site. It is obvious that this system of manufacturing and placing windows cuts costs considerably.

Actual practice has shown that fitting windows in openings which do not have the same dimensions costs as much as 1–$2\frac{1}{2}$ hours/window or between 0.15 and 0.30 hours/m^2. The total cost averages between 1.2 and 3 hours/window.

For windows of equal type and dimension, made according to standard size and fitted in accurately dimensioned openings, it took only between 0.7 and 1.5 hours/window (or 0.4–1 h/m^2). Working with accurately dimensioned windows and openings has resulted in a 50% saving in time as compared to the method used previously.

THE INSTALLATION OF SANITARY EQUIPMENT

So far with the conventional working methods used in many countries the plumbing system in the interior was installed in such a manner that the plumber measured off, cut, threaded and installed every single length of pipe or tube. This method is applied where the work is not planned on the basis of coordinated dimensions.

If, however, in one building or in a group of buildings several pipes of the same type must be installed, the man in charge of this work can apply a far more efficient method, for in this case all he needs to do is ascertain the right dimensions (lengths) only once. Under the more favourable working conditions in his shop he can cut one series of pipes or tubes for one and the same application. He can even combine particular sections to a certain required length (Fig. 7) which need only be conveyed to the site to be installed quickly and efficiently. This method has proved to be extremely efficient. While the old conventional method, including many manipulations, takes an average of three hours per running metre, the same type of installation takes 0.7–1 hour per running metre when the new method is applied. This means that in the latter case only between one half and one third of the time is required to do the same job.

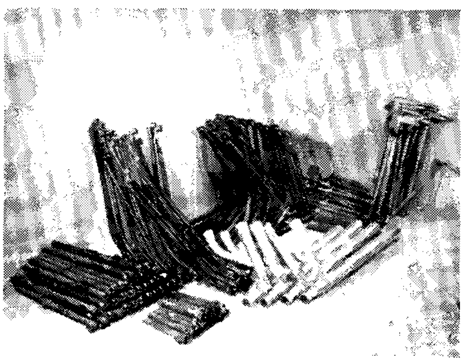

Fig. 7. Standard-dimension assembled pipe sections for sanitary installations.

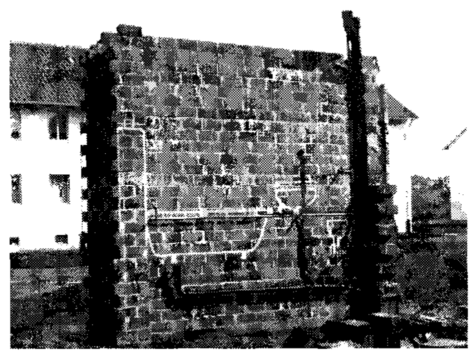

Fig. 8. Framework for the accurately dimensioned building of walls for sanitary installations.

The installation of pipes and tubes also covers the fitting fixtures themselves. When comparing the entire installation of a house, between 43 and 114 hours are required with the conventional method, depending on the type of building. When the efficient system is used, however, it takes only between 32 and 71 hours, which amounts to a total labour saving of between 25 and 34 per cent. If these advantages are to be fully used it is imperative that the dimensions do not deviate and that they are correctly converted for use in practice. In Germany this accuracy of dimensions has been attained by giving the bricklayer a template to enable him to do more accurate masonry work and to make all slits, holes and openings exactly to size. On other sites it has proved practical to erect a life-size model, showing the wall installation with all the pipes and fittings (Fig. 8). All the workers on the project could take the proper dimensions by studying the model and use the right dimensions for their own work.

The use of coordinated dimensions has again proved to be an absolute necessity if an efficient working method is to be ensured.

These three examples – masonry, windows and installation – will, we hope, have shown that even when building according to improved conventional methods, it is possible to do the job more efficiently.

To ensure the largest measure of success, however, it is imperative that the dimensions are rigidly coordinated throughout. It may be so that this method involves higher costs for the architect and the superintendent, since they have to do more figuring and calculating, but this is amply compensated by the important advantages of the more efficient building technique made possible by the improved method.

Dimensioning on the building site

UDC 526 : 69.05

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HISTORICAL REVIEW

The technique of enumeration and of measurement originates from man's need (1) to count the largest possible number of things, as he had to watch his flocks, and (2) to locate himself in time.

The concept of time came into being with the necessity to have a more stable agricultural order by observing the course of the days and seasons by the length of the shadow cast either by a staff or a monument erected for that purpose.

The exigencies of this evaluation of time which the organized life of the tribes required compelled man of this era to increase his precision of measurement; the most characteristic fact is that angles were measured well before linear dimensions because the directions were closely tied up with the appearance of a star or a constellation on the horizon.

The Chaldeans already possessed instruments similar to theodolites which were continued to be used until the invention of the telescope. They knew how to trace an angle of 60° by inscribing a hexagon in a circle; three lengths of cord in a linear proportion of 3:4:5 since antiquity enabled them to make a right angle, etc.

Thus, well before Euclid and Archimedes allowed geometry to arrive at a marvellous degree of elegance and method, man knew the most elementary concepts of marking-out. Our ancestors did not, therefore, await optical and mechanical improvements before tackling the problems of marking-out. In Egypt, for instance, they have left us a heritage of ancient edifices sufficient to form irrefutable proof of the extent of their ingenuity and capacity. In the centuries that followed, applied mathematics greatly developed navigation, architecture and, in particular, topography.

With the evolution of mechanics and optics, the technicians of today have developed a whole range of precision instruments, from the simple optical square via the transit and the level to the theodolite. Some of these instruments attain such a degree of precision that optical aberrations resulting from physical and atmospheric phenomena cause a lack of precision much greater than those caused by mechanical defects of the instrument itself.

PEGGING-OUT TECHNIQUE

In most of the publications on public works and topography this technique is neglected. Rules are followed which are the converse of those relating to the methods of topographic survey.

The bulk of topographic work is performed for graphical purposes or for calculation and, to obtain homogeneous results, they are freed from systematic and accidental errors. For the instruments direct and inverse sightings are used to eliminate errors of collimation, and for the calculations the uncorrected results of closure are compensated for after consultation of the tolerances.

In the transfer of dimensions at the site, everything is exactly the opposite. The results are given and the technician is compelled to materialize them in full scale with maximum precision. Even if the operator is able to learn the systematic errors of a tape by calibration or to correct the error of collimation of a theodolite, the same does not apply to unknown accidental errors.

This obliges the person responsible to consider carefully not only the mathematical and practical possibilities of the instruments but also to estimate the result of the errors arising from the application of the chosen pegging-out method. It is not the instrument that determines the conditions of application, but the precision of the result that has to be obtained.

Psychology also plays a part in this respect. Technicians cannot be warned too strongly against the dangers of professional and personal chauvinism, which consists of stating that only their method is perfect. Such an attitude leads to a rut and not to an improvement of the technical qualities of the operator.

THE INSTRUMENTS

For transfer of linear measurements in the horizontal plane and in buildings, few instruments satisfy the ideal conditions of simplicity of use, direct reading and accuracy. Instruments possessing most of these three qualities are, in increasing order of accuracy: the surveying chain (for reference purposes only), rods, steel tapes and Invar wires. For more or less inaccessible sites procedures involving surveying techniques make it possible to comply in an elegant fashion with certain problems of measurement, but they only very rarely fulfil the ideal conditions of use because of the cumbersome nature of the equipment and the frequent impossibility of setting them up at the required points.

TRANSFERRING MEASUREMENTS TO A BUILDING

This subject has been dealt with in the general report by Professor Ciribini, assisted by Mr. Maggi, that deals with the instructions for the second experimental dwelling construction programme of the High Authority for the European Coal and Steel Community. What follows is a brief explanation on the different places of marking-out with more details on the material and practical means to employ in order to elevate bench marks at Z = O levels up to higher storeys so as to obtain marks there for the places of the elements.

GENERAL CONSIDERATIONS

Within the general framework of a layout, the location of a building is decided upon by the commission that drew up the town plan. The difficulties relating to such plotting will

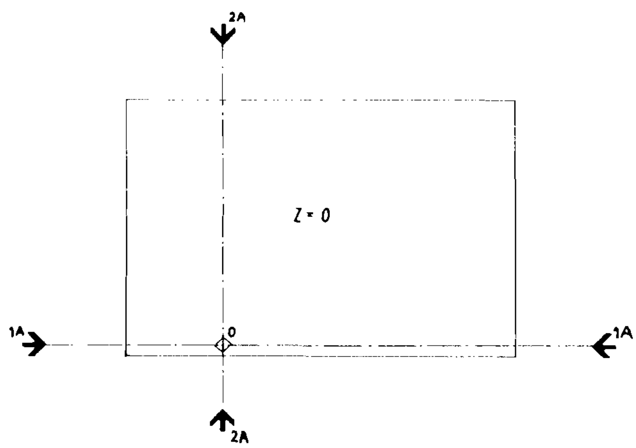

Fig. 1. General method of dimensioning: origin formed by the point of intersection of two mutually perpendicular main frontage lines 1A and 2A. (Instructions of the Second Experimental Programme of the European Coal and Steel Community.)

not be commented on. We are only concerned with the building, starting from the Z = O level of the first floor.

The installation of partitions, columns and other interior details is effected by means of marking claws and a steel tape. The principal bench marks are established either on the outside or on the building. We must now consider the transfer of these bench marks to each storey, or providing them with the possibility of a constant link between them.

CRITICAL SURVEY OF PROCEDURE – UTILITY OF A METHOD

Many clerks of work think to have solved this problem when they have marked the exterior angles of the structure at the finished Z = O level and plumbed the angles at each storey. This solution is acceptable for low buildings up to two storeys only, but it is not adequate for big projects and buildings with a steel structure or with different shapes at each floor or with changes in column distribution which must conform exactly with the figures accepted as a basis for the computation. In fact each point has two positions: a theoretical one based on the calculations and an actual one resulting from the exactitude of the marking-out. The ideal is a coincidence of both: aberration = 0.

The operator must choose the right marking-out method with a view to the requirements of the work, the desired precision, the traffic at the site, the location of dumps, etc.

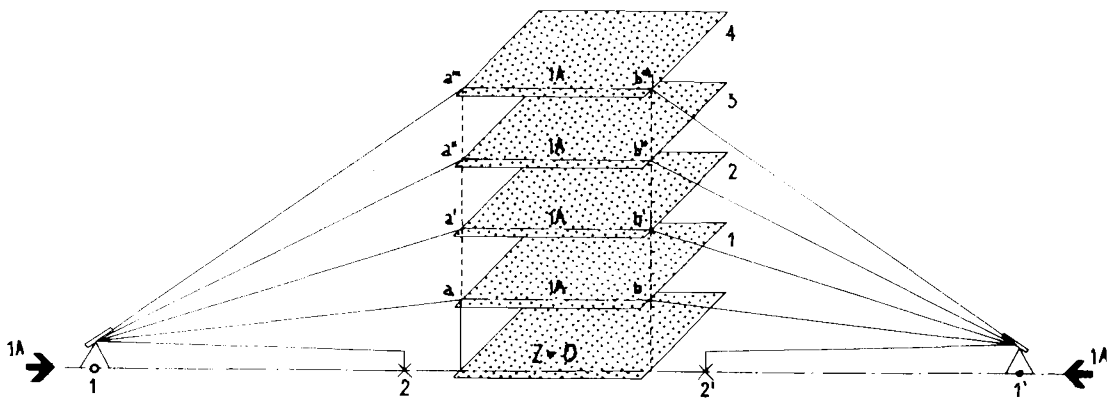

Fig. 2. General method of dimensioning: setting one of the main frontage lines out onto the various storeys by means of a tachometer. (Instructions of the Second Experimental Programme of the European Coal and Steel Community).

RATIONAL METHODS

Two logical methods of a continuous nature can be used. The first is indicated in the instructions for the Second Experimental Programme of the High Authority. The second is the result of the adaptation of the general principles quoted above to a site of special conceptions of form and construction procedure.

(1) The instrumental method (summary of the High Authority project instructions) may be illustrated as follows:

Let a building be constructed up to the ZO level. Four points 1, 2, 1′ and 2′ are materialized in the same plane at various points in the structure. Points 1 and 1′ can be stationed, points 2 and 2′ serve as a reference when the line of sight between 1 and 1′ is interrupted. Longitudinally, the operator placed at 1 or 1′ after having sighted on 2 or 2′, points a′, b′ or a″, b″ can be marked out on the upper floors by means of the theodolite. Transversely, points C and D can be elevated by means of a similar system, or better still and more simply by approximate stations in the plane CD at various points in the building.

(2) The second method has been studied because of the special nature of a French building site, "Le Konacker".

In view of the interesting features presented by this practical example, the data of the problem, the difficulties arising out of it and, finally, the solution, are given in a general report that follows.

Thanks to the mutual research with the Research Bureau of Milan, and by the suggestion of its director, Professor Ciribini, certain arrangements have further improved the possibilities of using this procedure for transferring dimensions, whilst at the same time not departing from the idea behind the method.

HIGH AUTHORITY INSTRUCTIONS APPLIED TO A FRENCH SITE

Introduction

The instructions (Annex B2 of the relevant documents) for the transfer of dimensions at the site form a very realistic method whose general principles can be applied at most sites. On the "Le Konacker" site in France, despite its special nature, the principles of marking-out could be respected and only the mode of operation varied as regards the exterior pegging-out and the transfer to the upper storeys of the axes which are indispensable for marking out the walls and partitions.

Topographic Location and Description of the Building (Fig. 3)

The "Le Konacker" site consists of two buildings. To keep this report short only the principal building, which is 202 metres long, will be dealt with here.

In plan

The structure with which we are concerned is 202 metres in length, made up at each end of a gable block with one cell per storey.

In the centre elementary blocks with a double cell per storey are staggered on two façade alignments. The staircase walls form a connection between the independent blocks with an expansion joint on one of the two common faces.

In elevation

There is a difference of approximately 12 metres in level between the two ends of the building. This difference in height is spread over the ZO level of the blocks, alternately per block or per group of two blocks, as a function of the slope of the street.

Each block consists of three or four storeys.

Equipment and materials used

The firm constructing the building uses metal shuttering with modular dimensions of 6.25, the basic panel being 2½ metres. The walls consist of hollow concrete cast in wall moulds.

Two major factors systematically handicap the normal performance of the marking-out operations as described in Annex B2 of the High Authority project instructions:

(1) Material obstacles

(2) The building programme.

Material obstacles

Dumps of materials, the embankments essential for keeping the crane balanced, the general movement of vehicles: all of these make it impossible to peg out a large number of points in the vicinity of the structure. Since, on the other hand, pegging out these points at a distance would make them useless, the building already being 202 metres long, it is therefore preferable to have the minimum of fixed points close to the structure and, above all, to surround them with a strong protective fencing.

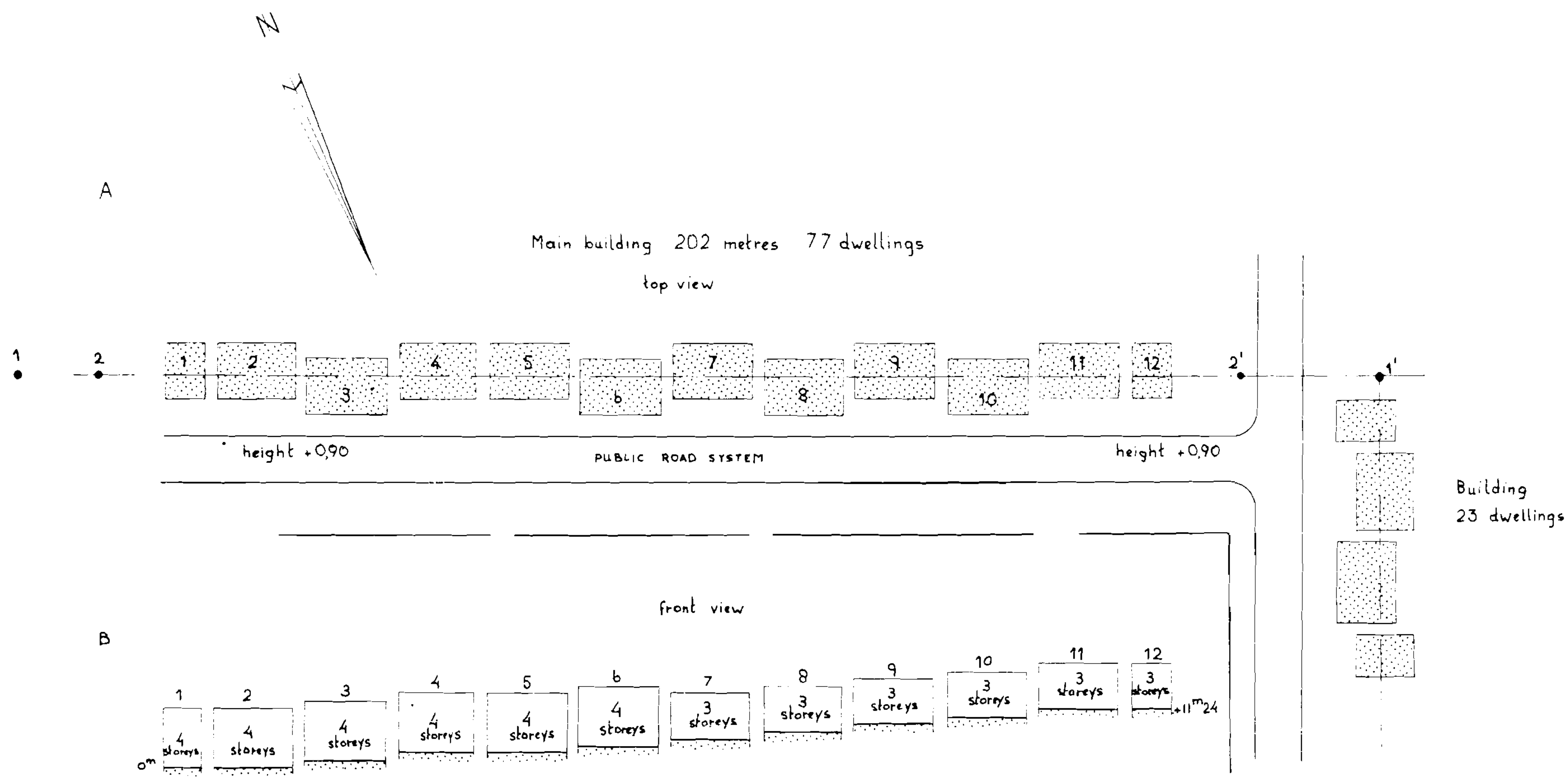

Fig. 3. Topographic location of the "Le Konacker" site. (A) Plan, (B) Elevation.

Building programme – rapid rate of progress

The builder works in groups of two blocks, from the excavation to the top floor, starting with block No. 1, the one at the lower end (Fig. 3, A and B).

His planning requires one storey to be built a day, walls and floors completed.

This rapid working technique demands accelerated marking-out on every unfinished floor. On the other hand, the height of the first two blocks 1 and 2 *ipso facto* interrupts the line of sight between zero points 1, 2 — 1′, 2′ (Fig. 3A). By assuming that these points can be materialized on the terrain and maintained in position, and given the length of the building, the prolongation of the single alignment 1′, 2′ up to each block would be equivalent, for nine tenths of the structure, to a dangerous extrapolation extending beyond the practical and rational field.

Because of the excavations and the work on the basement of the other blocks, it is impossible to make use of intermediate points, since they could only be employed temporarily.

Conclusions

For reasons of technique and rapidity, a study should be made of the adaptation of the instructions of Annex B2 to a marking-out technique that would be dependent on a minimum of fixed points, which are by no means certain to remain in position or which have to be used irrationally.

Marking-out block for block is, therefore, the most suitable method.

Transfer of Dimensions on the "Le Konacker" Site

Marking-out on the ZO level of the blocks

Choose an axis 1 — 1′ passing through the whole of the blocks 1 — 2 — 3 — 4 . . . 12 (Figs. 4 and 5). Materialize point 1′ very securely at a distance of 20–30 metres from block 12, and make sure that its position is preserved by a protective fence.

Once the ZO level of blocks 1 and 2 are completed, mark out A — B — A1 — B1 and supplement these sightings in plane 1 — 1′ by reading angles on two reference points I and II (steeple or lightning red) situated on either side of this axis at distances greater than those of 1 — 1′.

To mark out on blocks 3 and 4, 5 and 6, etc., on the ZO levels only, set the instrument up at B on each occasion, take a sight in plane 1 — 1′ on the last visible B1 point, check the readings against the reference points I and II. Once it has been checked that the system is properly set up, mark out the homologous series of A — B, *viz.* A3 — B3 — A4 — B4; for the other blocks, repeat the same operation until no longer possible.

Likewise, check the position of points A3 — B3 in relation to A2 — B2, and A4 — B4 in relation to A3 — B3, etc. Once points A — B, A1 — B1, A2 — B2, etc., are known, it becomes possible to perform marking-out on each isolated block by taking as transversal axis for this site the axis of the wall of the two cells, or for the gable blocks, which consist of only one cell, the axis of the wall plumb with point B. Points C and D are erected in the classic manner, using marking-out claws, after the iron plates have been embedded (Fig. 4) and the two points I and I_1 marked out.

The marking-out plan (Fig. 5) makes it possible to follow assembly operations and to know the origins of the arcs.

This study of the interior lay-out is valid for all the blocks and at all the levels. For the gable blocks, the marking-out of only one cell need be taken into account.

The only difference between the lay-out of the ZO level and that of the storeys above is the use on the ground floor of iron plates to receive points I and I_1.

Note: The transfer cannot be made via points A and B situated on the longitudinal axis, since these become invisible when the staircases are built.

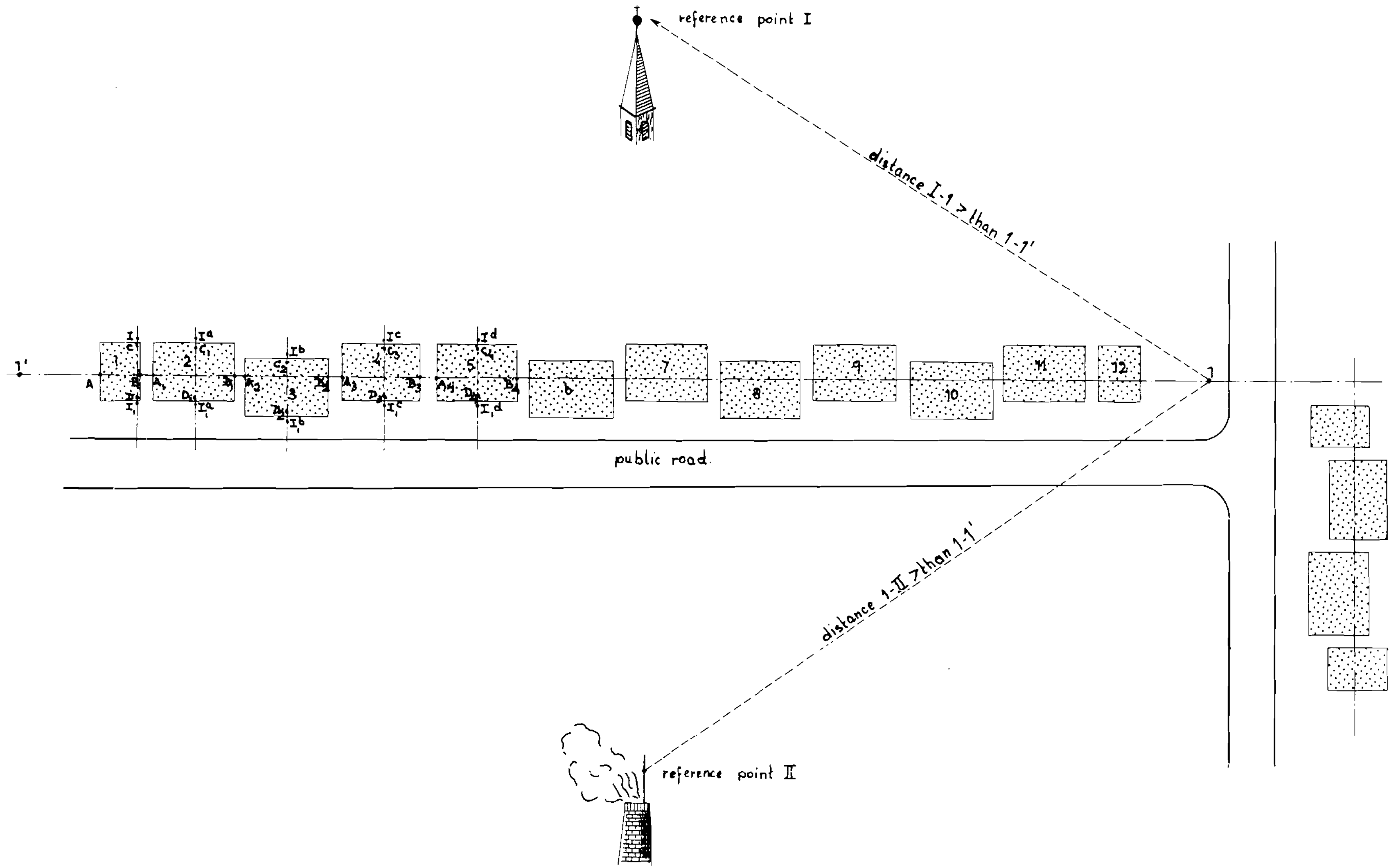

Fig. 4. Transfer of dimensions on the "Le Konacker" site.

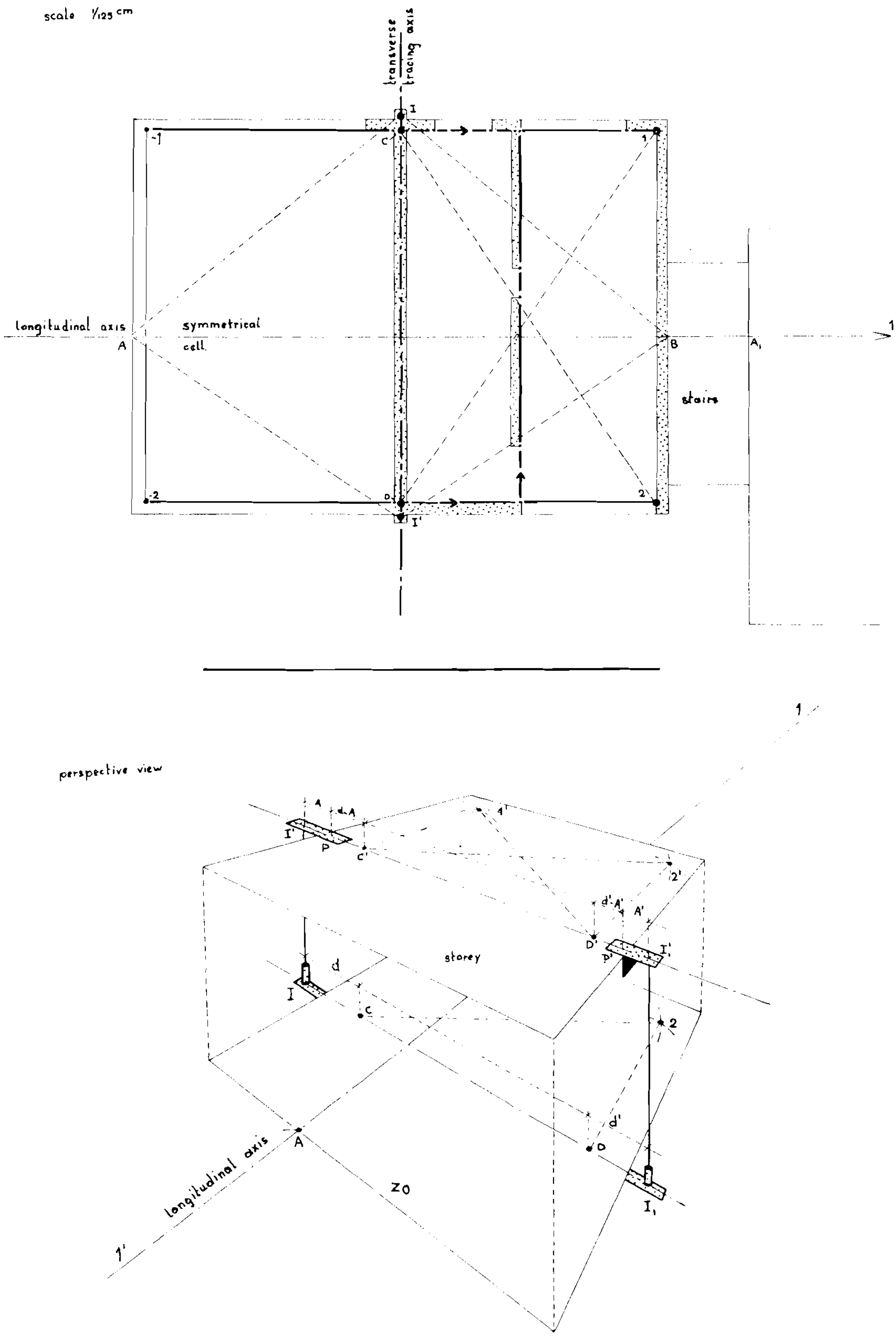

Fig. 5. Transfer of dimensions on the "Le Konacker" site.

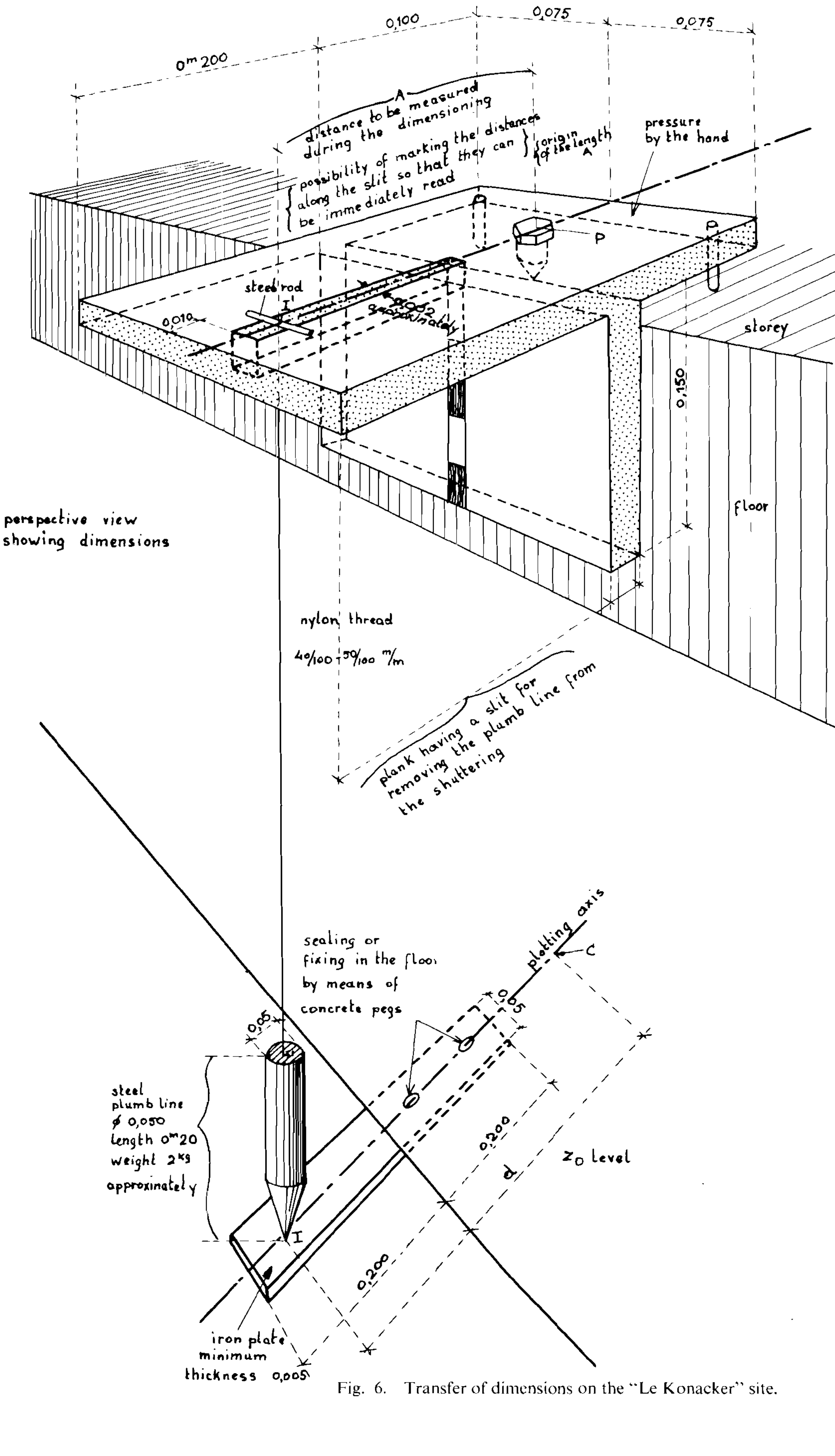

Fig. 6. Transfer of dimensions on the "Le Konacker" site.

Transfer of the transversal axis I, I_1 or C — D to the upper storeys (Fig. 5)

For reasons of speed and in view of the absence of outside points, the procedure using the tachometer is replaced by the heavy plumb-line method, as used at present in metal constructional work and in the mines for pit shafts extending to a depth of 100 metres and more.

Standardization of the plumb is obtained, if necessary, by immersing it in a container of water or oil. Its weight is a function of the height of the plumb line and can be rated before marking-out operations.

The small marking-out staff consists of an offset board allowing the plumb line to avoid the shuttering.

The use of this instrument has not changed. Coincidence with the vertical plane of elevation is effected with the plumb line and in the two directions (longitudinal and transversal). At the origin the coincidence was established by means of the tachometer in the vertical plane and in the only longitudinal direction.

BRIEF ANALYSIS OF THE TWO PROCEDURES

In the first case, the principal bench marks are outside the building and serve for the elevation

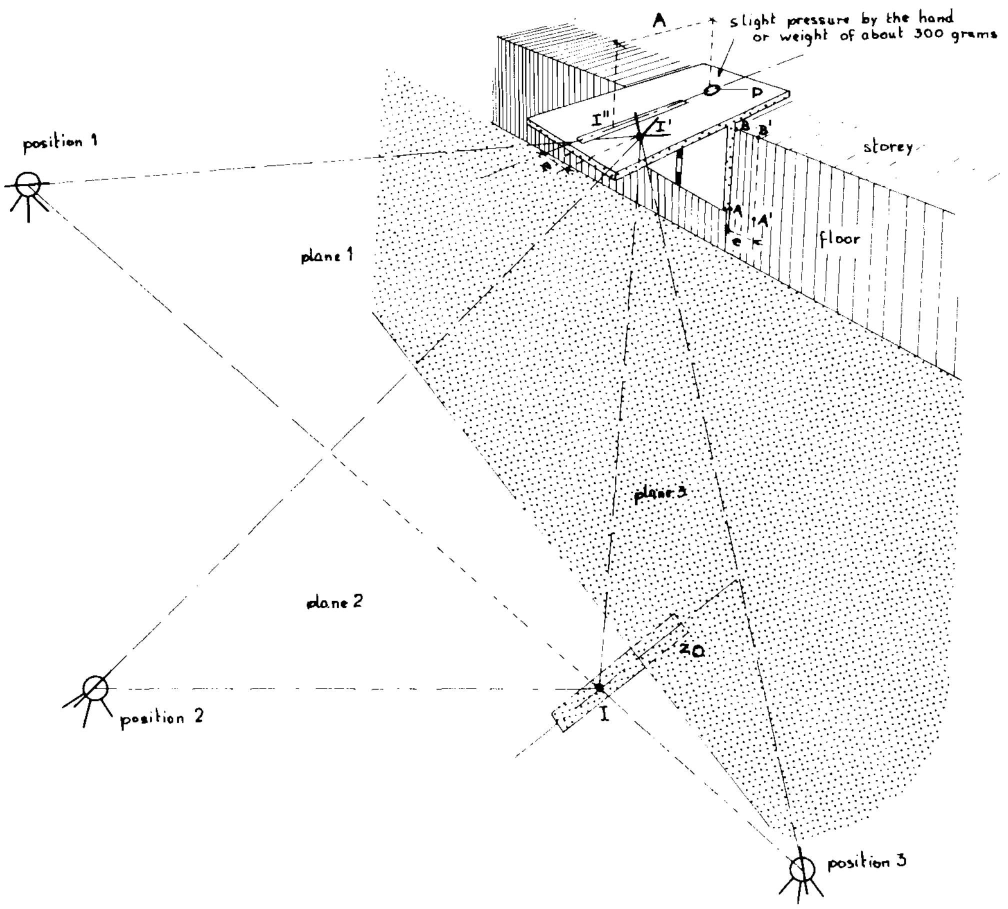

Fig. 7. Transfer of dimensions: useful method for bad atmospheric conditions, entailing the use of a goniometer (circle of direction-theodolite-tachometer) to transfer a point in the vertical direction. 1. Place levelling staff above point I, with a maximum divergence of 5 cm, by means of plumb line. 2. From the three positions surveyor sights point I and, by means of two points for each plane, lines of intersection are drawn onto the horizontal part of levelling staff to obtain I′; distance *e* is then measured. 3. On same side as I′ and with value *e*, a line parallel to A-B is drawn, *viz*. A′-B′(I′ may be situated on either side or on the axis of levelling staff going through P). 4. Slide levelling staff until $\overline{AB}$ coincides with $\overline{A'B'}$ and arrive at drawing point P.

of the other bench marks. The use of the theodolite is made indispensable. The method is indirect. It demands a repetition of the stations for every finished storey.

The procedure can be used for buildings with an average length of 50 to 100 metres and constructed continuously. It is essential that the operation be performed by a technician who has a good knowledge of how to check and adjust his instrument.

The second procedure utilizes the plumb line and the springboard for elevation. The method is direct, not very onerous and within the capacity of the average clerk of works. It seems to be rapid, easy and less abstract. Moreover, it can be generally used for all kinds of buildings.

Its drawbacks are: (1) wind, which is fatal to this method; (2) its accuracy, which, whilst very acceptable, is inferior to that of the theodolite.

CONCLUSION

The purpose of the above has been to show in simple fashion that the technique of the transfer of measurements, whilst appearing simple, brings in its wake technical considerations and exigencies that may not be disdained nor ignored in the practical field.

If it is easy to understand the lack of advantage in using a telescope to mark out a point 20 or 30 metres away, it is much less easy to foresee that using a method or an instrument involves the danger that a complete pegging-out operation will be systematically falsified. Such judgment forms the attribute of a good technician in charge of the transfer of measurements at the site.

Tolerances and fits in building

UDC 621.753 : 69

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TOLERANCES OF DIMENSIONS OF BUILDING COMPONENTS

The production of building components involves deviations of the predetermined dimensions of the components. Observation of the real dimensions shows that the distribution of these is a normal Gaussian distribution. This fact permits the principle of applying mathematical statistics in the study of dimensional variations and the dimensions or the deviations can be treated as chance variables.

However, for the purpose of such study, disturbances in the production process that may distort the variation must be eliminated.

To study the distribution it is fundamental to observe a large number of measurements of one type of component produced under highly identical technological conditions, either in the same plant or on the same site. To evaluate the distribution and to determine the variation the parameter σ, the mean standard deviation, can best be used.

Analysis of errors shows that in order to apply mathematical statistics for evaluation of the dimensional quality of production, more than 50 samples should be taken.

The production process causes negative or positive deviations from the theoretical dimensions. The range of deviations depends of the quality of production, the rigidity of moulds and the conditions prevailing in the producing plant. For a normal distribution, covering 99.73% of the production, an interval of 6σ has been taken for the range of deviations, but this range is too wide to take it as an appropriate tolerance in production and mounting, so that factors such as accuracy of assembly, etc., must be taken into account.

As building components are usually not easy to handle or to be trued up easily, incorrect dimensions inevitably cause loss of time and money. It is, however, possible to predict the dimensional deviation or specific tolerance by analysis of the production moulds.

The total tolerance T of the dimensions of the components made in one mould may be calculated, in accordance with Fig. 1, from the equation

$$T = T_f + T_k \tag{1}$$

where T_f is the tolerance of the mould and

T_k is the tolerance of component dimension for various positions of the mould.

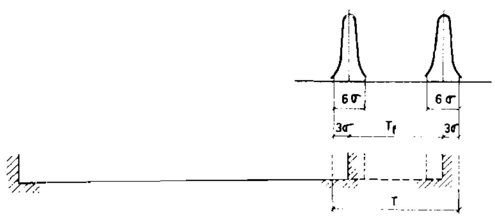

Fig. 1. Tolerance of components from a mould having a tolerance of dimension.

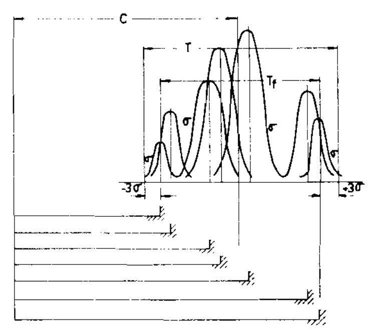

Fig. 2. The distribution of the dimensions of components manufactured in a mould with a changeable dimension within the limit T_f.

Above we assumed that an interval of 6σ covers the entire production. Then the tolerance of the mould can be calculated from the equation

$$T_f = T - T_k = T - 6\sigma \tag{2}$$

where σ is the standard deviation of the studied distribution for a given mould.

If many moulds are used, T can be calculated from the equation

$$\sigma^2 = \sigma_f^2 + \sigma_k^2$$

where σ = standard deviation of the entire collection of components;
σ_f = standard deviation of the moulds;
σ_k = standard deviation of dimensions of components made in one mould.

As $\sigma_f = \sqrt{\sigma^2 - \sigma_k^2}$, T_f can be found from the formula

$$T_f = \sqrt{T^2 - T_k^2} \tag{3}$$

Upon closer observation in the case of pouring concrete, it was found that the dimensional deviations depend on both the position of the mould and on the magnitude of the dimensions. It proved possible to determine the curve of tolerance for various dimensions and various ways of production.

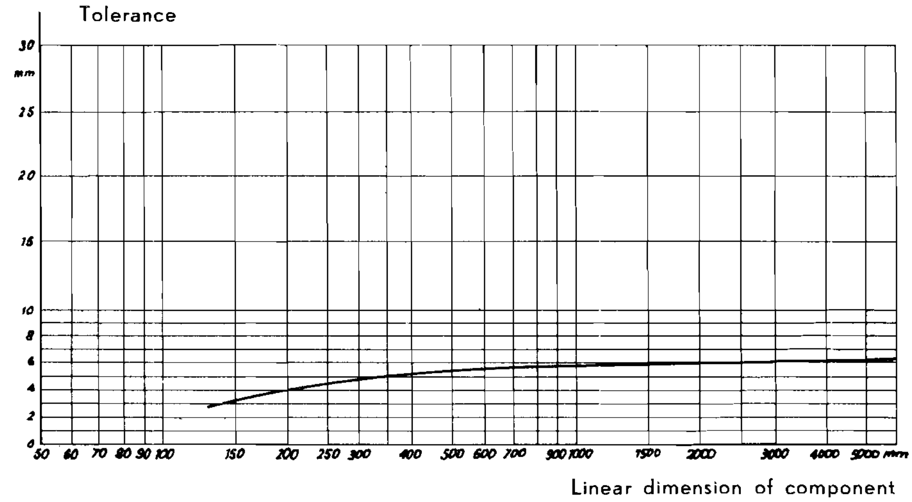

Fig. 3. Curve of the tolerance of dimensions of prefabricated components made in concrete and steel moulds

On the basis of many studies and with a view to the specific conditions of building, six classes of accuracy are proposed for concrete and reinforced concrete components:

Class	*Tolerance of dimension in mm*
1	$T_1 \leq 5$
2	$5 < T_2 \leq 10$
3	$10 < T_3 \leq 15$
4	$15 < T_4 \leq 20$
5	$20 < T_5 \leq 25$
6	$T_6 > 25$

Components of other materials, such as timber, plastics or materials produced in sheets or rolls, may have a different classification, dependent on method of production, accuracy of moulds, etc.

To check whether the dimensions are within the tolerances, gauges should be used as in the engineering industry. Obviously, classes of precision covering the entire range of building materials must be established in order to set up a classification of fits.

The errors made in installing a component result from displacing and twisting a component in its relation to a system of three rectangular coordination axes. Thus there are 6 degrees of freedom for the positioning.

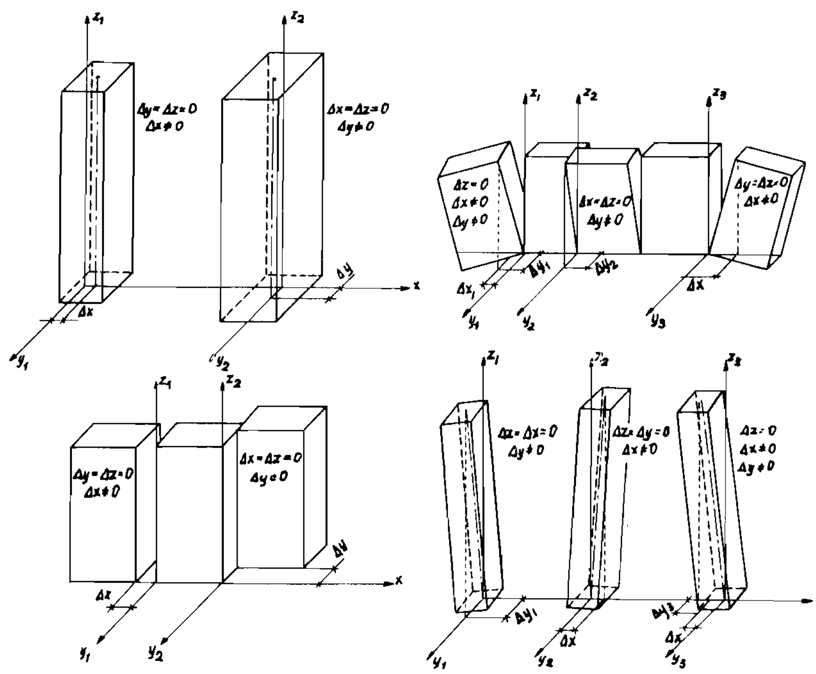

Fig. 4. Displacement and inclination of wall components and isolated components.

The displacement and inclinations of vertical components (Fig. 4) were dealt with by treating the observed errors as independent variables. We can determine the standard deviation and the total deviation equal to 6σ, along the x-axis or y-axis or from the origin of the reference system.

Thus the standard deviation along the x-axis for n deviations is

$$\sigma_x = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\Delta x^2} \tag{4}$$

or along the y-axis

$$\sigma_y = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\Delta y^2} \tag{5}$$

and for the origin

$$\sigma = \sqrt{\sigma_x^2 + \sigma_y^2} \tag{6}$$

where n = number of measurements.

Errors in positioning due to conditions and methods of mounting may either be compounded or eliminate each other. They may also be compounded geometrically. Three cases of positioning errors being compounded are illustrated in Fig. 5.

By investigation of the summation of errors from the point of view of probability, the standard error of positioning, limited in this case to four errors, can be found from the formula

$$\sigma_x = \sqrt{\sigma_{1x}^2 + \sigma_{2x}^2 + \sigma_{3x}^2 + \sigma_{4x}^2} \tag{7}$$

along the x-axis.

Analogically we can determine the standard deviation for the y-axis, but the standard deviation of the position proper of the component can be found from the formula

$$\sigma = \sqrt{\sigma_x^2 + \sigma_y^2} \tag{8}$$

The number of errors depends on the number of operations involved in the positioning. The positioning tolerance is determined in relation to the design requirements and the measuring instruments to be used. To establish the fit the tolerance of various components, sites and conditions of assembly must be determined.

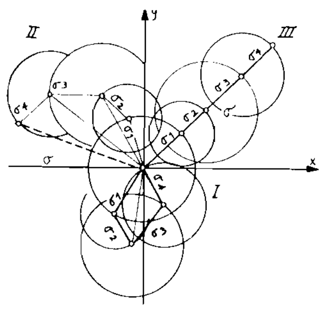

Fig. 5. Cases of geometrical addition of errors made during assembly of components.

TOLERANCES OF FITTING AND SYSTEM OF FITS

Different building components together form structural units. Assembling components with dimensional tolerances involves the question of fits. Building components are assembled as follows:

(a) by mortar;
(b) by fillers – granular, roll or plate materials – evening out the surfaces, but not joining the components;
(c) by fasteners – bolts, pins, etc. – without mortar;
(d) without mortar, fillers or fasteners.

Each method requires a different accuracy in the production of components, and hence different tolerances.

In establishing the number and limits of classes of accuracy one can best start from analysis of the distribution curve in order to find what proportion of the production can be regarded as faulty, assuming a tolerance that is acceptable for the construction. The class of accuracy gives a starting point for the producer and the technology he must apply. The average classes of accuracy applied in practice comprise the basis for the system of fits.

The components being placed one after the other, their dimensional deviations are compounded and the resulting overall dimension is the sum of real component dimensions. The producer, who does not sort out products according to sign of deviation, cannot supply batches of products whose deviations eliminate each other. Such compensation could take place by chance only if there were such chance errors that would not cause a shift in the mean dimensions with a view to the theoretical dimensions.

If $x_1, x_2 \ldots x_n$ are independent chance variables of standard deviations $\sigma_1, \sigma_2 \ldots \sigma_n$, then the deviation σ of the chance variable, which comprises the sum of $x_1 + x_2 \ldots + x_n$, can be computed from the formula

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 \ldots + \sigma_n^2 \tag{9}$$

Assuming $T = 6\sigma$ we can write an equation for the resulting tolerance

$$T_w^2 = T_1^2 + T_2^2 \ldots + T_n^2$$

or

$$T_w = \sqrt{\sum_{i=1}^{n} T_i^2} \tag{10}$$

The probability treatment of this question does not exclude the possibility that T_w, as defined in formula (10), may be exceeded in practice, but then with a probability of less than 1 %.

Suppose we analyse the parameters of the curve of distribution of fits, *i.e.* the mean value of the allowance D_L and the standard deviation σ_L. Let us assume that in an interval of constant dimension two components, coming from two groups of components of length x_1 and x_2, must be fitted (Fig. 6). The mean values of these groups are D_1 and D_2. If the chance variables x are independent, then the mean value of the allowance is

$$D_L = x - (D_1 + D_2) \tag{11}$$

and the deviation of the mean allowance is

$$\sigma_L = \sqrt{\sigma_1^2 + \sigma_2^2} \tag{12}$$

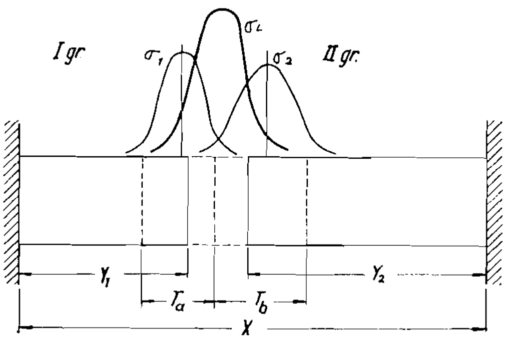

Fig. 6. Scheme of the system of fits in a constant interval of two groups of components with defined distribution of length dimensions.

The foregoing formulae are based on the theorem of compounding independent chance variables. We can generalise the above case: In an interval of width Y_i we must fit n components of width Y_i, where i is 1, 2, 3 ... n. The chance variables X and Y_i are independent. Their mean values are denoted by D_p and d_i and the standard deviations by σ_p and σ_i. The allowance has a distribution whose mean value is calculated from the equation

$$D_L = D_P - \sum_{i=1}^{n} d_i \tag{13}$$

and the standard deviation is calculated from the equation

$$\sigma_L = \sqrt{\sigma_p^2 + \sum_{i=1}^{n} \sigma_1^2} \tag{14}$$

In the case of an accurate hole ($\sigma_p = 0$) formula (14) assumes the form

$$\sigma_L = \sqrt{\sum_{i=1}^{n} \sigma_1^2} \tag{15}$$

Once we have the standard deviation we can find the distribution of allowances and establish the appropriate tolerance of fit. The distribution of allowances, as in formulae (13)–(15), is often useful for assembly of components.

Sometimes the thickness of the joint is taken into account, in other cases the gap allowing assembly by crane. Formulae (13)–(15) only serve to evaluate the allowance in fitting, without taking into account positioning measurement errors, as described under the section entitled "Assembly tolerances".

In view of dimensional tolerances, resulting positioning errors and jointing conditions, there should be some allowance L in assembly. Knowing the value of the component parts of L, we can determine its total value for the chance assembly of components.

Fig. 7 gives a sketch of a unit of two prefabricated columns and a beam with certain tolerances and placed in space with certain errors.

We denote: b = width of column;

T_b = tolerance of dimension b;

l = length of beam;

T_l = tolerance of dimension l;

C = theoretical distance between axes; and

T_w = total positioning tolerance for first or second column.

Let L consist of thickness of joint filled with mortar, width of clearance necessary for assembly and tolerances due to deviation of component dimensions and assembly. The maximum and minimum values of the allowances are then found from

$$L = (C - l - b) \pm \sqrt{T_w^2 + \left(\frac{T_b}{2}\right)^2 + \left(\frac{T_l}{2}\right)^2} \geqslant 0 \qquad (16)$$

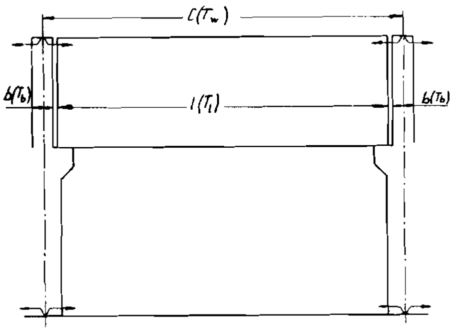

Fig. 7. Fitting a beam between two columns.

The value of the allowance for any other case can be found by analogy.

The fluctuation of allowances at the joints is within the limits of minimum and maximum values and is defined by the formula for tolerance of fit

$$T_L = L_{\max} - L_{\min}$$

By substitution of the values of formula (16), we obtain the value of tolerances of fit, depending on dimensional and assembly tolerances

$$T_L = 2\sqrt{T_w^2 + \left(\frac{T_b}{2}\right)^2 + \left(\frac{T_l}{2}\right)^2} \qquad (17)$$

From this formula it appears that the tolerance of fit is equal to the resultant of dimensional and assembly tolerances for the given joint.

The fits used in building can be discerned in three classes:

A: contact fit

B: loose fit

C: very loose fit with filler

Errors in measurement of position during assembly influence the fitting. Their values must, therefore, be taken into account when establishing the value of the allowance in the classes of fit.

CLASS A FIT

Fig. 8 shows a type of fit of two groups of components I and II. We assume that the boundary case of fit consists of the contact of components of dimensions with tolerances in the expected place. This assumption, without any detriment to the assembled structures, ensures the fitting of all components of groups I and II. Because of the tolerance of the components marked by shaded area, there is a gap that depends on the values of T_1 and T_2. It is proposed that in the contact class of fit the allowance should satisfy the following conditions

$$0 \leqslant L_A \leqslant 2\ \text{mm} \tag{18}$$

This formula expresses the condition for the appropriate selection of the class of accuracy of production of the component and limits the value of the resultant error made in positioning the component in space.

If we take into account only the tolerance of dimension, while ignoring the errors of assembly, the greatest value of the allowance L_A does not exceed the sum of the tolerances for the first and second groups of components

$$L_A \leqslant T_1 + T_2 \tag{19}$$

On the other hand, if the tolerances of dimensions and errors of assembly are taken into account, we get the equation

$$L_A \leqslant T_1 + T_2 + T_{w1} + T_{w2} \tag{20}$$

The condition resulting from formula (20) creates very stringent requirements of accuracy in the production of components and assembly of the structure. Contact fits, therefore, cannot be employed in ordinary assembly construction. They are used, however, in the joining of components of prestressed concrete structures.

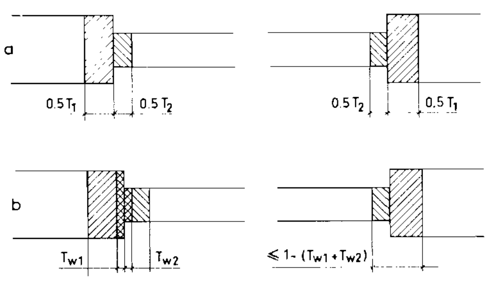

Fig. 8. Contact fit A (see text) for two groups of equipments of dimensions with tolerances: (a), without and (b) with assembly tolerances.

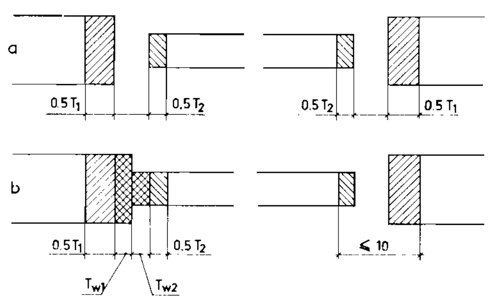

Fig. 9. Loose fit B (see text) for two groups of components of dimensions with tolerances: (a) without and (b) with assembly tolerances.

CLASS B FIT

A loose fit is the joining of two components in a manner that ensures a given allowance between them (Fig. 9) with the following condition being satisfied

$$2 < L_B \leqslant 20\ \text{mm} \tag{21}$$

Allowance L_B in the case of loose fit consists of the tolerance of the dimensions of the components of groups I and II and the resultant tolerance T_w from the positioning of the components. We therefore have

$$2 < L_B \quad T_1 + T_2 + T_{w1} + T_{w2} \leqslant 20\ \text{mm} \tag{22}$$

For a loose fit we assume, in addition, that the least value of the allowance $L_{B\min}$, taking into account the maximum tolerances of dimensions of the components, should be greater than or at least equal to the sum of the resultant tolerances for the position of the components of groups I and II. This means that

$$T_{w1} + T_{w2} \leqslant 2\ \text{mm}$$

whence

$$T_1 + T_2 \leqslant 18\ \text{mm}$$

These assumptions call for great accuracy of production of the components and accurate measurements during assembly.

These requirements are justified since greater allowances cannot be permitted for considerations of the safety of the structure as the components are joined without mortar or any other filler in the gap. The lower limit for the allowance – 2 mm – results from the necessity of having some leaway during assembly of the components. Practice shows that the accepted allowance makes possible free movement of the structure due to changes in temperature.

Loose fit is often used in structures assembled without mortar. This class of fit, given the assumptions mentioned above, also ensures perfect fitting of all components.

CLASS C FIT

This is a very loose fit in which the joint is filled and it has only a lower limit for the allowance as no upper limit is necessary in view of the fact that all sorts of fillers are used in the gaps between the components (Fig. 10).

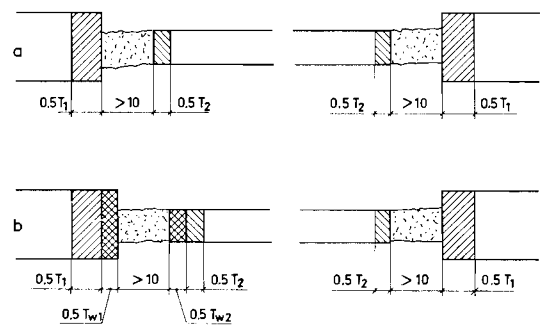

Fig. 10. Very loose fit filled with plaster for two groups of components of dimensions with tolerances: (a) without and (b) with assembly tolerances.

The very loose fit, therefore, satisfies only the inequality

$$L_C > 20 \text{ mm} \tag{23}$$

As in the case of the loose fit class, the allowance L_C is the sum of the tolerances T_1 and T_2 of both groups of components being joined and the tolerances set for the assembly T_{w1} and T_{w2}.

TABLE I

COMBINATION OF CLASSES OF ACCURACY OF PRODUCTION AND CLASSES OF FIT FOR CONCRETE COMPONENTS

Class of fit	*Class of accuracy of production of components*					
	1	*2*	*3*	*4*	*5*	*6*
A – contact fit	A1					
B – loose fit	B1	B2	B3			
C – very loose fit			C3	C4	C5	C6

TABLE II

VALUES OF ALLOWANCES AND TOLERANCES OF FIT FOR COMBINATIONS OF CLASSES OF FIT AND CLASSES OF ACCURACY OF PRODUCTION, NEGLECTING ERRORS OF MEASUREMENTS IN ASSEMBLY

Conditions	*Combinations of classes of fit and classes of accuracy of production*							
	A1	*B1*	*B2*	*B3*	*C3*	*C4*	*C5*	*C6*
Limits for allowance in class of fit	$0 \leqslant L_A \leqslant 2$	$2 < L_B \leqslant 20$	$2 < L_B \leqslant 20$	$2 < L_B \leqslant 20$	$L_C > 20$	$L_C > 20$	$L_C > 20$	$L_C > 20$
Limits for tolerance of production of component	$T \leqslant 5$	$5 < T \leqslant 10$	$10 < T \leqslant 15$	$10 < T \leqslant 15$	$10 < T \leqslant 15$	$15 < T \leqslant 20$	$20 < T \leqslant 25$	$T > 25$
	Values of allowances of tolerances of fit in joints							
Minimum allowance L_{min}	0	2	2	2	20	20	20	20
Maximum allowance L_{max}	2	20	20	20	30	40	50	50
Tolerance of fit T_L	2	18	18	18	10	20	30	30

Discussion

Apart from some more theoretical remarks full weight is given in the discussion to the aspects of the practice of building and its predominant role in any theory.

The progress made in practical application of tolerances in Sweden is reported by Mr. I. Nyquist (Sweden), who gives a comprehensive picture of the tolerances applied (Table I).

TABLE I

Item	*Tolerance in mm*		
	coarse	*mean*	*fine*
Concrete elements:			
Horizontal moulds of			
wood	±10	7	5
concrete	10	5	3
steel	7	4	2
1 m wide vertical moulds	7	5	4
Light concrete elements	4	3	2
Wooden elements	4	2	1
Room sizes	25	15	±10

Other aspects of practice, especially in small contractors' firms, are brought forward by Mr. Ph. Mouterde (France). In usual practice all main and detail dimensions for all kinds of operations are provided in one and the same drawing. It would seem to be preferable to present these separately in different drawings.

Apart from this it should be realized that not all cases of conventional construction have the same requirements of accuracy of dimensions and hence the tolerances should be adapted to the various individual cases. For example, with the use of concrete elements a relatively large tolerance would be perfectly acceptable as long as this can be accepted in the joints, the dimensions of which usually have a substantial flexibility.

In all cases where new methods of dimensioning and new apparatus are to be introduced, not only the nature of the project under consideration but also possible psychological resistances of the operatives should be taken into account. The introduction of a special "measurement controller" on the site seems desirable. Usually the most accurate method of dimensioning, not the most rapid, is asked for in each individual case.

Mr. A. Gigou (France), who also refers to terminology problems with regard to the subject matter, concludes that several methods of dimensioning may be applicable in a certain case, but economic considerations must be decisive in the choice between them.

Mr. E. Levin (United Kingdom) has the view that there is no absolute need for specific accuracy of measurements in traditional building, but there is with prefabrication. The nature of the building project and the construction method to be used are the main points to be taken into account when the question of accuracy of dimensions is dealt with.

Mr. W. Prey (the Netherlands) asks the rapporteur Mr. Noiré what savings were experienced with the method used for the "Le Konacker" site in France referred to in the Congress report.

Mr. J. Noiré firstly indicates the time-saving resulting from the use of main axes, which made it possible to avoid working from the four corners of the building. Also the use of the heavy plumb line resulted in speeding up the process.

As tolerances depend on the method of dimensioning used, the latter is highly important, though never an objective in itself. In the case in question it reduced errors.

Speaking about the use of double glazing, Mr. J. HONNOREZ (Belgium) warns against taking measurements of windows before erection. Even if manufacturers guarantee the dimensions of openings and their tolerances, this should not be done.

Double glazing cannot be trued up and one should bear in mind that even folding rules are not identical.

In a general comment on the Congress reports Mr. W. A. ALLEN (United Kingdom) makes the following statement:

The papers suggest that accuracy always leads towards economy, and little mention is made of the limits of accuracy which may, in practice, be economic. Several factors, of which a few are listed here, have a limiting influence.

Moisture movements of timber, especially when used in wet construction.

Distortion which occurs when wet construction dries out, *e.g.* brickwork subjected to different drying conditions between one side and the other.

Buildings settle a little during construction as the load increases.

Beams deflect a little when loads come on them.

Small errors in primary, secondary or tertiary load-bearing elements, *e.g.* in floor systems, may cancel each other out or add up to large errors.

It is technically difficult to pull and adjust a steel framework to be accurate in each part; average accuracy is all that can usually be hoped for.

There is a limit to the time which it is economic to devote to accuracy at one stage of building in order to save time in making adjustments at another.

It would be valuable at present to make operational studies on the site of the accuracy actually achieved and the causes of errors and to assess the implications of these for cost. A flow of publications in this field would build up a much more accurate picture of this problem than we have at present.

Ultimately, one of the major problems is to give the designer the economic parameters of design in terms of accuracy. Architects working to reduce cost have to design in ways which do not make demands for uneconomic accuracy.

Merely to demand more accuracy may increase rather than diminish costs.

In summarizing the different views, the Chairman (Prof. CIRIBINI), adopting the suggestion that was made for a CIB study group on the subject matter, emphasizes the necessity of close cooperation with practice.

It might be necessary, as a very first step, to start collecting data on the existing accuracy with the use of various materials and construction methods, in order to arrive at a realistic practical starting point for further work.

Subject 4

RESEARCH PROBLEMS CONCERNING LARGE CONCRETE ELEMENTS IN HOUSING

UDC 691.327/.328

MAIN REPORTS

G. F. KUZNETSOV
Academy of Building and Architecture (U.S.S.R.)

M. JACOBSSON
Director, "Statens Råd för Byggnadsforskning" (Sweden)

G. BONNOME
Inspector General at the Ministry of Construction (France)

ADDITIONAL REPORTS

V. A. GASTEV, P. P. SHAGIN AND D. P. PITLUYK
Academy of Building and Architecture (U.S.S.R.)

K. I. BASHLAY
Academy of Building and Architecture (U.S.S.R.)

N. V. MOROZOV AND F. V. USHKOV
Academy of Building and Architecture (U.S.S.R.)

Major scientific problems in the construction of prefabricated building of large-sized elements

UDC 691 327/.328(47)

G. F. KUZNETSOV

Academy of Building and Architecture (U.S.S.R.)

This paper is part of a general report on experience gained in dwelling construction with large elements in the U.S.S.R. and other Eastern European socialist countries: Bulgaria, Hungary, German Democratic Republic, Rumania and Czechoslovakia. Northern European and French experiences are, respectively, dealt with in reports by Dr. Jacobsson and Mr. Bonnome.

To set ourselves limits we deal with dwellings and leave industrial, agricultural and other buildings in abeyance.

INTRODUCTION

After the war mass production of dwellings increased in all Eastern European socialist countries. Compared with the seven preceding years, in 1959–1965 the production volume in the U.S.S.R. must increase 2.3 times. In townships alone 15 million flats must be built.

Czechoslovakia aims at 100,000 flats a year, as does the German Democratic Republic. In 1956–1960 Poland constructed 400,000 flats. Increase in volume is foreseen in Hungary, Bulgaria and Rumania.

All this imperatively demands development of factory production of elements, replacing monolithic concrete and small elements handled manually. The latter only remain where transport or economic reasons hamper development.

Large element dwellings can be classified in three groups:

(a) With walls of hand-laid bricks, concrete or natural stone, floors, partitions, staircases, etc., being erected by crane as large elements.

(b) With walls of concrete or brick "blocks" of up to 6 m^2 and 3 tons and with other large elements.

(c) With walls, partitions, floors, flights, etc., as finished "panels" of room size of up to 20–25 m^2 and 5 tons.

In terms of Prof. Mazure's report on the subject, group (a) indicates the "semi-fabricated" and (b) and (c) the "fully-fabricated" method. In towns and workers' settlements the first method is still predominant. So far the second, the "large block" houses, and the third, the "large panel" houses, represent only a small part.

The reason is the abundant availability of brick and stone producing plants. Increasing application of large elements and of new construction methods changes this situation, but techniques involving both large panels and brickwork, although economic, require a large labour force on site and make poor use of the plant.

To eliminate manual operations and to introduce factory prefabrication, mechanized production of large brick blocks has been applied in the U.S.S.R. and elsewhere since 1952, the effect being higher productivity and lower costs. The method is becoming increasingly popular and in Kiev, for example 53% of all dwellings were built in this way in 1958 and in 1959 the percentage was even higher. Large brick panels were used in 1959 in Moscow, Leningrad, Minsk, Kuibyshev, etc. (Fig. 1). Both large panels and blocks permit the same "fully fabricated" production as construction in concrete.

The volume of large panels and blocks has grown rapidly. For example, in the German Democratic Republic some 20,000 flats were built in this way in 1957 and over the next few years 62.5 % of all dwellings will be built with large blocks. In Czechoslovakia in 1960, 50 % of the total programme is carried out with these methods. In the U.S.S.R. extensive facilities are being set up to allow application of these methods for a major part of the programme of the coming 5 to 7 years.

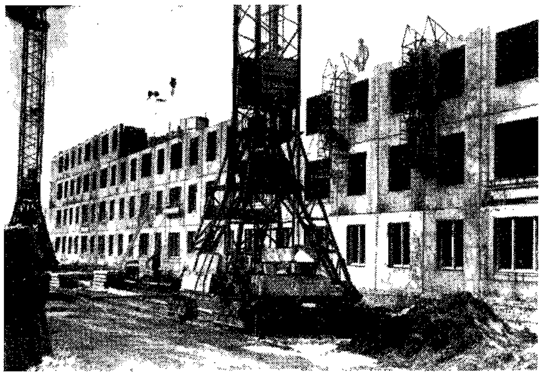

Fig. 1. Erection of dwellings with brick panels.

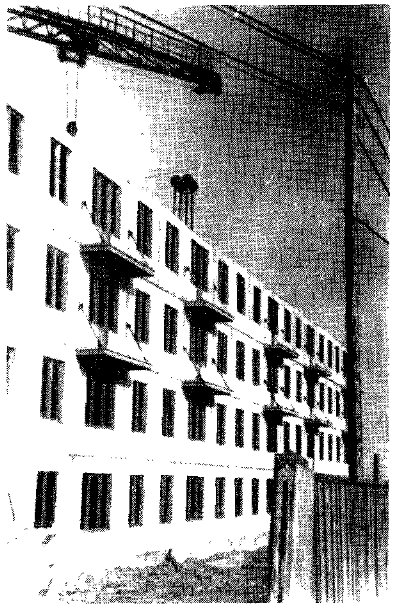

Fig. 2. Erection of dwellings with reinforced concrete panels.

These methods reduce labour and overall costs and promote better quality. For large block houses labour costs are 50–55 % and for large panel houses 30–35 % of normal labour costs, and total labour costs – on site and in factory – are 1.5–2 times less, the labour costs in the factory being dependent on the degree of mechanization. Also the total costs are less, though with smaller difference than for labour costs. With today's technology and level of mechanization large block houses are 4–5 % and large panel houses 8–10 % cheaper than normal brick houses and there are cases where large panel houses are 20 % cheaper.

Hitherto large blocks were applied more widely than large panels, because the latter require more complicated technological equipment, more powerful transport and mounting equipment and more advanced techniques. However, the large panel method is more efficient. It requires less material and labour and permits cheaper and faster erection (Fig. 2).

Economic estimates indicate that the capital investment for establishing "house factories" and large panel plants is reimbursed in 18 months or 2 years as the difference in cost of floor space compared with conventional building. The large panel method reduces the construction time and speeds up the operations. Hence this method is given special attention in the U.S.S.R. and other socialist countries.

On April 2, 1959, the Soviet Government decided to build large panel houses in 1959–1964 with a total floor space of 73 million m^2 and to raise the relevant factory capacity to 28.2 million m^2 of floor space in 1964. In Czechoslovakia at least 13 % of the programme in 1960 will be with large panels and similar increases are foreseen elsewhere.

The large-scale change towards large panels is a major national economic task in which science has been assigned a predominant role.

In the U.S.S.R. the large block method has been used since 1928 and after the war it has been developed in all Eastern European countries.

The large panel method made its entry at the end of the war. The Academies for Building and Architecture of the U.S.S.R. and of the Ukrainian Republic, the Building Academy of the German Democratic Republic and research institutes of Czechoslovakia, Hungary, Poland and Bulgaria conducted extensive research that led to the definition of theoretical principles of design of houses of the relevant types and to the development of factory production technology and it was helpful in the elaboration of some new systems of design together with industrial bodies, and in introducing these into practice.

Developments are based on the use of various kinds of concrete, with local materials as fillers, which do not require long hauls and the use of which is just as economically important as with conventional methods. This aspect is prominent in all research.

Proper selection of materials from local resources and of a design that fully uses the properties of the materials considerably influences low costs and are hence a major subject of research.

Design variants used in practice for mass housing of 3–8 storeys are shortly reviewed below.

Fig. 3 shows a variant of houses with brick walls or large slag concrete and brick block walls, generally at least 40 cm thick and hence with great bearing capacity. In this case the floors, mostly of long-sized planks, rest directly on the outer and inner walls; partitions are of gypsum, gypsum concrete panels or other materials. Owing to its simplicity this variant is widely applied in the U.S.S.R. and elsewhere.

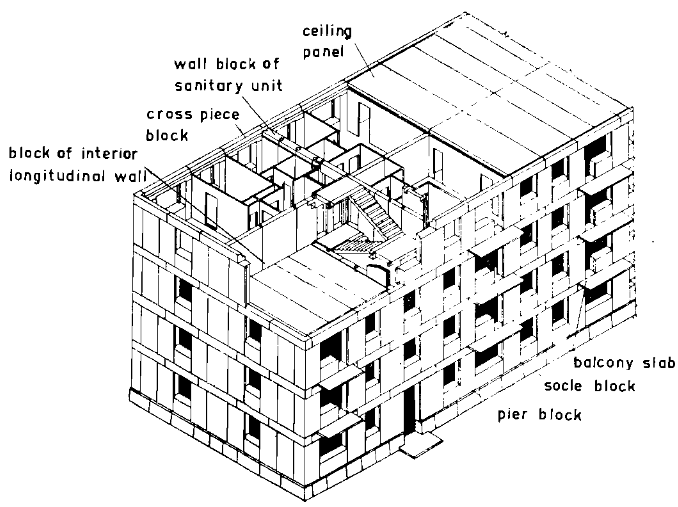

Fig. 3. Design variant of a large-block building "with three longitudinal bearing walls".

The variant "with three longitudinal bearing walls" is, however, confined to buildings with massive, sufficiently thick walls. With light walls, *e.g.* of large blocks of cellular concrete or with panel walls, the variant results in an increased dead load and a waste of material.

In large panel buildings the variants of Fig. 4 were used. The variant of Fig. 4a is more generally used; it is called the variant "with bearing transverse partition". Here the room-size floor panel rests on the partition and wall panels. Panels are coupled by welded steel plates bedded in the concrete or by concreting around projecting reinforcement. After concreting, this house becomes a spatially rigid structure of closed boxes (rooms). These were first built in the U.S.S.R. in Magnitogorsk in 1949–1950, and elsewhere later.

The variant of Fig. 4a is possible with panels of ordinary heavy concrete, light concrete and cellular concrete and also with brick panels.

The variant of Fig. 4b, called "with partial frame", is widely used with large panel construction of ordinary heavy concrete. Here the reinforced floor panels rest at the corners (at four points) directly on the outer wall panels and on the columns inside the building (without intermediate collar beams). Partitions between rooms and between flats are made of gypsum, gypsum concrete or other light panels.

This variant provides some reduction of reinforced concrete consumption – as compared with the variant of Fig. 2a – due to substitution by gypsum or other materials in non-bearing partitions. The total concrete consumption (including gypsum concrete) is about equal in both variants; the steel consumption is slightly greater in the variant with the framework.

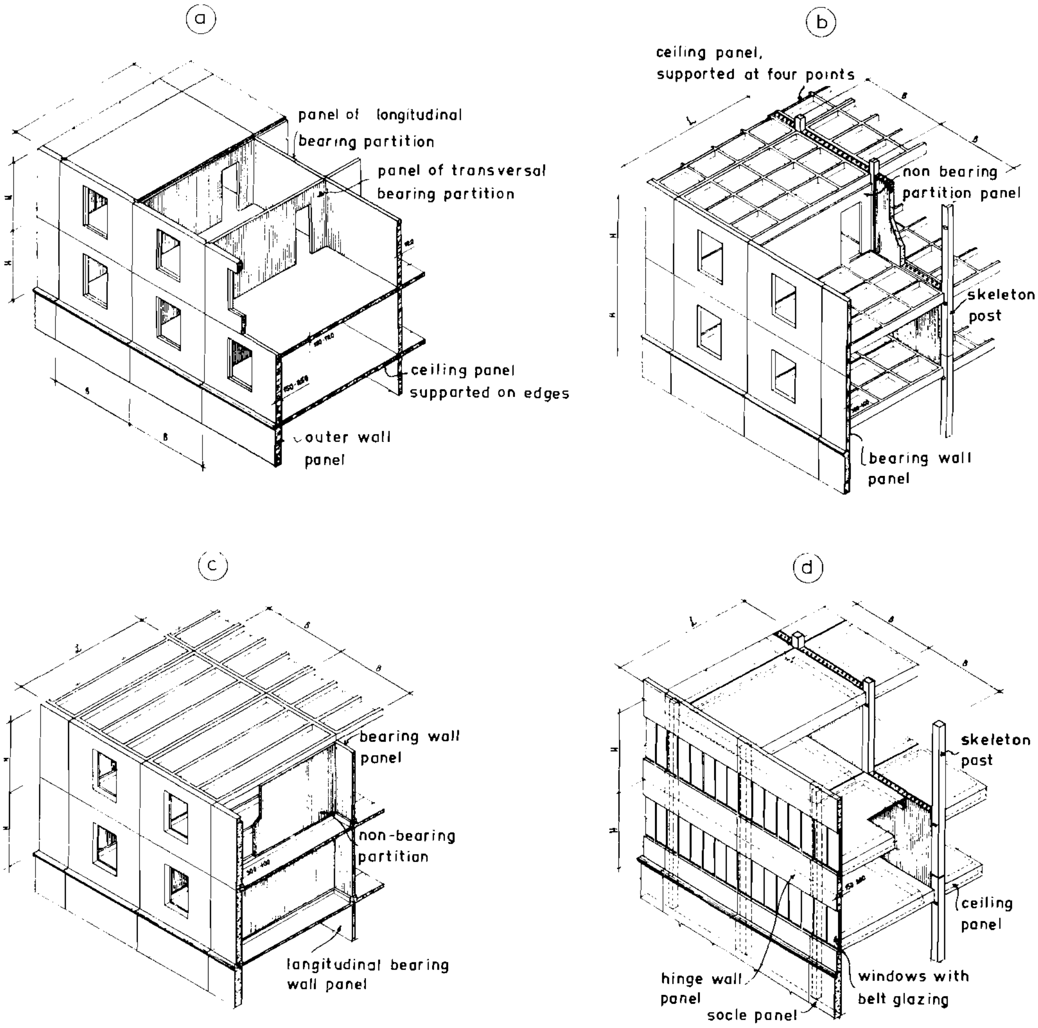

Fig. 4. Design variants of large-panel buildings. (a) With transverse bearing partitions, (b) with a partial frame, (c) with three longitudinal walls, (d) with a complete frame.

The variant of Fig. 4b (with partial frame) is, therefore, only recommendable in areas where gypsum or other cheap materials for partitions are available.

The variant of Fig. 4d, "with a complete framework", was adopted initially in large-panel housing development in the U.S.S.R. and elsewhere in buildings from 4 to 10 storeys in Moscow, Kiev, etc.

Experience has shown that with currently used materials for walls and partitions, framework panel houses involve greater costs than non-framework houses. The variant "with a complete framework" is, however, of considerable interest in view of increased application of plastics, aluminium, etc., for exceptionally light walls, partitions, etc.

Table I gives technical and economic data on large panel buildings of the different variants. These data are helpful to appraise the different levels of costs of materials.

TABLE I

COMPARATIVE TECHNICAL AND ECONOMIC CHARACTERISTICS FOR BRICK, LARGE-BLOCK AND LARGE-PANEL HOUSES (BUILT 1957–1958)

(Figures per square metre of habitable surface)

				Large-panel houses		
	Units	*Brick houses*	*Large block houses*	*With 3 longitudinal bearing light-weight walls*	*With transverse bearing reinforced concrete partitions*	*With partial framework*
Weight of construction	kg	3000	2770	2090	1590	1330
Amount of essential materials used:						
(a) bricks	pieces	330	—	—	—	—
(b) concrete (all kinds)	m^3	0.42	1.22	0.80	0.55	0.60
(c) cement	kg	152	320	280	155	151
(d) gypsum	kg	50	60	50	—	75
(e) steel [1]	kg	33.5	34.4	40	20.2	22.0
Use of labour on building site	per day	6.90	3.93	3.85	2.27	2.5

[1] Amount of steel for normal (not prestressed) reinforcement.

Prospects of further development tend to embrace: further reduction of weight and of costs of materials; higher degree of prefabrication; greater reliability and better functional qualities. Each of these is briefly dealt with below.

REDUCTION OF WEIGHT AND OF COSTS OF MATERIALS

The problem of reducing weight and costs of materials is common to most, if not all, industries; industrial construction methods made it even more significant than it was with conventional construction methods. As is known, costs of materials and components comprise about two thirds of the total cost of a house. Reduced costs of materials due to reduced weight is consequently one of the main reserve possibilities in cutting construction costs. Reduced weight also leads to cutting costs in transport, both internally in the factory and from factory to site. Hence reduction of weight has been given full attention in the U.S.S.R. and elsewhere and certain results have been achieved.

In the recent past a conventional brick wall and large element building weighed 3–3.5 tons/m^2 of floor space [2] and a brick panel weighed 1.5–1.6 tons/m^2.

Large panel houses built in 1950–1955 weighed about 2 tons/m^2. In 1958 this weight was reduced to 1.2–1.5 tons/m^2. As is known, brick walls of 2 and 2.5 bricks thickness weigh 900–1100 kg/m^2 of wall. Brick panels of 1959 weigh 350–500 kg/m^2 and large panel (reinforced) concrete walls weigh 200–300 kg/m^2. The widely used cavity and solid reinforced concrete floor slabs weigh 300–350 kg/m^2; since 1959 floor slabs (cellular and of a split type), weighing 150–200 kg/m^2, which provide the required sound insulation, have been applied.

[2] In the U.S.S.R. 1.5 m^2 of useful floor space corresponds to 1 m^2 of living space.

As a result of research and investigations in construction physics, new designs, reducing the weight and the costs of the required basic materials by half, have been developed and introduced in practice in a relatively short time.

Nevertheless, these problems remain pertinent, especially for cement and steel, and scientific analysis has shown that considerable reserves for cutting down weight and costs and consumption of materials still exist.

Even for ordinary heavy concrete the possibilities of rational design, proper selection of strength of material, modern methods of reinforcement and prestressed reinforcement, elimination of superfluous concrete, etc., have not been exhausted. For example, by preserving the variant of Fig. 2a, but making the panels void, it is possible to cut the consumption of concrete by 40% and of cement and steel by 30–35%, and the weight of the building to 1000 kg/m^2 instead of 1500 kg/m^2 with solid panels.

In the variant of Fig. 1 the use of prestressed reinforcement reduces steel consumption by 50%. The application of vibration of concrete, etc., allows a great reduction in cement consumption.

Particularly big prospects for cutting cement and steel consumption and reducing the building's total weight lie in the use of light concrete with porous fillers and cellular concrete for large panel houses. Here the cement and steel consumption is about 1.5 times less and the weight about 50% less than with ordinary heavy concrete.

Light concrete has, in the U.S.S.R. and elsewhere, primarily been used for outer wall blocks and panels. Cellular concrete has so far been applied widely to large block buildings and its use for large panel buildings started in 1958 but has not been extensive as yet. Improved heat insulation and greater strength, together with reduced volumetric weight, will, in this case, make its use still more advantageous.

Material consumption and the weight of the building largely depend on the chosen design variant. Despite extensive investigation the task of selection of an appropriate variant has not yet been finally resolved.

The variant with bearing walls and partitions of Fig. 4a is appropriate, if ordinary heavy concrete, light and cellular concrete and brick concrete are used [1], when walls and partitions are at least 8 cm thick. As a rule floor slabs and bearing partitions are 8–14 cm thick in this variant.

When the building is constructed of fine grained concrete, permitting thin-walled elements, *i.e.* "shells", then the walls of shells made by the cassette method may be 4 cm thick and those made by rolling may even be 1.5–2 cm thick (Fig. 5).

In houses according to the usual variant with bearing walls and partitions (Fig. 2a), as in an experimental house built in 1959 in Kopytovka Street in Moscow, the shells, linked in pairs by welding, form the panels of walls, partitions and floors. To obtain the required heat

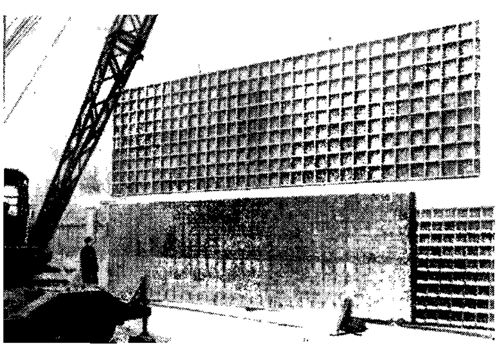

Fig. 5. Thin-walled shells fabricated by rolling.

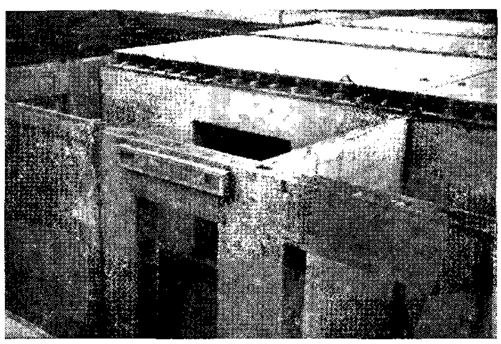

Fig. 6. Design of a large-panel house of thin-walled rolled shells.

[1] "Brick concrete" means vibrated brick masonry.

and sound insulation, wood fibre, mineral wool or other soft slabs are placed between the two shells. Fig. 6 shows a design of this type.

Apart from the great labour consumption in the production of two-leaf panels, another shortcoming is the small bearing capacity of the thin leaves under compression, due to longitudinal bending. Moreover, the joints between the panels are complicated.

The second variant of a thin-walled panel house is given in Fig. 7. Here we have a variant with bearing transverse partitions tending to bend like the web of a girder. This is the difference with the variant of Fig. 4a.

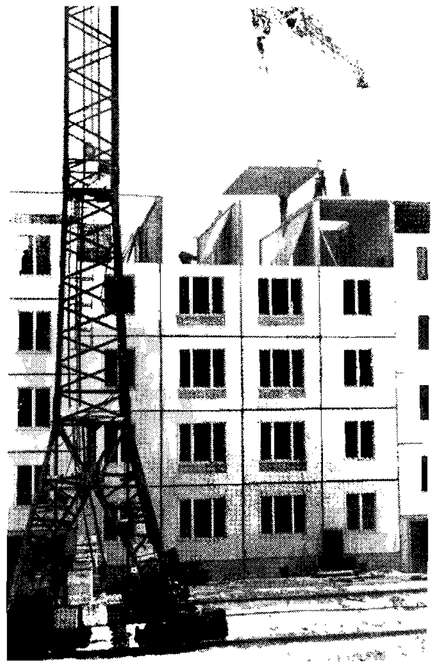

Fig. 7. Erection of a large-panel house with partition panels as diaphragm (tending to bend).

The panels rest on one another at the ends, at the points of the vertical framing ribs that take up the load of overlying floors. The horizontal framing ribs stiffen the panels and support the split-type floors: the floor panel rests on the lower rib and the ceiling panel on the upper. The wall panels are suspended, the longitudinal and non-bearing partition panels may be of gypsum concrete or other light materials.

An experimental house of this variant was built in 1958 in Block 14 of the southwestern district of Moscow and a number of them were built in 1959.

Table II gives technical and economic data on thin-walled panel houses as compared with ordinary concrete houses. It shows that the concrete consumption of these houses is about $1\frac{1}{2}$ times less in the case of the variant with bearing partitions, but the steel and cement consumption is much greater. Consequently, despite lower concrete consumption and smaller weight, these houses involve greater costs, and further investigations to improve the designs of fine-grained concrete houses and to find ways of reducing the cement consumption are required.

In our opinion the change from panels to spatial rigid "boxes" that form rooms is a promising trend for fine-grained concrete houses. The completely finished "boxes" are delivered from the "house factory" and mounted by crane. Modern factory production technology and up-to-date transport and mounting facilities permit a high stage of industrialization of factory production of entire units, such as finished rooms, hygienic

TABLE II

COMPARATIVE TECHNICAL AND ECONOMIC CHARACTERISTICS FOR NEW TYPES OF LARGE-PANEL HOUSES AND HOUSES MADE OF PREFABRICATED BLOCKS OF ONE ROOM (EXPERIMENTAL BUILDING 1958–1959)

(Figures per square metre of habitable surface)

	Units	*Large-panel houses*				
		With transverse bearing partitions without cavities (compact)	*With transverse bearing partitions of thin panels with oval cavities*	*Of thin rolled shells*	*With transverse bearing partitions taking bending moments*	*Houses made of prefabricated blocks of one room*
Weight of construction	kg	1590	900	1150	1150	1030
Amount of essential materials used:						
(a) concrete (all kinds)	m^3	0.550	0.300	0.390	0.350	0.330
(b) cement	kg	155	126	200	189	168
(c) gypsum	kg	—	—	25	—	—
(d) steel	kg	20.2	14.0	31.3	30.6	27.0
Use of labour on building site	per day	2.27	2.27	2.33	2.80	0.58

blocks, etc. This method is now being thoroughly tested; in 1959 experimental houses with finished block rooms were built in several towns.

HIGHER DEGREE OF PREFABRICATION

Another important task for science is the reduction of labour costs. The solution of this problem is closely related to the increase of prefabrication methods. With the change towards mechanized factory production, the index of prefabrication, defined as the ratio between labour costs not on the building site and total labour costs, has become of great importance. The closer the index is to unity, the greater the percentage of prefabrication.

Mechanized techniques are more efficient in the factory than on the site, where adverse conditions (weather, etc.) may prevail. Hence the economically correct tendency to transfer to the factory a maximum of operations, leaving for the site only the erection of finished components.

Those variants of factory-made buildings are preferable which, with equal total (factory + site) labour consumption, result in the lowest labour costs on the site. As is well known, the larger the element and the greater its possible prefabrication, the less the labour required on site.

In this respect large-panel structures are far better than large-block structures and block-room structures are better than large-panel ones.

The figures cited above, drawn from U.S.S.R. experience, support this thesis: labour consumption for large-block houses is about half, and for large-panel houses about one third of that of brick houses. Reduced labour costs on the site, together with the increased size of elements, result not only from a reduced number of mounting operations, but chiefly from the fact that large elements permit a transfer to the factory of most operations for finishing and erecting hygienic units. As is well known, these operations involve by far the highest labour costs with conventional methods.

In all Eastern European countries the tendency is, at a different pace, to replace small elements by large blocks and panels made in the factory, and to raise the percentage of factory labour investment.

Panels of room size become prevalent. They are delivered on the site with finished façade, inner surface, windows and doors, including glazing, painting, piping and heating appliances in the panel, etc. For room-size floor panels, the factory finishes both ceiling and floor (Fig. 8); the site shows only mounting and finishing of joints. This degree of factory completion cannot be achieved with floors of narrow planks or small elements.

To reduce labour costs at the site and to transfer the erection of hygienic units to the factory, so-called sanitary and ventilation panelshave become extensively used, and recently room components, *e.g.* bathrooms of reinforced concrete, gypsum concrete or asbestos cement, have been applied in the U.S.S.R. Delivery on site of complete rooms leaves only

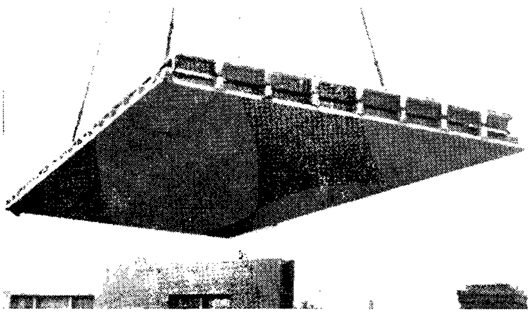

Fig. 8. Panel of an interfloor ceiling of the "split" type (consisting of two shells).

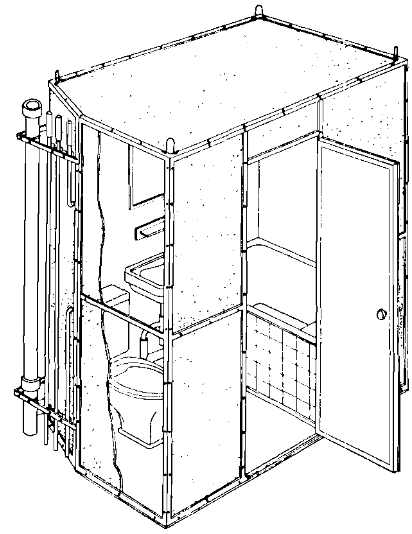

Fig. 9. Asbestos cement bathroom.

the connection to main services to be made. Since 1958 mass production of hygienic cabins has been set up in Moscow, Leningrad, Kiev and other places (Fig. 9).

As stated above, labour consumption with large-panel houses is brought to 0.45–0.5 man-day/m^3 of a house. Mounting involves only 0.05–0.1 man-day, *i.e.* not more than 20% of the total. The major part of labour is still spent on finishing after mounting. Hence

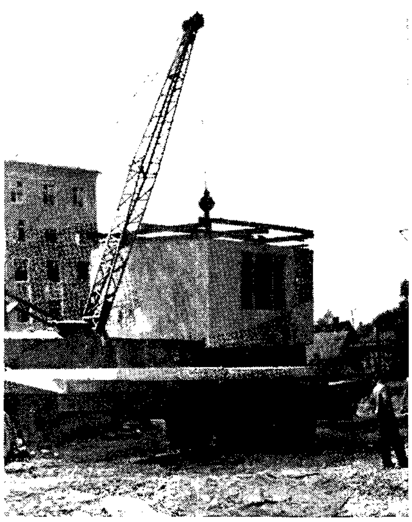

Fig. 10. Loading a block room on a trailer.

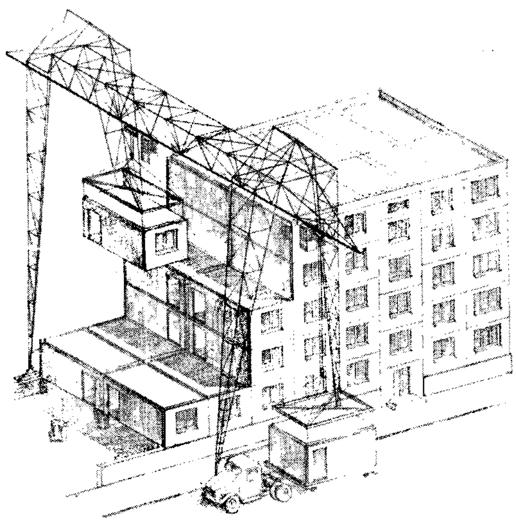

Fig. 11. Erection of a house by blocks of complete rooms.

a reserve for reduction of labour costs is available in improvement of large-panel structures and in a higher degree of prefabrication. The change from large panels to blocks of complete rooms, as described before, resulted in a further major reduction in labour costs (Figs. 10 and 11).

Table III gives approximate ratios between labour consumption on site and not on site for the different variants. As the figures show, larger elements lead to a decrease in site labour costs and in total labour consumption (site + factory). This is due to high mechanization and, recently, also to automation.

TABLE III

LABOUR REQUIRED FOR BUILDING 1 M² OF HABITABLE SURFACE OF HOUSES OF DIFFERENT TYPES OF CONSTRUCTION

	Brick houses		*Large-block houses*		*Large-panel houses*		*Houses of room-blocks*	
	Full days	%	*Full days*	%	*Full days*	%	*Full days*	%
Prefabrication of materials and details [1]	1.60	24	1.90	34	1.80	41	3.06	83
Transport of materials and details	0.35	6	0.33	6	0.20	5	0.10	3
Erection on building site	4.59	70	3.38	60	2.38	54	0.48	14
Total	6.54 100 %	100	5.61 86 %	100	4.38 67 %	100	3.64 56 %	100

[1] With calculation of the amount of labour for all separate and specialized work accomplished in the house-building factory.

For large brick blocks semi-automatic machines were used first in Czechoslovakia and later in the U.S.S.R. (Fig. 12). The semi-automatic machine for laying brick blocks consists of a frame for the laying, a reducer and a roller bed taking the moulded block. Mortar is spread by rolling a mortar bunker along the prearranged brick row. To lay the next row, a tray with prearranged masonry is lowered 75 mm by pressing a button and the operation is repeated. The finished block on the tray is brought to the seasoning section for hardening. With these semi-automatic machines the output per average man-shift is about 1500 bricks and per mason about 7500 bricks.

In the production of brick panels both stand and conveyer technology is employed. In the first case panels are vibrated by surface vibrators and in the second by vibration platforms. Labour costs are 4–5 times less than with the conventional method.

A number of moulding machines have been developed to make large concrete blocks. Ordinary heating, steam or electric heating is used to speed up the hardening of the blocks.

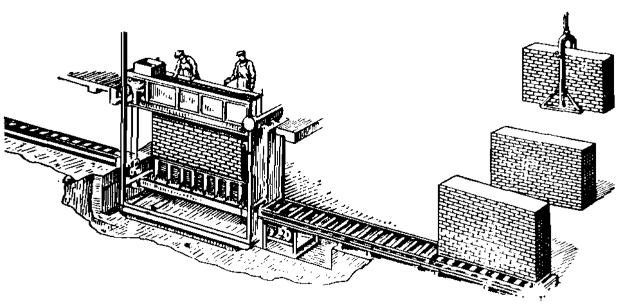

Fig. 12. Semi-automatic machine for large brick block masonry.

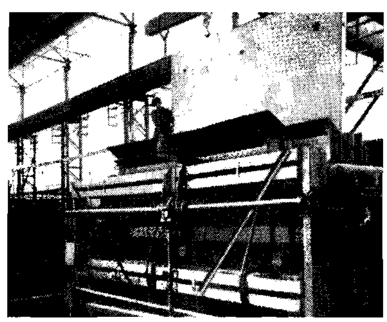

Fig. 13. General view of a machine for casting panels vertically in batteries (factory No. 12, Moscow).

The stand, line unit and conveyor methods are used in the production of reinforced concrete panels; the cassette and rolling methods of moulding panels are also finding wide application.

The battery method of concreting panels vertically has been employed in the U.S.S.R. since 1953. A number of machines have been developed in the U.S.S.R. to fabricate the panels of inner walls, partitions and floors (the Giprostrommash, NIAT, Karacharovo factory, etc.), which make it possible to mould up to 12 elements simultaneously. The use of steam heating in this case enables the products to be hardened in four to six hours. Fig. 13 shows a machine for casting panels vertically in batteries used in the Soviet Union ("cassette" moulding machine at factory No. 12 in Moscow).

Particularly wide opportunities for mechanization and, subsequently, for complete automation of the process of fabrication have been opened up by the method of continuous rolling of panels and thin-walled shells. Fig. 14 shows a continuous rolling mill developed by a group of Glavmosstroi engineers.

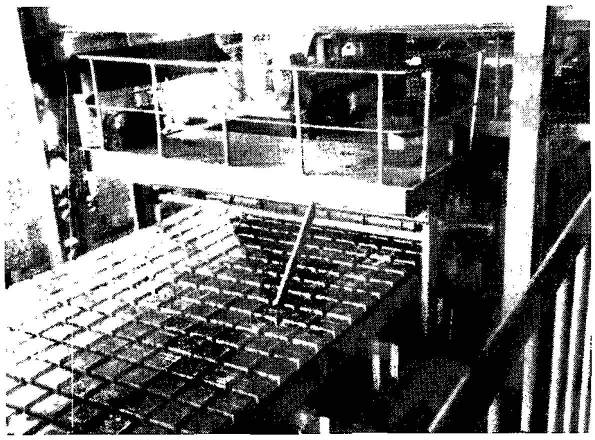

Fig. 14. General view of a continuous rolling mill for the fabrication of thin-walled shells.

The process of mechanized factory production of large-sized articles is constantly being improved both in the U.S.S.R. and in other countries.

GREATER RELIABILITY AND IMPROVED OPERATIONAL QUALITIES

The change to large factory-made elements implies prerequisites for greater reliability of the building and for its improved functional qualities. Factory methods of production enable a more reliable control of the quality of the products and materials used. At the same time the change from monolithic structures has called for a reappraisal of a number of notions associated with the rigidity and stability of the building, the service of the structures, *i.e.* maintenance (particularly when thin-walled articles are used), the provision of heat and sound insulation and other properties of the building.

The stability of a building with hand-laid stone walls, usually 40–65 cm thick, reinforced concrete floors and other widely accepted structures has, in the main, been ensured by the massive and monolithic nature of the construction elements themselves. The composite action of these elements increased the general stability of the building, but this as a rule was not taken into account.

The rigidity and stability of a building erected with panels of a small thickness as compared with the other dimensions can be ensured only by a composite action of these elements, properly coupled to one another.

A large-panel building acts like a homogeneous composite structure in which almost every element takes up not only the loads directly transmitted to it, but also those which act on the building as a whole. For example, floor panels bear the vertical load acting on them and work as horizontal diaphragms of rigidity to wind and other lateral loads; the transverse and longitudinal walls, bearing the loads from the floors above, act as vertical diaphragms of rigidity; the staircase is a type of buttress taking up the horizontal loads in the building, etc.

Static calculation of a large-panel building should take into account the composite action of the elements and of their relationship.

In the last decade a number of investigations has been devoted to the problems of the static work of frame and frameless buildings made of large-sized elements and to the methods of their calculation under various loads. The results of the investigations have been dealt with in detail in papers received from many countries. In the future scientists should centre their attention on:

Improving and simplifying the calculation of large-panel buildings as spatial structures (parallelepipeds), with due consideration for the effect of the method of coupling one element to another.

Investigating the work of large-panel buildings made of light and cellular concrete as well as of brick concrete, bearing in mind the peculiar physico-technical properties of such materials.

Studying the rigidity and stability of large-panel buildings and of those with structures in the shape of block rooms erected with thin-walled shells, as well as of those moulded as five-wall spatial elements.

Particular attention should be paid to investigating the work of buildings with prefabricated structures under seismic conditions and in the case of compressible soil and of permafrost. Research dealing with calculations of the strength and stability of buildings under such conditions should be continued and considerably developed.

The tendency towards lightening factory-made building structures and reducing the thickness of walls, ceilings, partitions and other elements, which has been justified both technically and economically, has raised the very pertinent problem of prolonging the service of the structures and, above all, of walls and coatings subject to the effect of varying atmospheric factors.

As long as walls of 40–65 cm or more were used, the freezing of a layer of plaster or facing, and even of a layer of the wall itself to a certain depth, though being undesirable, did not threaten the strength of the building. However, with a thin panel wall only 15–25 cm thick, and particularly in the case of walls consisting of shells only 20–40 mm thick, the hazard of a loss of strength is greatly increased when the materials are insufficiently resistant to changeable weather. Greater attention should, therefore, be given to the atmospheric and frost resistance of the material used in the structure of the walls.

In a number of industrial buildings, the impact of atmospheric factors is supplemented by chemical or, rather, physico-chemical effects. This has led to extended and more profound research in recent years on the nature of the phenomena which destroy the structures.

It should be noted at the same time that investigation into the problem of prolonged service of buildings greatly lags behind the study of the problem of their strength, rigidity and stability. The problem should be solved by drawing in a greater number of scientists. It would be useful to hear communications of representatives of various countries at a meeting of the CIB and to sum up the achievements in this field.

The problems related to improved operational qualities of large-panel buildings also include the problem of their fire-resistance. The general aspect of this problem is being studied by a special committee of the CIB. It is important that the knowledge accumulated in this field should be fully utilized in line with the concrete task of designing and constructing buildings of large-sized elements. An appraisal of the design variants should be made, as well as of the methods of coupling the elements to one another. Such a summing up would clarify the trend of ensuring higher fire-resistance of houses made of thin-walled elements.

Prefabrication of building structures and the reduction of their weight have raised a number of problems in the field of heat and sound insulation. It has, above all, enhanced the importance of a proper joint variant. A great deal has been achieved in this matter, yet a number of problems remain unsolved. These include finding reliable ways of packing both vertical and horizontal joints without using mortar.

Packing joints by means of a cement or mixed mortar has many important disadvantages. For instance: the use of mortar is made difficult in winter; the mortar adds supplementary moisture to the wall or some other element of the building, thereby unfavourably affecting the functional qualities (even though temporarily); the mortar joint does not possess the elasticity required during the expansion and compression under the effect of changing temperatures. A reliable variant of a joint without mortar and with the use of an elastic paste or resilient gaskets in the shape of a rope or a tape would be more suitable than a joint of mortar; apart from this, it would preclude the appearance of fine "hair" cracks which cause an accelerated destruction of the material at the joint and the penetration of moisture and sound through the wall. Methods of concreting the joints, and particularly of those taking up the load, have also not been thoroughly elaborated as yet.

Welded joints have found wide application in the U.S.S.R., as they greatly reduce difficulties in the erection of buildings in winter. A welded joint designed for the transmission of the full load provides a reliable structure at any low temperature and does not require much steel during erection. In other countries with a warmer climate, concreted joints are preferred; sometimes joints of a mixed type are used.

It is impossible to evaluate a method of jointing the elements of a building on the basis of theoretical considerations. The matter is to be decided by summing up the experience in various methods of jointing. Exchange of information and opinion by the participants of this Congress will undoubtedly be helpful in practical work.

The tendency towards making the structures of factory-made buildings lighter has extended the use of sandwich walls, ceilings and partitions. Differentiation of the functions of every layer in the wall (bearing, heat insulation, vapour barrier, finishing leaves) permits the selection of the most suitable material for each of them. The presence of layers with different elasticity in the ceilings and partitions helps to improve their sound insulation properties.

The second edition of the *Standards of Construction Heat Engineering* as well as the *Standards of Designing Protecting Structures of Buildings*, elaborated by the Institute of Construction Physics and Protecting Structures of the U.S.S.R. Academy of Building and Architecture jointly with the Moscow Construction Research Institute and published in 1959, contains a number of specifications as compared with the formerly published standardization documents. They do not, however, supply an answer to some questions arising with regard to buildings with light laminated walls, ceilings and partitions.

For example, building designers do not dispose of sufficiently precise data about vapour barriers or of simple methods of calculating laminated walls, which would enable the choice of variants reliable from the viewpoint of accumulation of moisture in the wall and which would preclude the hazard of the layer structure being destroyed during freezing.

The "volumetric weight of material and its heat conductivity" curve is still being used by designers in determining the rated factor of heat conductivity of concrete walls and coatings, while research of recent years points to the great effect of the structure and composition of concrete on heat conductivity. Investigation into the effect of the structure of concrete and other materials on their heat conductivity properties constitutes a typical problem.

The problems of heat resistance of light sandwich structures in hot climates have been studied quite inadequately. At the same time the matter is of importance for a number of countries with a hot summer, including the Central Asian republics of the U.S.S.R. For instance, observation of the standard requirements for heat resistance leads to the following paradox: the light panel walls designed for the town of Yakutsk, where the temperature in winter drops to — 50° C, require a thicker layer of heat insulation than in Tashkent, where the temperature of the air in summer is as high as 40–45° C. In the past, no attention has been paid to the heat resistance of a building when massive protecting structures were used.

The use of laminated ceilings and partitions has led to a substantial reduction of the weight of structures while improving their sound-insulation properties. It is worth noting at the same time that the designing of new types of ceilings has omitted the development of the heat-insulation theory. No method has yet been devised for calculating heat insulation of laminated ceilings and partitions, as well as of ceilings and partitions of the split type. The solution of this problem is a major scientific task.

Along with sandwich walls, single-layer panel walls of light and cellular concrete are widely used both in the U.S.S.R. and in other Eastern European countries.

Single-layer walls of porous clay filler concrete, perlite concrete and other light concretes, as well as walls of cellular concrete, may be approximately the same weight as laminated walls and yet simpler to fabricate and frequently cheaper than the latter. At the same time the properties of light and cellular concrete have not yet been studied comprehensively. Research should be aimed, amongst other objects, at further reducing the weight of concrete and increasing its strength, reducing the moisture absorption of cellular concrete and raising frost resistance.

Scientific investigations should strive for greater improvement of both the constructional and functional properties of buildings erected with large-sized factory-made elements.

CONCLUSION

The use of large-sized elements is the major trend of the developing techniques of building construction in the U.S.S.R. and other socialist countries of Eastern Europe. The economic advantages of this trend have been proved by experience.

Experience has also shown that the larger the size of the prefabricated elements and the higher the degree of prefabrication of building structures, the greater the economic effect. "Semi-prefabricated" construction is, therefore, replaced more or less rapidly in some countries by fully-prefabricated large-block and large-panel construction. Large-panel construction, with its advantages over large-block construction, is gradually becoming the predominant trend. So far large-block and large-panel construction accounts but for a small percentage of the total volume, but the significance of this kind of construction is growing rapidly. In 1965, this method will prevail in the U.S.S.R.

Large-block and, particularly, large-panel house construction, which is essentially a factory method of building houses, involves mechanization and gradual automation of the process of fabricating elements of building structures and transformation of the building processes on the construction site into erection.

Factory house construction has set science a number of important problems involving the reduction in the weight of the buildings and in the costs of materials, a higher degree of prefabrication of buildings, and improved functional qualities of the buildings. This paper has attempted at briefly elucidating these problems, so that their discussion at this meeting of the CIB should help in finding the proper and speediest ways of their solution.

REFERENCES

1 *The architecture and structures of multi-storey large-panel dwelling houses*, USSR Academy of Architecture, Moscow, 1954.

2 *Large-panel frameless houses*, USSR Academy of Architecture, Moscow, 1955.

3 G. F. Kuznetsov, N. V. Morozov and I. F. Livchak, *Manual for designing dwelling houses and public buildings with panel frame-panel structures*, Moscow, 1955.

4 *Large-panel construction*, collected articles, Mosckovsky Rabochy Publishing House, 1956.

[5] *Czechoslovak panel erection systems,* Construction and Architecture Research Institute, Prague, 1957.

[6] G. F. Kuznetsov, N. V. Morozov and T. P. Antipov, *Structures of multi-storey brick panel and panel dwelling houses.* Moscow, 1959.

[7] *Large-panel and large-block construction in the USSR,* Scientific Engineering Society of the USSR Building Industry, Moscow, 1958.

[8] N. V. Morozov and N. Y. Spivak, *Single and multi-layer wall panels for dwelling houses,* Moscow, 1958.

[9] S. N. Scherbakov, G. N. Prozorovsky and N. M. Kurek, *Construction in Czechoslovakia,* Moscow, 1958.

[10] *Housing Construction,* Proceedings of the 2nd Session of the USSR Academy of Construction and Architecture, Moscow, 1958.

[11] *Die Montagebauweise mit Stahlbetonfertigteilen im Industrie- und Wohnungsbau,* 2nd Internationaler Kongress, 1957, Berlin, 1958.

[12] *Precast and prestressed reinforced concrete,* Proceedings of the 4th Session of the USSR Academy of Construction and Architecture, Moscow, 1959.

[13] G. Brankov, Zhilischne sgradi, *Stroitelstvo,* No. 2, Sofia, 1957.

[14] *Large-panel housing construction,* Bulgarian Construction Research Institute, Sofia, 1958.

[15] H. Heisler, *Practice of erecting large blocks in the German Democratic Republic,* No. 1, 1958.

[16] *Large-panel house construction in the German Democratic Republic,* German Construction Academy, Berlin, 1957.

[17] *Hungarian Construction Bulletin* No. 1–2 and No. 3–4, 1958, published by the Technical Information Bureau of Construction, Budapest, 1958.

[18] G. Sebestyen, *Experimental Housing in Hungary,* Prefabrication, X, No. 48, 1957.

[19] *Polish planning problems,* Prefabrication, XII, 5, No. 62, 1958.

[20] *New structures in Rumanian housing construction, in construction and architecture abroad,* collected articles, Kiev, 1956.

Research problems concerning heavy concrete elements: Scandinavian experiences

UDC 691.327/.328(48)

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INTRODUCTION

According to the programme this Congress will be devoted to a number of problems of fundamental importance to the building industry. Important building research and building documentation problems and their results will be presented.

The present subject will be treated on the following basis. CIB members are primarily central national building research institutions. Their research problems and results are considered below. Research and experiment in building enterprises are treated only summarily because their results have been published in various places in Scandinavian and English periodicals in the survey *Prefabricated Building* of the OEEC [1]. Discussion will be concentrated on apartment houses. Industrial buildings have been treated quite amply at the congress in Dresden in 1957 [2].

DEFINITION AND SYSTEMATIZATION

During the last 10 years many experiments have been made with the aim of transferring house building from a product of handicraft to a more industrial production. Three lines of development can be clearly distinguished in Scandinavia:

1. Increased mechanization of the traditional building methods.
2. Development of new methods for on-the-job casting of cement.
3. Increased use of prefabricated building elements.

This discussion concerns primarily the last point but also has connections with the other two. Pre-built building elements are used in all types of house construction. In multi-family houses use is made of finishing elements, such as elements for partition walls, non-load-bearing outer walls, stairs, balconies, and garbage disposals. Elements used for the supporting shell are perhaps most used in Denmark but are of steadily increasing importance in other countries.

A building component which is built and more or less finished at a place other than the construction site is a prefabricated building unit. In order to call an entire house "prefabricated", the requirement should at least be made that part of the shell be prefabricated. The element should accordingly have been used in supporting walls, flooring, columns or beams.

If one divides the prefabricated building systems according to the weight of the elements, three groups are often distinguished. In the "light method" the elements are light enough to be handled by one or two men without mechanical assistance. Maximum weight is set at 100 kg. The other extreme, the "heavy method", requires particularly powerful lifting devices in handling. Elements involved are entire walls or floors of a room, or even a whole room. The method consequently requires powerful cranes mounted on stable foundations. The "medium weight method" involves all the intervening groups. Most types of cranes found in Scandinavia can be used in this case, even with extremely large crane arm extension.

Heavy concrete elements as used in this paper include elements which must be handled with the help of mechanical devices.

TECHNICAL AND ECONOMICAL CONDITIONS

Concrete has advanced to the foreground as one of the most important building materials in Scandinavia as well as most of the other European countries. Flexibility of form, high degree of strength and weather immunity are some of the qualities that have documented its considerable usefulness, even in apartment buildings. The cost of concrete construction has fallen in relation to constructions of most other building materials. The production efficiency of workers in cement mills had increased more than that in most of the other material producing industries. Distribution has been simplified by specially constructed trucks and unloading at the building site in containers by compressed air, etc.

Concrete, more than any other building material, has been the object of much technical and scientific research. Concrete technics have increased in this way. Better quality concrete has been achieved, particularly with respect to uniform quality; reinforcing steel today allows considerably larger loads than in the past. It has been possible to increase successively the permissible stresses in reinforced concrete structures (Fig. 1).

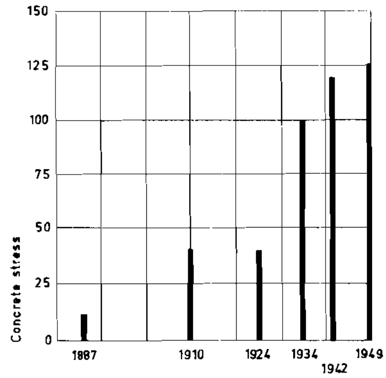

Fig. 1. Permissible stresses in reinforced concrete structures.

Heavy concrete elements are used in larger buildings (*i.e.* in multi-storey houses, office buildings, etc.). Space allotment for apartments in small and larger houses is not uniform in Scandinavia. Norway approaches the Anglo-Saxon type of home construction with separate small houses of one or, at most, two apartments. While these small houses in Norway have included about two thirds of the housing allotments in the last few years, in Denmark they have only accounted for 40–50%. Finland and Sweden are more generally adopting the continental type, and small houses have contributed only 30% of the housing allotments in the last few years, while multi-family houses have accounted for about 70% [3].

PREFABRICATED BUILDINGS – THE PRESENT SITUATION

Since the Second World War prefabricated building in Scandinavia, as well as in most other European countries, has started a real competition with traditional building methods. In Denmark, with its concentrated building construction, there have been better conditions than in the other Scandinavian countries. Many signs indicate that the most systematic approach has been made in Denmark. Experiences in this country have even, to a large extent, laid the basis for development in Norway. In Finland, prefabricated building is hampered by a special tax on factory-made elements. This tax is not imposed on work on the building site. In Sweden prefabricated building had during the last 20–30 years been used in small wooden houses and this year perhaps about 50% of Swedish one-family houses are prefabs. Multi-family houses are now to a great extent constructed with non-traditional methods. Of these, prefabricated buildings accounted in 1957 for 2100 apartments, non-traditional houses comprised 3.5% of the total housing production. In 1958, 3200 prefabricated dwellings were erected, or 5.1% of the total.

The non-traditional building methods have not been accomplished without making mistakes. Thus, they have often been met with disbelief. The National Swedish Committee for Building Research stated as early as 1955 that "it is necessary to make an inventory of the new building methods and to evaluate their results so that any worthwhile discoveries that appear are not lost among those of lesser value. After such an inventory has been made, the results should be distributed more widely. Ultimately a systematic application should lower building costs by a considerable extent. A thorough evaluation of results from prefabricated buildings and other experimental activities should include building costs, productivity and the finished product (*i.e.* the quality of the house)."

The investigation which followed this statement was motivated, among other things, by the fact that prefabricated buildings can influence government participation in building matters. The Swedish Government grants, amongst others, loans for new types of building equipment, and there may be reason to consider granting government loans to factories for the construction of elements. Prefabricated building on a large scale often demands that entire areas are planned at one time and influences in this respect the entire housing development planning.

While specialists in prefabricated building established that with the country's available manpower it is possible to build essentially more dwellings of equally good quality as in the past, specialists in traditional building methods point out that costs do not seem to be lower with the new methods, while at the same time questions arise about their quality.

The various methods are, however, undergoing rapid expansion. They have hardly reached their final expression at the present time. Comparison is, therefore, difficult. Similar viewpoints have been reached in Denmark [5].

As a basis for the investigations of the Danish Committee for Rationalization of Building Activities, it was the intention to make a statement presenting all existing knowledge of prefabrication. Disclosure of those problems suitable for examination by tests was sought. The investigations quickly revealed how intimately related all questions concerning prefabrication are – from the planning and detailed design of construction and installations to erection and completion on the site. One of the most important factors in prefabrication with large elements is complete pre-planning. This entails definite settlement at an early stage of the client's requirements, architectural design and engineering design, including structural, sanitary, heating, ventilating and electrical engineering.

One outstanding viewpoint deserves mention here, *viz.* the necessity of altering clauses in building by-laws based upon old traditions and materials, and to give functional demands or established Codes of Practice. It is not sensible that all demands in house building should continue to be based upon houses in brickwork with wood walls both with regard to dimensions and functions. The nature of the demands that each of the elements should fulfil is tabulated instead, but no figures are included.

The shaping of the elements is described both for several ordinary types and for those based on functional demands. These demands, expressed in figures, must be the aim of future building by-laws and Codes of Practice. A simple demand for equivalents with traditional buildings cannot be maintained. Fire regulations particularly may be cited, as they are often not based on rational demands.

There are elements involving entire walls or floors and elements with a width of 0.6 to 2.0 m. It is too early to say which sizes present the greatest possibilities for the future. If at least 150 identical elements can be cast in the same mould, a minimum price is reached. Some believe this will always remain the case, but others maintain that technical development will make it possible to produce smaller multi-purpose elements, cheaper in mass production. There is an apparent trend from the field factory to the established factory, where a rational production can be more easily arranged.

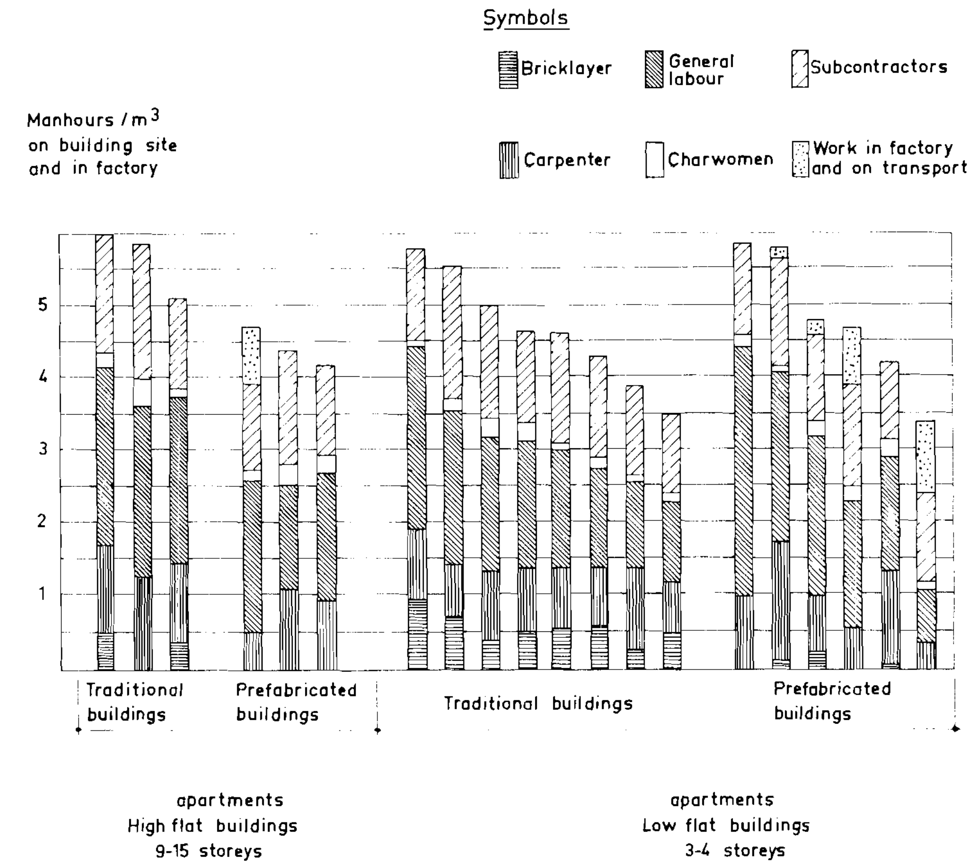

Fig. 2. Consumption of man-power in the construction of prefabricated buildings compared with that in traditional buildings.

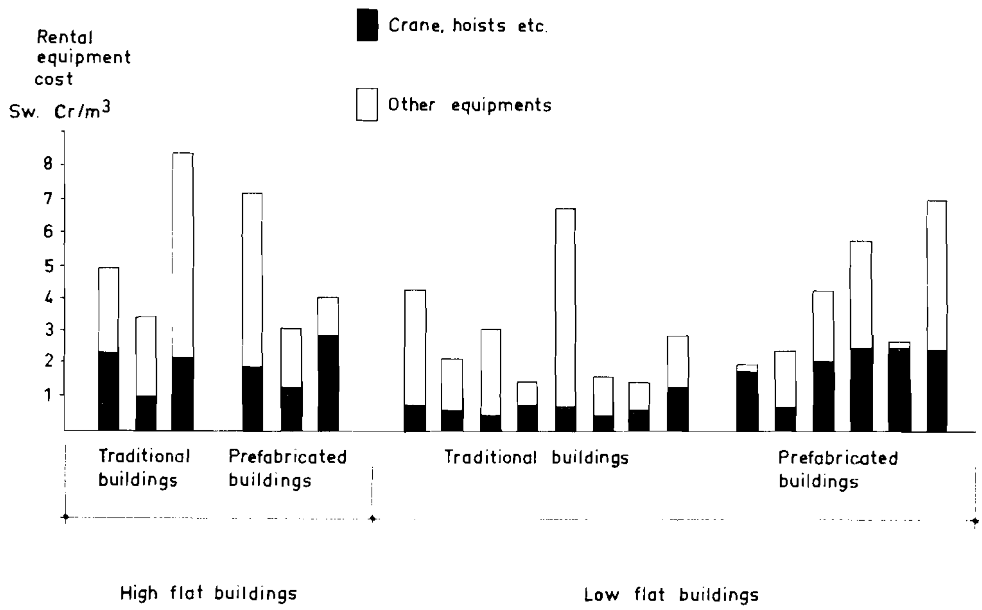

Fig. 3. Relative costs of mechanical equipment for prefabricated and traditional building methods (costs in Swedish Crowns per cubic metre).

In Sweden, comparisons have been made concerning man-power consumption in prefabricated and traditional buildings. Fig. 2 shows such a comparison, partly for high houses of 8–13 stories, partly for low houses of 3–4 stories. Man-power consumption in prefabricated buildings in relation to traditional buildings is considerably lower in tall houses than in low houses. The table on Fig. 2 shows the wide distribution owing to the fact that prefabricated building does not show a uniform picture but is continuously developing. This fact renders impossible a definite statement.

Mechanical equipment is shown in Fig. 3. The equipment is here calculated in rental cost of the machinery per m^3 of building volume.

Future work in Sweden will be concentrated primarily on continued studies of the working time and costs involved in various types of building systems.

STANDARDIZATION AND TOLERANCES OF DIMENSIONS

PROBLEM AND GOAL

The use of factory-made heavy concrete elements requires, as other building methods employing elements, that tolerances can be determined for exactness in the elements. The research task is to determine the optimum tolerances from the technical and economical viewpoints.

If mass-produced elements are to achieve widespread application, they must be arranged in a system with modular coordination and preferred sizes. The problems connected to this aspect are so extensive that they cannot be considered in this report.

RESULTS OF RESEARCH

Deviations can be reduced by rigid moulds and joints. The average deviation can be reduced by care of the moulds during construction and by strict control.

A really accurate production can be obtained only by statistical methods of control based on comprehensive experience regarding the various types of form work, so that the uncertainty in determining the standard deviation is reduced to a minimum. Tolerances should be specified and strictly maintained, but the costs of production are increased by unnecessary or unduly close tolerances.

The following information is taken from research carried out by Nyquist [7].

The accuracy of dimensions of a concrete element is directly dependent upon the type of mould, *i.e.* construction of the mould and the material of which it is made.

The following data concern the width of the element. Elements cast in horizontal wood moulds should have an accuracy of measurement between $\pm$ 5 and $\pm$ 10 mm, depending upon the type of wood, construction and number of times that the mould has been used.

Moulds of concrete allow a degree of accuracy of about $\pm$ 3 mm without rendering the costs prohibitive. In normal cases tolerance should preferably not be set below $\pm$ 5 mm.

Steel moulds constructed of heavy vertical sections and thick plates have been shown by Coignet, France, to have a tolerance of $\pm$ 1 mm, but it must be remembered that in this case a typical series production was involved with complex and expensive moulds. Relatively simple steel moulds should be able to yield an accuracy of dimensions of $\pm$ 3 mm.

"Package mould" is the name of one type of mould that is commonly used in Sweden for casting the element vertically. The package has bottom and side forms of U-shaped steel profiles. Between the steel side facings, plywood form sheets are fastened. Elements about one meter broad and cast vertically in a package need not yield a larger tolerance in breadth than $\pm$ 5 mm.

Investigations are currently being carried out to determine the deformation during the storing of heavy elements, primarily warping due to shrinking and creeping.

Measurements on cellular concrete elements indicate that manufacturers with modern cutting instruments can deliver products with tolerances of $\pm$ 2 mm for breadth and $\pm$ 1 mm for thickness.

Measurements on prefabricated shells show that deviations in room dimensions of one to two inches (25 to 50 mm) are not uncommon. Where there has been a need for great accuracy in measurement, it has been possible to succeed considerably in exacting these values. To desire smaller tolerances than $\pm$ 10 mm in room dimensions at the present time is certainly expecting the impossible.

STRUCTURAL PROBLEMS

GENERAL

The main part of this section has been taken from the report of the Committee for Rationalization of Building Activities of the Institution of Danish Civil Engineers [6].

Prefabricated buildings have given rise to problems concerning joints and clearances. One important aspect of these problems is the dealing with cracks due to shrinkage and settling. These cracks are more likely to occur when the components are large. The problems of wind- and water-tightness have, therefore, assumed a greater importance with the increasing number of prefabricated constructions.

The selection of jointing materials and principles of construction is often influenced by the standards to which the joints must conform if they are to fulfil their functions successfully.

Transmission of forces

Live load and dead load, wind pressure, etc. The stress in the jointing material is, according to the direction of the forces, either compressive (the most favourable) or shearing. There can be notched joints, bolt assemblies and other similar methods of jointing. The most important questions are the determination of the internal forces in the joints, of the strength of the joints and of the deflections in the joints.

Proofing against wind, heat, sound and moisture

Not all the joints in the face of a building can be locked because of movements due to creep, temperature variations, etc., and in this connection proofing against wind and moisture are the most important demands.

Freedom of movement

Some joints can be made rigid with cast-in locking pieces, but a relatively large number of joints must be able to take up movements, even if the building includes actual expansion joints.

Economic edge-shuttering

Complicated edges of components are economically feasible only in the case of very large orders, and tapering edges, etc., must be employed so as to permit the finished component to be removed from the mould easily. Protruding iron pieces should be avoided if possible or replaced by inserts.

Economic erection and jointing

The component must be simple and must enable quick mounting. The jointing must be easy to carry out, preferably self-shuttering, and the edges must be so shaped that a natural base is formed against which the gaps can be stopped.

The jointing material is usually mortar, preferably fairly dry to facilitate the work and reduce the shrinkage. Sprayed-on plastic pastes or mastics are often used in order to ensure water-tightness. Traditional methods, such as the insertion of zinc-locking sheet or stopping with oakum, are also used.

Types of joint

Types of joint, each with its own combination of essential demands, are:
Vertical facing joints;
horizontal facing joints;
horizontal joints between storey partitions;
vertical joints in inner walls;
joints between inner walls and storey partitions;
joints between beams, columns, walls, etc.;
joints around windows.

Especially in Denmark, the horizontal facing joints are often made on the fish-scale principle, which prevents the wind pressure from forcing water into the components. At the same time the thermo-insulating layer is often provided with drainage and ventilation so that condensation troubles are avoided, and the wind pressure on the vertical joints is equalized.

BUILDING RESEARCH RESULTS

Most of the "research results" are presented in the form of practical solutions which have been applied in completed buildings in Scandinavia. Many of them are described in articles in technical journals. Typical examples of building practice in Scandinavia have been published systematically [3, 6, 7, 8, 9, 10].

FUTURE PROBLEMS

A survey of most types of prefabricated buildings used is included in the programme of the National Swedish Committee for Building Research. Through this survey it is hoped to obtain a general summary both of the results already attained and of the remaining problems, which should be taken up either theoretically or, wherever necessary, through experimentation with models or full-scale houses.

Studies concerning transmission of forces between the wall elements will be particularly concentrated on the problems of the compressive strength in horizontal joints and the shearing strength in vertical joints. The current problems are, for example:

Experiments with cogged joints in order to compute their strength.

Studies of concentrated points of strength where the rupture theory does not apply.

Studies of thin columns, the statics of which are unexplained.

The studies of tightness and allied problems aim both at finding out how actually existing structures function in practice and are appropriately practical, and at establishing those qualities which are essential for joint solidification and how these should be determined.

SOUND INSULATION

The modern tenant has several tools producing high noise levels: the radio fitted with HiFi equipment and the television, whose sound control must be turned up high so that the neighbours hear that one can afford to have television. A higher standard of sound insulation is, therefore, necessary.

Practically all the development in prefabricated buildings points to poorer sound insulation. The elements and components are thinner, and their weight is reduced. From the point of view of sound insulation one is then, according to Scandinavian needs, faced with the choice of retaining a massive concrete wall of about 14 cm, when the minimum standard for airborne sound insulation can be met, or diminishing the thickness of the wall to a size which is warranted with regard to solidity and complementing it with an extra sound insulating covering. This example shows that sound insulation in prefabricated buildings brings with it an extra thickness of the element or an extra covering, both of which add extra costs to the building.

Impact sound insulation is of the utmost importance in flooring. In massive concrete flooring removal of plastering or rendering on the underside, as often practised in prefabricated buildings, is perhaps acceptable only when the floor thickness is not less than about 14 cm. It becomes more troublesome when the entire construction with joists and sound insulating materials on the load-bearing floors disappears and is replaced by a concrete flooring and a mat or parquet laid directly on the flooring. Numerous sound insulation problems arise in these cases.

During the last few years precast hollow concrete flooring has come into use, as well as constructions with thin concrete plates on supporting beams. At the present time there is no flooring of these types which, without special measures, can meet the insulating requirements concerned.

How are stair elements to be constructed so that the disturbing sound can be reduced to a minimum? How are sanitary installations to be arranged so that the noise can be eliminated as much as possible? How are disturbances in ventilation ducts in mechanical ventilating systems to be prevented? These are some other problems which appear in prefabricated building.

Studies of sound insulation problems in prefabricated buildings are being performed by the National Swedish Committee for Building Research. Measurements of sound insulation in different types of prefabricated buildings are being made and comparisons drawn with traditional buildings. Based on the experiences from this survey detailed sound insulation problems will be defined and studied in the laboratory. The intention is to get better knowledge of the sound transmission mechanism in prefabricated constructions and to develop new constructions with better sound insulation properties. Finally, the performances of constructions are to be controlled in full-scale tests on erected buildings. If such an investigation becomes the subject of a general discussion, the possibility arises of achieving a solution for the entire complex of problems in the long run.

HEAT INSULATION AND PENETRATION OF MOISTURE

One main advantage of the non-traditional building methods is that they make it possible to have much better heat insulation in the outer walls. In constructions which are used therewith, some problems with heat insulation, penetration of moisture, etc., materialize in a higher degree than in traditional buildings. These problems do not only concern heavy concrete elements and are, therefore, only mentioned here. (For further particulars see Subject 6: Flat roofs.)

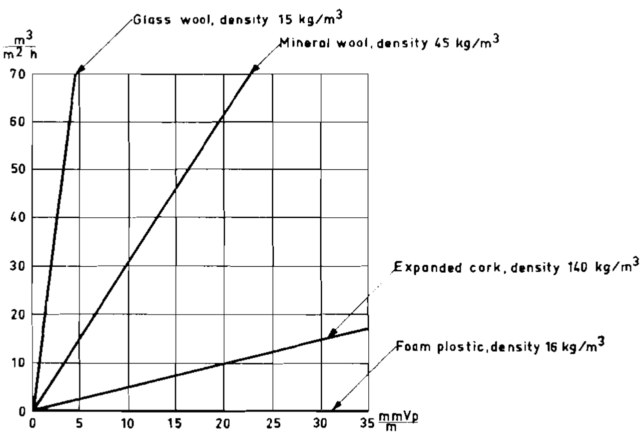

Fig. 4. Air transmission curves for various heat-insulating materials.

Heat-insulating material (foam plastic, mineral wool, etc.) most commonly has a porosity of more than 95 per cent by volume and the thermal conductivity, which is commonly set to 0.206–0.040 kcal/mh° C, is similar to that of air. In order to get low thermal conductivity of the insulating material the pores must be closed and not permit convection within the material. An important problem is, therefore, to investigate the air transmission of the highly insulating materials. Fig. 4 shows the actual air transmission in some heat-insulating materials.

Furthermore, heat flow may be considerably influenced by wind and rain penetration. Problems relevant in this respect are currently under investigation by Scandinavian research institutions.

Moisture may penetrate through walls and roofs in the form of water vapour or water. Heat insulation in walls and roofs, surface finishing, etc., is often damaged by moisture as a result of climate as well as of humidity and temperature conditions inside a building.

In general, moisture movement within parts of buildings is closely linked together with thermodynamic processes and must be studied as a simultaneous mass and heat transfer process. Several suggestions have been made to find methods for the numerical calculation of moisture movement within a construction. The equations used are radically simplified and approximated and have a limited validity. These methods, therefore, yield highly unsatisfactory accuracy if one compares them with the calculations used for strength, stresses, etc. Thus, there is a need for further basic research.

Full-scale tests under controlled conditions are necessary to solve the practical moisture problems. For this purpose a climate laboratory will be erected in Denmark and the tests will be prepared and run in cooperation with other Scandinavian building research authorities.

SURFACE SMOOTHNESS

Surface treatment can be made fundamentally simpler with factory-made elements than in traditional buildings. While a traditional wall is usually given a "plastering" (rendering) with a thickness of 10–15 mm before being painted or hanged with wallpaper, one now restricts oneself to painting directly on a concrete surface. Only the joints have to be filled out and smoothened first. If the surface is not smooth enough it is given a levelling layer of "sand paints". ("Sand paints" are made up of size-graded fine sand and filler material, *e.g.* beach sand and marble flour. Binding materials are, for example, simple glue solutions, cellulose glue, etc., and/or emulsions, such as polyvinyl acetate.)

An important task for building research is the establishing of norms for surface smoothness and the formulation of instructions for architects and builders so that they can choose from the many new kinds of paints available. Thus, attention should also be paid to the cost of creating a smooth and even concrete surface. The National Swedish Committee for Building Research has chosen to reach the goal through developing standardized testing methods and descriptions of qualities and properties.

CONCLUSIONS

"We cannot allow our efforts at being rational to cause a lowering in the quality of the dwellings" is a statement heard often from proponents of traditional building methods.

In the evolution of non-traditional methods, which were mentioned by way of introduction, only the production technique aspects were considered. An important task for building research organizations is to attempt, from various points of view, an evaluation of the quality of prefabricated buildings and to point the way to higher quality.

Sound insulation in many prefabricated buildings is poorer than what is considered normal in traditional buildings, but development points to higher quality. Heat insulation is better in theory but practical research problems remain, such as the attainment of tight joints.

The climate in concrete buildings with unplastered walls has been compared with that in plastered brickwork houses. It has been considered that the plaster on the inner walls of a room serves as a humidity regulator by accumulating moisture when many persons are in the room and when the exhaled moisture content of their breath is large. The plaster should subsequently release the moisture to the room air when the latter has become drier. In order to check whether this interpretation is correct air temperature and humidity have been continuously registered in living-rooms of brickwork houses with plaster on the inside and in concrete houses without plaster on the inside. Results indicate that in these cases no practical differences exist with respect to climate in the home.

Prefabricated housing seems – at least in Sweden – most often to result in design with large elements. The development towards large elements produced in long series results in the situation that the functional viewpoint cannot be taken into consideration in each individual case. Factory-made bathrooms and other large internal elements which have appeared in recent years must be modelled on the basis of function research. Studies made by the OEEC with modular coordination (with a module of 10 cm) form a step in the right direction. A later step in research is to create a basis for preferred sizes. In this way the design of prefabricated building can be adapted to the requirements of the occupant. This should be valid in the future when the standard of living – we hope – will be higher than today.

REFERENCES

1. *Prefabricated Building. A survey of some European systems,* OEEC, Paris, 1958.
2. *Die Montagebauweise mit Stahlbetonfertigteilen im Industrie- und Wohnungsbau,* VEB-Verlag, Berlin, 1958.
3. E. Strokirk, *Byggnader av förtillverkade betongelement,* Handboken Betong, Stockholm, 1958.
4. *Annual Bulletin of Housing and Building Statistics for Europe,* United Nations, Geneva, 1958.
5. The Committee for Rationalization of Building Activities, the Institution of Danish Civil Engineers. Publications in Danish, with summaries in English: *Survey of investigations by the committee; Composite prefabricated reinforced concrete structures; Modular coordination in Denmark; Joints in pre-cast construction* (in Danish and English); *Concentrated loads on beams; Accuracy in building construction; Rational design of facing components and their function* (including No. 2, Cold-conductors, and No. 7, Passage of moisture through outer walls); *Prefabrication in Denmark; Rationalization of pipe installations; Rationalization of electrical installations.*
6. H. Rahm and G. Thunblad: *Arbetskraftåtgång vid traditionella byggen och monteringsbyggen* (Manpower requirements in traditional and non-traditional building), the National Swedish Committee for Building Research, Stockholm, 1959.
7. I. Nyquist: *Måttnoggrannhet och toleranser vid monteringsbyggeri* (Tolerances of dimensions), the National Swedish Committee for Building Research, Stockholm, 1959.
8. F. Hageman: *Icke traditionella ytterväggar i hyreshus* (Non-traditional exterior walls in multistorey flats) (Swedish text with separate English and German summaries), the National Swedish Committee for Building Research, Report 41, Stockholm, 1957.
9. A. I. Johnson: *Elementbyggda höghus. Väg- och vattenbyggaren,* Stockholm, 1956, pp. 99–104.
10. P. E. Malmström: *Statiske problemer i montagebyggeri,* Byggeindustrien, Copenhagen, 1958, pp. 258–262.
11. P. Vissing and A. Lindberg Hansen: *Paddemyren- et montagebyggeri i Norge,* Byggeindustrien, Copenhagen, 1958, pp. 251–257, 275–280, 287–292, 303–308, 327–332.

French experiences in the use of heavy concrete elements

UDC 691.327/.328(44)

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GENERAL

HEAVY ELEMENTS IN THE PROCESS OF INDUSTRIALIZATION

The use of heavy concrete elements for dwelling construction in France is characterized by a marked preference for "heavy solutions". This is due to technical considerations rather than to reasons of taste. Before reviewing these considerations it should be stated that the use of heavy elements is undoubtedly the basis of the industrialization of dwelling construction. This is not a question of claiming priority for partial or full prefabrication, but of stressing that the efforts of a few pioneers, using heavy elements, have prompted the great body of others to take an interest in prefabrication of relatively great elements. They are now so widely used that prefabrication as a means of industrialization and industrialization itself are often confused. This trend dominates now, but heavy solutions come nearest to what seems desirable. The application of these techniques has – in France at least – led to numerous systems that differ more in production methods and use than in principle. Hence they will be studied here simultaneously, without being identified in their technical characteristics or specific problems.

Despite a certain initial advantage, their progress is, in France, slow. They represent only a very small portion of the country's whole range of building systems. Although the potential of the factories and plants represents some 10% of the annual dwelling construction, only 4 to 5% were actually built in heavy elements. This is certainly detrimental to this system and unfair to its financial economy. A brief analysis of the causes will be given in a subsequent section.

Nevertheless, very interesting applications have been realized in France for years already. The prototype stage is being passed and consequently reliable elements of a doctrine can be isolated in the present report.

SPECIAL CHARACTERISTICS OF HEAVY ELEMENTS AND LIMITS OF APPLICATION

One fundamental limitation lies in the need to use powerful handling equipment. This problem usually arises not in the factory, where possibilities are unlimited, but on the site and between factory and site. However, recent possibilities for more powerful site equipment enabled wider use of heavy elements, the weight of which increased with the power and capacity of handling equipment.

This increase involves other limits, *e.g.* the maximum possible dimensions in view of road or rail transport. Observing within this double boundary that (1) the increase of loads at a station or site for any production process is proportional neither to dimensions nor to weight of the elements and (2) the costs of transport and mounting depend more on the number of operations than on the volume or mass of the elements, one can understand the present general trend.

The choice of characteristics consists of combining two concomitant but clearly distinct objectives: to produce, in view of their destination and proportionally speaking, the largest possible elements and, secondly, in view of transportation and lifting-device limits, the heaviest possible.

We thus witness a double but contradictory phenomenon: for intermediate processes and traditional methods ever lighter elements, but increase of weight for heavy elements. Moreover, when the limit is reached and transport becomes impossible, the largest and heaviest elements are produced on site, *e.g.* with Estiot. Moreover, it is also on mass that the main factors of comfort depend, *i.e.* acoustics and heat insulation. Builders seek to obtain elements of the size of a wall section or a floor in one unit, jointed at the corners. Furthermore, there is a marked trend towards increasingly complex castings, as described in the section on tolerances.

Several general characteristics of prefabrication – though not exclusively of large elements – must be analysed here. A construction process has three essential characteristics: speed, cost and quality.

Speed will, doubtlessly, long be the most positive aspect of use of heavy elements. In sufficiently large stock yards, industrialists can rationally organize reserves and eliminate fluctuations of supply. As site work is, by definition, limited to simple assembly of finished elements, the time needed at the site will be very short under optimum conditions of supply, thus reducing the time the contractor has to put his men on the job. The building constructed can thus quickly be put into service. Moreover, it is here that the most immediate consequences affect the client in the form of appreciable financial savings due to elimination of interest on advanced capital as well as to earlier collection of rent for rapidly occupied dwellings. The problem of cost will be treated under "Financial considerations".

The quality, however, a characteristic with manifold consequences, deserves immediate further attention, according to the following aspects.

Intrinsic quality

It can be said that, after having been more mediocre than traditionally, owing to technical imperfection and insufficient experimentation, quality is improving and even surpassing today's average, except for some particularly qualified teams of workers or first class firms that execute specialist or luxury jobs. Particular care is given to facings for smoothness and choice of materials.

Apart from this, quality is even more serious with a view to architecture and comment is given below.

Habitable surface

Increase of surface is essential for attractiveness and, hence, the value of a dwelling. The surface has, in France at least, been reduced too much in social housing.

Current studies of the financial consequences of fluctuations of surface standards indicate that, if under certain conditions the surface is made to fluctuate around its initial value without modifying the number of rooms, the price per square metre of added or deducted surface is 0.45 of the initial square metre price. If the number of rooms is also modified, the average price variation coefficient as a function of the surface is 0.72. Generally, the coefficient oscillates between 0.48 and 0.72. Heavy industrialization should – though this an *a priori* assumption – decrease this to about 0.45, due the large part of investments that does not depend on surface in the financing. Experiences of other countries would be interesting here.

Thermal insulation and soundproofing

These two aspects are treated later in special sections.

Finishings

The noticeable quality improvement is mainly in the finishings. With heavy elements these are, in their execution, less dependent on the skill of operatives, owing to specialization in tasks and limited human interference in the mounting operations. Thus a good average quality together with a better than usual quality of appurtenances and installations is obtained due to conditions of installation.

Durability

Before leaving the quality aspect one matter that has to some extent attracted less attention should shortly be examined: the aging of constructions.

However thorough and long-lasting and perfect the methods and experiments to determine theoretically in a short lapse of time the corresponding conditions and physical effects of the time may be, only time itself will teach us how results of new techniques behave under atmospheric influences. New forms may, therefore, well be based on newly noticed shortcomings and it may, in particular, become necessary one day to reject the present uncovered façades and to return to classic means of protection: cornices, ornamental fronts and gutter-support elements used to prevent water penetration, dripping, etc.

GENERAL OBSTACLES TO THE EXTENSION OF THE USE OF HEAVY ELEMENTS

Once purely technical difficulties are eliminated, the remaining ones are psychological, commercial, administrative and financial.

In the economic field the driving force towards industrialization in France is the necessity for higher rates of pay to bring back the specialists who left the building industry for more productive and better paid jobs. Even use of heavy elements only partly solves the difficulties of recruitment of a good labour force.

However, difficulties arise from the very nature of the market. They have various causes: intervention by authorities and professional organizations; absence of unity of action to initiate construction; out-of-date structures; lack of initiative ascribable mainly to job superintendents, etc. The latters' individualism incontestably causes dispersion and breaking up of programmes and credits. Here lies the first, if not the main obstacle to mass expansion. It requires a special study beyond the scope of this paper.

One of the first consequences is doubtlessly the resistance of job superintendents and clerks of work against repetition. A creative frenzy usually dominates the first discussions on a project and the client is confronted with freakish, often imaginary, but always expensive notions of which he rarely thinks. The representatives of the client rather than the client himself make a point of honour of devising the original solution and demand innovations.

Experience shows that brand dwellings are, like cars, fully acceptable to the public, provided they are carefully planned and that "brand" is synonymous with "quality".

The principle of reasonable repetition should be completed by the notion of series, *i.e.* that continuous number of units advisable to be produced to write off the equipment which repetition justifies in the periods that are normally consistent with wear and tear on that equipment.

Shortage of continuous series, adapted to the production unit's potential, is also a principal difficulty. The number of site units remains considerable, with a ridiculously low average number of dwellings – from 65 per system for low-rent government-sponsored housing to 5 for the private sector.

These difficulties can be summarized in one practically solitary essential applying to all prefabrication but especially to heavy elements, *viz.* to produce industrially elements that are repeated in continuous series. The building problem thus becomes an elementary economic one of permanent and constant outlets and the creation of a commercial market.

CONDITIONS OF PRODUCTION AND TECHNICAL PROBLEMS

MANUFACTURE

The means

There are two separate trends: (a) the permanent – or semi-permanent – factory, tying up major assets; (b) the mobile site installation. The choice is not merely a question of preference, but is guided by many considerations, for example, relating to the commercial market: nature and extent of outlets, concentration of programmes. However, the important point is that the entire site job be done by one uninterrupted gang of "mounters", permitting efficient control and easy financial interest in the productivity of the total job.

It is evident that writing off installation costs under normal conditions (avoiding seriously burdening the unit cost price) makes it essential not to reduce production below a figure consistent with the equipment characteristics, but distinction must be made between assets inherent in the construction system and those resulting from adaptation to a given dwelling type (flexibility of process).

For the first category write-offs over 5 to 10 years are admissible. For the second, if the rigidity of a system should be limited and the use of heavy elements should not compel architectural design within too narrow lines, these assets should be written off as soon as possible (a maximum of two years). This does not exclude, if the market permits, the multiplication of production units by allowing for an accelerated write-off relating to the system of construction of common items operated at less expense (central concrete mixer, steam generating station, items of preparation: reinforcements, plant, etc.).

For production there is, therefore, a threshold, variable according to process, but generally corresponding to the capacity of a homogeneous unit of plant. It seems, for example, that the relative figures are at least 500 to 800 dwellings for the Camus process, about 500 for Logirex and at least 200 for Balency and Coignet. This does not mean that the construction unit on one site should correspond to this figure. In fact, one unit may serve several sites, provided they are not too widely scattered and allow rational use of the plant. The capacity is then fairly variable, being determined by the depreciation value of the equipment on the site. The figure of 100 dwellings for the construction unit could be adhered to, but for normal profitability a maximum action radius of 50 km is required with road transport.

The capacity of the production and construction unit of mobile installations is the same by definition (except for special cases): 120 to 150 or 180 dwellings for Barets or Estiot and 100 for systems using ceramics or prestressing Fiorio or Veran-Costamagna.

We may conclude that the minimum unit of construction or site is 100 to 180, according to the means of production used, *i.e.* permanent factory or mobile installation, the higher figure relating to the latter owing to more concentrated use of handling installations.

Given these thresholds, the annual capacity depends on production forecasts. For example:

Camus	Montesson	2400 dwellings per year at one location.
	other factories	1000–1200 dwellings per year.
Logirex		450–500 dwellings per year.
Balency		1500 dwellings per year.
Coignet	Rouen	600–800 dwellings per year.
	Lille	1200–1500 dwellings per year.

The plant

Here the choice likewise depends on the size of the series, but is also a function of the precision desired. Concern for precision leads to the use of perfected, mechanized plants of machined steel at greater costs, but producing excellent finished faces and usually equipped with heating facilities, permitting rapid setting and stripping of castings after short drying times. Thus the plant has a more rapid turnover.

Certain plants, *e.g.* those of Coignet, were first complicated but simplification is now sought. With other builders the trend is the opposite. The constant preoccupation is, however, to ever greater automation.

Most plants are permanently installed, the elements being moved. A conveyor supporting the mould is of very limited application (Roger Marie processes) because of the difficulty of balancing the phases of manufacture. For mobile installations the plant is more primitive and cheaper: cement forms and wood or sheet iron casting boxes, the re-employment and durability of which is mostly limited to one site. Since the costs of prime installation are lower, a high depreciation rate is not sought, and moulds are not heated.

The production

All elements are designed to be delivered with finished face. Where cleaning and superficial brushing are required, this is done when the casting is stripped or immediately thereafter.

In principle manufacture takes place horizontally, the outer face of the element on top or underneath, *viz.* on top for Camus, Logirex, Balency, Coignet, Estiot, etc., and underneath for Barets. With the last-mentioned process the inner face is plaster covered. Usual outer face coverings are reconstructed stone, stone cement, washed gravel or aggregate, mosaic or stoneware tiles, etc.

For suitable heat and sound insulation, façade walls usually consist of different layers of concrete, at least one incorporating an insulating product.

Interior elements are, irrespective of their complexity of shape, in principle of ordinary homogeneous concrete. The floors are either a solid slab, sometimes with a sunk-in heating coil (Camus, Logirex, Balency, Estiot, etc.) or a hollow slab made with lost shuttering (Coignet), or honey-combed (Estiot) or by hollow bodies of rough casting, *e.g.* concrete, terra cotta (Barets, Estiot, Fiorio, Veran-Costamagna, etc.).

Room-size wall panels are usually made, but certain builders, *e.g.* Balency, adhere to casting *in situ* floors by perfected shuttering, resulting in smooth underfaces that need not be plastered. The advantages claimed here are given below in a section on the choice of techniques and division of elements.

TRANSPORTATION

As previously stated, transport limitations determine maxima in dimensions and weight. Special trailers are mostly used, which have been designed in such a way that panels can be stacked vertically and symmetrically on both sides of a rack. Depending on the type, the trailer makes 3 to 6 trips per dwelling. Transport by rail or water is also possible. For example, Camus supplied their Langres site by barge from their Montesson works at a distance of about 300 km.

For mobile installations the problem of transportation is substituted by handling problems, requiring a no less serious study to avoid grave spalling, particularly during lifting. Various precautions are necessary (trimming, keying, protective casing, etc.). Especially for elements composed of equipment fitted in the installation, protection must be provided by packing. Thus, for example, Logirex's "polyblock" has a box that can be reused and may be seen as a prototype.

Very rigorous planning, in perfect harmony with the site needs, must be behind the despatch service to avoid supply breakdowns and blocking of the assembly site. Camus, in particular, extensively studied this matter on the basis of a system of multiple slips. Perforated cards from a special stencil are made, one for each site. Careful timing permits preparation of the slips at the start of the project or at least some months in advance. Well-planned tractor turning spaces – with road transport – permit their fulltime use, only trailers being out of action for loading and unloading. For example, nine tractors and 22 trailers could enable a daily supply of 35 trailer loads.

INSTALLATION

Choice of techniques, division of elements

Here particularly critical considerations, especially with regard to the characteristics of heavy elements, are involved. Due to the requirements resulting therefrom and the perfection castings can attain, the elements are more and more designed with due regard to their functional nature, *e.g.* complex shapes by casting, incorporation of secondary fittings of woodwork, piping and facilities for installing equipment. Thus façade elements, interior walls, partitions, floors, but also bearing shells (Balency), shafts (Balency, Coignet) or fully fitted sanitary units (Logirex, Barets), weighing up to 8–9 tons, are obtained.

The one-piece, room-size floor elements are, if not the heaviest, at any rate the most cumbersome. Heavy element systems have practically no floors in small elements. Due to progress in shuttering methods, the choice is between panels and cast *in situ* floors. For the latter the following advantages are claimed:

(a) Better load distribution, as floors bear uniformly on all elements.
(b) Taking up the tolerances in installation of vertical elements.
(c) Excellent monolithic connection.
(d) No necessity to weld reinforcements and easier to weld incorporated elements for heating, electricity, gas, etc.
(e) No transport of usually heavy and cumbersome elements.
(f) Possibility of adaptation to varied shapes, though starting from identical vertical elements.

For vertical panels the advantage of prefabrication is more marked, the shuttering of horizontal ones being easier. Here the solution devised by Foulquier should be mentioned. His heated shuttering permits a rapid handling of equipment, specially planned to be moved and quickly reutilized.

For foundations traditional processes are markedly preferred, though some experiments were made with special panels. Logirex is one of the few firms which still prefabricates foundations, although the sole-pieces are cast *in situ* with shuttering, designed for frequent reutilization.

Advanced research of blocks of the volume of a full room can also be mentioned. Mounting reduces to piling up cubes provided with mounting devices and all the necessary openings. This far-reaching solution is still in the experimental stage, though it has been seriously studied. The delivery of the basic cell on the site was planned completely fitted and painted, the joints to be fixed by plastic flanges.

Integration of secondary fittings; finishing

Secondary fittings are integrated to do the bulk of the work in a fixed position and to limit site work to simple assembly operations which are easier to plan, fewer in number and take less time.

Integration of door frames and woodwork has long been included in most systems and special devices have been found to enable the use of columns for installation of electrical wiring and fitting of switches, but some (*e.g.* Logirex) go even further, leaving only the installation and connecting of electrical fittings, appointments and painting to be done on the site. Here sanitary fittings and main piping are already in the polyblock, the nucleus of the dwelling, and joints or simple connections permit the connection of installations when ready for use.

With other firms, assembly by special appliances leads to a search for workers who are expert in more trades to do the finishing (Coignet, Balency). This type of specialization is now greatly favoured.

Tolerances and precision common to the various trades

Building is becoming an industry of assembly operations for elements that can be produced ignoring unity of time and place, which leads to a concept of indispensable precision and, therefore, tolerances.

Here opinions differ widely: some claim precision to be impossible, others assert it can be within a millimetre. These viewpoints tend towards opposite extremes. Confrontation is interesting so as to deduce the actual orientation. Even those who abandon precision (*e.g.* Barets) admit the principle of tolerances, though low compared with normal and traditional. Barets, in fact, adheres to a 1 cm per room tolerance and estimates that the use of wood in the plant permits this precision. This leads to our first notion: precision is a function of the characteristics of the material of the plant.

With Barets conception advantages are that wood gives not very repetitive plants, capable of frequent renewal and thus used for small discontinued series of models, giving flexibility to the process. Relatively large tolerances immediately require a certain play in the connections. They may not accumulate and therefore means to take up the play must be provided. These are the joints.

Two notions may be derived from the above:

The tolerance is applicable uniformly both to accumulated and to individual dimensions. This implies uniting these categories.

The tolerance must be the same for all works, whatever their nature, even if they are works of different trades.

Of those using the latter, Coignet seems to comply with the strictest limits. They claim to be within a millimetre and have the most mechanized, solid and precise equipment. However, they admit that initially the tolerance was not uniform for all work pieces and here they made progress, simultaneously simplifying the plant.

It must, therefore, be recognized that for some operations the tolerance is *a priori* easier than for others, due to the nature of the work or the characteristics of the material. Constancy and uniformity of tolerance must, therefore, be pursued.

Most systems lie between the extremes of Barets and Coignet and claim a precision of some millimeters. A tolerance of $\pm$ 2 to 3 mm, giving a fully acceptable overall tolerance of some 5 mm, seems a reasonable objective. Some complementary principles to be ascribed to a better process are:

Adjustment must be done on two points: suitably levelling a point is easier than aligning a line.

A system of temporary chucks, utilizing joint recesses, should permit satisfactory and simple vertical positioning.

Joints: wind bracing, interlocking, tightness and expansion

The problem of joints is fundamental. Solutions are usually similar for vertical and horizontal joints. Nevertheless, a distinction must be made between façade joints, offering absolute tightness and simultaneously allowing expansion, and internal or butt joints, where only interlocking is essential. Apart from fastening joints, the latter require no special precautions. The first, however, must more or less simultaneously provide water tightness and connection of elements. Mostly the slab cross section is recessed to house a small column serving this double purpose. Arrangements requiring no shuttering – the so-called self-shuttering system – are sought.

To ensure an effective connection a reinforcement is inserted that fastens on to the irons in anticipation of the panels (Camus, Logirex, Coignet, Barets, Roger Marie, etc.). Others install a light metal framework beforehand, having the role of a "tailor's dummy" and no bearing function. However, it aids the calculation of reinforcements and the installation and adjustment of panels.

Though vertical elements are often load-bearing, the column system often permits the transfer of some stress. For example, with Barets horizontal stresses are transferred to bearing floors and staircase wells. Prefabricated portals are also used in this system. The choice is dictated by financial considerations. In principle, this solution is more economic for tall structures. The bearing floors are more advantageous for constructions with five or fewer floors. Water tightness is ensured by lapped joints, vertically with decompression space, horizontally with weathering system. A plastic product, mastic or tape, is always interspersed. The usual decompression space cavity is sometimes used as a guide for assembly.

The expansion problem is generally solved by juxtaposition of independent or independently acting premises which, for a single block, rarely exceed 2 or 3 staircases in length, less than the length necessitating interposition of a special contrivance. Special precautions for soundproofing between adjoining premises are dealt with below.

Design and making of joints requires very special care. A considerable lap, crossing and possibly unkeying joints without impairing the aesthetic aspect, must be striven at. Hence the evolution of forms already foreseen. This is, in fact, the most delicate problem posed by use of heavy elements.

Thermal insulation and soundproofing

Problems here are very important owing to stringent requirements in prefabrication, especially of heavy elements. The difficulties can be summarized under two main headings, more usually inherent in façade walls:

Systematic elimination of thermal bridges between the two faces.

Efforts to achieve homogeneity of coefficients between the elements and their various parts. The desirability of a constant coefficient k cannot be stressed too greatly. More than an average must be realized: a balance of coefficients in the constituting elements.

The use of double or triple glazing, etc., is an indication of great progress here and is a step towards homogeneity of walls. The control of the thermal coefficient must, in the choice of solution, be completed by a main concept: thermal value. Though often neglected, it is highly important to have this value as large as possible in summer and in winter, especially when heating intermittently in rooms where the entire family is absent in daytime.

The soundproofing is (omitting impact noises that are satisfactorily dealt with by freely suspended floors) essentially a function of the weight, a fact illustrated by the process using the most material (Logirex), which has the best soundproofing.

The manufacture conditions for heavy elements give them an advantage over even highly developed traditional processes, as the latest applications confirm. Especially the absence of monolithicism considerably resists sound propagation, in particular, with inner bearing walls. Another solution lies in choice of floor coverings: moquette, various types of carpet, etc.

However, even the best solutions only solve the problem partly and other means have to be sought. One solution could be to isolate those rooms where installations or transmitting ducts cause noise, in particular the sanitary and w.c. bloc and, sometimes partly, the kitchen. Complex glazing here also has advantages, especially against airborne noises.

Most commonly used is the interposition of a cushion of expanded polystyrene, giving a satisfactory thermal and sound insulation, usually completed by the use of different concretes: pozzolana, vermiculite, etc., in successive layers.

In double walls (expansion joints) the same material should not be used for the two walls, or an insulating screen should be interposed.

The problems of condensation arise with those of insulation. Outer faces of elements must be extremely tight but not inner faces, which should form a type of reservoir. Bearing this in mind Barets leaves the plaster as it is, its porosity being important in making the premises habitable. Others use a last outside coating of more or less inferior mortar, not always giving equal satisfaction.

FINANCIAL CONSIDERATIONS

Comparison of costs of dwellings of the different systems is extremely difficult due to differences in floor areas, economic conditions, etc. This is all the more true as very dissimilar processes are encountered. Objective analysis requires application of considerable corrections, which entails estimating purely subjective factors: comfort, amenities, etc. Therefore it is delicate and risky to state a figure. The main factors to be considered are:

(1) Floor area: with equal comfort the price per square metre increases with reduction of floor area.
(2) Quality and degree of appointments.
(3) Speed of construction.
(4) Economy of utilization.
(5) Elements of comfort and amenities: isophony, aesthetics, harmony and proportion of arrangement, quality of finish, etc.

A recent study made with limited means for relating prices to a 50 (habitable) sq. m reference dwelling, even after applying well-founded corrections, contained such considerable divergencies, that corresponding figures cannot be quoted and certainly not be related with processes.

It is, however, interesting to note that in prices of April, 1958, they ranged from Fr. fr. 1,865,000 to 2,325,000 for the only construction built in Paris, including ordinary foundations. It is equally difficult to use sq. m prices, whether habitable or outside measurements. In the cases quoted the habitable sq. m price varies from Fr. fr. 39,700 to 44,920.

Comparison of labour needed per habitable sq. m proves equally variable: from 21.95/hour to 25.76/hour with no correlation to evolution of prices.

Finally, reasonably comparable results were obtained with traditional or intermittent processes developed for use on industrialized sites; such results that, at least under present market conditions, prefabrication with heavy elements cannot claim to be more economical than other processes, nor to be more economical in labour, because experience has shown that numerous traditional processes have made up their arrears and achieved much the same performance. This is due to the fact that price improvement in heavy elements is counteracted by:

(1) Wages, which, in the building industry, are not yet in balance with other industries (progress, explaining a considerable cost reduction, is recorded).

(2) Obligation to write off rapidly, which is normal as long as no continuity of market is assured and as one is still in the stage of first realizations, as with all new industries.

(3) Increasing importance of secondary operations.

ARCHITECTURAL ASPECT

This is one large drawback inherent in every repetition. The expansion of this method of construction is essentially a function of how architects solve this problem. Just as a transition was necessary to proceed from stone to reinforced concrete architecture, men of art now have to create an "architecture of industrialization", with acceptable aesthetics, fitness for habitation and a technique satisfying the essentials of industrialization and, especially, repetition. Although it is beyond the scope of this paper, some attention should be given to this important point.

The practical problem is that of the quality of facing materials of the façade, both during the construction and afterwards.

The indications on improvement of intrinsic quality are here of maximum value. The face or "skin" of a panel gives – doubtlessly temporarily – the main "richness" the author of the plan can use. The necessity of a minimum of research is clear. For example, it is more tolerable to repeat a façade with a balcony than one without.

As already suggested on the ground of functional requirements, it may not greatly complicate new methods to come back to new forms of traditional decorative elements. Removable adjusting elements would permit, at will, elements with or without string courses, frames, etc., just as certain moulds are extensible. In this way we shall arrive at more rigorous classicism in volume and proportion, especially for distribution of solid and voids. By its very nature, imaginative design is not repetitive. Large-scale plans must be studied in this light.

From the research dominating the approach and from its variation a happy balance may result. Distribution of volumes, good composition and a certain rhythm may palliate the austerity and uniformity of rigorously similar elements. The architect's talent can transform monotonous repetition into harmonious order. This short digression only intends to emphasize that there are enough means to counteract the drawbacks of repetition, but they must be studied to prevent lazy solutions such as painted patches in various colours that only spotlight mediocrity of architecture.

PROBABLE EVOLUTION

The preceding remarks show that there is virtually no great difference between the various systems. Through ten years of industrial practical experience (earlier applications were isolated experiments) the following main trends can be indicated:

In the technical field

(a) Standardization of jointing systems and search for self-shuttering devices;
(b) increase of the size of elements;
(c) integration of secondary elements;
(d) more and more complex castings *e.g.* sanitary units, staircases.

In the production field

(a) Trend towards average capacity production units, usually at the limit of the basic plant potential;
(b) a certain mobility of production units (sometimes mobile installations);
(c) improving plants, especially automation;
(d) systematic adoption of artificial curing for complex plants with heavy depreciation;
(e) simplification of work and labour specialization;
(f) reduction of construction time;
(g) attractive wages based on shift work.

Some of these aspects which are not the prerogative of heavy elements have not been treated in this paper: they are elementary for all industrialization.

The salient fact emerges from this list that henceforth improvements and profit should come from more analysis of details. Nevertheless, they may be considerable, as much can be done in the field of rationalization. The immediate future is that in this field, more than elsewhere, great progress can be expected by steady and continuous action for all systems.

A marriage of convenience seems desirable between heavy elements for bearing skeletons (longitudinal and transverse partitions, floors) and light façade elements (curtain walls, filling up façade cavities). Thus a greater variety of composition may result. Logirex's system or that perfected by Foulquier permit adoption of this formula and others will certainly follow suit.

Now it is up to the certainly advanced industry of heavy elements to develop new improvements in its organization and technics.

CONCLUSION

Contrary to the rather general view, a gain of some hundreds of kilograms is, in France, not the main problem. Reduction of weight is of little interest if it results in materials that are more expensive in market price or in manufacture. But the search for materials economic in both these respects is a main aim of French industrialists, the more so since, as indicated, inertia of mass and compactness are sought to satisfy technical factors of comfort, *e.g.* thermal value and sound insulation.

This does not mean that systematically ideal solutions, from the viewpoint of static and dynamic calculation or of waste of calories, should be sought, but the conviction should be that dwelling construction is both an art and a science, due to complexity of services to be supplied to occupants and to the latter's often irrational reactions. For there is a danger that, after the reproaches on excessive artistic care to architects, engineers may soon meet opposite reproaches.

Hence one thinks, as concrete elements will in any case be heavy, the first problem of French engineers is "quality". Quality in its broadest sense and in the light of all those matters that aim at maximum satisfaction of the demands man makes of his dwelling. This warrants the extensive comment of the present study. Never can prefabrication, especially of heavy concrete elements, afford mediocrity. Research for acceptable quality involves considerable consequences due to the client's and even the general public's prejudices, and due to instinctive reserve against all novelty.

All involved in prefabrication should be constantly aware of this imperative obligation, which is loaded with consequences for development of production conditions, and of the future of an industry barely started. One of the consequent and dominating objects is the commercialization of heavy elements by creation of a market in line with the efforts of industrialists and the possibilities of their equipment.

Apart from dwelling construction, application of separate elements should be investigated. These would be used for more or less dissimilar constructions, but benefit from partial industrialization, as normal with light elements.

Dimensional coordination should stimulate development, but cataloguing the most adaptable elements would certainly facilitate – if not ascertain – their commercialization, as no serious competition need be feared from this possibility of outlets for the homogeneous solutions. Above all the problem of constant outlet presents itself even more stringently for entire dwellings. The needs are present: let them be arranged and the market be organized.

Unfortunately, very strong opposition places a dangerous inertia in the way. Only very wide scope action could raise the required spirit. Can we hope that first clients and then architects, engineers and contractors would finally join efforts to embark upon thoroughly new developments, recognized as necessary and involving changes in methods and structures?

As for costs, present conditions would not seem to permit a substantial reduction by prefabrication. Increase of wages and improvement of working conditions for operatives prevail largely over price improvement. The latter will not come before building workers have a balanced position in the labour market. But to reach this stage, action by heavy elements prefabrication will stay predominant, as it was recently and still is now.

The question of details, raised where we discussed tendencies, requires special attention here. More precisely, a systematic chase after waste is the required aim:

Waste in manpower, due to its high cost. Bad or unadapted production processes burden labour costs especially for expensive and not abundantly available skilled workers. Bad division of elements and unbalanced planning of operations seriously have the same effects.

Waste in means, due to ambitious creation of tools out of proportion to the long- or medium-run objectives.

Waste in primary materials, due to bad use, costly applications, costly ostentation where no technical necessity exists, use of overestimated sections, of badly projected forms, etc.

The repetition of these errors, which are *a priori* insignificant, though not theoretically influencing the construction technology, interrupts the production rhythm, causes hesitations and rapidly ruinous delays.

The main possible progress here is the integration in the bulk of main elements of the largest possible number of secondary elements. Research into all connected operations, incorporating all elementary work, may permit factory producers of large elements to progress considerably ahead of less industrialized processes and also of site work shops, as they can much more easily realize the desired unit of precision.

Notwithstanding this, it does not seem necessary systematically to declare oneself "anti-site", because movable installations may, with technical progress, come to the same precision.

Today heavy industrialization plays the role of the spearhead of technical progress. Such industrialization will, in near future, come forward of necessity, as automation and cheap energy will fully take away from the remaining traditional activities the operatives and skilled leaders. The psychological importance of mechanization can already be seen at the sites. Operatives and engineers want to handle mechanical slaves and get away from other activities.

This view of the future should not be neglected when trying to appreciate fully the economic value of the means of advanced industrialization found in the large-panel systems.

Strength and stability of buildings constructed of large structural elements

UDC 624.042 : 691.327/.328

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The age-old experience in constructing buildings with monolithic walls provides so much practical data on the conditions of strength and stability of such buildings that checking of calculations is relatively unimportant and carried out by elementary methods. The extending practice of multistorey construction of large prefabricated units, however, requires a much more careful approach in calculation of strength and stability. At the same time a perfectly accurate calculation of these complex spatial constructions is so time-consuming that it becomes, in practice, almost prohibitive. Therefore the Leningrad Branch of the U.S.S.R. Academy of Building and Architecture carried out several studies to develop fairly reliable and at the same time simple techniques for the design of such buildings. Some of the results of these studies are presented below.

Buildings of large prefabricated components are characterised by the following principles of design:

1. Framed buildings with light members, designated as frame-and-panel buildings;
2. Frameless buildings.

In either case calculations are done in such a way that checking the general strength and stability of the building as a whole becomes possible, which is followed by calculation of individual structural units. The latter calculation being done by standard methods, the subsequent discourse will deal mainly with calculation of the general strength of both types of building.

CALCULATION OF FRAME-AND-PANEL BUILDINGS

A frame-and-panel building with crossties fixed during the assembly process may be regarded as a spatial multi-tiered frame, connected by the floors acting as rigid monolithic horizontal diaphragms to the rigid supporting system of transverse vertical diaphragms (lateral staircase walls) (Fig. 1).

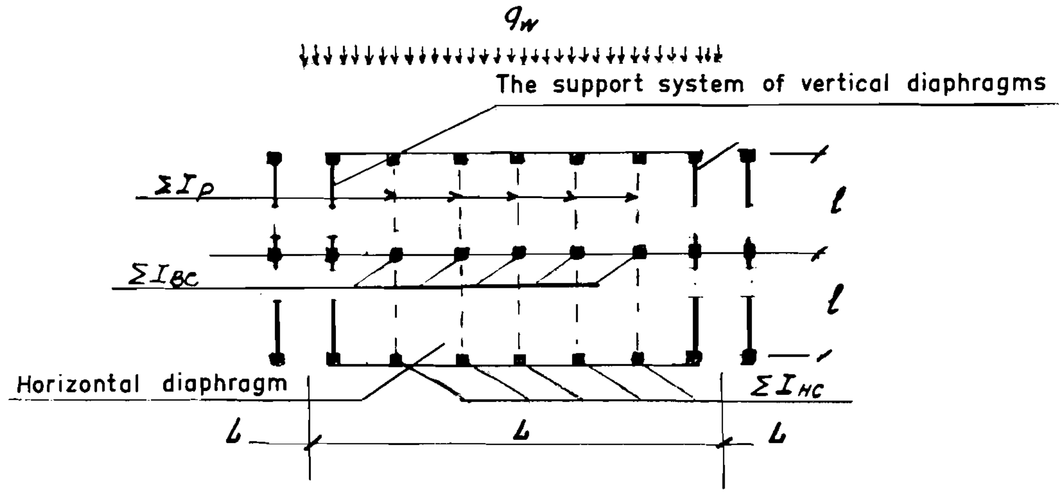

Fig. 1. Standard section of a frame-and-panel building with through vertical rigidity diaphragms.

Special studies have established that the stiffness of horizontal diaphragms in their plane is so great compared with the stiffness of the frame elements that these diaphragms actually ensure horizontal displacement of the frame connected to the vertical diaphragms which, provided the building is tall enough, may be regarded as beam foundations, one end of which is rigidly or elastically fixed in the ground.

As all plane frames of a typical section unit can be substituted by one reduced plane frame with aggregate moments of inertia I_r, I_{ns} and I_{vs} of crossties, external and internal columns can be determined by adding up the moments of inertia of all corresponding frame elements. Similarly the moments of inertia of the supporting vertical diaphragms can be added to obtain a common reduced moment of inertia. The vertical diaphragms of Fig. 1 are provided in case of a greater horizontal load, due to increased building height (up to 14 storeys).

In similar cases single-span (non-through going) diaphragms are sometimes provided in the form of ribbed reinforced concrete panels with insulating plates embedded in the panels during their fabrication. During the assembly of the buildings these panels are joined to the frame columns by means of cast-in lugs after the joints are caulked with *in situ* concrete. Treating such a juncture as a monolithic one, the adjoining columns of the frame should also be added to the aggregate rigidity of the through and non-through going vertical diaphragms.

In any case, the system of calculating a frame-and-panel building as a reduced frame unit (Fig. 2) reflects with passable accuracy the actual work of the building in space and allows a frame-and-panel building to be calculated statically by conventional methods for all kinds of

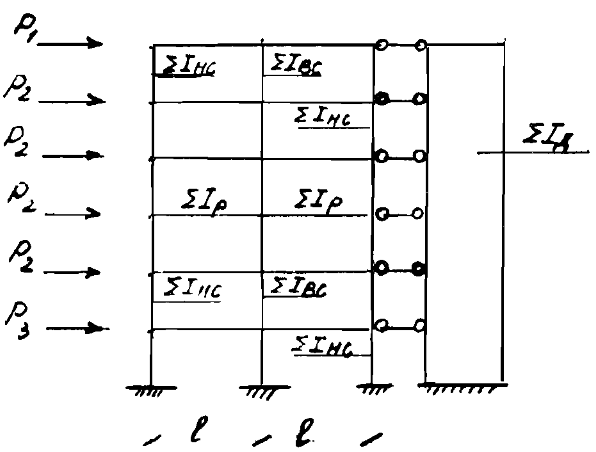

Fig. 2. Diagram of a reduced frame unit.

operating loads. An approximate method suggested by P. P. Shagin proved to be especially effective for calculating a reduced frame construction with fairly accurate results since it obviated the need for solving systems of equations.

From the results of calculations of a reduced frame unit it has been possible to establish certain specific features of the composite action of the frame and the rigid supporting system. It was shown that in contrast to a free frame the moments in frame element units increase not from top to bottom but in the reverse direction. At the same time, with a definite relationship between the height of the building and load, the moments in the upper zone of the supported frame are reversed and may then be several times greater than in the same zone of a free frame.

Another important feature which may be explained by the effect of the great rigidity of vertical diaphragms is the considerable increase of the moments in frame elements due to elastic turning of the foundations of these diaphragms, which not only more than compensate the total effect of the longitudinal forces upon the reduction of the main linear diagram of moments, but also increase the latter from three to four times in the lower and upper zones of the frame respectively. Finally, the moments in the upper and lower zones of the frame tend to equalize and the supporting system is relieved of a considerable part of the load. With increasing horizontal loads, as in the areas of the Far North (R = 154–195 kg/m^2) or in the seismic areas, and, similarly, with increasing height of buildings, the moments in the frame elements increase considerably. The calculation of a frame element for vertical loads is simplified in many respects, since a symmetrical constant load precludes the possibility of the nodes being displaced and at the same time the supporting system is also excluded from the diagram. The same, although approximate, technique may be used in the calculations for temporary vertical loads.

The strength and stability of vertical diaphragms are checked and the rigidity of the building is determined proceeding from the assumption of a rigid foundation.

CALCULATION OF FRAMELESS BUILDINGS

The vertical loads acting upon a building are, as a rule, located symmetrically in relation to the longitudinal axis of the building. Consequently, vertical loads acting upon the building do not cause horizontal displacements and therefore it may be calculated as a two-dimensional system of individual hinge-jointed constructional elements. The calculation of such a system presents no difficulties and therefore we shall leave it out of our discussion. The principal attention must be centred on calculations for horizontal loads.

With horizontal loads acting upon a building, rigidity is assured by the composite action of walls and floors as a result of the presence of the floors, which are rigid in their own plane. Moreover, the diaphragms impart stability to the entire contour of the building in plan. Thus, for simplicity's sake we may regard a frameless building as a cantilever thin-walled rod of a non-varying contour, the section of which is formed by the transverse and longitudinal walls. At the same time we must take account of certain specific features, such as the existence of apertures in walls, the division of walls into separate panels, etc.

The reaction of a building to a horizontal load depends to a considerable extent upon the strength of the junction between the transverse and longitudinal walls. If this joint is not strong enough, the latter do not take part in the general spatial work of the building for horizontal loads. Therefore, we should regard individual transverse walls connected by rigid diaphragms (floors) in their entirety as a reduced section of the cantilever rod.

In the case of a symmetrical or nearly symmetrical location of walls in plan, the displacement under a horizontal load will be the same for all walls. Therefore the total load acting upon a particular design section is distributed between individual transverse walls in proportion to their rigidity.

With an asymmetrical location of the transverse walls in plan, the point of application of the resultant of the external forces does not coincide with the centre of the section. Considering that, we should add to the forward displacement the displacement resulting from the rotation of the section through a certain angle α.

In view of the great rigidity of the floors the contour of the section remains unaltered in the horizontal plane. This makes it possible to establish the dependence between the displacements of individual points belonging to different transverse walls, but located in the same horizontal plane.

Provided the junction between the transverse and longitudinal walls is strong enough, the building forms a closed contour in plan. However, the calculation of a limiting wall, treated as a plate loaded with tangential stresses transmitted to it by adjoining transverse walls, has shown that the distribution of normal stresses in longitudinal external walls is extremely uneven. Normal stresses (the y-axis coincides with the direction of the wall's vertical edge) attain the highest values at the junction of transverse and longitudinal walls, diminishing towards the central part of the section under consideration. Therefore, to simplify calculations we may also treat as a reduced section of a cantilever rod such a thin-walled section of an open-profile with an invariable contour which consists of all the transverse walls and the adjoining sections of longitudinal walls of incomplete width which may be considered to be fully participating in the work of the transverse walls. We shall call that section of the longitudinal walls which acts compositely with the transverse walls the "useful width" of longitudinal walls. This width is determined by multiplying the distances between the transverse wall by a reduction factor, making allowance for the uneven stress distribution of longitudinal walls. In view of the fact that theoretical determination of the reduction factors, with due allowance for the effects of wall apertures and the division of walls into individual panels, is exceedingly difficult, they were determined on the basis of an experimental study of stress distribution in models of walls of different designs (Table I). This work was carried out after the popularization-optical technique with a model scale of 1 : 100.

TABLE I

TYPES OF INVESTIGATED MODELS OF LONGITUDINAL EXTERNAL WALLS

Type of wall model	*Description*
M-1	Model of a solid section wall.
M-2	Model of wall with rectangular apertures.
M-3	Model of wall with rectangular apertures divided into horizontal bands connected at individual points.
M-4	Model of wall with rectangular apertures divided into individual panels connected at corner points.

In designing the models it proved expedient to substitute an actual wall model, following the principle of similarity, by another equivalent model of the same width but of double height. Thus each half of the model, symmetrical in relation to the horizontal axis, represents an actual wall model. As a result, all the points of the model lying on its horizontal axis will have no vertical displacements. In this way it proved possible to simulate the undeformable wall footing in a simple and accurate way.

To prevent the plate from being thrown out of stability, the tangential stresses acting along the vertical edges of the model were applied in such a way as to produce tensile stresses in the model. The adopted distribution of tangential stresses follows the triangle law. In actual testing, distributed loads were substituted by a group of concentrated forces which

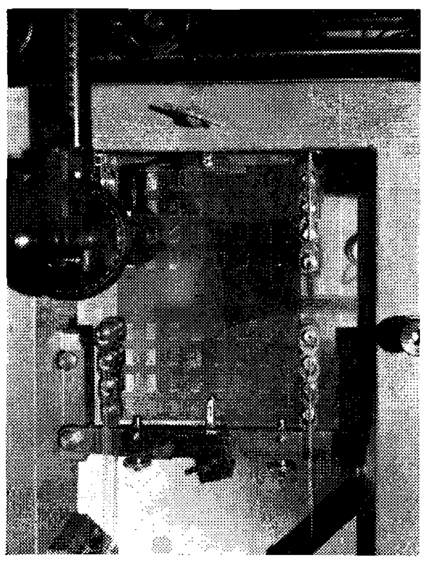

Fig. 3. Models of walls with rectangular apertures.

were applied to the model through special built-in lugs. A clear picture of one of the models investigated may be gained from Fig. 3.

The model was divided into separate panels by making 0.4 mm wide slots. The ratio between the length of the slots and the remaining panels corresponds to the share of the stresses absorbed by the embedded parts in relation to the full section of the wall, assumed to be fully monolithic. The investigation was carried out by the compensation technique. Three horizontal and one vertical sections were studied in detail.

Fig. 4 presents data on a section of the most interesting model from the viewpoint of design, which corresponds to the horizontal section of the wall at its base. The stresses are expressed in conditional units – millimicrons; if expressed in kg/cm^2 the only necessary change would be in the chart scale.

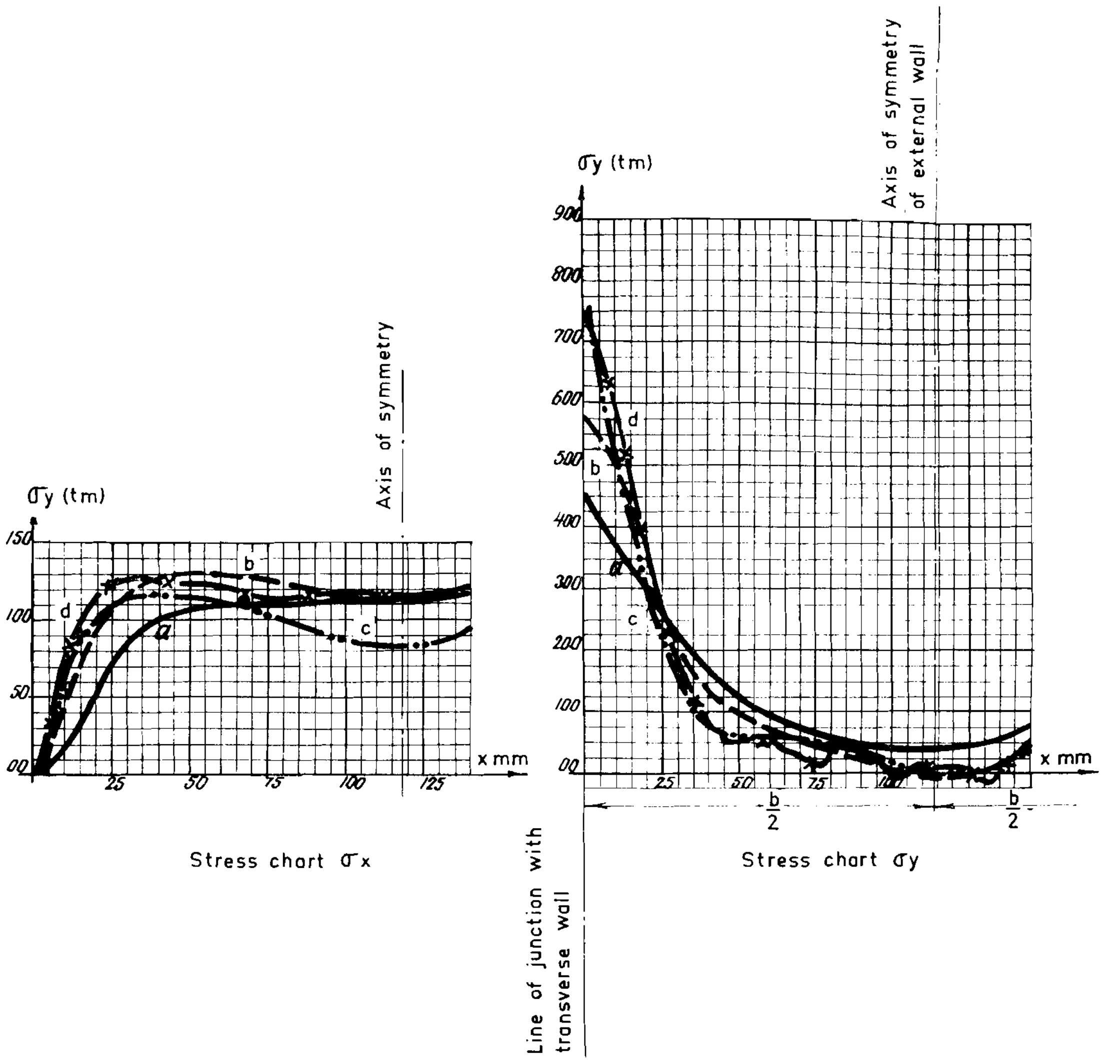

Fig. 4. Character of distribution of normal stresses over horizontal sections of exterior walls (at the foundation). (a) Model of wall type M-1, (b) type M-2, (c) type M-3 and (d) type M-4.

Experimental data confirmed the earlier theoretical deductions concerning the non-uniform stress distribution in longitudinal external walls. The general stress distribution in the types of model we have investigated proved to follow a similar pattern.

In view of the above, the useful width of wall, b, which should be considered as working in conjunction with transverse lateral walls, is determined from

$$S = b\eta \qquad (1)$$

where η is the reduction factor, and b the distance between transverse walls in plan. Here

$$\eta = \frac{(\sigma_y)_{\text{mean}}}{(\sigma_y)_{\text{max}}} = \frac{1}{b(\sigma_y)_{\text{max}}} \int_0^b \sigma_y \, dx$$

The values of reduction factors obtained experimentally for longitudinal external walls of 4–6-storey high buildings, with a distance of 20–25 metres between the transverse walls, are presented in Table II.

TABLE II

VALUES OF REDUCTION FACTORS FOR A HORIZONTAL WALL SECTION AT ITS BASE

No.	*Type of wall (longitudinal axis)*	*Value of reduction factor*
1	Wall of a solid section	0.355
2	Wall with rectangular apertures	0.258
3	Wall with rectangular apertures divided into horizontal (storey) belts	0.221
4	Wall with rectangular apertures divided into panels connected at corner points	0.204

For practical designing we may assume that the variation of the reduction factor along the height of the wall is linear (following the triangle law).

Although the longitudinal external walls are not fully drawn into the work of the transverse walls, they have a substantial effect upon the total rigidity of the building, increasing it 2–2.5 times. Thus it is advisable to design frameless buildings in such a way that there should be a reliable rigid connection between the transverse and longitudinal walls to assure their working in conjunction. This condition is often underestimated when constructing buildings of large prefabricated structural units and warrants special attention.

For the purpose of developing further recommendations for the practical calculation of transverse large-panel walls, specifically those weakened by apertures, an experimental investigation of such walls in a stressed state has also been undertaken. Firstly, we consider a wall weakened by a single asymmetrically located row of vertical apertures. This case is a typical one in practical apartment house designing. The effect of the division of the plane of the wall into panels may be assessed by comparing the patterns of stress distribution which were established as a result of investigating corresponding wall models.

Subsequently, we shall investigate other sections, both in a monolithic model and in one divided into separate panels.

THE EFFECT OF NON-UNIFORM GROUND COMPRESSIBILITY

The erection of brick apartment houses and those constructed of large units on non-uniformly compressible ground without properly reinforcing the construction of walls and foundations with special reinforcement belts not infrequently results in the formation of cracks completely through the walls and foundations and sometimes in failure. At the present time there is an increasing trend towards the construction of assembled frameless buildings with room-size panels, the construction of which is more rigid than brick buildings and those built of large units and, therefore, more liable to be affected by the consequences of non-uniform subsidences. In actual practice, however, the foundations and walls of such buildings are given inadequate reinforcement, or none at all.

With this in view, the Leningrad Branch of the U.S.S.R. Academy of Building and

Architecture has developed a method for calculating frameless buildings erected on non-uniformly deformable foundations.

This method proceeds from the consideration of a beam of a finite length on a Winklerian elastic foundation with a variable bed coefficient, varying symmetrically from K to aK, where the value of the index a can increase theoretically from 1 to ∞. If the system is designed for flexure, the variation of bed coefficients is reversed. A design proceeding from the assumption of a symmetry of non-uniform subsidences apparently yields an over-estimated result, but the calculation is simplified in many respects.

Below we present the main principles of the calculation method we are suggesting for frameless buildings with brick walls and those constructed of large units. With regard to the degree of compressibility the following classes of ground are recognized:

(a) Moderately compressible grounds, with a compressibility coefficient a from 0.005 and a porosity coefficient ξ of 0.5 to 0.8, with mean subsidences of 5 to 15 cm.

(b) Very compressible grounds of the first group with a compressibility coefficient a of 0.05 or a porosity coefficient ξ of 0.8 to 0.95, with mean subsidence upwards of 15 cm.

(c) Heavily compressible grounds of the second group with a porosity coefficient ξ of 0.95 to 1.10;

(d) Non-uniformly compressible grounds with a porosity coefficient $\xi > 1.10$.

Natural beds for wall footings on ground of the latter class include footings on peaty grounds or ground that alternately gets soaked, frozen and thawed and also on permanently frozen grounds which become compressible upon thawing (and heaving) and swelling ground, in the case when foundations of multistorey buildings are laid above the freezing depth.

In all the above instances of grounds of indeterminate compressibility the calculation is done after the limiting values of moments and transverse lateral forces have been calculated. Stable foundations have not been considered.

1. The calculation of the "wall-foundation" system falls into two stages: the first stage is to determine the reinforcements of belts and the maximum shearing stresses in the process building assembly, and the second to determine the same data for the complete building in relation to the remaining time of subsidence stabilization.

2. At both stages of calculation a double reinforcement is designed which corresponds to the resistance of the system to two possible forms of flexure. The lower reinforcement (Δf_u^i and F_u) is laid along the top of split pads of the composite wall footing. The upper reinforcement (f_0^i and F_0^i) is placed in the thickened seams along the top of wall panels of the storeys being assembled in houses constructed of large panels or in the floor planes of large prefabricated units and brick constructions.

3. At the first stage of calculations the area of the double reinforcement section (in cm^2) is determined by

$$f_0^i = f_u^i \frac{1}{\gamma_i} \cdot \frac{1000\, q_{i+1}}{\beta_i^2 R_a H_i} M \tag{2}$$

where R_a is the calculated design reinforcement resistance in kg/cm^2;

i the ordinal number of the storey being assembled, starting with the first storey;

H_i the design height of the system in metres, starting from the top of the split pads of the foundation to the top of the ith storey being assembled;

q_{i+1} the design load in tons per metre of the higher storey, including the weight of the wall, the pressure of the inter-storey floor and the assembly load; and

$\frac{1}{\gamma_i}$ the ratio characterizing the degree of strain of the system and the foundation during the assembly of the building calculated from

$$\frac{1}{\gamma_i} = 0.70 - \frac{i-1}{2(K-2)} \tag{3}$$

where K is the number of storeys being assembled.

If the assembly proceeds at a rapid rate, for instance, "from the wheels", the figure 0.7 in the formulae is replaced by 0.5.

β_i, the flexure characteristic of the general "wall-foundation system", is calculated by

$$\beta_i = \sqrt[4]{\frac{Aq_K}{EI_i}} \qquad (4)$$

where q_K is the design load in t/metre of the completed building and

A the characteristic of the non-uniformly compressible ground, which is determined, depending upon its porosity coefficient, by interpolation from Table III. The loads q_{i+1} and q_K are calculated without safety factors.

TABLE III

No.	Ground classification	E	A
1	Of indeterminate compressibility	1.10	12.50
2	Heavily compressible	1.10	16.00
		0.80	25.00
		0.80	25.00
3	Moderately compressible	0.50	40.00

EI_i, the reduced rigidity of the ith storey being assembled along its panels and apertures, is determined from

$$EI_i = E\frac{2I_1I_2}{I_1+I_2}$$

where I_1 and I_2 are the moments of inertia of the sections of the system calculated for wall panels and apertures, and E is the value of the minimum elasticity modulus in t/m^2 of concrete panels or wall blocks or assembly concrete in buildings of large-panel or large-unit construction.

For brick buildings the value E is determined approximately in accordance with the grade of mortar, Mrk, after the formula

$$E = 0.01\ Mrk\ 10^6\ \text{t/m}^2$$

in which the value Mrk is given in kg/cm^2, and M is the specific value of the bending moment of the system determined by interpolation from Table II by the design value of parameter $\beta_i l$, depending on ground category, where l is the length of the system in metres.

4. At the first stage of calculation the maximum shearing stress (kg/cm^2) is determined from

$$\tau^i_{\max} = \frac{1}{\gamma_i}\cdot\frac{0.15\,q_{i+1}}{\beta_i b H_i}Q \qquad (5)$$

where $\frac{1}{\gamma_i}$, β_i, q_i, q_{i+1} and H_i have the former values,

b is the wall thickness (m) and

Q the value of the transverse force, which is also determined from Table IV from the above value of parameter $\beta_i l$.

5. The section area of the double reinforcement (cm^2) at the second stage of calculation is assumed to be

$$F_0 = F_u = \frac{1000\,q_K}{\beta_K^2 R_a H_K}M \qquad (6)$$

where q_K and R_a have the values indicated above;

TABLE IV

βl	Moderately compressible		Heavily compressible				Of indeterminate compressibility	
	From A = 40 to A = 25		From A = 25 to A = 20		From A = 20 to A = 16		A = 12.50	
	M	Q	M	Q	M	Q	M	Q
2.32	0.143	0.183	0.143	0.183	0.143	0.183	0.143	0.183
2.50	0.153	0.180	0.161	0.189	0.165	0.194	0.167	0.196
2.75	0.157	0.170	0.174	0.189	0.182	0.204	0.209	0.224
3.00	0.156	0.154	0.184	0.180	0.204	0.200	0.221	0.218
3.25	0.152	0.136	0.190	0.170	0.217	0.195	0.246	0.220
3.50	0.146	0.121	0.189	0.158	0.228	0.189	0.262	0.217
3.75	0.139	0.108	0.184	0.143	0.224	0.174	0.266	0.205
4.00	0.133	0.096	0.174	0.129	0.218	0.161	0.260	0.192
4.25	0.121	0.084	0.164	0.114	0.208	0.145	0.254	0.176
4.50	0.113	0.073	0.156	0.101	0.197	0.127	0.250	0.161
4.75	0.104	0.062	0.144	0.086	0.184	0.110	0.235	0.140
5.00	0.095	0.052	0.133	0.073	0.171	0.094	0.219	0.120
5.25	0.087	0.044	0.124	0.063	0.161	0.082	0.209	0.106
5.50	0.081	0.038	0.118	0.055	0.154	0.072	0.203	0.095
5.75	0.075	0.032	0.110	0.047	0.146	0.063	0.195	0.083
6.00	0.070	0.027	0.105	0.041	0.140	0.054	0.189	0.073
6.25	0.065	0.023	0.098	0.035	0.130	0.046	0.176	0.062
6.50	0.060	0.019	0.090	0.029	0.120	0.038	0.162	0.052
6.75	0.056	0.017	0.084	0.026	0.112	0.034	0.151	0.046
7.00	0.054	0.015	0.081	0.023	0.108	0.030	0.146	0.039
7.25	0.051	0.013	0.077	0.020	0.102	0.026	0.138	0.035
7.50	0.049	0.012	0.074	0.018	0.098	0.024	0.132	0.033
7.75	0.047	0.011	0.071	0.017	0.094	0.022	0.127	0.030
8.00	0.045	0.010	0.068	0.015	0.090	0.020	0.121	0.027
8.25	0.043	0.010	0.065	0.015	0.086	0.020	0.116	0.027
8.50	0.042	0.009	0.063	0.014	0.084	0.018	0.113	0.024
8.75	0.041	0.009	0.062	0.014	0.082	0.018	0.111	0.024
9.00	0.040	0.008	0.060	0.012	0.080	0.016	0.108	0.022
9.25	0.039	0.008	0.059	0.012	0.078	0.016	0.105	0.022
9.50	0.038	0.007	0.057	0.011	0.076	0.014	0.103	0.019
9.75	0.037	0.007	0.055	0.011	0.074	0.014	0.100	0.019
10.00	0.036	0.006	0.054	0.009	0.072	0.012	0.098	0.016

H_K is the height of the system (m) from the top of the split pads to the upper reinforcement level;

β_K the above-mentioned characteristic, which includes the reduced rigidity value of the completed system with allowance for height H from the top of the split block pads to the top of the cornice block; and

M the value of the moment determined from Table IV after the values of the parameter.

6. The maximum shearing stress (kg/cm²) at the second stage of calculation

$$\tau_{\max}^{K} = \frac{0.15\, q_K}{\beta_K b H} Q \qquad (7)$$

where values q_K, β_K, b and H are taken from the preceding paragraph and value Q is determined from Table IV by the same parameter $\beta_K b$.

7. The total value of the foundation reinforcement indicated for the top of the split pads is found from

$$\sum F_u = F_u + f_u^1 + f_u^2 \ldots + f_u^{K-1} \qquad (8)$$

8. The total maximum shearing stress (kg/cm^2) which is determined with allowance for the assembly sequence of the system is

$$\tau_{\max} = \tau^{K}_{\max} + \varphi_1 \tau^{K-1}_{\max} + \varphi_2 \tau^{K-2}_{\max} + \varphi_3 \tau^{K-3}_{\max} \leqslant R_p \tag{9}$$

where R_p is the minimum design tensile resistance of wall material and φ are the reduction factors given in Table V.

TABLE V

Number of storeys		*Values of* φ	
7	$\varphi_1 = 0.98$	$\varphi_2 = 0.89$	$\varphi_3 = 0.64$
6	$\varphi_1 = 0.95$	$\varphi_2 = 0.84$	$\varphi_3 = 0.75$
5	$\varphi_1 = 0.96$	$\varphi_2 = 0.75$	$\varphi_3 = 0$
4	$\varphi_1 = 0.94$	$\varphi_2 = 0.56$	$\varphi_3 = 0$
3	$\varphi_1 = 0.89$	$\varphi_2 = 0$	$\varphi_3 = 0$
2	$\varphi_1 = 0.75$	$\varphi_2 = 0$	$\varphi_3 = 0$
1		$\varphi_1 = \varphi_2 = \varphi_3 = 0$	

9. Calculation by Table IV is restricted by the limiting value of the parameter $\beta l = 2.32$; if the latter diminishes the calculation becomes one of the "beam wall" type. In those instances, when the value is within the range of 2 to 2.32, the calculation may be carried out in accordance with the conditional characteristic

$$\beta = \frac{2.32}{l}$$

The calculation of a beam-wall system has not been solved theoretically as yet.

Precision design of large prefabricated reinforced concrete elements

UDC 691.327/.328 : 621.753

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Construction units prefabricated in factories must be assembled at building sites and must, therefore, correspond to both the design and the architectural composition without any previous selection or subsequent matching-up of separate units once they have left the factory. This requires similar units to be geometrically equal, *i.e.* interchangeable, and, therefore, manufactured with a fixed degree of precision, regulated by a tolerance system.

However, sometimes the actual dimensional deviations of units and those of the assembly considerably exceed the adopted standards. Usually specifications give no limitation of dimensions of supporting surfaces or of requirements of planarity of panels; the size of tolerances is not limited as a function of character of jointing and of the number of elements. There is poor agreement between the factory standards for prefabricated reinforced concrete articles and the requirements of specifications for reinforced concrete jobs.

The lack of consideration of existing dimensional deviations causes alterations in the mounting process, wasteful expenditure in labour costs, prolongation of construction schedules and increase of construction costs.

Application of prefabricated reinforced concrete in the U.S.S.R. is, besides a general and great increase in volume and in the extent of the assortment of articles, characterised by enlargement of constructions, use of large units and higher standards of prefabrication in the factory. The increase of overall element dimensions reduces the number of joints but increases the element's length, thus necessitating a greater accuracy of manufacture; a high degree of completion of a component demands a more thorough jointing. Use of large units – parallelepipeds – requires a high precision of lines of joints and of parallelism of jointed surfaces. Further development of concrete prefabrication will necessarily demand thorough precision design.

The building industry has no precision design for prefabricated reinforced concrete elements, nor an elaborate system of tolerances. At the same time the increasing use of large elements for dwelling construction urgently calls for a solution in this respect.

For the tolerance problem solutions are sought in two directions:

(a) At establishing standardized values of tolerances on the basis of a scientific methodology.
(b) At elaborating precision design methods to solve practical problems in the determination of tolerance values for reinforced concrete constructions and their details.

To arrive at a justifiable definition of tolerance values is a complex matter for which due consideration of constructive design requirements and of numerous factors relating to manufacture technology and erection of constructions is required. The complexity arises because both the interdependence of these many factors and the degree of their effect upon the tolerance value are, up to now, insufficiently investigated.

Dimensions and the shape of precast reinforced concrete articles have deviations from the nominal which are functions of the following production factors: geometrical errors of forming machines, moulds, tool attachments and appliances and the presence in them of thrust and concrete weight deformations.

Not all the geometrical parameters of articles have rigid and steady constancy in time. They change depending upon technological task, concrete consistency, coarseness of aggregate, the regime of vibration and of the delivery of concrete into forms, variations of temperature and, in addition, they change because of the natural wear of working surfaces and from hinges. At the present time there is no possibility of giving a mathematical expression of the value of the error of production as a direct function of the numerous conditions of manufacture and erection. Hence, in the solution of the problem of establishing rational tolerance values we now utilize statistical methods of investigation.

The first stage in the solution of the problem is the collection of statistical material: measurement and recording of actual dimensions of an article and of the position in erection. The second stage comprises a systematization of records, the drawing up of distribution curves and the calculation of statistical characteristics for a variety of conditions of manufacturing and erection.

The deviations calculated for the normal flow of the technological process are fundamental in the settlement of the size of tolerances.

The experience in the field of mechanical engineering, where the questions of interchangeability and tolerances have been studied for more than thirty or forty years, deserves attention. The basic concepts of tolerances, fits and dimensioning chains specified in mechanical engineering, as well as the system of determining the maximum and minimum actual and nominal dimensions, clearances and fits, are utilized in establishing the main principles regulating prefabricated reinforced concrete construction tolerances. The method of calculating the value of tolerances for details which are parts of units, by means of solving dimensioning chains with the application of the laws of the theory of probability, is applied.

As is well known, a distinctive feature of civil engineering structures is their unchangeability, rigidity and solidity after assembly. Prefabricated house building is characterized by a large number of linear dimensions of details entering a unit or making up a unit, with the prevalence of plane elements, *i.e.* panels and blocks.

"The shaft hole system", the terminology used in mechanical engineering, is not applicable in civil engineering. If we take the dimensions of components delivered for erection as the initial dimensions, then we may utilize "the system of panels", while if we consider the dimensions between the lay-out control axes as unchangeable, then we may apply "the axis system".

The actual shapes of machined surfaces differ from their theoretical geometrical shape by an amount equal to 0.2–0.3 of the value of the specified tolerance, and, therefore, shape distortions have no substantial value in the determination of the size of tolerances. The actual shape of reinforced concrete details and especially the plane of panels is of great significance in ensuring the prefabrication qualities of components of a building. The value of the deviation of the panel surface from the geometrical plane usually reaches the value of specified tolerances, or even exceeds them.

Permissible errors in the reciprocal position of units in a construction or structure and allowable deviations of the shape and dimensions of units which secure the specified maintenance requirements for the operation of the structure, are all determined by means of geometrical computations, with the use of positions of dimensioning chains and the theory of probabilities.

FACTORS DETERMINING THE SIZE OF TOLERANCES

The size of a tolerance must take into account design requirements guaranteeing a normal exploitation of the structure or of its individual parts and of the manufacturing and erection possibilities of the modern level of building technique and precision of measurement, which is determined by the condition of the concrete surface and by the measuring appliances used.

CONSTRUCTIVE DESIGN REQUIREMENTS

Existing constructions and structures, due to the inaccurate manufacture of separate components and due to errors in the assembly of units, are operated under conditions which are different from those specified by the designer. Inaccuracies in the manufacture of separate details lead to changes of geometrical dimensions of calculated cross sections, while deviations from the design position of these details at joints leads to changes of free lengths, spans, conditions of fixation, and to the appearance of eccentricities and changes in values of loads and moments.

Experience shows that prefabricated reinforced concrete constructions calculated by the limit design method give reliable service. This gives a basis for the assumption that manufacturing and erection inaccuracies of reinforced concrete constructions are to a sufficient extent calculated (or compensated) by the coefficients of conditions of work, overloads and uniformity of materials.

The study of the questions of how the strength, residual deformations, rigidity, crack formation and other limit conditions for which prefabricated reinforced concrete structures are calculated depend upon the real state of these structures, and, on that basis, the study of the determination of tolerances are undoubtedly of interest but are themes for special investigation.

MANUFACTURING TECHNOLOGY

Geometrical parameters of reinforced concrete constructions and components are made, altered and determined in the manufacture of the article. We have made 16,500 measurements of dimensions of form equipment and reinforced concrete articles. The results were systematized, distribution curves were drawn and statistical characteristics were computed.

Let us present some of the results of observations. Metallic forms for the manufacture of multi-hollow floor panels, depending upon the conditions of support or suspension, change the value of the deflection by 2 to 3 mm. In connection with the unevenness of vertical supports of the base, upon which the forms rest in the period of concrete hardening, the actual out-of-plane deviations were up to 30 mm. When the forms were stacked, with the bottom form laid upon the foundation, and checked with an accuracy of $\pm$ 1 mm, then the out-of-plane distortion of plates was from 5 to 8 mm. Insufficient rigidity of forms in use makes it possible for the lower surface to have a sag of up to 100 mm.

By vibration of forms filled with concrete on vibroplatforms, the edge forms are deformed

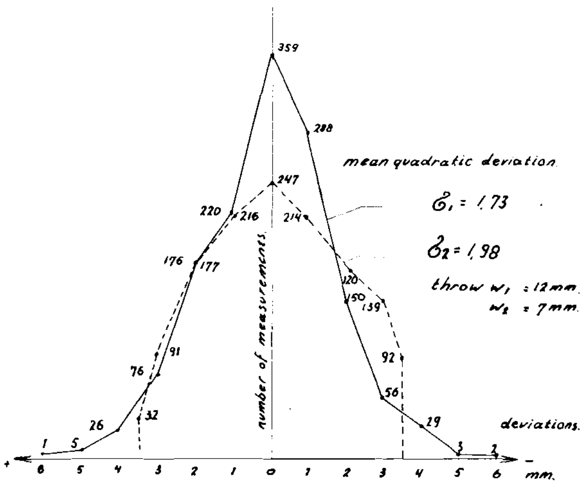

Fig. 1. Distribution curve of marks on the surface of form-cars (moulds) (1380 measurements). ——— measurements of forms in operation, – – – – by records in certificate (tolerance $\pm$ 3.5 mm). The curve breaks off abruptly at the boundary of the tolerance.

and the width of the article increases, especially in the middle of the form length, from 5 to 10 mm. If no ties are provided, the deformation of rims increases with each cycle along a curve which at first ascends and later fades away, reaching 36 mm. When plates were manufactured in metallic forms 140 mm high, their average height was found to be 150.2 mm. At a nominal width of the plates of 1190 mm, the actual average width was found to be 13.5 mm greater. At nominal lengths of plates of 3.0, 3.2 and 3.6 metres the actual average length was from 8 to 10 mm greater.

Measurements of travelling moulds have indicated a regular character in the distribution of deviations from the average plane of the pallet basis (Fig. 1). Form-cars whose bases were not machined mechanically were out-of-plane as follows: 7.4×4.4 m cars, 13 mm; 7.4×2.3 m cars, 8 mm. In forming panels on travelling moulds a gap equal to 11.5 mm is formed between the base and edge mould, which leads to a useless waste of concrete. The height of the panel, however, in this case had an average value of 221 mm at a theoretical dimension of 220 mm, and the deviations from the mean value were $\pm$ 20 mm.

In forming panels with a nominal 190 mm height, the actual average height was found to be 195 mm. It is characteristic that after forming, extracting wedges, removing forms and ceasing heat treatment the panel height decreases 5 mm.

The study of concrete forms for the manufacture of outer wall panels has shown that length deformations were at a variance of $\pm$ 2 mm to $\pm$ 13 mm and that the average value of length deviations was about 5 mm; width deviations were at variance from + 1 to + 10 mm and their average value was about 8 mm. The average value of the height of the edge mould was in correspondence with the nominal, but here there were deviations from + 10 to — 15 mm. The average value of out-of-plane surface deviations of matrices was 10–12 mm for the entire length, while local deviations per metre of length were 5–6 mm.

Smooth moulds covered with 6 mm sheet steel have out-of-plane deviations of 10 to 12 mm along the full length, while local deviations are -5 mm and local lips at joints of sheets were up to 2 mm. But if steel sheets with thicknesses from 8 to 10 mm are used, the surface is considerably better in quality. Local deviations reach 1 to 2 mm, while general deviations for the full size of the mould are from 7 to 8 mm.

A sample check of units produced over a number of years confirms that the average deviations from the nominal size as a rule have plus values.

The most important technological arrangement that determines the geometry of an article is the form. The geometry of an article depends upon the accuracy and rigidity of its forming surfaces and upon the reliability of the foundation it rests on. During the period of action of the compacting force the concrete, being a pseudo-liquid body, acquires mobility, fills the form and exerts a hydraulic pressure upon the rim fitting. Besides deforming the forms, vibration has a very harmful effect upon the permanence of the form dimensions, causing hinge, lock and edge mould wear.

When a reinforced concrete article is manufactured, some part of its surface is unconfined, *i.e.* it is not in contact with any part of the form. Usually this is the upper horizontal surface. In order that the surface should become even and smooth, the concrete is evened out and a surcharge is put upon the concrete during the period of its laying and compacting, with a subsequent finishing.

The design of the mould, whether stationary or mobile, has a considerable effect on the accuracy of the geometrical form and dimensions. In the conveyor method of manufacture, 17 impulses disturb the inertia of the formed concrete from the instant the article starts to its completion, due to the cyclic conveyor operation, disregarding a variety of bumps on rail splices, roll gangs. etc. In the mobile method of the organization of manufacture there are two such impulses when either pallets or forms are handled by a crane.

Of all the forms of organization of manufacture investigated from the point of view of securing the unchangeability of the geometry of articles made by forming, the stationary method of casting on moulds should be recommended.

Taking into account that the dimensions of reinforced concrete articles tend to increase as compared with their nominal values, in order to eliminate the waste of materials in the process of manufacture due to these increased dimensions, minus tolerances have to be specified for the dimensions of the article, directed from the nominal into the body of the article, and the technological equipment and fits should be designed on the basis of these tolerances.

ERECTION OF CONSTRUCTIONS

Conditions of erection determine the constructive design and planned solution of a structure and the design of the units of joints.

In designing buildings and structures the guiding requirements are the functional qualities, while erection conditions are secondary. However, the designer has to foresee that the constructions will suit a variety of transporting and erection conditions.

The accuracy of erection is, in the first place, determined by the accuracy of the manufacture of individual prefabricated elements and, secondly, by the precision with which they are assembled. Precision requirements for the manufacture of various kinds of constructions have to be differentiated depending upon the application of the construction.

Joints of prefabricated members, which control the transmission of forces from one loaded member to another, and which secure the safety of the protecting elements, play a decisive part in prefabricated home building. The number of joints, which are the weak spots in any prefabricated structure, should always be reduced to a minimum.

In the process of erection assembly of some of the members is limited in the size or by formerly erected structures, while other elements are erected consecutively. The accuracy in the assembly of prefabricated members depends upon the number of elements making up a dimensioning chain.

In order to obtain stability in the process of erection the mounted members must be given no chance for displacement. Frame members are columns with two degrees of freedom, while panels have one degree of freedom. In order to secure a panel, it must lose one degree of freedom; this only requires that a second panel be placed perpendicular to it and that they should be joined together. In order to secure a column, it has to lose two degrees of freedom, which can be attained by connecting it with two members that are mutually perpendicular to each other (and which, in their turn, are undisplaceable). The accuracy of erected constructions depends upon the stability in the process of erection.

The arrangement of flat splices perpendicular to the column axis unavoidably leads to the formation of an inclined clearance. In the practice of erection of reinforced concrete columns, inclined clearances usually are from 8 to 10 mm, while at times they even exceed 20 mm.

Columns with spherical joint surfaces can be easily erected, whether having concrete, metallic stamped or cast heads. Such a column splice makes any adjustment in line possible without disturbing the tightness of the joint and also ensures the axial transmission of loads.

Of all the joints between floor beams normally used, the method of jointing of a beam with a cantilever on a sloped surface, thus offering a chance to regulate the vertical marks of the collar beam ends, deserves attention.

Floor panels are placed on beams or on carrying wall panels freely supported. An even ceiling surface, without steps, requires that the lines of support be arranged parallel. In supporting floor panels on four points at the corners one of the supports must be in a position to be adjustable vertically.

Serious erection discrepancies are caused by panels which are distorted out of plane. In such cases floor members rest on three points, while wall elements have steps on the wall face. Of special significance is the provision of the minimum necessary size of a supporting surface, a reduction which may, due to stress concentrations, shear off the concrete.

Let us present some data obtained by analysis of 7,800 measurements made in the erection of a variety of reinforced concrete constructions.

Vertical marks of column heads have 31–37 mm deviations from the mean arithmetical horizon at each tier; they increase on the upper stories to 60–70 mm. The deviation of vertical height of column heads is of an accidental nature (Fig. 2). The height of the collar beams of the same columns to some degree follow the column head marks, and their deviations are also accidental. This permits the conclusion that the existing practice for controlling the column head vertical marks and adjusting level to a common horizon by means of introducing packing pieces, does not solve the basic problem of erection accuracy: that of securing the collar beams a horizontal position, so that the prefabricated plates can be laid on them in one plane. The temporary erection of columns, without adjustment, with a partial sampling of elements (from 5 to 10%), gives precision indices that are no less accurate, but lessens labour and reduces material expenditures.

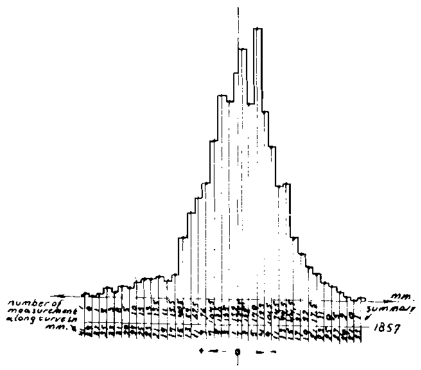

Fig. 2. Curve providing a practical summary of the distribution of the largest deviations from the arithmetical mean of the horizon (1857 measurements at 1 mm intervals). Horizontal scale 5 : 1; vertical scale, the number of marks for each given measurement. Mean quadratic deviation $\sigma = 10.4$ mm. Range $\pm 3\sigma = 6 \times 10.4 = 62.4$ mm. Throw $W = X_{max} + X_{min} = 41 + 33 = 74$.

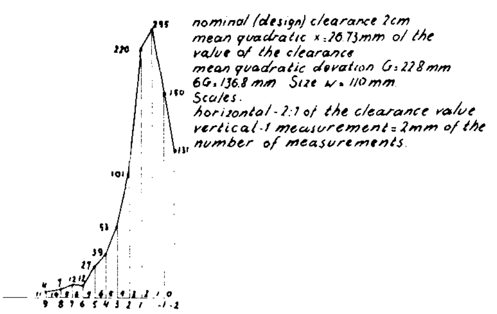

Fig. 3. Summarizing diagram of the distribution of 1051 measurements of panel clearances of outer walls – at the top and bottom of the panel – of large-panel frameless houses.

We have established the character of the distribution of vertical mark deviations, of the displacement from the designed panel axes and of gaps between them in large-panel houses (Fig. 3).

The most complex jointing of prefabricated elements of a building occurs in the erection of the stairway complex, since there the fully finished elements must be jointed on inclined angles and must provide smooth surfaces without steps. In order to compensate manufacturing inaccuracies the joint of the platform and of the flight of stairs must be solved for an inclined support.

For precision design, prefabricated reinforced concrete members may be united into groups:

(a) joined under an angle;

(b) joined in one plane;

(c) joined in a successive series of elements.

A characteristic erection requirement is the need to provide maximum clearances for mounting articles, which makes it possible to bring them easily into the desired location.

Based on the above, in the erection in accordance with the system of "constant axes", minus tolerances must be specified for individual prefabricated members.

SURFACE CONDITION

The surface of reinforced concrete panels has a natural unevenness formed by small cavities, the roughness of shaping surfaces and by aggregate on the free surface of the concrete.

Both unevenness and smoothness of a concrete surface may be determined by the value of the mean quadratic deviation of the section under investigation (on a section of a straight one-metre line: 200 points at 5 mm intervals) from the ideal surface.

The value of the mean quadratic deviation is an objective criterion of the surface condition. Each value of the mean quadratic deviation correspondingly represents a definite unevenness of the surface of concrete (Fig. 4).

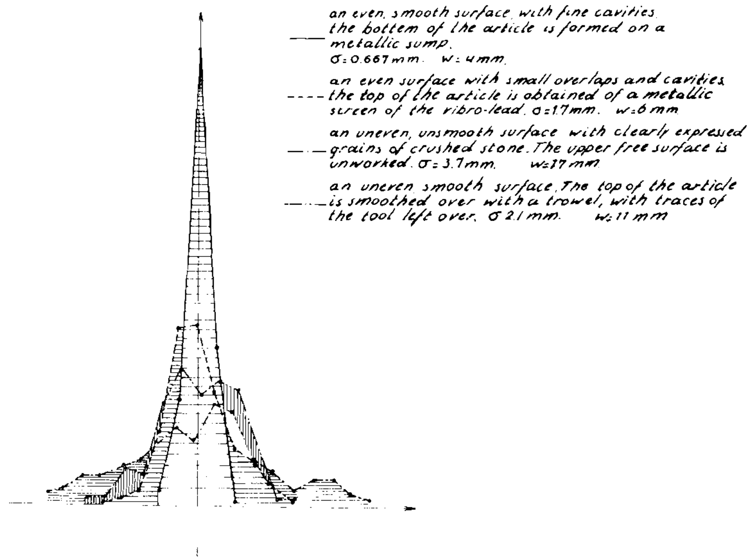

Fig. 4. Diagram of the surface states.

Concrete surfaces received after forming in metallic forms offer the possibility of measuring the article with a practical accuracy in the range of 2 — 3 mm. In the manufacture and erection of reinforced concrete constructions metallic tapes are used which have a 1 mm accuracy in measuring dimensions up to 2 metres and $\pm$ 5 mm for dimensions up to 20 metres.

CONCLUSIONS

On the basis of the well-known law of stability of a large-volume statistical series we can assert that if we have conducted measurements of dimensions of an article and of the position of constructions during erection for a normal process of technology, then the respective distribution of deviations characterizes the practical accuracy of manufacture and erection of the reinforced concrete articles. This may serve as initial data for the setting up of standardized tolerances.

The value of a tolerance is determined as the product of the value of the mean quadratic deviation of the practical distribution multiplied by some precision factor

$$\delta = 2t\sigma$$

The precision factor should be given a value between 2 and 4, depending on the application of the construction or structure and also taking into account the consequences of error. If we assume that the distribution is Gaussian and that the probability that the dimensions of the member will exceed the range of tolerances is 0.27% (the precision coefficient $t = 3$), then under a symmetrical arrangement the tolerance will be

$$\delta = \pm 3\sigma$$

Tolerances determined on the basis of practical deviations with a regular nature are being corrected continuously with the development of the manufacture of prefabricated reinforced concrete articles.

Depending upon the requirements of exploitation, conditions of joints, and values of dimensions, tolerances are grouped into classes of precision in a common system of tolerances.

It is not advisable to specify tolerances too closely, since with a rise of accuracy the cost of fitting rises hyperbolically, and in some cases the attainment of a higher accuracy is technically impossible.

The utilization of tolerance standards permits precision calculations to be conducted by means of laws of dimensioning series, expressing the geometrical connection between details and members which enter a unit or block.

In determining the closing link, which usually represents the distance between axes or the value of the clearance, standardized tolerance values are set up for all link components. The solution of the equation of a dimensioning chain about the closing link determines the value of its tolerance.

In determining the tolerance of component links for cases when the tolerance of the initial link is specified, the principle of equal effects (considering that the tolerance for all links has one value equal to the mean value) is utilized

$$\delta_{\Delta} = \left(\sum_{1}^{m-1} \delta_i^2 \right)^{\frac{1}{2}}$$

at $\delta_1 = \delta_2 = \delta_{m-1}$;

$$\delta_{mean} = \frac{\delta_{\Delta}}{(m-1)}$$

where δ_{Δ} is the tolerance of the initial link,

m is the number of links in the dimensioning chain, and

$\delta_1, \delta_2 \ldots \delta_{m-1}$ are the tolerances of component links.

If calculated tolerances should be practically unattainable, then compensating factors must be introduced for the construction, or partial mutual interchangeability should be resorted to, so that the tolerances would be summated by quadratics

$$\delta_{\Delta} = \frac{1}{t} \sqrt{\lambda_1 \delta_1^2 + \lambda_2 \delta_2^2 + \ldots \lambda_{m-1} \delta^2_{m-1}}$$

where λ are factors less than unity. The smaller the value of λ, the greater is the risk of upsetting the tolerance.

Tolerances should be specified with due attention to the state of the concrete surface and to the practical accuracy of measurements.

For the solution of the problem of establishing tolerances a systematic observation and an accumulation of measurements of dimensional deviations should be organized at the leading plants of prefabricated reinforced concrete constructions and at the erection sites of large-panel construction. Simultaneously, the state of the process of technology should be recorded and all the factors which affect accuracy should be comprehensively studied.

By making comparisons of the results of measurements of concrete samples taken from the current plant output with the accumulated standardized observations, the state and accuracy of the technological process can be verified.

For the further development of methods of specifying tolerances and for making accurate calculations it is necessary to organize an exchange of experiences of organizations which conduct such work.

Problems of jointing large elements in prefabricated dwellings

UDC 691.81 : 693.5.012.43

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In buildings made of large prefabricated elements, joints are essential for rapid assembly on site and for the external appearance of the completed building. They must, therefore, meet a number of requirements, the most important of which are architectural strength and operational and technological requirements.

The architectural requirements are, above all, associated with cutting the walls into separate elements, giving a certain rhythm in the segmented façade without affecting the essence of prefabricated construction. The outer decoration must be simple and simultaneously meet operational requirements, ensuring long service of façade and joint.

At the same time the weight of elements should comply with the crane lifting capacity and other transport facilities. Outer walls are usually cut into one or two room-size elements, since the larger the element the smaller the number of joints and the faster the assembly process (Fig. 1).

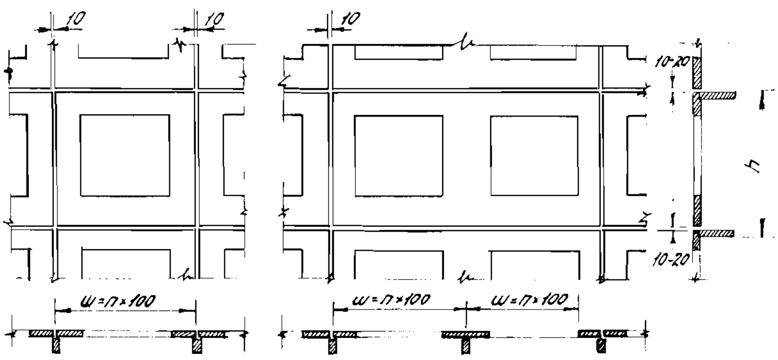

Fig. 1. Room-size elements for outer walls.

The strength of the joint must be related to general conditions of rigidity and stability of the building. Adequate transfer of vertical loads must be obtained. These requirements demand especially strict observation in case of load-bearing elements such as columns and beams that support outer and inner wall panels.

The operational requirements are associated with heat and sound insulation and also with air- and watertightness. The technological requirements are related with construction facilities that permit production of elements without complicated patterns, convenient erection and simple filling of clearances between mounted elements.

Below a brief outline is given of the design of joints used in the U.S.S.R., and of some results from the study of joints.

Design of joints in large-panel buildings is largely dependent upon the design of the panels themselves. Above all the tendency is, however, to make them of the simplest possible shape in order not to complicate the pattern of the panel.

The horizontal joints of outer wall panels are usually made on the upper edge level of the ceiling panel (Fig. 2a, b). Their accepted thickness is 10–20 mm. The planes of upper elements to be jointed are made straight and those of lower elements with rebates for supporting the ceiling panel (Fig. 2b).

During erection the horizontal joints are filled with cement mortar that is generally of a workable consistency and with a standard cone setting of 8–10 cm, trade mark 50. In winter calcium or sodium chloride are added to accelerate hardening. Joints without wet processes (no cement mortar) have so far found no wide application. Recently an attempt has been made to replace cement mortar by hemp ropes to fill joints of houses made by the cassette method.

Both horizontal and vertical joints are generally made open to the outside without any cover strips. On the outside the joint is pointed with cement mortar and furnished with chamfers, convenient for run-off of water. Sufficient attention is not always given to the last requirement and water may flow through the joint when filling with mortar is not done properly.

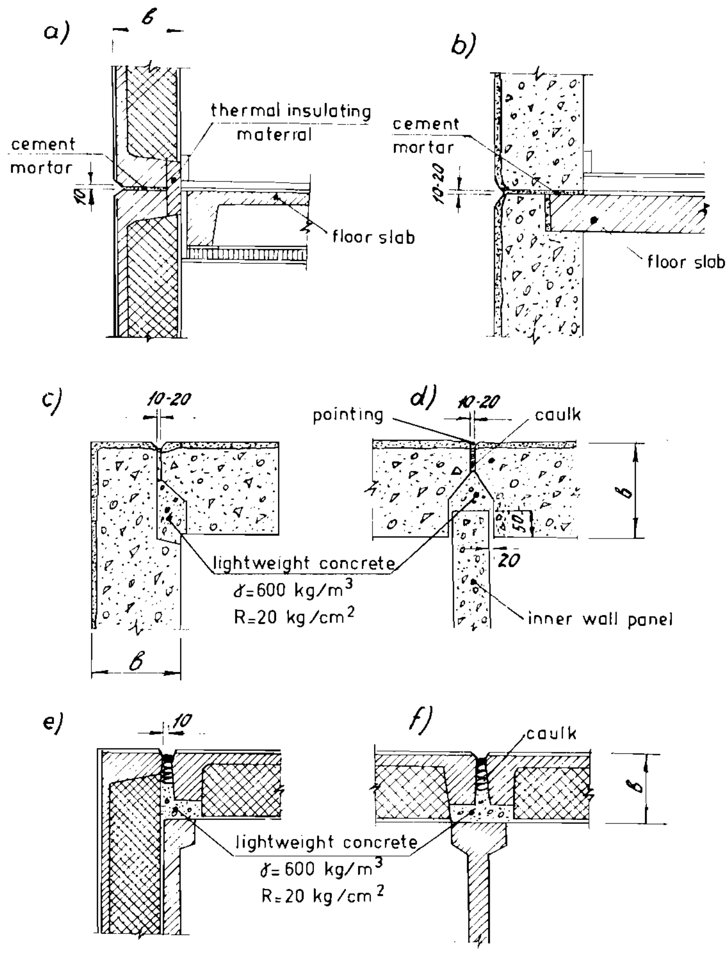

Fig. 2. Joints of outer wall panels.

For inner walls vertical joints are also on cement mortar. Sometimes, depending on the design of inner wall panels, jointing is done dry by steel insertions welded during erection. Vertical joints are mostly made opposite the inner wall panels. The vertical joint with the façade surface is generally 10 to 20 mm wide. The joints are made airtight by thoroughly filling with mortar. For this purpose they are made at least 6–10 cm wide on the side of the premises and the slot. This enables convenient filling (Fig. 2).

In order to prevent freezing, vertical joints are filled with light concrete, porous clay filler or slag concrete or fillers of foamed glass or foamed Keralite crushed stone, with a volumetric weight of $\gamma = 600 - 800$ kg/m^2 and a strength of 10–15 kg/cm^2. To avoid wet processes on the site, vertical joints are sometimes filled with slag cotton. Vertical joints of inner wall panels are likewise filled with cement mortar. If the clearances between elements are less than 10 mm, the joints are caulked with hemp fibre.

In panel buildings with frames the horizontal column joints and the beam connections with the columns are the most critical parts.

In joints of columns in multi-storey buildings, steel plates with a centring gasket are used, followed by electric welding along the perimeter or edge. In such a design the welded seam tends to produce compression. Therefore the upper and lower steel plates are made of the same size but the paint is removed from the plates to allow for use of a welded seam (Fig. 3a). The designs of these joints have been investigated and proved reliable in operation. In case of axial compression the joint can be calculated as follows. The force transmitted through the centring gasket is determined by

$$N_q = m(R_p)(F_q)p$$

where R_p is the rated prism resistance of concrete in compression;

F_q the area of centring gasket;

$p = \left(\frac{F}{F_q}\right)^{\frac{1}{3}} \leq 1.5$, *i.e.* the factor taking into account the increased stress on concrete compression under the gasket; and F is the area of the column cross section.

The effort transmitted to welded seams is

$$N_m = N - N_q$$

The height of the welded seam at the joint is

$$h_m = \frac{N_m}{\sigma_c l}$$

where l is the length of headband seam (perimeter);

σ_c the rated resistance of the welded seam in compression; and

m the factor of the conditions under which the joint operates. In calculations it is assumed that $m = 0.8$.

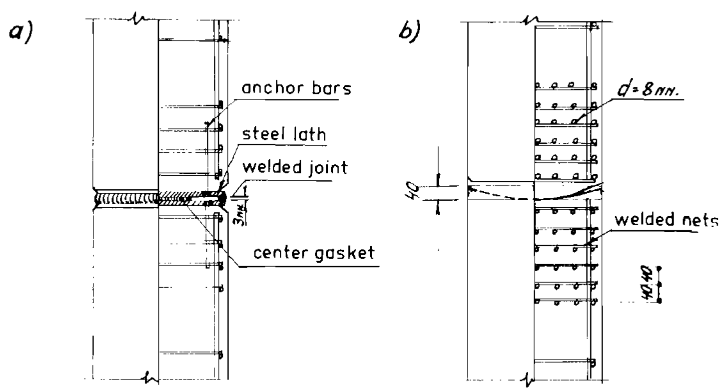

Fig. 3. Joints of columns in multi-storey buildings. (a) Allowance for the use of a welded seam; (b) spherical seating to reduce steel consumption.

To reduce steel consumption column joints are made with spherical seating (Fig. 3b). A greater bearing capacity at the point of the joint is achieved by setting additional welded shoes at the end of the columns.

According to experiments [1], the carrying capacity of the joint can be found from

$$N = F_b(R_q^n + 2\,\mu_k R_a^n)$$

[1] S. M. Krylov, *Investigation into the work and calculation of framework element joints in framework-panel buildings*, collected articles of the U.S.S.R. Academy of Building and Architecture, edited by A. S. Kalmanok. *Problems of calculating designs of dwelling houses and public buildings with prefabricated elements*, State Construction Publishing House (Gosstroiizdat), 1958.

where F_b is the area of concrete inside the outline of the shoe;
R_q^n the ultimate strength of concrete in compression;
R_a^n the norm resistance of grid reinforcement; and
μ_k the factor of indirect reinforcement

$$\mu_k = \frac{F_{r1} l_{n1} + F_{r2} l_{n2}}{l_1 l_2 n}$$

where $F_{r1} F_{r2}$ is the area of grid-rod cross section in longitudinal and transverse directions;
$l_1 l_2$ the dimensions of grid outline in longitudinal and transverse directions;
$n_1 n_2$ the number of longitudinal and transverse rods; and
n the distance between the grids.

The beam and column joint (Fig. 4a), with partial continuity, is made in multi-storey buildings by letting concreted I-beams and two rods project from the column and by welding them to the insertion parts of the beam. Angles and channel bars have been used instead of I-beams. The joints are so designed that partial continuity of the beam is provided, account being taken of the reduction of bending moment at support of the elastic system by 30%, due to plastic redistribution of moments.

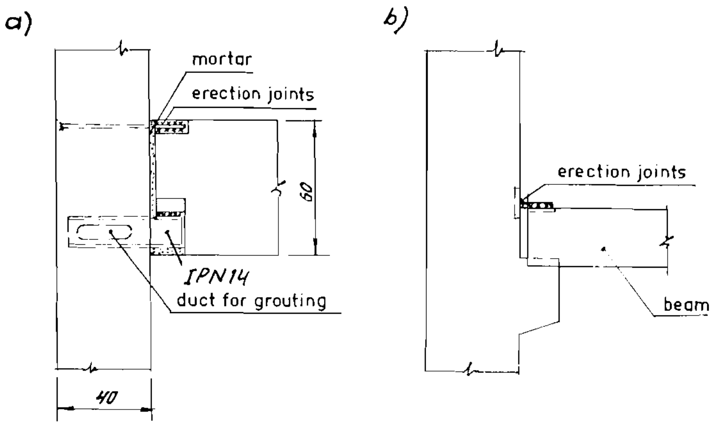

Fig. 4. Beam and column joints in multi-storey buildings. (a) A joint with a concreted I-beam and rods projecting from the column and welded to the insertion parts of the beam; (b) joints made with angle brackets concealed in the longitudinal walls.

The more rigid unit of the framework can be made according to the above variant, provided the insertion parts and the rods themselves above the beams are computed for forces arising when the beam is more nearly continuous with the column. Such units are used in buildings with a transverse disposition of the beams, where the supporting parts do not protrude from the overall dimensions of the beam cross section.

With a hinged beam support, the design of the unit can be greatly simplified and the consumption of steel for the insertion parts reduced.

In buildings with the columns located in the centre of the longitudinal axis, the angle brackets for supporting the span pieces can be concealed in the longitudinal walls; in this case the angle brackets can be made of reinforced concrete, and the span pieces as freely resting girders on two supports (Fig. 4b).

Experimental research has likewise pointed to the reliable operation of joints coupling columns to beams. Important experimental investigations have also been carried out to study the operation of the joints of inner wall panels and those of outer walls. Below are briefly given some results of the investigations.

The first experiments were conducted in 1951 by Gornov and Morozov (former Institute of Construction Engineering, U.S.S.R. Academy of Architecture), when the carrying capacity of the joints of panels 12 cm thick was determined on 16 samples (Fig. 5).

The first group of joint samples had flat ends, and the lead was transmitted directly from one element to another through the seams filled with cement mortar with a strength of 40 kg/cm^2, or without their being filled with mortar (Fig. 5a). In the second group of samples, the upper elements of the panels had bevelled angles (Fig. 5b).

Samples of the two basic groups of designs were made of heavy or light concrete. The samples of the first group, made of slag concretes, with a strength of 98 kg/cm^2 and with the seams filled with mortar, were destroyed at a load of 82.4 tons per linear metre; and those made of heavy concrete with a strength of 219 kg/cm^2 at a load of 230 tons per linear metre. The samples of the second group, made of slag concrete, with a strength of 187 kg/cm^2 and seams filled with cement mortar were destroyed at a load of 84 tons per linear metre.

The experiments have shown that there is no substantial difference between the carrying capacity of the samples with joints filled with mortar and those which were not filled. Deformation in the joints when the seams were not filled was about double compared with the joints with filled seams. For example, with half the ultimate load at the joints of the first group, deformation of the joint without cement mortar filling amounted to 0.8 mm, and with mortar filling to 0.5 mm.

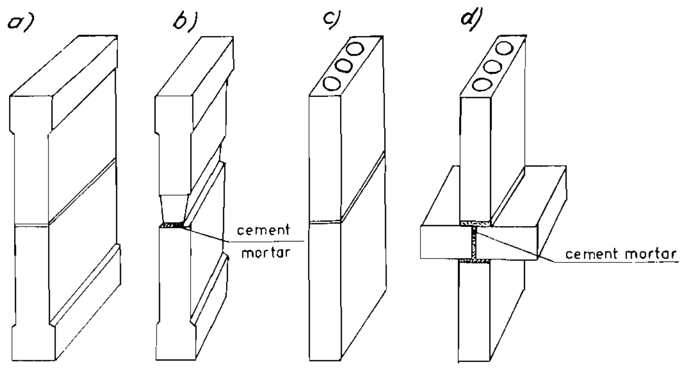

Fig. 5. Investigation into the operation of joints in inner and outer walls (see text).

To appraise the carrying capacity of the joints under investigation, let us point out that the rated load in five-storey buildings with a transverse disposition of the inner walls 3.2–3.6 metres apart, amounts to 25 tons per linear metre. Consequently, panel joints made of light concrete with a strength of 100 kg/cm^2 have a safety factor of more than 3.

A number of other investigations on the joints of wall panels were carried out between 1951 and 1956, of which we shall mention the experiments carried out by V. V. Spiridonov [1]. Experiments were conducted in 1956 (at the former Institute of Construction Engineering, U.S.S.R. Academy of Architecture) on 16 samples made of hollow concrete elements of panels and on 13 solid ones. The tests were carried out on samples of hollow panels 14 cm thick, which, according to design, had three types of joint (Fig. 5).

The first variant represents elements of hollow concrete panels resting on one another, between which mortar of a hard consistency was caulked throughout the area of the joint (gross) (Fig. 5c). The second variant differs from the first in that the mortar in the joint had been caulked only on the net area of concrete, *i.e.* the vertical voids are through-going at the point of jointing and have no mortar diaphragm. In the third variant of the joint, pressure from the upper element is transmitted to the lower through the floor panel separat-

[1] V. V. Spiridonov, The carrying capacity of horizontal joints of large-panel buildings, *Concrete and Reinforced Concrete*, No. 5, 1957.

ing the upper and lower wall panels, the mortar being caulked throughout the area of the element cross section, and the joint has two horizontal layers (Fig. 5d).

The seams in the joints were filled with a cement mortar with a strength of 50 kg/cm^2 and 150 kg/cm^2, and some joints were tested by filling the seam with sand.

It has been found from the experiments that when the grade of the mortar in the joints is not lower than the prism strength of the concrete at the elements to be jointed, the joint does not reduce the carrying capacity of the elements. When the grade of the mortar is higher than the prism strength of the panel concrete, the carrying capacity of the joint does not surpass that of the panels themselves. When the seams were filled with sand, the carrying capacity of the joint dropped to 0.45 N_e, *i.e.* that of the element to be jointed. The magnitude of the absolute deformations of the joints with loads of half the destruction load did not surpass 0.75 mm.

It is advisable to determine the carrying capacity of the joint from the formula

$$N = N_e \left(0.6 + \frac{0.4\, R_2}{R_q^n}\right)$$

where N_e is the carrying capacity of the element,

R_2 the ultimate strength for compression of the mortar in the joint, and

R_q^n the recommended prism strength (which should not be lower than 10 kg/cm^2).

The grade of the mortar should not be less than 10 kg/cm^2.

In 1958–1959, under the guidance of the author of this paper, tests were carried out of joints of rolled reinforced concrete panels and of vibrated brick panels. These tests have established that the carrying capacity of units on mortars of zero grade (joint on clay mortar) decreases by 70% compared with the joints made on cement mortars with a strength of 50 kg/cm^2.

The construction of dwelling houses of prefabricated large-sized elements has also posed the designers problems of heat insulation that play a very important role in the climatic conditions of the U.S.S.R., which are relatively more severe than in Western European countries. Since the very beginning of construction of prefabricated dwelling houses of large-sized elements, heat insulation research has acquired considerable importance and has exercised a great influence on the improvements in large-sized structures.

Under the guidance of A. M. Shklover, the laboratory of thermophysics of the former Institute of Construction Engineering conducted a number of experimental (F. V. Ushkov) heat engineering investigations and research under natural conditions (B. F. Vasilyev) during one decade (1947–57) in the field of construction of large-sized elements.

The major thermophysical problems which arose in connection with construction of prefabricated large-sized elements included investigation into thermal protection of vertical and horizontal joints. These problems were of the same importance as research on the effect of the cold bridges and moisture paths on the outer walls when a compact facing layer of ordinary heavy concrete is used on the outer surface.

The importance of the thermophysical problems so raised varies depending on the construction type of the outer wall element, *i.e.* the panel.

At present two basic construction types of wall panel prevail: the single-layer and the laminated type. Single-layer wall panels 25–40 cm thick can be made of ceramsite concrete, thermosite concrete, foamed concrete, foamed silicate and other atmosphere-resistant light concretes with a volumetric weight of 900–1200 kg/m^3, on binders and fillers which warrant the production of panels with surfaces to meet architectural requirements. Such concrete should possess an ultimate strength in compression of not less than 50 kg/cm^2 and a heat conduction factor of not more than 0.40 large calories/h.m °C.

The great advantage of single-layer light concrete panels lies in the simplicity of their fabrication as well as in the simplicity of coupling and finishing in erection. Owing to the uniformity of the structure of these panels, thermal bridges are excluded and high heat-protecting properties of walls are ensured. In this case it is most important that there should be as little blowing through the joint of the wall panels as possible. In this connection attention should be paid to thickened horizontal joints, in which higher percolation may be caused by a displacement of the mortar during the centring of the panels.

In the southern regions of the U.S.S.R., where showers accompanied by strong winds of a prevailing direction (Black Sea coast in the Caucasus, etc.) are a frequent occurrence, the design of the horizontal joint should prevent moisture from flowing or being blown into the premises through the joint. Various design variants of laminated wall panels are possible: two-layer, three-layer panels and those with cavities. In two-layer wall panels, the insulating material may be placed on the warm side of the wall and the reinforced concrete layer on the cold side, and *vice versa*.

From a heat-insulation point of view it is most advisable that the reinforced concrete layer should be placed on the inside, and the insulating material, which is atmosphere-resistant and decorative, on the outside. Such variants include brick and panel walls insulated with foamed glass, which provide a most proper solution to the questions regarding the moisture conditions of the walls. They make the matter of heat-conducting insertions quite superfluous and solve in the simplest way the problem of support for multi-storey ceilings. By their simplicity of forming and finishing the joints in erection, panels with an outer insulating layer are not inferior to single-layer light concrete panels.

In the provision for heat insulation, the cold bridges formed by the ribs of the panel frame and the stiffening ribs are most vulnerable in two-layer wall panels when the reinforced concrete plate is on the cold side of the protective layer and the insulating layer on the warm side, as well as in three-layer wall panels when the non-rigid insulating layer is placed between the inner and outer reinforced concrete plates. In this case, it is important that no dampness should appear on the inner surface of the walls and that blowing through be reduced as much as possible.

As stated above, from the viewpoint of heat insulation the division of large-sized elements into one-room sizes is most advisable. In this case the most vulnerable spots of jointing coincide and are easily concealed by ceilings and partitions. When the sizes are smaller, the joints play a greater role in providing the suitable heat conditions of the premises.

To find the best practical methods of eliminating the harmful effect of heat-conducting insertions, laboratory tests of vertical and horizontal joints were carried out in the climatic chamber of the thermophysical laboratory.

Fig. 6 shows the distribution of temperatures on the surfaces of three-layer reinforced concrete panels insulated with slag wool and asbestos cement sheets 14 cm thick, both in the absence and in the presence of the effect of wind. By a number of resistance thermometers installed in the most typical places and a diversity of heat-conducting insertions, it was possible to obtain a number of interesting results.

It can be seen from Fig. 6 that the heat flow does not only run in the direction perpendicular to the plane of the wall, but also along the outline of the panel. This is borne out by the gradual rise in temperature on the warm surface of the wall as the distance from the heat-conducting insertion increases, and by a similar drop of temperature on the cold surface of the wall.

Irrespective of their thickness, heat-conducting insertions, even as thin ribs, bring about such an abrupt drop of temperature of the inner surface of the wall that it sometimes proves to be below dew point. The effect of the insertions on the temperature of smooth walls is to reduce the temperature most drastically when the insulating layer has little heat conduction.

Proceeding from experiments and calculations, F. V. Ushkov evolved a formula which defines the conditions of permissible heat-conducting insertions of the rib type.

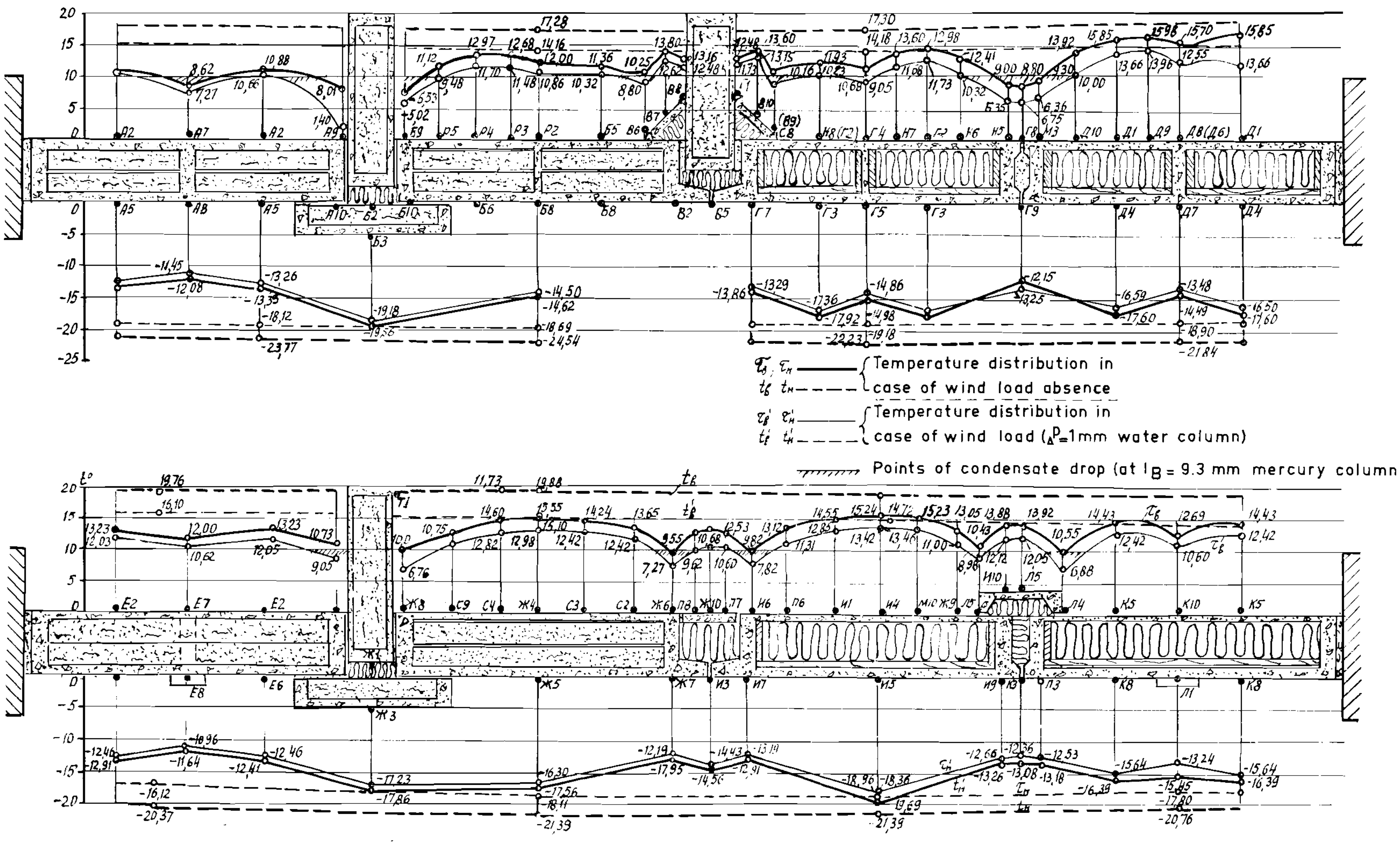

Fig. 6. Temperature distribution over the surfaces of three-layer reinforced concrete panels.

With $a/b \leqslant 0.2$

$$R_{0,i} \geqslant 0.65\,(R_0) \cdot \sqrt{\frac{(R_0)}{R_{0,s}}}$$

where R_0 is the norm resistance to heat transfer, determined according to the construction standards of heat engineering (Construction Standards and Rules);
$R_{0,s}$ (structure) is the resistance to heat transfer by the main cross section;
$R_{0,i}$ (insertion) the resistance to heat transfer by the heat-conducting insertion; and
a and b are, respectively, the thickness and height of the heat-conducting insertion.

With greater insulation of the three-layer panels, the resistance of heat transfer by the heat-conducting insertion, preventing the formation of dampness, should not be less than 0.6 of the norm resistance to heat transfer, *i.e.*

$$R_{0,i} \geqslant 0.6\,(R_0)$$

The negative effect exerted by heat-conducting insertions can be eliminated by inner or outer insulating pilasters of a width equal to one and a half times the thickness of the outer guard, overlapping the through-going ribs (Fig. 7). The pilasters insulating the outer angles and the elements insulating the angles of the outside walls on the inside should project beyond the smooth surface of the wall by a width not less than the thickness of the wall. (Fig. 8).

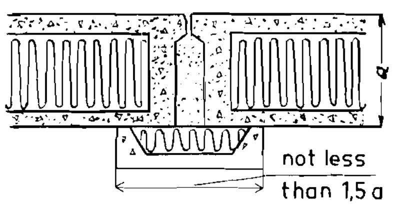

Fig. 7. Thermal insulating of exterior panel joints.

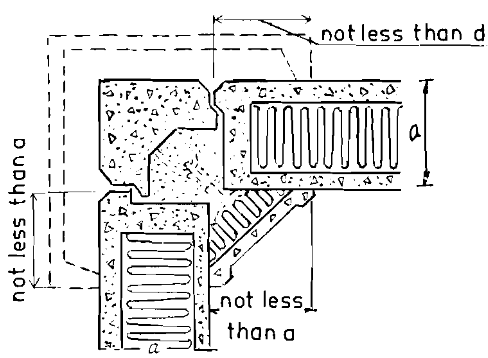

Fig. 8. Thermal insulating of exterior angles.

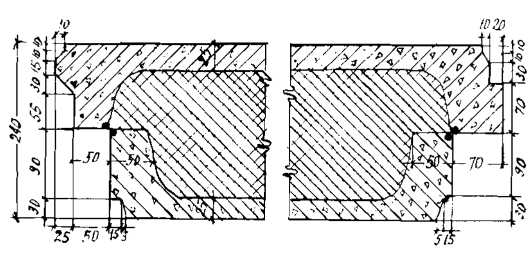

Fig. 9. A wall of double reinforced concrete panels with displaced trim ribs.

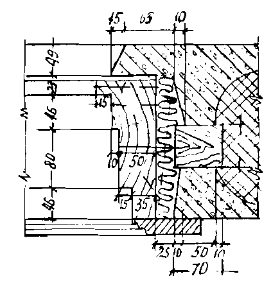

Fig. 10. Window opening trim.

As seen from Fig. 6, the effect of wind leads to deteriorated conditions of temperature distribution on the surface of the panels. Differences between the temperature curves obtained under different conditions of wind indicate infiltration.

In wall panels with staggered framing ribs (Fig. 9), the negative effect of through-going heat-conducting insertions is ingeniously eliminated without resorting to insulating pilasters. Such a wall consists of two reinforced concrete panels of different dimensions, with framing ribs. The inner panel is smaller than the outer by the width of the framing ribs. An insulating layer is placed between the two panels, following which the inner and outer panels are made to contact along the edge of the framing ribs and are fastened by welding material insertion parts placed in the ribs, thus forming a single wall panel. In this case the reinforced concrete framing of the window should be made by placing an insertion of low heat conduction, *e.g.* an impregnated timber batten (Fig. 10).

The distribution of temperatures along the joint of a reinforced concrete multi-storey flooring with three-layer reinforced concrete wall panels, provision being made for an insulated cornice, indicates that there are no factors conducive to the formation of dampness.

Fig. 11 shows the distribution of temperatures of the inner surface along the joint of two-layer panels with a reinforced concrete column, the framing ribs being insulated with slag wool plates 3.3 cm thick and the framing ribs without insulation, the operational data being $t_i = +18°$ C and $t_s = -30°$ C. As seen from Fig. 11, the additional insulation of

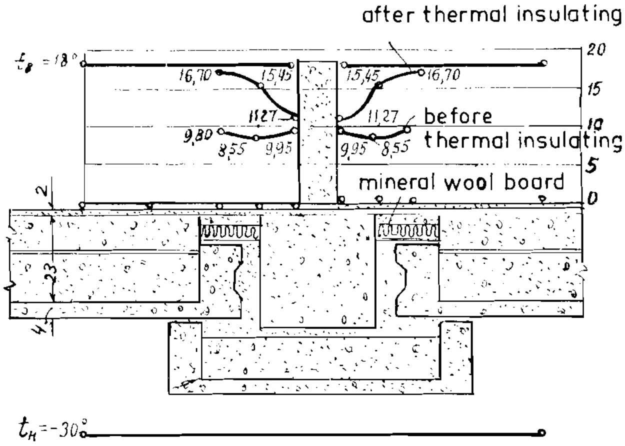

Fig. 11. Distribution of internal surface temperatures at the joint between two-layer panels and a reinforced concrete column at t_B 18° C and t_H — 30° C.

the framing ribs brought about a considerable rise in the temperature of the inner surface as compared with the side edge of the column. The rise was as high as 6.9° C.

Fig. 12 shows the distribution of temperature of the inner surface along the joint of two-layer carrying wall panels.

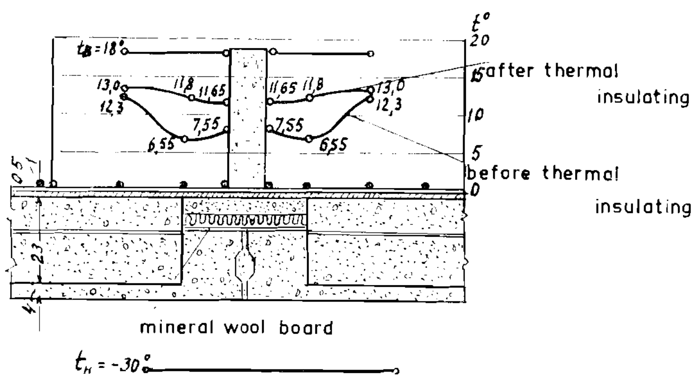

Fig. 12. Distribution of internal surface temperatures at the joint between load-bearing wall panels.

Insulation of non-through-going framing ribs of two-layer reinforced concrete panels with an adequate agent eliminates the negative effect of heat-conducting insertions. Attention should also be given to the insulation of the framing ribs at the junction of the wall panels and the interstorey ceilings, which considerably improves the temperature conditions of the floor in the area near the wall.

Fig. 13 shows the distribution of temperatures at the joint of two-layer reinforced concrete

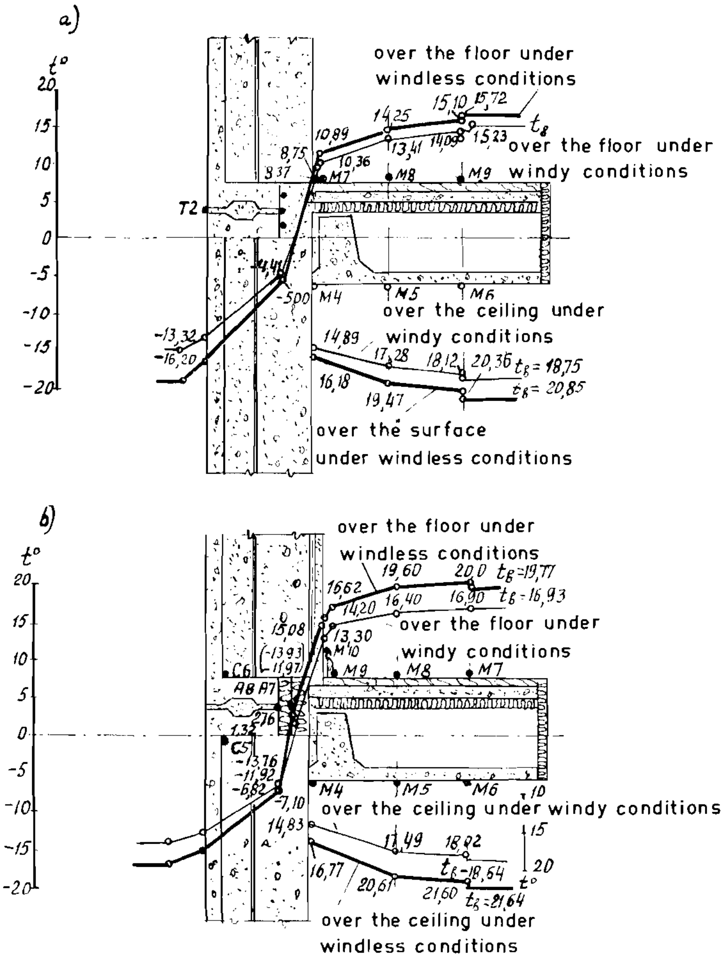

Fig. 13. Distribution of temperatures at the joint between wall panels and floor slabs: (a) before thermal insulation of trim ribs and (b) after additional insulation of trim ribs.

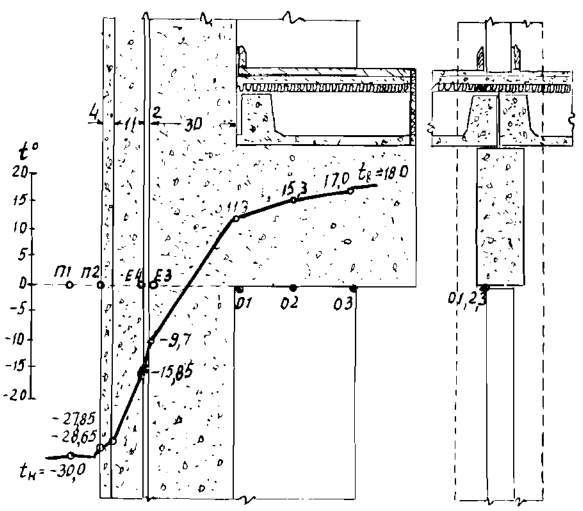

Fig. 14. Temperature distribution over the lower surface of a reinforced concrete edge beam under the influence of low temperatures on the column.

panels with an inter-storey ceiling before insulating the framing ribs and after their additiona insulation with two layers of slag cotton plates 6 cm thick.

No great concern should be caused by the temperature on the lower surface of the reinforced concrete beam of the framework when low temperatures act on the column (Fig. 14). Neither should any concern be caused by the temperature on the lower surface of the reinforced concrete beam on the inter-storey ceiling when low temperatures act on the end of it (Fig. 15). With a large volume capable of absorbing heat, the temperature conditions of the

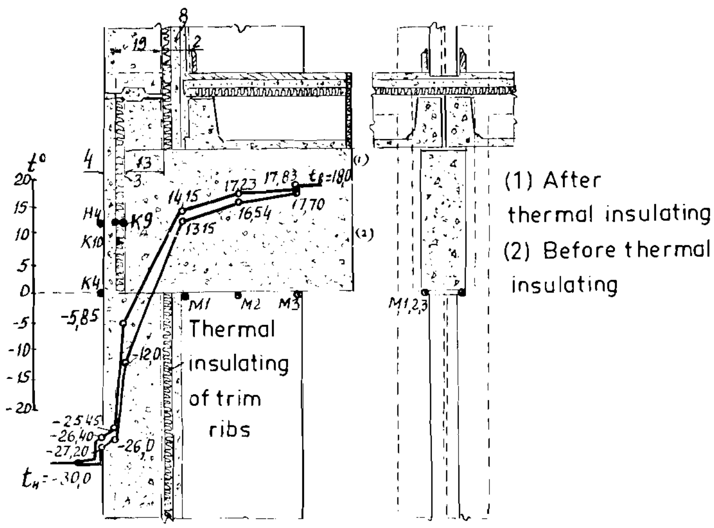

Fig. 15. Temperature distribution over the lower surface of a reinforced concrete floor girder under the influence of low temperatures on the end of the girder before and after thermal insulation of the trim ribs.

lower surface of the beam and the girder in the area near the wall prove to be more favourable than those along the inner edge of the column remote from the beam or opposite the framing ribs of the carrying panels located below the girder.

In laminated structures with cavities, and especially when the inner finishing layer is remote from the basic part of the wall, the temperatures become equalized on the inner surface of the wall, irrespective of the position of the inter-panel joints. In those cases the problem of constructing inter-panel joints should be viewed from a different aspect and is to be studied in connection with the moisture conditions of the wall.

The question then arises of the feasibility of making open joints between the reinforced concrete panels and of measures of protecting the wall from excessive cooling by outer infiltrating air.

Discussion

As a number of Congress participants had, with a view to the discussion, prepared more or less selfcontained reports in advance, part of which was distributed at the Congress, the present account concentrates on summarizing these contributions, leaving other contributions, though valuable, more or less in abeyance in order to cope with the problem of the extent of this account.

A special report was presented in French by MR. E. FOUGEA, former President of the French Society of Civil Engineers and President of the French Institute for Applied Research on Reinforced Concrete, who belongs to the Coignet firm.

The title of his report is *Construction with heavy concrete elements, modern methods of manufacture, transport and assembly*. The essential elements of the report are given here.

Ten years of heavy element construction in France warrants stock taking, weighing advantages, determining conditions of application and direction of further progress. Advantages are not the spontaneous findings but the results of long-term efforts, already started in 1892 when Edmond Coignet invented concrete prefabrication. By virtue of their age, traditional methods are little progressive, but prefabrication methods are evolutionary. They allow further perfection and bring new solutions and tangible progress as they deal with entire buildings. Prefabrication permits realization in one act of substantial parts of a building and rational organization, as opposed to the rather slow traditional methods, where different crafts work in sequence due to their independence.

To gain real profit from new methods, not adaptation or similarity with tradition, but modern solutions must be sought by elements that are: of large size; satisfactory for a maximum of functions; produced industrially; erected simply and rapidly; and that require no or very little further operation after erection.

The greatest possible dimensions compatible with destination and transport limits and handling equipment, designed accordingly, are required, as well as a maximum functional complexity. Manufactured elements should contain structure (concrete, steel), insulation (thermal, acoustical), lining (façade concrete, tiling, etc., floor and wall coverings) and the maximum possible equipment, *e.g.* façade window frames, electricity ducts, heating appliances, all holes for passing ducts.

The number of elements per dwelling cell must be low: 20 to 25.

Ease of erection is essential and must be automatic in that neither setting out before erection nor adjustment is necessary. Thus precision having the mechanical engineer's and not the mason's tolerance becomes a main quality.

MANUFACTURE

Quality of formwork is essential for appearance and precision of elements.

CRAFT PROCESSES

With well-made traditional formwork-concrete, plywood, steel-assembly and striking are difficult. Extraction is done by special tools or cranes on or near the site. The only advantage is no factory-to-site transport, but synchronizing of production and erection is difficult, stocks must be held and loading and unloading are irregular. Moreover, products obtained in this way have insufficient precision or finishing. The result is adjustments during erection, causing loss of time, reduction in economy and impossibility of scientific organization of work. Nevertheless, these techniques may be useful for small sites or where little repetition occurs.

However, one must not judge modern methods on these results only, since, as rightly stated MR. BLACHÈRE, one might then conclude that no simplicity of erection, precision of assembly, tightness of joints, high precision or facilitating secondary crafts' work is necessary.

INDUSTRIAL PROCESSES

Finished precision products require not formwork but automatically controlled and precise machines, permitting production in the most appropriate – usually horizontal – position and extraction in a rational position, *e.g.* vertical for vertical elements. Horizontal production and vertical extraction make reinforcement for resistance during extraction superfluous and save steel, which is required for only a few minutes of the element's lifetime.

Therefore moulding machines have rotating parts, edge forms and a fixed part: the base. Forms for flooring elements must also rotate as the topping is placed, then concrete is poured and later the elements turn through 180° for vertical transport.

To obtain accuracy, especially of edges, the edge forms must be rigid and mechanically brought into position. The bond between the concrete and the mould should be released before extraction. Only thus is tightness and precision assured. All movements of the forms should be slow and positive without human intervention to within one millimetre of their position. Certain machines for façade panel production have no less than 14 jacks, acting successively in groups under control of one single button.

Such machines are costly and must be used to produce many units in order to reduce the amortization on each product to a small extent. Therefore, in order to accelerate hardening, the moulds are provided with a heating system of hollow metal webs in which water or steam circulates. The concrete is thus hardened in two hours and six elements per day can be produced from each mould.

The value, maintenance and use of these machines demand that they be grouped in a factory, where optimum output is obtained. This factory is then completed by a transformer, a heating installation, air compressors, hydraulic compressors, cranes, a concrete mixer controlled by one man, automatic machines handling reinforcement steel and a gantry crane which serves the factory proper and the stock park.

TRANSPORT

The large sizes of the elements and the narrow loads permitted on roads usually necessitate vertical transport for all elements. They are transported on special trailers with due provision against chances of damage.

Timing must be in line with erection schedules. An average three-room dwelling requires three to four trailer loads. The action radius of the factory is about 50 kilometres, though examples of economic transport of up to 100 kilometres distance are known. Transport by ship is also used – see the example mentioned by MR. BONNOME.

ERECTION

Foundations are usually made traditionally. The remainder of the building is a matter of simple assembly, only requiring adequate lifting devices, the elements being taken from trailer directly to their ultimate position. The openings and rebates inherent in the various shapes of the elements allow assembly; the decompression openings are used as assembly guides; adjustments are automatic. Vertical elements rest directly on each other. The elements are simply kept in place by props connected to the units with bolts so that only the definite connection by cast *in situ* concrete remains to be done.

The secondary components arrive, in the same way, completely finished and need only be connected to the devices already available in the correct places. Fixing screws and bolts is the only operation. It is precision that permits the site to become a place of assembly instead of construction.

Professor KUZNETSOV defines the fabrication parameter as the relation between labour costs incurred off-site and the total labour costs. In France we define the parameter by comparing working hours. Both methods are similar. Studies of contracts have led to the coefficient of 0.69 excluding, and 0.58 including foundations.

ADVANTAGES OF THE INDUSTRIAL METHOD

The main advantage of the system is the possibility of further improvement. The direction is not that of searching for precedents but that of new development: it is the road of industrialization. This road already yields profits:

QUALITY

The machine's automatic precision allows a quality the hand of man can never attain. For example, heat insulation layers in façade walls can be adapted to every climate and concrete cast traditionally will, in comparison, always be mediocre and deteriorate much earlier.

ECONOMY

Mechanical energy, hundreds of times cheaper than human energy, is used. One man in one 8-hour day produces 1 kW-h, costing in France about 3000 francs, whereas 1 electric kW-h costs 30 francs. Apart from this there is the economy of continuity of work in the factory as opposed to cyclic site work.

RATE OF EXECUTION

The industrial methods enable a speed of construction incomparable to that of old methods. Consider the construction of the superstructure of a 50-dwelling building of 5 storeys executed in 12 days, irrespective of bad weather, in Saint Etienne du Rouvray near Rouen. Another 18 days and the occupants arrived in their completely finished dwellings. The total time was 1½ months all inclusive. The obvious advantages are reduction in interest on investments and early payment of rent.

WORKER'S CONDITIONS

Work is less dangerous and difficult, most workers being protected in the factory; site scaffolds are not required. Output is no longer a function of physical force but of skill and good organization.

SOCIAL IMPROVEMENTS FOR WORKERS

Specialization can rapidly be obtained. Unskilled site workers become skilled responsible operatives, remunerated accordingly.

SCIENTIFIC ORGANIZATION OF WORK

Rational organization, so difficult to establish and maintain, becomes possible on the basis of meticulous analysis of all details in advance, leading to rigorous programming without improvisation. Planning allows a substantial and constant increase of output without extra fatigue for workers.

CONDITIONS OF APPLICATION

There are few, for example:

Series production: increase in output and minimum costs per unit.

Standardization: As Prof. TRIEBEL has said, the most rational disciplines should count for buildings and their details. They must be typified and their elements standardized.

Creating teams of workers: Industrial construction results from teams whose members cooperate under the same regime, prescribed by technique and economy. As Mr. BONNOME said in his report, an architecture of industrialization must be created.

Market organization: The conditions at present operating in the market are often not adapted to industrialized building. Dr. JACOBSSON rightly indicates the by-laws and regulations based on old traditions. Irrespective of a certain inertia these obstacles will disappear and industrialization will advance by virtue of its necessity with regard to today's needs.

We agree with Prof. OVSYANKIN, who said that building development can only be realized by great technical progress, a higher level of building organization and technics, all based on extensive industrialization.

THE ROAD OF PROGRESS

As we said before, progress requires industrialization. That in turn requires progress of technique and organization. This is what we are studying in France with great intensity in our firms, laboratories and professional research institutes.

A special contribution was also presented by Mr. KURT MÅNSSON, civil engineer of the Associated General Contractors and House Builders of Sweden, Stockholm, under the title *Swedish prefabricated unit builders' views on building with large-sized units*, the text of which is:

The majority of the advanced building systems in Sweden has been developed by the building contractors, in close cooperation with a few important builders, manufacturers of building materials and consulting engineers and architects. Since the development work

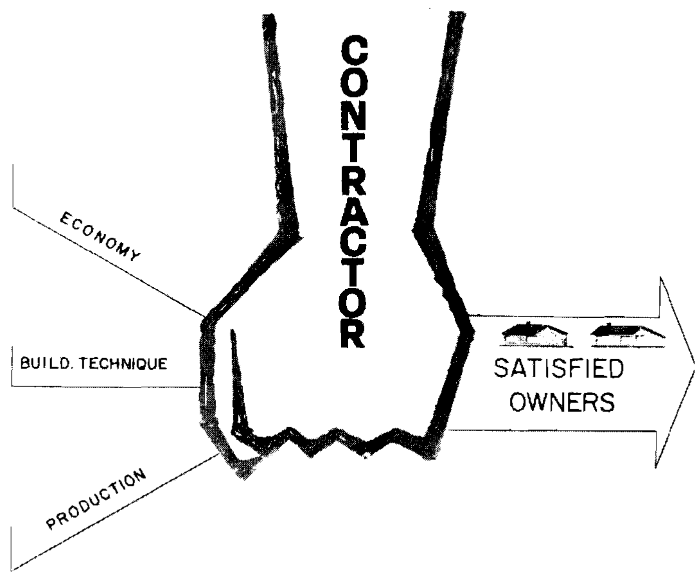

Fig. 1. Coordination of production, building technique and economy by development work carried out by people acquainted with work on the site.

has been in the hands of people who are acquainted with the problems on the site, it has been possible to coordinate production, building technique and economy into as perfect and well developed a system as may be allowed by the materials and machinery at present available (Fig. 1).

The contractors have consistently aimed at surpassing their competitors, but nevertheless they have met and exchanged information about their experience in technical matters (Fig. 2). Amongst the subjects discussed may be mentioned: surface treatment; size of

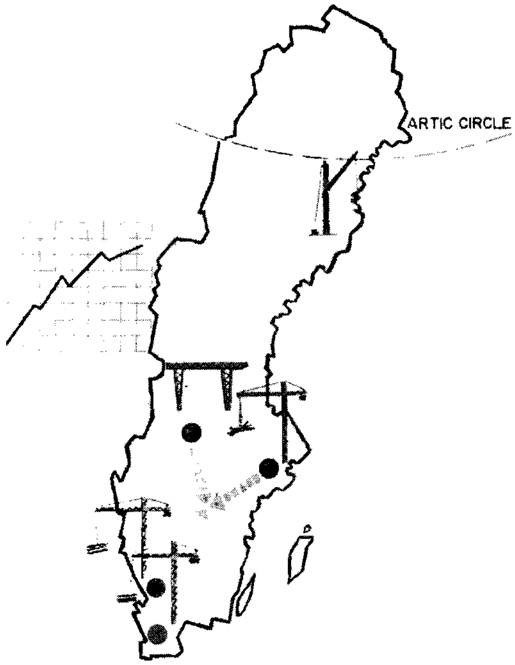

Fig. 2. Exchange of technical experience among Swedish contractors.

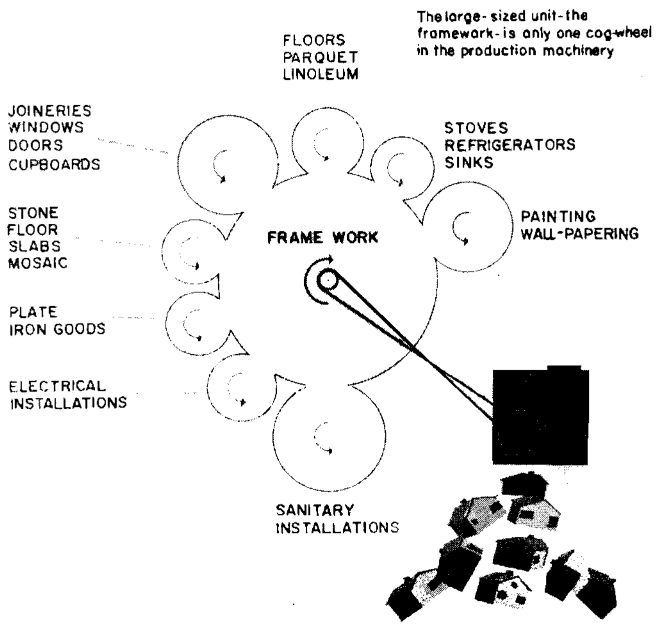

Fig. 3. Not only the heavy units but also the finishing processes must be regarded as an integral part of the entire construction.

prefabricated units; details of electrical installation; equipment for shuttering; sanitary installations; ventilating; heating coils in floors and walls; façade materials; tolerances.

People engaged in developing advanced building methods do not regard heavy units – the structure – as an isolated item. They consider the structure as an integral part of the entire house – a cog-wheel that has to fit all the other cog-wheels of installations and details which are necessary to make the building function properly (Fig. 3). In view of this the demands on research do not only concern heavy units but also the entire finishing side, such as electrical, sanitary, heating and ventilating installations, kitchen equipment and surface treatment.

The sanitary installations, etc., have to be coordinated with the framework in such a way that the total time of construction is reduced. This view on the basic problems is decisive for assembly building, or rather for system building, in our country. The term "system building" is used for building methods where all details down to the most minute detail of installation have been coordinated into a unit giving optimum results. The system may be a pure and simple assembly building or a combination of *in situ* construction and assembly building. The development of system building is illustrated in Fig. 4.

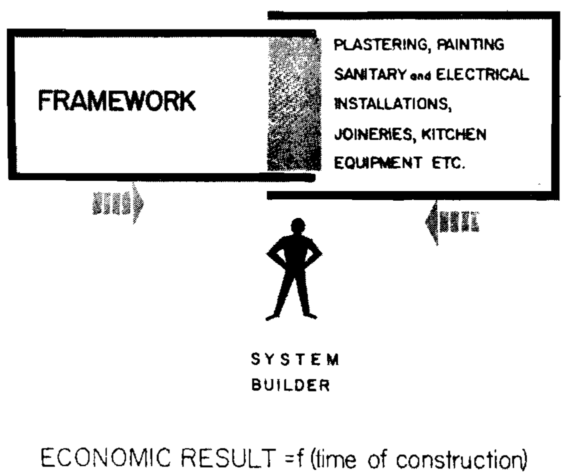

Fig. 4. The development of system building.

It is often hard to draw a dividing line between the system building and traditional building methods. System building has influenced the entire evolution of building. Some constructional solutions arrived at by the prefabricated unit builders are at present in common use on most building sites. These have been accepted and are today regarded as traditional, *e.g.* refuse chutes, stairs, light concrete units, balconies, joinery painted at the factory, and machine-finished plasterless surfaces.

According to the system building it has also become more common to utilize (a) coordinated and detailed preplanning; (b) load-bearing wall systems; (c) economic design of flats; and (d) general contracting, *i.e.* the entire contract is carried out under the general supervision of one contractor. Thus the secondary effect of system building involves a considerable advantage to the national economy.

A report recently published in Sweden shows an annual increase in productivity of 2–5 per cent., which is undoubtedly attributable to the advantages of system building and its secondary influences on traditional building (Fig. 5).

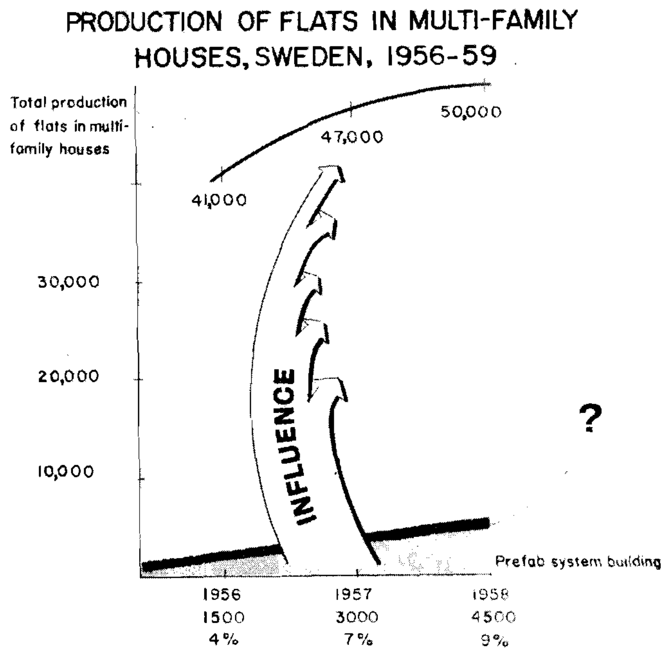

Fig. 5. The influence of system building on traditional building methods.

It is obvious that system building is well able to compete with traditional building. The savings through rationalization are perhaps not discernible in the final cost price, but the entire housing production profits by the influence of the prefabricated unit system on the general development. It is not known to what extent the prefabricated unit system has succeeded in forcing down the general price level or in checking the inflationary rises, but a great advantage achieved through this system is the decreasing demand for labour on the site (Fig. 6).

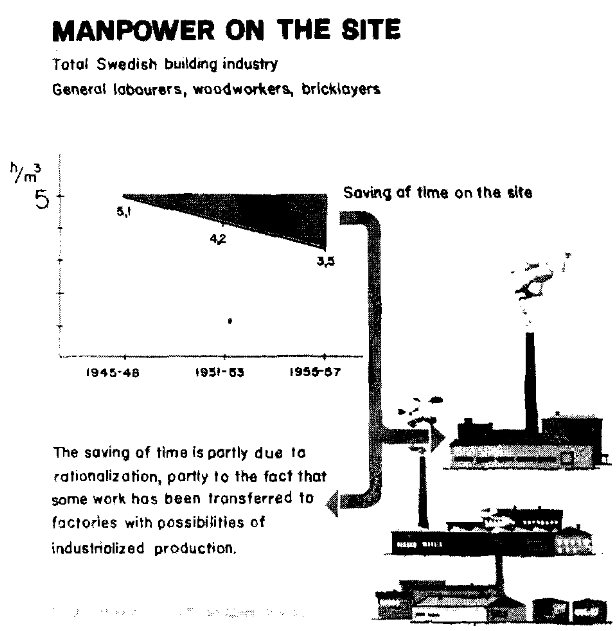

Fig. 6. Advantage of the prefabricated building system in reducing the amount of labour required on the building site.

What are the demands on research raised by system builders, particularly with regard to the present subject: large-sized units? Many of the successful results have been made possible not only through the intensive development work carried out by the contractors in close cooperation with consulting engineers and architects, but also through their adapting their production to the results of the research carried out by the industry of building materials and of the general research at universities and institutions. Nevertheless, many problems are still unsolved, the majority of which also apply to traditional building. However, some of the problems become more acute in the case of prefabricated unit systems: *e.g.* shrinkage of concrete units; design of joints and their interior and exterior sealing; façade materials, etc.; heat insulation; sound insulation.

These problems may be divided into those concerning material, which may be handled through manufacturers of materials and their laboratories; building technique, which may be handled by specialized research institutes; and production. Production problems are naturally best handled by the contractors themselves in their rationalization departments or by consulting engineers or institutions engaged for the purpose.

The shrinkage of concrete units is an important problem, especially in the case of interior partition units. Thus, the following questions have to be answered: Are there any admixtures that reduce shrinkage? Could the prepacked method be used?

If a reduced time of construction should be attained, the problem of shrinkage must be solved. The joints cannot be filled until the units have stopped shrinkage. Connected with these "joint" problems is the question of jointing material for exterior walls, its aging, etc. The contractors themselves are also interested in finding means of reducing the storage time for prefab units. The cheapest way is to hoist them straight to their permanent place in the building.

As regards façade materials there is an abundant choice, but we lack experience in the use of them. Possible materials are aluminium, asbestos cement, exposed aggregate, brick, etc. International cooperation is desirable.

In the field of heat insulation there is quite a number of good solutions, but further improvements should be attainable. The same applies to sound insulation, which in some cases has proved problematic.

Primarily, the problems mentioned seem to be connected with the composition and design of materials. It is our belief that the technical problems of production on the site will take care of themselves as soon as the technical problems connected with materials have been solved. A prerequisite *(sine qua non)* for the most efficient solution of the problem of production technique is, however, to create possibilities for industrialized building.

CONCLUSION

Do not study large-sized units as an isolated item, study them as an integrated part of the entire object.

Another short special report was made by Mr. I. NYQUIST of the National Swedish Committee for Building Research in Stockholm. This report deals with tolerance problems, a subject raised by the same author in the discussion on Subject 3. The text of the report is given here:

VARIATIONS IN DIMENSIONS

Variations in dimensions and measurements may be attributed to the following factors:

Measuring errors, *i.e.* errors due to the measuring tool being inaccurate or to the measurement being made in an incorrect manner.

Material movements resulting from changes in temperature and humidity, aging and plastic and elastic deformation.

Load deformation, *e.g.* in concrete moulds when the moulds are subjected to casting pressure.

Faults during curing. An investigation of the deformation arising during the curing stage with concrete units 1 metre wide and of room height showed that faults of this nature were appreciably smaller than those occurring during the manufacturing process.

Faults due to incorrect technique and systematic deficiencies (chance errors).

PRODUCTION LIMITS

Production limits are the limits within which the dimensions of a product may be expected to vary. These limits are calculated in accordance with the formula

$$\text{Production limits} = \text{mean value} \pm 3 \times \text{standard deviation}$$

where the standard deviation is

$$\left(\frac{\sum v^2}{n-1}\right)^{\frac{1}{2}}$$

i.e. the square root of the sum of the squares of the deviations from the mean value, divided by the number of measurements less one.

The production limits are used as an aid when it is desired to fix suitable tolerances for a product with a limited number of measurements.

ACCURACY OF VARIOUS TYPES OF UNIT

The following comments can be made about the measurements of different types of unit and finished buildings.

The accuracy of the dimensions of concrete units depends mainly on the type of mould used during the manufacturing process. As regards width and length it may be noted that simple horizontal moulds made entirely of wood result in units showing wide variations in dimensions. It is probably unlikely that tolerances less than about ± 10 mm can be achieved.

Stable, horizontal wooden moulds and moulds in which wood is only used for part of the construction, *e.g.* edge moulds of wood accurately attached to a concrete bottom mould, can result in more accurate dimensions. It appears to be possible to work to tolerances of ± 5 mm with such moulds.

Horizontal moulds of concrete with steel edge moulds should result in good dimensional accuracy without calling for any complicated procedure. It has been found possible to keep the tolerances within ± 5 mm. If necessary the tolerances probably can be kept down to ± 3 mm.

Horizontal moulds made entirely of steel or moulds in which the outer surface is of plywood supported by a steel underlay and the edge moulds are of rigid steel profiles, will probably result in units of such accuracy that a tolerance of ± 3 mm can be achieved if the work is done accurately.

Special horizontal steel moulds have been used in conjunction with the Coignet system in France. It is understood that tolerances of down to ± 1 mm have been achieved.

The dimensional accuracy of the thickness of units when casting in horizontal moulds depends on the material, the accuracy of the edge mould, the degree of filling and the means by which the concrete is compressed. Even if the moulds are good, large differences can arise in the thicknesses unless the casting is done with great accuracy. The mean values have a marked tendency to be too high. In the best series of measurements the standard deviation was 0.7 mm and the mean value 1 mm too large.

It should have been possible to keep to a tolerance of $^{+3}_{-1}$ mm. Other measurement series showed even greater standard deviations.

Batteries of vertical moulds of steel for units 1 metre in width probably allow tolerances of ± 5 mm in width and ± 3 mm in thickness without very accurate treatment of the steel components comprising the assembly.

The measurement accuracy of finished buildings seems to vary considerably. The results appear to be mainly dependent on the control exercised. The mean standard deviation when measuring the wall distance on six different types of prefabricated buildings was 9.9 mm. If allowance is made for the deviations in the mean values the production limits work out at more than ± 30 mm. However, by exercising constant control and adopting other measures it has been possible in some cases to bring the tolerance for room measurements, *i.e.* wall distance, wall length and room height, down to ± 15 mm.

Since, in some cases, standard deviations as low as about ± 3 mm are noted for such measurements it is possible that in special cases the tolerance can be kept down to ± 10 mm. However, such a close tolerance should be demanded only in exceptional cases since, as a rule, it involves fairly drastic measures for the control and rejection of unacceptable units.

A good survey method must enable accurate measurements to be achieved at low cost. Some of the general requirements are:

It must be simple to apply. A complicated method is seldom carried out in all details.

It should involve as few measurements as possible. Every measurement involves a measurement error of some degree.

Every effort should be made to use chain measurements instead of successive measurement methods.

It should facilitate the final adjustment of the units. A considerable portion of the crane time is taken up in doing this. This time can be greatly reduced if the units are fixed with stop edges, rests, supports, slots, etc.

The method adopted should be easy to check.

COSTS OF ACCURACY

The problem involved when setting tolerances for building units is to find a minimum for the total of the cost to the factory for small tolerances (*e.g.* increased machining, labour and material costs and the cost of inspection and rejection) and the extra cost of the construction job resulting from the delivery of units with excessive measurement deviations (*e.g.* the increased cost of adjusting, fitting, joining, dressing and surface treatment).

The cost to the factory for accurate measurements will, of course, be smallest in the case of units for which no tolerances are fixed. Consequently, tolerances should only be fixed where absolutely necessary and they should never be smaller than is economically justified by the requirements of the construction and the factory's resources.

REASONS FOR TOLERANCES

The reasons for establishing tolerances vary. Tolerances may be set to ensure that joints can be made according to programme, to achieve better measurement accuracy with a view to eliminating or facilitating additional work stages, to rationalize certain complementary work, *e.g.* pipe installations, to ensure the static function of bearing members, to reduce the dimensions of the unit and thus save material, to determine the division of economic responsibility concerning measurement accuracy between the purchaser and the manufacturer or to ensure that all the units in a series can be used on any site where this type of unit is prescribed.

Elastic solutions refer to makeshift components that may be used to enable the units to be erected despite poor measurement accuracy. There are occasions when such methods are to be preferred to close tolerances.

STANDARD TOLERANCES

A German proposal for standard tolerances refers all concrete units to one and the same tolerance class within which the tolerances are based solely on the production dimensions. This means that the method of manufacture which results in the greatest deviations determines the tolerances in the class. A point for discussion is whether or not a proposal for standard tolerances should allow for the fact that the accuracy of the dimensions of many products is greatly dependent upon the method of manufacture.

There is every reason to debate whether the standard tolerances should be related to the manufacturing measurement.

CONTROL OF TOLERANCES

To fix or promise tolerances without ensuring in some way or other that they are adhered to can hardly lead to the desired results unless, of course, the tolerances are comparatively large. It will, therefore, often be necessary to exercise some form of control, both during manufacture and on delivery. Several different methods involving statistical quality control can be readily applied in such cases.

Apart from the foregoing special reports the discussion showed that in Western Europe large element construction has to develop in competition with traditional construction under the existing system of contracting, whereas in Eastern Europe provision of large-size contracts over a sufficient time to offset costs of industrial development facilitates matters. Thus there is in Eastern Europe a greater degree of structural novelty. Western European delegates, nevertheless, tended to justify large element development by three arguments: firstly, the effect of better wages and working conditions for operatives in the case of industrialized production; secondly, the higher standard of finish and large number of modern services to be provided at reasonable cost by factory production; and, thirdly, the existing tendency towards an increase of wages is at a rate that would seem to be higher than that of costs of materials.

Subject 5

MASS HOUSING IN RAPIDLY DEVELOPING TROPICAL AND SUBTROPICAL AREAS

UDC 333.32(213)

REPORTS

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Mass housing in rapidly developing tropical areas: an introduction

UDC 333.32(213)

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Head of Tropical Building Section, Building Research Station (United Kingdom)

INTRODUCTION

Population growth and the attraction – economic and social – of town life make urban housing one of the most intractable problems facing rapidly developing countries in tropical regions. Very many new dwellings are needed to relieve overcrowding and provide passably tolerable living conditions, or at least to prevent them becoming worse, to control and eventually to replace the disorderly shack communities springing up in and around towns, and to provide homes for families moved from sites required for industrial and commercial development or from unsafe, insanitary buildings. In most countries housing is also needed for workers in new industrial settlements, as well as on schemes for agricultural improvement.

Most tropical regions – south and east Asia excepted – are not yet as densely populated as Europe (Fig. 1), none is as urbanised (Fig. 2). The majority of families are country

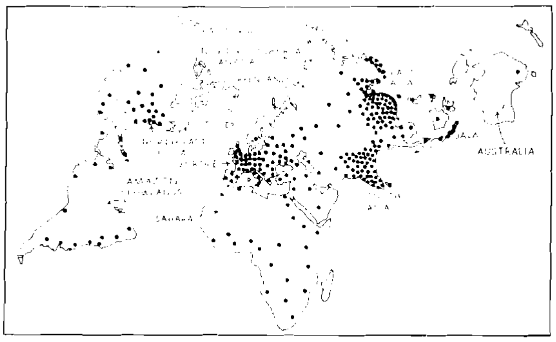


Fig. 1. World population. Except for south and east Asia, including Java, most tropical regions are not as densely populated as Europe. (Each dot represents approximately 10 million persons.)

people, usually peasant farmers. Many grow hardly enough to feed themselves, let alone have crops to sell for cash at the market. Their homes are simple, built with materials ready to hand: stones, earth, bamboo, grass, etc. But in some countries (Ghana, Ivory Coast and Malaya, for example) many peasant farmers have cash to spend on cement, sawn timber and metal roof sheets. Though possibly less pleasing to the eye, their houses are better places to live in – drier, more durable and, usually, healthier. The improvement of rural housing – and the influence, on one hand, of agricultural prosperity and, on the other, of local materials and building crafts – despite its importance must, however, fall outside the scope of this paper.

STUDIES OF URBAN SOCIAL CONDITIONS, INCLUDING HOUSING

Urban social conditions and, particularly, the patterns of urban growth and housing in economically underdeveloped areas (which, as Table I shows, include the majority of

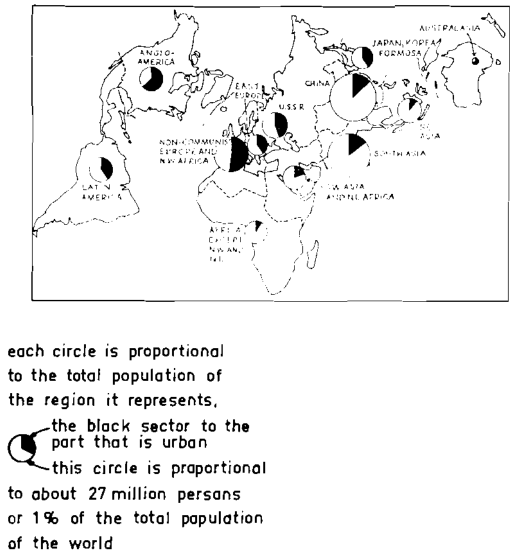


Fig. 2. World urban population. None of the tropical regions is yet as urban as Europe or North America.

TABLE I

A COMPARISON OF LIVING STANDARDS FROM THE MOST PROSPEROUS (I) TO THE POOREST (IV) COUNTRIES OF THE WORLD, RELATED TO CONSUMPTION OF ENERGY AND STEEL PER INHABITANT IN 1955 OR NEAREST YEAR

(Based on J. P. COLE (1959), *Geography of World Affairs*, Penguin Books, Harmondsworth, Middlesex.)

	The Americas	*W. Europe*	*E. Europe*	*Africa*	*Asia and Australasia*
I	Canada U.S.A.	Austria Benelux France Scandinavia Switzerland U.K. W. Germany	Czechoslovakia E. Germany		Australia New Zealand
II	Argentina Chile Cuba Uruguay Venezuela	Italy Spain	Hungary Poland Rumania U.S.S.R.	Union of S. Africa	Israel Japan
III	Brazil Colombia Mexico Peru	Greece	Bulgaria Yugoslavia	Algeria Egypt Morocco	Iraq Malaya Syria Turkey
IV	Bolivia Ecuador Guatemala Haiti			Ethiopia Sudan Tropical Africa	Burma Ceylon China Indonesia Iran Korea Pakistan Philippines Saudi Arabia Thailand

tropical countries) have been described in the United Nations report *The World Social Situation* [1]. Conditions in Africa south of the Sahara are surveyed in greater detail in a special chapter of the report and also in a comprehensive study *Social Implications of Industrialisation and Urbanisation in Africa South of the Sahara* [2] prepared under the auspices of the Unesco. An Inter-African Conference on Housing and Urbanisation was held in Nairobi in January, 1959. The proceedings of an early regional Housing Conference, held in Pretoria (1952), also describe conditions in many African countries [3].

Urban conditions in Latin America, including housing, are also described in the United Nations report, as well as in the report *Problems of Housing of Social Interest* [4] and other publications – mainly in Spanish – of the Division of Housing and Planning, Pan-American Union. The report of a Seminar on Housing Through Non-profit Organisations in Latin America, held in Copenhagen under the UN Technical Assistance Programme, forms the main content of UN Housing, Building and Planning Bulletin No. 10 (1956) [5], a special issue of which – Bulletin No. 6 (1952) [6] – had earlier been devoted to housing in tropical areas generally. Housing conditions in the Caribbean area are described in UN [7] and Caribbean [8] reports; for the West Indies, in particular, in annual reports of the Comptroller for Development and Welfare [9].

Urban social conditions, including housing, are a main concern of the UN Economic Commission for Asia and the Far East, which has reported on housing and building materials [10]. Social conditions were examined at a joint UN/Unesco Seminar in 1956 [11]. Workers' housing problems in Asian countries have been studied by the ILO [12]. The report and summaries of papers of a UN Seminar on Housing and Community Improvement held in Delhi were published as UN Housing, Building and Planning Bulletin No. 9 [13]. The report of a further Seminar on Housing Through Non-profit Organisations, held in Copenhagen under the UN Technical Assistance Programme, has also been published [14]. In 1958, an Asian conference on regional (physical) planning was held under UN auspices in Tokyo.

There is also an extensive literature dealing with conditions in individual countries; for example, the reports of a UN housing mission to Ghana [15] and of housing agencies like the Singapore Improvement Trust [16], the Hong Kong Resettlement Department [17] and the former Belgian Congo Office des Cités Africaines [18].

PATTERN OF URBAN DEVELOPMENT

Most of the rapidly growing cities of the less developed regions of the world are composed of several quarters which, though economically interdependent, are often imperfectly integrated socially and on occasion form politically distinct units. These quarters may be divided into:

(1) The modern commercial and administrative centre with its associated better-off residential areas and, in some cases, its publicly financed and administered workers' housing, where building is regulated by law and conventional techniques introduced from Europe or North America prevail.

(2) The "old centre" of narrow streets and densely occupied buildings usually of the "shop-house" type – overcrowded tenements over commercial premises and petty industries; an unimportant part of the newer towns of East and Southern Africa but the predominant section of older Asian cities.

(3) Areas of huts and shacks within or just outside the town boundary. Often built illegally of scrap materials on public or waste land, these areas are rural rather than urban in character despite the density of their settlement. Most of their inhabitants follow urban types of employment though they and their wives may add to the household income by keeping pigs or poultry and running small market gardens or let rooms to newcomers.

A recent survey of housing in Jinja, Uganda [19] – a town founded early this century and with a large migrant population – showed that a third of the workers lived in African built and owned housing on the fringe of the town, mostly mud huts with thatch or – increasingly – metal roofs, not conforming to building rules and sited haphazardly. A further third lived in accommodation which was provided, usually free of rent, by employers and which varied much in quality from neat police quarters to old, neglected lines. Only one in ten lived in houses built and run by government as a social service. An earlier survey of Singapore housing [20] gave much the same picture. One in five of lower-income households within the city were living in "attap" dwellings (timber huts with thatch roofs, mostly sited chaotically), one in three in "shop houses" (upper floors of brick or concrete buildings in the older parts of the city, usually divided into overcrowded cubicles), and only one in eight in publicly built and managed housing.

HOUSING PRIORITIES AND POLICIES

Such figures, from places where government has been exceptionally active in providing housing as a social service, indicate the scale of the problem facing most tropical countries. Few governments can afford the money or technical resources to house as a social service more than a minority of urban families. Only model or large employers are willing or able to house satisfactorily many of their workers. The mass of town dwellers, therefore, have to depend on their own initiative or on that of private entrepreneurs for shelter; for the poorer families this is often found in overcrowded cubicles or in shack settlements on the fringe of cities.

Faced with such a situation governments are finding that little benefit is to be derived from merely condemning and clearing these areas. Poverty – private and civic – and the demands of other social services and of wealth creating development usually preclude rehousing all the displaced in permanent buildings of an acceptable standard. Possibly conflicting economic and social claims compel governments deliberately or inadvertently to fix priorities. Directly and through local authorities, non-profit making organisations or, on occasion, employers build dwellings of lasting construction for selected groups: key workers, public employees, families cleared from slums, the most needy or those best able to pay an economic price.

However, it is being accepted more and more that in most tropical towns many families will have to continue to live in huts and similar short-life dwellings for some years to come and that, consequently, this form of mass housing cannot be ignored or condemned outright [21]. Rather it must be regulated to ensure that its layout, in particular, is orderly. Families may be helped with building plots, technical guidance, materials, etc.

Mass housing in tropical regions tends to take on one of three forms: housing of a lasting nature built by a public or social agency or sometimes by an employer; private building – often by petty jobbing builders – for owner-occupation or use as a lodging house in either durable or short-life materials; and self-help building by a family and friends, possibly with outside assistance and usually in short-life materials.

SOCIAL AND EMPLOYER HOUSING OF A LASTING NATURE

STANDARDS AND HOUSE PLANS

Table II shows that the floor space provided in mass housing in tropical countries is usually small – at least by post-war European standards. It reflects the lower standard of living which prevails (Table III). However, in a warm climate many household activities can take place out of doors, especially where there is a private yard and trees to give shade from the sun. The dwelling, at least for the less well off, serves mainly for sleeping and storage; indeed, in drier climates it is possible – even preferable in the hot season – to sleep out of doors.

Many early schemes were in the form of one-room dwellings with communal sanitation and possibly kitchens. The accommodation was often built to house single migrant workers[22].

TABLE II

COMPARATIVE SCALE OF DWELLING SPACE COMMONLY AVAILABLE IN DIFFERENT PARTS OF THE WORLD

(The following tentative scale – gross floor area per person – is based, wherever possible, on that usually provided or commonly available for a household of five under various circumstances in different countries. Figures are usually based on gross floor areas within outside walls on all floors occupied by the household.)

Location	*m²*	*Location*	*m²*
Conditions of serious overcrowding	**0.7–2.5**	Fiji, two-storey police housing (1958)	10.2
Three-berth European railway sleeping car compartment	0.76	Housing in E. Europe and parts of the Mediterranean; also in Latin America	**8–12**
Housing in some large Asian cities	**3–5**	Warsaw, flats (1953)	8.8–11.2 [2]
Static caravan (U.K.)	3–4.5 [1]	Greece, nucleus house (1951)	9.6
Hong Kong, legal minimum	3.25	Latin America, recommended minimum for social housing (1953)	12
Legal minimum for labour housing in some tropical countries	3.7	Social housing in W. Europe	**12–17**
Hong Kong Housing Society, one-room flat (1953)	4.3 [2]	Netherlands, minimum flats at Vlaardingen (1952)	12.6
Housing in Africa and similar tropical areas	**5–10**	England, Welwyn workers' cottages (1925)	13
Kenya, two-room flats (1947)	5.9	England, Housing Manual (1944) houses	15–16.7
Southern Rhodesia, detached bungalow (1955)	7.0		
Congo, two-storey terrace house (1956)	8.8		

[1] based on 4-person household.
[2] based on 6-person household.

TABLE III

COMPARISON OF STANDARD OF LIVING: WEALTHY (U.S.A.), INTERMEDIATE (ARGENTINA), AND POOR (INDIA) COUNTRIES

(Based on J. P. COLE (1959), *Geography of World Affairs*, Penguin Books, Harmondsworth, Middlesex.)

Standard of living	*U.S.A.*	*Argentina*	*India*
Food consumption: calories per day per inhabitant	3200 (1.8) [1]	2800 (1.6)	1800
Housing: rooms per 10 inhabitants	10 (5)	4 [2] (2)	2 [2]
Textile consumption: kg. of cotton yarn per year per inhabitant	10 (5)	4 (2)	2
Doctors per 100,000 inhabitants	120 (6)	70 (3.5)	20
Literacy: percentage of population over ten years of age literate	Almost 100%	87%	18%
Higher education: students per 10,000 inhabitants	150 (12.5)	40 (3.3)	12
Motor vehicles per 1000 inhabitants	390	33	1

[1] figures in brackets: number of times more than in India.
[2] very approximate figure.

In some Asian cities where land is scarce and there is much poverty, single-room dwellings continue to be built either with the communal latrines and ablutions like the Hong Kong Resettlement Department's seven-storey tenements [17] (Fig. 3) or as self-contained flats like those which the Hong Kong Housing Society have been building [23] (Fig. 4). Even when sub-divided with curtains or board partitions, as many of the Hong Kong rooms are, these dwellings are only acceptable for family living under exceptional circumstances. The tenements are planned for conversion into self-contained flats at roughly double space standards (Fig. 5). A feature of these single-room dwellings is the high percentage of total floor area devoted to circulation (about 30 per cent. in the Hong Kong tenement scheme).

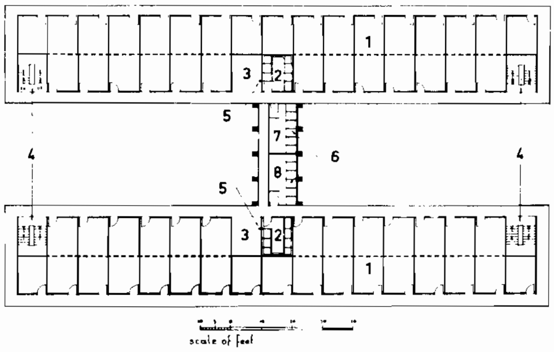


Fig. 3. Hong Kong Resettlement Department (1958). Typical floor plan of seven-storey tenements. The occupants of the 62 rooms share two water stand pipes, two bathing spaces and 12 flush latrines. Floor area 9.6 m². 1 variable partition, 2 bath, 3 washing area, 4 stairs, 5 stand pipe (mains water), 6 flush latrines, 7 men's and 8 women's conveniences.

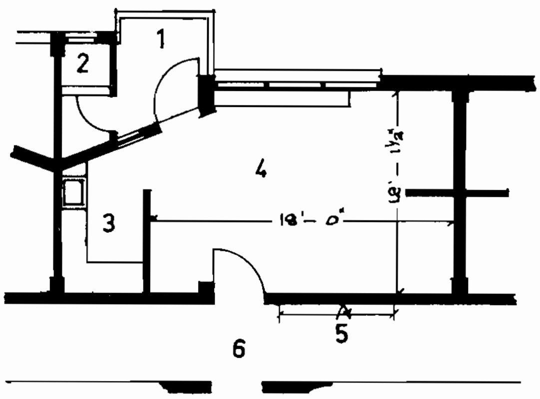


Fig. 4. Hong Kong Housing Society (1952). One-room self-contained flat for a six-person family at Shamshuipo. Floor area 26 m². 1 balcony, 2 flush latrines, 3 kitchen, 4 living area, 5 windows, 6 corridor.

In many tropical countries, the majority of less well off households – not living under conditions of severe overcrowding – are probably occupying between 5 and 10 m² of floor space per person (25–50 m² for a five-person household). Much social, and an increasing amount of employer housing is taking the form of a two, or preferably three-room dwelling with its own sanitation and kitchen. Examination of a large number of designs shows that most of the dwellings are of one of two types: the one-storey "four-square" plan, and the two-storey "terrace" plan. Both resemble European minimum house plans but are smaller in area and simpler.

Typical of the "four-square" dwelling – so named because it consists essentially of two front rooms (one of which serving as a day living-room, though it may be slept in at night) and a back bedroom and kitchen – are the Belgian Congo Office des Cités Africaines type

T. 19 (net floor area 28.2 m^2) [18] (Fig. 6), the Barbados Housing Authority's type 100 (37.1 m^2) [24] (Fig. 7) and the South African Bantu house type NE. 51/9 (47.4 m^2) [25] (Fig. 8). Many flats follow this plan, *e.g.* the Hong Kong Housing Authority's North Point scheme Type J (38.6 m^2) [26] (Fig. 9). Differences in area are due as much to the absence of passages and lobbies and to the small space allocated to the sanitation – in the Congo design a combined squat latrine/shower (1.05 m^2) – in the smaller types as to room size. (For comparison, the English post-war temporary bungalow – the popularly named "prefab" – of much the same plan but with a lobby passage, had a net floor area of about 57 m^2 (Fig. 10) [27].

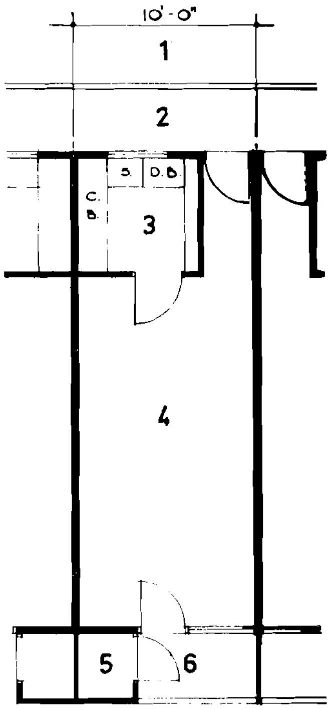
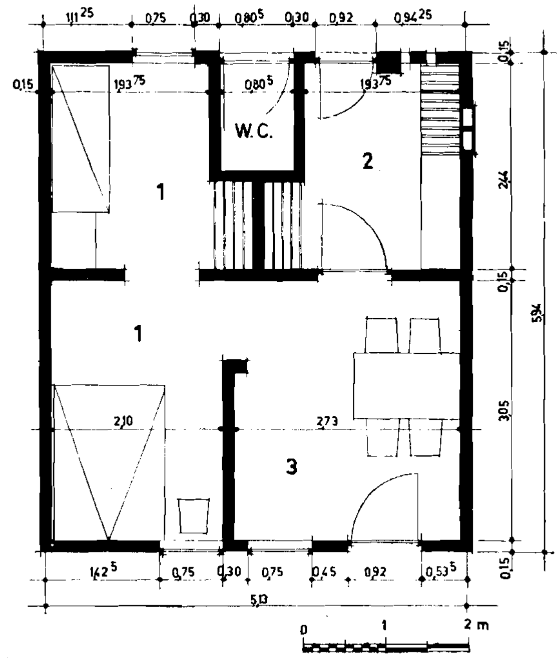


Fig. 5. Hong Kong Resettlement Department (1958). Conversion of two tenement rooms into a one-room self-contained flat. Floor area about 20–35 m^2. 1 unit width, 2 entrance balcony, 3 kitchen, 4 living accommodation, 5 toilet-shower, 6 private balcony.



Maison du type T. 19 – Stanleyville. Plan normal.

Fig. 6. Office des Cités Africaines, former Belgian Congo (1954). One-storey "four-square" house, Type T. 19. Floor area 28.2 m^2. 1 rooms, 2 kitchen, 3 living area.

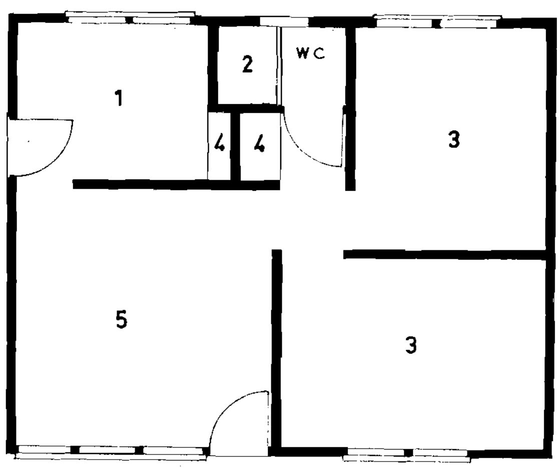


Fig. 7. Barbados Housing Authority (1957). One-storey "four-square" house, Type 100. Floor area 37.1 m^2. 1 kitchen, 2 shower, 3 bedroom, 4 cupboard, 5 living-room.

The plan has many advantages. It is economical: in South Africa – where building costs are low – the NE. 51/9 house with water-borne sanitation has cost about £ 325 [28]; the Barbados Type 100 house, £ 360 [24]. It can be built detached, in pairs or terraces. Where the climate permits, an open verandah can take the place of the kitchen. Additional living space can be provided by a walled courtyard at the back. One of the bedrooms can be planned with access from outdoors so that, as happens in East and Central Africa, it can be let to a lodger and the rent brought within the means of more families. Its main disadvantages are the rather long frontages which it needs (5 to 6 m and upwards). Through ventilation is available only at some loss of privacy – not an over-ruling matter in mass tropical housing. Skill in layout is needed if monotony is to be avoided in large schemes.

The "four-square" plan is much used for flats – for example, in Hong Kong [26] (Fig. 9), Singapore [16] (Fig. 11) and Mombasa. In an attempt to increase densities, two floors of flats, based on this plan, have been built in different parts of Africa, Fiji, Mauritius and

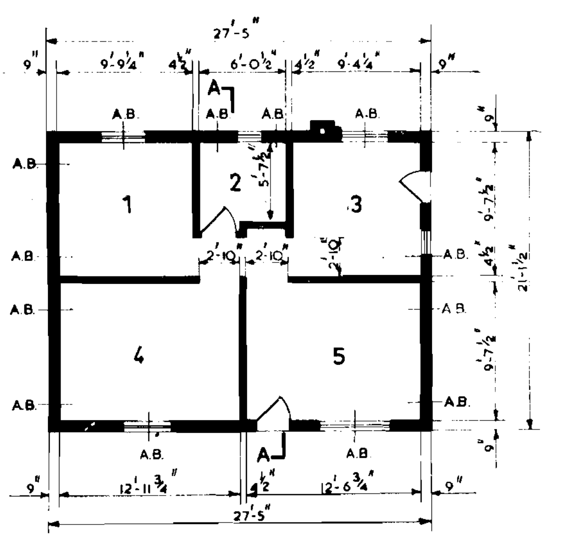


Fig. 8. South African National Housing and Planning Commission (1951). One-storey "four-square" house, Type NE. 51/9. Floor area 47.4 m². 1 bedroom (earth floor), 2 bath (concrete floor), 3 dining kitchen (concrete floor), 4 bedroom (earth floor), 5 living and sleeping quarters (earth floor).

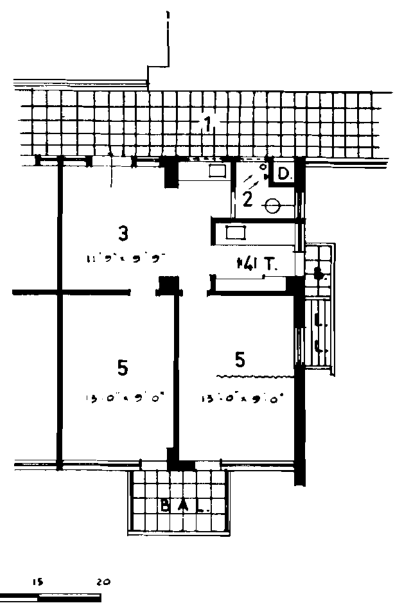


Fig. 9. Hong Kong Housing Authority (1955). Eleven-storey flats, North Point. "Four-square" plan, Type J. Floor area 38.6 m². 1 open entrance balcony, 2 bath, 3 living-room, 4 kitchen, 5 bed-room.

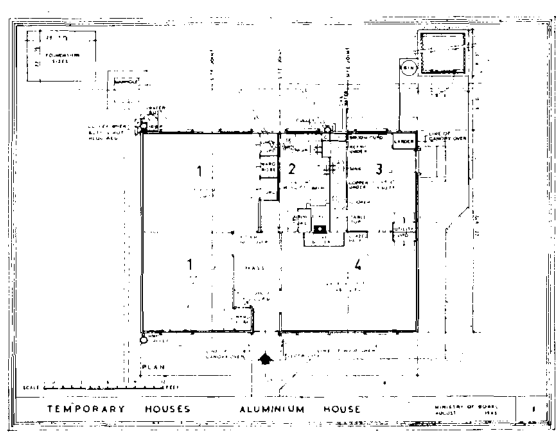


Fig. 10. U.K. Ministry of Works (1945). One-storey temporary prefabricated house of the "four-square" plan. Floor area about 57 m². 1 bedrooms, 2 bathroom, 3 kitchen, 4 living-room.

other tropical areas. There are few advantages. The slight increase in density hardly balances the cost of the concrete upper floor and staircase which usually is provided or the lack of direct access to a yard for the upper flat. As has been found in Fiji, two-storey terrace houses are a better way of increasing densities.

There is little to distinguish the two-storey terrace house being used increasingly in tropical countries for mass housing from its fellow in Europe except size and simplicity. Typical are the Belgian Congo Type T. 18 designs (net floor area 44 m²) [18] (Fig. 12), the British Guiana Housing and Planning Department Type 112 (45 m²) [29] (Fig. 13), Fiji Police houses (51 m²) and the Singapore Improvement Trust design (57 m²) [16] (Fig. 14). Usually the w.c. and wash stand are at ground level. Though floor areas are a little larger to allow for the stairs, frontages are shorter (from 4 m). An open staircase is advantageous in a warm climate as it facilitates ventilation by stack effect when there is no breeze. With an unceiled wood joisted floor, there is no overruling objection to a storey height of 2.3 m. In countries where it is customary to sleep on mats on the floor, a timber upper floor is welcomed. Bedroom windows,

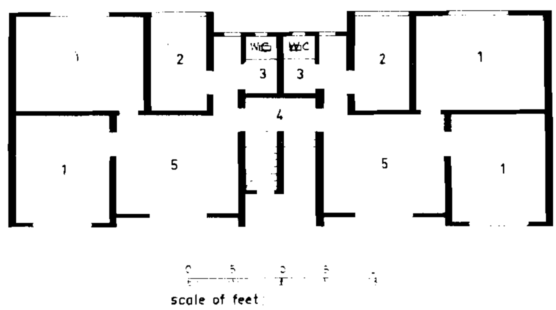


Fig. 11. Singapore Improvement Trust (1954). Three-storey flats, Alexandra Road. Typical plan of a pair of flats, each with a floor area of 51.3 m². 1 bedroom, 2 kitchen, 3 bath, 4 communal stairway, 5 living-room.

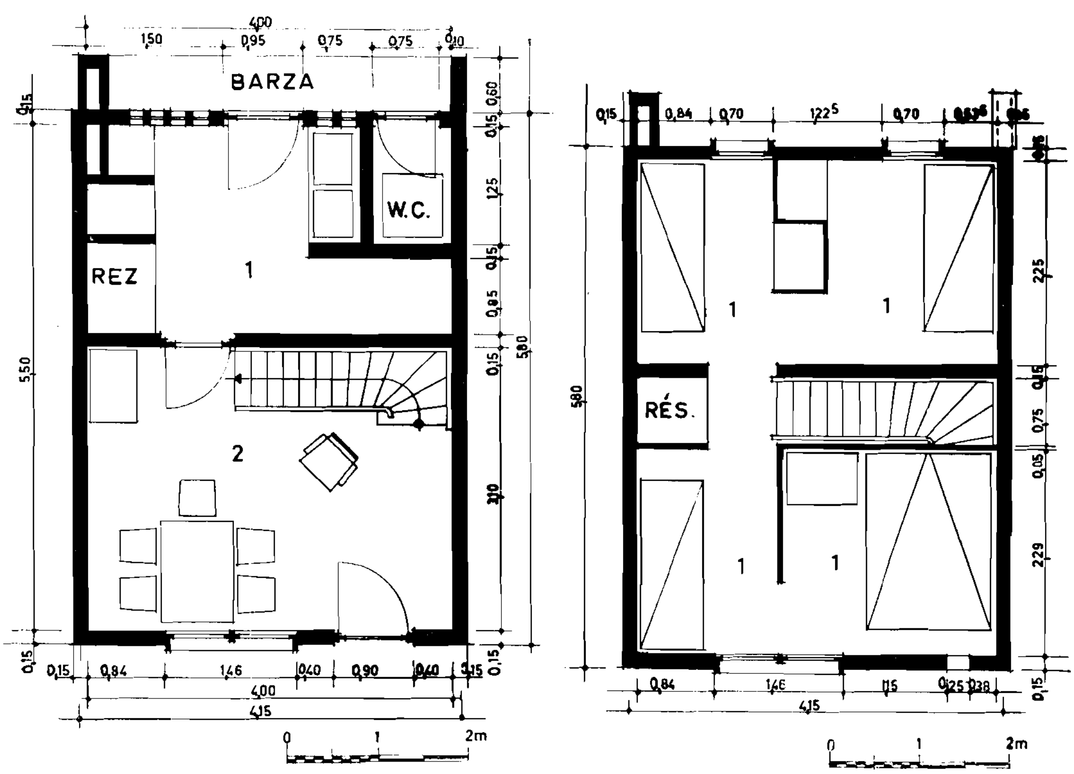


Fig. 12. Office des Cités Africaines, former Belgian Congo (1954). Two-storey "terrace" house, Type T. 18. Floor area 44 m². (Left) 1 kitchen, 2 living-room. (Right) 1 rooms.

being more secure against thieves, are more likely to be kept open at night. The judicious use of two and one-storey designs helps to prevent monotony.

CONSTRUCTION

Much attention has been given to ways of reducing the cost of "permanent" housing – possibly too much compared with the economics of layout and services. Three main lines of approach can be distinguished:

(1) Prefabrication: the erection of ready structures brought from a distance, even from abroad.

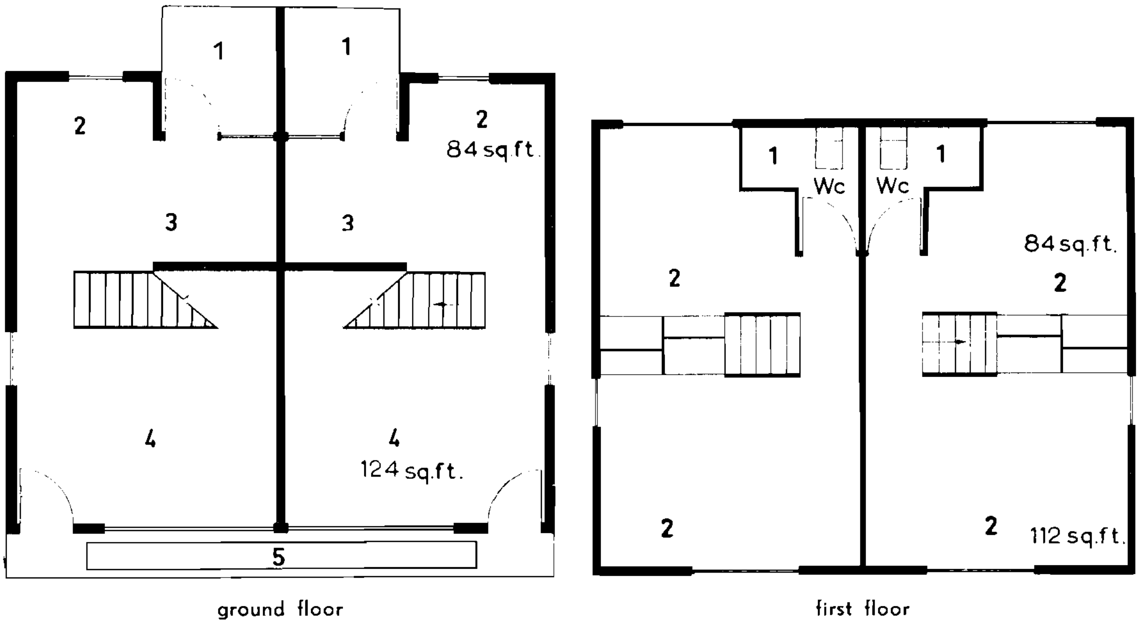


Fig. 13. British Guiana Housing and Planning Department (1954–57). Two-storey "terrace" house, type 112. Floor area 45 m². (Left) 1 terrace, 2 dining-room, 3 kitchen, 4 living-room, 5 flower box. (Right) 1 shower, 2 bedroom.

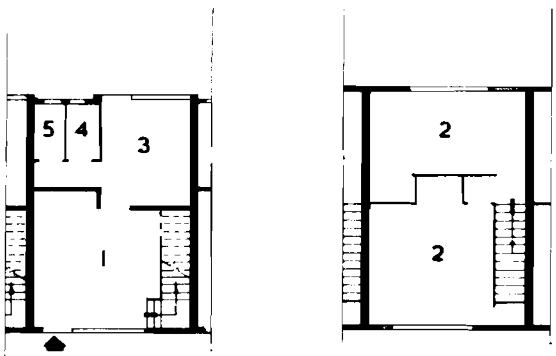


Fig. 14. Singapore Improvement Trust (1957). Two storey "terrace" house, Duchess Estate. Floor area 57 m². 1 living room, 2 bedrooms, 3 kitchen, 4 and 5 men's and women's conveniences.

(2) Mechanisation: the use of mechanical methods for handling, making and placing parts of a building, usually based on concrete.

(3) Rationalisation: the methodical use of traditional (with local materials) or conventional (using normal concrete block, brick or timber construction) building techniques.

Immediately after the last war, interest in the export of prefabricated structures to tropical and other developing countries was stimulated by shortages of materials and skilled labour overseas and by the need to find markets for prefabricated house industries in Britain, Sweden and some other European countries. Experience in the former Belgian Congo [18], where 2,200 houses were imported from a number of European countries in the late 1940s, confirms that of the United Kingdom [29a]. Only in specially favourable circumstances do imported houses compete in cost with local building. Only a few are suitable on design grounds.

Prefabricated and similar unconventional building systems based on local materials and manufacture have been used in various tropical countries. Some using timber, like that developed in Jamaica for rehousing the homeless after the 1951 hurricane, are adaptations of conventional methods. In Ghana, for a workers' housing project in connection with the proposed Volta River Dam, part fabrication of timber structures in the country and part importation was considered [30]. Increasingly, local fabrication of steel as well as timber components such as roof trusses is being adopted.

The use of precast concrete elements marks the transition between prefabrication and mechanisation. In many countries, varieties of precast concrete post and panel systems are in use [31, 32, 33]. It is possible to use simple equipment for casting, which may, in larger schemes, be carried out on the building site. The competitiveness of these systems compared with the more conventional concrete blockwork depends largely on the price and availability of aggregates – in many areas the gravel or crushed stone needed for precast units is scarce and costly while rather finely graded river sand for blockmaking is plentiful and cheap – and on local management and labour skills. In mass housing, the precast units are usually unlined and, being thinner and denser, may resist less well heat transmittance and rain penetration.

The use of novelties like concrete shells cast on inflated balloons, as in Dakar, and wheel-mounted steel moulds for casting a whole house in one operation, reported from Israel, has not yet made any significant contribution to cheap mass housing. The poor thermal behaviour and weather resistance of thin corrugated shell vaults formed by a cement plaster on coarse cloth, such as shown by the Indian Central Research Institute at the Delhi International Low Cost Exhibition (1954) [34], would seem to rule out this type of structure for general use.

In southern Africa, tilt-up concrete construction with no-fines concrete has been used extensively for mass housing [28, 35]. The operations are ingenious and labour-saving. They have shown savings over conventional methods when European artisans were employed but, with the growing use of skilled Bantu building workers and the greater use of conventional concrete blockwork, some of the advantages claimed seem to have been lost. In other tropical regions, aerated and no-fines concretes cast in place mechanically have been used successfully; large precast units using a lightweight pumice concrete have been developed in Kenya.

All these methods depend on the building of a considerable number of houses usually on the same site and to a more or less standard design. Experience in South Africa, Southern Rhodesia and Kenya – and on a smaller scale in Barbados – has shown that the rationalisation of conventional brick or concrete block techniques may result in equal economies. South African methods, by which building operations are broken down into relatively simple repetitive tasks and detailed, continuous cost studies are made, have reduced costs considerably as well as providing training on the job [25, 28]. The Barbados experience underlined the role of training, particular attention being given to the foremen [24].

Except in parts of South Africa where coal for burning is plentiful and bricks are cheap – 88s. a 1,000 (1954) – most of the techniques described make use of concrete. Roofs are covered with asbestos cement sheets, though metal sheets are also frequently used. Windows, door frames, purlins, etc., are of metal, timber or occasionally precast concrete. Floors are concrete, though the upper floors of two-storey houses may be timber. Though by European standards cement consumption in most tropical countries is low, as Table IV shows, production is expanding. For example, in East Africa the cement-making capacity in 1958 was almost 600,000 tons compared with less than 30,000 tons, using imported clinker, in 1950. It is likely, therefore, that in most tropical countries mass housing of a lasting character will largely be of concrete construction – usually more or less conventional in form.

TABLE IV

PORTLAND CEMENT CONSUMPTION IN SOME SELECTED COUNTRIES: KG/HEAD OF POPULATION (1957)

(Sources: Masalah Bangunan, October-November, 1958, derived from A/S Aalborg, Denmark; Overseas Building Notes No. 58; Bouw, February 28, 1959.)

Country	*Cement consumption*	*Country*	*Cement consumption*
Switzerland	485	Algeria	79
U.S.A.	348	Barbados	78
Venezuela	309	Mauritius	74
Netherlands	254	Brazil	65
Italy	245	British Guiana	59
United Kingdom	209	Egypt	53
Singapore	196	Belgian Congo	50 [1]
Union of South Africa	171	Tunisia	22 [1]
Japan	142	Thailand	20 [1]
Malta	133	Nigeria	17
Argentina	116	India	13 [1]
Jamaica	87	Pakistan	12 [1]
Malaya	81	Burma	7 [1]

[1] consumption in 1956.

PRIVATE HOUSE BUILDING: JOBBING BUILDERS

In many tropical countries private house building, at least in durable materials, only meets the needs of wealthier families. In few of these countries are efficient house builders to be found. Their absence is associated with the lack of reasonable facilities for loans for house purchase. Where they exist, and especially where government has developed building sites, as it has done in Malaya at Petaling Jaya, Kuala Lumpur, commercially built houses can be afforded by families with smaller incomes. (At Petaling Jaya, commercial builders have sold brick terrace houses for less than £ 600.)

Much private building is badly and wastefully designed, frequently by ill-trained "plan-drawers". Preliminary cost studies are neglected and cost control hardly exists. The work is contracted for at a lump sum price based on an arbitrary unit rate which ignores the simplicity or complexity of a design or on a labour-only basis, the building owner purchasing materials. Half-finished houses whose owners, through optimism and lack of sound technical advice, have temporarily run out of money are a frequent sight in less technically developed countries. Over a ten-year period of visits to Uganda, the slow progress of a large and substantial brick house on the Kampala-Entebbe road has personally been observed; it was not yet finished when seen last early in 1959. Such practices do not favour economical building, nor do they enable savings for house purchase to be put to best advantage.

The merit of rationalised building methods for large-scale housing – in contrast to prefabricated and mechanised construction – is that building workers and small contractors are trained in better conventional methods which they can subsequently apply to private house building. Too little attention has been paid to this feature of public encouragement to private builders. It is complementary to aid in the form of housing loan finance and the development of building sites.

In some tropical areas, for example, in Northern Nigeria and on the East African coast and also in many South East Asian countries, jobbing builders using local techniques and relatively short life materials – mud, wattle and daub, bamboo, local timbers – are to be encountered. Probably illiterate – at least in European language – these builders may be responsible, as they have been at Dar es Salaam and Zanzibar and Nigerian cities like Kano and Zaria, for a large share of new housing. Their work may cost more than half that of construction in durable materials and requires more maintenance. Mostly it takes the form of single-storey detached buildings which may house a family or an extended family or provide lodgings. Critics claim that such less durable buildings are more likely to deteriorate and become slums and, having to be spaced apart for reasons of fire and sanitation, are wasteful in urban land. On the other hand, they are usually less crowded than other types of dwelling, except well-managed public housing, and well suited to the climate. They are built within the indigenous economy and do not compete for finance and materials with large-scale building. They are more within the means of less well off families and, in particular, do not call for large initial sums of capital, being capable, as a recent social survey of Dar es Salaam shows [36], of continuous improvement. The introduction of graded building rules, permitting the use of simpler designs in local, short-life materials in designated areas of a town, is being used in East Africa as a means of controlling yet not discouraging this type of building [37].

Anyway, in the process of continuous improvement very noticeable in more prosperous communities, a gradual change from short-life to more lasting materials and the abandonment of local for more conventional techniques are apparent. Corrugated metal sheets take the place of thatch; door and window openings are framed in sawn timber and glazed sashes inserted; concrete takes the place of clay for the floor; earth walls are coated – sometimes unsuccessfully – with a cement-sand rendering; electric lighting is installed. The final product looks little different from its fellow built in concrete blockwork. Because of this, at least in places where sawn timber and cement are becoming more plentiful, which include an increasing proportion of tropical towns, it is debatable whether technical assistance should continue to be given to the improvement of local techniques. It may be better to ensure that jobbing builders become competent in conventional techniques and in simple business and costing methods and that "plan drawers" learn how to design economical and convenient dwellings. The value of large public housing schemes as a means of providing on-site training for petty builders and for developing models for new house designs tends to be underrated. Where the balance in cost on such schemes between mechanisation and building more conventionally is slight, the educational advantage of the latter should tip the scales.

More study should be given to the jobbing builders, their economy and techniques, using both traditional, short-life and conventional, more lasting materials. They have the advantage of the working participation of the master and low overheads. Expansion of their activities would mean an increase in indigenous wealth as well as a market for locally manufactured materials. They may be regarded as playing the same role in the building industry as the peasant farmer growing cash crops does in tropical agriculture.

SELF-HELP BUILDING

It may be incorrect to assume that the hut areas which fringe tropical towns are all built by the occupiers themselves. Social surveys have shown that many people living in these areas rent the rooms or bed spaces they occupy [19, 36]. The huts may be put up by jobbing builders or artisans in their spare time often for entrepreneurs who own the land, occupy it on some kind of temporary permit, or were first there as squatters. When there is a shortage of accommodation and reasonable prospects of employment, savings from rents or wages are paid to these builders for specific jobs of work. In Dar es Salaam, for example, it is usual to pay a jobbing builder some 300s. to cover a roof with corrugated iron sheets which have previously been bought from a trader, possibly on credit. Even roofs of flattened kerosene tins are put on by petty builders [36]. Nevertheless, where occupiers are more than casual tenants, they are likely to improve their dwellings by self-help as circumstances permit.

Where, because of disaster or rural poverty, immigration to towns gets out of hand, as happened in India and Pakistan in 1947 or in Hong Kong in 1949, shacks of scrap materials are put up by families themselves on any waste land available. Having little work, with encouragement and assistance such families can by self-help improve their dwellings or build better. They are like peasant peoples who are able to rebuild or improve their homes in the slack period of the agricultural year.

Much attention has been given to aiding self-help builders as a means of bettering housing conditions in tropical countries [5, 6]. It has many advantages for rural communities and the seasonally unemployed, but for town dwellers in more or less full employment it has limitations. One questions whether the elaborate community development techniques, such as are favoured in Puerto Rico and sponsored by the Housing Division, U.S. International Cooperation Administration [39], which are based on selected families working cooperatively under the guidance of trained instructors as amateur builders, might not be more usefully devoted to the technical and commercial education of a professional house-building industry. Such an industry exists in a more or less rudimentary form in many tropical countries. Attention can then be given to the provision of an adequate supply of serviced building plots, possibly in satellite communities, and to the construction of nucleus dwellings possibly by jobbing builders as a commercial venture – this happened in the first stage of Petaling Jaya, Kuala Lumpur [40] – which can be improved by housebuilders in their spare time or, if they can afford it, by professional builders.

CONCLUSIONS

The two more promising forms of mass housing in tropical countries are the rationalised and methodical use of more or less conventional techniques (using concrete blockwork, brick or timber construction) for large-scale social and employer housing of a lasting nature, and private housing by jobbing builders in local or conventional materials, preferably with public encouragement through the development of building sites and the organisation of loans for house purchasers. The two forms are complementary. The value of large public housing schemes for the on-site training of petty builders and the development of new housing designs should not be underrated.

Except in the crowded cities of Asia, the majority of less well off households not living in conditions of severe overcrowding occupy 5–10 m^2 of floor space per person or 25–50 m^2 for a five-person family. A large number of the dwellings being built by public housing authorities is of one of two types: the one-storey or "four-square" plan ranging in area from 28 to 47 m^2 in the examples noted, and the two-storey "terrace" plan ranging from 44 to 57 m^2. Both resemble European minimum house plans but are smaller in area and simpler.

Imported prefabricated houses have rarely competed in price with local building. The use of novel techniques like concrete shells has not yet made any significant contribution to cheap mass housing. Precast and tilt-up systems and those using lightweight material have been used successfully, but the rationalisation of conventional brick or concrete block construction may give equal economies. It has the advantage of easier adoption by petty builders.

Though by European standards cement consumption is low, production in tropical countries is expanding. Concrete is likely to be the main material for mass building in many places. Increasingly, houses built in local, short-life materials are being cement plastered and improved with concrete floors, etc., to resemble their initially more costly fellows built in concrete blockwork.

Though aided self-help building has many advantages for rural communities, refugee families and the seasonally unemployed, the elaborate techniques sometimes used for aiding urban families to work cooperatively on self-help building projects might be better devoted to the encouragement of efficient professional housebuilders.

ACKNOWLEDGMENTS

This work is part of the programme of the Building Research Board, and acknowledgments are made to the Director of Building Research for permission to publish the paper.

REFERENCES

[1] United Nations, *Report on the World Social Situation, including Studies of Urbanization in Under-developed Areas*, New York, 1957.

[2] Unesco, *Social Implications of Industrialization and Urbanization in Africa South of the Sahara*, Paris, 1956.

[3] CCTA, *Proceedings of the Regional Conference on Housing Research in Africa South of the Sahara*, Pretoria, 1952.

[4] Inter-American Economic and Social Council, *Problems of Housing of Social Interest*, Pan-American Union, Washington D.C., 1954.

[5] United Nations, *Housing Through Non-profit Organizations*, Housing, Building and Planning Bulletin No. 10, New York, 1956.

[6] United Nations, *Housing in the Tropics*, Housing and Town and Country Planning Bulletin No. 6, New York, 1952.

[7] United Nations, *Survey of Problems of Low-cost Rural Housing in Tropical Areas: A preliminary report with special reference to the Caribbean area*, New York, 1950.

[8] Caribbean Commission, *Aspects of Housing in the Caribbean*, Trinidad, 1951.

[9] SIR STEPHEN LUKE, *Development and Welfare in the West Indies*, 1957, H. M. Stationery Office, London (and earlier report of the Comptroller for Development and Welfare in the West Indies), 1958.

[10] United Nations, *Survey of Housing and Building Materials in Asia and the Far East, 1956*, Bangkok, 1956.

[11] Unesco, *Urbanization in Asia and the Far East*, Proceedings of the joint Unesco/UN Seminar, Bangkok, August, 1956, Calcutta, 1957.

[12] International Labour Organisation, *Workers' Housing Problems in Asian Countries*, Report II for Asian Regional Conference, Tokyo, September, 1953, Geneva, 1953.

[13] United Nations, *International Action in Asia and the Far East*, Housing, Building and Planning Bulletin No. 9, New York, 1955.

[14] United Nations, *Asia and the Far East Seminar on Housing through Non-profit Organisations, Copenhagen, July–August, 1956*, New York, 1958.

[15] United Nations, *Housing in Ghana*, prepared for the Government of Ghana by the UN Technical Assistance Housing Mission, 1957.

[16] J. M. FRASER, *The Work of the Singapore Improvement Trust, 1957*, Government Printing Office, Singapore, 1958.

[17] Commissioner for Resettlement, *Annual Departmental Reports 1957–58*, Government Printer, Hong Kong, 1958.

[18] X. L. DE SCHIERVEL, *Les Nouvelles Cités Congolaises*, Académie Royale des Sciences Coloniales, Brussels, 1956.

[19] P. C. W. GUTKIND AND W. ELKAN, *Housing in Jinja*, East African Institute of Social Research, Kampala, Uganda, 1957.

[20] G. K. SWEE, *Urban incomes and housing: A Report of the Social Survey of Singapore, 1953–54*, Government Printing Office, Singapore, 1956.

[21] G. A. ATKINSON, *Urbanisation and Town Growth in Africa. Problems of Mass Housing and Techniques Assisting Towards their Solution*, CCTA Inter-African Housing and Urbanisation Conference, Nairobi, 1958.

[22] K. C. CHARRON, *The Welfare of the African Labour in Tanganyika*, Government Printer, Dar es Salaam, 1946.

[23] Colonial Liaison Officer, *Housing in Hong Kong*, Colonial Building Notes No. 17, Building Research Station, Watford, 1953.

[24] J. C. WALKER, *Low-cost Housing in Barbados*. Colonial Building Notes No. 48, Building Research Station, Watford, 1957.

[25] D. M. CALDERWOOD, *Native Housing in South Africa*, University of Witwatersrand, Johannesburg, 1953.

[26] H. G. RICHARDS, *Annual Report of the Hong Kong Housing Authority 1954–55*, Government Printer, Hong Kong, 1955.

[27] Ministries of Health and Works, *Temporary Accommodation*, H. M. Stationery Office, London, 1944.

[28] National Building Research Institute, *Research Studies on the Costs of Urban Bantu Housing*, South African Council for Scientific and Industrial Research, Pretoria, 1954.

[29] Colonial Liaison Officer, *Housing, Building and Planning in the West Indies, 1957*, Overseas Building Notes No. 57, Building Research Station, Watford, 1958.

[29a] G. A. ATKINSON, Building Techniques Overseas, *Prefabrication*, July and August, 1954.

[30] L. DE SYLLAS, A Temporary Township on the Gold Coast, *Architects' J.*, February 21, 1957.

[31] Colonial Liaison Officer, *Housing in Fiji*, Colonial Building Notes No. 18, Building Research Station Watford, 1953.

[32] J. M. FRASER, *The work of the Singapore Improvement Trust, 1927–1947*, Singapore, 1948.

[33] Colonial Liaison Officer, *Uganda: Low-cost Housing Using Post-and-Panel Construction*, Colonial Building Notes No. 37, Building Research Station, Watford, 1956.

[34] Comfort Survey Committee, *Report on Low-cost Housing*, National Buildings Organisation, New Delhi, 1957.

[35] Colonial Liaison Officer, *Lightweight Concrete*, Overseas Building Notes No. 58, Building Research Station, Watford, 1959.

[36] J. A. K. LESLIE, *Social Survey of Dar es Salaam*, unpublished duplicated report to Minister for Local Government, Tanganyika, 1957.

[37] A. H. RUSSELL AND J. R. HATHER, *Aspects of Development within the Urban Area of Greater Kampala*, Report of Proceedings, Town and Country Planning Summer School, 1957, Town Planning Institute, London, 1957.

[38] J. P. COLE, *Geography of World Affairs*. Penguin Books, 1959.

[39] K. H. HINCHCLIFFE, *Leader Training for Aided Self-Help Housing*, Housing Division, International Cooperation Administration, Washington D.C., 1957.

[40] T. A. L. CONCANNON, *Town Planning in Malaya: Petaling Jaya New Town, Kuala Lumpur*, Colonial Building Notes No. 30, Building Research Station, Watford, 1955.

"Ekistics", the key to housing in developing areas

UDC 333.32

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INTRODUCTION

When experts speak of housing in developing areas and try to find solutions to this basic problem, they usually think and talk in terms of building materials, methods of construction and costs of house construction. They usually do not concentrate on problems of policies with regard to physical planning and housing or even broader problems of programming, preparation of programmes, etc.

The degree of attention we pay to the different subjects, one can say, decreases as we move from the single house to a national scale. This is due to a large extent to the fact that the majority of people concerned with and working on housing are engineers, builders, architects and not policy makers, economists, physical planners. Thus attention is paid mainly to the single house. But the problem of housing is of a national scale. Had it not been a problem of national scale, then it would have been much easier to solve and there would be no need for such reports as the present one and such meetings as the present one. It would have been the work of architects and builders to design better houses and to build them. After all, it is not difficult to build some dozens of houses.

The fact that today housing problems assume large proportions and have actually become problems of national scale, compels us to look at them with a different eye and the ways to meet them should be considered more as a national task than individual efforts.

The present report is an attempt to show how, by enlarging the scope of our research, we can find ways to meet the housing problems, which are especially acute in developing areas.

HOUSING PROBLEMS IN DEVELOPING AREAS

THE IMPACT OF DEVELOPMENT

In order to find a way to solve the housing problems, we first have to understand them as well as possible.

Housing was in the past, up to a generation or two ago, no greater problem for most countries than the problem of food or clothing and health. In many cases it was even a minor problem as people could always build some kind of house whilst they could not always find the appropriate kind of food. If there was a major problem in underdeveloped areas, it was the lack of appropriate food and certainly not the lack of houses.

The situation has been changed, however, since development started. Development was first started in some northwestern European countries and the northern part of the American continent, and during the present generation, especially since the last war, the notion of development spread throughout the world. People became interested in developing their countries either because of the urge of imitation or because of increased demands generated by their contact with other peoples. When people became development-conscious, housing became the great problem.

This was mainly due to the phenomena of urbanization, which started on a big scale in the developing countries; to industrialization, which went side by side with urbanization; and to the gradual organization of government and social services, which itself created additional demands for better housing. Thus, the lack of proper houses corresponding to the new needs of the upcoming classes of urban dwellers, industrial workers, managerial classes of the government and social services, became the most apparent problem in the developing countries.

Attention was turned to the creation of more and better houses. After all, when people speak of bad housing conditions they think of the houses themselves and ask for more and better houses.

However, this effort to solve housing problems by producing more and better houses has not succeeded at all, with the exception of very few cases where problems were of very small scale and financial means and talent in government and business circles and professional and skilled labour were available. In every other case the failure was complete and it would not be wrong to state that housing conditions today are becoming continuously worse in the urban areas of most of the developing countries whilst they remain at the same level as before in the rural areas, which actually means a lower level because the rural inhabitants require more and better houses than before. The causes of these worsening conditions were not always technical; on the contrary, in most cases they were not.

THE REAL HOUSING PROBLEMS

The main cause of the housing problems created today is the great change in demand for houses and housing facilities in general. This is the result of two important factors: the increase and movement of population with its splitting of old patriarchal families, and the rise of income. New health conditions, allowing a greater increase of the population than before, have not been followed by an increase of the productive capacity of the people, who produce perhaps the same number of houses of the same quality as before whilst the needs are now much greater. On the other hand, the splitting of families has created the need for more housing units for the same numbers of people.

Even for a stable population entering the era of development, however, the changes in its geographical distribution are such that new colossal needs for houses have been created in all urban and industrial centres. The people now tend to abandon certain areas and to concentrate in others. The change of the pattern of geographical distribution is big. People are tending towards new central functions, new market centres, new centres of administration.

Thus, even if we have a country with a stable population, we have a problem of creating new houses in urban centres because people cannot take with them their old homesteads from the countryside.

To these two basic problems of additional needs in numbers of housing units we have another which is of the greatest importance. This is the change in requirements, the demand for higher standards. The fact that the factory worker was up to now working in the fields, in the mud, toiling with the soil all day and was satisfied to go back to a hut with a thatched roof and a mud floor, does not mean that the new industrial worker who now works in a concrete or stone building with a good roof, with a well paved, clean floor and perhaps air-conditioning, will be satisfied to go back to live in the same house.

We cannot expect an individual worker, who has now become a servant of the machine and who has to protect, maintain and oil it, to return at night to live on a damp mud floor. This man has much higher requirements which, if not satisfied, will not allow him to become a good industrial worker and will actually make him wonder if the machine is the real ruler of our era and he is simply its servant rather than its master. For all these reasons it is no longer possible for the industrial worker and the technically advanced man of our day to satisfy himself with the old standard of housing.

Thus we come to the conclusion that today we need much greater numbers of houses in new localities for people requiring much higher standards of living.

INADEQUATE POLICIES INCREASE THE PROBLEMS

The tasks described above are so great that they require efforts on a national scale, and yet they have not been met by the proper policies. We can state very definitely that in most of the developing countries there is complete lack of national policies and national programmes to provide for the necessary allocations of public funds and mobilization of private resources to meet this problem.

The building industries as a whole have not been adjusted to the demand, building materials have not been produced to meet the needs, people are not trained, methods of financing have not been studied and the countries are unable to meet the problem.

This is largely due to the lack of understanding of the role of housing in the development of the country in programmes of economic development. People overlook the human factor, they speak of directly productive sectors, and consequently they have the social and human problems of displaced, dissatisfied people who do not help in the successful implementation of overall development programmes.

There is also a lack of proper regional conceptions, lack of understanding of the changing regional patterns. We have cases where many houses are built by private people or by governments just in the wrong areas, in the areas which are not going to develop in the future. The fact that the national development programmes do not provide adequate measures for housing causes many houses to be built in the wrong areas and thus a certain part of the housing production potential is wasted.

To these weaknesses we have to add the lack of proper physical town plans which help the creation of the proper housing projects. Everybody tends to create projects with wide streets and, incidentally, with relatively narrow avenues. Great expenditures are involved in the creation, the maintenance and the operation of housing projects of the wrong kind. The people who started them are discouraged by the colossal cost involved and people living in them are disillusioned because these projects are never completed owing to lack of financial means. We have many cases where the authorities who created such expensive projects did not complete them; we have other cases where completed projects were passed over to municipal authorities which were unable to maintain them and which again passed the responsibility to State governments or federal governments which were faced with economic problems.

These practices result from the lack of trained people to face the problems of developing countries, people to look at the overall problem, and hence the planner or the one who replaces him because of the lack of appropriate numbers of planners is trying to copy the old Western city which he has seen in books and magazines. He overlooks the fact that financial, economic, climatic and other conditions are completely different.

This brings us to another point, *viz*. the lack of a proper design adjusted to the climate and the economy of a country. The tendency to copy the Western patterns, which are really patterns of northwestern Europe, in countries which have completely different conditions, is creating insurmountable problems for people who find themselves in a new environment, much more expensive than it should be and serving their needs much less. In this way people are again disillusioned, authorities are disappointed and think that the problems cannot be met.

Finally, we have to state that there is a lack of understanding even in the use of local materials as soon as attempts for housing begin. People tend to build houses corresponding to British specifications, produce bricks according to British standards, follow types of construction and imitate materials produced in other countries for completely different conditions. The very fact that even in countries which require very simple walls with continuous ventilation through them, attempts have been made to build low-cost houses with heavy brick walls, shows how wrong the conception is in many cases of the real problems and the methods by which they can be solved.

THE CAUSES OF INADEQUATE POLICIES

Let us try to find out why, as we have analyzed in the previous section, the policies are so inadequate. There are many reasons for that, and they are all due to the fact that we are going through a transition era, from the static era of practically no development, to the era of rapid development.

The economic planners who are usually in charge of the economic development of a country overlook the size of investment in housing and settlements and pay very little attention to this whole sector which they leave without any guidance or plan. But the investment in the whole field of housing is very big. Actually, the less developed a country the bigger the investment in proportion to the other sectors, as capitalists in underdeveloped countries invest practically nothing in industry and very small amounts in transportation and communication. In fact, the whole of private investment goes into agriculture and housing and human settlements. Thus, the greatest natural sector of investment is overlooked by economic plans, left without any control and usually when development starts, more is spent simply on bigger numbers of luxurious houses, without contributing to the solution of the problem.

There is a legend that when economic development starts, investment in housing drops by necessity. This is not true, however. Investment in housing may fall proportionately to other activities but increases continuously in absolute figures, even without any guidance, and even without any assistance from the government.

Then we must look at the fact that social planning did not proceed side by side with economic planning. Let us not overlook that the overall development programmes are usually called economic development programmes and too much attention is paid to the sectors which are going to increase production directly. In many such programmes the human factor is completely overlooked and no attention is paid to the people themselves, who look for something new in a developing economy.

One of the most characteristic examples of the lack of understanding of the human aspects and of the lack of social planning is the fact that land remains in complete ownership of big landowners who, when they recognize the trend towards big cities and industrial centres, raise the prices of the land and by this mere fact become the enemies of organized housing efforts, as more and more national funds have to be spent for the acquisition of land and not for the actual construction of houses.

The housing effort required is such, and the number of technically trained people so small, that physical planners, the natural leaders of the rebuilding and expanding of cities, are not at all at work in most cases or, if so, they limit themselves to existing areas, to the projects which pay, and they follow patterns of existing settlements because they do not have the skill, the talent and perhaps even the time to think of the broader problems which arise in our era.

Planners and designers of houses are either citizens of Western, developed countries or native citizens who have been trained in the West. By necessity they have been influenced by alien solutions and they transplant them without due consideration to the completely different conditions which exist in each country. Here we arrive at the basic weakness of training planners and designers who do not learn the scientific approach to the problems but the technique of solving problems of the countries where they are trained, which means that these people become technicians able to work out certain examples of solutions but not the scientists to open new lines of thought and to find the appropriate solution in every case.

Finally, the increase of production which is required dictates much greater use of local methods of construction, and in a better way; much greater standardization in implementation; more research; new materials based on local raw materials. This requires a great deal of effort and research which is very seldom made and hence great local resources, materials and skill remain unexploited.

CONCLUSION

There is no doubt that in spite of the efforts made in many countries, people are now living worse in relation to their income than before the beginning of development. We have only to cross some developing countries in order to find thatched or straw huts, mud huts or tin shacks, with a very low level of construction but equipped with radios, refrigerators, some with electricity and even a motorcar parked in front.

To anyone who has been to these countries, this is a picture which remains very strong in his mind: the village, the small hamlet, the suburban areas, consisting of very sub-standard houses, the occupants of which are able to acquire other mechanical and electrical gadgets, buy appliances, use other facilities, but are not even conscious of or able to build a better house. As long as we look at housing solely as a problem of constructing houses we will fail. The housing problem is a much broader one and we must be prepared to look at it, understand it, and meet it.

"EKISTICS", THE SCIENCE OF HUMAN SETTLEMENTS

WHAT IS "EKISTICS"?

There is undoubtedly a need for a new approach. The approach should not be technical and should not teach us a certain technique of "how to build a house" or even how to devise a layout under certain conditions, but the scientific approach, because conditions differ from country to country, region to region, time to time and specific project to specific project. Our approach should be scientific; it is the scientific approach that we need, the approach which will allow us to recognize situations and then find the appropriate solutions and not the technique which will teach us how to apply known methods.

"Ekistics" is the science of human settlements. Ekistics should open to us the road to the solution of housing problems. It begins by looking at the housing effort as a whole and simultaneously as part of a national effort for development. Ekistics connects development, which is the cause of housing problems, with housing itself. It guarantees a policy which starts from the statement of main causes and assures that the effort to be made is the proper one. Ekistics, by conceiving the whole, can give the directives for each effort to be made within it.

Ekistics in action has to be expressed in scientific terms, in ekistic policies and ekistic programmes. Physical plans to which we are used, designs and estimates of quantities and the description of building materials are really only two- and three-dimensional expressions of programmes. Housing programmes should be the main weapon for the realization of our goals. Let us not forget that the main factor we have to face today is the factor of time, because time increases our problems. And yet the main weapon we have in our hands for the solution of our problems, which cannot be solved overnight, is the factor of time, as it is only in accordance with a long-term programme that we can face such colossal problems. Problems have been created over years, decades and centuries and we cannot face them in similar periods. The time factor becomes a very important one, the technique of designing and planning is not enough, we need a technique where the time factor plays a great role, a technique for long-term programmes. Let us not forget that in economic development, where we have progressed much more, we do not speak of short-term goals but of long-term programmes and we have developed special ways of instituting them.

FROM ECONOMIC PLANNING TO EKISTICS

The development of a nation is usually based on economic development, although economic development is not an aim in itself. The proper share of available resources should go into housing. It does not help to say that housing is nonproductive. This is very naive. Housing, like everything else, has to get its share of the national effort. If it receives less than its share then there is a lack of proper balance and we have disturbances and dissatisfaction of the people; we have, really, socially displaced persons, unrest, and an upsetting of the economic effort which was our goal when we neglected housing.

If, on the other hand, we give more for housing than the proper share we have a delay in economic development because we shift the resources from other sectors to housing.

The question, therefore, is: "what is the proper share?" This is something that cannot be answered by an all-encompassing rule. We must find for each case what the proper share of housing within the national development programmes is. This is the greatest task for ekistics. If, for example, in one case housing is inadequate and the country is not yet prepared to glance at industrial development then perhaps this country should start by dedicating a big effort to housing. If, on the other hand, the goal is immediate industrial development, then we should proportion housing to the new industries which are created in new places in order to attract labour and develop the type of labour which we need to serve the new types of industries.

In many cases, although it is not so recognized, housing is more necessary percentagewise at the beginning of development. The reasons are the following:

(a) New development requires movements of people towards new cities and new places and proper housing will facilitate such movement of the people, facilitate their settlement near the industrial centres, and will make them happy and attract them to newly irrigated and newly settled lands.

(b) Housing is also necessary at the beginning of the programme in order to mobilize more easily the human resources of the country. It is much easier to mobilize people to build their own houses than to mobilize them for big public projects, even of a colossal interest. A house being an item of personal property, every person can afford the labour to build it without complaints if he sees that he is going to use it directly for his family. A big project does not appeal to him at all in the same way.

(c) Housing is also indispensable at the beginning of a programme in order to train people gradually for higher skills. Actually, the simpler skills required in an overall development effort are the skills required in housing. These are simpler than the skills required for big public works and for industries. Housing is a very good site and a very good workshop to start training a farmer into a skilled labourer. We can start by training masons who intend to become fitters and by teaching electricians simply how to make installations within houses and then select from them the highly-skilled electricians for complicated installations.

Housing is also a sector where we can achieve a better balance of resources to requirements. In housing we can study many types of solutions which are impossible in industry. One cannot create an industry in a developing country without importing all the equipment perhaps from abroad, but in houses one can always choose between a solution based only on local materials (after all, people have been building houses without importing materials for centuries and centuries) and houses requiring building materials from abroad. With housing we can regulate how much of the funds in foreign exchange can be spent on this sector and how much for other sectors.

In the preparation of economic programmes we have to decide how much money for housing will come from private people in a combination of capital and labour, and how much from the government. It is here that we can regulate the market of available labour resources to serve these schemes. Some of the best rural schemes may have no value at all if not combined with improvement of houses and the creation of new ones.

It is within the economic plan that we must find the answer to such basic problems as the balance between income of various classes and value of the houses. It is unrealistic to start with houses that are not directly related to the incomes of the people. Sometimes the income is so low that houses cannot be built for these people and then we have to face the problem whether these people will mobilize their available labour resources to build these houses or, if fully employed, they have to obtain assistance from the government to build. Yet this assistance must not be beyond the possibilities of the country as a whole because then it will not lead to the success of the housing programme but only to the creation of demonstration projects.

It is also within the frame of the overall national development plan that urban land policy should be worked out. Land prices in the urban areas should not be permitted to rise and kill every effort of housing as it has happened in many countries. Corresponding policies have to be developed.

It is within the frame of economic development programmes that the building material industries have to be developed, from the highest order to the lowest and from handicraft to the more elaborate industries. It is within the same national development programme that labour policies have to be conceived which will enable the mobilization of labour resources for housing in a proper relation to the mobilization of labour for other sectors of the economy.

FROM SOCIAL POLICIES TO EKISTICS

To confine studies to economic planning and to ekistics and interrelate them would be wrong. We have to start with social policies and derive ekistics policies from them.

Ekistic requirements impose certain social policies, *e.g.* the acquisition of urban land at reasonable prices. Ekistic policies should be the main initiator of urban land reform. There is too much talk in all developing countries about rural land reform whilst urban land reform remains the key to many other national problems.

Conversely, social policies should influence ekistic requirements. This means that if the government has set certain social rules, these will have also to be expressed in large ekistic targets. If the government wants to give the rural land to the farmer, it should take it from the big landowner and help the farmer create and settle in a village, as in most cases he has been a serf up to now, moved around from parcel to parcel of land owned by the big landowner who, in many cases, was doing this in order not to let the peasant settle down, and he gradually became a citizen who could claim certain rights. There is no question that people responsible for housing cannot remain at the end of the chain, like mechanics receiving orders from the economic and social branch and other branches. They have to influence decisions in most of the countries; otherwise the effort will break down at a very early stage on problems like the lack of sufficient urban land, its exorbitant prices or the insufficiency of skilled labour, high cost of materials, bottlenecks in their production or lack of foreign currency for their importation.

The persons responsible for housing should be the ones to initiate right at the conception of the economic and social policies of the government the measures which are going to influence housing activities more than if they remain at the end of the chain and wait for all other branches to take their decisions and then have to struggle with the results achieved through economic and social policies.

Let us not forget that human interests are always the goal, and not the construction of houses. It may be better to build only part of the houses for 10 families than a complete house for one family. We should not start by conceiving the house and then seeing how we can build it, but we should start by conceiving the economics of a society and the social goals by mobilizing best and utilizing best our resources for the largest possible number of people.

Social goals should always aim at satisfying the largest numbers of people in the classes which are in greater need of better housing facilities for the achievement of the national goals.

EKISTICS EXPRESSED IN REGIONAL PROGRAMMES

No progress can be achieved in the housing development of any area unless there is a regional programme. A regional plan should be the two- and three-dimensional expression of such a programme. It is the housing development programme which is important and which has to be conceived. If we take out of our actions and calculations the time element then we cannot achieve any results. There is no housing action which can be expressed only in a plan. This is an impossibility. The plan is static whilst the solution of problems is dynamic. It is, therefore, of the greatest importance to understand that we cannot achieve anything by planning and designing in two and three dimensions. We have to put the time factor into every consideration to conceive a long-term programme, to work out shorter programmes and express all of these in two-dimensional and three-dimensional plans.

Once we consider the dynamics of housing developments and we begin to look at everything through the time factor, then we have to understand the changes which take place in the geographical distribution of settlements. This is equally important. It is impossible to have development in any area without having continuous dynamic changes of the settlements, their size, their interrelationship, their contents and their structure. And these changes we have to understand in advance in order to be able to serve any area with housing programmes.

These changes can be of different kinds. There can be changes in the whole ekistic pattern consisting of several settlements spread over a certain area. The important centres may change, new settlements may have to be created, the whole interrelationship and the hierarchy of functions among settlements may alter.

Some of the most important changes are the changes of market centres. Even without the creation of new settlements, without the creation of new economic functions like industry and mining, the new rural settlements in a certain area will, because of their natural development, undergo changes in the importance of the market centres. The distances between them, because of new means of transportation, acquire a different meaning. Whereas in the past people walked or travelled on horseback or camelback towards a market centre, which was at a distance of 15 or 20 kilometres from their villages, they can now with the same effort reach centres lying at distances of up to 80 or 100 kilometres within the same time by new means of transportation, which means that some market centres are losing importance, whilst others are gaining. It is, therefore, essential to understand the whole pattern of markets and the area served by the markets in order to understand the new problems arising in settlements, the declining settlements, prospering settlements, etc.

There are also other types of changes which are more apparent and more easy to understand. These are the changes due to the creation of new settlements, which can be mining, industrial or agricultural settlements. This means the creation of new densities, the influence of these new settlements on the surrounding ones and new interrelationships within a whole area.

Let us not forget that the most important fact that has to be understood in every area is its geographic structure and its influence on the settlements. The big city builders in areas which are now entering the phase of development should, like Alexander the Great, have geographers as advisers, who are able to decide about the need for new settlements in developing areas.

Programmes of action have to be decided according to the new patterns of settlements to be developed. This makes it necessary to understand the character of every area and the phase of development which its settlements are going through at a given moment.

These types and phases of developing areas can be classified in the following catagories:

(a) Areas which are developing and where development is justified economically.

(b) Areas which are developing but where development is not justified economically and will not continue.

(c) Areas which are stable and where this stable position is justified.

(d) Areas which appear to be stable but whose stability is not justified and, therefore, will be upset later, for better or worse.

(e) Areas which are retarded, and where this is economically justified because there is no possibility to develop them economically.

(f) Areas which are economically retarded unjustifiably because they have been overlooked, have not been aided, and where existing natural potentials will create a much more important development and turn them from depressed into fast-developing areas.

It is obvious that policies have to be decided for every such area in a different way and only after a real understanding of the phase they are in. On the basis of these policies the sizes of settlements at present and in the future have to be decided and only then can the functions within them be determined, as well as the action to be taken for every one of them. Then action will follow in accordance with the expected trends in every area and in every settlement.

EKISTICS EXPRESSED IN MASTER PROGRAMMES

Just as we have to approach the problem of regional programmes without limiting ourselves to physical plans, in the same way we have to approach the problems of the development of cities with major long-term programmes which will define the trends of population and of the economy before proceeding to anything related to the physical development of a city. In this way we arrive at programmes arising out of the needs of the city and its possibilities for development.

With such programmes we shall be able to estimate the sizes of the different projects to be created in houses or buildings or other facilities down to the land areas which are required and can be developed within the city. After defining the sizes of the different projects and the areas required for them we are able to proceed to physical plans and define the sites of the different functions within a master plan, the arteries and other features for the complete design of the city, which will be only an expression of the long-term programme conceived for it. Following this, we have to draw up partial programmes of, say, the urban economics, including everything related to the economic development of the city and referring to the possibilities of public and private financing for its development, programmes of community facilities, programmes of houses, public buildings, etc.

EKISTICS EXPRESSED IN DESIGNS

Following the conception of regional programmes for major regions and master programmes for the cities, we can proceed to designs which are intended to meet the problems of particular localities. We should be convinced from the start that we cannot transfer a design from one country to the other or from one region to the other, especially in the underdeveloped areas. Everything has to be conceived anew with a clear understanding of the conditions of the developing countries, from the community layout to the house design; everything has to be designed on the basis and the knowledge of local conditions.

A basic problem which arises when designing for the developing areas is the problem of cost. We have certainly to know the budget of the city, the budget of the community, of the family or of the school committee for their corresponding projects. We have to estimate how much can be spent now and how much in the future. If we decide on the realistic then we have to face the following dilemma: if we relate the expenditure for the project to the present incomes and budgets, then the project will very soon be surpassed by natural evolution in a developing economy; it will be very small and will not serve its purpose any more. If, on the other hand, we base our estimates of cost on the future possibilities of financing, we create a project which will be impossible to finance and, even if it is financed, it will prove uneconomic because it will not be economically in balance with the classes which are using it.

Consequently, in developing countries we must decide to plan for the future but to build for the present. This means that we must conceive big and construct small, we must think every time how many years the house is going to last, how many years a road is going to last, how much of it can reasonably be built now and how much should be justified in five, ten and fifty years.

In the case of housing, this leads to the conception of the growing house. The same goes for schools, public buildings, etc., although in a house the notion of growth may be expressed in number of rooms, whilst in a school building, where all classrooms will be necessary right from the beginning, it may be expressed in degrees of finishing and facilities, so that the same building will cost less at the beginning and will be completed with the passing of years and the increase of the income of the community.

In this connection we must remember that most facilities, especially houses, already exist locally and if we want to be realistic and adjust our new projects to the existing economic conditions we must think more of the evolution of local types of houses than of a revolutionary change, which is really impossible if there is no revolution also in the economics of the area, in the social habits, in the technical possibilities, etc.

When thinking of new and developing countries, of countries where there is no traditional or modern technique, we should not speak of modern conceptions or modern architecture but we should speak and think of local architecture which will have to be improved gradually and constantly and which will be more modern for the country, much more adjusted to the local conditions and will serve the people better than what is called modern abroad.

We have to recognize that no revolution is possible in housing where a whole nation is involved and where the total labour force is concerned. We cannot consider new imported techniques because we are not dealing with one single building where, after all, we can import some skilled labour, but with a question of building for millions of families and with the total labour force of the country, which cannot change its habits and skills overnight.

When designing we have to consider the basic fact that we must develop what is healthy in the country. Our role, really, should be the role of an archaeologist who excavates to find what already exists and the role of a farmer who plants a tree and looks after its growth. We have to be sure that we plant the right seed and that we look after the gradual growth of housing as one of the natural expressions of the country and people as a whole.

This is the reason why we often have to use the system of experimentation in everything we do. We are not allowed to, and we cannot create a revolution; we have to organize an evolution in the housing conditions and in order to be sure about the road that we are going to follow, the balance which must be kept between local and imported materials, local and imported techniques, present-day economic conditions and future development; we must test new ideas in small scale and experiment continuously.

EKISTICS IN MATERIALS AND CONSTRUCTION

The same ideas as the ones we expressed in physical designs should influence our thinking in developing policies and programmes on materials and methods of construction.

We must start with the national interests which usually impose the mobilization of all local resources. These local resources can be in raw materials and skilled labour or they can be in local industry, which can produce new materials based on the local raw ones.

We must study the possibilities existing in the country and use them in the best possible way. We have to use local materials and methods and develop them gradually since we must be sure about the best type of development, not to learn it from abroad, and we have to convince the total labour force to follow this evolution of techniques.

This poses a big problem: What will be our position regarding the experience gained abroad? There is no question that we have to use this experience in the best possible way, but we should not transplant the findings as they would have been implemented in another country. We should study what has already happened in other countries and see in what way we can adjust it to the country we are concerned with.

It is here again that we must use as much as possible every type of experimentation and carry out all possible research. There is one point, however, that we have to insist upon in this question of research. Very often in new countries we start research from the very beginning on problems which have already been encountered in other countries. We stress the point that in most cases the best type of research starts in the library and the first people on research should accumulate and use the experience already gained in other countries and then decide about the new fields of research or experimentation for the new country. I have seen so many cases of experimentation and research on problems already answered that I have to insist when speaking of research and experimentation that we must first evaluate the experience already gained before proceeding to new experiments.

The same problems as the ones faced in building materials and methods of construction exist with local labour, and, therefore, any programme for better materials and better methods of construction has to include a plan for training skilled labour at different levels: in the urban areas, in the rural areas, etc.

If we look realistically at the housing efforts in most countries, especially the under-developed ones, we must immediately admit that large efforts have failed in most cases. We may find good projects and bad projects, but we do not have cases where a whole country has really reformed the housing conditions. The failure is usually one of scale if it is not also a failure of quality in the small projects, because usually it is the failure in quality that leads to a failure in scale: a failure to meet the real problem, of which the most characteristic element is its size.

When discussing housing we are usually met by the reaction that housing is a luxury, but here we must remember that housing is not only a luxury but a basic goal of national development programmes, as well as a means of their successful operation. Through housing, as we have already explained, we can achieve certain targets of the programme, help the people to move into the new areas to be developed and assist certain economic and social classes which are either suffering more or are the backbone of economic development, strengthen certain depressed areas until other types of economic development take place, etc.

WHY HOUSING?

At this point we should ask ourselves if housing is really necessary. This question is usually asked by many people, especially in the course of economic planning and allocation of resources. It is better to break the question down to its several elements:

Is housing a productive investment?

Yes, housing is a productive investment, at least as productive as any other investment under a well-balanced programme.

Is it a luxury?

No, it is not a luxury. It is indispensable.

Does housing increase labour output?

Yes, more than any other investment.

Is housing an item of high priority?

Yes, housing is in many cases an item of very high priority.

Is housing an important part of a development programme?

Yes, housing is a very important part of the development programme.

Should not housing be left to the private citizen?

No, housing cannot be left to the private citizen alone – it is too late for this to be possible.

Should it be the concern of the government?

Yes, it should be the concern of the government, otherwise the problem will never be solved and even private initiative will yield no results.

The reasons for the answers to all these questions are explained below.

It has sometimes been said that housing is not a productive investment and should not be included in development programmes. If we ask what "productive" is, the answer often is investment in industry, agriculture or stock-breeding. Certainly, factory buildings and grain silos and stables for cows are productive, but we cannot build good factories and stables to protect machines and livestock and leave the workers in mud huts. We cannot treat our workers and peasants lightly. We must protect them at least as fully as good machines. They are at least equally valuable, even if we ignore the human aspect and only think in terms of economic values, since they are skilled people whose training has cost time and money.

Consider the skilled worker in a modern power plant where everything must be clean and kept warm in winter and cool in summer. Can he return home to find his child with pneumonia lying on a wet mud floor in a cold, windswept hut? Will he not detest the machine which is protected and cared for and hate a society which leaves him homeless in order to serve a monster of steel?

Even if we ignore all else and speak in abstract economic terms, housing is at least as productive as all other investments in a development programme. There is no productive and non-productive investment but there are reasonable and unreasonable programmes, and balanced and unbalanced programmes.

Housing is no luxury. It is a need for every nation and for every development effort.

Housing is a part of any well-balanced programme of economic development. Housing is an economic target.

Investment in housing creates increased labour output. A worker who can spend most of his spare time in a comfortable house does not feel emotionally repressed and can resume his daily task with renewed physical and mental powers, thus being able to work and produce more.

For this reason not only governments but also large enterprises devote large amounts of capital to provide their workers with good houses.

Housing investment increases employment. Of all development projects housing spends the highest percentage on labour and the lowest on materials. This means that for every penny spent on housing a greater amount goes to the local labour force than in any other group of projects.

This certainly makes supervising personnel more necessary but most of these people can gradually be recruited locally and trained for the job. It is a matter of proper planning in good time.

But housing is not only necessary for economic reasons: it is also necessary for social reasons.

How are the people to benefit from higher incomes? The first thing they will ask for will be more and better food and the second, better living conditions. How can better living conditions be provided for people without better houses? It is impossible. Houses are the foundation of a better life. This is especially true if living conditions are very bad, as in many parts of the world.

Think of the people who earn a higher income and are unable to live in a better house. They may buy a radio or even a television set but they will live in mud huts under very unhealthy conditions. They will suffer from heat and cold, from intestinal diseases and pneumonia.

Why the higher incomes then? Why economic development programmes? Housing is a primary social target.

Has housing a high priority in a development programme? Yes, it has, because it is the most sound preventive measure against disease and death, social unrest and social upheaval.

Why build big hospitals if people live in the mud? The slums are destroying the health of the people and sending them to the hospitals. How many hospitals can be built and how big must the cemeteries be? Good houses in good time will decrease the number of people in need of hospitals and the great expense of caring for them.

Good housing will create happy and satisfied human communities. Housing is a high priority item in any development effort.

But action in housing is not only imperative on economic and social grounds. Housing is also necessary as a result of disasters, floods, fires and other causes. Immediate action is then necessary. Otherwise the economy will be dislocated, the people will be unhappy, the social bounds broken.

Housing can mobilize all the local contractors since it can be divided into large or small projects and employ the entire managerial potential of the country. Only in this way will new contractors gradually be forthcoming for greater and greater projects until development as a whole can be undertaken by local people.

Housing can contribute to preventing inflationary pressure since it can be extended to cover the country and make use of all local resources of manpower, materials, management and transportation.

This is why housing can be started and applied throughout the country more quickly than other programmes, provided that there are good plans and the proper organization to guide the effort.

Why not leave housing to the private citizen? Because it needs
ample land,
common facilities,
good plans for houses,
many materials,
much labour
and funds that private people can only provide in the long run all at once in the space of a generation.

All these can only be made available now by the government, otherwise
land prices will soar;
there will be no water supply;
sewerage will not exist;
people will have to walk in the mud;
prices of materials will sky-rocket;
skilled labour will be scarce;
and plans will not exist and a new tower of Babel may be started.

It is too late to leave this colossal task to private citizens – they are already too far behind, especially those in greatest need. Housing must be undertaken by the government for the sake of all.

WE MUST USE EKISTICS FOR A COMPLETE PROGRAMME

Without ekistics, without the overall study of the problem, we will lose precious time. Travelling around the world I have seen first-rate technical experts struggling to face huge problems by themselves in order to solve an essentially economic and social problem with their technical experience, trying to face a really local problem with the experience they gained usually abroad in other environments under different conditions. I mention just one simple example in this last instance: I have seen people wondering why most countries are still insisting on insulation of roofs with a layer of earth and not with lighter materials, and they never stopped to multiply the amounts needed for these lighter and so-called cheaper materials by the enormous number of houses which have to be built. They have not estimated the terrific cost of transporting these materials even if they are supplied as a free gift to the people up to the last village in mountains or deserts. It is clear that in these countries, where people have been using earth for their houses for thousands and thousands of years, this may be the solution for a few more generations, especially in the most remote areas, even if we know that there are technically much better and much lighter materials.

I have seen architects frustrated because their modern designs (and by modern they considered what they had learned in a Western European or North American school) would not be accepted without discussion in other countries. I have seen economic planners who avoided worrying about housing and building and its experts, because the experts themselves were usually unrealistic and would not look at the economic and social aspects of the housing problem.

If we want to solve the housing problems of any country, especially an underdeveloped one, we should not hide our heads in the sand, even if we discover many unknown details there. We should, however, keep our heads up and look around and understand the enormity of the problem and the need to look at it as a great national task. We must understand that the solution of the housing problem is not in the details which have to be taken into consideration and studied and solved in their turn, but in the general conception of the housing problem as one of the biggest problems which a country, especially a developing one, has to face: a problem huge in size, of tremendous economic, social, political and cultural implications for the future of peoples and countries.

Housing for the masses of Indonesia

UDC 333.32.(91)

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INTRODUCTION

Since 1920 the main stimulus to housing policy in Indonesia has been consideration of public health. The objectives have been to reduce the dangers due to poor environmental hygiene in the urban areas arising from bad housing conditions and overcrowding (see Appendix). In the period between 1920 and 1940 many homes were constructed in the large towns.

Since the war the situation has deteriorated further owing to the enormous flood of immigrants from the countryside into the big cities. Urban administration has been unable to cope with the inrush of people, many of them drifting and many also entirely unaccustomed to life in the big city. By applying rural techniques of house building and sanitation to urban areas, they have reduced standards of public health to still lower levels and have now created a grave problem which is in some measure faced by every urban administration of Indonesia and, indeed, of South and South-East Asia generally.

The emphasis in the prewar housing policy has been preserved, but owing to the conditions stated above the health and sanitation aspect is becoming increasingly important. A positive approach to the housing problem was started in 1951 in order to ensure that the whole population (including those living in the rural areas where the danger to public health due to bad sanitation is less acute) has the opportunity of obtaining decent dwellings of a high minimum standard, the level of which will be raised in relation to the general economic level of the population of Indonesia. This standard has been variously defined according to differences in conditions in the islands which make up the country. In Timor, for example, the introduction of a proper roof would be a considerable advance, whereas in Java it is possible to specify floor space requirements, the wall materials to be used, etc., in much greater detail.

At present, because the majority of people live in the rural areas (it is estimated that only about 10% of the population of Indonesia live in "urban areas" at the present time [1]), emphasis is placed on these areas.

This does not mean that urban problems will be neglected. The present urban housing problem is due to the fact that rural-type housing has been constructed in areas where it is inappropriate. This will have to be solved not only by slum clearance schemes on the normal public housing model, but by tackling the problem at its roots and educating the rural and semi-urban dweller in such matters as personal and environmental health and hygiene.

It has been suggested that there are three main ways in which the housing problem in less developed countries can be tackled:

(a) By public housing schemes.
(b) By use of jobbing builders.
(c) By aided self-help methods.

Methods (a) and (b) have hardly been used in Indonesia during recent times; on the other

[1] *Estimated Housing Needs of Indonesia*, unpublished draft by IR. LIEM SIANG HOK, Table 4.8.

hand, the use of aided self-help is indigenous to the Indonesian culture. For this reason, as well as those mentioned above, the main emphasis in this paper will be on rural and semi-urban housing problems, particularly in relation to solutions of the self-help system.

GEOGRAPHY AND POPULATION OF INDONESIA

The housing problem cannot be separated from the specific geographic and population pattern of Indonesia.

Indonesia, an archipelago of about 3000 large and small islands, is spread over a territory as vast as that between Madrid and Moscow. It covers a land and sea area of 10 million square kilometres, of which 15% is land.

Its 85 million inhabitants (in 1956) are not equally divided over the islands. Java, the smallest of the "big five" islands, has 65% of the population and a population density of 417 persons per km^2, which is very high when compared with the average for the whole country of 43 persons per km^2.

The annual increase of the population is estimated about 1.5 million, of which possibly 1 million takes place on the already overcrowded island of Java. This figure gives an indication of the problems.

Owing to the extensiveness of the country, its island structure, its high mountain ranges and its population patterns, there are great variations in customs, living-habits, religions, standards of living, skills and literacy. There are more than 19 languages with more than 100 dialects, which creates communication problems, although since 1942 the national language "Bahasa Indonesia" is increasingly in use as a universal medium throughout this archipelago.

THE HOUSING PROBLEM

The magnitude of the housing problem in Indonesia is such that some 600,000 new decent dwellings should be built annually during 50 years in order to overcome present shortages and overcrowding, population increase and renewal of the existing housing stock. At the same time that the housing problem is being dealt with, social programmes enabling the development of educational and health facilities must be developed. Thus housing takes its part in the overall programme for social betterment in these areas.

One persistent problem in this whole programme is the provision of sufficient finance for social development. As a rule, the more highly developed countries spend large proportions of their national incomes on "social overheads" such as housing and community development. In the less-developed countries, where the need for economic development is basic, the proportion is much lower. In Indonesia, for example, only 12% of the total expenditure on general reconstruction is set aside for social projects. Of this, 8.5% of the total is for education, 2% is for public health and only 0.7% for housing. The last figure may be compared with an average of 5% in Europe. This works out at only Rp 0.25 or US $ 0.01 per capita each year between 1956 and 1961.

In contrast to these small totals, the bulk of the national income is set aside for basic needs such as food and clothing. It is, indeed, difficult for the accumulation of capital equipment to keep pace with the rapid growth of population in the country.

Family income levels are very low at present in Indonesia. The following data (Table I) are provided in evidence of this. The information is the product of three sample surveys, one taken in an urban area of Djakarta (Senen), the second in the suburban village of Andir, on the outskirts of the city of Bandung, and the third in the rural district of Tjikarang. (The official conversion rate at the time was US $ 1 = Rp 30.—.)

According to the family living survey which was taken in Djakarta in 1958, only about 12% of the average income is spent on housing, including about 4.5% on rent and repairs. Thus

TABLE I

Monthly income (rupiah)	Urban Kampong: Senen (July, 1956) Number of families	%	Semi-urban village: Andir (July, 1956) Number of families	%	Rural village: Tjikarang (March, 1957) Number of families	%
0 – 199	391	9	523	36.3	282	30.6
200 – 499	2302	53.2	672	46.6	516	56.3
500 – 999	1049	24.2	184	12.8	90	9.8
1000–1999	375	8.7	30	2.1	13	1.4
more than 2000	150	3.5	2	0.1	1	0.1
unknown	61	1.4	31	2.1	17	1.8
	4328	100	1442	100	919	100

even in the case of individual budgets, the amount expended on housing is very small indeed and special methods have to be adopted to overcome this capital deficiency.

As in other less-developed countries, in Indonesia the poverty of resources and the high cost of operations in the rural areas still constitute important obstacles to the expansion of services in education, health, home improvement, etc. These obstacles are being ingeniously dealt with in a number of cases by special techniques adapted to the rural needs and resources, such as rural health centres, mobile home improvement, demonstration units, rural community development and other approaches relying upon "self-help".

AIDED SELF-HELP

BACKGROUND

Much of the backwardness and poverty of rural population can be attributed not only to lack of material means (such as land and credit) but also to ignorance, isolation and apathy, to lack of organizational means and, in general, to adherence to traditional customary practices and lack of any idea of experiment progress and development.

Self-help methods – or, better, mutual self-help methods – are in the villages of Indonesia an inheritance of the centuries. Self-help is not only applied to the construction of roads, bridges and houses, but is also used when help is needed in cases of sorrow and happiness.

Fragmentation of agricultural land and the rapid increase of population result in disguised unemployment and declining purchasing power. It is a custom and a general practice that holders of land do not object to the fact that relatives and, in many cases, also non-relatives join them and work for them on their land. A provisional investigation in 1940 on Java Island shows that 70% of the dwarfholdings were less than 0.5 ha.

Considering the low percentage of the national income devoted to housing, aided self-help in housing permits wide distribution of the benefits from funds available. It tends to conserve resources and to avoid excessive capital expenditure by use of underemployed labour and locally available materials and, in general, benefits from the intangible but nonetheless real advantages which accrue from heightened community spirit. Only in this way can many houses of improved standard be brought within the reach of all people.

The role of the Government in this respect is to encourage the growth of this community spirit by training and educating the people in the conversion and better use of their physical and human resources.

PRACTICAL DIFFICULTIES

As stated above, only a small proportion of family cash income is expended on housing.

This follows naturally from Indonesia's mild tropical, humid climate in which food and clothing are more important than shelter to the average person.

Because of these low income levels, building material can only be acquired by self-collection, self-extraction or by barter between inhabitants of different villages. Thus sand and gravel may be extracted from nearby rivers and timber and bamboo are normally grown in the village itself. If these basic materials are not available, barter must be used, and this may sometimes be a lengthy process: it may take more than one year to accumulate by barter sufficient roof tiles for the construction of a house 50 m^2 in area. Moreover, due to shortage of money, these building materials have to be transported by laborious means – by bicycle or on the shoulder – and this limits the distance which can normally be traversed in barter trade. There is no doubt that local production of building materials in places near to the village is the best solution.

Usually there is no money available for repairs and maintenance of buildings: in the Djakarta survey mentioned above, an average of only 0.86 % of the total family income was set aside for this purpose.

The time factor is not important in the village if savings are effected in the ultimate cost of the house by taking longer to build it. A case was reported from the island of Sumatra where the construction of a house was delayed by a period of 10 years to acquire timber of first-class quality for the frame and panelling of the house.

Bearing all these factors in mind, there is a natural resistance to abandoning traditional, well tried methods of construction for new techniques unless it can be satisfactorily proved that substantial savings can be achieved as result of their introduction.

PROBLEMS OF TRAINING AND DISSEMINATION OF INFORMATION

Apart from basic difficulties of obtaining finance and materials, there is an acute shortage of trained personnel who are equipped to disseminate the new techniques. This is indeed a problem common to all less-developed countries. Only very few people are available with sufficient technical background to teach methods of house building; but because these people have mainly an urban background, they often lack practical first-hand knowledge of village building practices, and difficulties arise due to the fact that they cannot gain the confidence of the village people.

About five years ago, mobile demonstration units were established for the purpose of guiding self-help methods into the most fruitful channels. In practice, however, many difficulties were met in this connection because of the extreme length of time necessary for the teams to get the projects started. Thus, as subsequent case studies will show, there seems to be no proper alternative to the presence of a really active and enthusiastic native of the village itself who is prepared to devote time and energy to the development of the project.

The main problem here, once again, is that of finding a well-trained teaching staff. Possibly one way of obtaining this would be to encourage people from selected, more highly developed villages to "transplant" their techniques to other villages. A method similar to this was employed by UNTAA when a group of five Burmese (one engineer, two foremen and two villagers) came to Indonesia some years ago to be trained in village tile-making for a period of a year. The intention was that this team should "transplant" Indonesian techniques to Burma. No final report has yet been received on the success of this scheme, but it is being awaited with the greatest interest.

All of these solutions meet with continual difficulties due to the barriers of the older traditions and widespread illiteracy. To achieve the required impact, full-scale demonstration projects have to be devised which are sufficiently simple to enable the message to get across to the people.

For the complex housing problem the Indonesian Government has established two national bodies: in 1951, the People's Housing Department, which is a policy-making and executive body; and, in 1955, the Regional Housing Centre, which takes up the research on the socio-economic and the technological aspects of housing. The Regional Housing Centre is a joint project with the ECAFE-UNTAA.

CASE STUDIES

It is helpful at this stage to consider four specific projects where the employment of aided self-help has achieved noteworthy results.

Torongredjo village, Batu, East Java

In this village, the headman, without any form of external aid whatsoever, has changed the whole aspect of the village from an exceptionally backward one to a flourishing, prosperous place. In the five-year period 1952–1957, about 497 houses out of the total of 648 have been rebuilt, roads widened and properly paved, public baths constructed with piped water installations, community facilities such as schools, meeting halls and sport fields provided and the agricultural output increased.

Pasar Minggu, West Java

In this semi-urbanised village near Djakarta two primary schools have been constructed in the short period of eight months. This work was entirely a spare time occupation, and took place under the leadership of the two villagers. Assistance was provided from outside the village in designing the buildings, giving technical advice where necessary, and providing non-local materials.

Goa, near Tjirebon, West Java

In this village, 40 new houses are being built for the lowest income groups, using entirely new techniques of stabilized earth blocks which form the walls. Once again, assistance is given in the design of the houses, in general technical guidance and by the provision of a long-term loan for buying non-local materials. In addition, on-site training of future instructors is being given by the mobile demonstration unit which is responsible for advice on this project.

Tjipajung village, Tjikarang, West Java

Here, a rural policlinic has been constructed. Under the integrated health plan of the Indonesian Government, it is proposed that general hospitals should be established in the main towns, with rural hospitals in the district and outpatient clinics at the village level. The duties of the coordinating public health nurse at the village level include collection of vital statistics, health education, environmental sanitation and reporting of contagious diseases.

As a first condition for the provision of external aid for this project, a satisfactory health service had to be established as a corporate effort by all the villagers, and this had to be maintained by the active participation of the villagers in organising health services for their community.

CONCLUSIONS

Certain conclusions may be drawn from these case studies, and these are discussed in the paragraphs which follow.

In Torongredjo, Goa and Tjipajung, it is reported that a period of more than one year was required in order to convince an active group of people of the need for self-improvement – in fact, to push aside their fundamental apathy. This long preparatory period undoubtedly contributed in no small measure to the ultimate success of the schemes. In the course of these intensive discussions, specific needs had sufficient time to crystallize.

Once the people can be convinced on the need for improvement, the project should be designed in such a way that their own desires are satisfied. If this can be achieved, as it was in Torongredjo, then it is possible for the project to gather momentum and speed, which is of considerable psychological value in subsequent projects. For this reason also, it seems necessary to choose the location of the initial projects with an eye to rate of progress: the success of the first one can contribute enormously to the success of those following.

The further utilization of employment potential in these places has often resulted in a much longer time needed to complete the project than with normal contract labour. This is obvious when it is remembered that the work is mainly undertaken as a spare-time activity. As an example, in Tjipajung the 8446 manhours of work required to construct the clinic were spread over a period of 325 days – or only 26 manhours a day. Though productive in using available village manpower potential, these long periods have caused large overheads due to high operation costs of the mobile demonstration unit to the project concerned. This necessitated, for example, the premature withdrawal of the unit from the Goa village, before the work was eventually concluded.

Experience in Torongredjo shows that the efforts of one active leader can completely change the face of a village. In this village, however, Dutch villa-type houses were copied as models for village housing as replacement of the previous deteriorating bamboo shacks. To construct them, a carpenter and bricklayer were hired for a period of two years, during which time they trained the villagers in the required techniques: at the end of this period, all bricklaying and woodworking was done by the villagers themselves.

Since on-site training is the most economical way of training from the point of view of the villagers themselves, this method is being developed as the most satisfactory.

This way was, in fact, used in Torongredjo; in that village the cost of bringing in a mobile demonstration unit would have been prohibitively high (Torongredjo is some 600–700 miles from Djakarta, the base). The fact that such a unit was not used served to lower technical aid costs enormously.

In the first projects, it seems better to improve on existing local techniques rather than to introduce new ones: it is common experience that the introduction of new techniques invariably leads to the loss of manhours before their application is fully absorbed. This can be disastrous on initial projects, where speed and completion is essential. Furthermore, new techniques need closer supervision and control in their execution; unless this is done, results may be very disappointing, thus endangering the whole future of the aided self-help idea.

In Goa, stabilized landcrete soil blocks are introduced for the walls. Owing to the withdrawal of the demonstration unit, followed by a replacement of the active village head, the speed and the quality of the work are slowing down.

It must be finally recognized that the changing of popular attitudes regarding living-habits and customs is a lengthy process. Often success may be achieved by steadily raising housing standards, this being an important factor in overcoming psychological, social and cultural barriers. A small improvement in house design at little cost to the villagers often has more impact on the ultimate success of the project than a large engineering achievement.

The most acceptable and effective way in which Government departments can encourage the development of the projects is the giving of free advice in the application of techniques through the medium of trained demonstration teams or the supply of artisans and the provision of material not readily available in the village, such as nails, etc.

THE ROLE OF BUILDING RESEARCH

As previously stated, it is considered that in the less-developed tropical countries, where only a small percentage of the national income is available for housing and the people as a rule only have just enough income for the barest subsistence, but where there are possibilities for utilization of unused manpower resources, aided self-help is the best system for implementing housing schemes.

A low-cost house in the aided self-help system is a house designed for the lowest annual labour utilization and lowest annual cash expenditures. Materials and special skill which will give problems of replacement in case of defects should not be used.

Research in the field of housing in rural areas should concentrate on finding the most effective ways of helping the villagers to solve their problems and to adapt improved techniques applicable to local conditions.

Improved and/or better utilization of abundantly available "disguised" labour and local materials should be studied as a means of ensuring more sanitary and durable housing. Materials produced at a distance and imported materials, *e.g.* nails, should be eliminated.

In this whole field, building research can assist in the following ways:

(a) Developing methods by which the desire to achieve an improved standard of living can be stimulated.

(b) Developing designs and methods of construction which will be an improvement on existing cheap village house building or which will be longer lasting, yet will not call for additional expenditure in cash or for the use of materials, like nails, which have to be brought from a distance or imported.

(c) Finding ways of communicating new techniques to the most illiterate people, which will at the same time be adapted to local village conditions. In this connection, the making of small-scale models often yields very profitable results.

(d) Finding ways of transplanting sound existing techniques from one area to another. In this connection, a survey should be made of the existing techniques. Centralized mobile demonstration units are not practical for an extensive country, owing to the high operation costs.

(e) Adapting progressive standards for the gradual improvement of the house and its environment, and avoiding exceptionally high standards which will unduly increase the cost of housing.

(f) Making a careful survey and study of indigenous Indonesian dwellings, showing the natural process of their evolution. The result may point to the most appropriate dwelling for the physical and social needs of the Indonesian people.

(g) Finding simple and cheap methods for the construction of a safe rural water supply system and safe sewage disposal.

(h) Promoting building material and building component industries in rural areas for the utilization of "disguised" labour and local materials and thus raising the present low economy of the people.

APPENDIX

EXTRACT OF SURVEY RESULTS

The following table gives a picture of the conditions of houses of the masses. It is extracted from sample surveys made:

(1) In an urban kampon, Senen, in the heart of the capital city Djakarta (total population 2,500,000) 2115 houses were visited in July, 1956.

(2) In the semi-urban village Andir, on the edge of the second-biggest town in West Java (total population 1,000,000) 864 houses were visited in July, 1956.

(3) In the rural area Tjikarang, located 40 km east of capital city Djakarta and 150 km northwest of Bandung, 822 houses were visited in March, 1957.

TABLE II

HOUSING CONDITIONS OF THE INDONESIAN POPULATION

From the total of 100% in each area	*Senen (urban)* %	*Andir (semi-urban)* %	*Tjikarang (rural)* %
Houses with more than:			
1 family [1] in one house	48.7	35.1	6.7
2 families in one house	23.6	13.8	1.9
Families with more than:			
4 persons in the house	51.6	39.3	48
6 persons in the house	26	8.9	18.9
Houses with a floor area:			
smaller than 10 m^2	13.5	22.2	1.7
10–39 m^2	32.2	46.4	20.5
Houses with a tiled roof	68.6	99.8	96.2
Houses with a dry floor (concrete tile or raised bamboo/timber floor)	58.4	94.5	7.5
Houses with safe piped water	54.5	1.3	0.3
Houses with septic tank (no central sewerage system exists)	3.1	0.3	1.3

[1] A family is regarded as a group of persons who eat together.

The need for research in relation to mass housing in rapidly developing tropical Africa

UDC 333.32 (6)

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INTRODUCTION

Judged by European or American standards, Africa south of the Sahara does not have many large towns. It is only during the present century, particularly since the First World War, that cities and towns have started to grow at a fairly rapid rate.

Population increases, which can be attributed directly to reduction in inter-tribal warfare on the one hand and to improved hygiene on the other, have forced the pace of urban growth. This growth was further stimulated by the universal expansion in industrial development, which was intensified after the Second World War. Another important factor was the improvement in communications and transport, which, *inter alia*, made rural African peoples aware of the attractions of the cities and towns with their social amenities and ever-increasing variety of consumer goods.

A large proportion of rural people in Africa lives precariously at subsistence level and earns little or no cash income from the traditional agricultural or pastoral activities. Their only sources of cash would be trading and paid employment, for both of which there are better opportunities in the towns and cities. Moreover, sophistication of the townsman has become a symbol of status eminently desirable to the rural African.

Settlement in the towns of Africa takes place regardless of whether housing and related amenities are available or not. New arrivals overcrowd already congested quarters or erect shacks of whatever materials are available at no cost on any piece of vacant land. Unless some official control is exerted, such dwellings are erected chaotically at high densities, so creating squalid shanty towns which offer little or nothing in the way of amenities, services or security, and which consequently provide good breeding grounds for ill health, discontent and crime.

This picture is, of course, not unknown in European and American cities, where overcrowding and slum development are features of many towns and cities. However, it differs from most of these in the feature of shanty town development and in that the migrants to African towns are relatively much poorer and less adapted to urban living than their European and American counterparts.

These are the aspects which demand particular attention in formulating a housing policy. That overcrowding could develop during the war is understandable in view of other preoccupations. However, after the war local and central authorities tended to become aware of their responsibilities in this connection and were forced to face the problem of finding ways and means of providing decent dwellings in adequate numbers. This required both short-range and long-range planning and in addition land, equipment, materials and labour.

AN APPROACH TO MASS HOUSING AND THE CASE FOR RESEARCH

In order to approach the housing problem intelligently, planning must be based on fundamental information if it is to be both valid and economic. It is necessary to obtain information on the populations to be housed, their numbers, family sizes and composition, their incomes and expenditures, in order to determine their rent-paying ability and their basic requirements for dwellings. Studies must be made of the minimum standards of accommodation which would be permissible under the circumstances, so as to ensure decent family living; in addition, suitable constructional requirements have to be laid down to ensure that the buildings erected provide adequate protection against both the climate and the weather and have a durability that would justify expenditure of public funds.

MINIMUM STANDARDS OF ACCOMMODATION

Minimum standards of accommodation must be related to the needs of both the individual and the family. For such standards, the dimensions of doors, rooms and equipment are determined not by conventional design practice but by the human scale in order to ensure that the individual and the furniture which he requires can fit into the house without undue physical restriction. The family requirements are related to the needs for privacy, separation of the sexes, especially of children above adolescent age, and space for cooking, toilet and ablution facilities. Minimum requirements for lighting and ventilation must also be taken into account. Consideration should be given to the fact that cooking in the open air is traditional in many parts of Africa. Moreover, it is probably desirable for people who have their heritage and background in the soil to have some space for gardening activity.

The standards that apply in other countries are not necessarily acceptable, for, as already described, the conditions in Africa differ in important respects. For instance, in the tropics the thermal environment of a house obviously is quite different to that in the temperate region, and this determines such factors as minimum standards of ventilation, ceiling insulation requirements and orientation of the building, particularly with regard to the undesirability of having openings facing east and, even more important, west, as these have a profound effect on heat gain respectively during the morning and afternoon periods. Moreover, as far as lighting is concerned, the basic information on daylight, in respect of sky illumination and ground reflection, available in temperate zones, is not immediately applicable in tropical Africa. Therefore, in all these fields there is scope for study and collection of information before standards can be laid down. This indicates the need for research.

SOCIO-ECONOMIC ASPECTS OF HOUSING

Similarly, with regard to socio-economic conditions, surveys should be undertaken to establish the trends in average family sizes and family size distributions; composition in terms of head of the household, numbers of children, and other dependants. African families are frequently extended families, *i.e.* they often consist of more than parents and children: this may have to be allowed for in design and planning.

Information on family income and pattern of expenditure in terms of food, clothing, transport, heating and cleaning materials, medical care and recreation, is required to establish what proportion and what actual amounts can be considered to be available for paying rents. Such surveys require field studies by sociologists and careful analysis of the results if intelligent planning in terms of the needs of the people and what they can afford, is to be carried out.

SOIL PROBLEMS AND SOIL SURVEYS

Apart from these aspects it is necessary to take into account the soil conditions encountered in a housing estate since foundations have to be as simple and of as low a cost as possible. However, in many areas of Africa, soil conditions lead to much difficulty, particularly in respect to volume change leading to cracking of structures and consequent high maintenance charges. In particular, mention can be made of the problem of heaving, a condition which is hardly known in the Middle East, India, Australia and in most of Europe, but affects parts of the world, most regions of Africa, and which has led to considerable damage to structures. Examination of soil from this point of view also requires careful study since virtually no two soils are identical and additional factors such as degree of dessication and position of the water table play a part in heaving.

If it is established that the soil may lead to troubles of this character, research is required into the best methods of constructing the building to resist soil movements or to accommodate them. There are many methods which could be employed, but the greatest problem is to find one which is economical; economy, of course, is particularly vital in the case of mass housing, since any increased costs on one house must be multiplied by the number of houses affected to give some idea of the total additional costs which would have to be met. In view of this, it is advisable to carry out soil surveys of any areas considered for large housing estates, making use of special techniques such as geophysical and aerial surveys where necessary. Often the more economic solution is to avoid bad soil conditions by finding alternative land, even at higher cost.

BUILDING MATERIALS IN RELATION TO NATURAL RESOURCES, CLIMATE AND DURABILITY

In most of tropical and sub-tropical Africa, industrialisation has not yet taken root and, therefore, unlike more developed areas, manufactured building materials are available in limited amounts, leaving relatively little choice and sometimes no choice at all. Many parts of the continent are still largely or wholly dependent on imports for such basic materials as cement, steel, timber, asbestos cement, glass and fittings generally. Moreover, the performances of some of the materials used in building, when exposed to tropical conditions, particularly high temperature and high humidity, and to direct rays of the sun, are not known and therefore require further study.

When establishing new industries, in most parts of tropical Africa it is necessary to take into account particularly the lack of skilled labour, lack of fuel and power, and the greater dependence therefore on manual labour instead of mechanised processes. Another important factor is the question of economics of production; where no industry exists and where the demands for a particular material are such that local manufacture cannot be justified, importation is the only method of obtaining building materials. However, at a certain stage of demand it may become economic to produce materials locally, but unless such an industry is established on a firm footing from the onset, there is always a risk of its failing owing to price-cutting by importers bent on eliminating competition. Careful market research is, therefore, to be recommended in such cases.

THE NEED FOR A TEAM APPROACH

The objective of research on housing should be the provision of facts on which to act. The many facets of the housing problem for which data are required dictate that a team representative of a wide range of disciplines should be employed. For instance, architects, engineers and town planners are required to study minimum standards of accommodation and related aspects to provide a planning framework; sociologists should study the population to be housed, their economic conditions and family size distribution, and from the data obtained, present an intelligent picture on which the planners can work; physicists must examine the weather conditions that apply and so influence the design of the house to ensure an internal environment satisfactory for living. The chemist and materials engineer must examine the materials available, their performance, durability and resistance to various destructive agents that may occur. The structural engineer must examine the type of structure which is proposed and establish its performance under various conditions of load, movement of foundations, wind forces, roof loads and damage by hail. The foundation engineer and engineering geologist must examine the soil to establish its suitability for services and foundations for buildings and roads and must assess the need for special precautions if soil conditions are poor. Finally economics and costing experts are required to coordinate all cost aspects of the undertaking.

None of these activities can be carried out in a vacuum. They require exchange of ideas, constant consultation and teamwork under conditions that enable close cooperation. This can best be achieved in one organization and, because many of the studies require laboratory facilities, a research organization specially equipped to provide these facilities would allow the team the most efficient environment in which to achieve their objectives. Such an institution requires drawing offices where initial planning and subsequent details can be worked out so that concepts can be given practical form, and laboratories for research in the fields of engineering materials, soil mechanics and physics, with the necessary experimental facilities and equipment. In order to translate research findings into practical reality there is a need for close collaboration with those responsible for financing and for administering housing, with experts on building costs and with the building industry, both departmental and private, which has the experience and the knowledge to organize execution of the work. Most important, however, is the creation of a sound research team, imbued with a sense of the urgency of finding a solution both valid and economic.

HOUSING RESEARCH IN SOUTH AFRICA

South Africa's experience in the low-cost housing field has borne out the value of research and has demonstrated the need for a research organization, backed with adequate funds, to undertake detailed studies in this important field – housing for Africans living in urban areas.

A survey conducted at the end of 1951 had shown that about 170,000 dwellings were required immediately to house those living in shacks and overcrowded premises.

It was estimated that, taking into account the growth of the cities, an additional 186,000 houses would be required to allow for newcomers over the period 1952–1961 inclusive. Therefore, the indications were that some 35,000 houses would have to be built per annum over the decade mentioned if at the end of the period there were to be no housing shortages in the towns. To achieve this target with the methods of construction and the ruling costs at the time was out of the question in terms of the economy of the country.

This problem provided the stimulus to discover how to make available housing of an adequate standard and at a cost commensurate with the country's resources and, possibly, within economic reach of the individuals to be housed.

For this purpose a number of research committees were set up, each with the task of covering specific problems that had to be faced. In the first instance, minimum standards of accommodation had to be drawn up. This required considerable study of standards used within the country as well as in other parts of the world and relation of the information to the basic requirements of the people to be housed, taking into account the needs for health and for decent family living. Having established these, it was necessary to examine the possibilities of constructing houses to meet these standards and yet to achieve reduced costs.

Prototype house designs were prepared to conform to the minimum standards and, at the same time, to achieve efficient planning, dimensioning and detailing to ensure low cost. Once promising designs had been developed, experimental housing was carried out using both orthodox and unorthodox methods of construction. During this stage detailed studies were made of the possibilities of reducing the amount of materials and improving the efficiency of labour, until it became clear which of the range of orthodox and unorthodox construction methods appeared to be most promising.

The next stage in the programme was to establish the minimum standards of performance to which these houses had to comply. Such performance standards were drafted in relation to minimum requirements for structural stability, rain resistance, indoor thermal environments as related to health, durability, as well as for general requirements relating to fire-proofing and vermin eradication. The necessary conditions had to be established for each of these aspects, which required a considerable amount of research work.

Once the requirements were established, practical experiments were carried out on each of the methods of construction which satisfied the following conditions:

(a) It must be capable of conforming to the minimum standards of accommodation;

(b) It must have low-cost potential;

(c) It must be applicable to methods of mass production;

(d) It must have a reasonable chance to satisfy the minimum performance requirements.

This research work, which has been described in detail elsewhere [1], has been an important factor in making it possible to carry out large housing schemes in many centres of South Africa and to produce houses at costs which range from two thirds to half of the costs obtained before the research work was commenced. Such houses have proved adequate for family living. Up till the present, approximately 100,000 houses of this type have been constructed at costs not exceeding, on the average, £ 250 per house.

Because of the low costs achieved much more could be done with the housing funds available. Moreover, and perhaps more important, a very much larger proportion of the people to be housed could now become the owners of their own houses. Finally, public money was invested more soundly. In this way not only could the responsibilities for house subsidies and for maintenance be removed from central or local housing authorities, but stable populations, house proud and with a stake in good administration and in maintenance of law and order. tended to evolve in the new townships.

In addition to houses a housing estate also needs services, administration facilities, community centres, schools, clinics, hospitals, recreation facilities and many other social amenities, and since these in themselves pose many problems to which the solutions are not ready to hand, particularly for new types of communities such as are found in Africa, there is tremendous scope for applying research techniques to gain more information of value to the administrator, the medical officer, the town planner and the social worker. By providing amenities which meet the needs for healthy urban development, communities which have a degree of coherence and of community feeling tend to evolve.

RESEARCH ON ADMINISTRATION SERVICES AND COMMUNITY FACILITIES

Some of the most urgent problems in this connection which affect Africa, although, of course, not exclusively, concern:

(a) Water supply and distribution in places where water is often scarce.

(b) Sanitation and sewage disposal for people whose concepts of hygiene are generally primitive.

(c) Electricity supply where per capita consumption is low because of low buying power.

(d) Roads and streets where vehicle taxation can yield only limited revenue.

(e) Community facilities like schools, clinics, hospitals, markets and recreation facilities, for which the patterns of requirements are not established and funds are often difficult to find.

There is considerable scope for studying the cost of services and of administration, not only to assess their effect on housing costs, and therefore on rent, if the costs of these factors are to be charged to the inhabitants, but also to allow comparison between one scheme and another in order to seek ways of reducing overall costs. Few urban administrations seem to know the true costs of the various services they provide and administer; often there is also much confused thinking on the relationship between costing and methods of financing schemes.

HOUSING RESEARCH AND ITS APPLICATION IN AFRICA SOUTH OF THE SAHARA

Much work has been done in Africa that is of direct importance to housing authorities. In particular, valuable studies have been made of the African populations in their tribal settings in rural areas, the causes of their migration to towns, their adaptation to town and city life in its various phases, the evidences of tribalism in the towns and how this tends to break down gradually to be replaced, generally after a hiatus during which there is little social cohesion, by a new structure of a more urban character. Such studies have been published in many territories and through various media [2].

Notwithstanding the divergence in sizes and types of towns and the activities which have led to their establishment, as well as differences in the kind of people and their backgrounds, there are some remarkable similarities in the urbanisation pattern through Africa south of the Sahara. This has involved migration to towns and settlement both in shanty townships built chaotically on the outskirts and in already overcrowded existing housing. The development of housing by public authorities which only accommodates part, often only a relatively small part, of the total population to be housed is also a fairly general feature. Health standards applied in these towns are based on European practices, but in few cases there have been permissive regulations for intermediate or lower standards which can be applied for more primitive types of housing so as to take into account the lesser needs acceptable to the new migrant to the towns and to meet more realistically the general economic situation. For instance, in Kampala studies are now being made of the feasibility of providing houses of different standards, from the grass hut to the small but well-finished house, to accommodate different income groups.

Where authorities have realised the need to clear slums and redevelop areas, there have been studies made of the possibilities of satellite development or clearing redevelopment on site, taking into account the need for reducing densities, both per unit area of land and per unit area of house. Methods of financing housing have also been studied in various territories. Of particular interest in this regard are the various schemes that have been developed in the former Belgian Congo, where the Fonds du Roi and the Fonds d'Avance have been used for subsidised and economic housing respectively. Systems of roof-loan, which are not dissimilar to the methods used by the Fonds du Roi, have achieved remarkable success also in various countries of West Africa, thus permitting the individual, assisted by financing agencies, to proceed with house construction.

Many studies have been made by civic and central authorities in carrying out mass housing schemes, detailed investigations being made to ensure that costs remain within reasonable limits. Much more research, however, is needed to establish the true requirements of the African for whom housing is to be provided. Both dwellings and township lay-outs are often quite ill-adapted to the needs felt by the people who are to occupy them. Little is known of these needs, because no attempts have been made to study them: rather facilely, they are assumed to be similar to those of people with whom the designer and planner (usually an expatriate and invariably one enjoying a much higher standard of living) are familiar. Moreover, these needs will change, and do change, as the migrant from a rural area settles in a town and adapts himself to new social relationships and new ways of living, particularly those of the European; for the urban African tends to demand a European-type house and services, as well as furniture of European character, regardless of the fact that their uses are often neither wholly understood nor fully utilised by him.

SURVEYS OF MATERIAL RESOURCES

There is a special need for surveying the natural resources of Africa in relation to building materials. Such surveys would bring to light more economic materials than used at present and would stimulate studies of processes for making them available to the building industry.

Examples of valuable work in this regard are the exploitation of the pumice deposits in the Rift Valley near Nairobi for lightweight concrete houses, the use of coffee husks as fuel for producing good quality hollow clay building units near Kampala and the use of local timber for demonstration houses in French Equatorial Africa.

The last-mentioned is perhaps of particular significance: in Central and West Africa vast tropical forests exist which have so far only been exploited at points near ports or rivers which facilitate export of the timber. There is no tradition of building in timber in Africa, if one ignores wattle and daub construction as well as even more primitive methods involving bent laths covered with palm leaves, thatch or straw. Timber houses such as constructed traditionally in Scandinavia, Canada and Australia are virtually unknown, except as experimental houses.

In view of the potentialities of timber houses in the forest-rich territories, there is much scope for breaking down conservatism and prejudice; considerable investigation is, therefore, justified. Much work can be done not only to overcome popular misconceptions about timber houses, but also to solve the more real problems associated with building in timber, as, for example, timber-destroying organisms such as termites, borer and fungi, problems of heat exchange between a building and its environment, sound insulation for lightweight partitions, painting and decorating of timber exposed to the weather and cost comparisons between timber houses and conventional houses.

CONCLUSIONS

With important exceptions, the provision of housing in the countries of Africa is very inadequate because the resources of these countries are insufficient to meet the needs in terms of European standards. The housing which is done is, therefore, frequently only a part solution, with some of the inhabitants obtaining housing of relatively high standard, while the rest remain in shanties or in overcrowded slum quarters. The new migrants are accustomed to low accommodation standards and unless rigid control is exerted, overcrowding even in new housing schemes tends to develop. Higher standards can only develop hand in hand with general economic development and both demand factual information if their future is to be secure and valid.

There is no clear understanding of the needs felt by the people regarding housing; neither is it yet established what the pattern of requirements of urban dwellers will be in the future because growth of African towns is too rapid and changes in patterns of living are still rather unpredictable. These considerations complicate the planning of houses and housing, and support the case for extensive and intensive research to reduce ignorance and provide planning data which will lead to valid rather than arbitrary solutions.

There are many common features in the housing problems of the different countries of Africa south of the Sahara. In realization of this, the Commission for Technical Cooperation in Africa south of the Sahara (CCTA) has established an Inter-African Committee for Housing which promotes active cooperation between the governments concerned and which, through CCTA, arranges periodic conferences on housing matters. In this way the different governments become more fully aware of the problems that are involved as well as of the research and development work that has been done and still is being done [3] in relation to housing in Africa.

ACKNOWLEDGMENT

This paper is submitted by permission of the South African Council for Scientific and Industrial Research.

REFERENCES

1 *Costs of Urban Bantu Housing*, National Building Research Institute Research Report DRIO, S.A. Council for Scientific and Industrial Research, Pretoria, 1954.

2 *Social implications of industrialization and urbanization in Africa south of the Sahara*, report prepared by the International African Institute, London, under the auspices of Unesco, Unesco, Paris, 1956.

3 *Proceedings of the Second C.C.T.A. Inter-African Conference on Housing and Urbanization*, held in Nairobi, January 1959. (In preparation by the Secretariat of the Commission for Technical Cooperation in Africa south of the Sahara, London.)

The problem of urban housing in India

UDC 333.32(540)

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Council of Scientific and Industrial Research (India)

INTRODUCTION

During the last eight or ten years large housing colonies and estates and even new cities have been constructed in the urban areas of India and there has been considerable activity in the building industry throughout the country. Yet for various reasons the demand for housing continues to exceed the supply and the overall position shows little sign of improving. There has been a marked increase in population during the last twenty years. The influx of refugees in 1947 and subsequent years added greatly to the number of those who required to be housed. Industrialization and the many large-scale projects now in hand not only absorbed a great deal of the construction industry's capacity but led also to further increases in the urban population.

Throughout the Second World War very few houses were constructed. Meanwhile costs have risen steadily since 1939 and it is no longer economically possible to build houses for the lower and middle income groups at rents which they can afford to pay. For example, the economic rents of one-roomed and two-roomed tenements are about Rs 28/— and Rs 41/— per month respectively, whilst the incomes of about 50% of those who would normally rent them does not exceed Rs 100/— and less than 10% earn more than Rs 300/— per month. Private enterprise at one time financed and constructed these houses but it no longer finds it profitable to do so and as a result the Government, in addition to constructing accommodation for a large proportion of its own employees, and these have increased enormously in number since 1947, has had to subsidize housing in various ways for the low income groups. The capital available for this purpose is necessarily limited because of the large developmental programmes in hand, and so these specials chemes affect only a small part of the urban population.

GOVERNMENT SCHEMES FOR SUBSIDIZING HOUSING

During the first Five Year Plan period (1951–56) and in subsequent years substantial housing schemes were undertaken by the various Ministries of the Central Government, and by the State Governments and Local Bodies to house refugees and their own employees. At the same time work in the private sector provided some accommodation for those who could afford to pay high rents or to purchase their own houses. Meanwhile the Government undertook to subsidize housing under a number of schemes which are still in operation.

Under the Industrial Housing Scheme loans and grants are made to State Governments, Statutory Housing Boards, Industrial Employers and Registered Cooperative Societies of Industrial Workers for the construction of one- and two-roomed tenements. Though the conditions under which loans and subsidies are granted appear favourable, the funds made available have not been fully utilized. There have been difficulties in procuring sites at reasonable rates and within reasonable distances of the workers' places of employment, and rising prices made it difficult to keep within the ceiling costs originally laid down. There has been a shortage of technical and administrative personnel to complete the various projects and employers have been unwilling to divert funds from productive to non-productive purposes and to assume responsibility for owning housing estates and for all that is involved in administering them. Measures have been taken to make the scheme more readily workable and some improvement is already noticeable.

The Low-Income Group Housing Scheme was introduced in 1954 and was designed to help individuals and members of cooperative societies whose annual incomes did not exceed Rs 6000/—. Assistance is restricted to 80% of the cost of the site and construction and is limited to Rs 8000/—. Again for similar reasons the scheme has not achieved all that was expected of it. State governments have now been permitted to let houses constructed under this scheme on a no-profit no-loss basis to eligible persons and action has been taken to make the working of the scheme simpler.

The Slum Clearance Scheme enables State governments to receive assistance from the Central Government for slum clearance and improvement projects. It was intended that the persons affected would be subjected to the minimum of disturbance and would be rehoused as near as possible to their existing places of employment. Their ability to pay rent is small, and this limits the kind of accommodation which can be provided. For example, in Bombay and Calcutta the prescribed cost is Rs 6000/— per tenement. The Central Government provides 25% as a subsidy and 50% as a loan repayable in 30 yearly instalments, and the State government provides the remainder. Progress has been slow and a Committee has recently reported on the measures which should be taken to ease administrative difficulties and facilitate the work of slum clearance under this scheme.

Finally, the Government has revived a scheme which operated before 1937 whereby government employees can borrow sums up to a maximum of Rs 25000/— for the construction of their own houses, loans being repayable at 4½% interest over a period of 20 years.

These schemes will, in time, ease the situation but they cannot by themselves solve the problem of the acute shortage of housing. Attention is accordingly being paid to the measures which should be taken to expand the materials and construction industries and to lower building costs generally.

MATERIALS, CONSTRUCTION AND COSTS

In the larger cities many impressive multi-storey blocks of flats, hotels and houses have been constructed using modern materials and the most up-to-date methods of construction. The demand for these buildings has been so great that costs have not been a primary consideration. For the general run of housing, however, costs must decide the pattern of materials, standards and methods of construction.

In most parts of India bricks are comparatively cheap and it will generally be found that alternatives to brick masonry walls are more expensive. Steel and cement have been in short supply and are relatively expensive and it has always been necessary to be most economical in their use. Cement is now becoming more readily available and it is probable that when the steel plants now under construction come into production steel also will be available in quantity.

Timber is scarce and expensive in most places and though efforts are being made to make the lesser known varieties available for construction purposes it is likely to remain so.

Labour is not expensive but it is often criticized as inefficient. Yet a great deal of work is done at piece rates, and if materials are regularly supplied at the site construction proceeds at a satisfactory rate. Labour costs work out at 30–35% of the total, a figure which makes it difficult to see how mechanization can result in any great saving in cost. In general, therefore, most houses and flats will have brick or stone masonry walls, flat R.C.C. roofs with some form of terracing, polished grey cement or terrazzo floors and teak or deodar joinery. Building costs, though high in the content of Indian economic conditions, compare favourably with those prevailing elsewhere. (For further information about costs see Tables I and II.)

TABLE I

MIDDLE AND LOWER INCOME GROUP HOUSES – DETAILS OF COSTS

Type	*Total plinth area (sq. ft)*	*Cost of building portion (Rs)*	*Plinth area rate building portion (Rs/sq. ft)*	*Cost of sanitary and water supply (Rs)*	*Cost of electric portion (Rs)*	*Total cost including services (Rs)*	*Total plinth area rate (Rs/sq. ft)*	*Brief specifications*
D 2	1670	20,475	12.26	2,035	2,035	24,545	14.17	Brick masonry in cement lime mortar, 50% flooring in terrazzo *in situ* and 50% in 1 : 2 : 4 cement. Joinery in second-class varnished teakwood. R.C.C. roof with lime surkhi terracing.
E	1000	10,340	10.34	1,094	1,094	12,528	12.53	Brick masonry in cement lime mortar. Joinery work in first class Deodar. 1 : 2 : 4 cement concrete flooring R C.C. roof with lime surkhi terracing. Joinery work painted.
F	670	6,976	10.41	850	850	8,676	12.95	Brick masonry in cement lime mortar. Joinery work in second-class Deodar painted. 1 : 2 : 4 cement concrete flooring. R.C.C. roof with lime surkhi terracing.
G	550	5,860	10.65	584	584	7,028	12.76	(Same as type F.)
H	300	2,928	9.76	312	312	3,552	11.84	As above, except brick masonry in mud mortar and half brick partition in 1 : 2 : 4 cement mortar.

DETAILS OF ACCOMMODATION

D-2 Type	*E-Type*	*F-Type*	*G-Type*	*H-Type*
Living-room	Living-room	Living-room	Living-room	Living-room
2 bedrooms	2 bedrooms	Bedroom	Bedroom	Sitting alcove
Dining-room	Dining-room	Lounge	Verandah	Kitchen
Lounge	Lounge	Kitchen	Kitchen	Bath and w.c.
Kitchen and store	Bath and w.c.	Store	Bath and w.c.	Enclosed courtyard
2 bathrooms and w.c.'s	Kitchen	Bath and w.c.	Enclosed courtyard	
1 servant room with w.c.		Enclosed courtyard		

TABLE II

TYPICAL PRICE LIST OF BUILDING MATERIALS AT DELHI, DECEMBER 31, 1958

S. No.	*Description of materials*	*Unit*	*Rate (Rs)*	*Remarks*
1	Aggregates			
	3/4″ to 1 1/2″ gauge	100 cu. ft	25.00	At quarry site
2	Sand			
	coarse	100 cu. ft	31.00	At quarry site
	fine (river)	100 cu. ft	10.00	At river site
3	Lime (unslacked)			
	Satna	ton	62.74	Godown
	Dehradun	ton	88.27	Godown
4	Cement	ton	125.84	Central stores issue rate
5	Bricks			
	first class	1000 pieces	31.00	At kiln site
	second class	1000 pieces	27.00	At kiln site
6	Rubble	100 cu. ft	59.00	At quarry site
7	Stone slabs for flooring			
	1 1/2″ thick Red	100 sq. ft	53.12	Ex Godown
	1 1/2″ thick Kotah	1 sq. ft	3.00	Ex Godown

S. No.	Description of materials	Unit	Rate (Rs)	Remarks
8	Tiles			
	brick tiles	100 pieces	36.00	At kiln site
	cement tiles (6″ × 6″ × 3/4″)	1 dozen	6.00	Ex Godown
9	Timber			
	Hard wood			
	C.P. teak (first class in scantlings)	cu. ft.	19.50	Ex Godown
	C.P. teak (second class in scantlings)	cu. ft	14.50	Ex Godown
	Soft wood			
	Deodar (first class in scantlings)	cu. ft	13.50	Ex Godown
	Sal wood (in scantlings)	cu. ft	12.00	Ex Godown
10	Steel (untested)			
	M.S. round bars			
	1/4″ diam. to 1″ diam.	ton	725.00	Central stores issue rates
	Light structural			
	Angle iron (1″ × 1″ × 9/64″)	ton	675.00	Central stores issue rates
	Heavy structural			
	m.s. channels	ton	707.00	Central stores issue rates
	r.s. joints	ton	636.00	Central stores issue rates
	C.G.I. sheets	ton	909.00	Central stores issue rates
11	Asbestos cement sheets			
	1/4″ thick, plain	sq. ft	0.68	Ex Godown
	1/4″thick, corrugated	sq. ft	0.64	Ex Godown
12	Paints and varnishes			
	Oil paint for wood and steel work	imp. gal.	34.00	Ex Godown
	Copal varnish	imp. gal.	12.93	Ex Godown
	Super spar varnish	imp. gal.	28.87	Ex Godown
	Dry distemper	cwt	100.56	Ex Godown
13	Glass panes (Indian)			
	7/32″ thick in sizes from 2 to 7 sq. ft	sq. ft	2.00	Ex Godown
	Plain sheet glass (22 oz.)	sq. ft	0.50	Ex Godown
14	"Sitabord" flush doors (synthetic resin bonded, 1 1/2″ thick)			
	Commercial	sq. ft	3.00	Ex workshop Sitapur
	Decorative (teak face)	sq. ft	5.00	Ex workshop Sitapur
15	Bitumen, for hot application:			
	Maxphalte 80/100	ton	412.00	

PREFABRICATION AND LARGE-SCALE TECHNIQUES

It is against this background of costs that proposals to prefabricate complete houses and to mechanize the industry on a large scale have been examined. Many Indians who have visited Europe and the U.S.A. have admired the energy and imagination with which other nations have tackled their housing problems and have asked why the industry in India does not take similar action. Even if it were possible to show that prefabrication and mechanization on a large scale was economically sound, it is certain in present circumstances that the capital and foreign exchange necessary to finance housing factories could not be made available. Moreover, the difficulties with which an industrialist has to contend in setting up a new industry are such that no one would attempt to do so unless assured of a constant regular demand and no one is in a position to guarantee this. The different transportation services in the country are working to capacity and the movement of heavy components to distant sites is a further difficulty. Moreover, the Government is unwilling to add to the problem of unemployment and this in itself virtually rules out large-scale mechanization.

PRECASTING AT THE SITE

This does not, however, rule out some measure of mechanization and prefabrication and as prices rise these will be resorted to. The *in situ* construction of R.C.C. roofs is a time-consuming process and involves the use of form work which is steadily becoming more expensive.

It has been found that the use of precast roofing units, lintels, staircases, etc., manufactured at the site, is a practical proposition and greatly speeds up the rate at which buildings can be constructed. Very little capital investment or imported plant is necessary and workmen learn the processes quickly. As an example mention may be made of a project recently completed in the Punjab where some 1400 houses were required to be constructed urgently. Doubly curved shell units measuring $4' \times 4'$ and weighing 275 lbs were cast at the site. They were of one-inch concrete with reinforced edge beams and were easily handled by four men. They were laid on R.C.C. joists and concrete was then poured to form the flanges and level off the roof. They showed a saving in steel and cement compared with the usual R.C.C. roof construction and no centring was required. Most of the work was done by unskilled labour and the finished roofs are in every way satisfactory.

Prestressed precast units have been successfully incorporated in multi-storey buildings and it is thought that when high tensile steel is manufactured in the country this form of construction will be economical. Here again it will be necessary for a long time to manufacture units near the site and to avoid long hauls.

There is scope for further mechanization on a limited scale. Concrete mixers, vibrators, hoists, small cranes, etc., are already in use but a great deal of work is still done by human effort. As soon as other mechanical aids can be manufactured locally they will certainly be more generally used.

Other directions in which action is being taken to increase the number of houses constructed and to cut down costs include:

(a) The expansion of existing building material industries and the development of new industries. Here the main difficulty is that of finding foreign exchange for the import of essential plant.

(b) Greater control of the types of building constructed: cutting down the number of so-called prestige buildings and concentrating on purely functional structures. Here the danger of overcentralized control and the administrative difficulties of enforcing austerity standards in a country the size of India have to be borne in mind. And for Indians, who have a long and impressive record for stately and monumental building, these are unpopular measures.

(c) The methods usually advocated for increasing building productivity: better planning beforehand, better management on the works and a better flow of materials to the site.

AIDED SELF-HELP SCHEMES

In countries where unemployment is a serious problem, proposals based on aided self-help have a strong appeal. The housing project referred to above was carried out by army troops working under the direction of their own officers. They were given a good deal of technical assistance and they employed skilled labour for the more difficult tasks. The success of the scheme seemed to demonstrate the practicability of aided self-help on a large scale. Where the persons concerned have an organization capable of ordering and accounting for stores and the discipline and control necessary to produce concentrated effort, and where the time of those concerned can be devoted almost entirely to construction work, then and then only is aided self-help feasible in urban areas. Where those requirements are lacking and men have to earn their livelihood in some other employment it is practically impossible for any such scheme to be a success.

In drawing up the Slum Clearance Scheme it was intended that wherever possible State governments and local bodies should provide the occupants with a developed and demarcated site and a limited quantity of building materials, leaving it to the occupants to build their own houses to a prescribed pattern on a self-help basis. It has been found that this part of the scheme has very limited application. In rural areas the position is different as the villager is not fully occupied for long periods during the year and mutual and aided self-help schemes form an important part in the Indian Government's plans for improving village housing.

BUILDING RESEARCH

Much more is expected of building research in India than it is ever likely to be able to accomplish. It is not enough, for example, to study building materials and their performance under the climatic conditions to which they are exposed and to publish results. Most industries in India have little or no research facilities and they look to the National Laboratories for advice and help to a greater extent than elsewhere. Government departments expect advice on problems which affect the granting of import licences and the setting up of new industries, and questions of why indigenous materials cannot be used in preference to imported materials must be studied and answered expertly. Planning and development are the concern of government, and industry is being directed to a greater extent than elsewhere; a building research institute must be careful that its enthusiasm does not make it blind to the fact that processes which are successful in the pilot plant stage are not always commercially feasible. Advice is continually sought from foreign experts but there is a natural desire that Indians should have a decisive say in matters affecting the industrial development of their country and the National Laboratories are expected to provide this expert advice.

In the field of building materials much still remains to be done on clays and clay products and the measures which should be taken to expand the brick industry: also on cements and concretes, on lightweight aggregates and on the utilization of industrial wastes. Much work also is necessary on paint specifications and the performance and weathering of paints, on the corrosion of steel and on the performance and development of roofing materials. In a country where nearly 80% of the population live in villages attention must continue to be paid to the stabilization of soils, the waterproofing of mud plasters, the use of bamboo as a reinforcement and to any development which might economically be applied to the improvement of the village house.

More work is necessary on the transfer of heat through walls and roofs and on the thermal behaviour of buildings under Indian conditions: also on problems relating to air conditioning, to acoustics, and to the non-destructive testing of materials. Work still to be done in the field of Structures includes the examination of measures likely to lead to economy in the use of steel and cement; to the production of precast prestressed units; to the development of indigenous prestressing equipment and to the study of shell structures.

In foundation engineering considerable work has still to be done on foundations in expansive clays, the settlement of building foundations and the bearing capacity of soils.

Under building operations, study is required on the extent to which mechanization can economically be applied; to the breakdown of construction costs and ways and means of stepping up productivity; to the more efficient utilization of space in buildings and to the standardization of building components. Many building practices – for example, the waterproofing of flat roofs and the construction of expansion joints – require to be re-examined and improved.

If the work which remains to be done appears formidable it is a considerable consolation to recall the very generous help which the C.B.R.I. receives from other countries. The Institute is in close touch with individuals and organizations in Europe, the Commonwealth and the U.S.A. It has had the pleasure and good fortune to welcome visitors from practically every country working on building research. Many of its scientists and engineers have received training abroad. Indians have naturally to apply not only the work and conclusions of others but also their own imagination and knowledge to the solution of India's housing problem, but it is pleasant to be able to record that India has benefited greatly by the international cooperation which exists in the field of Building Research.

ACKNOWLEDGMENT

The author wishes to thank the Director of the National Buildings Organization for information on costs, etc., used in the writing of this paper.

Improvement of traditional housing for the rural population in North Africa

UDC 333.32(61)

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The problem of improving the traditional housing of the rural population in North Africa is a typical problem of improving housing in an overpopulated country where the average income is low. This is essentially the problem of improving the accommodation of three quarters of the world's population. Only the different climatic conditions introduce any variations and these variations are not very great: the countries where man can survive with a very low standard of living are necessarily countries with a high mean temperature, *i.e.* countries with a warm temperate climate, a tropical climate or an equatorial climate. The most striking climatic difference is whether there is a cold or cool season or not.

In countries with an insufficient standard of living man lacks enough of everything: food, clothing, culture and housing. It will be clear that if the standard of living rises, if the individual income increases, all the characteristics will rise more or less simultaneously. As the efforts of those responsible for undeveloped countries are all directed, more or less successfully, towards increasing individual income and raising the standard of living, is there reason to embark upon a special campaign for housing? Would it not be advisable to await the effect of the general progress of these countries on the field of construction?

It would seem that special circumstances do, in fact, justify a special campaign for the improvement of housing. The chief ones are the following:

A frequent fault of housing in underdeveloped countries is the disorder of centres of population. Order costs nothing more than a little imagination and discipline, and besides the satisfaction of, as it were, the moral order that it brings, it provides opportunities for improvement and extension, *i.e.* the opportunity of beginning a certain capitalization of effort.

The traditional housing of underdeveloped countries is based exclusively on the use of local natural materials, which are, incidentally, employed in most cases with great skill. But the contact between the most traditional environments and the modern economic world allows the introduction of new materials with qualities which make them more interesting for certain uses than traditional materials: binders, materials in tension, sheets, etc. The introduction of these new materials requires studies and popularization.

Normally developed countries have housing techniques which were created for them. These techniques adapt poorly to the construction of housing of an intermediate level such as is suitable for underdeveloped countries in the course of improving their standard of living. There is thus a specific problem concerning countries which, having already made some progress, may hope for better accommodation than the traditional housing and which have not yet reached the stage where they can lay claim to the housing of normally developed countries.

Quite often the countries concerned do not have populations with a farming tradition, but pastoral and more or less nomadic populations. It is an established fact that the growth of population leads the nomads to settle down, but that does not give them a tradition of building. The other problems quoted above are, therefore, joined by problems peculiar to the cessation of a nomadic life.

Finally, in underdeveloped countries the labour force is very often underemployed; the labour that is incompletely employed may be invited to work on housing for itself.

All these aspects of the problem are to be found in North Africa: North Africa is characteristically an overpopulated region where the civil peace maintained for many years, the aid given in periods of famine and the development of public health have led to a growth in the numbers of the population that has almost exceeded the development of natural resources – which has essentially been performed in the fields of agriculture and mining – and that has almost outpaced the changes in social environment brought about by culture, urbanization and enrichment, changes which in general have led to a reduction in the rate of expansion of the population. It may be estimated that the population of North Africa has quadrupled in the last century and its rate of growth remains exceptionally high. Many of the population come from nomadic tribes.

The traditional materials of rural construction are, in general, rammed earth or clay or limestone brick. Good quality wood and metals were unknown. Consequently, much of the housing retains its temporary nature: the mud shack and the hut constructed from branches on a base of clay, worthless structures which are periodically destroyed by storms or fire. Certain regions (the Tunisian Sahel, especially Kabylia) have, however, a tradition of building in brickwork, but with little or no good quality material.

Finally, the state of the population does not permit them to lay claim to European-standard housing as yet, because of the cost of the latter. What kind of steps can consequently be taken to improve housing, means being what they are?

The solution that we shall explain below is applicable to all underdeveloped countries and is, moreover, similar to that adopted generally in Africa or in various countries of the Far East.

It should be stressed that the aim of this solution is to improve housing conditions within the context of a generally low level of means; it is a provisional solution, since the final solution will have to be achieved by a general improvement of the standard of living and the income level, making it possible to bring housing and other features in line with those of normally developed countries. The solution adopted has two aspects: firstly, administrative and financial and, secondly, technical.

The formulae for assisting construction in developed countries with their mechanism of loans, interest rebates, assuming the keeping of files, title deeds, etc., adapt poorly to the situation of the rural population of North Africa. A special formula has, therefore, been recommended as follows.

The assistance given is assistance in the form of a grant of materials and help by specialized labour and technical direction of operations. This assistance is given to the head of a family who are building their own house. In all cases where those concerned do not have the necessary land – and this is the usual situation – it also consists of the allocation of a plot of ground; this land is either given or sold on credit (in Algeria it is taken from public land or given to the authorities and ceded free of charge to those concerned); this land is provided with the indispensable equipment, roads are constructed, the water head-limit is determined. The size of the plots depends on the way of life of the people concerned.

These operations relating to land inevitably expand assistance to housing, making of it an operation of parcelling out, of town-planning: the access road has to be laid out, a water supply has to be provided. This is work whose costs have to be borne by the community, making maximum use of the local labour force and, therefore, creating resources for the population at a time when they are coping with the effort of creating their accommodation.

It is, therefore, necessary to draw up a lay-out that is human and pleasant, and this is perhaps the most difficult task of all. The officials who take part in this work are too frequently tempted to adopt regular plans which are monotonous and out of place. It requires a special talent to design a small residential centre using contrast to give it life and personality, concentrating interest on a small square, a fountain, an old tree, the few shops and an unrestricted view. However, it is not necessary to be a great sociologist to persuade oneself that such a design is indispensable to the real life of the centre one is trying to create. Human societies are like plants: they take root only at the cost of certain precautions.

The assistance given is aid in kind: materials, advice, specialized labour. The giving of this assistance necessarily supposes the very direct intervention of some official body. This opens the way to a difficulty that has to be guarded against: the civil service has a natural tendency to take the whole of the construction of the house for its account, the recipient being nothing more than a spectator. The civil service finds it easier to have things done well and under its command so that it is often difficult to have it done correctly – at least at first – by the interested parties. The latter also often tend to leave things to the "Government".

The pitfalls are numerous and deep. First of all, if the man for whom the house is being built does not play an important part in the construction of that house, government expenditure on that work is considerably increased, which changes the whole aspect of the problem. At the same time, the advantage of making use of labour incompletely utilized on something else is lost. Furthermore, it is very difficult for the government to aid its nationals to improve their housing or to construct "government dwellings" themselves.

In the second place, this system will inevitably lead to the building of houses that are "too good"; certainly not too good in an absolute sense, but too good in relation to the means that can be devoted to housing. And, since it makes the houses too good, it will make too few of them; how many efforts have not fallen into this trap! One has to have the courage to make mediocre houses in order to make a lot of them.

Finally, if the man who is going to live in the house does not build his "own" home but waits until it is offered to him, his critical instincts are going to develop: instead of being satisfied with the improvements, he is going to be discontented with the imperfections. Furthermore, he will not be attached to his house. He will not try – in any case, he will not know how – to improve and extend it later.

Care must therefore be taken that the operation retains its nature of a "beaver project", or building by the person concerned with his own hands.

In the technical field, the operation consists of a constructional technique and of a plan. The constructional technique is chosen for each site and is governed by the local resources. It has to be economic of course, but it must also be such that the man who is going to live in the house can help to build it and can later extend it by himself.

All such houses in North Africa are single-storey ones. The material is bearer brickwork with ties at top and bottom. Rammed earth has not been adopted; its durability is questionable as soon as construction leaves anything to be desired; moreover, it reminds the population of the mud hut: it is not considered as being capable of constituting the material for durable housing. Rubble-stone masonry is possible when there are quarries that the inhabitants can work themselves, but it requires experienced masons. The most general solution is the concrete block: the interested parties help to quarry and to prepare the materials required and assist in block-making, for which machines are usually employed.

Roofing consists either of tiles on joists or prefabricated domes or slabs; the fittings are the simplest possible: rammed earth for the floor, doors and solid shutters. The structure consists of a rectangular shape of about 18 square metres, with interior partitioning. It is completed by an enclosure formed by walls of rammed earth or of masonry and often by a thorn hedge in which there is frequently a lean-to of 4 to 7 square metres forming a kitchen, if that is the local custom.

The amount of assistance at present given for such structures in Algeria is Fr. fr. 200,000. Hundreds of villages and tens of thousands of houses have been built on this system in Tunisia since 1951 and in Algeria. In Algeria from 1955 to March, 1959, 328 villages with 20,700 houses were completed, of which 12,300 houses were built between March, 1958, and March, 1959. The Constantine plan provides for the construction in five years of 100,000 buildings of this kind.

What is the lesson to be drawn from these operations? We believe that the principle of them is good and well adapted to a rural country just beginning to acquire facilities, and that it can even be extended to suburban populations. The main difficulties that still have to be solved are, in particular, improving the insulation against the heat of the summer sun; it would be necessary to increase the thermal mass of the walls and, especially in the Sahara, to find an economic means of providing sun screens. Technicians must devote their efforts to these two problems.

Professional training for mass housing in the tropics

UDC 373.63 : 333.32(213)

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REQUISITES FOR ECONOMIC DEVELOPMENT

Housing must be understood as part and parcel of the economic development of a region. Economic development requires:
- (a) a developer;
- (b) an effective demand for its results;
- (c) finance;
- (d) suitable land;
- (e) suitable materials;
- (f) technical man-power.

This paper is concerned with the last of these requirements, technical man-power for housing, but it is necessary to keep the other five in mind. The men and skills needed for mass housing are related to the type of developer who initiates a particular project, to methods of financing, to the groups of users who supply the effective demand, to questions of building land (limited urban or ample rural) and to building materials.

HIERARCHIES OF TECHNICAL MAN-POWER

The building industries of the West have developed elaborate pyramids of technical professions. At the base are the unskilled labourers. The next tier is formed by trained artisans, led by foremen, overseers, technical draftsmen, land surveyors, clerks of works and contractors. The top of the pyramid is formed by the highly skilled professions of town planners, architects, quantity surveyors and structural engineers.

THE MAN-POWER SITUATION IN THE TROPICS

Two questions arise: how far have the fast developing countries of the tropics followed the patterns set in Western Europe and the U.S.? and how much of this elaborate build-up is needed to cope with the urgent task of mass housing?

UNSKILLED WORKERS

None of the tropical regions, not even the less densely populated countries of Africa and the Middle East, is short of unskilled labour. What is more, recent experience has shown that the illiterate immigrants who crowd the towns of the tropics can be trained to acquire the skills needed to lay bricks or blocks, assemble reinforcement, mix and cast concrete or handle carpentry and joinery work.

ARTISANS

Most urban areas suffer from shortages of trained workers. Industrial schools and training centres exist, but do not train sufficient numbers to meet the demands of rapidly expanding housing industries. The UN Housing Mission to Ghana estimated that the country would require schools turning out at least 480 skilled artisans a year in order to cope with a minimum programme of 7,200 small houses per year [1]. The Mission recommended an expansion of training facilities, the import of skilled workers and foremen from Italy and the adoption of accelerated methods of training on the basis of the French system known as "Formation Professionelle des Adultes", as adopted with great success in Dakar [2]. Training facilities in many other tropical regions are as insufficient as those in Ghana.

FOREMEN AND OVERSEERS

Skilled building workers and artisans can receive their basic training in technical schools. Foremen and overseers must grow out of the ranks of artisans and craftsmen. Building operations depend on teamwork. The qualities of leadership needed in a good foreman – reliability, talent for organisation and capacity for handling other men – become apparent in the day-to-day work at the building site. There would be no reason to assume that building practice in the tropics could not produce as many "born leaders" as it does in the West if it were not for the necessity of having overseers and foremen who are literate and can read drawings.

Until literacy has become almost universal, men who can read and write command employment that is more lucrative or provides a higher social status than manual labour in a building trade. An educated boy will not become a bricklayer's, carpenter's or plumber's apprentice in the hope of working his way up to the position of foreman or overseer. The ideal of the "people's army of house builders" with leaders who have worked their way up from the ranks, cannot be realised without special adult training facilities which allow selected workmen to learn reading, writing, arithmetic, drawing and understanding of plans as a preliminary to the promotion to the position of foreman, overseer or even to becoming a working builder or contractor.

India, Pakistan and a few other tropical countries have technical schools, usually connected with Public Works Departments, where boys with secondary education can train to become overseers or draftsmen. Apart from the fact that the overseer who has not grown out of the ranks is at a disadvantage when leading older and more experienced men, the numbers of overseers and draftsmen trained in these schools are insufficient for the needs of mass housing.

GEODETIC SURVEYORS

Survey departments have in many countries established schools for the training of their own staff. Few of these are large enough to cope with departmental needs, and there is an almost universal shortage of men trained to survey a building site and take levels. This affects not only house building but also other vital requirements of economic development, such as the establishment of boundaries and registration of titles in many African territories.

CONTRACTORS AND BUILDERS

Building contracts are undertaken either by foreign firms interested mainly in large projects or by local entrepreneurs who usually start as purveyors of labour or suppliers of materials and slowly graduate to bigger tasks in the field of construction. Many are handicapped by shortage of working capital, technical know-how and business experience.

TECHNOLOGICAL PROFESSIONS

Developments in the professional field must be understood with reference to the histories of the countries concerned. Army officers and military engineers were first in the field [3]. They were followed by civil engineers concerned mainly with public works. Architects appeared late and planners still later. In 1952, London had one architect for every 1350 inhabitants, while India had less than one for every million, most African countries less than one in 500,000, Jamaica one in 100,000 and Abyssinia one in 11 million. The number of planners was even smaller and the profession of quantity surveying is practically non-existent in the tropics.

The number of professionally qualified men has increased in the last seven years. Architects' schools have been started in Ghana, Nigeria, Uganda, India, Indonesia, Burma, Singapore, Hong Kong and the Philippines. Graduate courses for town planning exist in Bandung (Indonesia), Bangkok (Thailand) and in Delhi and Kharagpur (India). Yet, with the exception of the Philippines, most tropical countries must reckon with shortages of architects and planners for many years to come.

Most tropical countries thus find themselves faced with the need for mass housing programmes to be tackled by professional armies with plenty of men, an inadequate number of officers (architects, planners, etc.) and an even less adequate number of the intermediate ranks represented in the building field by foremen, overseers, draftsmen and builders.

PROPOSALS FOR TRAINING PRIORITIES

The building up of elaborate man-power pyramids as they exist in Western countries obviously takes time and can contribute little to the solution of immediate and urgent housing needs in fast growing towns. Questions of technical training for mass housing must be approached differently.

The clue lies in the role of the developer. Past thinking has attributed too much importance to governments, local authorities and industrial employers as initiators of housing developments. George Atkinson, in his introduction to the discussion of mass housing in rapidly developing tropical areas [4], has shown that "the mass of town dwellers... have to depend on their own initiative or on that of private entrepreneurs for shelter". In other words, in the tropics, as in most Western countries, the individual home builder will be the most important developer in the field of housing. Technical training, to be effective, must serve his needs.

In England, the designing of houses is supposed to be the concern of four highly specialised and skilled technical professions: the town planner, the architect, the quantity surveyor and the structural engineer. In practice, the majority of small houses is built without any of them. The contribution of the architectural profession to the building of small houses consists less of individual designs than of the provision of patterns that are copied by small house builders all over the country.

This may or may not be a desirable state of affairs. It is certain that the small developer in the tropics who invests much smaller amounts than his Western counterpart will adopt similar methods. He will not employ an architect and pay professional charges for an original design. He will employ a small builder who will produce an exact or modified copy of a house that appeals to his client.

Technical training for mass housing should, therefore, give priority to two tasks: the training of competent small house builders and the provision of an élite of architects to specialise in the provision of good patterns for use by house builders.

THE HOUSE BUILDER

The first of these two tasks is by far the more difficult of the two, involving as it does either the creation of a new profession or the up-grading of an existing one. A good house builder is more than an overseer, clerk of works or "plan-drawer", yet less than a fully qualified architect. He should know enough of architecture to design a small house or adjust a standard design to a particular location and supervise its construction. He should be enough of a planner to handle questions of site layout, enough of an engineer to cope with simple structural problems and enough of a surveyor to estimate costs and present accounts for building operations. He may act as designer and adviser to a middle class client or investor, but more often he will be a house building contractor. His services would no doubt be in demand not only for housing but also for municipal works and for a multitude of minor building jobs; in short, he would be the "general practitioner" of the building professions.

The curriculum of a school for the training of house builders would have to vary from country to country but, broadly speaking, may follow the pattern of the German "Bauschule". The emphasis should be on practice rather than theory [5]. Success of a school for house builders is less an educational than a social problem. Artisans and technicians have established and respected places in the societies of the West. Their social status dates back to the days when their guilds ran the towns of northern Europe together with those of the merchants and bankers.

The towns of the tropical East and South have no such traditions. The overseer, technician, clerk of works or skilled draftsman finds himself in a social no-man's-land between the university graduate and the wealthy on the one side and the coolie labourer on the other. Unless a suitable social status for the house builder is established, recruits for the new profession will not come forward and all effort and expenditure on training facilities will be in vain.

Here is an important field for research in "social engineering", a subject that may be as important for mass housing as research into new materials. The right kind of designation, a suitable professional organization, political representation, something corresponding to a Royal Charter laying down a professional code, are among the means might help to achieve this objective. The first step must be the recognition that technical training for mass housing presents a formidable challenge to the social scientist.

THE TECHNOLOGICAL PROFESSIONS

House builders are needed in large numbers to cope with an ever increasing need for small individual houses. They will supplement but not replace the technical professions. Ideally the architect, planner, quantity surveyor or structural engineer with full professional training and status should be recruited from the ranks of house builders, in the same way as the medical and surgical specialist grows out of the ranks of the general practitioners of medicine. Countries not hitherto committed to the British professional set-up may adopt this solution; others may continue their present system of ecudation and professional organization, but will be well advised to institute special evening classes for house builders who want to advance and become fully-fledged technologists. Such advancement, even if infrequent, will be of benefit for both professional groups: the profession of the house builder will cease to be a cul-de-sac and that of architecture will gain a few ambitious men with a background of practical experience that is different from the rest.

It will be for the architects to provide the ideas and patterns for the house builders to copy. This task must be treated as a social service for which architects should be employed by the State.

PATTERN BOOKS AND INFORMATION SERVICES

Patterns for mass housing should be more than the type designs used by public works departments. They should incorporate the theoretical and practical knowledge accumulated by builders and research workers in the tropics. In fact, pattern books could be at the same time text books and become a means of bringing the results of building research to every house builder in the country.

The building industries of the tropics are young, as are the building professions and research organizations. They can avoid some of the mistakes of the West and build up from the beginning efficient methods for the exchange of experiences and dissemination of information [6]. Technical training in particular can be helped and accelerated by the universal adoption of a standardized system of classification for plan patterns, codes of practice and research results. Architects and house builders should be brought up to subscribe to comprehensive information services which would keep them up to date and provide them with technical information in a form designed for convenient storage and reference.

Tropical building research and the art of designing for tropical conditions have made great strides in the past decade. The time has come to put increased knowledge to use through the right kind of technical training and through effective information services.

REFERENCES

1 C. Abrams, V. Bodiansky and O. Koenigsberger, *Report on Housing in the Gold Coast,* United Nations Technical Assistance Administration, New York, 1956, p. 90.

2 *Cf. Mission d'Etudes de Problèmes de Travail,* Bureau de l'Inspecteur de Travail de l'A.O.S., Route d'Ouakam, Dakar, Senegal.

3 G. A. Atkinson, *Architectural Association Journal (London),* 69, 773, (1953) 7.

4 G. A. Atkinson, *Mass Housing in Rapidly Developing Tropical Areas: An Introduction,* this volume p. 248.

5 For a detailed plan for a school of this type *cf.* R. Gardner-Medwin and J. A. L. Matheson, *Report to the Council of Kumasi College of Technology, Gold Coast, on Professional Education in Subjects Allied to Building,* Annex to O. Koenigsberger, *Report on Housing in the Gold Coast,* Part II, United Nations Technical Assistance Administration. New York, 1956, pp. 19–50.

6 D. Bullivant, *The Architects' Journal (London),* April 2 (1959) 505–521, May 7 (1959) 695–700.

Discussion

In addition to the papers circulated before the Congress, reports were given on housing activities in the Congo, Hong Kong and Libya.

CONGO

Mr. E. Scaillon (Belgium) reviewed the work of the Office des Cités Africaines; he illustrated his talk with a film. Features of the housing problem in the Congo were the low average income of the population, the lack of an urban tradition and the rapid growth of population in urban areas. Housing should not be regarded as an isolated activity but as part of a general plan for urban development. Only about 20% of the population could afford to pay for their own housing, the remaining 80% needed some kind of financial aid. Aided self-help had a useful role to play provided that it was undertaken within the framework of a well thought-out town plan. With aided self-help housing maintenance was, however, likely to cost more because the builders were less skilled. Mr. Scaillon referred to cost studies carried out by his Office, particularly with regard to the development of self-supporting roofs of steel and asbestos cement sheeting.

LIBYA

Mr. W. Podwapinsky (Poland) described his work with a United Nations mission to Libya. Features of the country's housing problem were: population largely nomadic with strong tribal allegiances, 90% being illiterate; no locally born engineers or architects; poor natural resources; a severe climate with very hot summers; few local industries. Migration of country people to the two main towns was leading to their uncontrolled growth and was creating a problem of shanty-town settlements.

The only readily available building materials were soft limestone and sand, all other materials were imported. Both climate and the social background influenced low-cost house design, which was based on the following principles:

1. Minimum floor area per person: 3.5 m^2.
2. No more than two persons per room.
3. Courtyard-type house plans providing a private, screened working area for women folk.
4. A squat-type toilet with shower overhead; a wash-tub and sink in the courtyard (Moslems pray five times a day and wash in water before praying).
5. Construction was modular throughout, the basic module being $25 \times 25 \times 25$ cm. This permits interchange of building elements.
6. Rigid standardization of elements (doors, windows, etc.).
7. Substantial open space for courtyards and playgrounds, resulting in an economical population density of 420 persons/hectare (170 persons/acre).

HONG KONG

Mr. W. W. E. Collard (Hong Kong) spoke of the very high population densities which had to be provided for. An already difficult housing situation had been considerably aggravated by war damage and the post-war influx of refugees. The Hong Kong Housing Authority, which had been provided by the Government with 5% loans for a 40-year period, was building multi-storey flats. Space standards were low (about 3.5 m^2 per person) and densities high (more than 2000 persons per acre, or 5000 persons per hectare).

GENERAL DISCUSSION

From the papers and discussion which followed, it was clear that the serious and most urgent problem of mass housing in rapidly developing countries did not depend only on technical solutions. The administrative and financial aspects were at least as important. Even within the technical sphere, as Mr. G. A. ATKINSON (United Kingdom) stressed, the planning and construction of housing areas and the infra-structure of towns was a more important and difficult problem than that of individual dwellings. Mr. E. SCAILLON (Belgium) underlined the need for well administered technical organisations to carry out housing programmes. Mr. P. PH. ARCTANDER (Denmark) considered that there was little room for improvement in the traditional use of local materials. Of greater importance was the provision of the basic sanitary and technical services of a community. Well thought-out plans, related to national development as a whole, were of more value than technical novelties.

AIDED SELF-HELP

Miss R. M. FREAN (South Africa) considered that aided self-help in urban areas was costly. The effort put into house building by men who had already spent their day working in industry could not but be detrimental to their normal work. Mr. G. A. ATKINSON (United Kingdom) noted that aided self-help methods had been most successful when applied to rural areas and to places where there was seasonal unemployment, or where there was a great influx of people without permanent work. The importance of relating aided self-help schemes to town plans was stressed by Mr. E. SCAILLON (Belgium).

LOCAL MATERIALS

In view of the fact that most of the countries under consideration had an abundant supply of labour, intensive construction methods which used local materials to the fullest possible extent needed to be studied.

Mr. P. PH. ARCTANDER (Denmark) considered it was often better to build less durable houses with relatively cheap local materials than to build in solid, durable, imported techniques. When properly applied such local materials had proved satisfactory. In India, as both Sir H. WILLIAMS (India) and Mr. N. S. PARTI (India) mentioned, the problem was to develop local building material industries. In a country where there was an unlimited supply of unskilled workers, prefabrication and mechanization were of little use.

Mr. J. DREYFUS (France) drew attention to the need to train technicians so that the results of experience in research could be applied quickly. Under certain conditions prefabrication had its uses and there should be flexibility in choosing technical solutions. For example, in Africa one may have to use only one sixth of the amount of cement required for house building in metropolitan France.

DESIGN AND PLANNING

The same flexibility was necessary in house planning. Mr. J. DREYFUS (France), in referring to housing standards, differentiated between hygienic requirements such as water supply, sewerage, etc., and social needs, particularly those of adapting to urban ways of life. The provision of reasonably comfortable living conditions, especially protection against heat, should not be excluded. Mr. P. CHOMBART DE LAUWE (France) said that it was not often possible to delay construction until the basic sociological studies, which could take a long time, were completed. Nevertheless, there were investigations which could be made rapidly.

The creation of a local industry involves a major training problem. Mr. D. A. G. REID (United Kingdom) noted that as the demand for better quality work increased the need for more skilled craftsmen and technicians grew. From these better trained men might be selected potential candidates for further subprofessional training. Dr. O. KOENIGSBERGER (United Kingdom) summed up the problem of the training of building technicians in urban areas as follows:

1. Information and documentation services were just as important in tropical countries as in Europe.

2. In providing such services it was important first to decide for whom they were meant.

3. Public bodies only meet a small part of the housing needs. Information research services should not exclude the people who build for themselves.

4. Improved housing depends first on better trained designers and builders.

5. In no tropical countries were there yet adequate training facilities for the building professions, but as development could not wait until these had been provided there must be priorities. The first priority was the training of people who could both design and build, the general practitioners of the building industry.

6. The training institutes of more developed countries should allow some of their staff to help in this work of training local building technicians.

Subject 6

FLAT ROOFS

UDC 69.024.3

GENERAL INTRODUCTION

T. W. PARKER
Deputy Director of the Building Research Station (United Kingdom)

REPORTS

T. ISAKSEN
Building Research Institute (Norway)

R. HANSON
Civil engineer (Sweden)

F. G. THOMAS
Building Research Station (United Kingdom)

Technical problems of flat roofs

UDC 69.024.3

T. W. PARKER
Deputy Director of the Building Research Station (United Kingdom)

In my capacity as chairman of the Congress session on the subject "Flat roofs" I would like briefly to introduce the papers to be presented and to give a preliminary review on the subject matter.

THE FUNCTION OF A ROOF – THE WAYS OF FULFILLING IT

Let us first consider the function of a roof and the constructional means to fulfil this function.

It is evident that a roof must provide protection against atmospheric conditions. This must be interpreted as protection not only against wind, rain and snow, but also against excessive solar heat gain and excessive heat losses. Obviously the effect of each climatic influence depends on the siting of the building, and the importance of the various physical, chemical and mechanical properties of the materials used varies accordingly.

In traditional wall construction, one single material combines several functions. The masonry of an outer wall combines a load-bearing function with protection against rain and wind and with good thermal insulation and sufficient fire resistance. However, in traditional roof construction the tendency is to use a special material for each separate function. For example, a roof may have a timber load-bearing structure, a layer of light material or air to provide thermal insulation and fire protection, another layer to protect against rain and sometimes even a further layer to reflect solar radiation.

We find these layers also in various types of flat roofs, but there are important exceptions, *e.g.* timber or cellular concrete flat roofs where one material combines both the structural and the insulating functions. The use of different materials for different functions tends to simplify research aimed at achieving the most successful combination.

For brick construction, it would be out of the question to try to develop a form of the material that would provide a better heat insulation without making completely sure that the bearing capacity and the capacity to resist rain are still adequate. For roofs, however, it is perfectly possible to strive at a better thermal insulation or an improved waterproof layer without violating any of the other properties of the roof. Nevertheless, one cannot go too far in this direction, since experience shows that the different layers are not wholly independent, but do influence one another directly or indirectly. Moreover, the conditions to be met by roofs are generally more severe than those to which walls are exposed.

Summarizing, one can expect the relative importance of certain specific functions of the roof to vary in a certain degree with geographic regions, with the materials that can be procured economically and even with the calculation methods or construction techniques. But in the first instance there are some common factors, even if they have a relative and varying importance, and in the last instance the exchange of information, as in today's meeting, permits us to compare and to discern the different solutions.

THE PARTICULAR PROBLEMS OF FLAT ROOFS

It would seem to be generally recognized that flat roofs present, at least in northern European climates, more or newer technical problems than traditional pitched roofs. Some of these problems are related to the necessity of a watertight rather than a porous covering as provided by concrete and ceramic tiles; others are concerned with the need for a continuous covering that nevertheless must be able to follow the movements of the entire building it covers.

The particular problems of flat roofs considered at the British Building Research Station include:

1. Durability of exterior covering.
2. Value of different materials for insulating layers, and, especially, difficulties caused by moisture: how to prevent water from getting in the insulating layer and how to get it out once it is there.
3. Structural precautions against wind effects, especially for light roofs.
4. The problem of expansion joints in flat concrete roofs.
5. Measurement of heat losses and the relation between the details of the roof construction and heat transmission, as well as condensation risks.
6. Exclusion of solar heat.
7. Risk of fire for combustible roof coverings.
8. Durability of parapets.

This list is not exhaustive but gives examples of the problems met. Participants may wish to discuss others that are more urgent to them. The reports presented deal with northern European conditions, and it would be valuable if participants who have experience of the behaviour of flat roofs in tropical or subtropical conditions could contribute.

THE WORK OF CIB ON THE SUBJECT

In the former Research Section of CIB a Working Commission composed of representatives of CIB members in Norway, Sweden, France, U.S.S.R. and the United Kingdom studied some of the problems, in particular those of common interest to participating countries. Initially Mr. R. Hanson of the Swedish "Statens Nämnd för Byggnadsforskning" was reponsible for organizing the work; later Mr. T. Isaksen of the Norwegian "Byggforskningsinstitutt" took over. The special problems studied by the Commission are moisture trapping in the watertight layer and the means to solve this difficulty – a problem especially treated by the Norwegian member – and the durability of roof coverings – a problem especially treated by the Swedish member. Both studies are completed now and the reports by Messrs. Hanson and Isaksen may serve as a starting point for our discussion.

The third report, by Dr. F. G. Thomas, on wind effects, deals with a different aspect and, in the absence of Dr. Thomas through illness, will be introduced by Mr. Simms, who collaborated with him.

After our discussion we have to deal with one particular question. The Commission has completed its present programme. It may be desirable to put new items on its programme and suggestions would be of interest.

Now I invite Mr. Isaksen to introduce his report.

Moisture migration and removal of moisture by ventilation from porous materials used in flat roofs

UDC 69.024.3 : 699.82

T. ISAKSEN

Norwegian Building Research Institute (Norway)

INTRODUCTION

One of the main problems studied when the CIB Working Group on Flat Roofs started its work, was the failures of such roofs due to moisture. Among the members of the group the situation was as follows.

In Sweden, discussion on flat roof constructions and failures had taken place since 1948 and, judging from the reports of the Swedish National Committee for Building Research, these discussions had been rather impetuous. Mr. R. Hanson had investigated the roofing failures on some 200 roofs and he had later planned large laboratory scale experiments to find the diffusion constants and the capillary constants in brick and two gas concrete materials, *viz.* Ytong and Siporex.

In England, condensation troubles had occurred rather frequently in sheeted bungalow walls and in sheeted roof constructions covering industrial buildings. Test roofs were erected in the Roof Laboratory at the Building Research Station in Garston for investigation of condensation problems.

In France, Centre Scientifique et Technique du Bâtiment was studying condensation in sheeted constructions in a large roof laboratory.

In Norway, Professor Holmgren, at the Norwegian Technical University, had finished his preliminary research on ventilated and unventilated heavy flat roof constructions covering two small test huts. A new roof laboratory with test panels up to a length of 12.4 m had just been started. In 1951, Mr. Prestrud had written a report (Norwegian Building Research Institute Report No. 4) on a preliminary research on 25 roofs where the moisture content in the screeding and the thermal insulation was measured in 1950 and 1951.

During the years from 1953 to 1959 the above-mentioned investigations have all been finished and published as reports of the respective research institutes.

From the last meeting of the Working Group in Stockholm in 1958, we know that the major work on moisture problems in flat roofs in the near future will be carried out in the Soviet Union and the United Kingdom, where comprehensive investigations are planned or have been started. At the same meeting, research work in Russia was presented by Mr. I. E. Chlusov. (A translation has been made into Norwegian.) It is a very capable work and of the greatest interest for building research scientists. Mr. Chlusov has worked out a theory which makes it possible to calculate the time necessary for raising the moisture content from a certain level to another given level for all kinds of porous materials used in flat roofs, for various constructions, and under various climatic conditions. Mr. Chlusov also calculated the ventilation rate necessary to avoid such a rise in the moisture content. His theory is valid for the hygroscopic moisture contents. In the Soviet Union this is natural because the Russians are working with prefabricated, dry roof elements on a great scale.

In the usual flat roof constructions in Norway and in many other countries, unfortunately, we must consider a much greater free water content than that for which Mr. Chlusov's theory is valid. For such roofs it is necessary to make the ventilation so effective that the water content can decrease to the upper limit of hygroscopic moisture content within a relatively short time. How to obtain this has been the main aim of the research in Norway. This paper gives the main results of the Norwegian investigations.

NORWEGIAN RESEARCH

Failures of roofs present a great economic problem in Norway. Leakages have frequently occurred; the necessary maintenance is sometimes so extensive that a rebuilding of the roof is the only solution. Some roofs, however, have served remarkably well during 15–20 years, even unventilated roofs. Some ventilated roofs constructed after the Second World War are as bad as the old, unventilated ones.

American, Swedish and other investigations indicated that the major part of the roofing damages, like blisters, bucklings, etc., may be due to a wet underlay. In an Arctic climate, a great moisture content in a flat, compact roof always implies dangers to the construction; many leakages are due to frost-cracked screedings. In Norway, it was decided therefore to examine the moisture problem in the construction underneath the roofing. We have, accordingly, tried to find the influence of the water content on the heat loss and maintenance of the various constructions, and how to reach the necessary decrease in water content.

The investigations have lasted nine years and have been carried out in specially constructed roof laboratories and on actual roofs. The roofing itself has not been thoroughly investigated, but the condition of the roofing is described on every roof studied.

The research programme for the Roof Laboratories was:

1. To compare the drying-out process in ventilated and unventilated test panels. Test samples had to be taken from every part of the construction.
2. To compare the drying-out effects of various ventilating systems.
3. To find possible advantages and disadvantages of a different location of the ventilating system.
4. To solve the problem of "residual moisture-vapour diffusion from the room" in unventilated constructions with a concrete slab carrying thermal insulation and roofing on the top.
5. To measure the heat loss through ventilated and unventilated constructions.

The research programme for the actual roofs was to establish:

(a) The amount of water in the usual flat roof constructions.
(b) The drying-out effect of various ventilating systems.
(c) The condition of various thermal insulations, especially weak ones, in unventilated constructions.
(d) The ventilation effect on the durability of weak thermal insulation materials.
(e) Whether a high water amount is always a condition for damages in the roofing.

RESULTS FROM TWO SMALL TEST HUTS AT THE TECHNICAL UNIVERSITY OF NORWAY, TRONDHEIM, NOVEMBER, 1948 – NOVEMBER, 1952

The test roof panels were constructed on two older experimental houses in the summer of 1948.

The design of the roof panels and the results are shown in Fig. 1. Inside temperature and humidity were kept constant, + 20° C and 75% respectively, the latter corresponding to a vapour pressure of 13.2 mm of mercury. The moisture content in the roof was calculated from borings made in the gas concrete, which had a weight of 0.725 g/cm^3. The results were published by Professor Holmgren in the *Teknisk Ukeblad* (The Technical Weekly Journal), No. 26, 1953.

Results

1. A large initial difference was found in the moisture content in ventilated and unventilated panels.

2. In the unventilated panels, the moisture content varied with the seasons. There was no real difference between the results from the four panels, the plotted curve is the same for all of them. No effect from the vapour barrier facing the room could be detected.

3. The moisture content varied very little in the ventilated sections; mutual differences were also very small (Common curve).

Conclusions

1. The insulation in the ventilated panels was already dry when the measurements were started in November, 1948.

2. The insulation in the unventilated panels stayed moist through the whole testing period, and had about the same moisture content in November, 1952, as in November, 1948.

3. Since the houses were small and the roofs were constructed in the summer, all the

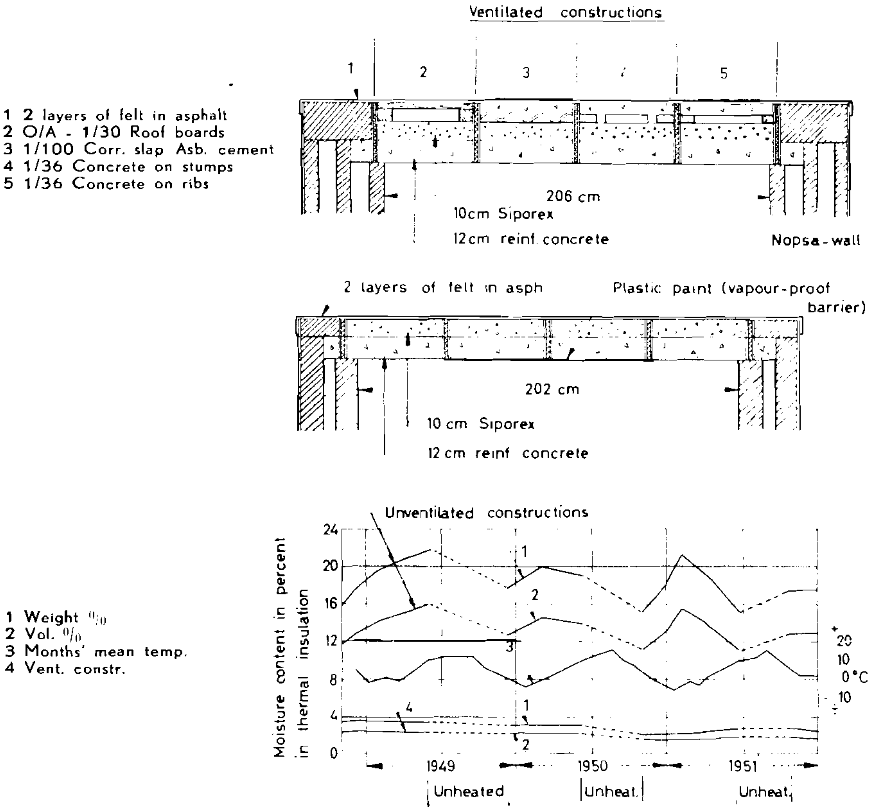


Fig. 1. Small Roof Laboratories, N.T.U., Trondheim.

sections had received the same amount of water precipitation. The initial difference between the moisture content in ventilated and unventilated sections is thus an expression of the ability of the ventilation system to dry out the insulation. The drying-out period is calculated from the time when the roofing was placed until the first specimen was bored out.

A rather important and frequently disputed question was still unanswered: Was the residual moisture from the construction period or the diffusion of water vapour from the room through the concrete slab the decisive factor? The results may indicate either answer according to the way they are interpreted. As the houses had to be torn down to make room for new constructions, it was not possible to proceed any further with this problem.

RESULTS FROM A LARGE ROOF LABORATORY IN TRONDHEIM, DECEMBER, 1953 – MAY, 1957

The design of the roof panels is shown in Figs. 2 and 3. Inside temperature and humidity

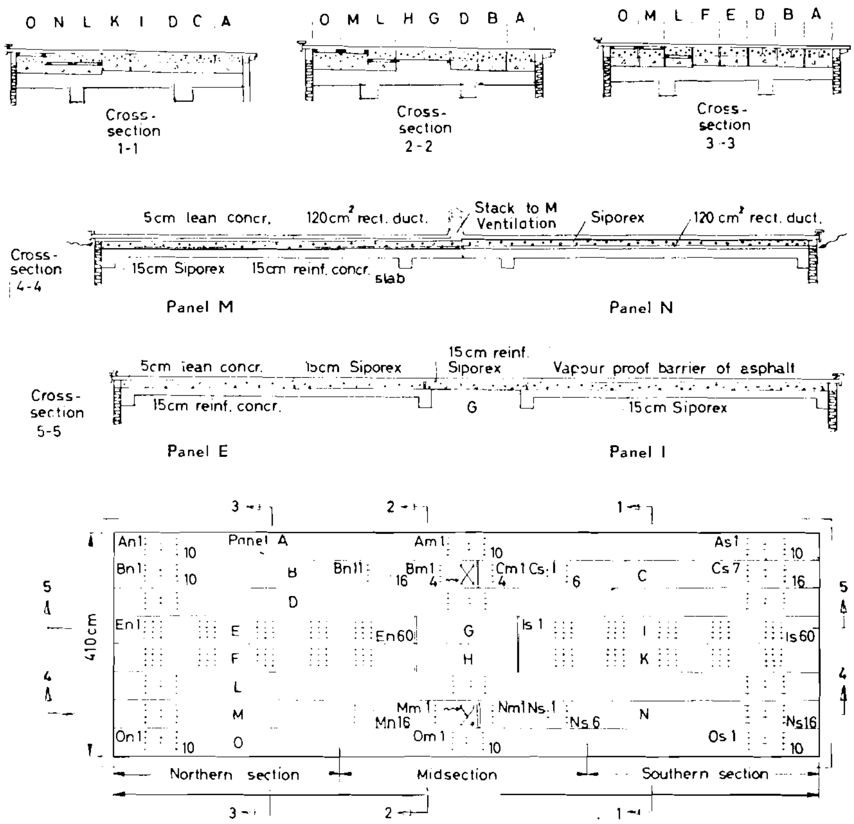


Fig. 2. Large Roof Laboratories, N.T.U., Trondheim.

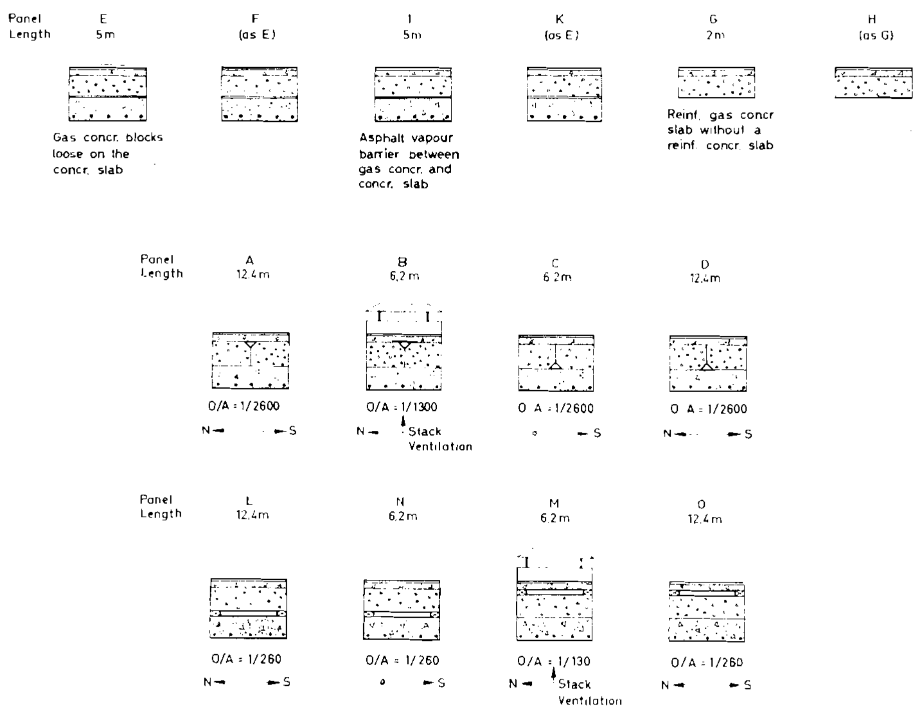


Fig. 3. Cross sections of the test panels. Group 1, panels E, F, I and K; group 2, panels A, B, C and D; group 3, panels G and H; group 4, panels L, N, M and O.

were kept constant, +20° C and 65 %, respectively, corresponding to 11 mm of mercury.

The drying-out process (Fig. 4)

The moisture content in the materials was calculated from borings of test specimens. The concrete slab under the insulation material was provided with concrete cones, which could be taken out, making borings from the insulation and screeding possible.

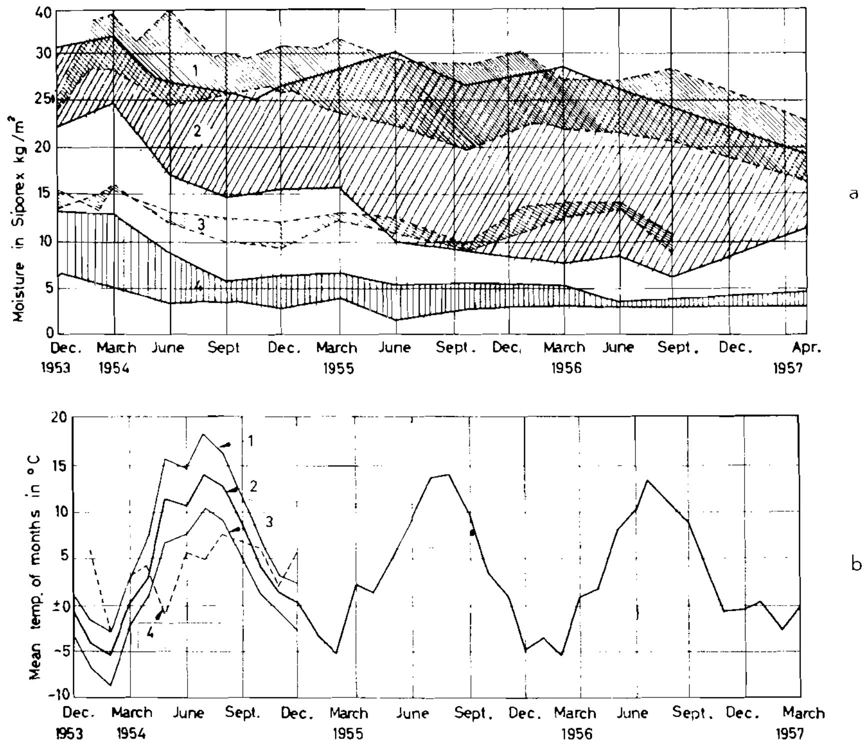


Fig. 4. (a) Drying-out of cellular concrete in all panels. 1. Unventilated with concrete slab (E, F, I and K). 2. Poorly ventilated triangular ducts 12 cm² (A, B, C and D); upper limit, panel B; lower limit, panel A. 3. Unventilated structural cellular concrete slab (G and H). 4. Well ventilated rectangular ducts 120 cm² (L, M, N and O); upper limit, panels L and N; lower limit, panels M and O. (b) 1. Mean maximum temperature of the month (of day maxima), 2. monthly mean temperature, 3. monthly mean minimum temperature (of day minima), 4. relative humidity.

For the gas concrete the results were as follows:

December, 1953–March, 1954

Even the first results showed a very distinct variation in the water content of the various panel groups, from 4 to 20 per cent. vol. In panels with a concrete slab, this difference must be due to the ventilating rate: the well ventilated panels were dry half a year after the roofing was put on, while the unventilated panels still kept the same water amount.

March, 1954–May, 1957

The upper and lower limit in each group have approached each other. Panel A suffered from a vapour leakage from the room side, and the water content increased in the mid and southern section of the panel. The structural gas concrete slabs G and H had a varying moisture content during one year; but they were as wet in June, 1956, as in December, 1953. The panels of group 4 got rid of some water during March–June, 1954. They are drier than what is assumed in the Norwegian Building Regulations to be a normal water content, and they remained dry during the rest of the test period. The unventilated panels with a concrete slab did not dry out, nor did they become wetter.

The concrete slabs (Fig. 5) were drier in the well ventilated panels. The difference between the wettest slabs in group 1 and the driest in group 4 was very small, only 2% vol.

The variations in water content of the screeding (lean concrete) are theoretically rather great during a whole year. Since our tests were bored out only in spring or early summer, they must not be considered as an average. The screedings kept nearly the same water amount in all panels.

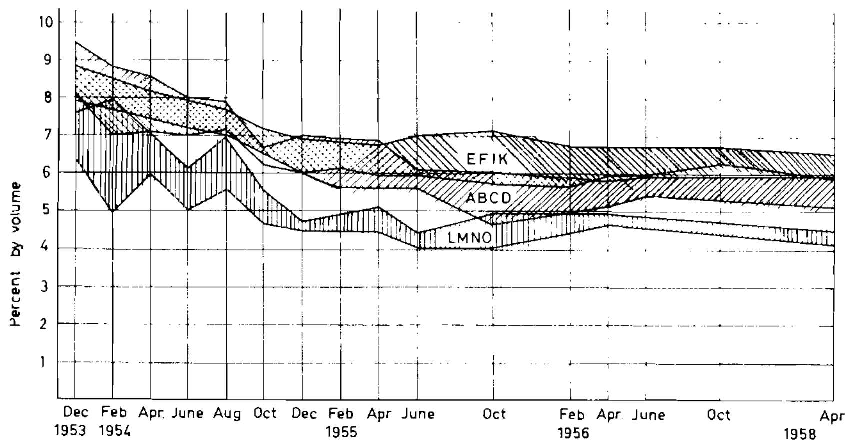


Fig. 5. Moisture content in concrete slabs.

The ventilation rate of the various panels

Measurements of wind speed in narrow ducts were carried out by Mr. B. G. Collins of the Building Research Station with staff members from the Swedish National Committee for Building Research and from the Norwegian Building Research Institute as attendants. The main results are presented in Fig. 6. In Fig. 7 the quantities of wind from various directions are quoted as a percentage of the total wind quantity for the years 1954, 1955 and 1956 (Voll Meteorological Station, Trondheim).

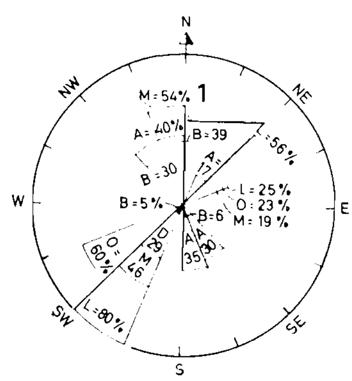


Fig. 6. Wind speed in all ducts expressed in percentage of free wind from certain directions. 1 = free wind speed.

The measurements had to be made during a relatively short period. The wind came only from the directions quoted here. We had no chances of making measurements in all panels at the same time when the wind came from one specific direction.

The air speeds in the big ducts are rather great compared with the small ducts. The difference is clearly visible for the south-southwestern directions. The other graph may give an impression of the wind directions in Trondheim. The sector south-southwest to west contains the greatest air speeds. The big ducts let through 60 times as much air as the smallest ones did.

The reason why panel M was obviously so much drier than panel B was the effective duct of the former panel. The drying-out of panel B might have been much improved if the duct had been deeper and narrower at the top. A more rigid "ceiling" covering the duct and a precise laying-out of the gas concrete blocks might lead to a better drying-out in panel B than in panel A. The ducts of A and B were propped after some of the borings and had to be opened.

The ducts of panels M and O were covered with 5 cm prefabricated concrete plates capable of carrying inspection traffic. Rigid 3 cm concrete blocks between gas concrete and the plates permitted a reasonable shifting of the gas concrete blocks.

Air temperature and vapour transport in ducts

In the Trondheim climate the differential of the vapour pressure from the room to the duct between thermal insulation and concrete slab might reach more than 10 mm of mercury near the openings. If the duct is too sparsely dimensioned, crevices and holes through the concrete slab lead the vapour from the room into the thermal insulation. This might have happened in panel D, where, unlike the situation in all other panels, the moisture

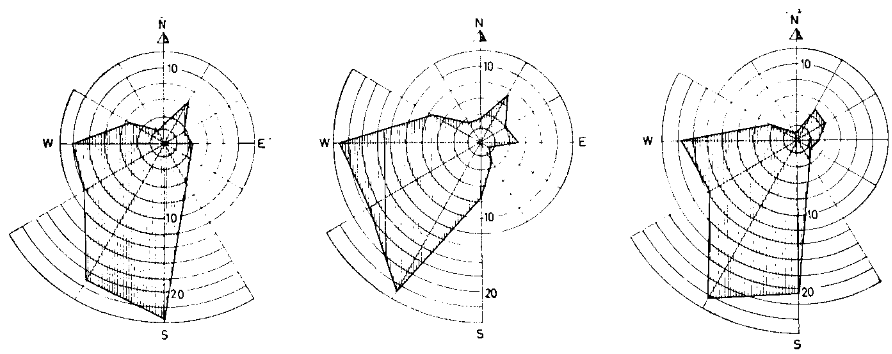


Fig. 7. Air quantities in percentage of the total from 12 directions in 1954, 1955 and 1956 based on observations at the Voll Meteorological Station, Trondheim.

content is higher near the openings than in the mid section. Results from the measurements of vapour content of the air in the duct of panel D show that the air is nearly saturated a few metres from the end facing the wind. Measurements in panel L, on the other hand, indicate a very effective ventilation with comparatively moist air occurring only in quiet weather.

In the duct between thermal insulation and screeding of panels M and O the vapour pressure, in the winter, is nearly the same as outside. It sometimes occurred that the ventilation air carried small amounts of vapour condensation to the lower side of the screeding. During the day the screeding reached a higher temperature, and the vapour transport was reversed.

Residual moisture-vapour diffusion in unventilated constructions with concrete slabs insulated on the top

Fig. 8 is an example of the condition in panel F on February 1, 1956, when air from the space between the gas concrete blocks was sucked off through Dehydrite filters. The gas concrete insulation contains, in this case, an average of 18.5 per cent. water by volume. Hygroscopic saturation for this type of gas concrete, according to Swedish investigations, is reached at about 3.5 per cent. by volume. The lower part of the removed samples, in the same group where air was sucked off, contained about 16 per cent. water by volume. Based on this, it could be assumed:

1. The air in the pores of the gas concrete is saturated with water vapour, including the

part situated closest to the concrete slab. Under the conditions measured, the vapour pressure is higher here than in the room below the concrete slab. It is, therefore, rather improbable that the water vapour can diffuse from the room up into the gas concrete insulation and accumulate there. Diffusion of water vapour can take place when the vapour pressure in the room is higher than that in the top surface of the concrete slab, or when water vapour from the room is condensed in or on the underside of the concrete slab. In our case, such a condensation could not take place.

2. It has not been possible to ascertain any drying-out in the construction.

3. From 1 and 2 it follows that it is the moisture content from the construction period which moves up and down in the construction according to the seasons.

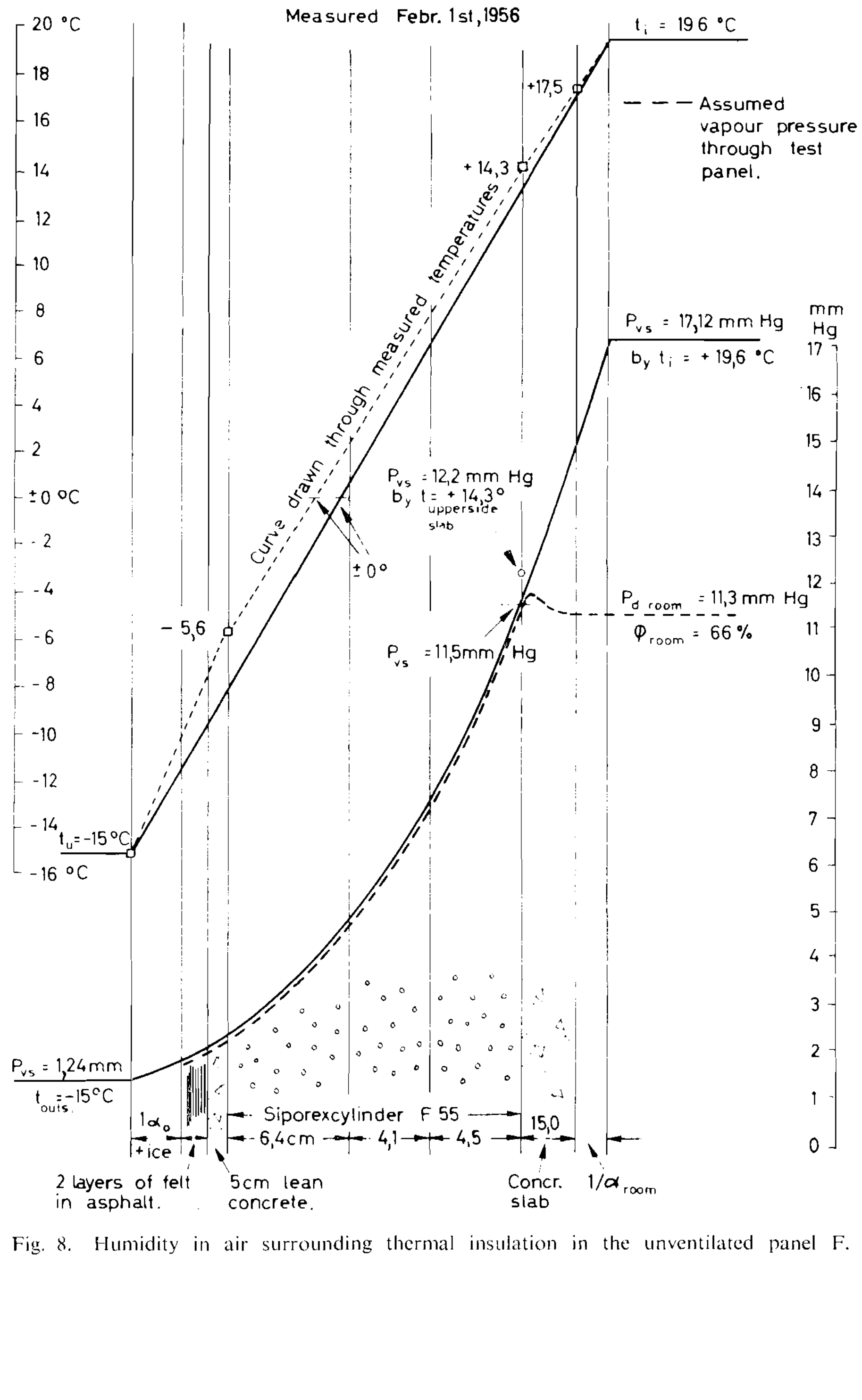


Fig. 8. Humidity in air surrounding thermal insulation in the unventilated panel F.

Heat loss through the panels

The results are presented in Table I.

Remarks: The theoretical heat transmission coefficients are based on the thermal conductivity of the water content in the panels. Ventilation effects, snow insulation, etc., are not included. The measurements carried out in the winter 1956–1957 are not complete, as the lack of recorders and other equipment made it impossible to investigate all panels at the same time. But the results are rather instructive and, therefore, have been quoted here.

Unventilated constructions. – The results of the measurements are rather similar to the theoretically estimated values based on a known water content. The panels F and J let through 30–40% more heat than allowed by to the Norwegian Building Regulations. The measurements were, however, carried out during an unusually mild winter with snow covering the panels during a great part of the test period.

TABLE I

THEORETICAL AND MEASURED HEAT TRANSMISSION COEFFICIENTS IN PANELS

Panel section		*Dec 1953 (kcal/m²h° C)*		*Mean results (Fall, '56) (kcal/m²h° C)*		*Calculated values 4% vol. (Bldg Code) (kcal/m²h° C)*	*Mean results (Winter, '56–'57) (kcal/m²h° C)*	*Mean results all measurements (kcal/m²h° C)*	*Remarks*
E		1.11		1.11		0.75	Not measured		
F		1.10		1.04		0.75	0.97		
J		1.19		1.12		0.75	1.05		
K		1.15		1.05		0.75	Not measured		
G		0.99		June, '56 0.98		0.82	Not measured		
H		0.97		0.98		0.82	0.83		
A	North	0.97		0.72			0.87		Panel A, measured near openings in south and north, lacks some heat insulation along eastern side
	Mid	1.09	10.3	1.04	0.81	0.75	1.02	0.97	
	South	1.03		0.76			1.02		
B	North	1.08		1.04					
			1.13		1.09	0.75	Not measured		
	Mid	1.19		1.14					
C	Mid	1.15		1.04			0.94		
			1.11		0.98	0.75		0.93	
	South	1.08		0.92			0.92		
D	North	1.11		1.05			1.16		Panels C and D are measured 2 meters from the south end
	Mid	1.05	1.07	0.98	1.01	0.75	0.89	1.06	
	South	1.04		1.00			1.12		
L	North	0.86					0.96		
	Mid	0.83	0.84	0.65		0.75	0.82	1.18	
	South	0.82					1.77		
N	Mid	0.94					0.70		
			0.88	0.69		0.75		1.06	
	South	0.83					1.41		
M	North	0.69					0.87		
			0.75	0.65		0.75		0.77	
	Mid	0.81					0.67		
O	North	0.72					1.15		O lacks heat insulation along western side
	Mid	0.77	0.74	0.65		0.75	0.96	1.12	
	South	0.73					1.26		

The poorly ventilated panels. – The results are very close to the theoretically estimated values based on the actual water content. The measured heat flow through the panels is, however, from 24 to 41 % greater than allowed by to the Building Regulations.

The well ventilated panels. – All panels have a lower water content than foreseen in the Building Regulations. The cooling effect from ventilation in panels with the duct close to the concrete slab is clearly visible, especially near the openings facing the wind. The panels L and N have a heat flow 41 to 57% greater than that allowed by the Building Regulations. If the measured values are compared with the theoretical ones from 1956, the ventilation seems to increase the heat flow through the panels. The increase was for

Panel L = 81 %
Panel N = 49 %
Panel M = 18 %

The constructions might be improved near the openings of the ducts. A blanket of mineral wool should be placed on top of the concrete slab. This improvement would not prevent a cooling down of the inner part of the panel, and in this way the duct would only be moved higher up in the thermal insulation.

The results seem to point out that the correct location of the duct is in the upper part of or above the thermal insulation.

It is very difficult to construct roofs like M and O. The drying-out results, however, make it evident that the duct may be much smaller than here.

ACTUAL ROOFS

The investigations were carried out during spring or summer of 1950, 1951, 1955 and 1956. Samples were bored out on about 100 roofs. The moisture content was measured in different thermal insulations used over rooms with varying climate, from apartments to paper mills.

The main impression after the investigation is that designers have no clear understanding of the great quantity of water which is usually trapped in their constructions. Owners and designers are usually shocked when, for the first time, they are confronted with damages like blisters, ridges, cracks and bleedings in the inspected roofings.

Some thermal insulation materials are used in constructions where destructive processes are to be expected. Shredded wool slabs, for instance, have collapsed in nearly all inspected roofs where they were sandwiched between two layers of concrete.

The high moisture content is caused by rain, splash, bad storing of materials and, last but not least, the thermal insulation materials being far from dry when they are delivered at the construction site. After the first investigations from 1950 to 1951, Mr. Prestrud, in the NBRI Report No. 4, emphasized the necessity of using tarpaulins or tented roofs during the period of roof construction. It seems to be very difficult, however, to convince the owners of this fact.

CONCLUSIONS FROM INVESTIGATIONS OF ACTUAL ROOFS

1. Roofs without thermal insulation, in our climate, are an impossible construction over heated rooms. The strain of the roofing will be too hard because of temperature movements in the concrete slab and freezing of condensation water.

2. Pumice and slag used in unventilated constructions have not proved to be satisfactory.

3. Expanded cork slabs have kept their quality when the vapour barrier of asphalt is carefully pasted on top of the concrete slab. When the roofing was put on in dry, warm weather or under tented roofs, etc., the roofs inspected served well.

4. The ventilation rate is usually too small, especially when the thermal insulation consists of airtight materials like light-weight concrete.

5. Structural unventilated slabs of light-weight concrete are too often used over hot and damp rooms. The water content, in the worst cases, is 5–6 times as high as foreseen in the Norwegian Building Regulations.

6. Ventilated gravel layers of light-weight concrete have been investigated on a very small number of roofs. The roofs were wet because of wrong grading of the granules: a great mass of very small sized granules made the layers too airtight.

7. Macadam roofs where the thermal insulation was ventilated on top or on the lower edge were rather dry. The grading varied between 10 and 20 mm in the macadam layer. Normally, the openings to the free air had a good design. The wood wool slabs kept their consistency in this type of roof.

8. Our roofings, normally consisting of two layers of asphalt felt brushed with hot asphalt, seem to be too weak, as the strain will frequently be too hard in our climate. Experience in America and Canada has shown that a roofing consisting of 3–4 layers of pliable felt mopped in hot asphalt and protected on top with a gravel layer, is much to be preferred. A great number of roofing damages, especially blisters, are due to poor workmanship in pasting the asphalt felts. Here our experience is in line with that of Mr. Hanson.

9. Most roofs will probably serve well without damage or leakage when the thermal insulation and the roofing are put on dry. It is absolutely necessary to make propaganda for the use of tented roofs or permanent covers, especially because the Norwegian roofs are normally finished in the autumn or in the early winter.

10. Maintenance is usually totally neglected.

ARCHITECTURAL DATA SHEETS

To make the results from the research more widely known, the Norwegian Building Research Institute has prepared a loose-leaf series of so-called Architectural Data Sheets (Byggdetailj-blad). The sheets dealing with flat roof constructions can be bought by everyone and used without a great deal of special technical knowledge. The general sheet, NBI (26).001, has been translated into English and is presented as an appendix. From this data sheet may be seen the practical conclusions from the investigations.

So far, six sheets about flat, compact roofs, two sheets about double roofs, three about roof terraces and two about roofing of flat roofs have been printed. The sheets will be kept up to date, and it is hoped that they will improve the planning and construction of flat roofs in Norway.

REFERENCES

British Standards Institution, *Mastic asphalt roofing*, London, 1952, 47 pp., illus. (British Standard Code of Practice, 144.201).

Chlusov, I. E., *Om beregning av fuktighet i flate takkonstruksjoner* (Determination of moisture in flat roof constructions), Moscow, 1958, 20 pp., illus. (translated into Norwegian from Russian).

Croiset, M., *Condensation sous les couvertures autoportantes en aluminium*, Cahiers du Centre Scientifique et Technique du Bâtiment, Paris, 1958, no. 31, Cahier 259, pp. 6–15, illus.

Eichler, F., Das konstruktive Flachdach: Bauregeln, Baufehler, *Technik (Berlin)*, 1956, 228 pp., illus.

Hanson, R., *Calculation of moisture content of exterior walls and roofs*, Stockholm, 1958, 16 pp.

Moisture characteristics of lightweight concrete and brick, Stockholm, 1958, 14 pp.

Papptak, klistrade dubbeltäckningar (Felt-covered roofs; glued double coverings), Stockholm, 1954, 24 pp., illus. (The Swedish State Committee for Building Research, Brochure 7.)

Takterrasser, vattenisolering och beläggning (Flat roofs, waterproofing and covering), to be published as a pamphlet by the Swedish State Committee for Building Research.

Holmgren, J. and T. Isaksen, *Ventilated and unventilated flat, compact roofs*, Oslo, 1959, about 140 pp., illus. (Norwegian Building Research Institute, Report 27.)

Lund, C. E. and R. M. Granum, *Principles affecting insulated built-up roofs*, Minneapolis, 1952, illus. (University of Minnesota, Institute of Technology, Engineering Experiment Station, Bulletin 34).

PRATT, A. W., *Condensation in sheeted roofs*, London, 1958, 40 pp. illus. (National Building Studies, Research Paper 23.)
PRESTRUD, K. K., *Massive tak. Noen forløpige undersøkelser of anvisninger* (Flat, compact roofs), Oslo, 1951, 36 pp., illus. (Norwegian Building Research Institute, Report 4.)
RICK, A. W., *Dachpappen*, Heidelberg, Chemie und Technik, 1956, 212, XVI pp., illus.
Ursachen, Vermeidung und Beseitigung von Wellen, Falten Blasen und anderen Mängeln bei der Eindeckung mit Dachpappe, Heidelberg, Chemie und Technik, 1957, 51 pp.

APPENDIX

(26) Compact roofs	.0 General	COMPACT ROOFS Ventilation and Heat Insulation	NBI(26).001

0 GENERAL INFORMATION

01 This sheet has been prepared on the basis of experiences from actual houses and from roof laboratories. Experience has shown that it is necessary to ventilate the majority of compact roofs. Structural roof sections of reinforced gas concrete can be used without ventilation with the following reservations:

1 The sections should be as dry as possible, *i.e.* they should be protected against moisture during storage and construction.
2 There should be no vapour-proof barrier between the sections and the room air (diffusion-tight pane, for example).
3 The heat insulation of the roof should be sufficient to prevent any condensation at any time on the underside of the roof.
4 The water vapour pressure in the room under the roof should never be higher than 9 mm Hg.

02 This sheet is mainly concerned with roofs over heated buildings. The roofs for other types of buildings, especially for cold storage houses, etc., should be designed completely different from the methods shown here.

03 Moisture in the insulation may be due to

1 Construction moisture.
Those factors which are decisive for the degree of construction moisture are:
The moisture content in the materials when they arrive from the factories; the degree to which the materials absorb moisture or dry out during storage on the building site; the climatic conditions during the construction period, particularly if the construction method requires a supply of moisture, as, for instance in pouring concrete *in situ*.
2 Leakage in the roofing.
For construction methods and quality of roofing, see NBI (47).301.
3 Condensation of water vapour from the interior.
Decisive factors are the humidity of the air under the roof, to what degree this moisture can penetrate into the materials in the roof and the ability of those materials to get rid of the moisture.

These factors should be considered when deciding the requirements for the ventilation.

04 When the moisture is to be removed by ventilation of the insulation, the design of the ventilation system will depend upon:

1 The temperature and humidity of the air outside and the temperature and moisture content in the roof itself.
2 The wind conditions on the building site.
3 The location of the roof with respect to the prevailing wind directions,

terrain and neighbouring buildings.

4 Location of ventilation openings to the open air.

5 Dimensions of openings and ducts.

05 Some of the ventilation systems for compact roofs most frequently used today are:

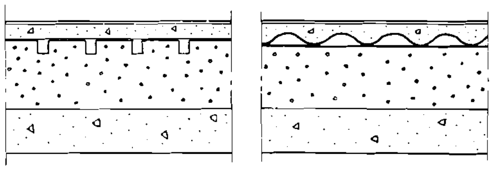


Fig. 05a. Light-weight concrete poured directly on the roof construction with small ducts or grooves for ventilation, or with corrugated sheets forming the ducts.

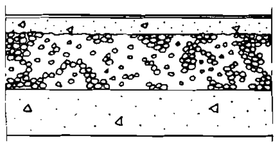


Fig. 05b. Light-weight (heat insulating) gravel with grains coarse enough to let the ventilation air through.

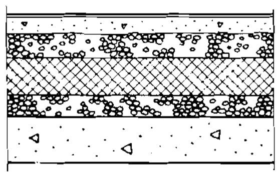


Fig. 05c. Gravel macadam roof with ventilated gravel section on structural concrete slab; then a heat insulating material and another ventilated gravel section on the top of this (patented design).

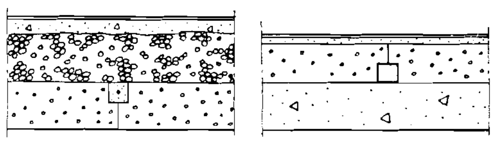


Fig. 05d. Roof sections of light-weight concrete with small ducts in the elements or otherwise ventilated, and concrete slab with light-weight concrete insulation with ducts or grooves for ventilation.

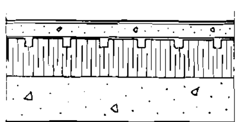


Fig. 05e. Expanded cork, shredded wool slabs, etc., with grooves for ventilation. The grooves could be in top of the insulation or they could be covered with a thinner section of the same insulation material.

1 DESIGN AND CONSTRUCTION

11 As an aid in calculation of the size of the ventilation ducts, the ratio O/A is used, where O is the total area of the pores, grooves or ducts through which the air passes, and A the area of the roof surface served by these ducts. If the total area O is found to be too small by calculations, then O has to be made larger so that larger amounts of air may pass through, or the lengths of the ducts between the openings to the open air have to be made shorter. This can be done by introducing ventilation stacks, which will also reduce the roof area A.

12 Below O/A are listed four different types of material. The factors to be considered are mentioned in 02 and 03 and will, for a great part, have to be estimated within wide limits.

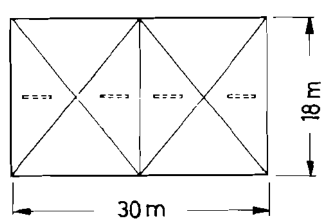
.1 Light-weight concrete
O/A = 1/500–1/1000

.2 Light-weight (heat insulation) gravel
O/A = 1/500–1/1500

.3 Expanded cork, shredded wood slabs, etc.
O/A = 1/1000–1/2000

.4 Mineral wool O/A = 1/2000

Calculation example:



As an example, a comparatively wide house and a material which requires a high degree of ventilation have been chosen:

O/A = 1/500. Area of roof surface: 3000 × 1800 = 5,400,000 cm².

(a) Openings to the open air only on the longer sides of the house:

The sum of the areas of the primary ducts has to be:

$$\frac{5{,}400{,}000}{500} = 10{,}800 \text{ cm}^2$$

e.g. per running metre cross section of the roof

$$O = \frac{10{,}800}{30} = 360 \text{ cm}^2$$

The primary ducts per running metre cross section of the roof should be one of 60 × 6 cm, two of 36 × 5 cm, four of 15 × 6 cm, etc., depending upon the number and the shape of the ducts that are preferred. If it is impossible to make the ducts so large, it will be necessary to arrange openings to free air on the roof; for instance, by means of ventilation stacks.

(b) Openings to free air on the longer sides of the house and through stacks in the centre of the roof: $O/A = 1/500$.
Areas of roof surface:
3000 × 900 = 2,700,000 cm².
Primary ducts per running metre cross section of roof:

$$\frac{2{,}700{,}000}{500.30} = 180 \text{ cm}^2$$

which is divided in suitable cross section areas of primary ducts; for instance, ten of ten 3 × 6 cm. Dimensions, location and construction of openings to the free air are made according to the rules in 14, 15, 16, 17 and 18.

13 The most important parts of the ventilation system discussed here are shown in Fig. 13.

14 Primary ducts

141 Primary ducts are those pores, grooves or ducts in or above the heat insulation material where the moisture in the material is given off to the air. The centre distance should be short, 10–15 cm, for instance, in materials where the diffusion resistance is high and the capillary action low. The centre distance can be increased in diffusion open materials and in materials with a high capillary action. In a gravel section the air spaces between the grains form the primary ducts.

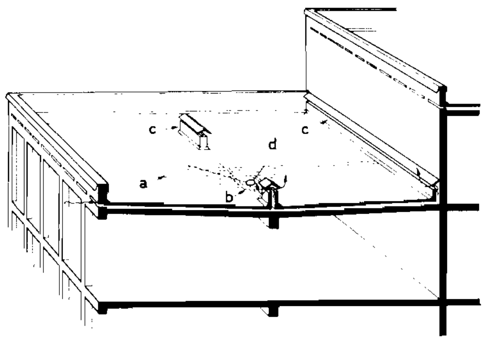


Fig. 13. Ventilation system: a – primary ducts, b – collecting ducts, c – ventilation stacks, d – rain gutter.

142 When ventilation is planned, due consideration should be taken of the prevailing wind directions at the building site and the primary ducts arranged so that they run parallel to their wind direction.

143 The primary ducts should be located over the heat insulating material or as high up in the material as possible. This is because the moisture usually accumulates under the roofing material, and because ducts located under the heat insulation may form cold bridges and lead to subsequent damages. In a gravel section the air will be distributed over the whole section and concentrated cooling-down will only take place near the ventilation openings.

When the primary ducts are over or high up in the heat insulation, the heat insulating capacity of the roof will be reduced from 2 to 15 per cent., depending upon the conditions. The insulation should be made correspondingly thicker.

144 The ducts must have a cross section of

at least 6 cm^2 to give effective ventilation. This is not the case when gravel is used, as the air openings between the grains act together.

15 Collecting ducts

151 The collecting ducts connect the primary ducts with the open air through openings. Along cornices, between ventilation stacks, around drains, skylights, substructures, etc., collecting ducts may be necessary (see Fig. 151).

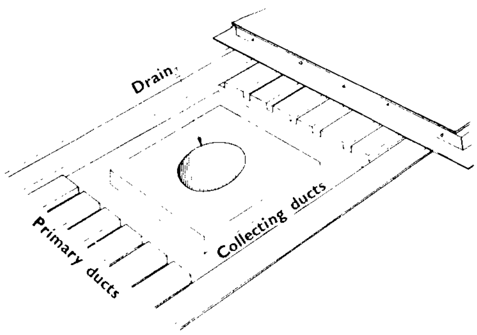


Fig. 151. Collecting ducts around a drain connect the primary ducts with each other.

152 If a duct with a limited cross section is filled with gravel, the effective cross section of the duct will be approximately equal to the openings between the gravel grains.

153 The cross section of the collecting ducts has to be equal to or larger than the sum of the cross sections of the primary ducts they serve.

To secure a good distribution of the air, the distance between the openings of the collecting ducts to the open air should not exceed two metres.

16 Ventilation openings in the wall.

161 Ventilation openings in exterior walls give the most effective ventilation because of the increased pressure on the wind side of the building and the diminished air pressure on the lee side. The air is thus forced through the ducts. The wall openings should, as far as it is possible, be on the same level as the primary ducts (Fig. 161, a and b).

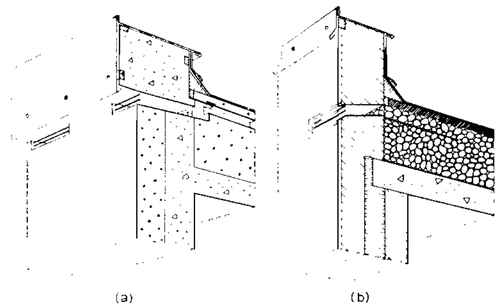


Fig. 161. Examples of ventilation openings in a wall.

162 Openings in the walls should have a net cross section area at least equal to the sum of the cross sections of the primary ducts that they serve. The distance between them should not be more than two metres.

163 Ventilation openings in the walls should be arranged so they have a decline down toward the louver. The bottom should be trowelled smoothly, impregnated against moisture or flashed.

164 Wall openings through concrete or other types of material with inferior heat insulation should, if possible, be specially heat-insulated to prevent cold bridges.

165 The louvers should be made of material with good corrosion resistance. Louvers for façades that are not rendered should have claws embedded in the concrete or the masonry.

166 In districts with heavy wind and snow, there is a risk that snow can be forced into the ventilation system and supply moisture. This can be prevented to a certain degree by providing an air chamber between the wall opening and the ventilation system. The velocity of the air will be reduced in passing the chamber and the snow will settle. Fig. 166 shows the principle.

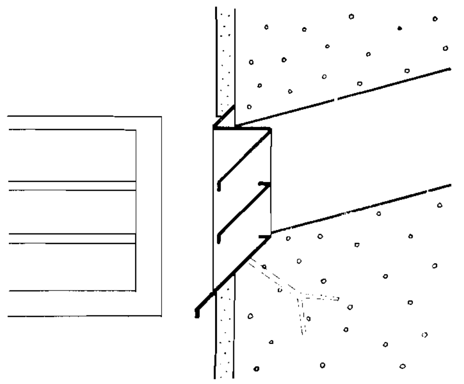


Fig. 165. An ordinary type of opening for less severe climates.

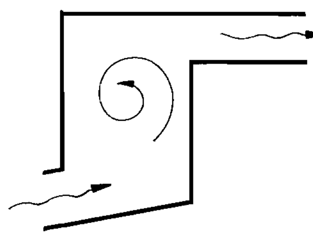


Fig. 166. An air chamber between the wall opening and ventilation system could possibly solve the problem of wind and snow.

17 Ventilation stacks.

171 Ventilation stacks are frequently necessary when the primary ducts are long and have small cross sections or when the roof is joining a higher wall on one or more sides.

172 Ventilation through stacks is less effective than through wall openings; the volume of air passing through a stack is only 20–50 per cent. of that passing through wall openings, depending upon their location on the roof, the shape of the roof, etc. The stacks should, therefore, have a cross section opening that is five times that of the total cross section of the primary ducts that they serve.

173 The height of the ducts must be determined according to the amount of snow on the building site and should always be tall enough to prevent them from being buried in the snow. The stacks should be heat-insulated, the moisture in the return air will otherwise condense on the walls of the stacks and drip back into the insulation. The stack cover should be lined on the underside with a moisture absorbing material.

174 Stacks should be constructed as shown on Fig. 174 (a, b, c and d). Wood used for the construction of stacks should be fully impregnated. The stack top and sides should be covered with galvanized steel sheets painted with a rust-protective paint, unless a better construction is preferred.

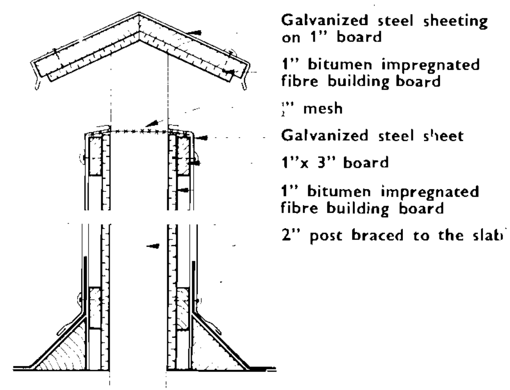


Fig. 174a. An air chamber between the wall opening and ventilation system could possibly solve the problem with wind and snow.

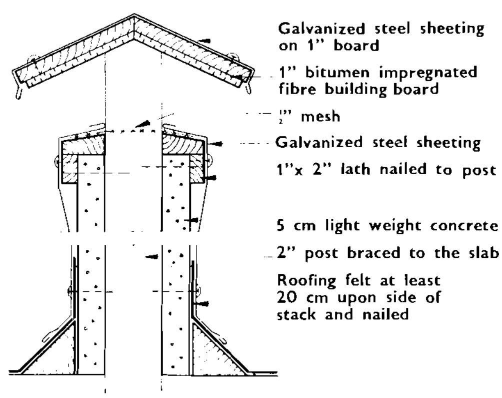


Fig. 174b. Stack insulated with light-weight concrete blocks.

18 Other ventilation possibilities.

181 If ventilation stacks already exist on the roof for other purposes, they should, as far as possible, be used for the ventilation of the roof also. Stacks

of this type give a much more effective ventilation than the low ventilation stacks.

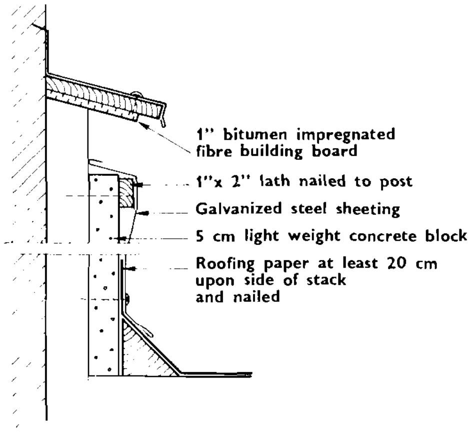


Fig. 174c. Stack along wall against neighbouring building.

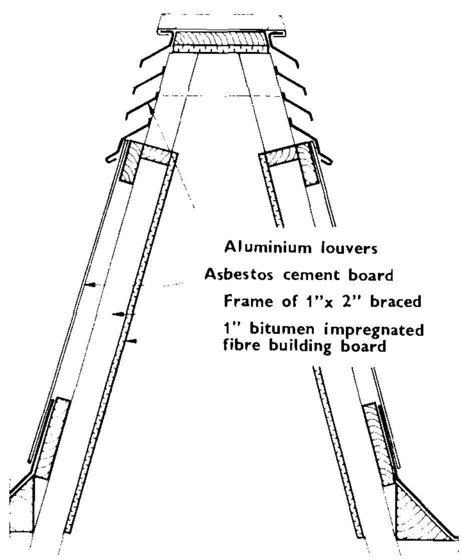


Fig. 174d. The shape of the stacks can be varied on roof terraces either for aesthetic or other reasons, as shown in this figure.

182 When possible, lead the collecting ducts into a taller, heated neighbouring building and into a stack built on the roof, an effective buoyancy ventilation will result (Fig. 182). If the ventilation ducts are led through heated rooms, they have to be insulated if condensation is to be avoided.

183 Under particularly difficult conditions, it might be necessary to have a permanent mechanical ventilation of the roof. If the ventilation air is preheated, it must not contain any moisture at all to prevent condensation in the roof when it is cooled off. Roofs with a suspended ceiling where fresh air is led in between the ceiling and the roof

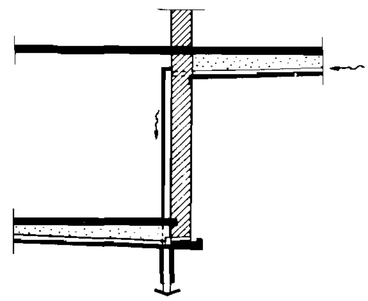


Fig. 182. Principle of buoyancy ventilation through taller, heated neighbouring building.

construction and from there into the room (see Fig. 183), have proved to dry out the construction sufficiently, even under very difficult conditions.

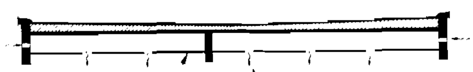


Fig. 183. Supply of fresh air above suspended ceiling.

184 Mechanical ventilation for drying out the construction moisture can, in some cases, be arranged by connecting the duct system in the roof with the ventilation system of the building. Another possibility for a quick drying out is to make the dimensions of the duct system too big and then close up some of the openings when the construction moisture has been removed.

2 HEAT INSULATION OF ROOFS

21 The Building Code of 1949 lists the minimum requirements for heat insulation of roofs over heated rooms, according to the different climate zones (see Fig. 21). Within each cli-

matezone distinctions are made among three categories of buildings:

(a) Dwellings, hotels, office buildings, schools, etc.

(b) Hospitals, old people's homes, nursing homes.

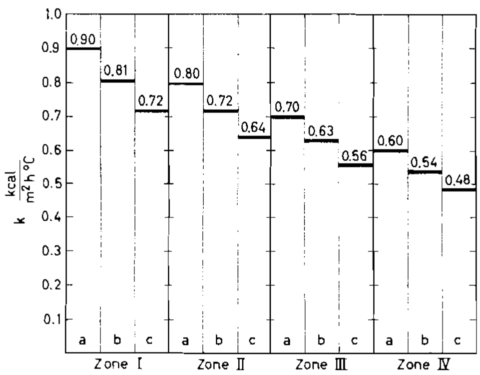


Fig. 21. The Building Code's minimum requirements for the heat insulation of roofs. a — dwellings, office buildings, schools, etc.; b — hospitals, old people's homes, etc.; c — bathing institutions.

(c) Bathing institutions with temperatures above about 20° C.

The requirements are listed for category (a). For category (b) the Building Council can decide that the *k*-values be reduced by 10 per cent. and for category (c) by 20 per cent.

It should be noted that the requirements are minimum requirements. It is economical to insulate better than the Building Code requires.

3 LITERATURE

31 KR. K. PRESTRUD, *Massive Tak*, N.B.I. report No. 4, 1951, 32 pp.

32 J. HOLMGREN AND T. ISAKSEN, *Ventilated and unventilated flat, compact roofs*, N.B.I. report (under trykking).

Deterioration of flat roof coverings: Experience from field investigations

UDC 69.024.3 : 69.059.2

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THE PROBLEMS IN SWEDEN

Flat roofs are becoming more and more common in a large part of the world. This development has been made possible by the discovery at the end of the 19th century that it was possible to construct a waterproof covering at moderate cost with the help of tar or bitumen. Since that time technique has progressed and new materials have been developed, but coal-tar pitch and bitumen are still the predominant waterproofing substances used on flat roofs. Several types of plastic material have also been developed in the last few years.

However, as a result of the many unfortunate experiences that have been encountered with flat roofs, this development has slackened. The life span in many cases has not been as long as calculated. As a matter of fact, it was said in Sweden during the 1940s that flat roofs were not suitable in the severe climate there. For this reason, the Government Committee for Building Research put the problem of flat roofs on its programme. The investigation, which has been carried on by the author, has continued with varying degrees of intensity since that time.

The life span of flat roofs depends primarily upon how long the roofing material remains impervious, but also on general performance. The entrapped building moisture is also of considerable importance as well as, possibly, moisture from interstitial condensation. These factors are, to some extent, dependent upon each other but the problem of roof covering can be treated more successfully by itself.

A preliminary survey of flat roofs in Sweden has shown that if consideration is confined solely to those roofs which, from all points of view, are correctly constructed, the following life spans of the most common roofing materials can be expected: Self-finished roofing felts with a top layer of self-finished bitumen felt, about 20 years; mastic asphalt roofing, mastic asphalt which forms a finished surface on shaded roofs, more than 30 years; protected built-up roofing, 2–5 layers of roofing felt alternating with bitumen or coal-tar pitch, more than 30 years.

The life spans given above may be considered to cover the demands placed upon a roofing material. The long life depends primarily upon the fact that coal-tar pitch and bitumen are very stable if protected from solar radiation, which causes rapid deterioration. Of considerable importance also is the fact that less stable materials, such as textile and animal fibres, become sufficiently stable if they are completely enclosed by thick tar or bitumen layers.

The problem of flat roofs has arisen because all too many of them have been improperly constructed. As the following discussion shows, about 15 per cent. of the self-finished roofs, about 50 per cent. of the mastic asphalt roofs, and even 50 per cent. of those having protected built-up roofs in Sweden have been faultily constructed.

The goal of Swedish research has been primarily to offer advice and instruction on avoiding the most common failures of the different types of roof. On the other hand, no attempt has been made to develop new types of flat roofs. Swedish investigations have been limited to studies of older roofs and detailed work on the restoration of damaged roofs, as well as to supplement this work by investigations on new roofs. No laboratory work has been done. Experiences encountered in the investigations have been presented in, among others, two pamphlets issued by the Building Research Committee: *Papptak* (self-finished felt roofing) [3] and *Takterrasser* (roof terraces) [5], the latter of which is currently in the press. In the following sections, a concise account of the general survey of older roofs is presented first, followed by a brief survey of the more detailed studies made on various types of roofing materials. In connection with the latter, an account is given of the methods of investigation as well as of the most common mistakes in roof construction and ways of avoiding them.

SURVEY OF OLDER ROOFS

In the early part of the 1950s, the author made a survey of 280 flat roofs in various parts of Sweden [1]. He also obtained data from surveys made by four different materials manufacturers. These investigations involved 166 roofs. Approximately 20 roofs were included in more than one of these surveys. The total roof surface area investigated was approximately 600,000 m^2.

The roofs investigated were chosen completely at random. Nevertheless, it is possible that the investigator was subconsciously directed towards deficient roofs.

SUPERFICIAL INVESTIGATIONS

Observations have been primarily confined to visible parts of roofs. Furthermore, general relations, such as the construction and age of the roof as well as the nature of the underlying area, have been noted. No precise conception of the relationships involved in the interior of the various types of roof construction has been obtainable. In many cases the various types of roof construction have been so new that observations cannot be considered to have given definite results.

DETAILED INVESTIGATIONS

More detailed observations were made in some cases (in connection with the superficial investigations) on different types of damage on various parts of the roofs. These injuries should yield a positive clue in the search for the main cause of deterioration in specific cases. Comprehensive moisture sampling of the thermal insulation of the roofs has also been made.

The roofs that were to be investigated more thoroughly were selected with regard to the particular questions which were to be examined. Some of the roofs, among them newly built ones, have been studied continuously.

TREATMENT OF THE MATERIAL INVESTIGATED

On the basis of the material which has been assembled, efforts have been made to ascertain the frequency of unsuccessful cases in different types of construction, and the causes of failure.

Characteristics of unsuccessful roofs

The material used in constructing a roof and, particularly, the material used in the waterproofing layer deteriorate more or less slowly. A roof can thus be said to have a certain life span, and if it has required substantial repair before this period expires, it can be considered to have been unsuccessful. The life span of a self-finished roof has been assumed to be 20 years, that of other roofs 30 years.

In the course of the present investigation, roofs which were repaired or stood in great need of repair at a time before their stated age expectancies, were considered unsuccessful. A roof was considered in need of repair if moisture periodically penetrated through the ceiling in the form of water droplets or water marks.

In concrete roofs the point of origin of moisture penetration is almost always revealed by permanent spots in the form of salt efflorescence, mould or blistered paint. Cellular concrete roofs seldom have moisture spots, as a result of which the information gathered in these cases was obtained from persons who lived there.

Roofs which had surpassed their calculated life spans were judged possibly deficient with reference to the moment when moisture penetration first appeared.

Causes of failure

Moisture spots, etc., have four main causes, *viz*.

Leaks in the waterproofing layer.
Leaks in various general features.
Entrapped moisture.
Diffusion of moisture from inside.

Leaks in the waterproofing layer

Leaks in the waterproofing layer usually cause considerable dripping from the ceiling when it is raining or when snow melts. In the case of cellular concrete or wooden roofs, the dripping always forms directly under the injury in the roof. On the other hand, it is possible in the case of concrete roofs that the dripping develops at some distance from the damage. The existence of leakage can easily be established in self-finished felt roofs and mastic asphalt roofs. The cause is more difficult to isolate in protected built-up roofs.

Leaks in various general features

Leaks in various features, such as roof lights and upstands, also cause considerable dripping in connection with rain and melting snow. Dripping usually occurs directly below, or near the leak.

Entrapped moisture

Entrapped moisture in concrete roofs can give rise to moisture spots, especially in the early years. In the spring and late summer it can also cause leakage of limited proportions. The moisture actually seeps through along connected passageways. Entrapped moisture seldom leaves any noticeable marks on cellular concrete and wooden roofs.

Diffused moisture

Condensation of moisture may occur in the roof, under the waterproofing layer and within the roofing material. In damp localities and during the cold parts of the year, water vapour can condense under the roof covering in sections where the thermal insulation is poor. Considerable dampness may then occur.

Condensation under the waterproofing layer or within the roofing material can give rise to a high moisture content in the construction and even moisture seepage. This occurs, above all, in roofs with air spaces. Constructions lacking air spaces seldom contain signs of moisture seepage. That entrapped moisture or diffused moisture is responsible for moisture seepage has been revealed by samples taken from the thermal insulation of the roofs.

COMPARISON OF DIFFERENT TYPES OF CONSTRUCTION

The material which has been collected and studied has yielded information about whether each individual roof could be thought to be successful or not and on the main causes of possible failures. To make a proper statistical comparison of different construction types is not possible, as the assembled material is too inadequate with regard to the many factors that influence them. In regard to age, particularly, it is only traditional construction that can present, statistically, a fairly correct picture. Table I shows the connection between the various construction types and common causes of failure among traditional roof types. The five main types accounted for are relatively homogeneous and those variations which do occur probably lack significance.

TABLE I

NUMERICAL DISTRIBUTION OF SOME DIFFERENT KINDS OF FAILURES IN INVESTIGATED ROOFS

	Mastic asphalt coverings	*Concrete roofs* *With protected built-up roofing*	*Concrete roofs* *With self-finished felt roofing*	*Cellular concrete roofs with self-finished felt roofing*	*Wood roofs with self-finished felt roofing*
Total investigated	28	32	70	205	21
Total unsuccessful	14	17	13	29	5
Failure owing to:					
Leaks in waterproofing	7	10	11	16	2
Entrapped moisture	0	4	6	2	0
Diffused moisture	0	0	0	18	3
Leaks in particular features	9	6	3	4	0

In order to determine how well the table figures agree with reality, it is necessary to know the age of the roofs investigated and how their respective deficiencies were distributed among the various age groups. A closer examination of the material reveals that serious damage to a roof commonly occurs as early as during the first year. The percentage of roofs seriously damaged in the first 0–3 years is approximately the same in the sampled roofs as in older roofs. Many of the roofs investigated were, however, relatively new and the possibility exists that damage may occur later but prior to the end of the calculated life span. Thus, the actual number of unsatisfactory roofs should be larger than that indicated by the investigation. For reasons enumerated above, the investigation can be considered to have included more unsatisfactory cases than exist in actual distribution. It may be assumed, therefore, that the frequency of unsatisfactory roofs found compares with reality.

INVESTIGATIONS OF SELF-FINISHED FELT ROOFING

COMMON DEFECTS

A self-finished roof is exposed to considerable strain – both climatic and mechanical – which eventually damages the material. Among other things, the ultra-violet sun rays cause deterioration of the bitumen, so that after 15–20 years raw paper fibres are exposed and the material becomes non-watertight. However, other defects can occur much earlier.

Such serious defects include holes, tears, ruptures, wrinkles, blisters and improperly installed general features (*e.g.* improperly installed pipes). It sometimes happens that the uppermost bitumen layer swells and falls away.

The frequency of damaged roofs and types of injuries are shown in Figs. 1–7 [2, 3]. The manner in which injuries occur and their explanation is also discussed.

The materials which are used – primarily roofing felt – have, with very few exceptions, exhibited an ability to resist normal mechanical and climatic strain in a satisfactory manner. Holes and tears are caused in most cases by insufficiently strong roof decks, particularly porous wallboards. Such material is, therefore, seldom used now and damage of this type is now less common. Cases like these are not included in Fig. 1. Most roofs have been damaged by ruptures which are caused by movements in the deck and by wrinkles resulting from defective attachment between the bottom felt layer and the deck.

Movement in the roof deck (cracks as small as 1 mm in breadth can cause a well-mopped roofing felt to rupture) is caused either by unsuitable roof construction or by carelessness in its execution. In order that felt roofing shall be durable, the deck must form, to the greatest extent possible, a stationary unit. This requirement is fulfilled almost without exception by reinforced concrete roofs if there is no smoothing layer over the thermal

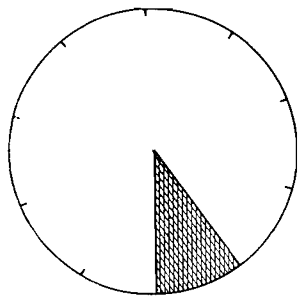


Fig. 1. Method of indicating proportionally the frequency of particular damages (see Figs. 2–17).

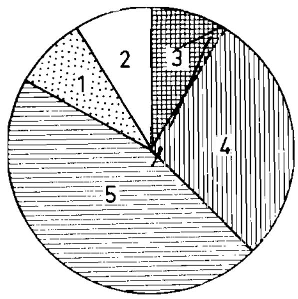


Fig. 2. Frequency of various types of damage. 1 blisters, 2 other injuries, 3 holes and tears, 4 ruptures, 5 wrinkles. Examples of these types of damage are Figs. 3–7.

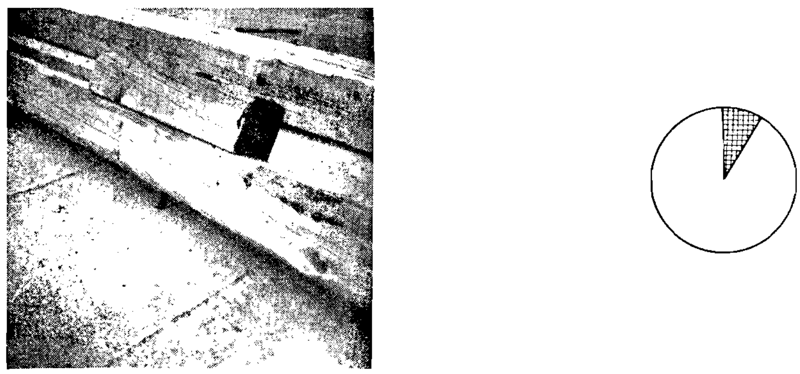


Fig. 3.

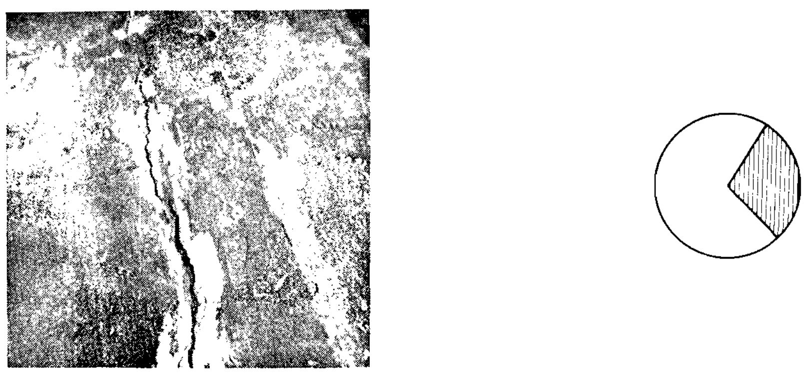


Fig. 4.

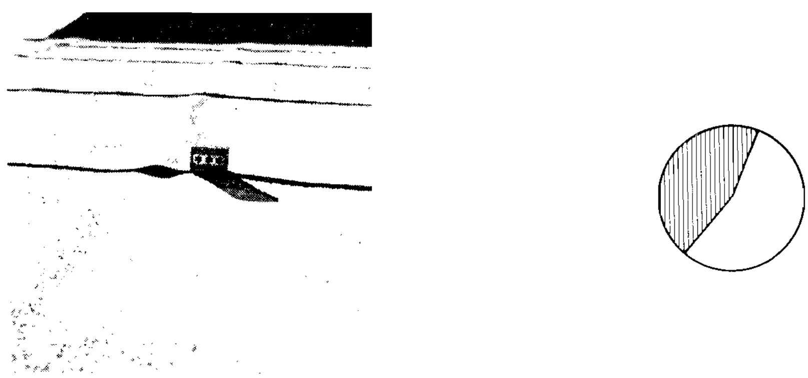
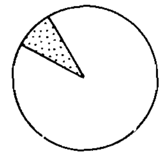


Fig. 5.



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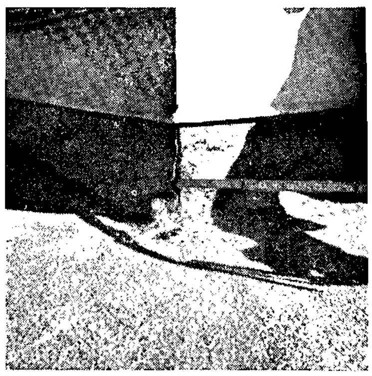

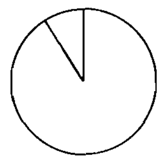

Fig. 7.

insulation layer. The risk of cracks along the cross joints arises in roofs made of cellular concrete slabs.

Poor attachment between the roofing felt and deck is often the fault of the roofing man. However, the cause may be an insufficiently firm deck (for example, it may become frozen and split) or it may be due to an insufficiently smooth deck. The time of year and weather conditions at the time when the roofing felt was mopped are also of considerable importance.

MEANS OF AVOIDING THE COMMON CAUSES OF DAMAGE

The inventory of various types of damage, which is explained in Figs. 1–7, shows that adequate attachment to a stationary and hard roof deck is the most essential factor in achieving better results with felt roof coverings. In order to prevent the felt layers from separating from each other or from the deck, strong emphasis must be placed on mopping them with hot bitumen. The ideal is adhesion over the whole area. To achieve this in practice is, however, very difficult and one is compelled to reckon with some unmopped spots. Even such small spots can cause defects, particularly blisters. The risk of damage is imminent only in the case of large spots, particularly where they form coalescing units. They can then form incipient wrinkles, which are the most serious consequence of poor attachment.

INVESTIGATIONS OF MASTIC ASPHALT ROOFING

COMMON DEFECTS

The investigation involved 45 mastic asphalt roofs (without protective coating). About half of these leaked [5]. Among the roofs protected from solar radiation (*i.e.* areas enclosed by buildings), only one in three leaked. The defects causing the leaks could be determined when the upper surface was examined.

Separation along joints

Separation along joints occurs easily at hollow glass block windows, entrance stairways and the like (Fig. 8). Mastic asphalt cannot adhere directly without attachment by skirtings to adjacent building walls.

Fifteen of a total of 23 leaking roofs had joint separations. Leaks can be sealed temporarily if the joint cracks are filled with caulking compound, preferably twice a year.

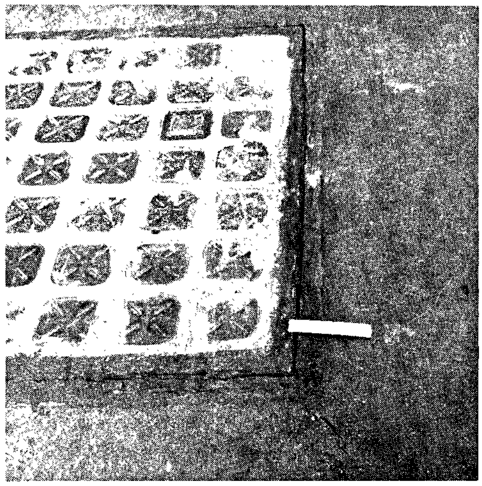

Fig. 8.

Fig. 9.

Ruptures

In cases where mastic asphalt is to serve both as a covering and waterproofing, it must be prepared with a very firm consistency. There is considerable risk that it will acquire cracks upon cooling (Fig. 9). Even if it is made softer, it will rupture easily if the deck cracks.

Eleven of 23 leaking roofs had ruptures.

Blisters

The strong daily temperature variation in mastic asphalt "pumps up" entrapped air unless the air comes in contact with a pressure-equalizing layer (Fig. 10). Roofs which are not exposed to sunlight or have a special protective coating over the mastic asphalt do not contain blisters.

Eighteen of a total of 45 roofs investigated contained blisters. Only in exceptional cases did they cause leaks.

Damaged upstands

Skirting of mastic asphalt should be protected from sunshine and so constructed that no serious damage occurs if they protrude several centimetres from the wall (Fig. 11).

Twenty of a total of 45 roofs contained more or less damaged skirtings. Only in exceptional cases did they cause leaks.

Through pores

Moisture in the under layer is vaporized when the warm liquid asphalt is spread, whereupon permanent pores are easily formed (Fig. 12). The risk is greatest in the case of thin mastic asphalt layers 10–12 mm thick. Pores have not been noted in the old-fashioned type of mastic asphalt layers, which are much thicker, but on the other hand, they have been found in the modern thin waterproofing layers.

MEANS OF AVOIDING THE COMMON CAUSES OF DAMAGE

If unprotected mastic asphalt is subjected to sunshine, it should not be used in Sweden or in other places having temperature variations greater than, for example, London and Paris. Experiences in countries with milder climates are quite satisfactory.

Fig. 10.

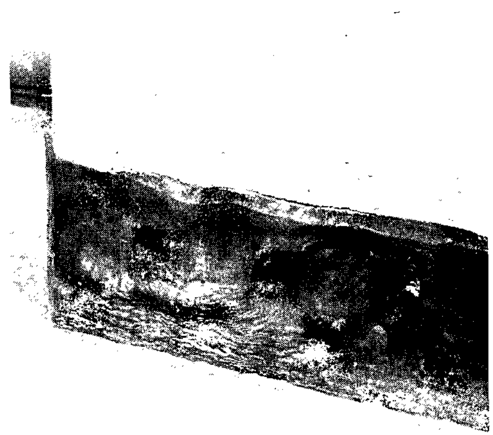

Fig. 11.

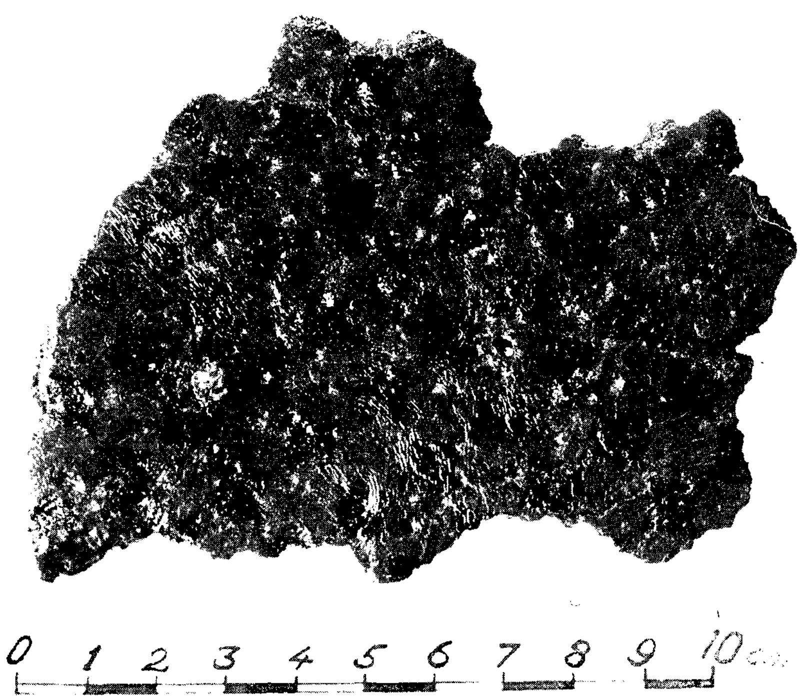

Fig. 12.

INVESTIGATIONS OF PROTECTED BUILT-UP ROOFS (ROOF TERRACES)

COMMON DEFECTS

Fifty roof terraces with protected built-up roofs have been investigated. In about half of these, waterproofing ability has failed (*i.e.* the under surface has noticeable moisture spots or the terrace has had to be reapplied after a short time). Furthermore, 30 additional similar terraces have been investigated at the time they were applied, and the defects which caused water penetration are enumerated below.

Holes and tears

The thin felt layers are very sensitive to mechanical injury before and during the application of the protective coating, particularly where the roofing felt layers do not rest directly on the deck (Fig. 13).

Thirteen of 30 damaged roofs had holes or tears when the house was built.

Fig. 13.

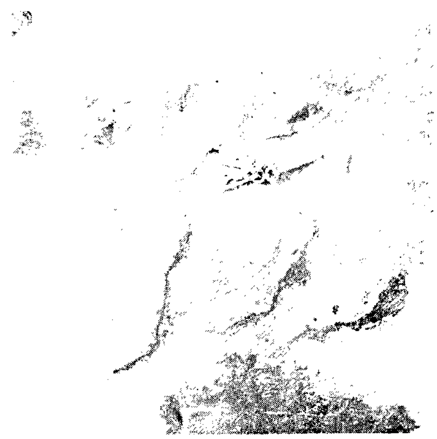

Fig. 14.

Ruptures

Normally, the waterproofing layer is applied upon a facing of non-reinforced concrete. This facing often cracks, whereupon the felt ruptures (Fig. 14).

Water penetration between the layers

Water has penetrated in cases where the space between the layers was only partially filled with bitumen (Fig. 15). The density has, for this reason, been much diminished and the permanency of the roofing felt is reduced.

Twenty-two of 30 investigated damaged multi-layered roofs had so little bitumen between the layers that water could penetrate between them.

Defectively constructed and installed general features

Basic plans of various general features of construction have been nearly non-existent and the necessity has arisen to improvise upon the solution of this problem. Figs. 16 and 17 illustrate examples of defective details, the former a window which is situated too low, and the latter a vertical supporting beam which extends directly through the waterproofing layer without protective collars.

Nine of 30 damaged roof terraces had defectively installed features.

Thus, it has been possible to determine that the most important causes of damage are movement in the deck, mechanical injury before and during the application of a protective coating, biological and chemical destruction and non-professional installation.

The most severe strain encountered is caused by movement in the deck. Vertical movements can be avoided by means of proper construction, but horizontal movements cannot be completely eliminated. This compels the waterproofing layer to tolerate some degree of stretching.

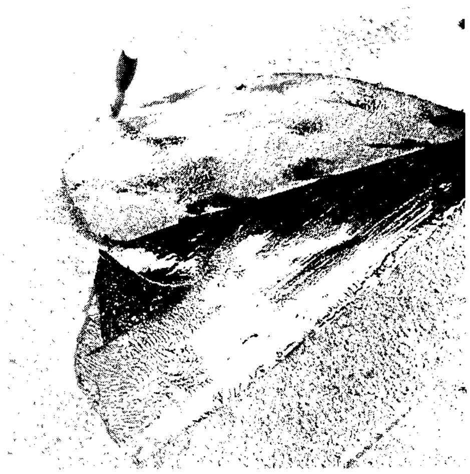

Fig. 15.

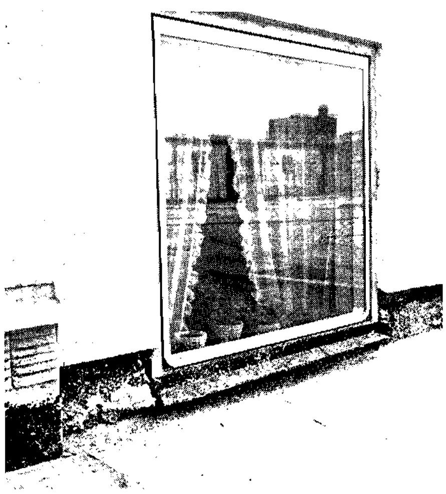

Fig. 16.

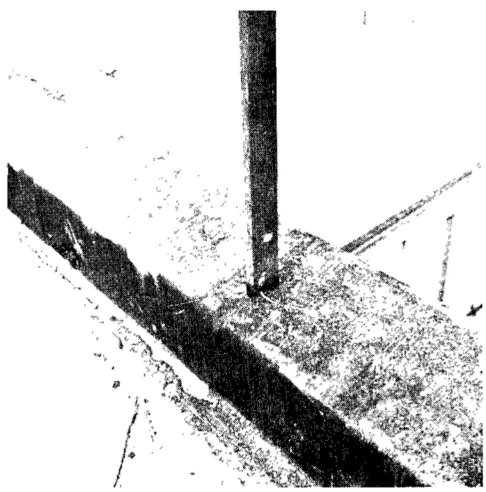

Fig. 17.

Even if the work is well done and the waterproofing layer is covered immediately with a protective layer, it often happens that damage occurs to it during subsequent building construction. Therefore, it should be as thick and mechanically durable as possible.

With respect to the fact that it is possible to expect a life span of 30 years for such roofing, the powers of resistance against chemical and biological deterioration must be great.

The job of applying the waterproofing layer will be more efficient if ductile material is used and if the work is planned so that installation is made under dry and warm conditions.

Further advice on utilizing this general information is given in another report [5] which is currently in press.

CHOICE OF TYPE OF WATERPROOFING

Waterproofing is commonly a combination of several factory or on-the-job installed layers, whose characteristics can be somewhat different. These layers can be placed together in a variety of ways, and many different types of built-up roofing have resulted. Several of the types used in Sweden are explained in Figs. 18–22.

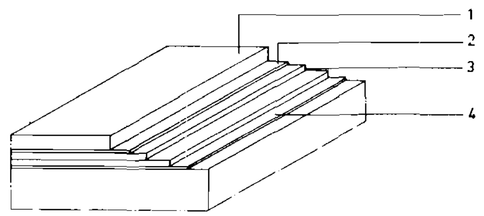

Fig. 18.

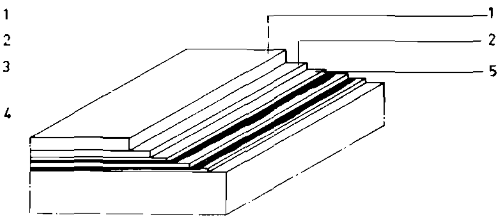

Fig. 19.

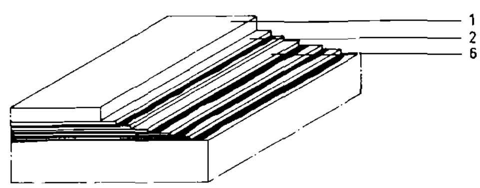

Fig. 20.

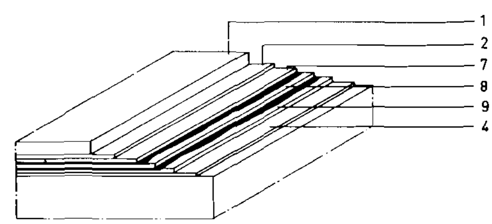

Fig. 21.

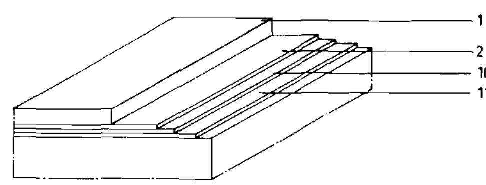

Fig. 22.

1 Protective coating, 2 Friction lowering layer, 3 2 layers 10–12 mm mastic asphalt insulation, 4 Vapour barrier (oiled paper), 5 3 layers sanded bitumen felt and 2 layers bitumen, 6 4 layers saturated bitumen felt and 5 layers bitumen (applied as a solution), 7 Self-finished bitumen felt, 8 3 mm bitumen mat, 9 Mastic asphalt, 10 Sanded bitumen felt, 11 Soft plastic sheet (with welded joints) (See Figs. 18–22).

Despite the fact that conditions for waterproofing can differ considerably among different roof terraces, there are probably some definite minimum requirements which in normal cases should be fulfilled. It should be possible to determine these by means of "quality norms". Prerequisites necessary in order to confirm these "quality norms" are that the technical building and material problems in waterproofing constructions are clarified. Nevertheless, these "quality norms" are so complex that, despite some research in various places, the knowledge of them is still very scanty. Yet, by means of earlier studies it has been possible to outline several methods of approach having general validity with respect to how a waterproofing layer for roof terraces should be compounded. These methods of approach are based on those requirements that can be made in order to ensure the avoidance of the most common causes of damage, as well as on the previously explained characteristics of the different types of filling material and multi-layered fabrics.

As a matter of course an attempt is made to give some criteria for the evaluation of different types of waterproofing construction. Some of the criteria are taken from foreign sources.

A waterproofing layer should possess the following properties:

(a) *Elasticity and heating qualities*

It should tolerate stretching. (French norms [6] state that a waterproofing layer, at the lowest temperature for which it is constructed, should, upon testing in a special arrangement – a "fissuremètre" – tolerate a stretching of at least 3.5 mm and, furthermore, should tolerate the same amount of stretching back and forth throughout 150 successive trials.)

(b) *Robustness*

The total waterproofing layer should be at least 7 mm thick.

(c) *Heat sensitivity*

The uppermost bitumen layer should not be more than 1 mm thick.

(d) *Formation of a common unit by the layers*

The bitumen felt should be thinner than 2.5 mm if it is to be applied at a temperature lower than + 5° C. The lowest layer, which usually lies loose, is not included. Roofing felts must not be broken during cold weather.

The bitumen layers should be at least 1.4 mm thick between the different sheets if hot bitumen is used.

(e) *Permanence of material*

The outermost layer should be of a material that will not rot or corrode.

(f) *Easy detection of individual errors in installation*

The waterproofing insulation should be composed of at least three layers exclusive of the mopping layer. The total number of layers may possibly be reduced if the working conditions are such that possible mistakes can be observed upon inspection.

(g) *Compensation for the fact that the deck is often damp and the weather rainy*

The bottom felt layer should be dimensionally stable; however, this is not necessary when it is mopped on to the deck.

CONCLUSION

Research concerning roofing materials used in flat roofs is in progress in various parts of the world. Specific mention should perhaps be made of Australia [8, 9], but investigations there are still in their early stages. Swedish research can be considered as oriented surveys which are directed solely to providing instructions on means of avoiding the most common mistakes and to determining which problems are most urgently in need of solution.

In the future it is hoped that research will be brought to bear on more thorough studies of the different requirements of the waterproofing layer as well as the manner in which different factors influence its resistance to deterioration. This research should, among other things, result in:

1. "Quality norms" for waterproofing construction in flat roofs.
2. Construction rules for the deck beneath the waterproofing layer.
3. Construction rules for the application of protective coatings over the waterproofing layer.
4. Calculation of dampness in the deck and thermal insulation materials [4].
5. Principles of construction for different features.

REFERENCES

[1] R. Hanson, *Hur har våra plana tak fungerat?* Byggmästaren, B2, 1952.
[2] R. Hanson, *Papptak – några erfarenheter från en inventering*, Byggmästaren, B3, 1953.
[3] R. Hanson, *Papptak – klistrade dubbeltäckningar*, Broschyr 7, Statens nämnd for byggnadsforskning, 1954.
[4] R. Hanson, *Fukt beräkning av ytterväggar och yttertak*, Byggmästaren, B3, 1958.
[5] R. Hanson, *Takterrasser – vattenisolering och beläggning*, Småskrift från Statens nämnd för byggnadsforskning (Under tryckning – will be printed, 1959).
[6] Cahier des Charges concernant l'Etanchéité à la Société Nationale des Chemins de Fer Français, 1950.
[7] E. R. Ballantine and K. G. Martin, *Pliability Testing of Bituminous Coated Roofing Felts*, Report 02.1–6, Division of Building Research, Melbourne, 1958.
[8] K. G. Martin, *The Addition of Inorganic Fillers to Bituminous Coatings for Roofings*, Report 02.5–3, Division of Building Research, Melbourne, 1958.

Wind effects on roofs, with particular reference to flat roofs of lightweight construction

UDC 69.024.3 : 624.042

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THE CHARACTERISTICS OF WIND

GENERAL

The wind never blows perfectly steadily, its speed and direction are continually varying. The variations in speed may be relatively slow, lasting for several minutes, or they may last for only a short while. The short-period variations or gusts may reach very high speeds, usually about 50 per cent. greater than the mean wind speed at the time.

Not only does the wind vary with time, but the further one gets above the ground, the stronger the wind. In an open, level situation it has been shown by Deacon [1] that the wind speed increases with height, on average, according to

$$\frac{v_h}{v_{10}} = \left(\frac{h}{10}\right)^{0.17} \qquad (1)$$

where v_h is the wind speed at a height of h metres and v_{10} is the wind speed at the standard height of 10 metres. This relationship may not apply when there are numerous obstructions to the free flow of air, such as vegetation and building.

In a strong wind the air is very turbulent and consequently pockets or eddies of fast-moving air are brought down into the slower moving air below, so producing the higher speed gusts. On average the gust speed u does not increase with height so rapidly as does the mean wind speed, the relationship found by Deacon being

$$\frac{u_h}{u_{10}} = \left(\frac{h}{10}\right)^{0.085} \qquad (2)$$

It is probable that the speed of the very highest gusts varies with height even less than this.

Individual eddies seem to descend to the ground at an angle and rarely affect the whole height of tall vertical structures at one time.

INSTRUMENTS USED TO MEASURE WIND SPEED

The observations on wind characteristics made above are based on measurements made with Dines pressure-tube anemometers, which will respond to gusts with a duration of 2 to 5 seconds. It is clear from the nature of gusts that the maximum speed recorded will depend on the speed of response of the anemometer. In the Dines instrument, the pressure and suction produced by the wind in two tubes in the anemometer head are transmitted through large-bore tubes to a water manometer at the foot of the tower on which the instrument is mounted. A pen attached to the float records the movement of this float, and hence the pressure difference produced by the wind at the mast-head.

More recently a new type of rotating cup anemometer has been coming into use. This drives a small electrical generator, the output from which is recorded continuously on a strip chart recorder. As this instrument has a rather quicker response to changes in wind-speed than the pressure-tube anemometer, it is to be expected that it will record higher gust speeds.

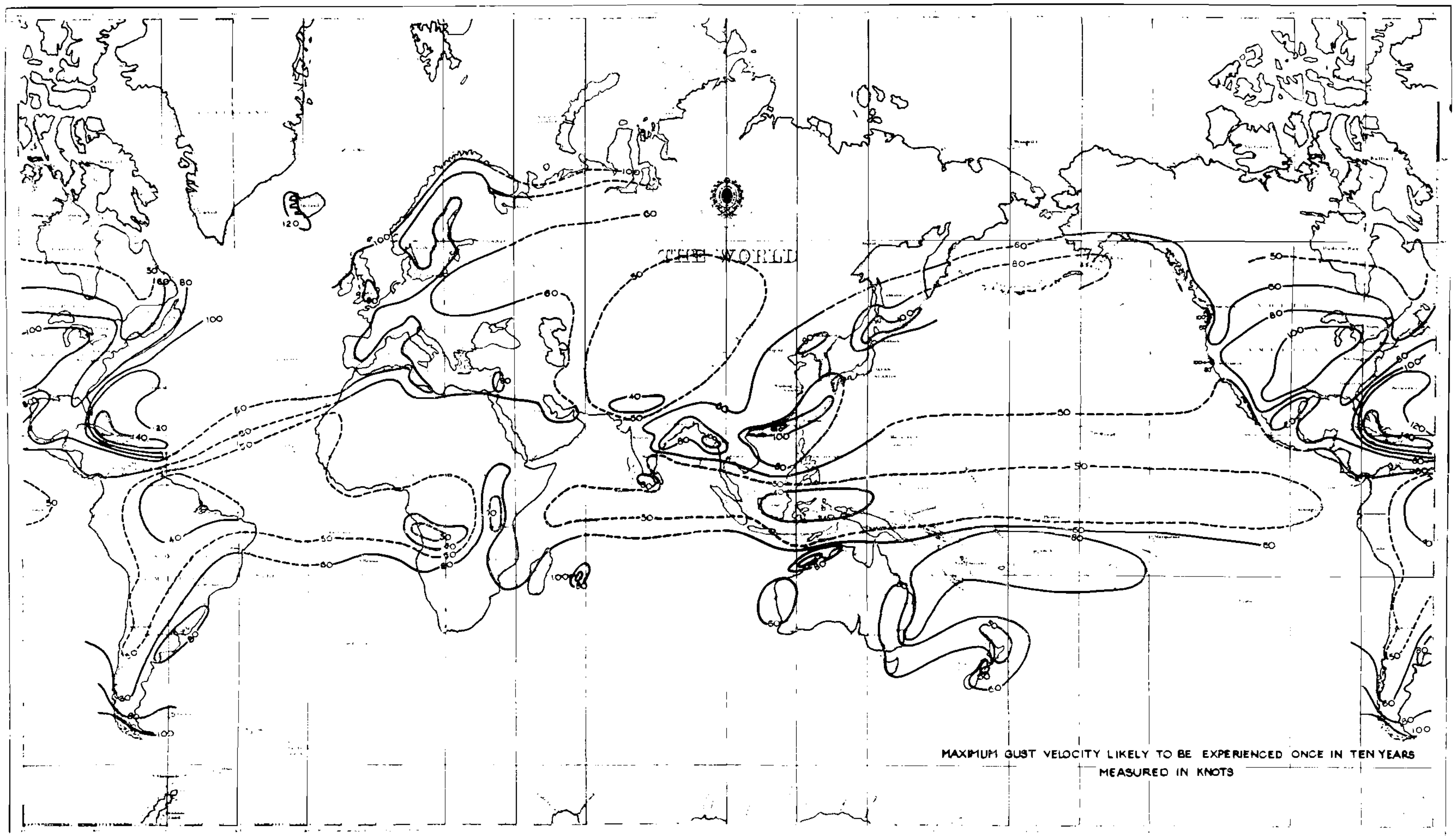


Fig. 1. Maximum wind velocities to be expected in various parts of the world (by courtesy of the Meteorological Office of the British Air Ministry).

GEOGRAPHICAL VARIABILITY

On the average the wind speed decreases markedly with distance from the sea. All the coasts of the British Isles are strongly exposed to winds, although the winds experienced on the east coast are on the whole less than on the west. The highest mean hourly wind speed at a height of 10 metres, likely to be exceeded only once in 10 years, is about 40 knots [1] in southern England, about 45 knots on eastern coasts, and 50 knots or more over much of the western coasts. The corresponding highest gust speeds in a 10-year period are about 70 knots in southern England, 80 knots along most coasts, and up to 90 knots or more in the western isles.

All these figures apply to well exposed sites, with anemometers 10 m above the ground. Obstructions to the free flow of wind would, of course, considerably modify the picture.

The maximum gust velocities likely to be experienced once in ten years are shown in Fig. 1 for the whole world. The map illustrates the variation from place to place, but should not be regarded as giving exact data for any particular locality.

The wind velocity likely to be experienced in a period of time increases with the length of this period. The designer must, therefore, if wind effects are a critical feature of his calculations, decide on the desirable life of the structure in mind and obtain data on the likely maximum wind velocity corresponding to this life. Data obtained by the Meteorological Office in England have suggested a relationship between the maximum wind velocity and the period during which this maximum is to be expected. For example, if the maximum gust velocity likely to be experienced once in ten years at a particular locality is 80 knots, it is probable that a gust velocity of nearly 100 knots will occur during a period of sixty years.

TOPOGRAPHICAL VARIABILITY

Although wind speeds in general decrease away from the sea, the wind at any place depends also on the type of country. In hilly country the wind may vary greatly over very short distances. There will be a tendency for the air flow to be channelled along valleys, irrespective of the direction of the wind in the free air. Locally, these valley winds may be exceptionally severe when the wind is from a particular direction.

When wind encounters a hill it is forced to rise and the streamlines of the air flow are brought together; there is in consequence a region of high wind speed near the brow of the hill (Fig. 2). This effect is most marked over steep-sided hills facing the wind, but may be important even with quite gentle hills in relatively flat country.

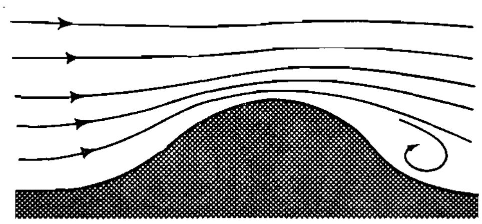


Fig. 2. Diagram showing air flow over a hill, with concentration of streamlines at the brow resulting in higher wind speeds at this point than in the free air at the same height.

These effects are so complicated and vary over such short distances that it is not possible to display them on a small-scale map like Fig. 1. When considering the probable wind speed at any particular site it will be best to obtain the advice of the appropriate meteorological authority.

[1] For conversion factors, see Appendix.

THE EFFECT OF BUILDINGS ON WIND FLOW

Buildings themselves affect the flow of the wind. Under some conditions the sheltering effect may be noticed for a distance down-wind of several times the height of the building. In the immediate vicinity of a building, however, and especially around the edge of the roof, the wind speed may be appreciably greater than in the free air, just as it is over a hill.

In general, the wind will be greatly slowed down in a town although in places there may be appreciable channelling of the wind, as in a valley. It is uncertain whether these channelling effects can give rise to wind speeds high enough to cause damage during an otherwise normal wind, but it has been found that the distribution of damage during gales may be markedly affected by the lay-out of roads and buildings.

PRESSURE DUE TO WIND

GENERAL

Investigations of wind loads on buildings have been made for more than fifty years but the results were not adopted to any great extent in building regulations in Great Britain until the preparation of the Code of Practice C.P. 4, Chapter V, Loading, published in 1944. Although experiments at the beginning of the century had shown that a resultant external suction occurred on the leeward slopes of roofs, engineers were loath to introduce refined methods of analysis of the effects of wind pressure on buildings. However, work of the Building Research Board that was completed in 1939 gave a clear picture of the true distribution of wind pressure on the walls and roofs of simple buildings [2], and for design purposes simplified rules were developed.

The Revised Code of Practice, C.P. 3 – Chapter V (1952), is now the basis of most structural engineering design in Great Britain so far as the effect of wind is concerned. The current model by-laws of the Ministry of Housing and Local Government specify that wind loading on a building shall be calculated on the basis of this code.

The pressures that are developed on any obstruction to the wind are usually given in terms of the dynamic head of the air flow, which is equal to $\rho V^2/2g$, where ρ is the density of air, and V is the wind velocity. The total pressure p on the obstruction depends on the shape and dimensions of the obstruction (tests on model buildings in a wind tunnel have indicated a maximum value of p of about 20 per cent. more than the dynamic head). All wind pressures to be adopted in design are, therefore, related, in the British Code of Practice, to a "basic wind pressure p", where

$$p = 1.2\,\rho V^2/2g \tag{3}$$

The basic pressures, reproduced in Table I, are related to the height of the building above the general ground level and are coupled with four degrees of exposure relevant to different localities. The wind velocity included in Table I is the highest value of the mean velocity over a period of one minute at an effective height of 40 ft (12 m) that is likely within the life of a building in a particular locality.

Owing to the importance of local topographical features, gradings based on geographical location can be used only as a rough guide, and designers must obtain more information about the particular site before deciding on the wind velocity to be assumed. The local authority concerned with the control of building will usually decide the appropriate value on the basis of experience and records of previous high winds. They, in turn, may well obtain advice from meteorological authorities.

The mean wind velocity over a period of one minute is used at present as the design criterion in the British Code. Meteorological records, however, are usually in terms of the one-hour mean velocity or of the maximum gusts. It is assumed in the code that gusts lasting only a few seconds may be of little importance in their overall effect on buildings

TABLE I

BASIC WIND PRESSURE

Effective height of building (ft)	*Basic wind pressure p (lb/sq. ft)*			
	Exposure A (*V* = 45 *m.p.h.*)	*Exposure B* (*V* = 54 *m.p.h.*)	*Exposure C* (*V* = 63 *m.p.h.*)	*Exposure D* (*V* = 72 *m.p.h.*)
Up to 10	4	6	8	10
20	5	7	9	12
40	6	9	12	16
80	9	12	17	22
120	10	14	19	25
160	11	16	22	28
200 or more	12	17	24	31

since (i) a gust affects only part of a large building and the increased local pressure may be outbalanced by a momentary reduction in pressure elsewhere, and (ii) inertia of the building will reduce the effect of short-period gusts. It is usually sufficient to assume that the one-minute mean velocity is 10 m.p.h. more than the one-hour mean velocity.

INTERNAL PRESSURES

The main effect of wind on a roof takes the form of an external pressure normal to the surface of the roof, but in addition air flow through the cladding of the building and through openings in the cladding can build up an internal pressure acting normal to the underside of the roof surface. Both external and internal pressures can be expressed as multiples of the basic pressure p.

Generally the designer is concerned with buildings where the cladding permits the flow of air into or out of the building, but where there are no large openings. Such buildings may be described as being of normal permeability and the internal pressure recommended in the British Code for these buildings is $0.2\ p$ acting normal to the roof surface. This value will be positive or negative depending on the direction of the wind and on the disposition of the openings.

If the openings are mainly on the windward side the wind will blow through the openings, creating a positive internal pressure. If the openings are mainly on sides other than the windward side, the passage of wind around the house will tend to draw air out of the house, creating an internal suction. In the Code of Practice, the term pressure is used in a general sense, a negative sign being used to indicate suction. Hence, for normal conditions of permeability, the internal pressure may be expressed as $\pm\ 0.2\ p$.

Where the openings on one side of a building are large compared with those elsewhere (for example, in hangars), the internal pressures may be as much as $\pm\ 0.5\ p$, depending on the direction of the wind. If one side of a building is completely open the same pressures are applicable, but the code gives no guidance for the pressures on roofs of buildings with no walls at all.

EFFECT OF THE PITCH OF A ROOF

Wind-tunnel tests on models are useful in determining the effect of the pitch of the roof on the distribution of wind pressure on its surface. Typical distributions of pressure on three types of roof as obtained from model tests are shown in Fig. 3. It will be seen that the distribution is not by any means uniform but, for simplicity of design, the code recommends uniform distribution over each of the main surfaces of a roof. Table II, reproduced from the code, gives the external wind pressures for wind blowing at right angles to the eaves, set out at 10-degree intervals of slope. For slopes up to 35 degrees, wind causes suction over the whole roof and the uplift can be further increased if an internal pressure is simultaneously acting.

LOCAL PRESSURES

The wind pressures discussed so far are the average pressures acting over large areas of the roof. Pressures much higher than these often occur locally. In addition, high pressures occur near the edges of the roof owing to the local eddies set up where the wind first strikes the roof.

These local wind effects are important as regards the roof covering and the code recommends a design pressure for coverings equal to the pressures of Table II numerically increased by 0.3 p. It will be noted that this is, in fact, an increase of 0.1 p on the total design

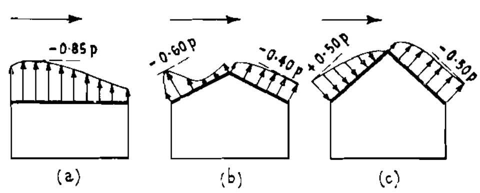


Fig. 3. External pressures and suctions on roofs, with wind normal to eaves for (a) flat roof, (b) 23½° roof pitch and (c) 45° roof pitch.

TABLE II

WIND PRESSURES ON ROOFS OF VARYING PITCH

(wind normal to eaves)

Slope of roof on windward side	*External wind pressure*	
	Windward slope [1]	*Leeward slope* [1]
0°	— 1.00 p	— 0.75 p
10°	— 0.70 p	— 0.50 p
20°	— 0.40 p	— 0.45 p
30°	— 0.10 p	— 0.45 p
40°	+ 0.10 p	— 0.45 p
50°	+ 0.30 p	— 0.45 p
60°	+ 0.40 p	— 0.45 p
70°	+ 0.50 p	— 0.45 p
80	+ 0.50 p	— 0.45 p
90°	+ 0.50 p	— 0.50 p

[1] Windward and leeward halves in the case of a flat roof.

pressure for the main roof structure of a building with normal openings (*i.e.* with an assumed internal pressure or suction of 0.2 p). The roof covering must be designed for the worst outward or inward loading; for low slopes the worst total inward loading is when the wind is not blowing at all. Actually the relevant clause in the code does not give the corresponding increase to the pressures of Table II for a building with large openings but by implication this should be 0.6 p.

Fastenings for the roof sheeting are required to resist the higher local pressures specified for the covering of the roof. Also, in order to allow for the more serious effects of wind near the edges of the roof, they must be designed to resist a suction of 2 p when they are within a distance of 15 per cent. of the span from the eaves, and 15 per cent. of the length from the gables. For conventional roof coverings, fastenings have been developed as a result of experience; for new types of covering or fastenings, the code rules provide a criterion for checking their probable adequacy.

DIRECTION OF WIND RELATING TO BUILDING

It is, of course, necessary in design to assume that the wind may blow in any direction relative to the building. The experimental evidence available at the time the British Code was drafted was mainly limited to wind-tunnel tests in which the wind was usually directed at right angles to one or other of the main faces of some basic shapes of model. The design wind pressures given in Table II, for wind normal to the eaves of a building, were based on the results of these tests and the code makes no reference to the pressures on roofs arising from wind blowing in any other direction. The provisions for increased forces on fastenings near the ends of buildings allow partially for the effect of wind blowing on the ends, but for the general roof structure it can apparently be assumed that a consideration of the forces arising from wind normal to eaves will ensure reasonable safety against wind from any other direction.

Although for general design purposes it is necessary to avoid undue complication, it is worth noting that local pressures on roofs, particularly near the edges, may be greatest when the wind blows at an angle midway between normal and parallel to the eaves. The effect may be of particular importance for small buildings, such as houses, and especially if the roofs are of low pitch and of lightweight construction.

As an example, wind-tunnel tests have recently been carried out at the National Physical Laboratory [3] on a rectangular model representing a relatively new shape of building with a monopitch roof of 6 degrees slope. Tests were made with the wind direction varied through 360 degrees. The suctions determined with the wind normal to the eaves were not very different from those recommended in the code. However, with the wind directed at a corner of the model the suction of quite appreciable areas of the outer portions of the roof was greater than the basic pressure p; also extremely high suctions, of 5 p or more, were measured on very small areas of the roof in the vicinity of the corner at which the wind was directed. The actual distribution of wind suction for this worst direction of wind is shown in Fig. 4 in the form of contours on one half of the roof plan.

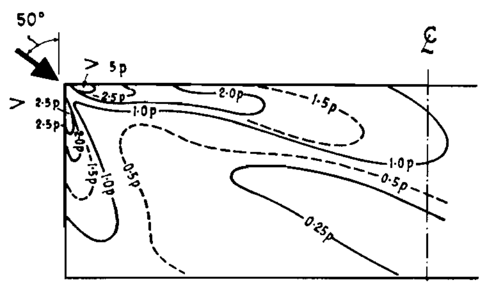


Fig. 4. Plan of monopitch roof of 6° slope, showing the distribution of external suctions for a wind blowing at an angle to the high front of the building.

OVERHANGS

The small portion of a roof projecting beyond the walls at eaves level is a common constructional feature of the traditional roof. In many forms of roof, the effect of wind acting on the underside of a small roof overhang would have no special significance, and this is probably the reason why the code makes no specific mention of feature. However, it does deal with the limiting case of a very large overhang, *i.e.* a building completely open on one side, and recommends an "internal" wind pressure of $\pm$ 0.5 p acting on the underside of the roof for wind blowing into the open side. It will be noted that a positive internal pressure is equivalent to a suction on the top of the roof. Thus, where it is necessary to include the effect of wind on the underside of a roof overhang it is suggested that, until further experimental data are available, the value of $\pm$ 0.5 p mentioned above be accepted for the pressure beneath the windward overhang. This corresponds to a suction load acting on the area of roof directly above the overhang, to be added to whatever external wind load has been calculated for the top surface of the particular roof.

As regards the leeward overhang, it would seem, from a comparison of the actual wind pressures on windward and leeward walls recorded in Appendix 3 of the Code, that a value somewhat less, say 0.3 p, might be assumed to act as a suction on the underside of the leeward overhang.

SOME DESIGN CONSIDERATIONS FOR FLAT ROOFS

STRENGTH AND STABILITY

Strength of a roof is its ability to carry load without failure by overstress. The load includes the self-weight of the roof, wind load, an imposed load to allow for snow, and, in some cases where access to the roof is provided, an imposed load to deal with possible concentrations of load on or in the roof structure. The design of a roof of normal construction on a stress basis using working loads given in codes or by-laws presents no great difficulty, although the designer now has to consider carefully the effect of wind, which can sometimes, for instance, lead to a reversal of stress in the members of the roof structure. It is common practice to allow increased working stresses when wind effects are considered, so long as the increase is wholly due to the wind.

Stability of the roof is its ability, by virtue of its self-weight alone or with anchorages or fastenings, to counter the uplift effects of wind. In the past with roofs of traditional design and material, stability rarely called for special anchorages. But the recognition that considerable wind suction occurs on some forms of roof makes it incumbent upon the designer to investigate closely the possible need for anchorages in order to ensure an adequate margin of safety against the roof as a whole being detached from the rest of the building.

The margin of safety to be used in designing roofs to resist uplift or overturning is not stated in any British code or by-law. British Standard 449 for the design of steel-framed buildings specifies that the stabilizing moment of any structure as a whole shall be at least 1.5 times the overturning moment due to wind and other forces. Since roofs are more responsive to the effect of wind than the building as a whole, a higher margin is desirable. For small house roofs, for example, it would be reasonable to ask for a stability factor of at least 3.0, *i.e.* twice that called for in respect of a steel building as a whole; these factors are related to the wind effects deduced from the maximum one-minute mean wind velocity, and the factor of 3.0 for roofs corresponds roughly to a factor of 1.5 in relation to the effect of the maximum likely 10-second gusts.

MONOPITCH ROOFS

The design data contained in Table 11 were established by tests of roofs with equal windward and leeward slopes. They can probably be used also for roofs of unequal slopes if the difference between the slopes is not more than 30 degrees or so, but cannot be expected to be wholly satisfactory for monopitch roofs, where one wall of the building is considered fictitiously as the second slope of the roof.

However, until more experimental data are available, it would probably be reasonable to assume that the external suction on a monopitch roof is the same as that given in Table 11 for a windward slope of the same pitch.

LIGHTWEIGHT HOUSE ROOFS OF LOW PITCH

With the present tendency towards lightness in construction, troubles have been experienced because the suction due to the wind is sometimes sufficient, if the roof pitch is low, to cause the roof to lift if it is not adequately anchored to the walls. Lightweight roofs of houses have comparatively little inertia and can respond to gusts of wind more readily than the larger, heavier roofs of bigger buildings. The recommendations of the Code of Practice may not, therefore, be wholly satisfactory for these lightweight roofs and a safer basis for design is suggested below. It is assumed that the roof members are properly connected together to act as a whole in resisting wind and other forces.

In a block of several houses, the end houses may be more seriously affected by wind blowing at an angle to the face of the building and it is desirable, therefore, to give special consideration to the stability of their roofs.

Except for the end houses, the external wind suction should be deduced from Table II but the suction should be assumed to be increased to 1.5 p within a distance of 4 ft (122 cm) from the windward edge of the roof. The external wind suction on end houses should be assumed to be 50 per cent. greater than those of the other houses, and also the suction should be assumed to be increased to 2.25 p for a distance of 4 ft (122 cm) from the end of the roof for the whole depth of the house. For a flat roof, these external suctions are illustrated in Fig. 5.

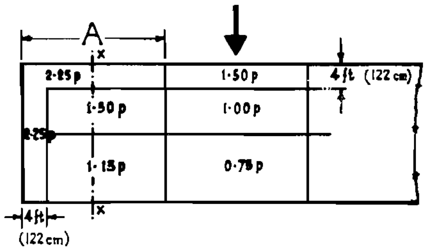


Fig. 5. Roof plan of block of houses, showing distribution of external wind suctions to be assumed in the design of flat roofs of lightweight construction (wind normal to eaves). The dimension A indicates the length of the end house.

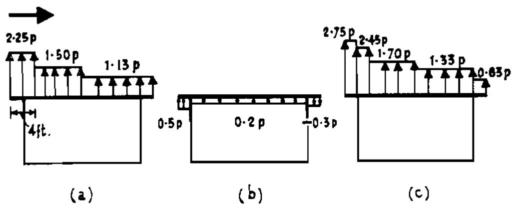


Fig. 6. Section through end house of a block of houses (at X–X of Fig. 5) showing (a) external suctions, (b) wind pressures below roof (*i.e.* internal pressure and pressure beneath overhangs) and (c) total suction on the main roof (*i.e.* sum of effects shown in (a) and (b)).

The internal pressure, also tending to lift the roof, should be assumed to be 0.2 p as specified in the code for a building with normal openings. Where a roof has overhangs, the upward pressure under the overhang on the windward side may be taken as 0.5 p and the suction under the overhang on the leeward side as 0.3 p. The resulting total suctions for an end house with a flat roof and overhangs are shown in Fig. 6.

In order to provide an adequate margin of safety where no special anchorage of the main roof structure is provided and the effects of wind suction have to be resisted by the weight of the roof alone, this weight should be at least sufficient to prevent uplift or overturning of the roof when the forces due to wind are assumed to be increased to three times the normal values calculated in accordance with the above recommendations.

When the dead weight of the roof is insufficient to satisfy this requirement, special anchorage must be provided such that the weight of the roof, together with the holding-down strength of the anchorage, is at least sufficient to prevent uplift or overturning of the roof when the forces due to wind are again assumed to be increased to three times the normal values.

It is important that the assumed strength of special anchorages should be realistic in relation to the variability of this strength and the standard of workmanship probably attained on the site. Where permissible working loads are given in codes or by-laws (*e.g.* for bolting or nailing) it should be assumed that the strength is not more than twice the working values.

In the past, house roofs required no special anchorage. Accordingly, where such special provision is necessary for lightweight roofs of low pitch, it is desirable to draw particular attention to the need for this anchorage in the contract documents so that adequate supervision is arranged on the site to ensure that the anchorage is satisfactory. It should also be noted that although a minimum margin of safety has been introduced into these recommendations, a much higher margin can usually be obtained with little increase in cost.

The wind forces on roof coverings and fastenings should in general be deduced on the basis adopted in the code, *i.e.* the suction on the coverings should be taken as 0.1 p greater than the total values (including the effect of internal pressure) recommended above for the main roof structure. The fastenings should be sufficient to support these forces on the covering, and those fastenings within a distance of 4 ft (122 cm) of the span from the eaves of interior houses should be capable of resisting a suction of 2 p on the area of covering that they support. For end houses it is probably best to design the fastenings for a suction of 3 p on the covering over the full area of the house.

SPECIAL ROOFS

The British Code of Practice does not deal with all practical conditions of wind loading. It is stated in the Appendix to the code that "where the shape of the building in elevation and/or plan is unusual, or there are particularly large openings in the walls, or where there are no walls, as in a Dutch barn, available data are insufficient to justify well-defined recommendations for estimating the effects of wind, and in these cases, and also for exceptionally large buildings, wind-tunnel tests would be useful, if obtainable."

For buildings with no walls, such as Dutch barns, or for framed buildings during construction when infilling wall panels have not been built, it is probably safe to assume that the worst internal pressures beneath the roof arise when partial filling of the barn, or partial cladding of the framed building, leads to conditions similar to those of buildings with one side open, *i.e.* the pressure or suction beneath the roof is 0.5 p.

REFERENCES

1 E. L. Deacon, Gust variation with height up to 150 m, *J. Roy. Meteorol. Soc.*, 81 (1955) 562–73.
2 A. Bailey and N. D. G. Vincent, Wind pressure on buildings, including the effects of adjacent buildings, *J. Inst. Civil Engrs.*, October (1943) 243–275.
3 C. Salter, Wind loadings on flat-roofed buildings, *Engineering*, October 17, 1958.

APPENDIX

CONVERSION FACTORS

Velocities

1 knot = 1.15 miles per hour
= 1.85 km per hour
= 0.516 m per second

Pressures

Dynamic head = $\rho V^2/2g$
= 0.00256 V^2 lb per sq. ft
(V in miles per hour)
= 0.00193 V^2 lb per sq. ft
(V in knots)

1 lb per sq.ft = 4.882 kg per sq.m

Discussion

NATIONAL EXPERIENCES IN THE SUBJECT MATTER

UNITED KINGDOM

Commenting on the reports of Mr. T. ISAKSEN and Mr. R. HANSON, Mr. A. G. DAY, of the British Building Research Station, refers to substantial trouble that occurred in his country with flat roofs owing to both moisture included during construction and entry of rain.

The greatest difficulties have occurred with concrete roofs provided with a lightweight concrete screed. Exposure to the open air gives, on average, an increase of moisture rather than a drying-out effect. A temporary shelter during construction would help, but is a costly provision. Once construction is completed lightweight concrete screeds between a waterproof layer above and a dense structural roof below dry out very slowly, if at all.

Solutions may be sought in the direction of

(1) Embedding 2″ withdrawable rubber tubes in the concrete screed so as to provide ventilation ducts.

(2) Making the lightweight concrete with the lowest possible amount of water.

(3) Laying a no-fines screed, which allows water to drain through it on a roof deck that has been provided with drainage holes.

The experience in the U.K. with defects owing to roof movements is similar to that in Mr. HANSON's country. Fully banded felt roofing has to follow the movements of the roof and for this reason even very little movement causes damage to the covering layer and consequent leakage. Laying the felt loose introduces a risk of damage by wind suction. Spot sticking or laying the felt loose and loading it with tiles are ways of overcoming this difficulty. For decks, nailing the first layer has been found most satisfactory.

Contrary to Mr. HANSON's experience, fibre board is considered to have given good service in Great Britain as an underlay and insulating layer beneath built-up bitumen felt roofing.

BRAZIL

Prof. E. TOLEDO of the University of Sao Paulo presents information on a successful and economical form of construction of flat roofs in his country, which has a hot and humid (tropical) climate.

This construction comprises prefabricated concrete slabs as a walking deck over a long-pitch corrugated sheet roof that provides the main barrier to entry of water.

OTHER POINTS OF DISCUSSION

USE OF GLASS AND GLASS FIBRE

Mr. J. HONNOREZ (Belgium) is surprised that the reports do not mention specifically the use of glass fibre felt. This material, relatively new on the market, meets very well the requirements of resistance against chemical attack and of mechanical strength.

The use of double glazing also with a view to resist wind effects should be seriously considered.

In reply, Mr. R. HANSON makes it clear that his report is not meant to indicate in detail all possible solutions. In Sweden, glass fibre felt has been successfully used for years as an underlayer for self-finished roofing and built-up roofing. Trouble is experienced during very cold weather, when the felt becomes brittle.

With regard to double glazing Mr. L. G. SIMMS states, in reply, that the British Building Research Station undertook to test wind forces on windows on behalf of glass manufacturers, resulting in a report giving thicknesses of glass for different openings and different wind loads. The influence of transfer of forces from outer to inner panes was, however, not examined.

USE OF CELLULAR CONCRETE

Mr. G. BÅVE and Mr. C. GEMMEL, both representing lightweight concrete industries in Sweden, advocate the use of cellular concrete.

Mr. G. BÅVE refers to the costliness of special provision for ventilation in roof construction. In cellular concrete such provision is often not necessary. In Sweden some 75% of all roofs are made of this type of material and experience shows that these roofs dry out until a state of moisture equilibrium has been reached. A main point examined in Sweden is to decide when ventilation must be provided. The aim is not to arrive at complete drying out of the concrete, but to reach an acceptable moisture content corresponding to the relative humidity of the air. Obviously this humidity varies with day and night, winter and summer.

Mr. C. GEMMEL supports this view. He points out that distillation of moisture in an upward direction is balanced by a downward capillary movement.

Mr. P. A. DE LANGE (the Netherlands) agrees that cellular concrete may have the advantages mentioned in buildings such as offices, etc., but does not think that the same would hold good for dwelling houses in other countries. Countries like the Netherlands and United Kingdom certainly have a higher level of relative humidity than Sweden. Apart from this, the moisture production in dwellings tends to be considerably higher than in offices.

Finally, some suggestions are presented for subjects for further study by the CIB Commission and the conclusion is reached that the Building Research Station in the United Kingdom shall coordinate future action.

Subject 7

FUNDAMENTAL ASPECTS OF TRANSMISSION OF KNOWLEDGE

UDC 002:69/72

MAIN REPORT

L. M. GIERTZ

Chairman of the International Building Classification Committee (IBCC) (Sweden)

and

J. VAN ETTINGER AND K.L. DE VRIES

Director and Deputy Director of Bouwcentrum (the Netherlands)

This report has been made on the basis of the cooperation of other members of the CIB group of documentation experts. At the Congress a separate IBCC report in English and the IBCC *Building Filing Manual*, prepared by an IBCC team, were obtainable.

Transmission of knowledge: Some fundamental and practical aspects

UDC 002 : 69/72

L. M. GIERTZ

Chairman of the International Building Classification Committee (IBCC) (Sweden)

and

J. VAN ETTINGER AND K. L. DE VRIES

Director and Deputy Director of the Bouwcentrum (the Netherlands)

PROBLEMS OF SOCIETY

THE NEED FOR TRANSMISSION OF KNOWLEDGE

Neither an individual nor a team of individuals can comprehend any longer the knowledge produced in the world of today; they can at best absorb and use a very restricted part of it. How often does the practitioner meet a problem that may well have been solved already somewhere else, but for which he cannot find that solution!

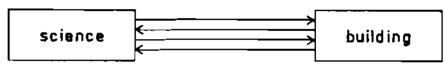


Fig. 1. In former times there may have been a complete mutual contact and a continuous exchange of ideas, knowledge and experience between the practitioner and the scientist.

The growth and development of society lead to specialization and thus the exchange of knowledge and experience becomes more and more difficult.

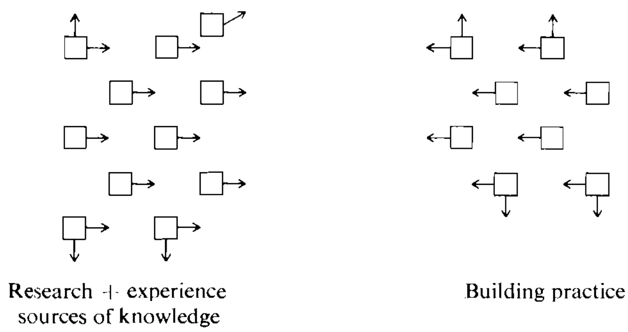


Fig. 2. The partners in the total game are drifting further apart both by the increase of their number and by the process of continued specialization.

There is today also a double language barrier between sources of knowledge and users of knowledge: there are the normal linguistic barriers which are felt more strongly now, when the distances are so short, and there is also the growing complexity of "trade languages", by means of which specialists continue to isolate themselves and through which the transmission of their knowledge is hindered.

Society, and with it building, has now become so complicated, that knowledge and experience, largely spread over the world, are not used sufficiently for the creation of buildings because of the fact that the transmission of knowledge between sources and users is totally inadequate.

However, there is not only too little communication: there is also too much information. The flood of books, periodicals, brochures, folders, films, lectures, etc., poured out over the world is meant to establish communication and to transmit knowledge, but it largely fails to effect its purpose because insufficient adaptation to the needs of the user takes place.

THE FUNCTIONS OF THE TRANSMISSION OF KNOWLEDGE

The functions of the transmission of knowledge are:

(a) to bring science and practice more closely together so that there will be a mutual understanding of problems and needs (integration of science and practice);

(b) to bring under control the uncoordinated and unmanageable stream of data now flooding offices and to relate it more carefully to the users' needs (canalization of knowledge).

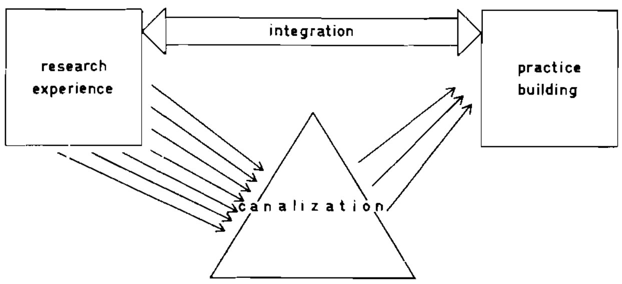


Fig. 3. Integration and canalization are the two primary functions of transmission of knowledge.

Integration

The continuous development of specialization is a general problem of society, the solution of which is an essential condition for the well-being and happiness of coming generations. If no well-considered counterbalancing takes place, specialization undoubtedly leads to isolation with all its dangers of lack of mutual understanding and conflict. We may consider against the background of this general problem what practical steps could be taken in order to contribute, within the limits of the building field, to breaking down the barriers. Integration in this sense is a service intended to establish shorter circuits.

Canalization

The second aim for the transmission of knowledge is to establish possibilities of reducing to reasonable size and to direct at the practical need the almost unmanageable stream of data.

The flood of information can no longer be managed by the ordinary practitioner: the stream of information must be reduced and adapted to practical needs. This canalization includes:

1. tracing of sources of knowledge;
2. collecting the data available with these sources;
3. rendering these data accessible, including, amongst others, registration, classification and filing. This part of the canalization has been called passive documentation. Then follows, however:
4. selection of data, translation, rewriting and publishing in a form manageable for the user (active documentation);
5. distribution of selected knowledge by modern means of communication, such as exhibitions, films, courses, radio, television.

These activities are so closely interrelated (a new step necessarily follows a preceding one), that they must be dealt with in their entirety.

Only in special cases can scientists report on their results and practitioners on their experience in such a way that these reports are suitable for a canalized information stream. Mostly, intermediary organs will be needed. Many publishers and editors of periodicals may feel the responsibility to produce such organs, but as a general solution we cannot rely only on commercial publishers, we also need information centres with well organized national and international contacts and comprehensive files of knowledge. Such centres could equally fulfil a useful task in stimulating the integration mentioned before.

ADDITIONAL FUNCTIONS

The collection, selection, rewriting and making available of knowledge offer the opportunity not only to cover the existing patterns of various needs, but also to discover what needs are not covered by existing knowledge and to make practitioners aware that they do not use fully existing information.

This discovery of unsatisfied needs gives an important indication on the direction in which future research should go.

Making the practitioners aware of their needs is a subject to which some more remarks may be devoted. In many cases the required knowledge is available but cannot be applied simply because of the fact that the user is not convinced of the importance of the application. Here the "transmitter" is faced with aspects such as: resistance against change ("we managed all right last time"); dosing: how much new knowledge can be swallowed by a man within a given time; training processes; and the extent to which the "receiver" is open for transmission in an auditive or in a visual way.

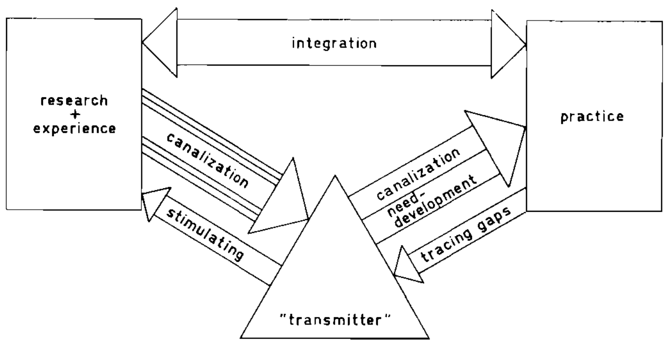


Fig. 4. Transmission of knowledge will have to develop its own techniques in order not only to canalize and facilitate the flow of knowledge, but also to induce this stream (stimulating research by sounding existing needs) and to reinforce it (stimulating the use by developing latent needs).

THE MEDIA FOR TRANSMISSION OF KNOWLEDGE

Media for transmission of knowledge are dispersed all over the world. Journals, periodicals, pamphlets, books, radio, television, etc., are such media, brought together here under the heading "dispersed media". On the one hand, these media take a useful share in the task of spreading information; on the other hand, they often fail to be efficient as they are lacking in coordination and adaptation to the users' needs. Adaptation of data and a deliberate choice of media for transmission of knowledge are within the reach of information centres, as numerous media can be concentrated with them (data sheets, exhibitions, lectures, etc.).

Thus, as far as integration fails to fulfil the aims, the practitioner must be served both by media dispersed all over the world and his own country and by information centres where data and media are brought together.

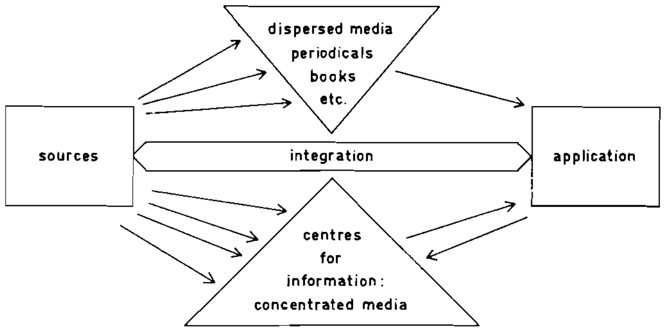


Fig. 5. The stream of knowledge in a desirable form.

PROBLEMS IN THE BUILDING FIELD

PROBLEMS OF THE BUILDING PRACTITIONER

The first resolution of the first General Assembly of CIDB in 1950 requested "...the Executive Committee to take all practical steps to promote the widest distribution of documentation to the users – architects, engineers, scientists, contractors, manufacturers, administrators, etc. ..., and to adapt it as nearly as possible to their real needs."

What are the real needs of the practitioners?

The structure of building practice

In the building field, in planning, construction and control of one building, at least twenty more or less independent bodies are involved:

Preplanning:	Client, Financing body, Functional consultant.
Planning, calculation and design:	Architect, Structural engineer, Sanitary engineer, Heating and ventilation engineer, Electrical engineer, (Experts on acoustics, lighting, etc.), Quantity surveyor.
Construction:	Building contractor, Subcontractors (*e.g.* for excavation, asphalt, plumbing, electrical installation, ventilation installation, lifts, glazing, painting, flooring, etc.). (Firms supplying materials and components not mentioned here.)
Control:	Town planning office, Building authority, Health authority, Fire protection authority, Civil defence authority, Labour protection authority, Community service bodies (*i.e.* for water, sewerage, gas, electricity).

The organization may vary from country to country but the outlines of this scheme are essentially the same everywhere in the modern world.

When analysing the needs for information of practitioners, arbitrarily chosen from the table, variations will be found in subject interest but not in the general requirements. This makes it possible to visualize the concept of "practitioner" by one certain person and his office without essentially limiting the reasoning, *e.g.* an architect with an office of medium size. The architect was chosen because he is the least specialized member of the team and consequently he has the greatest need for organising his information. It is evident that the complicated teamwork of building could not be organized without a pattern of agreed conventions.

Any system to be accepted by building practitioners must be designed according to this pattern. Luckily enough there are features in this pattern which are the same everywhere (building types, functional elements, materials, components and tools); only trades are so considerably different that trade division cannot be used to characterize the pattern.

General requirements of a practitioner's office

The documentation needs of the practitioner are well arranged files for papers related to his day-to-day work and an office library consisting of (a) a set of books, including handbooks on subjects of his professional interest, (b) a set of binders or folders for the storage of the stream of useful sheets and pamphlets, such as reports, standards, codes of practice, regulations, trade catalogues, etc., that enter his office in an ever increasing amount, and (c) a big waste-paper basket to take the useless papers included in the same stream. Another important need is an easy access to knowledge he does not possess in his own office.

Usually the practitioner will not possess so many books in his office library that the arranging of his books would present him with great difficulties. The classification of books is not his main problem; it is more a problem of official libraries and abstract services. Practitioners mostly seem to prefer books, but even if books were used to a greater extent than is the case today, it remains evident that they must be complemented by other types of documents containing an additional quantity of new information, such as reports, regulations, standards, codes of practice, trade catalogues and all other kinds of current information, including the notes and working papers of the practitioner himself.

The practitioner dislikes all these pamphlets and sheets in different formats, although they are offered to him as an aid for his work. The publishers of such documents apparently are not aware of the fact that these days the amount of such documents has grown to such extent that great difficulties are caused when they must be stored in the practitioner's office and that the practitioner can simply no longer keep pace with the ever increasing stream of these documents. The practitioner will ask for a method to arrange all his documents (papers, pamphlets, leaflets, etc.) and, preferably, also his type drawings according to one "easy" system of classification, and by the word "easy" he would mean two things: (a) main grouping in accordance with his way of thinking (the pattern); (b) simple notations for these main groups.

This method of arranging documents in a practitioner's office is what is usually called filing.

The filing problem

The practitioner needs – besides his own library of books – one file of well-arranged informative documents. He wants his filing problem to be solved and all publishers of the documents concerned to be convinced that they must adapt their documents to fit into the practitioner's file.

Documents (excluding books) to be filed must comply with precise demands in three respects, *viz.* format, classification and perforation.

The question of format has, in principle, and also to a great extent in practice, been solved. The standard format A4 (210×297 mm = $8\frac{1}{4}'' \times 11\frac{3}{4}''$) has been accepted as the only format for filing. This means that the practitioner should only need to have filing equipment of a size to contain this format. The practitioner may well desire all documents (excluding books) which have a long-term value to be presented to him in this format, so as to enable him to file them properly.

The question of classification is obviously a very difficult one. The practitioner wants all documents to be classified in advance, so that they can be placed automatically in his file. Facing his own problem only, the practitioner, however, often does not realize the consequences of such a preclassification. As a matter of fact, preclassification of a particular document results in all users of that same document having their files arranged according to the classification of the document. This is the strongest argument in favour of using a universal classification also for filing. If an endeavour is made to limit the field covered by a particular classification made for the purpose of filing by a restricted group of specialists (*e.g.* architects), then very soon difficulties will arise for two reasons:

(a) Firstly, the specialist (architect) for whom the special classification was meant may well wish to collect series of documents that are not included in that particular classification;

(b) Secondly, numerous documents prepared on behalf of the specialist in question (architect) may be equally valuable to other specialists (*e.g.* health authorities or brick manufacturers), which would mean that the latter would have to use the same system of classification for their files.

In practice many a special classification has not survived due to these difficulties.

The question of perforation is linked to the question of the type of binders that will be recommended. It seems that the user would prefer a system of thin binders – or folders – for one subject only per binder. The binders ought to have visible headings when stored in boxes on shelves or when hanging in drawers.

Requirements for data not available in the office

However well organized a practitioner's office may be in documentation matters, the practitioner will again and again run into problems for which he has no answer at hand. This raises the question of his need for access into the enormous amount of knowledge spread all around him or even hidden from him.

After a trial over many years to introduce abstract cards into the practitioners' offices in order to cover at least part of those documents the practitioner does not possess himself, CIB documentalists, who are active in the field of the abstracts exchange, now have arrived at the conclusion that the best access to hidden knowledge is, for the practitioner, not to keep his own files of abstract cards but to remain in direct contact with a professional information centre.

PROBLEMS OF THOSE WHO PUBLISH DOCUMENTS

Up till now there has been no programme defined for the publishing of information for practitioners' offices. Even "publishers" – including authorities, research institutes and editors of trade catalogues – who really wished to do their utmost to reach the practitioners have often failed because practitioners do not read unless they are forced to. An ever growing amount of information and decreasing prices for information seem to have killed the feeling for the value of the information. If the practitioner receives one article a week to read, he will probably read it, but if he gets ten articles and thirty catalogues and lots of other papers every week he can no longer assimilate the information. That is the dilemma. The programme for the altering of this situation is based on the fact that the stream of information steadily increases and consequently the practitioner cannot be "educated" to read carefully the documents arriving in his office. The "publisher" therefore has to decide:

(a) whether the document should, after a rapid glance, go into the waste-paper basket;
(b) whether the document is meant for storing until the moment it may be asked for in the practitioner's office.

This does not concern books. The book market will principally not be influenced by a programme for the future. Polygraphies are not wanted. Well-arranged handbooks and good books on specific subjects are always welcome.

The real problem concerns pamphlets and leaflets and other documents (reports, codes of practice, etc.) as mentioned before.

The lack of agreement on format has given "publishers" every opportunity to make experiments in transmission of knowledge. There are hundreds of pamphlets meant for nailing on the wall in the office on the site, but there is no room for them on these walls. There are hundreds of pamphlets and leaflets of different format lost in offices, hiding the most important information. There are hundreds of classification systems invented for different purposes by different societies, publishers, periodicals, firms and even information centres with the aim of "helping" the practitioner. But practitioners are getting more and more confused; they are fed up with documents and still hungry for information.

This, then, is today's problem of those who publish documents for practitioners' information.

PROBLEMS OF THE INFORMATION CENTRE

Introduction

The practitioner collects his information from his own experience; directly from scientists and scientific institutions; from dispersed media such as books, periodicals, etc.; and from institutes specialized in canalization of knowledge and adaptation in accordance with the needs of the practitioner, *i.e.* the information centre.

The information centre, thus, is a kind of collective organ for all practitioners and the problem of handling the stream of knowledge in the centre has much in common with the problems the practitioner meets in his work.

The problem of establishing and organising an information centre, although important, is neglected not only because different countries have found different solutions, but also because the subject has so many and such interesting aspects that it would take too long to deal with.

General remarks

(a) An information centre should preferably be an institute independent of any special group or trade.

(b) Its function has to be served by a well organized contact with groups representing different aspects of building science and building practice.

(c) The information offered to the consumer must necessarily be impartial, concise and quick.

Looking back to the fields of transmission of knowledge as summarized above (furthering integration; canalization by tracing of data, collecting, arranging, selecting, adapting and disseminating them; detecting gaps and promoting consumption of knowledge), it is readily seen that, in fact, an inventory of activities of an information centre is at hand. From these some practical subjects can be deduced.

Tracing and collecting data (references, abstracts)

An information centre on building probably need never go so far as to try to obtain every existing document in this field. What is needed is a world-wide system of signals, enabling every centre or library or research institute to trace the data it deems of importance for its activities: consequently, an international service of references and/or abstracts. It will be the task of the "signallers" in this service to separate important data from unimportant ones and to make in this way the first excision in the overwhelming quantity.

Arranging data (classification, terminology)

To the same extent as the practitioner needs a simple classification to arrange his documents, the same need presents itself to those people whose particular occupation it is to collect and disseminate knowledge. From the point of view of the information centre it is clear that classification systems have to fulfil a dual requirement. They must allow for the arrangement and the making accessible of the material collected in the information centres (for purposes of cataloguing, literature research, exchange of bibliographical data, etc.), but at the same time they must, as far as this material is accessible to the practitioner, be easily understood. Hence this requirement pleads for a uniform system which can be handled by the practitioner in the office as well as by those whose main task it is to collect and deal with information. In this connection it may be observed that the point of view of the information centre should not conflict with the work of existing libraries, research institutes, etc., since it is also their task to arrange the material and to make it accessible. The information centre has, moreover, to take into account the demands of the layman, who must be enabled to find his way into the material available in the information centre with a minimum of aid by documentation experts.

When arranging a comprehensive quantity of material, the problem of terminology makes itself felt. It is well known that in various linguistic areas important work has been done in order to unify terminology. This work will have to be extended by international cooperation.

Selection and adaptation of data (digests, bibliographies, data sheets, translations)

A main task of the information centres lies in the field of selection of data in such a way that they can be consulted by the practitioner in the most simple way (active documentation). This means not only selecting or often re-grouping and rewriting for the sake of simplifying the language, but also bringing together data which are dispersed and publishing, *e.g.* in loose-leaf documentation systems, in a way to meet all demands of format, perforation, preclassification and so on, which can be made with a view to easy handling of the material.

It has become clear already in the past that the multiplication and distribution of titles of, amongst others, books and articles with which the practitioner should build up his own well arranged card file, do not solve his problems.

Also more elaborated references, such as abstracts, are not very welcome in the practitioner's office. They are indispensable for mutual contact between information centres, libraries, research institutes, etc., but will probably not easily be introduced in other circles. As the practitioner is not served with original documents, it will be necessary to supply him with data that will save him the trouble of keeping comprehensive card files and of searching them. In this connection digests, bibliographies on selected subjects and, of course, the above-mentioned documentation sheets can serve to advantage.

If the main task of an information centre is to prepare knowledge fully on behalf of the practitioner, the linguistic problem immediately presents itself. Investigations have made it clear that even research workers make use of a stock of literature in which only a very low percentage of titles emanating from outside their own linguistic area is found. For practitioners this situation will even be less hopeful. It is undoubtedly of vital interest that national information centres import foreign data on a large scale into their own country. However, one has to be aware of the fact that the translation of foreign data in every country is a task which cannot be fulfilled without special measures.

Dissemination of data (communication media, latent needs)

When disseminating knowledge the question is not only how to meet existing demands but also how to realize such a transmission of available knowledge that the practitioner is induced to make use also of that knowledge which he did not know to be of value to him.

It is a task of information centres to pay full attention to this problem and to make use of all the knowledge and means which modern communication theories and techniques have developed so far. The dissemination of knowledge by means of documents, though being the generally most familiar form, is by no means the end of the story. Courses, lectures, discussion meetings, exhibitions, excursions, experimental building projects, radio, television, etc., will often effect transmission of knowledge in a much more direct and arresting way than well-produced documents.

What has been done to meet the requirements arising from the need for transmission of knowledge?

The problems are similar in all countries. The way of acting, therefore, as far as joint interests are concerned, has been:

(a) To create an organization for international cooperation with sufficient authority to make recommendations.

(b) To agree internationally on a general pattern for the arrangement of knowledge (classification and filing) and on methods and means for the exchange of information.

BASIS FOR AGREEMENTS

The establishment of the United Nations Organization after the end of the Second World War proved to be of immediate importance also for the development of building documentation. The U.N. Economic Commission for Europe, the Housing Sub-Committee and the Housing and Town and Country Planning Center, U.N. Headquarters, New York, from the very beginning took a great interest in the promotion of building documentation. The U.N./E.C.E. was the sponsor of the Conference on Building Documentation, October 6–15, 1949, at Geneva.

The establishment of an international organization in this field and the realization of an international exchange of abstracts of building literature were considered to be immediately needed. Three technical problems of a general scope were involved:

1. international cooperation in the field of documentation;
2. form and contents of abstracts;
3. international uniformity of classification and filing.

These topics were already being eagerly discussed by international institutions of learning on a more general level.

The International Federation for Documentation (FID), first and foremost, was concerned with this at its annual conferences. Especially, it was recommended at The Hague in 1948 that an International Committee on Building Classification should be formed.

Organizational endeavours of the building people themselves were started in connection with the International Reconstruction and Town Planning Exhibition, Paris, 1947, continued at a restricted Expert Conference at Brussels, February, 1948, and were finally stated in the resolutions of the Geneva Conference in 1949. As a result the International Council on Building Documentation (CIDB) was set up at Paris in 1950, where the First General Assembly took place in October.

A Working Party on Classification was also established and linked with the FID in 1952. On this occasion the International Building Classification Committee (IBCC) was established. This permanent committee, consisting of six members nominated by the CIB Executive Committee and six members nominated by the FID Council, plus 13 coopted expert members, is responsible directly to the two bodies mentioned for the development of building classification and filing.

The Second General Assembly of the CIDB was held at Geneva in June, 1953. At that occasion the organization was transformed into the International Council for Building Research, Studies and Documentation (CIB), which since then has been FID's partner in the IBBC.

AGREEMENTS ON DOCUMENTS FOR FILING

The fact that the practitioner can no longer handle all the different documents which are offered to him was stated at the first meeting on building documentation in Paris, 1947. The resolutions made at that meeting still form the basis for the CIB agreements of today although there have been modifications according to later discussions and experiences.

The most important features of the recommendations as they stand today are as follows.

Books are preferred to information in leaflets, etc. It has been recommended that publishers print abstract cards referring to books simultaneously with the books concerned and disseminate these cards to all libraries and information centres. The cards might also be used for informing practitioners of the existence of the book. The card shall be in accordance with international rules for abstracting (see Agreements on the exchange of information).

It was deemed desirable that books should not be printed bigger than A4 format. Books bigger than that cannot easily be stored in the library. The title of the book must be clearly visible when the book is placed on the shelf. "Series", year volumes of periodicals and other polygraphies are not considered as books. They hide the information they want to bring. Polygraphies, including periodicals and other "series" publications, therefore, should be considered as collections of monographs, each monograph being treated as a single document for filing.

Documents for filing (excluding books) are accepted as complements to the books; they shall be:

format A4 (210×297 mm $8\frac{1}{4}'' \times 11\frac{3}{4}''$);

preclassified for filing;

prepunched for filing.

Format needs no further comment. A4 is an internationally agreed paper standard size, at present accepted in most countries.

Preclassification for filing is the most important and most difficult requirement. The problem is treated separately in the following section. The classification should be printed on the first-page, right-hand upper corner of the document in a space of length 40 mm and height 20 mm, divided in two parts by a horizontal line. Below the line shall be printed the appropriate UDC number according to the rules of the ABC. Above the line shall be printed the special filing system of the practitioner.

Prepunching shall be made for the binders or folders of practitioners. In most countries the punching is standardized with the A4 format but there are differences in practice. The latest recommendation is: two holes of 5.5 mm diameter, spaced 80 mm symmetrically in height and with a centre 10 mm from paper left edge. The prepunching, however, is not considered to be of prime importance, as every practitioner will have his own punching apparatus for his binders.

All these questions of standardization are treated generally by ISO, the International Standardization Organization, with which the CIB has close contacts.

AGREEMENTS ON CLASSIFICATION

It can be stated today that the decision made at the Geneva Conference ten years ago of adopting the Universal Decimal Classification (UDC) as a common classification tool for building documents was justified, and very notable results have followed.

Abridged Building Classification (ABC) for Architects, Builders, Civil Engineers

A selection from the Universal Decimal Classification, compiled by CIB, Copenhagen/Stockholm, February, 1954, 59 pp., first preliminary edition, has been issued in 1954 in 300 copies. It was followed by the second edition, published by the Documentation Section of the CIB, Bouwcentrum, 1955, 70 pp., and valid until 1965.

Translations of the second edition are published in the following languages: Dutch, Finnish, French, Japanese, Norwegian, Serbo-Croatian and Swedish. Ready for printing are: Danish, German, Hungarian and Russian. Manuscripts under preparation: Italian, Portuguese and Spanish. In all there are 15 languages. The publishing work will be completed in due course.

Following a decision of the IBCC at its Fifth Meeting in 1958 energetic sales promotion must be carried on from now until the expiration of the validity of this edition in 1965 so that the world of building may learn what is offered through this booklet. The CIB recommendations that the UDC, as presented in ABC, should be used for classification has been widely accepted. Building centres in all parts of Europe now use this classification for their retrieval machinery (mostly card-files). Building abstract cards for the international exchange organized by CIB are classified accordingly. Most encouraging is the fact that more and more editors of periodicals print the appropriate UDC number on the first page of the articles so that they may be cut out and filed. Also an increasing number of research institutes classify reports according to UDC for filing and some building universities and architectural academies are arranging not only their libraries but also the contents of study books accordingly. For the practitioner in the offices of architects, engineers and contractors, or for building research stations, information centres, authorities, institutions and special libraries it offers a universal and simple tool for handling ordinary literature of all kinds.

It is a great advantage for everyone to have in his own language the group headings of an accepted universal system in ABC. The UDC revision and development work organized by the FID has also profited by the ABC activity. Rules of preferences for main-aspect groups and the choice of "entrance numbers" in doubtful cases have been standardized and concisely explained in the rules of application. Certain adaptations according to modern needs of groups within section 69, Building, have been accomplished and included in this part of the 4th (English) complete UDC edition, published in 1957 by the British Standards Institution.

Special building filing systems

An investigation into existing building filing systems was started by the IBCC in 1957; in the beginning of 1958 the Secretary, assisted by the members, had collected much representative literature on the subject. The final report is included in the IBCC publication *Recent Development in Building Classification* (September, 1959).

It appears from the study that the picture as a whole is complicated and confusing. Most of the systems, designed as they are for special purposes by a single person or a team representing certain professional or national points of view, cannot be accepted for a more widespread application. Only a few are of sufficiently high standard that they can be discussed in this respect, and only one, the SfB system, is suitable as a complement to the universal decimal classification UDC and is designed in order to facilitate the filing of trade catalogues and trade information especially in the building field.

Therefore, according to a CIB recommendation the IBCC has published the *Building Filing Manual*, which shows how the filing according to UDC numbers is simplified and improved by a first division according to main groups and tables on buildings and building parts and on building activities.

AGREEMENTS ON THE EXCHANGE OF INFORMATION

In CIDB and CIB the abstracts and the abstract exchange have been, from the beginning, one of the main questions for both the research and documentation member institutes.

The Conference on Building Documentation (Geneva, 1949) made a survey of possibilities for a building abstract exchange service for housing, building techniques and town planning. The General Assembly of the CIDB (Paris, 1950) – taking into account existing ISO recommendations for abstracting – advised members to make a start using abstract cards of size and layout shown in the examples. The advice was followed by some ten countries in the next few years.

Similar abstracts, not strictly conforming to the CIB recommendations, are published by seven more countries. The abstracts are selected and written on a national or regional basis, in most cases by research or documentation institutes, and exchanged between members.

Detailed rules for the selection of the documents to be included in the service have been drawn up. As a guiding principle it has been accepted that a subject should be included if it has a direct influence on the design, construction or cost (in a general sense, *i.e.* including cost of building, maintenance and technical operations) of houses or other buildings and if, in addition, it is of value to other nations. The results, which have been carefully studied by CIB from 1953 onwards, are useful, but nevertheless the service has deficiences (see Improvement of the abstract service). Moreover, the problem of availability of original documents must be solved.

LANGUAGE BARRIERS

International exchange of information is useful and will further transmission of knowledge, provided that the contents of documents, etc., are correctly understood and translated. Two things are important in this connection:

(a) the correct understanding of each technical term in one's own language;

(b) the correct understanding in other languages.

The ABC editions in various languages give some help for translation and questions of terminology. For more extensive translations and exact description of building terms, however, they are inadequate. Time and again the problem of terminology has been the subject of discussions at CIDB and CIB conferences and in the former CIB documentation section. Several trials have been made to start practical work in this field but most of them failed, probably because funds were lacking. This problem needs further study (see Language barriers).

RECOMMENDATIONS FOR COOPERATION BETWEEN NATIONAL INFORMATION CENTRES

In 1950 the CIDB stated that an answer to the request for availability of data which do not necessarily belong to the inventory of a practitioner's office should be given by information institutes. CIDB recommended:

1.1 It is recommended to undertake intensive propaganda so as to facilitate the establishment of National Building Documentation Committees or Centres. Each Committee or Centre should at least be able to give information on other organizations, to play a role as Information Centre and to indicate the fields and the limits of the activities of such Information Centres.

1.2 In each country one or more Centres should be able to supply, within the framework of the arrangements made by the National Committee, at least the following data:
information on existing publications;
information on existing materials for construction purposes;
addresses of completed projects of particular interest;
addresses of manufacturers (construction materials, plant, site equipment, etc.);
addresses of highly specialized technicians.

1.3 Information on existing documentation should be widely distributed amongst users and producers of documents related to building.

Since 1950 in various countries information centres or national committees have been founded and existing centres have extended their activities.

The scope of the centres or committees, however, differs from country to country. Some of these confine themselves to exhibitions only, others to documentation work, but there are also examples of centres covering an extensive part of the field of research, documentation and information. The establishment of an intensive international cooperation consequently is in no more than an initial stage.

BRINGING AGREEMENTS INTO ACTION

Many an international agreement (and not only in the building field) has been welcomed with enthusiasm at conferences and forgotten or neglected afterwards. This situation is not necessarily due to a lack of interest from countries or persons concerned, but may also arise from the circumstance that the results reached at international meetings are often insufficiently disseminated.

It is certainly a task of the CIB and its member organizations, equipped with a bulletin and, recently, a full-time Secretary-General, to promote the transmission of knowledge as far as recommendations and agreements of preceding years are concerned.

A summary of agreements on documentation and information may be inserted in the CIB bulletin and further widely disseminated as a first manual for the practice of transmission of knowledge by CIB members.

CLASSIFICATION

The *Building Filing Manual* published recently by the International Building Classification Committee (IBCC) was the result of ten years of intensive studies on the subject and has to be accepted as widely as possible. It is based on existing systems and no alterations will be made until 1965. In the meantime, however, the IBCC will carry on its work. The *Building Filing Manual* indicates the direction of future development in building classification. The IBCC team which is engaged in developing the project has stated that:

"... Uniformity in international classification practice can be achieved sometime in the future by making use of a universal classification in combination with simple, coordinative subject field systems. This solution means that the universality might be represented by a hierarchical division of the total knowledge into subject fields, such as is the case with the basic divisions of UDC or Dewey's decimal classification, but modernized in accordance with the latest scheme of art, science and technology.

"For each of the subject fields a special faceted classification is required. The facets relevant to each field may be compared and unified so far it seems practical. A subject analysis covering each field may be designed and published together with a list of all existing subject fields."

This programme is, of course, a long-term one. It should be noted that the proposed new system will also affect the UDC. If conditions are favourable it may be completed in the next ten years. The team hopes to receive sufficient subsidies to submit the first draft in 1960. After practical tests to be carried out by Bouwcentrum it might be possible to present the draft for discussion in CIB and FID in 1962. Such discussions will need a period of at least five years and it will probably take three more years for the programme to be finally accepted and printed in several languages. The original language of the system will be English.

This work, however essential, should not confuse practitioners and publishers who are now gradually accepting the SfB + UDC method as presented in the IBCC *Building Filing Manual*, 1959. Full attention should, therefore, be given to the promotion of the use of this manual regardless of what might result from the IBCC development work in the future.

STANDARDIZATION OF DOCUMENTS AND OFFICE FILES

Standardization of documents is a necessary condition for easy arrangement of office files and, therefore, for accessibility of information in the practitioner's office.

The recommendations on size, layout and perforation of data sheets agreed upon ten years ago and repeatedly stressed by CIDB and CIB documentalists are in force and there is no reason for changes, except for minor points. In some cases the 1949 recommendations may be unnecessarily detailed, but the major points and their application should be strongly promoted.

It may once more be said that articles in journals often contain most important information. The publishers of journals should, therefore, have these articles printed in such a way that they are suitable for being filed as information sheets, *i.e.* every article to have size A4, to begin on a right-hand page and with the UDC number according to ABC on its first page.

On the one side, producers of documents must be persuaded to follow international rules recommended up till now, and it is undoubtedly a task for CIB to take action in this field; on the other side, "consumers" of documents can hardly do any more than refuse documents which are not up to standard, and use their waste-paper baskets for them.

EXCHANGE OF INFORMATION

Improvement of the abstract service

The abstract exchange system (see Agreements on the exchange of information) has during the last ten years developed into a valuable means of communicating knowledge between participating information and documentation centres and, through these, it has served practitioners. The interest shown by countries that do not participate as yet is increasing and there are positive expectations for a good coverage of literature.

Out of the experience gained up till now some points may be worth mentioning.

In many countries the main function of the abstract is to indicate to the reader whether he should purchase the original document. Hence it is more important to have short abstracts immediately available than to get longer abstracts which include more data that are chosen in a subjective way.

The international exchange has proved to be of specific interest to information centres. It is important that those centres in the various countries have the necessary sources for supplying further information on a mutual exchange basis (*i.e.* bibliographies, lists of books, etc.). The abstract service needs to have in every country an information centre to fall back upon. It is not sufficient for practitioners in one country to obtain abstracts that are prepared for international exchange. It is important for a national centre to make national abstracts for the practitioners of its country and to add further data on request. From such national abstracts, covering the national literature more or less exhaustively, abstracts for international exchange can be selected and multiplied at relatively little cost.

CIB cannot terminate its activities in the field of the abstract service before a CIB member or other institute is found in every country to participate in the international exchange of building abstracts and before the present methodology is improved.

In order to take into account the experience gained and to bring the abstracts question up to date the General Secretary of CIB should guide and stimulate members that are working today with different kinds of abstracts and should encourage countries which have no abstract service to make a start. This action should be undertaken in accordance with the existing rules of CIB, FID, ISO and Unesco (a help for the start can be I. Karlén's recent study on the efficiency of the existing service) and with the needs of institutions, libraries and information centres. The last-mentioned requirement is important to prevent a new unmanageable stream of references being poured out over the heads of librarians and documentalists; they might only require abstracts on literature which is not easily traced in existing sources of bibliographical information.

The number of documents that are published is increasing by 100% over a period of 10 to 20 years. The cooperation in building research and practice between countries and regions is also increasing all over the world. Hence the problem of how to indicate and draw attention to literature on certain subjects is of great importance and must be studied carefully.

Specific attention must be given to matters such as widening the field of subjects (today, attention is mainly concentrated on housing and town planning only), selection of data, coverage of the totality of important data, taking over and division of the work for those areas that cannot take their share in the cooperation as yet for economic or organizational reasons, establishing a subject division that will enable an expert to follow easily the literature of a certain subject field, etc.

Improvement of the abstract service is an item on the draft programme for CIB's activities during the next three years.

Extension of the exchange of information (documents)

Extension of reference services can promote the transmission of knowledge and solve problems of information centres and practitioners, if properly made and restricted to essentials.

Between the original documents and their bibliographical data lies a range of types of references giving more or less information about the originals, such as annotated bibliographies, abstracts, digests and condensed full documents, that can all be published in different ways. Examples of types of references have been given in a small special exhibition at the CIB Congress.

If international cooperation, *e.g.* in CIB, finds a key to the questions of how to select in every country the knowledge which may be of international interest and which should consequently be specifically referred to and of how to organise the transfer of such references, a considerable contribution to the transmission of knowledge will be made.

In the near future it should be possible to find in nearly every country an institute (often it will be an information or documentation centre) prepared and able to act as national centre for the selection and exchange of information which is of international value. With a chain of such national centres, CIB can stimulate and help as far as exchange of information is concerned to find the response needed to reach definite results. In the first place the improvement and adaptation of the abstract service will be accelerated. Secondly, with the abstract service as a "backbone", the organization of the exchange of additional information (digests, condensed full documents, etc.) will be within reach.

Extension of the exchange of information (subjects)

Exchange is not only served by referring to documents as soon as they are published, but also by issuing surveys about the development of knowledge in a certain field. Such surveys can, for example, be given in selected bibliographies, trend reports and data sheets.

What is said about a chain of national centres for the furthering of reference services applies to this kind of information as well. Only if a well-equipped working apparatus is handling information problems nationally, can a sound basis be found for international cooperation and exchange. From the surveys mentioned above on the international level, the selected bibliographies, trend reports and data sheets are mainly of interest for research workers and information centres. Data sheets, on the other hand, give condensed information which should be useful for the practitioner as well.

If cooperation of information centres could lead to a coordinated active ("condensed") documentation, resulting in the production and dissemination of data sheets in a way already known in some countries, the practitioner would have immediate benefit from these activities. Meanwhile it can be stated that extension of the CIB bulletin with selected bibliographics is nearing realization.

LANGUAGE BARRIERS

Language for the exchange of information

It is not up to building documentalists and information offices to find world-wide solutions for the problem of differences in language, which interferes with the development of international cooperation generally. Nevertheless, at present no world-wide conventions in this field are in force and the transmission of knowledge in building needs a practical guiding principle to enable language barriers to be crossed by exchange of building information.

Such a guide could be the principle of "three language levels", which is being discussed in CIB circles. Level One (according to this concept) is the level of national languages, used naturally as the main language in every country.

Level Two is the level of "key languages" and contains, in fact, a selection of national languages which are more or less easily understood in a reasonable number of countries. The most important key languages of today seem to be English (dominant in the Western region) and Russian (dominant in the Eastern region). Other important languages of more than national importance and therefore eligible as key languages are Chinese, French, German and Spanish. Key languages should be used for publications of more than national importance and hence offer two advantages:

(a) A country publishing in the key language of the region concerned contributes to the international exchange without withholding too much information from its own country (the key language is current in the country concerned);

(b) Regional agreements can be reached by nominating one body (*e.g.* an information centre) as acting institute for issuing in the key language information collected from outside the region concerned.

Level Three contains one language only, serving as international language for the exchange between key language regions as far as the key languages are not mutually understood. Up till now English has been widely accepted as such an "international" language.

It seems worth while to have the "three language levels" principle accepted as a guide for language problems in the exchange of building information and to bring the principle into practice by choosing as a first step, for example, two centres in the Russian speaking and in the English speaking region, which could start with international exchange and act as disseminating centres for the regions concerned, collecting information from each other.

Terminology and translations

It has been stated above that correct understanding of each technical term in one's own language and in other languages as well are necessary for the exchange of information.

Both problems could be solved through international standardization of concepts in particular fields of subjects and through establishing appropriate terms for these concepts in every language (*e.g.* the UDC as presented in the ABC and the Glossary in the Report on Modular Coordination in Building, EPA No. 174). The task should be solved step by step in the frame-work of the CIB. A standard presentation of the terms of each field through meaningful sentences, supported by illustrations, is necessary (*viz.* Table I). The translations of such presentations in other languages would give parts of a dictionary and would at the same time present a basis of a future CIB Building Dictionary in the form of a book.

Multilingual CIB monographs and further translations of them with their alphabetical indexes would also present bricks to work with and could serve for the purpose of translations. Moreover, the availability of every technical book and document in several languages offers excellent possibilities to correct translations of other documents in the same field, especially when provided with an alphabetical index. It is worth consideration that CIB should publish a bibliography on such books and other documents, as far as the translations of the documents concerned are up to standard.

A NETWORK OF CENTRES FOR INFORMATION AND DOCUMENTATION

It has been stated before that the organization of information centres (or, in a more restricted sense, documentation centres) depends largely on the specific circumstances in the country concerned. Some main features, *e.g.* independency and impartiality, have been mentioned already.

It is not deemed useful to develop general patterns according to which these centres should organize their activities. More important than giving general rules for the organization

TABLE I

CIB Dictionary Dictionnaire	Modular co-ordination	. Coordination modulaire	
Sheet . Feuille	Terminology x/	. Terminologie x/	721.013
1959, Sept.			001.4 =20 =40

--- 389.63:69 ; 69.002.2 ; 69.057.1

a INTRODUCTION

a INTRODUCTION

aa The fundamental problem associated with the industrialization of building : to increase the variety in assembly of prefabricated components on the site, while maintaining a limited range of standardized sizes for the production in the factory; therefore a suitable choice of dimensions with a view to their relation in building - the dimensional co-ordination - is indespensable.

aa Le problème fondamental de l'industrialisation du bâtiment : accroître la variété des possibilités d'assemblage des éléments préfabriqués sur le chantier, en maintenant une gamme limité des grandeurs normalisées pour la prodoction en usines; pour cette raison une choix approprié des dimensions en vue de la construction - la coordination dimensionnelle - est indespensable.

ab Modular co-ordination : the achievement of dimensional co-ordination by means of a module the common unit of measure particularly specified for dimensional co-ordination .

ab Coordination modulaire : réalisation de la coordination dimensionelle au moyen d'un module unité de mesure déterminée particulièrement pour une coordination dimensionelle .

ac The specific terms are arranged corresponding to the main aspects of the subject: design, manufac - ture, building.

ac Les termes spécifiques sont arrangés correspondant aux aspects principaux du sujet: établissement du projet, fabrication, construction.

. . . . . .

b DESIGN

b ETABLISSEMENT DU PROJET

. . . . . .

c Reference grids are one of the aids to simplify the building design.

c Quadrillages de référence constituent l'un des procédés pour simplifier l'élaboration des plans de construction.

ca The sizes of the grids differ, but a square rectilinear system is normally used.

ca Les dimensions du quadrillage sont différents, mais on utilise normalement un tracé à maille carré.

. . . . . .

d The Modular reference system

Modular line

Modular point

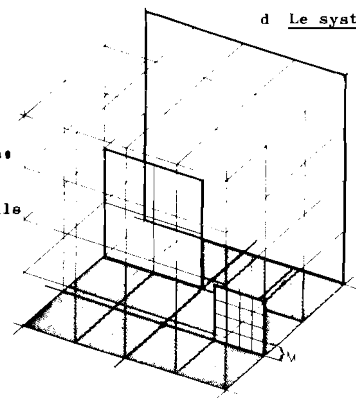
Modular grids

Module grid: spaced at intervals of the module

Planning grid: spaced at intervals which are multiples of the module

Modular plane

Modular space grid



d Le système modulaire de référence

Ligne modulaire

Point modulaire

Quadrillages modulaire

Quadrillage au module: maille di 1 module

Quadrillage de plan: maille multiple du module

Plan modulaire

Réseau modulaire

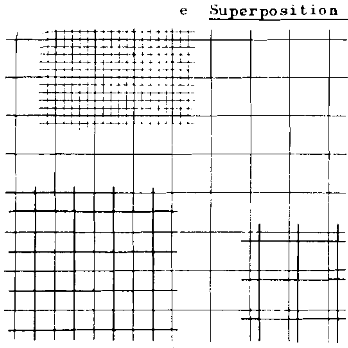
e Superposition of grids

e Superposition des quadrillages

Module grid — Quadrillage au module

Planning grid — Quadrillage de plan

Component grid — Quadrillages pour éléments



x/ Example/some selected chapters/ based on the Report EPA N°174

x/ Example/quelques chapitres choisis/ d'apès le Rapport AEP N°174

. . . . . .

g MANUFACTURE

. . . . . .

h Classification of building material

ha Materials		
hb Components	hc Sections	
	hd Units	
	he Assemblies	
hf Functional elements		
hg Systems of building		

. . . . . .

Alphabetical index
/parts refering to this example-sheet/

. . . . .

g FABRICATION

. . . . . .

h Classification des matériaux et éléments de construction

ha Matériaux		
hb Matériaux et éléments dimensionnés	hc Matériaux semi-finis	
	hd Matériaux finis	
	he Eléments complexes	
hf Eléments fonctionnels		
hg Systèmes de construction		

. . . . . .

Index alphabétique
/parties référant à cette feuille-éxample/

of these centres seems to be to assist in furnishing data about existing centres and their ways of operating, in the training of personnel and to consider possibilities of future cooperation between centres in a world-wide network.

Collecting and disseminating experiences of information centres

In 1958 the Bouwcentrum, Rotterdam, cooperating with the International Federation for Housing and Town Planning, the Dutch Organization for Industrial Research TNO and others started an International Course on Building, with opportunity for the participants to choose one out of five specializations, the fifth one being transmission of knowledge. Bouwcentrum was glad to find among the participants one choosing that specialization and actually engaged in establishing an information centre. The course, started in 1958, will be repeated in 1959 (and, probably, in succeeding years as well). It seems worth consideration to collect gradually more data about experiences of existing information centres and to put them at the disposal of participants of the course and eventually to bring them together in a concise manual for further dissemination.

Training of building documentalists

More and more organizations and firms wish to establish documentation departments. Therefore it is not the information centres only that benefit if assistance is given to the training of documentalists.

It is apparent that there are few people with the necessary experience to build up and run such departments and to manage them on the basis of personal experience, and, similarly, there is a dearth of qualified assistance. Consequently the training of documentalists must be a matter of serious concern to all those who realize the importance of documentation as a foundation for research and as a step towards rationalization.

Documentation can serve many fields of knowledge. Training, therefore, must embrace two stages: a basic training in documentation and a specialist training directed towards the particular subject field. Training facilities for the basic training are offered in several countries mostly on a private (non-governmental) level. As far as is known today, it is in no case regarded as full professional training. The syllabuses today contain so many features in common that one can say that the lines of the basic training are generally recognized. Essential differences are shown, however, in the weight given to certain aspects. Nevertheless, in various countries the basic training of documentalists covers the needs.

This is not the case with courses for documentation training in a particular subject field; whoever is in practice as a subject documentalist today, has grown up in the job without outside help. Firstly three points must be stressed:

1. Special subject training cannot stand alone – it is essential to have a basic training first and to extend this for the particular subject.
2. Only documentalists who have worked for some time in a documentation centre in their particular specialist field after their basic training should be admitted to subject training, so as to ensure that they have a thorough knowledge of the subject and its documentation needs.
3. Subject training in documentation can only be conducted by people who have built up their own organization and are thoroughly conversant with the subject field and documentation technique.

Turning now to the main theme of "Training of building documentalists", it will be seen that these three principles form a programme of work.

The responsibility for the training of building documentalists, it seems, is essentially a job for CIB. If this principle would be accepted, the next tasks would be:

provision of teaching material;
establishment of a syllabus;
collection of teaching material.

The collection of the training material requires the collaboration of all the member countries, as information is required from each country. (A list of training material is given in Appendix I.)

As main points for the training programme are mentioned here:

1. Organization of building documentation;
2. Special functions of building documentation;
3. Establishing a building documentation centre;
4. Work flow in a building documentation centre;
5. Classification systems in the building field;
6. Establishment and running of technical building information services;
7. Literature handling;
8. Costing for installation and operation of a building documentation centre, for literature handling and information service;
9. Time and work control in a documentation centre;
10. Reader relations; telephone and written inquiries; visitors' reading room.

(A more detailed programme is given in Appendix I.)

Future cooperation between information centres: a network

In the foregoing pages the necessity of an international cooperation between national information centres has been stressed repeatedly. Participation in improvement of the abstract service, exchange of publications and other information, and a programme for production and dissemination of data sheets are some of the points mentioned before where activities of and cooperation between information centres are essential.

The same applies in the problem of languages: realization of the principle of "three language levels" (see Language for the exchange of information) requires at least one active centre in every key language region cooperating with centres in other regions. Terminology work will be difficult to control in countries where no body qualified to handle this problem is available, unless an information centre or national committee takes its share in the international work.

Moreover, the results of international activities with regard to, for example, classification and standardization of documents, can be successfully propagated if in every country a national centre can organize and give support to the dissemination of these results. There is every indication today that in several countries the development of information centres has gone so far that there are actual possibilities to give international cooperation a definite form, preferably under the auspices of the CIB. As soon as the network of information centres is established the possibilities of transmission of knowledge can be further extended.

Not only can the international exchange of information on building be assured, but also the study and the exchange of information on methods and means of transmission can be extended. Techniques of visual and auditive aids, methods of giving information and instructions can be studied jointly and the results can be spread quickly, thus serving the transmission of knowledge, building and, finally, society.

SUMMARY INCLUDING CONCLUDING STATEMENTS

THE PROBLEMS

Neither an individual nor a team can comprehend any longer the knowledge produced in the world of today. The growth and development of society lead amongst others to specialization; transmission of knowledge becomes more and more difficult.

Hence science and practice must again be brought more closely together (integration) and the stream of data now flooding the world must be brought back to a manageable size and directed in accordance with the needs of the user (canalization). Moreover, needs which are not covered by existing knowledge must be traced and research directed to these needs.

Knowledge which is not used must be brought into practice by developing an awareness of latent needs.

The practitioner

The practitioner prefers books for the "storage" of knowledge in his office. Other documents he wants to be of standard format (A4), preclassified and in all other respects easy to file and to trace.

The practitioner asks for a method of arranging these documents and for publishers to be convinced that documents not in accordance with agreements on standardization are wasteful.

Arrangement means classification. The number of data available in the practitioner's office is and must be restricted. The practitioner asks for an easy access to all other data which might be of importance for him, preferably to be found in the same part of every information centre dealing with his special problems.

Publishers

Publishers, including authorities, research institutes and editors of trade catalogues, have to deal with the problem of how to add to the ever growing stream of documents without their publications getting lost. As far as books are concerned the problem is of minor importance; for all other documents, analysing and following the requirements of the practitioner with regards to format, classification and other aspects of presentation for easy filing and retrieval are essential.

Information centres

Information centres collect information and disseminate it. They should preferably be independent organizations, with well organized contacts with groups representing different aspects of science and building, and issue impartial information concisely and quickly.

The task of an information centre includes: furthering integration of theory and practice, tracing data, collecting, arranging, selecting, adapting and disseminating data; detecting gaps and promoting the use of knowledge.

They are, amongst others, in the need of a world-wide system of references for the tracing of data (reference service) and a universal classification system; they ask for solutions of problems of terminology and translation, exchange of information (digests, bibliographies, etc.) and production of condensed data sheets (active documentation). Development of techniques of transmission of knowledge is of vital interest to them.

WHAT HAS BEEN DONE

The United Nations Economic Commission for Europe sponsored the Conference on Building Documentation (Geneva, 1949), from which resulted the foundation of the CIDB, transformed in 1953 into the CIB. CIB and FID together established IBCC.

Under the auspices of these organizations agreements were reached, amongst other matters, on standardization of documents for filing (format, preclassification, prepunching, etc.), classification and exchange of information. The Abridged Building Classification, ABC (a selection from UDC), was compiled and published in eight languages (translations in four more languages to be printed in due course; three more are in preparation). Existing special building filing systems have been investigated and a new coordinated system, combining UDC with a special system for building (SfB) has been published in the IBCC *Building Filing Manual* (September, 1959).

For the exchange of information, directives were given with regards to an international abstract service, about ten countries participating in the service up to the present and seven more countries offering similar services.

For the breaking down of language barriers, the ABC editions in various languages

– due to a special layout – give a certain amount of help. Trials have been made with terminology problems, but without practical results.

Directives – although limited ones – concerning the establishment of national building documentation committees or centres have been given in 1950. Since 1950 in various countries centres or committees have been founded and existing centres have extended their activities.

WHAT HAS TO BE DONE

Members of CIB engaged in documentation and transmission of knowledge propose that a number of the following main points should form part of the programme of CIB for the next three years.

Agreements

Agreements reached in foregoing years must be brought into action. A summary of these agreements should be published in the CIB Bulletin and the circulation supported by reprints in national periodicals.

Classification

IBCC has announced already that it will develop a coordinated classification system and that a first draft will be tested by the Bouwcentrum. Introduction of any other system should be postponed. Meanwhile translation and use of the ABC and the IBCC *Building Filing Manual* must be promoted.

Standardization

Let everybody involved in building take his share in convincing publishers that documents should be according to requirements to prevent the loss of knowledge and to promote its use.

Exchange of information

Exchange of information must be improved:

(a) It is CIB's task to promote the extension of abstracts production and exchange and the adaptation of abstracts to the needs of research institutes, libraries and information centres.

(b) Extension and adaptation of abstract services must be followed by extension of the exchange of documents or data from documents (*e.g.* microcards, digests).

(c) To the exchange of information on documents must be added information on, for example, bibliographies and trend reports.

(d) The information on subjects has to be completed by a well-organized production of data sheets (active documentation) which will be circulated to practitioners.

Language barriers

Gates must be opened in the language barriers.

(a) The principle of "three language levels" should be discussed internationally and, if agreed upon, be brought into practice by organizing (as a first step), for example, two "linguistic" centres, one for the English speaking region and one for the Russian speaking region.

(b) An inquiry into the possibilities of standardizing terminology is urgently needed; a loose-leaf illustrated dictionary, published gradually, might be attainable.

CIB monographs and reports and their translations should be provided with alphabetical indexes referring to the main terms.

Information network

An international network of centres or committees for building information and/or documents must be organized.

Experiences with establishment and running of information centres might be compiled in a manual.

The opportunities for instruction and exchange of experience of persons involved in establishing and operating information centres, as given in the Bouwcentrum International Course on Building must be improved and enlarged.

The possibilities for arranging the international training of building documentalists must be examined.

Since in various countries information centres or committees have been founded, the organization of their cooperation in a world-wide chain can be realized; CIB could make the first move.

An international chain of national information centres and committees will have the task of developing methods and means of transmission of knowledge and to further the exchange of all the material that is available in this field.

ACKNOWLEDGEMENTS

Valuable contributions to this paper have been made by R. Mölgaard-Hansen at the request of the International Building Classification Committee (IBCC); he is responsible for the paragraphs on classification.

Dan Fink made valuable suggestions for the section on standardization of documents, etc. Data for the subject "Exchange of information" were furnished by him, by I. Karlén (who has made an extensive inquiry into the situation today) and others.

The ideas with regard to languages for exchange of information are from E. Nicklin and O. Stach, those on terminology and translation from M. Molè; Miss C. Müller is responsible for the section on training of building documentalists.

The "Bibliography on Building Documentation" (Appendix 2) has been compiled by R. Mölgaard-Hansen, with the assistance of members of the IBCC and the CIB group of documentation experts.

APPENDIX I

LIST OF TRAINING MATERIAL AND DETAILED PROGRAMME

List of training material

Information on:

1. Organizations
   - 1.1 Top-level building authorities: their activities.
   - 1.2 Professional institutions of architects, engineers, etc. Lists of members.
   - 1.3 Trade associations of the building industry and building materials industry. Lists of members.
   - 1.4 Patent offices.
   - 1.5 Standards institutions.
   - 1.6 Documentation associations.
   - 1.7 Publishers' associations.
2. Building centres. Building exhibitions (permanent and periodic)
3. Teaching and building research
   - 3.1 Associations for the promotion of science and technology.
   - 3.2 Universities. Technical colleges.
   - 3.3 Research institutes. Building materials testing laboratories.
4. Technical libraries: range and subject

5. Documentation centres
   5.1 For building and architecture. General.
   5.11 For special aspects of building, *e.g.* roads, house building.
   5.2 For town and country planning.
   5.3 For housing.
   5.4 For building law.
   5.5 For ancillary subjects, *e.g.* paints, optics.
6. Publications
   6.1 National bibliographies or similar reviews of the national book production.
   6.11 Publishers' catalogues (only where no national bibliography is available).
   6.12 Bibliographies on building.
   6.2 Building directories.
   6.3 Periodicals relating to building or its ancillary subjects.
   6.4 Serial publications of building research institutes and technical or scientific organizations.
   6.5 Official publications, building laws, regulations, etc.
   6.6 Standards.
   6.7 Patents, copyright.
   6.8 Encyclopaedias, dictionaries, glossaries.
   6.9 Data sheets, card indexes.

For courses the material should be listed and arranged by country; a collection of sample and exhibition pieces is desirable. There should be as complete a collection as possible of specimen copies of glossaries, dictionaries, the most important periodicals and documentation tools.

Detailed programme

1. Organization of building documentation
   1.1 Within the country.
   1.11 Collaboration with other documentation centres within the country in the same or complementary fields.
   1.2 Collaboration with foreign building documentation centres.
   1.3 Definition of the range and coordination of work with documentation centres in the same or complementary fields.
2. Special functions of building documentation
   2.1 For research.
   2.2 For administration.
   2.3 For architects' and engineers' offices.
   2.4 For contractors, including site offices.
   2.5 For publishing.
   2.6 For reference sections of public libraries.
3. Building up a building documentation centre
   3.1 General equipment. With or without sales department. With or without reading room.
   3.2 Handling of special collections (plans, drawings, photos, films, models).
   3.3 Layout of card indexes for different purposes.
   3.4 Technical equipment for reproduction selection, etc.
4. Work flow in a building documentation centre
5. Classification systems in the building field
   5.1 Comparative evaluation of various systems.
   5.2 Independent work in the field of decimal classification.
   5.3 Reliable operation of any other classification system which may be introduced into the documentation centre in question.

6. Establishment and running of technical building information services
   6.1 Information sheets.
   6.2 Data sheets.
   6.3 Card indexes.
   6.4 Editing and reviewing technical reports.
7. Literature handling
   Literature selection, title bibliographies with or without annotation.
8. Costing for installation and operation of a building documentation centre, for literature handling and information service
9. Time and work control in a documentation centre
10. Reader relations. Telephone and written inquiries. Visitors' reading room.

Plans, illustrations or sketches on the layout of documentation centres should also be requested, as well as trade catalogues with technical data on furniture, processes and equipment.

APPENDIX 2

BIBLIOGRAPHY ON BUILDING DOCUMENTATION

Compiled by R. Mølgaard-Hansen, Secretary of the International Building Classification Committee (IBCC), Technical Library of Denmark, Øster Voldgade 10, Copenhagen K.

Introduction

This bibliography covers mainly publications on building documentation issued during the post-war period until June, 1959. It is divided into three parts.

A: Articles, papers, proceedings, etc., are arranged chronologically, this being indicated by a two-digited year number. The titles covering a single year are again classified in a helpful way by means of the following designation:

a = Generalities and miscellaneous
c = Classification and filing
d = Dissemination: abstracting, digesting and indexing
n = Needs of the users for documentation
p = Publications and distribution
t = Terminology

Finally, a sequential number is assigned to each publication listed.

B: Abstract journals, digests, indexes, etc., are arranged according to country of origin.

C: Authors' names, arranged alphabetically, with an indication of relevant sequential numbers.

CIB, CIDB, and UN publications mentioned here may be obtained from the CIB General Secretariat, Bouwcentrum, Weena 700, Rotterdam, and FID publications similarly from the International Federation for Documentation, Hofweg 7, The Hague (the Netherlands).

A. *Articles, papers, proceedings, etc.*

38a1 WINSER, J. K., *Information services in the building industry,* Trans. 14th Conf. FID, Oxford, 1938, Vol. 2, p. 189–191.

45n2 TEGNESTUENS ORGANISATION, Fem Arkitekter redegør for Opbygningen af deres Tegnestue, *Arkitekten,* 47 (1945) 1–16 (Examples of the organization of five Danish architectural offices).

46c3 DIDELIN, P., Classification méthodique des activités du Bâtiment, de la Construction métallique et des Travaux Publics selon la méthode de M. G. Cordonnier, *Inst. Techn. du Bâtiment et des Travaux Publics,* X, 7 (1946) 35.

46c4 ROBERTS, D. M., Application of the Universal Decimal Classification in the building industry. Some suggestions for filing office papers and trade catalogues, *Proc. Brit. Soc. Int. Bibliography,* 8 (1946) 23–27.

47a5 PENN, C. T., Sources of Information for Architects. *Roy. Inst. Brit. Architects J.,* 55 (1947) 29–33.

48a6 GIERTZ, L. M., Byggdokumentationens internationella organisation, *Bygglitteratur,* 3 (1948) 157.

48a7 Herzner, E., Zur Arbeitsmethodik des Architekten. 1. Rationalisierung auch in der geistigen Arbeit. – 2. Die Arbeitsmittel des Architekten. – 3. Die Ordnung des Stoffes. – 4. Die praktische Durchführung, *Bauhelfer*, 3 (1948) 623–628.

48c8 The Royal Society Scientific Information Conference, 21 June–2 July, 1948. Report and Papers submitted. U.K., London, The Royal Soc., 1948, p. 203–204. Emphasizes increased, international use of the UDC in spite of its deficiencies; recognizes the necessity of an improved, eventually new, classification.

48c9 *SfB building register and its application*. Edited by the SfB Coordination Committee for the Building Trade, Sweden. Report of June 11, 1948, 18 + 72 p. (prepared by the Secretary, L. M. Giertz).

48c10 Nicklin, E., SfB Byggregister, *Bygglitteratur*, 3 (1948) 133–134.

48c11 SfB Byggregister och CDU, *Bygglitteratur* 3 (1948) 11, 213–214, 231.

49a12 United Nations, Housing and Town and Country Planning, Report of the Secretary-General (Doc. E/1343 : 8 June 1949, p. 6). Defines the purpose of an integrated U.N. programme on Housing. See pages 43–47 and 57–58: Exchange of information.

49a13 Arctander, P., Byggedokumentation – et internationalt samarbejde under udvikling, *Arkitekten Ugehaefte*, 51 (1949) 38, 153–155.

49a14 Beusekom, H. G. van, Internationale Bouwdocumentatie, Conferentie van deskundigen te Genève, *Bouw.*, 4 (1949) 46, 819–821.

49a15 Evans, B. Agard, International Collaboration in the Field of Building, *ASLIB Proceedings*, 1 (1949) 2, 138–143. Reviews decisions concerning building documentation made at the International Reconstruction and Town Planning Exhibition at Paris in 1947 and of the restricted Expert Conference at Brussels in February, 1948.

49a16 La Conférence sur la documentation du bâtiment à Genève du 6 au 15 octobre 1949, *Les cahiers de la documentation, Bruxelles*, 3 (1949) 134–144.

49a17 U. N. Economic Commission for Europe, Conference on Building Documentation, Geneva, 6–15 October 1949. *Proceedings*, 225 p., mimeographed. (Doc. E/ECE/111 – E/ECE/HOU/BD/2).

49a18 U. N. Economic Commission for Europe/Housing Sub-Committee, Note by the Secretariat on the convening of an International Conference on Building Documentation (Doc. HOU/BD/1). Defines the primary objectives of the Conference.

49a19 Evans, B. Agard, *Proposed International Union of Building Documentation Committees* (Doc. HOU/BD/5).

49a20 Giertz, L. M., *General Notes on Building Documentation* (Doc. HOU/BD/4).

49a21 Nicklin, E., Byggnadsdokumentation, *Byggaren*, 26 (1949) 10/11, 106–108.

49a22 Rusert, K., Zur Arbeitsmethodik des Architekten. 1. Rationalisierung in der geistigen Arbeit. – 2. Das Klassifizieren nach der Dezimalklassifikation. – 3. Normkartei des Wissens. – 4. Noch einmal: Kartei des Wissens, *Bauhelfer*, 4 (1949) 6, 159–161.

49c23 *Adoption and Adaptation of the Universal Decimal Classification*, Report of Working Party No. 3 (Doc. HOU/BD/12 – Proc. Conf. 1949, p. 42–44).

49c24 Delune, J., *Note on Amendments and Improvements to be made to the Building Sections of the Universal Decimal Classification* (Doc. HOU/BD/WP3/6 – Proc. Conf. 1949, p. 158–160).

49c25 Evans, B. Agard, *Note on the UK Ministry of Works Abridged UDC Schedule* (Doc. HOU/BD/WP3/3).

49c26 Lorphèvre, G., *Report on the Universal Decimal Classification* (Doc. HOU/BD/WP3/4 – Proc. Conf. 1949, p. 125–150).

49c27 Roberts, H., V. Moleworth and G. A. Lloyd, *Adoption and Adaptation of the Universal Decimal Classification in Great Britain* (Doc. HOU/BD/WP3/5 – Proc. Conf. 1949. p. 151–157).

49c28 Winther, E., *Requirements of the Users of the UDC* (Doc. HOU/BD/WP3/2).

49c29 *Problems of Filing and Classification*, Report of Working Party No. 4 (Doc. HOU/BD/11 – Proc. Conf. 1949. p. 45–46).

49c30 American Institute of Architects, The AIA Filing System and Alphabetical Index (AIA document No. 172); and the AIA Filing System for Architectural Plates and Articles (AIA Document No. 261) (Doc. HOU/BD/WP4/4 – Proc. Conf. 1949, p. 181–185).

49c31 Giertz, L. M., *Swedish SfB Building Register* (Doc. HOU/BD/WP4/2 – Proc. Conf. 1949. p. 161–170).

49c32 Guérin, P., *The Cordonnier Classification applied to Building and Civil Engineering Technics* (Doc. HOU/BD/WP4/3 – Proc. Conf. 1949. p. 171–180).

49c33 Wåhlin, E., *Basic Principles and Outline of a New Universal System of Classification* (Doc. HOU/BD/WP4/6).

49c34 *Classificazione Decimale Universale*. Riduzione Italiana delle sezioni riguardanti l'edilizia. Consiglio Nazionale delle Ricerche, Rome, 1949, 27 p.

49c35 Ditmas, E. M. R. and M. Gosset, Report on the Restricted Conference of the International Federation for Documentation (FID) at The Hague, June 17–23, 1948, *ASLIB Proc.*, 1 (1949) 57–67. Recommendation of the establishment of a joint international committee on building classification having as one of its aims the comparative study of the UDC and SfB systems as applied to building.

49d36 *Scope and Nature of Abstracts*, Report of Working Party No. 1 (Doc. HOU/BD/14 – Proc. Conf. 1949, p. 22–31).

49d37 *Abstracting with particular reference to building documentation*; note by the Unesco Secretariat (Doc. HOU/BD/3 – Proc. Conf. 1949, p. 71–77).

49d38 Broek, J. H. van den, *Scope and Nature of Abstracts*; *report made on behalf of Users* (Doc. HOU/BD/WP1/4 – Proc. Conf. 1949, p. 99–109).

49d39 CÉAS, G. B., *Scope and Nature of Abstracts; report made on behalf of the Architects* (Doc. HOU/BD/WP1/3).
49d40 MARINI, A., *Character and Bearing of Abstracts; report made on behalf of Research Organizations* (Doc. HOU/BD/WP1/2 – Proc. Conf. 1949, p. 92–98).
49d41 *Organization of an International Abstracting Service*, Report of Working Party No. 2 (Doc. HOU/BD/16 – Proc. Conf. 1949, p. 32–41).
49d42 *Organization and Financing of an International Documentation Service for the Building Industry*, note by the Secretariat (Doc. HOU/BD/6 – Proc. Conf. 1949, p. 78–91).
49d43 ANDEL, GERDA H. VAN, *Cooperation in the Field of Reproduction and Distribution of Documentation Cards* (Doc. HOU/BD/WP2/4 – Proc. Conf. 1949, p. 117–121).
49d44 EUGENIO, C., *Organization of an International Abstracting Service* (Doc. HOU/BD/PW2/9 – Proc. Conf. 1949, p. 122–124).
49d45 CEDOC, Resolutions passed at the International Congress on Building Documentation, Paris, 1947, and Report of the Meeting on February 27, 1948, in Brussels (Doc. HOU/BD/WP2/7).
49d46 GARDNER, A. L., *Note on the British Abstracts Journal "Building Science Abstracts"* (Doc. HOU/BD/WP2/8).
49d47 GIERTZ, L. M., *Building Documentation in Sweden* (Doc. HOU/BD/WP2/2).
49d48 GUÉRIN, P., *The Abstracting Service for Periodicals at the Technical Institute for Building and Public Works (Paris)* (Doc. HOU/BD/WP2/5).
49d49 MAREČEK, F., *Organization of an International Abstracting Service* (Doc. HOU/BD/WP2/3 – Proc. Conf. 1949, p. 110–121).
49d50 VESTEL, L. DE, *Note concerning the International Organization on Building Documentation* (Doc. HOU/BD/WP2/6).
49p51 *Recommendations for Building Publications and Official Building Publications*, Report of Working Parties 5/6 (Doc. HOU/BD/15 – Proc. Conf. 1949, p. 47–53).
49p52 ETTINGER, J. VAN, *A Combined Paper relating to Catalogues, Trade Literature and Data Sheets* (Doc. HOU/BD/WP5/4 – Proc. Conf. 1949, p. 190–196).
49p53 GARDNER, A. L., *The National Dissemination of Published Information on Building* (Doc. HOU/BD/WP6/2 – Proc. Conf., 1949, p. 197–210).
49p54 GOULDEN, G. I., *The Use of Films in the Building Industry* (Doc. HOU/BD/WP5/3 – Proc. Conf. 1949, p. 186–189).
49p55 HOLM, K. L., *Housing and Planning Information in the USA: An Outline* (Doc. HOU/BD/WP5/8).
49p56 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO), *Report of Findings on the Subject of Format* (Doc. HOU/BD/WP5/2).
49p57 MAREČEK, F., *Official Building Publications* (Doc. HOU/BD/WP6/3).
49p58 MÖLLER-SÖRENSEN, P., *Recommendations for Building Publications: Periodicals* (Doc. HOU/BD/WP5/5).
49p59 VESTEL, L. DE, *Paper relating to Work already accomplished in Belgium* (Doc. HOU/BD/WP5/6).
49p60 VESTEL, L. DE, *Recommendations for Building Publications* (HOU/BD/WP5/7).
49t61 *Terminology*, Report of Working Party No. 7 (Doc. HOU/BD/13 – Proc. Conf. 1949, p. 54–55).
49t62 GORYNSKI, J., *Note on Terminology* (Doc. HOU/BD/WP7/5 – Proc. Conf. 1949. p. 215–217).
49t63 GROSBORNE, H., *Building Terminology* (Doc. HOU/BD/WP7/3 – Proc. Conf. 1949, p. 210–212).
49t64 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO), *Report on the Meetings of the Technical Committee ISO/TC-59* (Building Construction) (Doc. HOU/BD/WP7/2).
49t65 NICKLIN, E., *Note on Terminology* (Doc. HOU/BD/WP7/4 – Proc. Conf. 1949, p. 213–214).
50a66 Building documentation, *The Builder*, 108, 5607 (1950) 145–146.
50a67 La documentation du bâtiment, *Rev. Documentation*, 17 (1950) 29–30. Report of the Conference on Building Documentation in Geneva, October 6–15, 1949.
50a68 RINGLEB, W., Dokumentation im Bauwesen, *Gas- und Wasserfach*, 91 (1950) 24, 311.
50a69 STATENS KOMMITTÉ FÖR BYGGNADSFORSKNING, *Utredning rörande referettjänstens ordnande inom byggnadsfacket*, Avlämnad 16 juni 1950 av Referattjänstkommittén, Stockholm, 1950, 49 pp. + 7 suppl.
50a70 CIDB (International Council for Building Documentation) First General Assembly, Paris (from 23 to 28 October, 1950). Secretariat of the CIDB, Paris, 1950, 47 pp. Available also in French version.
50a71 L'ASSEMBLÉE GÉNÉRALE CONSTITUTIVE DU CONSEIL INTERNATIONAL DE DOCUMENTATION DU BÂTIMENT, Rapport sur la conférence tenue à Paris 23–28 octobre 1950, *Les cahiers de la documentation, Bruxelles*, 4 (1940) 126–133.
50a72 INTERNATIONAL COUNCIL FOR BUILDING DOCUMENTATION, *Rev. Documentation*, 17 (1950) 191–192.
50c73 *Classification and filing*, Report of Working Party No. 5 (Doc. CIDB/GT5/5(50) – Proc. Gen. Ass., p. 21–22).
50c74 DANISH BUILDING CLASSIFICATION COMMITTEE, *report on the UDC* (Doc. CIDB/GT5/4(50) – Proc. Gen. Ass., p. 45–46).
50c75 EVANS, B. AGARD, *Working Party on Classification*, (Doc. CIDB/GT5/1(50) – Proc. Gen. Ass., p. 41).
50c76 LLOYD, G. A., *British recommendations for preferred use of the various subdivisions* (of UDC) (Doc. CIDB/GT5/2(50) – Proc. Gen. Ass. p. 41).
50c77 NICKLIN, E., Internationella aspekter på SfB byggregister, *Byggaren*, 27 (1950) 6, 76–78.
50c78 TAVARES, J. F. C., *Improvements to be made in the methods of the Universal Decimal Classification* (Doc. CIDB/GT5/3(50) – Proc. Gen. Ass., p. 42–45).
50d79 *Progress in documentation; Organization of exchanges; Inquiries*, Report of Working Party No. 2 (Doc. CIDB/GT2/5(50) – Proc. Gen. Ass., p. 17–18).

50d80 ARCTANDER, P., *Report on the organization of the exchange of abstracts* (Doc. CIDB/GT2/2(50) – Proc. Gen. Ass. p. 31–33).

50d81 CLÉMANDIÈRE, J. DE LA, *Usefulness of an international system for translations* (Doc. CIDB/GT2/3(50) – Proc. Gen. Ass., p. 33).

50d82 JOHANNESSEN, R., *Building Documentation in Norway* (Doc. CIDB/GT2/4 – Proc. Gen. Ass., p. 33–34).

50d83 PEPE, C., *Report on the situation of building documentation and on its possibilities of development* (Doc. CIDB/GT2/1(50) – Proc. Gen. Ass., p. 27–31). Result of a world-wide inquiry.

50n84 *Needs of the users; Necessity for documentation; Methods of increasing its usefulness*, Report of Working Party No. 1 (Doc. CIDB/GT/15(50) – Proc. Gen. Ass. p. 17).

50n85 CÉAS, G. B., *The architects' needs in the field of building documentation* (Doc. CIDB/GT1/2(50) – Proc. Gen. Ass., p. 26).

50n86 DELUNE, J., *Abstracts as adapted to the actual needs of building technicians* (Doc. CIDB/GT1/3(50) – Proc. Gen. Ass., p. 26).

50n87 GIERTZ, L. M., *Report on practitioners' use of documentation* (Doc. CIDB/GT1/1(50) – Proc. Gen. Ass. p. 25).

50n88 SABATIER, H., *Note on the use of statistics for documentation purposes* (Doc. CIDB/GT14/(50) – Proc. Gen. Ass., p. 27).

50p89 *Publications and distribution*, Report of Working Party No. 4 (Doc. CIDB/GT4/4(50) – Proc. Gen. Ass., p. 19–21).

50p90 ETTINGER, J. VAN, *Report of the provisional Executive Committee concerning publications* (Doc. CIDB/GT4/1(50) – Proc. Gen. Ass., p. 36–39).

50p91 JONATHAN, F., *Note on the granting of a certifying seal for publications conforming with the recommendations of the CIDB* (Doc. CIDB/GT4/2(50) – Proc. Gen. Ass., p. 40).

50p92 *Note on the creation of information bulletins*, presented by the French Committee for Building Documentation (Doc. CIDB/GT4/3(50) – Proc. Gen. Ass., p. 40).

50t93 *Terminology*, Report of Working Party No. 3 (Doc. CIDB/GT3/6(50) – Proc. Gen. Ass., p. 19).

50t94 GARDNER, A. L., *Suggestions for the working party* (Doc. CIDB/GT3/2(50) – Proc. Gen. Ass., p. 36).

50t95 GROSBORNE, H., *Report on the work carried on by the French working party on terminology* (Doc. CIDB/GT3/3(50) – Proc. Gen. Ass., p. 36).

50t96 VESTEL, L. DE, *Technical commission on terminology* (Doc. CIDB/GT3/1(50) – Proc. Gen. Ass., p. 34–35).

51a97 MÜLLER, CLARA E., Die Arbeiten der bautechnischen Auskunftsstelle der Forschungsgemeinschaft Bauen und Wohnen, *Nachrichten für Dokumentation*, 2 (1951) 2, 69–72.

51c98 NETTELBLADT, B., Basic principles and requirements for systems of classification and the PAM system, *Tekniska Litteratursällskapet, Meddelanden*, 4 (1951) 15, Stockholm.

51c99 SAUTTER, L., Systematische indeling der bouwstoffen, elementen, constructies, *Bouw*, 42 (1951) 717–719.

51d100 Arkitekten's referattjeneste, *Arkitekten Ugehaefte*, 53 (1951) 3, 13–14.

51d101 *British Building Summaries*, prepared by the libraries of the Royal Institute of British Architects and the Ministry of Works for the British Building Documentation Committee. Draft specimen, September, 1951. Contains 44 digests classified according to the UDC.

51d102 Les feuilles de documentation de C.E.D.O.C., *La Construction*, 7 (1951) 12, 16.

51n103 MARQUET, J., La documentation dans l'entreprise de construction, *Organisation et Statistiques du Bâtiment (Paris)*, 4 (1951) 3, 66–70 and 4, 108–113. Analysis of the forms of publications needed and methods of classification recommendable.

51p104 UNITED NATIONS, HOUSING AND TOWN AND COUNTRY PLANNING, *Announcement of the availability of technical publications in the fields of building, housing and town and country planning through the United Nations technical assistance administration*, New York, 1951, 18 pp.

51p105 Passage du stade de la recherche à celui de l'application industrielle, *Organisation et Statistiques du Bâtiment (Paris)*, 4 (1951) 5, 142–146. Description of six different types of documentary publications used in Great Britain within the field of building.

52a106 The application of research, *Builder*, 182 (1952) 5696, 577–578; 5697, 615; 5698, 649.

52a107 BRODIE, R. J., Building documentation, *Building Research (Canada)*, 1 (1952) 3, 69–72.

52a108 COOK, RUTH V., The library of the Department of Architecture, *Harvard Library Bulletin*, 6 (1952) 2, 263–269. Abstract, see *Journal of Documentation*, 9 (1953) 88.

52a109 GIERTZ, L. M., Baudokumentation in Schweden. *Nachrichten für Dokumentation*, 3 (1952) 2, 76–80.

52a110 KARLÉN, I., Byggnadsdokumentation, *Tidskrift för Dokumentation*, 8 (1952) 5, 49–54, Stockholm.

52a111 LARSON, C. T., The U.S. Building Industry: A. Case Problem in Communications, *American Documentation*, 3 (1952) 4, 208–213.

52c112 BRISCH, E. G., *Brisch Building Classification*, prepared for the British Building Documentation Committee, E. G. Brisch & Partners, 26 Victoria Street, London S.W. 1, September, 1952, 16 pp.

52c113 FINK, D., Meeting of Specialists on Building Classification, Copenhagen, Sept. 30–Oct. 3, 1952, *Rev. Documentation*, 19 (1952) 3, 81–82. Establishment and First Meeting of the International Building Classification Committee (IBCC).

52c114 INTERNATIONAL BUILDING CLASSIFICATION COMMITTEE, a joint CIB/FID committee: The Terms of Reference (FID Communication F 52–130, Dec. 1952). Annual Reports: 1953/54 (FID Communication F 54–58), 1955 (FID Communication F 55–120), 1956/57 (Informations FID, 7 (1957) 11, 41), 1957/58 (Informations FID, 8 (1958) 12, 30).

52c115 Müller, Clara E., Wie ordne ich mein Schrifttum? Die Dezimalklassifikation als Ordnungsmittel für bautechnisches Schrifttum, *Bauzeitung*, 57 (1952) 2, 78–80.

52c116 Mölgaard-Hansen, R., On the use of UDC in Building Classification, *Review of Documentation*, 19 (1952) 2, 27–30.

52d117 Ewing, A. F., J. van Ettinger and B. A. Evans, *Rapport établi par le Groupe de Travail chargé d'étudier la méthode de distribution des analyses, la question de la répartition des tâches et les incidences financières de la répartition* (Doc. CIDB/GT2/1(52).

52n118 Giertz, L. M., *Documentation for building practitioners* (Doc. CIDB/GT1/6(52).

53a119 International Council for Building Research, Studies and Documentation (CIB), *Report on the Proceedings of the First General Assembly* (from 25 to 30 June 1953) in Geneva, 92 p., mimeographed (Doc. CIB/28).

53a120 CIB, *Programme of work of the section on documentation* (Doc. CIB/28, p. 83–90).

53a121 Cahiers du Centre Scientifique et Technique du Bâtiment, Numéro experimental, Paris, 1953: Conseil International de Documentation du Bâtiment. Assemblée Générale, Genève. 25 à 30 juin.

53a122 *Role et Activités du Conseil International du Bâtiment* (Cahiers C.S.T.B., No. exp. 1953, p. 3–12).

53a123 Moine, A., *Rapport sur la Documentation du Bâtimen dans les pays du Moyen-Orient* (Cahiers C.S.T.B., No. exp., 1953, 4 p.).

53a124 *Première Assemblée Générale du Conseil International du Bâtiment pour la Recherche, l'Étude et la Documentation* (CIB), Genève-Paris 1953. (Cahiers C.S.T.B., No. spécial, Paris, October, 1953, 162 p.). Includes proceedings of the CIB meeting at Paris, October, 1953.

53a125 Ettinger, J. van, and L. M. Giertz, *Comment appliquer des connaissances aussi diverses à la construction d'un seul bâtiment* (CIB/Ass. Gén., Genève–Paris 1953, p. 97–106).

53a126 Ettinger, J. van, and L. M. Giertz, How can we realize the knowledge of so many in one building, *Housing and Town and Country Planning Bulletin*, 8 (1953) 66–72.

53a127 *Conference on Building Documentation*, Washington, D.C., December, 1953. Sponsored by the United States Building Research Advisory Board and the American Institute of Architects. Source of printing unknown.

52a128 International co-operation in building. E.C.E. Assembly meets in Geneva, *Builder*, 184 (1953) 5758, 994.

53a129 Ansteinsson, J., Litteraturtjenesten for byggefagene, *Murmesteren*, 38 (1953) 5, 91–95.

53a130 Ewing, A. F., International collaboration in building research, *Architects' J.*, 117 (1953) 3018, 24–25.

53a131 Müller, Clara E., Bautechnische Auskunftsstelle, *Bauingenieur*, 28 (1953) 10, 376–378.

53a132 Müller, Clara E., Dokumentation des Bauwesens, *Bundes-Baublatt*, 7 (1953) 5, 212–213.

53a133 Müller, Clara E., Dokumentation des Bauwesens. Kartei des Wissens und Können, *Deutsche Zeitung und Wirtschaftszeitung*, 8 (1953) 33, 19. Beilage Leistung und Fortschritt (Wohnungsbau).

53a134 Müller, Clara E., Der Weg zur Baudokumentation, *Bauwirtschaft*, 7 (1953) 791–794.

53c135 Holm, K. L. and C. T. Larson, *Development Index; with particular reference to buildings and communities*, United States, Ann Arbor, Univ. of Michigan, 1953 (without pagination).

53c136 Thompson, A., Rules for Subject Headings, Periodicals Subject Index, Royal Institute of British Architects, *Journal of Documentation*, 9 (1953) 3, 169–174.

53n137 Broek, J. H. van den, *Needs of documention for architects*, 3 pp. (Doc. CIDB/SEC/15(53).

53n138 Gardner, A. L., *Needs of building research stations with regard to documentation*, 3 pp. (Doc. CIDB/SEC/15(53).

53n139 Plumier, M., *Les besoins en documentation des entrepreneurs*, 4 pp. (Doc. CIDB/SEC/15(53).

53n140 Sabatier, H., *Note sur les besoins de documentation des autorités administratives en matière d'habitation*, 5 pp. (Doc. CIDB/SEC/15(53).

54a141 Eisemann, F., Dokumentation für die Baupraxis, *Nachrichten für Dokumentation*, 5 (1954) 3, 146–147.

54a142 Legget, R. F., *Building documentation outside the United States*, a paper prepared for presentation at the Conference on Building Documentation, sponsored by the Building Research Advisory Board and the American Institute of Architects, Washington, December, 1953. (National Research Council, Division of Building Research, Ottawa, Canada: Technical Paper No. 18, 1954, 8 pp.)

54a143 Müller, Clara E., Dokumentation der Bautechnik, *Fundamente*, 6 (1954) 4, 48–50.

54a144 Müller, Clara E., Dokumentation in der Bautechnik, *Jahrbuch des gesamten Bauwesens*, 1953/54, Darmstadt, Otto Elsner, p. 85–87.

54a145 Rôle et activité du Conseil International de Documentation du Bâtiment, *Review of Documentation*, 21 (1954) 1, 19–20.

54c146 *Abridged Building Classification (ABC)* for Architects, Builders, Civil Engineers. A selection from the Universal Decimal Classification, compiled by CIB, Copenhagen/Stockholm, February, 1954, 59 pp. First preliminary edition, valid until December 31, 1954.

54c147 Giertz, L. M., ABC – ett urval av UDK-nummer för byggnadsfacket, *Tidskrift för Dokumentation*, 1 (1954) 1, 4–6.

54c148 Schoendorff, Ellen, Classification for building documentation, *American Documentation*, 5 (1954) 2, 79–92.

54d149 Danish Digest Service, *Extension of the building documentation activity* (CIB Bulletin, 1954, 6, p. 9–10).

54d150 Floren, L., The scientific exchange service of the Interamerican Housing Center, *Indian Librarian*, 9 (1954) 3, 98–101. Abstract, see *Journal of Documentation*, 11 (1955) 3, 165, or *CIB Bulletin*, 5 (1954) 12–14.

54d151 *Faellesfortegnelse over 250 byggetekniske tidsskrifter,* offentlig tilgaengelige i 7 danske biblioteker. Udg. af Statens Byggeforskningsinstitut, Komiteen for Byggedokumentation. København 1954, 12 pp. Union catalogue of 250 building journals accessible in Danish Libraries.

55c152 *Abridged Building Classification (ABC)* for Architects, Builders, Civil Engineers. A Selection from the Universal Decimal Classification by International Building Classification Committee, second edition, publ. by the Section Documentation of the CIB, Bouwcentrum, Rotterdam, 1955, 70 pp. Valid until 1965. Translations published in the following languages: Dutch, Finnish, French, Japanese, Norwegian, Serbo-Croatian and Swedish.

55c153 BRISCH, E. G., Subject Analysis in Eighty-One Concepts, *ASLIB Proceedings,* 7 (1953) 3, 157–162.

56a154 MÜLLER, C. E., Dezimalklassifikation und Bauwesen, *DK-Mitteilungen,* 1 (1956) 3, 11–12.

56a155 VESTEL, L. DE, La recherche appliquée à la technique industrielle. La Documentation et l'information exacte, *Industries et sciences,* 32 (1956) 4, 29–34.

55c156 EVANS, B. AGARD, Note on the Abridged Building Classification, *ASLIB Proceedings,* 7 (1955) 3, 129.

56c157 EVANS, B. AGARD, A classification and filing scheme for builders. Brief notes on the "Abridged Building Classification" (ABC) prepared by the International Building Classification Committee, *Builder,* 190 (1956) 5902, 511.

56c158 KYLE, BARBARA AND E. G. BRISCH, Something new in classification, *Special Libraries,* 47 (1956) 3, 10–105. Abstract, see *Journal of Documentation,* 12 (1956) 3, 213.

55c159 LUNDBY, S. E., UDK i bruk byggefaget, *UDK Bulletin,* 1 (1955) 3, 62–70.

56c160 LENZ, F., Zur einheitlichen Anwendung der Dezimalklassifikation in der Dokumentation des Bauwesens, *Dokumentation,* 3 (1956) 4, 78–81.

56c161 SPIEGEL, H., Die Sammlung von Arbeitsunterlagen in der betrieblichen Praxis der Architekten- und Ingenieurbüros und der Bauwirtschaft, *Nachrichten für Dokumentation,* 7 (1956) 2, 53–60.

56d162 MEGGERS, EDITH R., Selected Bibliography on Building Construction and Maintenance; Building Materials and Structures Report 140. Ed. by the U.S. Dept. of Commerce and Natl. Bureau of Standards, 2nd Ed., Washington, 1956, 40 pp. List of U.S. research and test reports.

56d163 UNITED NATIONS BUREAU OF SOCIAL AFFAIRS, *International Film Catalogue of Housing, Building and Planning,* New York, 1956.

56n164 KARLÉN, I., Dokumentationsproblemer indenfor byggeindustrien I og II, *Byggeindustrien,* 7 (1956) 6, 101–104, 7, 118–122.

56n165 VENTRIS, M., The handling of architects' information: (1) Introductory and the handling of trade literature, (2) Books and pamphlets other than trade literature, *The Architects' Journal,* 124 (1956) 693–699, and 748–754.

56p166 KOSEL, G., *Die Deutsche Bau-Enzyklopädie als Mittel einer grundlegenden Verbesserung der Kooperation in Bauforschung und Entwurf,* Ministerium für Aufbau, Berlin, 1956, 11 pp. Othe rworks: *Enzyklopedija architektury,* Moscow, 1940, and *Stroitelnaja enzyklopediya nowogo tipa,* Moscow, 1947.

57a167 CIB, *Report on the Proceedings of the Second General Assembly,* Geneva, September, 1956 (CIB Bulletin, 1957, 1–2, p. 1–21).

57a168 CIB, *Compte rendu de la deuxième Assemblée Générale,* Geneva, September, 1956. (Informations sur les activités du CIB, Mai 1957, 16 p.)

57a169 CIB, *Programme de la Section de la Documentation* (Doc. CIB/ST11(56). (Informations sur les activités du CIB, Mai 1957, p. 16.)

57a170 La recherche et la documentation au service du bâtiment, *Bâtir,* No. 70, p. 1–3.

57a171 ROUJOB, F. E., Nécessité de l'exactitude de la documentation dans la construction, *Industries et sciences,* 33 (1957) 1, 47–51.

57c172 BILLMAN, H., Klassifikationssystem för byggnadsfacket, Stockholm, *Byggmästaren,* B10 (1957) 229–236.

57c173 *British Cost Analysis* (Ministry of Education: Building Bulletin, 1957, no. 4). System of enumeration according to elements.

57c174 *Clasificarea zecimală pentry construcții și archtectură și extrase necesare din celelalte domenii,* Ministerul construcţiilor şi materialelor de construcţii. Centrul de documentare techniča. Bucharest, 1957 (mimeographed): Vol. I–IV + Appendix (Selected tables); Index alfabetic: A–K and L–W (two volumes). UDC selection.

57c175 COLLIN, TORBORG, ABC, norsk forkortet desimalklassifikation for byggefaget, 1955, Bokanmeldelse. *UDK-Bulletin, Oslo,* 3 (1957) 1–2, 39.

57c176 Klassifikation zur Deutsche Bau-Enzyklopädie für die Einordnung des Stoffes, Beilage zu Bauplanung, *Bautechnik,* 1957, No. 7.

57c177 NICKLIN, E., SfB-systemet, *Byggaren (Finland),* 8 (1957) 101. IBCC report No. 1.

57c178 UNITED NATIONS BUREAU OF SOCIAL AFFAIRS (Housing, Building and Planning Branch), *Note on documentation techniques in housing, building and planning, United Nations and other systems of classification and indexing,* September, 1957, 8 pp. (typed).

57c179 SAUTTER, L., *Gliederung des Bauwesens: Grundlage für "Das grosse ABC des Bauens",* Deutscher Fachzeitschriften- und Fachbuch-Verlag die Bauzeitung (Deutsche Bauzeitung), Stuttgart, 1957, 25 pp.

57c180 *Universal Decimal Classification,* English Edition of the *Classification Décimale Universelle* of the Fédération Internationale de Documentation: 69. Building; Materials, Construction, Trades. B.S. 1000. London, 1957, 36 pp. (FID publ. No. 179).

57d181 Müller, Clara E., *Alphabetisches Stichwortverzeichnis zur Schriftumkartei Bauwesen nach der Dezimalklassifikation*, Wilhelm Ernst & Sohn, Berlin, 1957, 84 pp.
57p182 Roujob, F. E., (CIB) *Comparative study on Secondary Schools*. November 1957. Part 0–1, 21 + 28 p. Text in English, French, German, Russian.
58a183 Bird, E. L., The problem of technical information, *Roy. Inst. Brit. Architects J.*, 65 (1958) 10, 331–339.
58a184 Brunton, J., Building trade literature, *Builder*, 116 (1958) 6031, 748–751, 3 illus.
58a185 Dorrenboom, A. J. J., Technische documentatie van woningen, *Bouw*, 13 (1958) 29, 736.
58a186 Evans, B. Agard and J. Farradane, *Training the Scientific Information Officer*, preprints of papers for the Int. Conf. on Sci. Information, Washington, D.C., 1958, Area 7, p. 79–84.
58d187 Evans, B. Agard, *International Cooperative Abstracting on Building: An Appraisal*, preprints of papers for the Int. Conf. on Sci. Information, Washington, D.C., 1958, Area 2, p. 177–181.
58a188 Karlén, I., Egenskapsredovisning för byggvaror, *Byggmästaren (Sverige)*, B 11 (1958) 223.
58a189 Müller, C. E., Dokumentation des Bauwesens. Erwiderung zum Aufsatz von Gerhard Grimm, *Deutscher Baumeister*, 19 (1958) 7, 309–311.
58c190 Erikstad, K. and E. Nicklin, Et nytt klassifikasjonssystem for byggefaget, *Bygg (Norge)*, 7 (1958).
58c191 Karlén, I., Att hålla reda på bygglitteratur, *Väg- och Vattenbyggaren*, 6 (1958) 131.
58d192 Draheim, W., Einrichtungen und Dienstleistungen der zentralen Bauinformation bei der Deutschen Bauakademie. *Dokumentation*, 5 (1958) 4/5, 77–88.
58n193 Grimm, G., Die Nutzung der Fachzeitschriften, *Deutscher Baumeister*, 19 (1958) 5, 210.

B. *Abstract journals, digests, indexes, reviews, etc.*

Austria

Oesterreichisches Dokumentationszentrum für Technik und Wirtschaft, Wien 4, Karlsplatz 13: *Oesterreichische Dokumentation auf den Gebieten des Bauwesens und der Architektur.*

Belgium

Centre Belge de Documentation et d'Information de la Construction (CEDOC): *Cedoc-biblio.*

Czechoslovakia

Ústřední technická knihovna ČSR (Central Technical Library of the Czechoslovak Republic), Prague 1, Náměstí primátora Dr. Vacka 5, Klementinum: *Přehled technické a ekonomické literatury – Stavebnictví* (Survey of technical and economic literature – Building).
Výzkumný ústav výstavby a architektury (Research institute for building and architecture), Prague 1 – Malá Strana, Letenská 3: *Výstavba a architektura – Dokumentační zprávy* (Building and architecture – Survey of documentation).
Ústřední technická knihovna ČSR, Prague 1, Klementinum (Central Technical Library of the Czechoslovak Republic): *Přehled technické a hospodářské literatury – Stavebnictví* (Survey of technical and commercial literature – Building).

Denmark

Statens Byggeforskningsinstitut, Borgergade 20, Copenhagen K.: See Scandinavia, cooperative enterprise, *Byggelitteratur, Building Abstract Service.*

England

Building Research Station, Garston, Herts: *Building Science Abstracts*, and *Building Research Station Digest.*
Ministry of Works Library, Lambeth Bridge House, London, S.E. 1: *Accession List, Library Bulletin*, and *Consolidated Building References to Articles in Periodicals.*
Royal Institute of British Architects, 66 Portland Place, London, W. 1: *RIBA Library Bulletin.*
Leonard Hill Technical Group, 17 Stratford Place, London, W. 1: *Building digest.*

Finland

Statens Tekniska Forskningsanstalt, Lönnrotinkatu 37, Helsinki: See Scandinavia, cooperative enterprise, *Byggelitteratur, Building Abstract Service.*

France

Centre Scientifique et Technique du Bâtiment, 4 Avenue du Recteur-Poincaré, Paris 16e; *Cahiers du C.S.T.B.*
Fédération Nationale du Bâtiment et des Activités Annexes, 33 Avenue Kléber, Paris 16e: *Bâtir.*
Institut Technique du Bâtiment et des Travaux Publics, 19 rue de la Perouse, Paris 16e: *Annales, Supplément: Documentation technique.*
Ministère de la Reconstruction et de l'Urbanisme, Cité administrative, Avenue du Parc de Passy, Paris 16e: *Bulletin de documentation et d'information.*

German Democratic Republic

Deutsche Bauakademie – Zentrale wissenschaftliche Bauinformation, Berlin C 2, Wallstrasse 27, DDR:

Bauinformation. A monthly publication containing abstracts, digests and a survey of the activities of the Central Scientific Centre of Information on Building.

German Federal Republic

Dokumentationsstelle für Bautechnik, Stuttgart: *Schrifttumkartei Bauwesen.* Verlag Wilhelm Ernst & Sohn, Hohenzollerndam 169, Berlin.
INTEX Prospekt-Gesellschaft M.B.H., Hildebrandstrasse 9, Düsseldorf: *Intex Prospekt Dienst, Abteilung B: Arbeits- und Ausschreibungsunterlagen für das Bauwesen.* Hrsg. in Zusammenarbeit mit dem Bund Deutscher Architekten BDA.
Kartei für Bau, Raum und Gerät, Feldstrasse 34, Düsseldorf.
Beck, Heidenheim-Brenz: *Fachkartei Bau, Referate-Organ für das gesamte Bauwesen.*
Bauverlag GmbH, Wiesbaden; *Zement-Kalk-Gips-Schrifttumkartei (ZKG).*

Hungary

Hungarian Central Technical Library, POB 12, Budapest 8: Editorial Office of *Hungarian Technical Abstracts.*
Müszaki dokumentációs központ, 12 Akadémia-u, Budapest V: *Épitöanyagi szemle.*
Épitésügyi téjekoztatási központ (Hungarian Information Centre of Building). Budapest V, Kossuth Lajos U. 17: *Hungarian Building Bulletin – Ungarisches Bauwesen Rundschau.* Digest on Hungarian building literature in English and German languages.

Indonesia

Lembaga Penjelidikan Masalah Bangunan, Bandung: *Abstracts* (Indonesian – English).

Israel

Building and Techniques Research Institute by the Association of Engineers and Architects, Haifa: *Dappim* (Abstracts in Hebrew – English).

Italy

Consiglio Nazionale delle Ricerche, Centro Studi sull'Abitazione (Comitato Nazionale Italiano di Documentazione Edilizia), Piazzale delle Scienze 7, Roma: *Documenti di architettura e industria edilizia.*

Netherlands

Bouwcentrum, Weena 700, Rotterdam: *Documentatie Bouwwezen.*
Bureau Documentatie Bouwwezen, Rotterdam: *Arbeidsvoorwaarden Bouwvakarbeiders,* and *Prijzen Bouwmaterialen.*

Norway

Norges Byggforskningsinstitutt, Blindern, Oslo: See Scandinavia, cooperative enterprise, *Byggelitteratur, Building Abstract Service.*

Poland

Instytut budownictwa mieszkaniowego (Institute for Housing), Warsaw U 1, Nowy Swiat 69: *Przeglad dokumentacyjny zagadnien mieszkaniowych* (Survey of documentation on questions of Housing), published as supplement to the monthly journal *Miasto* (The Town), and *Przeglad dokumentacyjny zagadnien inwetycyjnych* (Survey of documentation on questions of investments), published as supplement to the journal *Inwestycje i budownictwa* (Investments and Building).
Instytut techniki budowlanej (Institute of Building), Warsaw, Wawelska 2: *Przeglad dokumentacyjny budownictwa* (Survey of documentation on Building), published as supplement to the journal *Inzynieria a Budownictwo* (Civil Engineering and Building, and *Przeglad dokumentacyjny materialow budowlanych* (Survey of documentation on Building Materials), published as supplement to the journal *Materialy budowlane* (Building Materials).
Instytut organizagji i mechanizacji budownictwa (Institute for the organization and mechanisation of building), Warsaw, Wawelska 2: *Przeglad dokumentacyjny organizacji i mechanizacji budownictwa* (Survey of documentation on organisation and mechanisation of Building), published as supplement to the journal *Budownictwo przemyslowe* (Building for Industry).
Besides these abstract journals the Centralny Instytut Dokumentacji Naukowo – Technicznej (Central Institute for Scientific and Technical Documentation), Warsaw, Al. Niepodleglosci no. 188, publishes in several thematical series abstracts on cards (A 6) of technical literature on building.

Portugal

Laboratório Nacional de Engenharia Civil, Avenida do Brasil, Lisboa: *Documentação Recolhida na Biblioteca* (Article indexing in Portuguese).

Rumania

Ministerul constructiilor si materialelor de constructii (Ministry of Construction and Building Materials) – Institutul de cercetari stiintifice pentru constructii, materiale de constructii si industrializarea lemnului – Centrul de Documentare tehnica (Institute for Scientific Research of Construction, Building Materials and Wood – Centre for Technical Documentation), Bucharest, Bd. Anul 1948, No. 10: *Bulletin de Informare Tehnica* (Bulletin of Technical Information).

Scandinavia

Danish, Finnish, Norwegian and Swedish Building Research Institutes in cooperation: *Byggelitteratur, Building Abstract Service.*

South America

Centro Interamericano de Vivienda, Apartado, Aero 6209, Bogota: 2000 indexes a year, issued monthly.

Spain

Colegio Oficial de Arquitectos de Cataluna y Baleares, Avenida José Antonio 563, Barcelona: *Abstracts*, 4000 a year, issued quarterly.

Sweden

Statens Nämnd för Byggnadsforskning, Styrmansgatan 26, Stockholm C.: See Scandinavia, cooperative enterprise, *Byggelitteratur, Building Abstract Service.*
AB. Svensk Byggtjänst, Kungsgatan 32, Stockholm C.: *Svensk Bygglitteratur.*

Switzerland

Centre Suisse de Documentation du Bâtiment, Halwylstrasse 15, Berne: *Documentation du Bâtiment;* tiré à part du *Bulletin technique de la Suisse Romande.*

U.S.S.R.

Akademija stroitel'stva i architektury SSSR, Moscow K 9, Puškinskaja 24: Referativnyj žurnal "*Stroitel'stvo i architektura* – žurnal Akademii Stroitel'stva i architektury (a new monthly abstracts journal first published in 1959).

Yugoslavia

Jugoslovenski centar za tehničku dokumentaciju, Beograd, Admirala Geprata 16: *Bilten dokumentacije – Gradjevinarstvo i arhitektura* (Abstracts on cards A 7).
Centra za unapredjenje gradjevinarstva, Savezna gradjevinska komora, Beograd, Božidara Adžije 21: *Dokumentacija za gradjevinarstvo i arhitektura* (incl. digests, translations, sheets of architectural and technical documentation).

International

CIB, General Secretariat, Bouwcentrum, Weena 700, Rotterdam: *CIB Bulletin.*
U.N. Housing, Building and Planning Branch, Bureau of Social Affairs, United Nations Headquarters, New York: *Housing and Town and Country Planning Bulletin* (now the United Nations publication *Housing, Building and Planning*).

C. *List of authors*

Other reports

Apart from the preceding general report, a number of other reports can be mentioned.

1. The International Building Classification Committee (I.B.C.C.) presented a report entitled *Recent developments in building classification.*

This roneotyped report, which costs Swiss francs 5.—, contains an introduction by L. M. GIERTZ, Chairman of the IBCC, and the following five IBCC reports:

(a) The SfB system, by E. NICKLIN.

(b) A study of building filing systems, by R. MØLGAARD HANSEN.

(c) Bibliography of building classification, compiled by R. MØLGAARD HANSEN.

(d) Towards a composite classification practice within the building field, an introduction by R. MØLGAARD HANSEN on behalf of the IBCC team on building filing systems.

(e) A building filing manual, recommendations for filing presented by DARGAN BULLIVANT on behalf of the IBCC team on building filing systems.

The last item was separately introduced and is referred to below.

Four co-rapporteurs presented reports that dealt in more detail with specific aspects of the general report, orally. These oral contributions are now summarized.

2. MR. DARGAN BULLIVANT, architect, United Kingdom, introduced *A Building Filing Manual.* A detailed survey is given in the report mentioned under (1) above, as well as in a reprint of the *Architects' Journal* for September 17, 1959.

The IBCC team on building filing systems has completed a manual to guide practitioners in setting up a comprehensive filing system in their offices and to enable producers of information to pre-classify their products in such a way and to give these such a form that they will automatically fit into the practitioners' files.

The recommended system, which can be used for small personal as well as for large office filing systems, is the result of a study of existing systems and of the conclusion that a universal system which is widely used by special libraries, the UDC, should be used for classifying subjects of general knowledge, such as law, sociology, specialist engineering, science, etc., but that for the other subjects which form the practitioner's daily working knowledge and on which he has most documents, a more simple system, closely related to building practice, should be used. As such a system the SfB system applied in Scandinavia comes nearest to the requirements. Thus the new system is based simultaneously on UDC and SfB. The tables of the manual provide two main groups, *viz.* one on "functional elements and buildings", from which the item "buildings" can be isolated as an independent main group for filing purposes, and one on "general, building construction and products". Each main group is subdivided into a limited number of groups all carrying simple notations. The idea behind this grouping is to have a classification and filing system coming as near as possible to the actual process of thought of the practitioner in building.

The obvious complement to the system is the standardization and uniformization of documents, for which the report of Mr. BULLIVANT gives suggestions in line with earlier decisions of CIDB and CIB. An illustration finally shows how the suggested standard practice can work for an office file.

3. Mr. I. KARLÉN, Director of Svensk Byggtjänst (Building Centre), Sweden, dealt with the subject *Availability of documents* and put great emphasis on the need for an effective international system to render important existing publications accessible.

Exchange of literature abstracts

One means is the exchange of abstracts between CIB members. An abstract should firstly quickly enable its reader to decide whether he wants to read the document referred to. Hence indicative abstracts are required rather than more elaborate but more slowly forthcoming informative abstracts. Abstracts may serve information centres rather than practitioners, who may use such centres as a source of information based on national abstracting activity and international exchange of data. The participation of such centres in an international abstracts exchange should be a relatively small – and hence not costly – complementary activity to their national work.

The common rules required for an effective international exchange should be applicable also to the greatest possible extent to national activity.

Method of abstracts distribution

Central collection and distribution of abstracts is more costly and requires more preparation time than decentralized exchange. As the market for abstracts is limited mainly to information centres, the financing of central publication would be difficult. Therefore a decentralized multilateral exchange is preferable. The task of coordination and stimulating the participation would be with the General Secretariat of CIB, which should take all steps to make the exchange more and more valuable.

Further information

Apart from abstracts, information centres should also be enabled to supply additional information, obtained from their foreign colleagues in a form suitable for practitioners' use. It is certainly a task of CIB to establish an effective system of mutual exchange of information to this end.

Rules and recommendations for abstracts exchange

With due regard to earlier decisions the following rules for production and distribution of abstracts are suggested:

(a) Subject field: building and town planning, including architecture, housing, heating and sanitary engineering, social, legal and economical aspects; abstracts on civil engineering subjects to be marked specially.

(b) Selection – criterion: original and of international or regional value – may be made by a national committee.

(c) Character: indicative, not informative.

(d) Language: original and English (or French) at the back.

(e) Printing: on one side of paper (translation at the back).

(f) Format: DIN A7, even if space not fully utilized.

(g) Classification: UDC code at top left.

(h) Cases of publication containing both domestic and international abstracts: foreign abstracts to be specially marked.

(i) Distribution: per participant 9 copies of each abstract to other active participants.

(j) Further information: exchange on basis of separate agreements.

Apart from these rules the following recommendations are made:

(a) Contents: brief and precise without abbreviations; characterizing the relevant document by one word: law, critical survey, research report, standard, etc.; first-hand results to be marked "original work"; author's authority and profession to be indicated; vague titles to be clarified by explanatory paraphrase; number and nature of illustrations to be mentioned; literature lists to be mentioned; in cases of documents on specific buildings, names of architect, structural engineer, etc., to be mentioned.

(b) Bibliographical references: according to ISO recommendation No. 23, draft of August, 1958.

(c) Year of publication of abstracted document: to be repeated at top right, opposite UDC code.

(d) Abstracts in an abstracts publication: to be listed according to UDC.

(e) Method of production: such that clipping or cutting into size A7, without pasting, is possible.

Complementary data

CIB should consider the future production of longer informative abstracts or digests, such as the U.S.S.R. VINITI, on selected original important reports, complementary to the abstracts exchange.

Conclusion

As the flow of published data will increase by 100% in some 10–20 years a good system of "signals" is of vital importance. The abstracts exchange is a first step. The problems to be solved include:

action by CIB's General Secretary to improve the system and to extend its scope;
gradual widening of the covered subject field;
setting principles for covering fields of knowledge;
elaborating principles for selection;
abstracting for countries that cannot participate by subdivision of tasks between other participants;
a subject division to enable specialists to follow the literature in their field of interest;
more extensive use and form of complementary information.

4. Mr. M. Molè, Head of the Documentation Bureau at the Centre for Development of Building and Public Works, Yugoslavia, presented an illustrated report on the subject *Some problems of terminology and translation in the field of building*, containing some proposals with regard to transmission of knowledge between different linguistic areas and to questions of translation practice. The means documentalists, translators and experts have to take cognizance of in documents in foreign languages are many and varied, but mostly unsatisfactory and not easy to handle. Non-uniform terminology aggravates the problem:

(a) Each specialist uses his own knowledge of language, obtained in widely different ways by different specialists.

(b) A second source is alphabetic general and technical glossaries, with or without explanatory comment and pictures. The Unesco "Bibliography of Scientific and Technical Multilingual Dictionaries" provides a list of such glossaries. The documentation service "Dokumentationen der Technik" in Munich announces the edition of a full list of technical glossaries. Such glossaries are easy to handle, but do not give many technical terms or cannot give correct interpretations.

(c) The third source of technical terms is formed by technical publications. Handbooks give widely accepted terms, whereas new terms are found in monographs, periodicals and, especially, standards. If alphabetical indexes are provided it becomes easy to trace the paraphrase of a term that permits its correct understanding and consequent translation. Illustrations add another positive element.

(d) When good translations of technical documents, illustrated and provided with alphabetical index, are available, tracing of correct translations of terms becomes very easy. If, for example, similar pages out of different editions of the handbook "Hütte" in different language versions are taken, the illustrations of a certain term can be traced via the alphabetical index of one version and the translation of the term is found with the same illustration in another version. This way of tracing translations is also possible with books such as

"Neufert Bauentwurfslehre", "Mittag Baukonstruktionslehre" and "Brockhaus Dictionary".

(e) As already mentioned in the main report on the present subject, it would be extremely useful if the CIB Bulletin would give "Bibliographies on translations of building publications", printed in two copies so as to permit the establishment of alphabetical files and files according to subject.

Fig. 1 gives an example. National Documentation Centres should provide the relevant data to the CIB General Secretariat in the form of small cards, as illustrated in Fig. 2. Only translations of good quality should be included. Publication of such bibliographical references would permit (1) those centres that use the original language to learn for what languages the relevant publication may serve translation purposes; and (2) those centres that use the translation to learn for what further languages, apart from the original, the relevant publication may serve translation purposes.

(f) Alphabetic indexes greatly facilitate the use for translation purposes. Consequently, it would be very useful if CIB added such indexes to publications that have different language versions. The Congress book might be the first example, the more so as the Congress reports contain many technical terms. Each subject should be treated as a CIB monograph, so that 10 CIB monographs with alphabetic index become available. The alphabetic index should then give, by means of a simple system of codes of reference, indications as to where a term is found in different language versions.

(g) In the same way of simple indication by a code, one could imagine that CIB would select some well illustrated handbooks, etc., and publish an alphabetical index of technical terms. The effect would be that, with a minimum of effort, an excellent technical dictionary would be provided in two parts:

(i) "systematic part", comprising the already published documents;

(ii) "alphabetic part", specially edited.

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624 = 30
Hütte – Des Ingenieurs Taschenbuch.
27. neubearb. Aufl. III Band.
Mit 2086 Textabb.; XXIV, 1304 S.
(Mit alphabet. Register)
Berlin: W. Ernst & Sohn 1951

Original

624 = 40
Hütte – Manuel de l'ingénieur.
Traduit sur la 27e édition allemande.
Avec 2086 fig., XXXVI, 1435 p.
(Avec la table alphabétique des matières)
Paris et Liège: Béranger 1953

Traduction

624 = 861/862
Hütte – Inženjerski priručnik.
Prevod 27. preradjenog nemačkog izdanja.
Knjiga III, 1 i 2 deo.
Sa 706 + 1380 slika u tekstu; XXVII, 1512 str.
(Sa azbučnim registrom)
Beograd: Gradjevinsk a knjiga 1956, 1958.

Prevod

Fig. 1

624 = 30 Hütte – Des Ingenieurs Taschenbuch. 27. neubearb. Aufl. III. Band. Mit 2086 Textabb.; XXIV, 1304 S. (Mit alphabet. Sachverzeichnis) Berlin: W. Ernst & Sohn 1951   Original

recto

624 = 40 Hütte – Manuel de l'ingénieur. Traduit sur la 27e édition allemande. Avec 2086 fig., XXXVI, 1435 p. (Avec la table alphabétique des matières) Paris et Liège: Béranger 1953   Traduction

verso

Fig. 2

The systematic part would not be easy to handle, but it need not be separately edited and would still give the most authentic interpretation of each term.

(h) However, by a larger effort of CIB members it would be possible to arrive step by step at a much more condensed systematic part of such a dictionary.

On the basis of the ABC classification groups, sheets with technical terms could be elaborated, thus establishing the necessary and logical liaison between terminology and classification. Standardized presentation of terms, interpreted by means of intelligible description, provided with illustrations would be required. Table I of the main report gives an example.

Translation and publication in exactly identical layout and adding an alphabetical index would result in an excellent dictionary.

(i) It is suggested that cooperative action by CIB members should be undertaken. CIB members should provide the necessary funds and engage the required experts to elaborate drafts for the above-mentioned sheets in their own language and simultaneously in English or French. They should then send these sheets for comment to all members of CIB and, next, the sheets should be edited ultimately in key languages – at least English, French, Russian and German.

To economize in costs of printing blocks and to provide bilingual dictionaries immediately, the sheets should ultimately be published in a bilingual way. For practical and geographical reasons it is suggested to have English–French sheets published by the linguistic centre for English in Rotterdam, with the assistance of English and French members, and to have Russian–German sheets published by the linguistic centre for Russian in Prague, with the assistance of Russian and German members.

The overall coordination would be assured by the General Secretary of CIB, assisted by a commission of specialists (probably of IBCC). Members would receive the appropriate dictionary and could themselves add a text in their own language.

(j) Obviously, photographic reproduction would quickly permit the making of a four-language CIB dictionary as a book. Fig. 3 gives a schematic outline of a bilingual sheet. In the same way the pages of a four-language dictionary can be arranged.

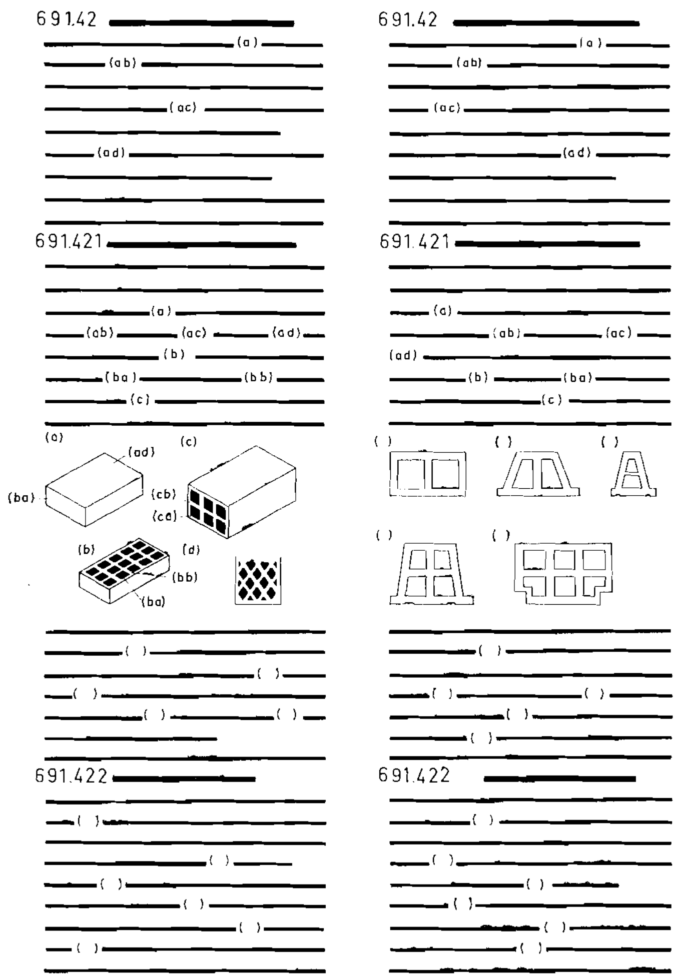

Fig. 3

5. Mr. O. Stach, Deputy Director of the Institute for Building Research and Architecture, Czechoslovakia, introduced the theme *A network of linguistic information centres.*

In order to canalize more and more the large flow of information it would be efficient if in each country one information centre were to assume the role of main building information centre, belonging to a standing international network of such centres. The accessibility of foreign information would, via such centres, be greatly improved.

National centres

Only bodies that meet high requirements, both with regard to their own professiona standing and constant touch with the various groups of specialists and with regard to their linguistic capacities, could act as such national centres.

Members of CIB in the same country may decide which body is to assume such a role, either on its own or in cooperation with other national members. The task of each centre would be to select and translate relevant information and to send it to the other centres and to the CIB secretariat. Obviously, each centre should, therefore, have staff that is not only highly qualified in building and economics, but that has at the same time a good working knowledge of the major languages.

Absolute decentralization

The network would act on the basis of complete decentralization. Each centre would carry the costs of its own share in the work and would provide its results to the others free of charge.

Accepting as a principle the supply of a maximum of three copies to each centre the total edition per relevant document may gradually grow to some 100–150 in future.

Regional centralization

If one centre could assume the above-mentioned task not only for its own country but also for a well chosen and limited region, including a number of countries using the same "key language", the number of centres of the network could be reduced, thus simplifying the work. In practice, there are such linguistic regions for English, Russian, French, German, Chinese, Spanish and also Swedish.

The exchange between regional centres would still require these centres to be able to work in some five languages. That is why it seems useful to select a minimum number of languages, each practicable in the highest possible number of countries.

Key languages for two main linguistic regions

Most probably English and Russian are such languages, the first being known in a large number of CIB member institutes and the second being used all over Eastern Europe.

Application of this principle would result in a flow of data either to regional centres or directly to national centres in one of these two languages only. Since certain centres would not have sufficient linguistic capacity, they could together, in their region, select one centre that has such capacity and that would care for translation and distribution in a regional language. As in this way a certain centralization is introduced the relevant centres ought jointly to decide on the division of tasks involved in the translation services, etc., of the regional centre on behalf of all. The same would apply for the two regional centres working in the two key languages.

If, during an initial period, one of these centres would have to provide translations into the other key language, the principle of reciprocation of services could not be applied and funds out of the CIB budget would have to be provided for this work.

Concluding remarks

In the above way the principle of "three language levels", elaborated in the general report, could be applied in practice.

The coordination could be entrusted to CIB's central organs, which would watch the application of correct principles and methods and the selection of important subjects, and which would keep a central information file, edit a journal and special central publications, etc. Thus progress could be made on the difficult road of international exchange of information.

Apart from those by the preceding co-rapporteurs, a separate communication was also presented by Mr. B. M. SKOROV.

6. Mr. B. M. SKOROV of the Institute of Economics of the Academy of Building and Architecture, USSR, discussed *Problems of international information on building*.

The fact of CIB's existence resulted into two distinct trends in the sphere of international information:

(a) information of CIB members on its activities,

(b) organization of international information on building problems.

(a) Definite decisions, meriting the greatest attention, have been taken on the first matter, particularly the publication of a CIB information bulletin. This should be issued at least quarterly and contain information on CIB activities, on work by international congresses, commissions and individual members of CIB, on experiences in organizing national information services, etc. As the bulletin is rather small, it would be useful to organize the exchange of supplementary information, such as full scientific communications, presented at meetings and congresses. These questions are not new, but the matter of language is.

Following a decision of CIB's Executive Committee, it is planned to arrange for translation of the bulletin and other documents that fall under the exchange programme into Russian in the USSR on behalf of those countries that use Russian as a main language, while Czechoslovakia is to undertake the publication and circulation to countries where CIB has members. The general coordination of the exchange should be entrusted to the CIB Secretariat, the staff of which may have to be increased for this purpose.

(b) Organizing an international information service is a more complex matter.

The yearly amount of all sorts of publications is, according to 1956–1958 statistics, about 100,000. Thus it is exceedingly difficult to locate a required publication and even more difficult to keep up with new improvements reported in various publications.

The prime condition to solve the problem of mutual information in CIB is the systematization of scientific knowledge and the unification of building terms. The systematization of scientific knowledge should be done in accordance with some uniform classification. As the IBCC is involved in this matter, it will not be discussed here.

Until 1965 we shall have to use the ABC classification, though this does not meet present-day requirements. Evolving a unified system of building terms is more complex, and here present activities are of an inadequate scale. According to earlier suggestions, the first step should be to take stock of terms in current use. Then these terms should be distributed to CIB members for checking and, where necessary, supplementing the stock. Next a working commission should examine and approve the stock and collect proposals from all members regarding the terms in the respective divisions assigned to them. Following the classification of the composite stock, the terms should be published in the order of classification in the languages of all countries where CIB has members. At the initial stage this document may serve as a good multilingual building dictionary.

At the second stage each member should formulate the definitions of the terms assigned to them and a general terminological dictionary may be compiled. This work is time-consuming and could be coordinated by the above-mentioned commission.

In order to arrive at a flexible form of a mutual information service in CIB, keeping pace with new printed publications, the following suggestions are made in the sphere of exchange of abstracts.

In each country a member should systematically prepare brief abstracts on building literature. There should be no restrictions of length, form, etc., so that each member can follow the way that suits him best. A mandatory condition, however, is the good quality of the abstract. Abstracting of literature that has a reference nature, such as standards, technical specifications, etc., is first of all desirable. Each participating member should publish the abstracts in a sufficient number of copies to circulate them to all CIB members, preferably monthly, or bi-monthly or, at least, quarterly.

Every country could freely translate the abstracts received and distribute them in any form. Thus the costs of the work would be automatically distributed proportionally amongst the countries.

Besides this, working commissions could also arrange for exchanges of technical documentation on specific problems. Similar exchanges ought to be arranged in the sphere of research work undertaken in different countries. Here abstracts on results of completed research projects may serve. It would also be expedient to organize exchange of information on building exhibitions, congresses, etc., both 3-4 months prior to their opening as well as after their completion.

These targets only cover the initial stage of the work to be done. Other forms of exchange, such as excursions to current projects, research centres, etc., and technical films should also be undertaken. Today these activities are confined to international congresses. They should not be limited to conferences but mutual invitations on a wider scale should thus lead to a live form of mutual ties, substantially broadening international contacts.

DISCUSSION

Further to the verbal introduction of most of the preceding reports other contributions to the discussion can be mentioned.

ANALYSIS OF NEEDS

Mr. S. R. Ålund (Sweden) draws specific attention to the fact that the realistic basis of building up any information activity ought always to be a correct insight into the demand for information by the various groups of specialists and in the meeting of this demand. An indispensable starting point is consequently a systematic market analysis in this respect. Although such a market analysis is primarily a matter of national concern a certain measure of international cooperation would be valuable in order to benefit from the comparison of the results obtained at national level in this respect.

OFFICE FILING PRACTICE

Mr. L. M. Giertz (Sweden), one of the main rapporteurs, gives explanatory comment on the material displayed at the occasion of the Congress in a small special exhibition. This exhibition shows various types of existing documents and reference documents, thus making it extremely clear what type of problems the practitioner receiving all these documents faces with regard to storage and retrieval.

A filing equipment developed by Mr. Giertz himself and referred to in the report, entitled "A building filing manual" is also shown in the exhibition.

TRAINING OF BUILDING DOCUMENTALISTS

Mr. S. E. Lundby (Norway), referring to the suggestions with regard to training of building documentalists as presented in the general report and prepared by Miss Clara Müller (Federal German Republic), expresses doubt on whether or not this training is at all a matter of international concern. Miss Müller explains that, in her opinion, the basic training of documentalists is indeed a matter of national concern, but that in the specialized training that has to follow, an additional, international element, *e.g.* by means of special seminars, could be valuable.

Mr. A. B. Agard Evans (United Kingdom) suggests that it would be valuable if CIB were to organize, about every other year, a seminar for building documentation. Is it not a specific task for CIB to arrange for the compilation of a handbook on building documentation? One could, in point of fact, think of two books, one of which would be made to meet the specific requirements of less developed countries.

ORGANIZATION OF AN INTERNATIONAL BUILDING DOCUMENTATION SERVICE

Mr. I. KARLÉN (Sweden), referring to the proposals for the organization of an international documentation service presented by the President of CIB to the Housing Committee of the United Nations, thinks that the different views expressed at the present Congress clearly point towards a different solution. Hence Mr. KARLÉN would like the relevant study Commission to reconsider the matter in the light of these views.

AN INTERNATIONAL CHAIN OF INFORMATION CENTRES

The significance of a standing network of information centres being recognized, it is decided that a small commission, composed of Messrs. J. VAN ETTINGER, I. KARLÉN and O. STACH, will be established in order to study the practical organization of such a chain of centres and to forward relevant proposals to CIB.

Subject 8

HEAT INSULATION AND MOISTURE EFFECTS

UDC 699.86 : 699.82

MAIN REPORT

H. REIHER
Director of the "Institut für Technische Physik" (German Federal Republic)

ADDITIONAL REPORTS

A. TVEIT
Building Research Institute (Norway)

E. F. M. VAN DER HELD
Professor at the University of Utrecht, Advisor to T.N.O. (the Netherlands)

P. W. MARKE
Civil engineer (Denmark)

M. CROISET
"Centre Scientifique et Technique du Bâtiment" (France)

Laboratory studies on heat insulation and moisture effects and their practical application

UDC 699.86 : 699.82

H. REIHER

Director of the "Institut für Technische Physik" (Federal Republic of Germany)

In the U.S. the medical treatment and care of patients suffering from rheumatism (5 per cent. of the population) costs about 900 million dollars yearly. In 1955, 190 million working hours were lost as a consequence of this disease. About half the number of cases are caused by damp houses and working rooms. Fifty per cent. of all allergic affections of the respiratory system are caused by dust in houses, produced among other things by destruction of organic matter through biological organisms (which readily multiply, especially in damp buildings) and their spores.

From these facts alone it will be understood how harmful excessive dampness in buildings may be. This made it necessary to engage on a study of the problems connected with dampness in buildings in order to find suitable methods of eliminating the damage done by moist building materials. The fact that problems of this kind in houses and working rooms are more frequent today than they used to be before should be ascribed to the lighter building constructions used and the more intensive use of modern dwellings. Thus recent investigations covering more than 700 occupied rooms in modern houses showed that 30 per cent. of the bedrooms and 28 per cent. of the kitchens showed damage due to dampness caused by inadequate planning, faulty materials or constructions and unsuitable habitation.

Apart from the hygiene of problems associated with this situation, modern housing also involves considerable economic problems, such as that of efficient heating.

In Germany about $\frac{1}{3}$ of the quantities of fuel produced in the country are used for domestic heating purposes, and conditions are similar in other countries. Therefore any savings in fuel consumption effected by drier and consequently better heat-insulating walls mean both private and public economic advantages.

In many European and non-European countries these dangers have been recognized during recent years and extensive investigations in laboratory and practice are being carried out in order to reduce moisture penetration in building elements – particularly the exterior walls – of residential houses and thus to ensure healthy climatic conditions in these houses.

Extensive studies, partly in the form of laboratory investigations and partly in the form of long-term comparative tests with traditional houses (*e.g.* on test sites in England, France, Norway, Switzerland, Germany and various countries outside Europe) have been carried out to examine the effects of climatic conditions (especially heavy rainfall) and of the habits and intensity of living in these houses on moisture conditions of exterior walls and indoor air.

In order to gain a general insight into the problem of the influence of humidity on heat insulation by building elements we will make a selection from the many data collected from practical experience, laboratory and field tests that are already available.

This study will include:

1. Directions and regulations on heat insulation issued for the building trade, especially residential building; laboratory test results and their evaluation.

2. Experience gained in actual practice and from field tests in "artificially inhabited" test houses and with test walls constructed by traditional methods.

3. Measures taken to keep outer walls dry and consequently to create a hygienically sound room atmosphere.

DIRECTIONS CONCERNING HEAT INSULATION

In order to ensure specific hygienic conditions in dwellings built with subsidies from public authorities, mainly under social housing schemes, it is necessary to observe certain heat insulation figures for external construction elements.

These figures, which were derived from practical experience and laboratory investigations, are laid down in most countries in official regulations and standard specifications (see references). Heat insulation standards for various building elements in force in some central European and north European countries (Sweden, Denmark, England, Holland and Germany) are listed in Tables I and II. The German figures correspond to those in force in Austria and Switzerland with minor deviations (Bundesministerium für Wohnungsbau, 1959).

A comparison of these figures shows in what manner the varying climatic conditions (from a continental climate to an oceanic climate with the gulf stream) affect the heat insulation measures to be taken in the countries mentioned. In Denmark, England and Holland it is sufficient to lay down a few minimum insulation values which are valid for the entire area. In Sweden and Germany the variation in weather conditions makes it necessary to divide the country into several districts. In France, Austria and Switzerland minimum heat insulation values are adapted to local climatic conditions and show wide variations.

The minimum values laid down in these regulations and standards for heat insulation, $D = 1/A$ ($m^2h^\circ C/kcal$) (from wall surface to wall surface), and for heat transmission k($kcal/m^2h^\circ C$) (from air to air), are established from practical experience of the need to prevent condensation of water vapour on interior wall surfaces and from laboratory data on heat transmission characteristics of building materials.

In the German standard specification DIN 4108, for instance, the influence of the average moisture content establishing itself under practical conditions in building materials has been taken into account in that the heat transmission values corresponding to actual moisture contents are used in calculating the wall thicknesses required to provide the necessary heat insulation. It remains to be verified by laboratory and field tests to what extent these assumptions correspond to modern practice.

In former housing practice the observation of these minimum requirements has, in most instances, resulted in satisfactory climatic conditions in living and working spaces. At least the percentages of damage caused by dampness in houses were low and mostly to be ascribed to faulty construction and unsuitable habitation. With the introduction of modern building and insulating materials in house construction – especially lightweight constructions – the exterior walls are affected to a greater extent by weather conditions, primarily heavy rainfall. As a consequence, they lose a considerable part of their heat insulating properties. In addition, the exterior walls of many comparatively new dwellings built under social housing schemes absorb excessive moisture due to overcrowding.

RESULTS OF FIELD TESTS OF "ARTIFICIALLY INHABITED" HOUSES WITH TRADITIONAL WALLS

Most field tests simulating actual practice intended for investigating the relationship between heat insulation and moisture conditions or humidity in wall materials and indoor air are carried out on test objects placed in the open air and exposed to various weather conditions. In these test rooms "artificial habitation" was created by suitable heating, moisture development and ventilation corresponding to the living habits with intermittent heating as is usual in dwellings built under social housing schemes. In this connection it is

TABLE I

HEAT INSULATION STANDARDS FOR CONSTRUCTION ELEMENTS ESTABLISHED FOR RESIDENTIAL BUILDING IN SOME EUROPEAN COUNTRIES

(expressed in terms of heat transmission coefficients k (kcal/m²h°C) ($\alpha_i = 7$; $\alpha_a = 25$ kcal/m²h°C)

Sweden					*Denmark*		*England*		*Holland*		*Germany*			
Class	*Heat insulation*										*Class*	*Heat insulation*		
	IV	*III*	*II*	*I*								*I*	*II*	*III*
WALLS														
Brick walls weighing over 1,400 kg/cu.m	1.15	1.05	0.95	0.85	Exterior walls of common brick	1.2	Exterior walls	1.47	Exterior walls of habitable rooms	1.5	Exterior walls over 300 kg/sq.m	1.56	1.35	1.19
Brick walls weighing from 1,100 to 1,400 kg/cu.m or insulated concrete	1.05	0.95	0.85	0.75	Exterior walls of lightweight concrete	1.05			Exterior walls of secondary rooms	1.75	Partition walls; stair-well walls	1.73	1.73	1.47
Other walls mainly of stone materials weighing 100 kg/sq.m minimum	0.95	0.85	0.75	0.65	Exterior walls of reinforced concrete or heavy concrete with insulation	1.05			Partition walls	2.0	Lightweight exterior walls below 300 kg/sq.m			
Wood walls and other materials weighing below 100 kg/sq.m	0.75	0.65	0.55	0.45	Other exterior walls	0.9					Up to 400% decrease			
					Interior walls with unheated secondary rooms behind them	1.7								
ROOFS AND FLOORS														
Ceilings of stone material under unheated spaces (attics)	0.65	0.65	0.55	0.55	Roofs	0.7	Roofs (Roof and ceiling above top storey)	0.98	Floor ceilings of habitable rooms over open air or intensively ventilated spaces	1.5	Ceilings separating from attics	1.05	to	1.2

Sweden: Class	Sweden: Heat insulation IV	III	II	I	Denmark		England	Holland		Germany: Class	Germany: Heat insulation I	II	III
Wood ceilings under unheated spaces (attics)	0.55	0.55	0.45	0.45	Ceilings between stories over not particularly cold unheated spaces, *e.g.* basements with insulated heating conducts	0.65	Basement ceilings	Ditto for secondary rooms	1.75	Basement ceilings	0.87	0.87	0.87
Ceilings of stone materials under open air	0.55	0.55	0.45	0.45				Ditto for habitable rooms over slightly ventilated spaces	1.75	Roofs over open passage ways	0.57	0.5	0.44
Wood ceilings under open air	0.45	0.45	0.35	0.35				Ditto for secondary rooms		Inclined and flat roofs; ceilings under terraces	1.19	1.19	1.19
Over basements with uninsulated heating conducts	0.7	0.7	0.6	0.6	Ceilings between stories over open air or particularly cold spaces, *e.g.* passageways, garbage disposal places, or over particularly hot spaces like boiler rooms, bakeries, etc.	0.5		Ceilings between habitable rooms					
Over unheated spaces or direct on the ground	0.55	0.55	0.45	0.45				Roofs direct over habitable rooms					
Over open air	0.45	0.45	0.35	0.35									

TABLE II

HEAT INSULATION STANDARDS FOR CONSTRUCTION ELEMENTS ESTABLISHED FOR RESIDENTIAL BUILDING IN SOME EUROPEAN COUNTRIES

(expressed in terms of thermal resistance $1/\lambda$ /m²/h°C/kcal)

Sweden					*Denmark*		*England*		*Holland*		*Germany*			
Class	*Heat insulation*										*Class*	*Heat insulation*		
	IV	*III*	*II*	*I*								*I*	*II*	*III*
WALLS														
Brick walls weighing over 1,400 kg/cu.m	0.67	0.75	0.85	0.98	Exterior walls of common brick	0.64	Exterior walls	0.49	Exterior walls of habitable rooms	0.45	Exterior walls over 300 kg/sq.m	0.45	0.55	0.65
Brick walls weighing from 1,100 to 1,400 kg/cu.m or insulated concrete	0.75	0.85	0.98	1.13	Exterior walls of lightweight concrete	0.76			Exterior walls of secondary rooms	0.35	Partition walls; stair-well walls	0.3	0.3	0.4
Other walls mainly of stone materials weighing 100 kg/sq.m minimum	0.85	0.98	1.13	1.34	Exterior walls of reinforced concrete or heavy concrete with insulation	0.76			Partition walls	0.16	Lightweight exterior walls below 300 kg/sq.m			
Wood walls and other materials weighing below 100 kg/sq.m	1.13	1.34	1.62	2.02	Other exterior walls	0.92					Up to 400% increase for 300 kg/sq.m for 20 kg/sq.m	 0.45 1.3	 0.55 1.85	 0.65 2.5
					Interior walls with unheated secondary rooms behind them	0.31								
ROOFS AND FLOORS														
Ceilings of stone material under unheated spaces (attics)	1.28	1.28	1.56	1.56	Roofs	1.24	Roofs (Roof and ceiling above top storey)	0.83	Floor ceilings of habitable rooms over open air or intensively ventilated spaces	0.42	Ceilings separating from attics	0.55	0.55	0.55

Sweden: Class	Heat insulation IV	III	II	I	Denmark		England		Holland		Germany: Class	Heat insulation I	II	III
Wood ceilings under unheated spaces (attics)	1.56	1.56	1.96	1.96	Ceilings between stories over not particularly cold unheated spaces, e.g. basements with insulated heating conducts	1.14			Ditto for secondary rooms	0.32	Basement ceilings	0.75	0.75	0.75
Ceilings of stone materials under open air	1.62	1.62	2.02	2.02			Basement ceilings	0.28	Ditto for habitable rooms over slightly ventilated spaces	0.22	Roofs over open passage ways	1.5	1.75	2.0
Wood ceilings under open air	2.02	2.02	2.66	2.66										
Walked-on floors/ceilings: Over basements with uninsulated heating conducts	1.17	1.17	1.41	1.41	Ceilings between stories over open air or particularly cold spaces, e.g. passageways, garbage disposal places, or over particularly hot spaces like boiler rooms, bakeries, etc.	1.6 1.75			Ditto for secondary rooms	0.15	Inclined and flat roofs; ceilings under terraces	0.65	0.65	0.65
Walked-on floors/ceilings: Over unheated spaces or direct on the ground	1.56	1.56	1.96	1.96					Ceilings between habitable rooms	0.16				
Walked-on floors/ceilings: Over open air	2.02	2.02	2.66	2.66					Roofs direct over habitable rooms	0.78				
									Ditto over secondary rooms	0.45				

attempted to carry out these investigations at the same time with the greatest possible number of test houses built according to the standards set for them and preferably built from all usual building materials by all existing building methods, so that the same climatic conditions and habitation of the houses are ensured for all test objects.

The experiments carried out during the last six years with the cooperation of the German Ministry of Housing, building associations and the building industry on 25 of such test houses on a site near Holzkirchen, in conjunction with comparative observations in occupied dwellings in the so-called "Alpenvorland" (at an altitude of between 900 and 1,800 feet) resulted in certain conclusions on the mutual influence of heat and moisture conditions in exterior walls and indoor air. The results of these investigations are of great value since the dimensions of exterior walls were chosen in conformity with DIN 4108 standards for heat insulation class II, while later the meteorological station in the region in question stated that this region belonged to heat insulation class III. Some data from these investigations that are considered useful to our study will be given here (Reiher *et al.*, 1958).

In almost all test houses it was found that owing to different exposure to climatic conditions there were considerable differences in moisture content of similarly built exterior walls facing different directions. The moisture content of exterior walls facing the weather side (in Holzkirchen, the west walls) as a rule was a multiple of that of the other exterior walls (Figs. 1 and 2). The resultant decrease in heat insulation caused differences in temperature of the interior wall surfaces (Fig. 3) and, consequently, differences in condensation of water vapour from the indoor air. In corners behind large pieces of furniture this led to increased moisture content of the plaster and mould formation (Fig. 4), particularly in unventilated or insufficiently ventilated rooms (bedrooms) and in rooms with a high air humidity (insufficient heating and ventilation in kitchens and bathrooms).

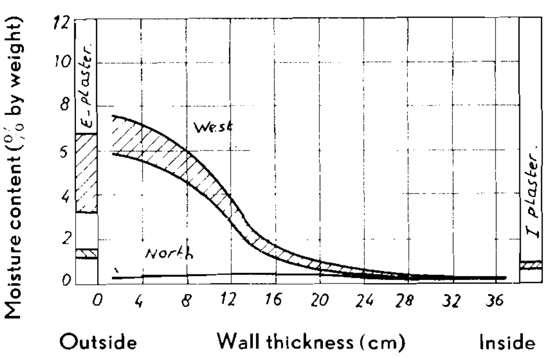

Fig. 1. Variation in moisture content of the north and west wall of a house built of 38-cm solid bricks. Test period from December, 1954, to March, 1955.

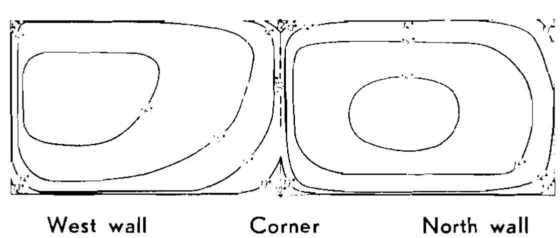

Fig. 3. Variation in temperature of the inner surface of the west and north walls of a test house built of 38-cm solid bricks (indoor air temperature + 20° C; outdoor air temperature — 2° C).

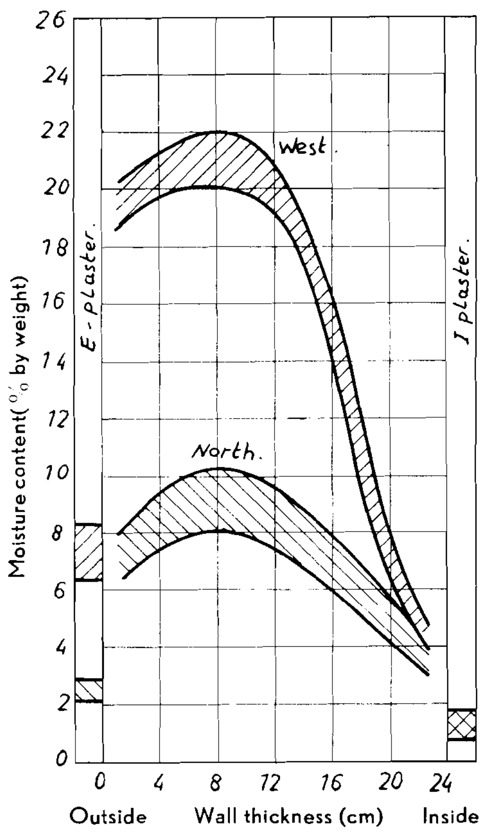

Fig. 2. Variation in moisture content of the north and west walls of a house built of 24-cm solid pumice-stone concrete bricks. Test period from December, 1954, to March, 1955.

A certain relationship was observed between moisture contents of wall materials, interior plaster and indoor air, so that in many instances the moisture content of the plaster could be taken as a measuring rod for hygienic conditions (Fig. 5). A clear picture of the relationship between heat and moisture conditions over a long period was obtained by observations made in two test houses as shown in Figs. 6 and 7 (outdoor and indoor air temperatures,

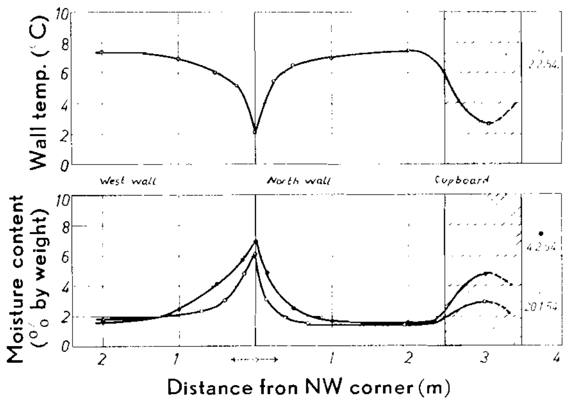

Fig. 4. Variation in temperature of interior plaster on west and north walls of house G 7 (25-cm solid sand-lime bricks), 1.20 m above floor level, measured at two different dates during habitation tests according to schedule No. 3. A soft-board sheet was placed against the north wall to simulate a cupboard. The variation in temperature (average outside temperature measured on 2.2.1954: — 13.4° C) demonstrates the considerable decrease in wall temperature in the north-west corner and behind the cupboard.

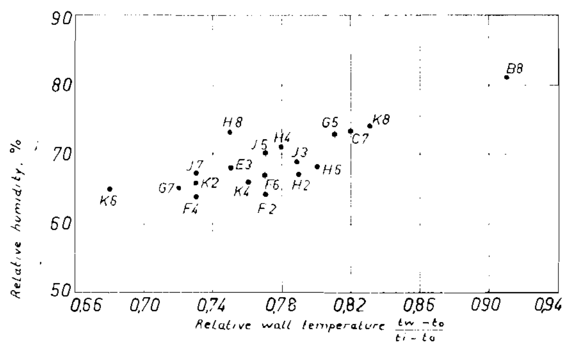

Fig. 5. Relationship between relative humidity establishing inside the house and moisture content of internal rendering (main values of measurements of moisture content in plaster in north and west walls) at the end of test series 6, 1955.

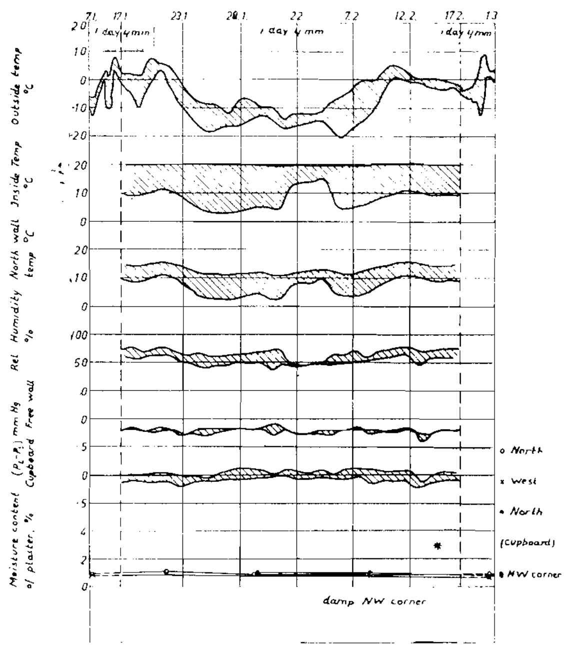

Fig. 6. Variation of outdoor and indoor temperatures, north wall temperature, relative air humidity and differential vapour pressure $p_L - p_S$ for free north wall and north wall behind cupboard in a test house built of 38-cm solid bricks. The difference between actual water vapour pressure of the air and the pressure of saturated water vapour $(p_L - p_S)$ at the given wall temperature is a measure of the risk of condensation. Condensation will take place when $p_L - p_S$ has a positive value. Measurement of outside temperature fluctuations allows a comparison with the various fluctuating values inside the room, *i.e.* an evaluation of the thermal stability of the construction. Test period from 17.1 to 17.2.1954. Intermittent heating. From February 1 to 5, 1954, the room was also heated during the night with 2 kW.

average temperature of interior wall surface, air humidity, vapour pressure at the free wall and behind furniture, moisture content of plaster). From the variation in vapour pressure the probability of condensation can be established (positive values).

A mould test has proved a reliable test in establishing poor insulation and excessive moisture content (Fig. 8). In these tests, suspected wall areas are coated with a substance which promotes the growth of mould in cases of insufficient heat insulation and excessive water on the wall surface.

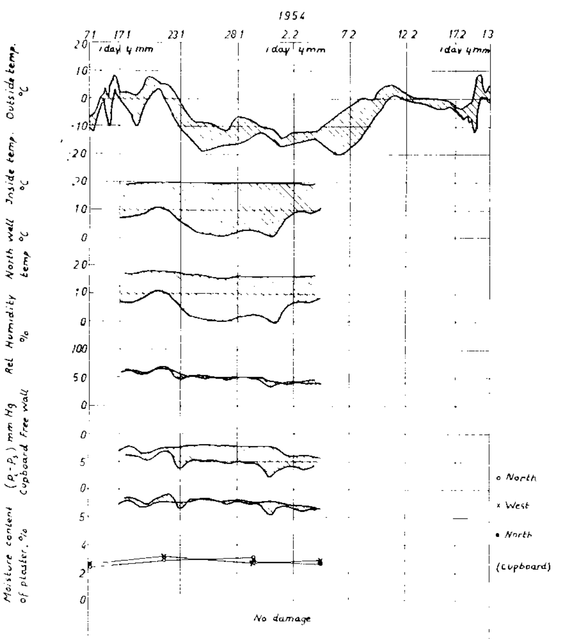

Fig. 7. Variation of outdoor and indoor temperatures. North wall temperature, relative air humidity and differential vapour pressure $p_L - p_S$ for free north wall and north wall behind cupboard in a test house built of timber framing with lightweight wood-wool board. The difference between actual water vapour pressure of the air and the pressure of saturated water vapour $(p_L - p_S)$ at the given wall temperature is a measure of the risk of condensation. Condensation will take place when $p_L - p_S$ has a positive value. Measurement of outside temperature fluctuations allows a comparison with the various fluctuating values inside the room, *i.e.* an evaluation of the thermal stability of the construction. Test period from 17.1 to 3.2.1954. Intermittent heating. From February 1, 1954, the room was also heated during the night with 1 kW.

The experimental determination of average moisture contents and average heat transmission values of west walls exposed to rain and north walls not exposed to rain, which was carried out in most test houses, showed that the heat insulation standards laid down in the regulations (*e.g.* DIN 4108) were not sufficient in those cases where the exterior walls were not protected against increased water penetration under rainfall and excessive water vapour condensation on the inside (Table III).

These data from field tests with artificially inhabited houses were completed with numerous measurements in occupied houses (Fig. 9) and with data from recent systematic laboratory investigations of conventional wall constructions, sponsored by the German Ministry of Housing. According to data so far obtained with brick, sand-lime brick and pumice-stone concrete walls (Fig. 10), an increase in moisture content of 1 per cent. by weight results in an increase in average heat transmission coefficient of the wall of 20 per cent. for brick, 12 per cent. for sand-lime brick and about 2 per cent. for pumice-stone concrete. It is, therefore, not surprising that exterior walls exposed to heavy rainfall are very often lacking in heat insulation properties, although their dimensions correspond to the set standards.

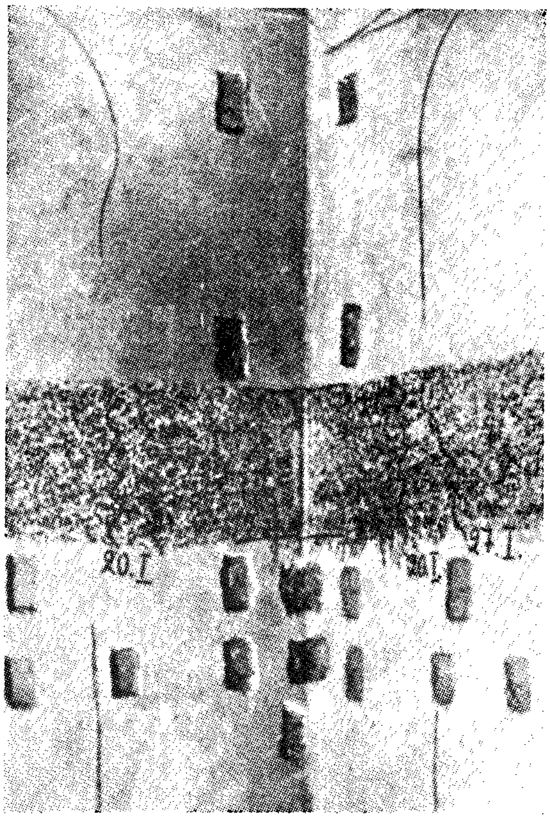

Fig. 8a. Mould test: Wall with poor heat insulation; mould formation on the entire wall area covered with a nutrient medium. Insanitary conditions. Additional heat insulation of walls and corners is required.

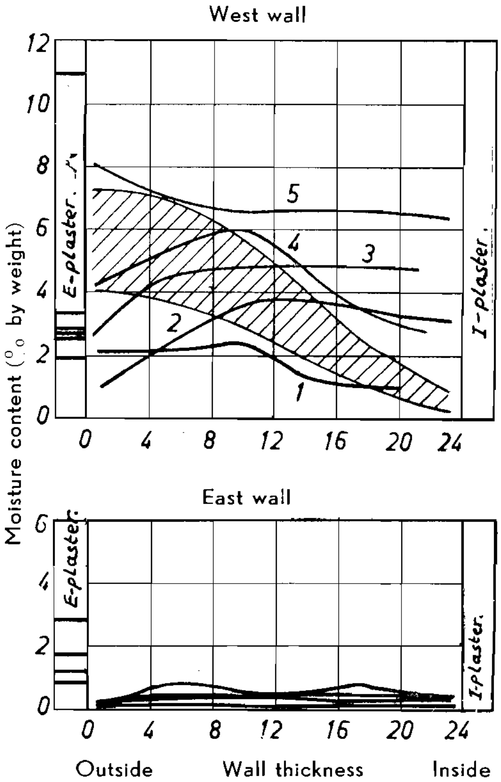

Fig. 9. Variation in moisture content of exterior walls of occupied houses built of 24-cm upright hollow blocks near Holzkirchen. The external rendering on the walls where measurements 3, 4 and 5 were taken in some places showed fine hair cracks. The shaded section refers to the moisture contents measured on the walls of the Holzkirchen test houses built from 25-cm hollow blocks (honey-comb pattern) and 25-cm hollow blocks (grid pattern).

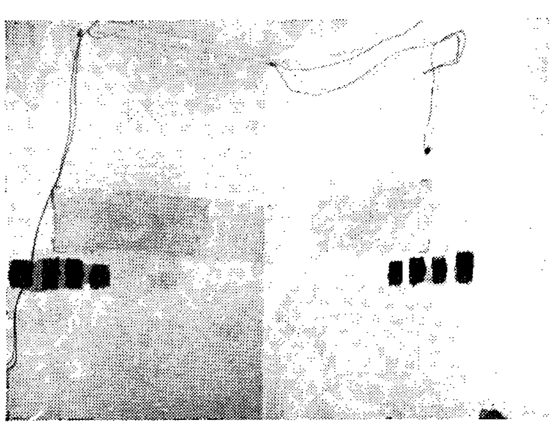

Fig. 8b. Mould test: wall and corner adequately heat insulated. No mould formation on the areas covered with nutrient medium.

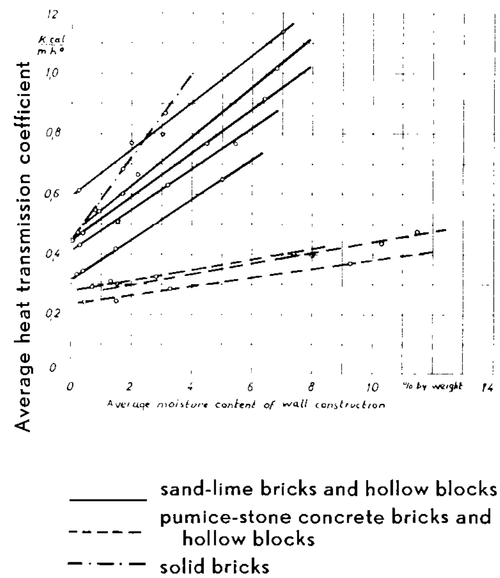

Fig. 10. Average heat transmission coefficient of walls built of different kinds of materials, *viz.* sand-lime bricks and hollow blocks; pumice-stone concrete bricks and hollow blocks; solid bricks.

TABLE III

HEAT INSULATION VALUES FOR NORTH AND WEST WALLS OF TEST HOUSES BUILT ON BEHALF OF THE GERMAN MINISTRY OF HOUSING

Wall material	*Wall facing*	*Wall thickness, cm with plaster*	*Wall thickness, cm without plaster*	*Weight of wall material kg/cu.m*	*Average moisture content % by wt.*	*Average moisture content % by vol.*	*Measured thermal resistance 1/λ (with plaster) sq.m/h° C/kcal*	*Measured thermal resistance 1/λ (with plaster) sq.m/h °C/kcal; averages*	*Measured heat transmission coeff. λ (without plaster) kcal/mh °C*
F2 Solid brick	N	41.5	37.7	1560	0.15	0.23	0.505 0.530 0.530	0.52	0.80
	W	41.5	37.7	1600	2.5	4.0	0.460 0.450 0.460	0.46	0.90
K6 Solid brick	N	16.0	12.0	1560	0.5	0.8	0.233 0.218 0.226	0.22	0.70
	W	16.0	12.0	1560	0.5	0.8	0.204 0.203 0.200	0.20	0.80
F4 Solid sand-lime brick	N	42.0	38.0	1920	6.3	12.0	0.306 0.310	0.31	1.46
	W	42.0	38.0	1920	8.5	16.3	0.292 0.289	0.29	1.57
K2 Single-grain concrete	N	41.5	37.5	1570	1.05	1.65	0.306 0.309 0.312	0.31	1.44
	W	41.5	37.5	1570	1.15	1.8	0.318 0.313 0.310	0.31	1.44
G5 Pumice-stone concrete bricks	N	28.0	24.0	840	9.8	8.2	0.765 0.753 0.768	0.76	0.35
	W	28.0	24.0	840	13.5	11.3	0.620 0.630	0.62	0.42
H6 Porous concrete	N	19.5	15.0	730	11.0	8.0	0.915 0.885	0.90	0.18
	W	21.5	17.5	730	40.0	29.2	0.580 0.576	0.58	0.33

Among the essential results of the comparative field tests on the relationship between moisture content and heat insulation in building elements may be mentioned the explanation of the following main causes of excessive water penetration in part of the exterior walls:

(a) Fast penetration of rain through external rendering and slow drying, caused by unsuitable rendering material whose technological properties and moisture controlling capacity are not adapted to the properties of the building material used for the walls.

(b) Excessive condensation on the walls due to low temperatures at the wall surface and excessive humidity of the indoor air caused by inadequate planning (*e.g.* short-time heating from adjacent rooms) and by unsuitable habitation (insufficient ventilation with unheated air).

It is the object of various building research stations to eliminate these two main sources of trouble (Cammerer, 1939; Kreüger, 1924; Krischer, 1956). At the test site near Holzkirchen, for instance, an experimental project is used in which test walls made of different building materials with different kinds of rendering and the same type of indoor plaster on the west walls (exposed to rain) and the east walls (not exposed to rain) of an experimental building placed in N-S direction could be heated (Figs. 11 and 12). This allows the effect of heavy rainfall and the influence of plaster and wall material on moisture penetration in the west walls to be determined.

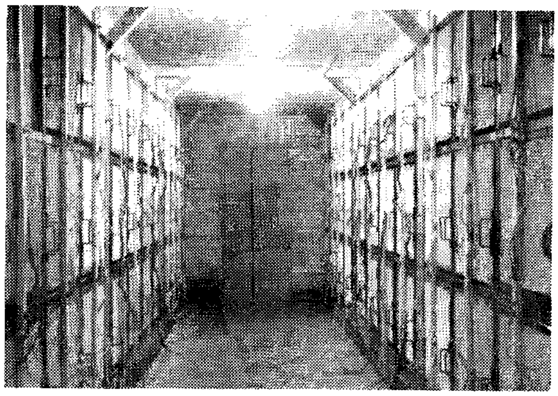

Fig. 11. Test house on Holzkirchen test site for making comparative tests with plaster; inside view.

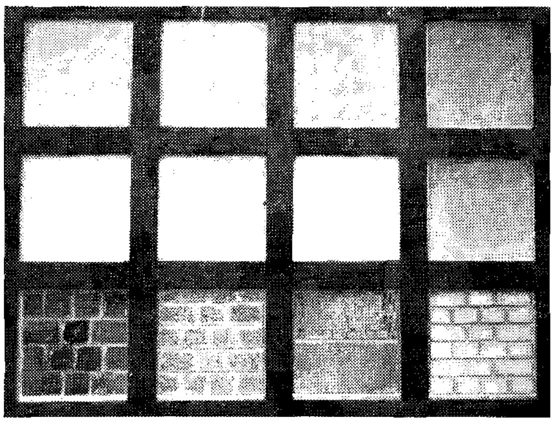

Fig. 12. Test house on Holzkirchen test site for making comparative tests with plaster; part of west exterior wall with built-in test pieces.

The results of these measurements of water absorption by west walls and the corresponding behaviour of east walls as shown in Figs. 13 (a, b and c), the effect of a waterproofing compound added to normal rendering as shown in Fig. 14, and the performance of such a waterproofed rendering over a period of several years, as shown in Fig. 15, seem to confirm the experience made repeatedly in actual practice that one and the same kind of rendering is not suitable for all kinds of building material and that high-grade plasters with suitable additions of waterproofing agents may allow even the weather-exposed walls of a house to be kept dry. However, it is not yet possible to draw a final conclusion on the various modern types of rendering and waterproofing agents, especially as far as their durability is concerned, or to establish a positive relationship between rendering and wall building material in accordance with the requirements of damp control and of their technological behaviour, until profound investigations have been made over a long period.

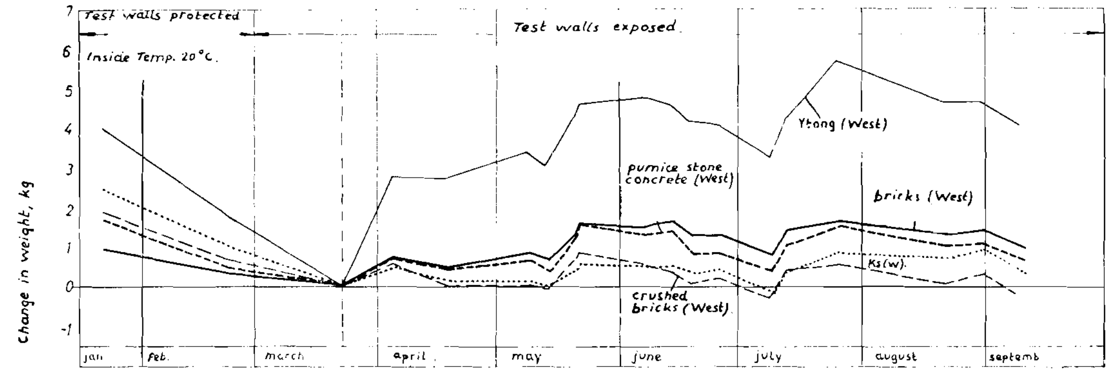

Fig. 13a. Variation in moisture content in test walls built of different materials finished with the same kind of plaster (west walls, exposed to rain): lime plaster on Ytong, crushed brick, hollow blocks, solid sand-lime bricks and pumice stone-concrete.

First coat of plaster		*Finish coat of plaster*	
Cement	1	Cement	0.1
Hydrate of white lime	2	Hydrate of white lime	1
Sand	9	Sand	3.5

(All figures are parts by volume)

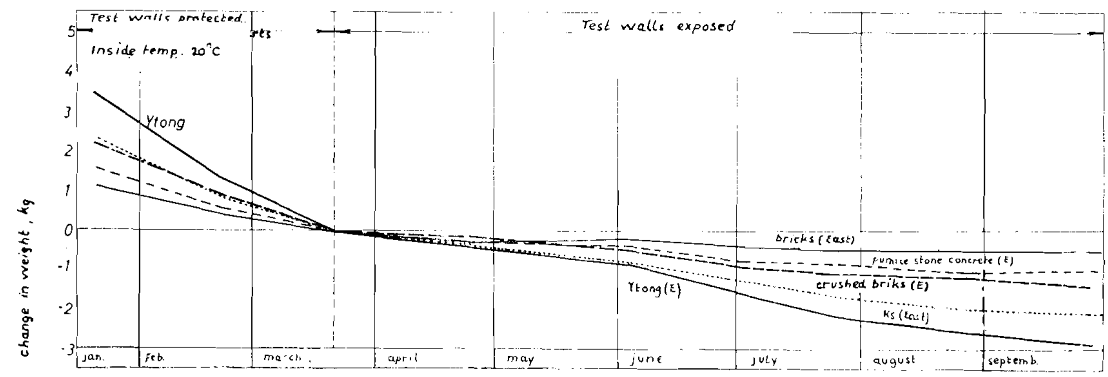

Fig. 13b. Variation in moisture content in test walls built of different materials (east walls, not exposed to rain): lime plaster on Ytong, crushed brick, hollow blocks, solid sand-lime bricks and pumice-stone concrete.

First coat of plaster		*Finish coat of plaster*	
Cement	1	Cement	0.1
Hydrate of white lime	2	Hydrate of white lime	1
Sand	9	Sand	3.5

(All figures are parts by volume)

REVIEW OF METHODS OF PROTECTING EXTERIOR WALLS AGAINST MOISTURE ABSORPTION

The data on investigations concerning the water absorption by exterior walls through rain and through indoor air humidity that are so far available – from which some essential aspects have been dealt with in the foregoing pages – may be expected to be incorporated in a range of regulations aimed at the prevention of trouble due to dampness in dwellings, especially in respect of planning, construction and habitation of houses.

PLANNING

(1) All habitable rooms should be heated either individually by a single heating unit

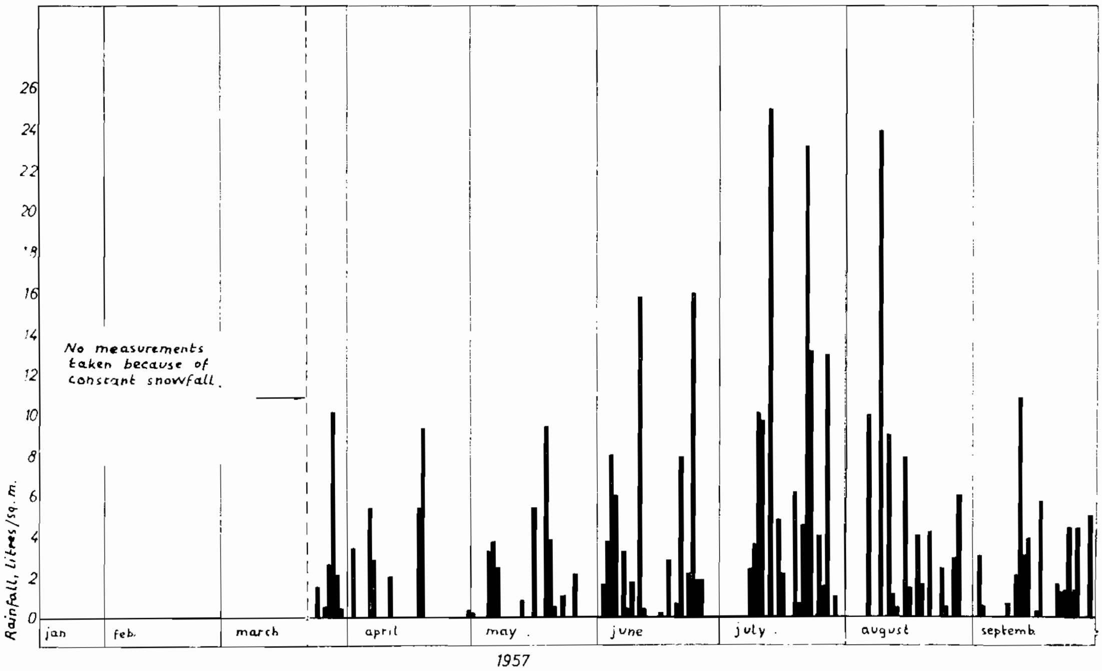

Fig. 13c. Quantities of rain fallen on test walls (west walls) during the period from March to September, 1957.

for each room or by a central heating plant, and not by hot air drawn from any adjacent room or kitchen.

(2) Water vapour produced in kitchenettes or intensively used dining-space kitchenettes, bathrooms, etc., should be discharged into the open air by means of a suitable ventilating system, where possible, direct from the source (*e.g.* by a vapour collector or the like).

(3) Exterior walls facing north and those exposed to the weather are more subject to water penetration than the other walls and should, therefore, be dimensioned for greater heat insulation (thicker wall or additional heat insulation). Corners should be extra insulated or rounded off.

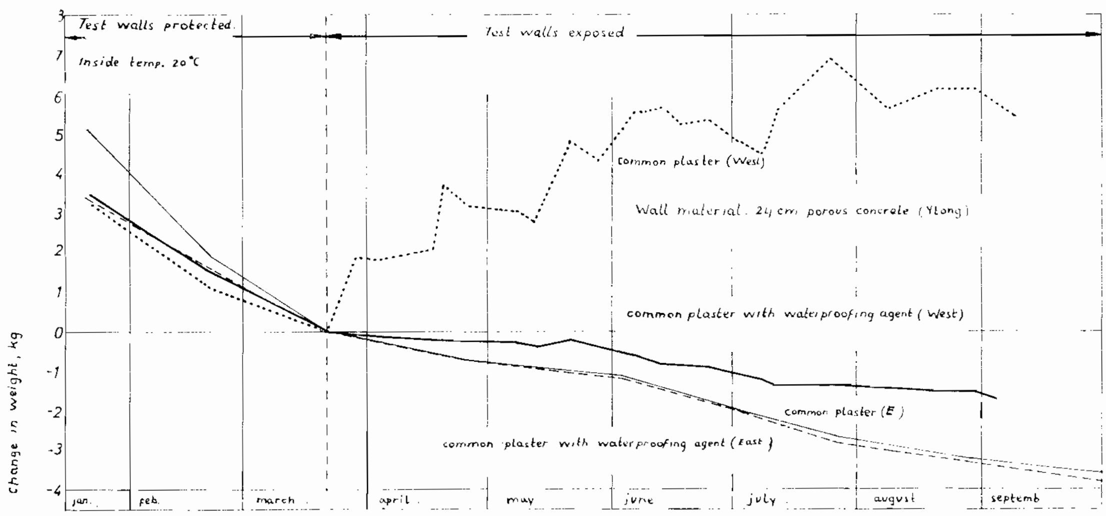

Fig. 14. Effect of a waterproofing agent on the water penetration in a wall. Variations in moisture content of wall elements over the test period from March to September, 1957. Changes in weight refer to the situation at the beginning of free exposure to weather (March, 1957).

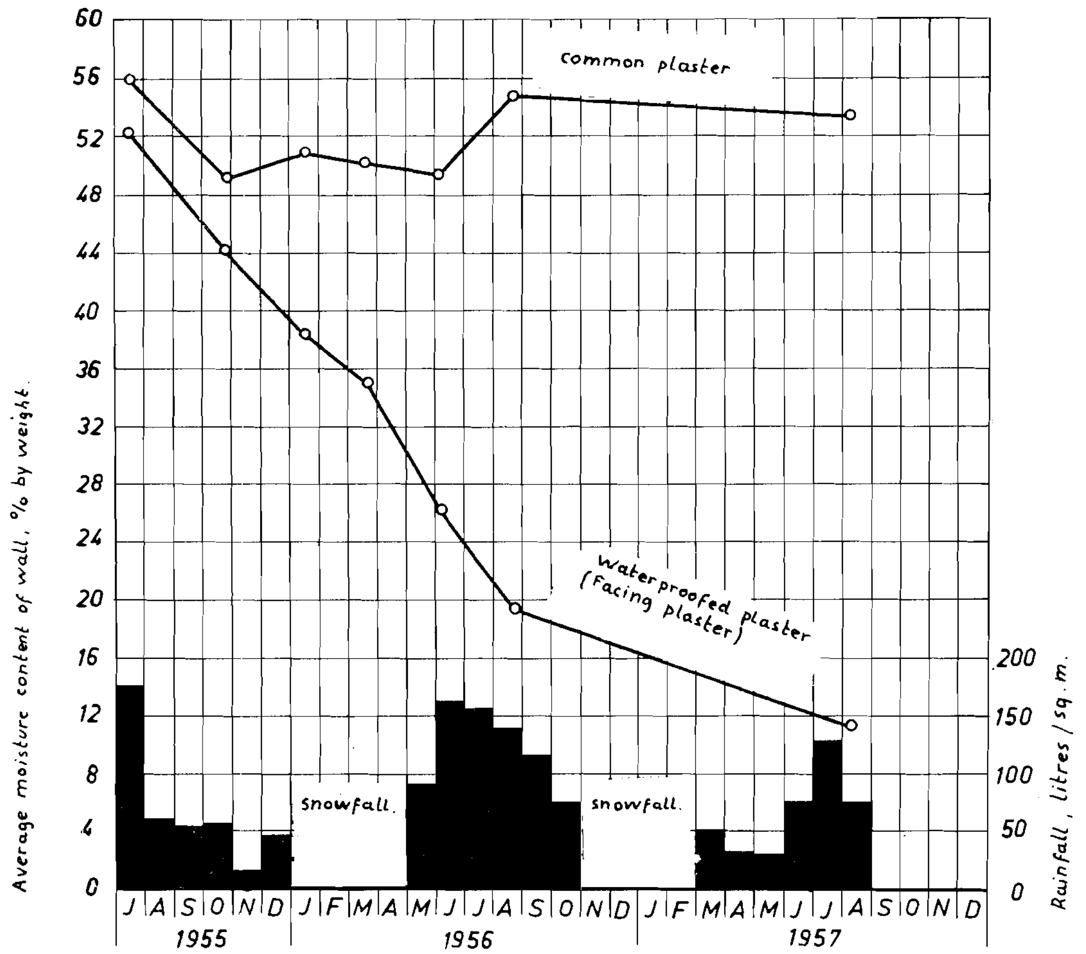

Fig. 15. Variation with time of average moisture content in west walls built of porous concrete with different kinds of plaster (common plaster and special type facing plaster). Measured quantities of rain per month per 1 sq. m of west wall area.

CONSTRUCTION

(1) Careful selection and preparation of jointing mortars and plasters. The technological properties, heat insulating and moisture control characteristics of jointing mortars and renderings should be adapted to the wall materials used, since otherwise the drying of the exterior walls would be hampered. (Dense and heavy jointing mortars used on properly heat insulating bricks may cause cold spots and hair cracks between mortar and bricks; dense external renderings which are not adapted to the wall material and therefore mostly develop cracks, reduce the moisture control characteristics of the building material.)

(2) External renderings used on weather-exposed walls require particular attention to their composition and application. They should prevent the penetration of heavy rain but not impede the transmission of damp from inside to outside through the wall. Approved special plasters (facing plasters) and suitable proofing agents should be used to ensure a lasting effect.

(3) Exterior walls made of capillary materials exposed to the weather (mostly west and north walls) should be thicker and provide better heat insulation than the other exterior walls and should correspond to the next higher heat insulation class because water penetration into the walls cannot be prevented by a suitable exterior plaster or otherwise.

HABITATION

(1) No large pieces of furniture like cupboards or beds should be placed against exterior

walls facing north and those exposed to wind and rain since damp patches and mould are liable to form behind them.

(2) Habitable rooms, particularly bedrooms and kitchenettes, should at least be slightly heated in wintertime by means of their own heating appliances, because in case of heating by draught air from adjacent rooms there may be serious condensation (or even ice formation) on cold walls and pieces of furniture.

(3) Living spaces, particularly bedrooms and kitchens, should be repeatedly ventilated every day to prevent excessive dampness collecting in them.

REFERENCES

Directives and standards for heat insulation of buildings

Sweden

Anvisingar till Byggnadsstadgan, *Kgl. Byggnadsstyrelsens Publikationer*, 1950: 1.

Norway

Byggeforskrifter av 15. Desember 1949, Forsynings- og Gjenreisningsdepartmentet, Oslo, 1950.

Denmark

Regler for Beregning af Varmetab fra Bygninger, Teknisk Forlag, Copenhagen, 1953.
Tekniske krav og vejledning etagebyggeri, published by Ministry of Housing, March, 1953.

United Kingdom

Housing Manual, 1949, Technical Appendixes, published by the Ministry of Works and Ministry of Housing and Local Government, 1951.

The Netherlands

Natuurkundige Grondslagen voor Bouwvoorschriften, Deel I: Thermische Eigenschappen en Ventilatie van Woningen (Physical Bases for Building Regulations, Part I: Thermal properties and ventilation of dwellings), published by Hoofdcommissie voor de Normalisatie in Nederland, V 1068, 1951.

Germany

DIN 4108 *Wärmeschutz im Hochbau*, published by Deutscher Normenausschuss, Berlin W 15, July, 1952.

Austria

ÖNORM – B 8110 *Hochbau, Wärmeschutz und Wärmebedarf.*

Greece

Standards according to DIN 4108.

Bundesministerium für Wohnungsbau (Ministry of Housing – Western Germany), Bad Godesberg, 1959, *Junge Ingenieure sehen sich um*, pp. 35 and 36.

REIHER, H., H. KÜNZEL AND D. SODEN, *Wärme- und Feuchtigkeitsschutz in Wohnbauten* (Freiland-Versuchsstelle bei Holzkirchen), Verlag Wilhelm Ernst & Sohn, Berlin, 1958.

CAMMERER, J. S., Der Einfluss der Feuchtigkeit auf den Wärmeschutz von Bau- und Dämmstoffen nach dem internationalen Schrifttum, *Wärme- und Kältetechnik*, 41 (1939) 126.

CAMMERER, J. S. AND H. SCHÄCKE, *Feuchtigkeitsregelung, Durchfeuchtung und Wärmeleitfähigkeit bei Baustoffen und Bauteilen*, Verlag Wilhelm Ernst & Sohn, Berlin, 1957.

KRISCHER, O., Trocknung fester Stoffe als Problem der kapillaren Feuchtigkeitsbewegung und der Dampfdiffusion, *VDI-Beiheft Verfahrenstechnik*, 4 (1938) 104–110.

SCHÜLE, W. AND R. JENISCH, *Feuchtigkeitstechnik Untersuchungen in beheizten Kleinküchen*, Forschungsgemeinschaft Bauen und Wohnen, Stuttgart, Edition 57, May, 1959.

JESPERSEN, H. P., Bestemmelse af varmeledningstal for bygge og isoleringsmaterialer ved varierende fugtindhold, *Varme*, 14 (1949) 41–49, Copenhagen.

JESPERSEN, H. P., Die Wärmeleitzahl feuchter Stoffe und ihre Messung, *Gesundh. – Ingr.*, 74 (1953) 187–193.

KERSTEN, M. S., *Bull. Univ. Minn. Inst. Technol. Eng. Expt. Sta.*, 28 (1949).

KREÜGER, H. AND ERIKSON, *Undersökningar rörande byggnadskonstruktioners värmeisoleringsförmaga*, 11. I V A – handlinger No. 36, Stockholm, 1924.

KRISCHER, O. AND H. ROHNALTER, Die Wärmeübertragung durch Diffusion des Wasserdampfes in den Poren von Baustoffen unter Einwirkung eines Temperaturgefälles, *Gesundh. – Ingr.*, 60 (1937).

KRISCHER, O. AND H. ROHNALTER, Wärmeleitung und Dampfdiffusion in feuchten Gütern, *VDI-Forschungsheft*, 402 (1940).

NARAYANAMURTI, D., Versuche über die Feuchtigkeitsbewegung in Holz und anderen Körpern beim Trocknen und über das Wärmeleitvermögen feuchten Holzes, Beih. Verfahrenstechnik No. 2. zur *VDI-Zeitschrift*, 1936, pp. 13–23.

ROWLEY, F. B. AND A. G. ALGREN, Thermal Conductivity of Building Materials, *Univ. Minn. Eng. Expt. Sta. Bull.*, 12 (1937).
SCHÜLE, W. AND H. SCHÄCKE, Untersuchungen über den praktischen Feuchtigkeitsgehalt von Aussenwänden aus Bimsbaustoffen. *Gesundh. – Ingr.*, 72 (1951) 3.
DE VRIES, D. A., The Thermal Conductivity of Granular Materials, Annex, 1952–1 in *Bulletin de l'Institut International du Froid*, pp. 115–130.
WATZINGER, A. AND B. KINDEM, *Om Byggningsmaterialers Varmeisoliering*, Trondheim, 1935, in Kommission bei F. Bruns.
WATZINGER, A., B. KINDEM AND B. MICHELSEN, Untersuchungen an Massenaustauschstoffen für Weg- und Eisenbahnbau, Saertrykk av *Meddemelser fra Veidirektoren*, 6 (1938) 473.
WATZINGER, A., Varmeledningstall for Byggematerialer (test results 1920–1949), *Norges Teknisk-Naturvitenskapellige Forskningsrad Byggeteknisk Utvalg Rapport*, No. 1/1949, Oslo, 1949.
WISSMANN, W., *Über das Verhalten von Baustoffen gegen Feuchtigkeitseinwirkung aus der umgebenden Luft*, Dissertation, Darmstadt, 1954.
Ziegel-Bau-Taschenbuch, 1953. Diagram on p. 79, by request of Institut für Technische Physik, Stuttgart.
KRISCHER, O., *Die wissenschaftlichen Grundlagen der Trocknungstechnik*, Springer-Verlag, Berlin–Göttingen–Heidelberg, 1956.
BASTINGS, L., *Dampness and Mould in Modern Houses*, Department of Scientific and Industrial Research, New Zealand.
BASTINGS, L., Some physical aspects of domestic comfort, *N.Z. Sci. Rev.*, 8 (1950) 83–87.
MYRRE, G., *Klimaets Innvirkning pa Velisolerte Teglsteinsvegger, Erfaringer fra provehus og laboratorieforsok*, Norges Byggforskningsinstitutt Saertrykk No. 35 (1959) and further activities of this institute.

Various reports of the following institutes:
Building Research Station, Garston;
Eidgenössische Materialprüfungsanstalt, Zürich (EMPA);
Institut für Technische Physik, Stuttgart;
Centre Scientifique et Technique du Bâtiment, Paris;
Research Institute for Public Health Engineering T.N.O., The Hague;
National Research Council Canada (Division of Building Research), Ottawa;
Statens Byggeforsknings-Institut, Copenhagen.

Heat transmission through masonry walls: Measurements carried out at the Norwegian Building Research Institute's wall laboratory in Trondheim

UDC 699.86 : 69.022.3

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The Norwegian Building Research Institute has since 1950 performed a series of investigations concerning the heat transmission through various types of walls. The first experiments, comprising measurements of the thermal transmittance values (U-values) for frame walls with mineral wool insulation, were carried out in occupied dwellings [1]. As the measurements sometimes had to be carried out in rooms used by the occupants, difficulties in heat flow determinations arose owing to unstable temperature, etc. Experience from those measurements led to the design and construction of a special wall laboratory in 1953–54. This wall laboratory was erected by the Norwegian Building Research Institute and financed by the Institute and the manufacturers of the various building and insulation materials, as well as by other interested parties.

It will be seen from Fig. 1 that the wall laboratory is a long low building, about 3.5 m wide and with a total length of 29 m, including a room for recording instruments. Partition walls divide the laboratory into small rooms, each room having four or six test panels, 1.3–1.5 m wide and 3.0–3.2 m high. The roof is of wood, insulated with mineral wool and covered with bitumen felt. In the six northern rooms the floor is an insulated concrete slab. In the other rooms the floor is of wood insulated with mineral wool. The test panels are separated from one another, so that each wall is easily removed and a new one put in. The rooms are heated by thermostatically controlled electric tubular heaters placed in the middle of the floor, and there are devices for controlling the humidity of the air in all rooms.

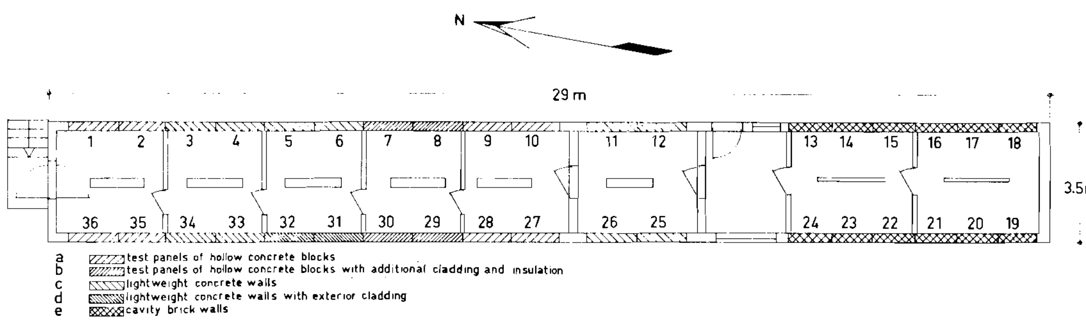


Fig. 1. Plan of the wall laboratory.

The longitudinal axis of the house is orientated approximately north-south, so that the test walls, which are placed side by side along the length of the house, face either ENE or WSW. The space around the wall laboratory is open, so that all the test walls, practically speaking, have no protection against wind and weather. The west walls are subjected to severe winds and driving rains but the east walls are not, because of the climatic conditions in that location. The amounts of driving rain from the different directions are shown on Fig. 2. The values are mean values of daily observations over a ten-year period. The west walls receive, however, more direct solar radiation than do the east walls. To determine the influence of the climatic conditions and the orientation of the walls on the heat loss, the two opposite test panels are practically always identical, *e.g.* panels 1 and 36, Fig. 1.

The heat loss through the walls is usually measured by means of thermo-electric heat-flow meters on the inside face of the wall. In rooms with high relative humidity, special hot boxes are used. For solid walls, the heat flow is measured only in the middle of the wall; for walls with cavities, heat-flow meters are used over the total height of the wall.

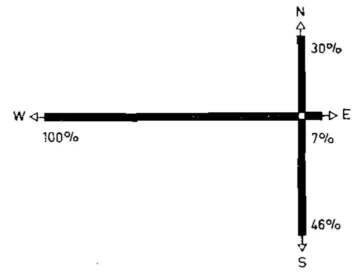
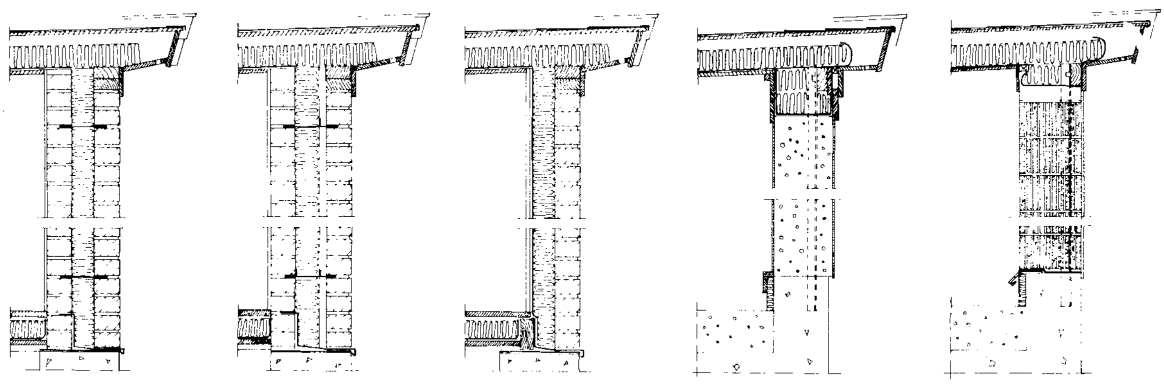


Fig. 2. Distribution of driving rain near the wall laboratory. Yearly average values during the ten-year period 1943–53: north, 1387 mm (30%); east, 329 mm (7%); south, 2124 mm (46%); west, 4549 mm (100%).

Each heat-flow meter is recorded 16–17 times per day by means of recording potentiometers. This is also done for all temperatures measured either by thermocouples or resistance thermometers. For the daily control, all room temperatures are read from mercury thermometers. A meteorological screen equipped for measuring the humidity of the air, maximum and minimum temperatures, etc., is placed outside the wall laboratory. The vertical precipitation and the amount of driving rain are recorded daily, while the wind velocity is recorded continuously.

The first walls that were tested were 24 walls of hollow concrete blocks (Fig. 3). These test walls were constructed in the summer of 1953. To ensure a workmanship that would



a b c d e

Fig. 3. Vertical cross sections of the test panels. a. Cavity brick wall (Cavity filled with insulation material), b. Cavity brick wall (Cavity partly filled with mineral wool insulation), c. Brick veneer wall, d. Test panel of lightweight concrete, e. Test panel of hollow concrete blocks.

correspond to practice, the construction of the walls was left to a mason contractor. The blocks used were of three different types delivered from three different factories. Common to them all was that they had nine rows of 0.8 cm air spaces and dimensions of about $30 \times 15 \times 25$ cm. The bulk density of the material in the blocks was about 1700, 1800 and 2000 kgs/cu. m for the different qualities, corresponding to block weights of about 1400, 1500 and 1700 kg/cu. m.

All the walls were rendered both on the inside and the outside. The thickness of the rendering was 15–20 mm. As an attempt to try to evaluate the influence of the mortar joints on the heat flow, the joints were varied both with respect to thickness and workmanship. The regular types of joints, such as completely filled joints and joints with two or three mortar strips, were used and in a couple of walls there were completely open vertical joints.

The measurements were started a year after the walls were constructed, and were continued without interruption from November, 1955, until the middle of May, 1956. The room temperature was maintained at about 20° C in five of the rooms, and at about 13° C in one room. The humidity, which was not controlled, varied from 30–55 per cent. in the first five rooms and from 50–85 per cent. in the last one, depending upon the outside climate and the moisture received from the walls. There was a considerable amount of rain during the autumn of 1955, so that some of the test walls facing west showed rain penetration through the joints and were very damp when the frost period started around the middle of December. There were, on the whole, low outside temperatures and mostly cloudy weather during the whole period after Christmas.

A new series of measurements was carried out during the winter of 1957–58, including a series on concrete block walls with an exterior cladding, with or without additional insulation. Two identical panels, one facing west and one east, were given an exterior cladding of asbestos-cement shingles nailed to vertical $^5/_4'' \times 4''$ unplaned boards at a centre-to-centre distance of 30 cm which were nailed directly to the wall by means of hardened steel nails. The air ducts between the boards were open below and in direct contact with the outside air. The top openings of the ducts were protected by a horizontal board.

On two other panels a layer of 20 mm thick sewn glass-wool blankets was placed on the outside. The blankets were suspended vertically with nailed butt joints and fastened to the wall by means of $1'' \times 4''$ unplaned boards placed vertically at a centre-to-centre distance of 30 cm. A cladding of asbestos-cement shingles was fastened on the outside. No attempt was made to close the air space under the cladding at the bottom of the sections.

These four panels were all included in the 1955–56 measurements, but then without cladding or insulation.

Four other walls, constructed of a lighter type of concrete block, were also studied. Two of these were included in the 1955–56 measurements. The horizontal joints in these walls were made with a template to form ten separate strips of mortar, while the vertical joints were made with two separate strips of mortar. In addition, two new test walls were constructed where the template was used for both the vertical and horizontal joints.

The room temperatures and the relative humidities were much the same during the measuring periods 1955–56 and 1957–58, but the outside climatic conditions were better during the last period with less driving rain and more solar radiation.

In the period 1955–56 the U-values were found to be in the vicinity of 0.9–1.0 kcal/m^{2}h °C for the walls of the lightest blocks, compared with 1.1–1.3 kcal/m^{2}h °C for the walls of the heaviest ones [2]. For those walls where no rain penetration was observed on the inside, the U-values were the same for east and west facing panels of the same construction. West facing panels, however, which showed more or less signs of rain penetration through the joints, gave substantially higher U-values than the east facing panels of the same kind [3].

The walls that had no asbestos-cement shingles or mineral wool insulation showed 10% lower U-values for the period 1957–58 than 1955–56. This decrease must be ascribed to the improved weather conditions. The test panels in which a template was used both for the horizontal and vertical joints gave 4% lower U-values than the test panels where the template was used for the horizontal joints only. For the two walls with asbestos-cement shingles and insulation and for the two walls with asbestos-cement shingles only, the U-values were found to be 0.54 and 0.76 kcal/m^{2}h °C. The U-values measured 1955–56 for the same walls were about 1.2 kcal/m^{2}h °C.

The increase in air-to-air resistance is thus 1.0 m^{2}h °C/kcal for the test panels with additional cladding and insulation and 0.5 m^{2}h °C/kcal for the test panels with cladding only. The increase in heat resistance can mainly be attributed to three factors:

(a) The additional heat resistance of cladding and insulation.

(b) Improved weather conditions.

(c) The test panels have dried out because of protective cladding.

Factor (a) is estimated at 0.70 m²h °C/kcal, or 70 % of total increase in heat resistance for panels with cladding and insulation. For panels with cladding only, factor (a) amounts to 0.15 m² h °C/kcal, or 30 %.

Factors (b) and (c) will thus amount to 0.30 and 0.35 m²h °C/kcal, for the test panels, mentioned in the same order as above, which means 30 % and 70 % of the total increase in heat resistance. It is difficult to distinguish between the influence from factor (b) and (c), but the 10 % decrease in U-values for the unprotected test panels (see above) indicates that factor (c) is the dominant one.

The heat transmittance through the walls varied considerably with the time of the year and the variations were found to be larger for the west walls than for the east ones. This was caused by the more marked variations in the climatic conditions for the west walls, such as driving rain, and partly also by direct sunshine on the walls. Fig. 4 thus shows the variation of

$$\frac{Q}{\Delta t_{a-a}}$$

in the measuring period 1955–56, expressed in terms of the mean value of

$$\frac{Q}{\Delta t_{a-a}}$$

Q is the heat flow, and Δt_{a-a} is the air-to-air temperature difference. The

$$\frac{Q}{\Delta t_{a-a}}$$

values are for both directions and are average values for the 12 test panels. The heat trans-

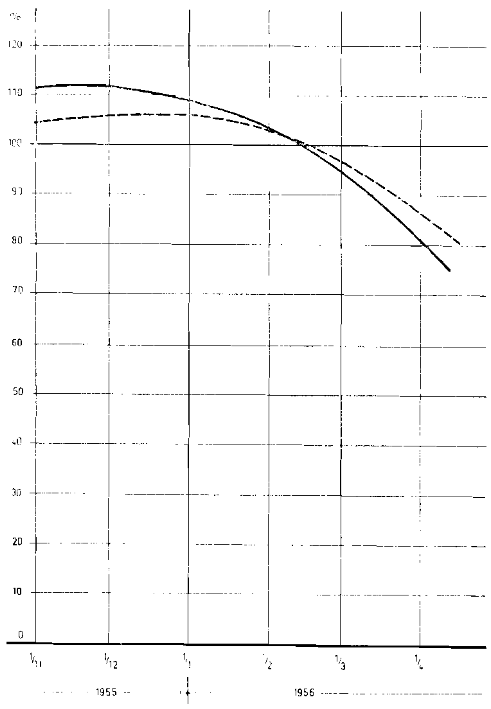


Fig. 4. Smoothed curves showing the variation of the ratio $\frac{Q}{\Delta t_{a-a}}$ for walls of hollow concrete blocks. Measured during the period Nov. 1955–June, 1956. The curve drawn in whole line refers to west faced walls, the dotted line refers to east faced panels.

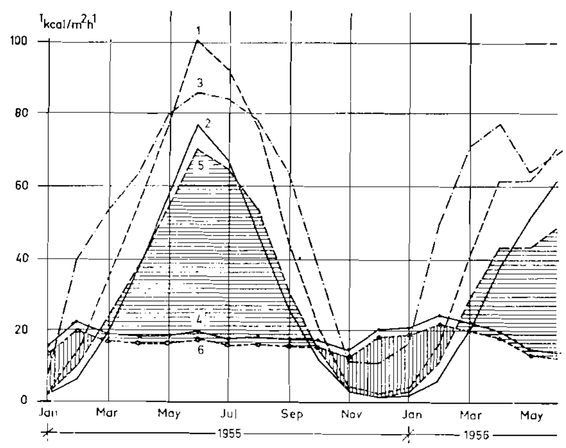


Fig. 5. Heat exchange by radiation, computed values for the conditions at the wall laboratory Jan. 1955–June, 1956. The curves 1, 2 and 3 give the computed total solar radiation on vertical walls faced **1** east or west **2** north **3** south. Curve 5: Amount of solar heat which may be absorbed by east or west walls having an absorptivity $a = 0.7$ for solar radiation. Curve 4: Net long wave radiative heat exchange, assuming the emissivity $\varepsilon = 1.0$ for walls and surroundings. Curve 6: as curve 4, but assuming the long wave emissivity $\varepsilon = 0.9$ for the walls and $\varepsilon = 1.0$ for the ground. Horizontally and vertically hatched areas indicate radiative heat gain resp. heat loss. (The lines are drawn only to connect the points giving the computed monthly mean values.)

mittance through the west walls, computed as the mean for the first half of the measuring period, was a little more than 20 per cent. higher than the corresponding value for the second half of the period. The difference was only 8 per cent. for the east walls, however. The higher heat transmittance figure for the first half of the period was partly caused by a higher moisture content in the walls, but also by the fact that, at that time, the heat radiation from the wall was greater than the heat radiation to the wall, *e.g.* a heat radiation loss was taking place. Around the middle of February the radiation loss and the radiation gain were about equal and after this time the amount of heat radiation that the wall received was greater than the amount that was lost, *e.g.* a heat radiation gain was taking place.

This is illustrated in Fig. 5. The curves 1, 2 and 3 give the total amount of solar radiation, *i.e.* the direct and diffuse radiation on vertical walls exposed to the respective directions. The values are computed on the basis of observations taken at a meteorological station near the wall laboratory. The monthly solar radiation is evaluated from the solar heat radiation by clear sky, taking into account the observed cloud factors [4]. Curve 5 indicates the amount of solar heat which may be absorbed by vertical walls facing east or west and having an apparent absorptivity for solar radiation $a = 0.7$. Curve 4 gives the net long wave radiation, *i.e.* the heat radiated from the walls diminished by the radiation received from the water vapour in the atmosphere [5] and radiation from the ground, assuming the walls and the ground have an emissivity $\varepsilon = 1.0$ [6]. As the outer wall surface temperature and ground temperature were not recorded, they are in this calculation assumed to be the same as the outside air temperature. Curve 6 gives the net long wave radiation, assuming an emissivity of 0.9 for the wall surface. The horizontally and vertically hatched areas indicate the radiation heat gain and heat loss. The computed values are by no means exact, and even if they were, it would be difficult to use them for anything other than to illustrate the great influence of radiation on the heat transfer from the outer wall surface and on the heat loss from the wall as a whole.

The radiation curves undoubtedly explain to a certain extent the great variation in

$$\frac{Q}{\Delta t_{a-a}}$$

and show the desirability of a correctly determined sol air temperature, as the normal meteorological readings do not adequately describe the weather for purposes of calculating its effect upon the surface heat exchange, particularly when solar radiation is involved.

The wall laboratory was enlarged in 1957 to include 12 test panels of insulated brick walls. There are three types of wall (see Fig. 3a, b, c):

(a) Cavity brick wall: the 10-cm cavity is filled with mineral wool or other types of insulation material.

(b) Cavity brick wall: 70 cm, mineral wool bats insulation fastened to inner leaf by means of special binders, 3-cm air space.

(c) Brick veneer wall with a wooden frame and 10-cm mineral wool insulation. Vapour barrier and 13-mm plaster board on the inside.

All the outer leaves are in hard-burned perforated bricks, while the inner leaves are in the same type of brick, but more lightly burned. Mortar and workmanship are the same for all the test walls, all of which are plastered on the inside.

For purposes of drainage, a zinc flashing painted with asphalt was placed in the bottom of the walls, and drainage openings were formed by leaving the vertical joints in the bottom course unfilled. The vapour-proof barrier in the roof is extended only to the inner leaf, so that the air in the cavity is connected with the outside air.

For the brick walls, the heat flow and the distribution of the heat flow were measured over the total height of the wall and the heat transmittance coefficients were calculated on the basis of the apparent mean heat loss for the whole wall. In addition to the temperature of the room air and the outside air, temperatures were measured at various heights on the inside and the outside of the inner as well as the outer leaves. In this way the surface resistances and the heat resistance of the various wall components could be measured.

The measurements were started in the autumn of 1956 and are still being continued. Besides the heat flow and the temperature measurements, determinations of the moisture content in the walls, etc., were made.

For the cavity walls facing east with 10-cm mineral wool in the cavities, a heat transmittance coefficient of about 0.36 kcal/m²h °C was found both for the winter of 1956–57 and 1957–58. For the walls facing west and of the same construction, the figures were found to be 0.44 and 0.41 kcal/m²h °C for the same measuring periods. The heat transmittance coefficients are higher for the west walls than for the east walls because of more severe exposure to wind and driving rain. The heat transmittance coefficients for the west walls were somewhat lower during the winter of 1957–58 than the winter of 1956–57. This was partly due to more favourable weather with less wind and driving rain and partly to other causes. During the 1956–57 measurements, all the vertical joints in the bottom course were left open in all the test walls, while during the 1957–58 measurements only six of the walls had open joints and then only one in each wall. The remaining six walls had no open joints. It is, therefore, likely that part of the decrease in the heat transmittance coefficient was caused by a reduction in the degree of ventilation of the cavities after the majority of the open joints were closed.

The heat transmittance coefficients for the cavity walls were somewhat higher than for the veneered walls, for which the U-value was found to be about 0.25 kcal/m²h °C. The reason for this was the pronounced "cold bridge" which occurred because the inner leaf was placed directly on the foundation. The primary effect of this "cold bridge" is a marked cooling down of the lower part of the wall caused by the direct heat conduction from inner leaf to foundation with the consequent increased heat loss. The "cold bridge" might, for walls of this type, also have a secondary effect which results in an increased heat loss in the top of the wall. The air will flow from the outer to the inner leaf in the bottom of the cavity due to the convection. This air will not be heated appreciably before it has reached a certain height in the cavity, because the lower part of the inner leaf has been cooled down. This causes an increased heat loss also in the upper part of the wall.

In Fig. 6 is shown the distribution of the apparent U-values measured for the different heights of the walls, expressed in terms of the mean U-values for the walls. The ratio

$$\frac{Q}{\Delta t_{a-a}}$$

was approximately constant for the whole height of the veneered walls, except for a slight increase near the very top of the wall, where the insulation was open to the outside air and where part of the insulation consequently was cooled down appreciably.

All the cavity walls with the cavities completely filled with an insulation material showed approximately the same heat-flow distribution. The heat flow was at a maximum at the bottom because of the "cold bridge", at a minimum in the middle of the wall and increased somewhat towards the top of the wall because of the outside air cooling off the top part of the insulation.

The heat flow through the two test walls with a 3 cm space decreased considerably towards the top of the wall. The heat flow is at a maximum at the bottom, both because of the "cold bridge" and because of the convection in the air space.

In the autumn of 1957, 12 of the concrete block walls were removed and replaced by test panels of lightweight concrete. The material, which was in the shape of blocks, slabs or staves, had bulk densities of about 450 to about 700 kg/m³. The material was delivered by three different factories. The masonry work and the surface treatment were done by a regular mason, according to the directions given by the manufacturers.

The type of joint consequently varies from one test wall to the next, apart from the two opposite walls facing east and west, where they are always identical. There are thus glued joints, 2–3 mm thick joints where a special mortar was used, completely filled joints or joints with two strips of activated lime-cement mortar or pure cement mortar, with the thickness of the joints varying from 3 to 8 mm. For the treatment of the exterior and interior surfaces, different types of thin rendering coats or more traditional types of rendering were used and also impregnating liquids or special masonry paints, according to the directions of the manufacturers. An exterior cladding of asbestos-cement shingles on battens was used on two of the walls facing west. Ten of the test panels have a thickness of 25 cm, while two of them are 30 cm thick cavity walls with leaves of 10 cm thick lightweight concrete blocks. The 10 cm wide cavity is filled with a granulated insulation material.

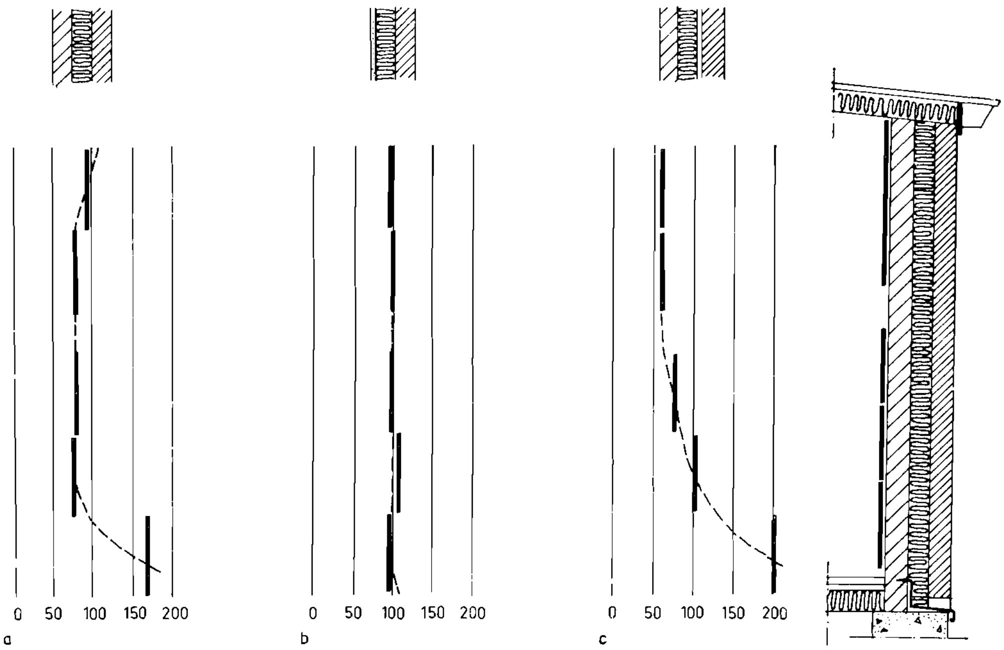


Fig. 6. Apparent distribution of *U*-values over the height of the cavity brick walls and brick veneer walls. The *U*-values are expressed in terms of the mean *U*-value for the respective walls.

The moisture content in the material at time of delivery was determined and varied from about 1.5 to 9.5 per cent by volume, varying for the different materials. The measurements were started late in the fall of 1957 and are still being continued. No additional humidity was supplied during the winter of 1957–58 to enable the walls to dry out as well as possible. The relative humidity of the air in the test rooms varied, therefore, inside the 30–50 per cent. range with a room temperature of about 20° C. From autumn, 1958, the room humidity was maintained at 45 per cent. Besides the heat-flow and temperature measurements, determinations of the moisture content in the walls were taken at regular intervals by boring out specimens of the wall material. The samples were normally taken at three different heights.

The first moisture content determination was made half a year after the walls had been constructed. At that time a considerable drying-out of the materials having the highest moisture content had already taken place. The distribution of the moisture was as expected at that time of the year, *i.e.* the moisture content increased towards the outside of the wall. The next determination was made one year after the walls were finished. A considerable drying-out had taken place during the spring and summer of 1958, so that there was no longer any marked difference in the moisture content for the different walls. The greater part of the free moisture in the walls had been given off and the moisture content was generally evenly distributed over the wall thickness.

It is apparent from the results from the winter of 1957–58 that there was little difference in the heat transmittance for the east and the west walls. This is because the moisture content has probably been the same in the east and west walls, as the moisture from the construction period has been dominant during the first period after the construction. There has been a marked decrease of the heat transmittance coefficients because of the drying-out of the walls.

The equivalent thermal conductivity for the wall materials, calculated on the basis of the heat transmittance coefficients for the period November, 1957–May, 1958, is in the range of 0.1–0.19 kcal/m h °C. More accurate values will be calculated when the moisture content in the walls has become more stable.

Experience from the other tests also shows that there is reason to expect variations from one season to another because of, among other factors, the changing climatic conditions.

REFERENCES

1 A. Tveit, *En metode til måling av varmegjennomgangstall for vegger og bjelkelag* (A method for measuring the coefficient of thermal transmittance for walls and floors), Oslo, 1953, 22 pp., illus. (Norwegian Building Research Institute, Report No. 8).

2 A. Tveit, *Klimaetsinnflytelse på betonghulsteinveggers varmeisolasjon* (Influence of the climate on the thermal resistance of hollow concrete block walls), Oslo, 1959, 52 pp., illus. (Norwegian Building Research Institute, Report No. 30).

3 N. Holmquist, *Undersökning av värmeförlusten genom väggar, med speciell hänsyn tagen till regnfuktighet* (Studies on heat transmission through walls, with special respect to moisture by rain), Lund, 1953, 84 pp., illus. (The State Research Institute for Farm Buildings, Report No. 30.)

4 T. W. Johannessen, *Varmeutvekslingen i bygninger og klimaet* (Heat exchange in buildings and the climate), Oslo, 1956, 258 pp., illus. (Norwegian Building Research Institute, Report No. 21.)

5 A. Angström, Människans värmeomsättning genomstrålning i det fria, In *Ingeniörsvetenskapsakademien*, Rationaliseringsproblem inom bostadsuppvärmningen, Stockholm, 118 (1942) 147–151.

6 G. Brown, *Värmeövergång vid byggnaders ytterytor* (Heat transfer at exterior surfaces of buildings), Stockholm, 1956, 126 pp., illus. (The National Swedish Committee for Building Research, Transactions No. 27.)

Studies carried out in the Netherlands on the *in situ* determination of moisture in walls

UDC 699.82 : 69.022 : 69.001.5 (492)

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The probe method has been used in the Netherlands in different ways and for different purposes. It has been turned to account in Wageningen Agricultural College (by Dr. D. A. de Vries and other experimenters) for the determination of moisture in the soil; in Delft Heating Research Section (abbreviated A. W.) of the Central Technical Institute T.N.O. (by H. B. Vos and J. van Minnen) for measuring the conduction of heat in materials having a higher density than 400 kg/cm^3 (in the case of rocks and at high temperatures the method actually offers great advantages over other methods); and again in the Delft Indoor Climate Section of the Research Institute for Public Health Engineering T.N.O. (abbreviated I.G.) in collaboration with the above-mentioned A.W. (by Engr. E. van Gunst and H. J. Erkelens) for determining the thermal resistance of walls under practical conditions.

In all three cases the moisture concerned is contained in pores. The determination of the moisture content of walls is a different matter. One either has to remove some bricks from the wall and determine the moisture content by drying, or one has to be content with methods which, whilst they do leave the wall intact, give cause for more or less serious objections.

Various methods for the determination of moisture have been tried, *viz.*

1. *Resistance measurements:* With this method electrodes spaced at certain distances are lodged in the wall and the electrical resistance measured. The value of this resistance depends, however, to a large extent upon salts incidentally dissolved in the water and upon temperature. The method can, therefore, only be used for ascertaining whether there are any water-filled capillaries, continuous or discontinuous, between the two poles in an otherwise electrically insulating material, which means that a dividing line has to be drawn between "comparatively wet" and "wet" and between "comparatively dry" and "dry". This method is being used with the I.G. and with the T.P.D. (Technical Physical Service of the Technical University of Delft) for tracing moisture spots in walls, *i.e.* for qualitative purposes [1]. (The meaning of this dividing line is, of course, vague.)

2. *Measurement of the dielectric constant* of the material by applying H.F. voltages between two electrodes: Every sample has its own characteristic for the dielectric constant as a function of the water content. The required degree of accuracy is high, so that the research was restricted to preliminary experiments of an investigatory nature.

3. *Thermal conductivity measurements:* The thermal conductivity of heavy porous materials such as brick increases greatly with the moisture content of the material. This consideration naturally suggested the use of thermal conductivity measurements as a means of determining the moisture content. It is necessary, however, to do this in such a way that the result is not affected by the displacement of moisture caused by the difference in temperature applied. This requirement can be fulfilled by selecting very slight differences in temperature in the case of steady-state methods or by employing non-steady-state methods. Experimenters in the Netherlands have confined themselves to the non-steady-state method: the use of the probe. The mathematical basis of this non-steady-state method, in which the coefficient of heat conduction is deduced from the manner of formation of the temperature field around an electrically heated wire, is based firstly upon homogeneity of the material, and secondly upon a sufficient distance between the heater and the limiting outer faces of the sample.

In a wall there is no guarantee of homogeneity; brickwork is interspersed with mortar joints and in concrete there is gravel. Moreover, the moisture will not be homogeneously distributed throughout the wall.

Only if the heater is lodged in the centre of the wall and is parallel to the boundary surfaces will the second of the above requirements be fulfilled. This can only be achieved, however, by lodging the heater wires in the wall during its construction. Existing walls cannot be tested in this way.

The moisture content in a wall will, as a rule, be non-homogeneous in the direction perpendicular to its surfaces. The temperature field surrounding a heater running parallel to the wall surfaces will show isotherms consisting of straight lines running parallel to the heater, but a plane perpendicular to the heater cuts these isotherms according to closed curves which, owing to the non-homogeneity of the moisture content, are positioned asymmetrically with respect to the heater. No general solution can be indicated. A solution can only be found when assumptions which greatly simplify the problem are made regarding the dependence of thermal conductivity upon position in the wall. The real problem lies in a different sphere, as we measure a dependence of temperature upon time and from this try to deduce something about the distribution of moisture. It would be necessary for this purpose to lodge several heaters at different depths in the wall.

In order to arrive at a measuring method that is workable in practice, a combined department of the A.W. and I.G. therefore proceeded to lodge the heater in a vertical position in the wall; they realized that whilst the mathematical difficulties certainly would not be reduced in this way, the practical difficulties would be. Now it is true that at a certain depth in the wall the moisture field is homogeneous in a plane situated perpendicular to the heater and the temperature field symmetrical with respect to the heater, but the temperature field is influenced from the direction parallel to the axis in a manner that varies with the depth in the wall.

The practical execution of the measurement is as follows: A hole 4.1 mm in diameter and with a length conveniently taken as 22 cm is drilled in the wall. A thin glass tube coated with glue is inserted in this hole; external diameter of tube 4.0 mm, internal diameter 3.0 mm. This tube remains lodged in the wall, and the actual probe can be slid into it. The probe also consists of a thin glass tube, this time with an external diameter of 2.8 mm and an internal diameter of 1.2 mm, inside which the heater is mounted. The latter (double-folded constantan wire 0.3 mm in diameter) is glued to a multiple thermo-element (diameter 0.1 mm, 1 main wire, *e.g.* constantan, and 7–11 outlet wires, *e.g.* copper or manganin, with thermopoles at equal distances).

This overcame the practical difficulties, but certainly not all the theoretical difficulties. We shall now deal with the latter one by one.

THICKNESS OF THE PROBE

The temperature distribution around a probe of infinite length composed of various materials can be calculated if the following suppositions are made:

1. Cylindrical symmetry exists.
2. The material's characteristics do not depend upon temperature.
3. The material outside the probe is homogeneous in composition.
4. The measurement relates only to the temperature rise occurring as a result of heat production in the heater.
5. Heat conductivity inside the probe is infinite.
6. Heat production per unit of length and per unit of time at a given moment leaps from its original zero value to a prescribed value.

The solution found for this applies outside the heater also, subject to the condition that any temperature differences existing inside the probe do not change during the test. This could be realized physically if the temperature differences which actually occur inside the probe after a long time existed right from the beginning of the test. This supposition thus takes the place of 5. Let us call the solution θ_s.

At the beginning of the test there are actually no differences in temperature inside the probe which originate from our energy source. It is, therefore, necessary to insert a correction function θ_c at the beginning, so that the true temperature distribution θ is given by

$$\theta = \theta_s + \theta_c \tag{1}$$

As all the energy produced is used in developing the temperature field θ_s, the θ_c field will have no energy fed to it. Furthermore, at the beginning of the test θ must be 0, *i.e.* $\theta_c = -\theta_s$. θ_c is the temperature field in which the collected heat remains constant but increasingly disperses (see Fig. 1). At the location of a thermo-element $|\theta_c|$ will have to be $\ll \theta_s$ during the observations, *e.g.* $\theta_c = -0.01\,\theta_s$. Under normal conditions this requirement will be fulfilled.

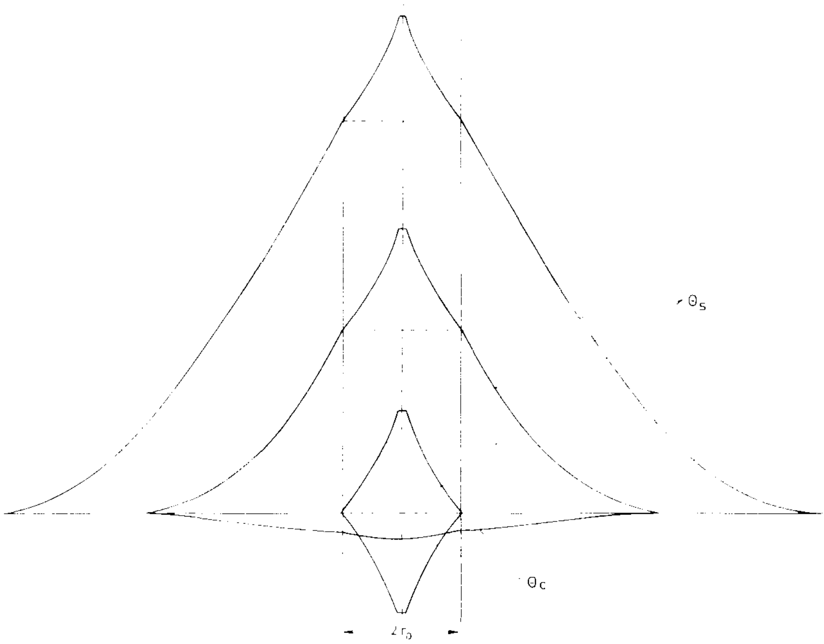

Fig. 1. Temperature distribution curves for θ_s and θ_c (see text).

The principal solution is given by an integral which we express in the form

$$\theta_s = \frac{q}{4\pi\lambda} \mathrm{F}\left(\frac{r^2}{4at}, \frac{r_0}{r}, \frac{c\rho}{c_0\rho_0}\right) \tag{2}$$

For a very thin heater, $r_0 \to 0$, the function F passes into the exponential integral

$$\mathrm{K}_1\left(\frac{r^2}{4at}\right) \tag{2a}$$

In formulae (2) and (2a)

q = heat produced per unit of length and per unit of time,
λ = thermal conductivity,
r = distance from the axis of the probe,
t = time lapse since switching on the current,
$2r_0$ = diameter of the probe,

c = specific heat,
ρ = specific mass,
$c_0\rho_0$ = average specific heat per unit of volume of the probe,

$a = \dfrac{\lambda}{c\rho}$ is thermal diffusivity,

F = function given by the integral, and

$K_1(z) = \displaystyle\int_1^{\infty} \frac{\exp(-zw)}{w}\,dw$ is the exponential integral in Unsöld notation.

In Fig. 2, taken from reference 2, the temperature rise related to the logarithm of the time is plotted at $r = r_0$ for various values of $c\rho/c_0\rho_0$; for $r_0 \to 0$ we have

$$K_1\left(\frac{r^2}{4at}\right)$$

having as asymptote the dotted line

$$\theta_{as} = \frac{q}{4\pi\lambda}\left\{-0.5772 + \ln\frac{4at}{r^2}\right\} \tag{3}$$

For $4at/r^2 \geqslant 100$ all the curves coincide sufficiently to be represented by (3), at least for

$$0.5 \leqslant \frac{c\rho}{c_0\rho_0} \leqslant 1.55$$

We can now define our requirement for θ_e by the following statement: Every probe for which $|\theta_e| \leqslant 0.01\,\theta_s$ at $4at/r^2 \geqslant 100$ gives, above the indicated times, measurements that can be used without correction.

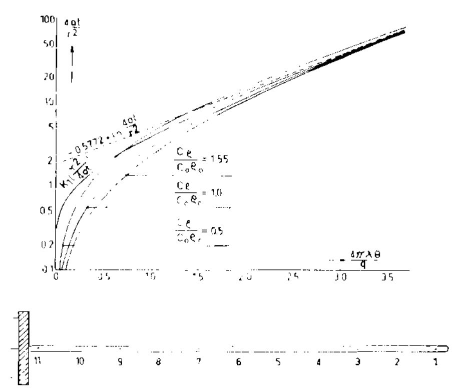

Fig. 2. Temperature rise related to the logarithm of time at $r = r_0$ for various values of $c\rho/c_0\rho_0$.

FINITE LENGTH

The temperature distribution in the vicinity of a very thin probe of finite length is given by

$$\theta = \frac{q}{c\rho(4\pi a)^{3/2}} \int_0^l \int_0^t \exp\left\{-\frac{r^2 + (z - z^1)^2}{4a\,(t - t^1)}\right\} \frac{dz^1 dt^1}{(t - t^1)^{3/2}}$$
$$= \frac{q}{4\pi\lambda} \int_{r^2/4at}^{\infty} \frac{1}{2}\left[\operatorname{erfc}\left(-\frac{zv^{\frac{1}{2}}}{r}\right) - \operatorname{erfc}\left(\frac{(l - z)v^{\frac{1}{2}}}{r}\right)\right] \frac{\exp(-v)}{v}\,dv \tag{4}$$

in which the new quantities

z = the distance along the heater,

l = the length of the heater and

erfc = the complementary error function.

The slope in the temperature, ln t in diagram, is therefore

$$t\frac{\delta\theta}{\delta t} = \frac{q}{4\pi\lambda}\cdot\frac{1}{2}\left[\text{erfc}\left(-\frac{z}{\sqrt{4at}}\right) - \text{erfc}\left(\frac{l-z}{\sqrt{4at}}\right)\right]\exp\left(-\frac{r^2}{4at}\right) \qquad (5)$$

In order that in the middle of the heater

$$\frac{1}{2}\left[\text{erfc}\left(-\frac{\frac{1}{2}l}{\sqrt{4at}}\right) - \text{erfc}\left(\frac{\frac{1}{2}l}{\sqrt{4at}}\right)\right]$$

may remain close to unity, *e.g.* $\geqslant 0.99$,

$$\frac{\frac{1}{2}l}{\sqrt{4at}}$$

at the end of the test ($t = t_2$) must not be smaller than 1.82[5]. Hence

$$t_2 \leqslant 0.0188\frac{l^2}{a}$$

Furthermore, at the very first measuring point ($t = t_1$)

$$\frac{4at}{r^2}$$

must be $\geqslant 100$ in order that l may be written for the e power, so that

$$t_1 \geqslant 25\frac{r^2}{a}$$

If, for sufficient accuracy, t_2 is required to be $\geqslant 10t_1$, it is necessary that

$$0.0188\frac{l^2}{a} \geqslant t_2 \geqslant 10t_1 \geqslant 250\frac{r^2}{a} \quad \text{or } l \geqslant 115\,r$$

This is true for every material. However, both limiting times shift in the same way with changing thermal diffusivity.

The diameter of the hole is 0.41 cm, so that 115 r is 23.6 cm, but l is only 22 cm; in other words, a slightly smaller time range than a factor 10 satisfies the stipulated requirements and then only for the middle of the heater.

The deduction given only holds good for a symmetrical case in the z direction. In reality only the part that is inserted deepest in the wall conforms to the suppositions, assuming that the source of error emanating from the other end does not penetrate to this part.

In this case the term

$$\text{erfc}\left(\frac{l-z}{\sqrt{4at}}\right)$$

with respect to

$$\text{erfc}\left(-\frac{z}{\sqrt{4at}}\right)$$

may be ignored, so that the slope in a $\theta \leftarrow \rightarrow \ln t$ diagram is given by the equation

$$\frac{\delta\theta}{\delta \ln t} = t\,\frac{\delta\theta}{\delta t} = \frac{q}{4\pi\lambda}\left[\tfrac{1}{2}\,\mathrm{erfc}\left(-\frac{z}{\sqrt{4at}}\right)\right] \qquad (6)$$

B. H. Vos and J. van Minnen have tested this formula on Ytong cellular concrete.

The factor

$$a = \tfrac{1}{2}\,\mathrm{erfc}\left(-\frac{z}{\sqrt{4at}}\right)$$

determines the curvature of the measuring curve.

We see that all curves for $t \rightarrow 0$ and $0 < z < \infty$ "jump away", touching a straight line parallel to

$$\frac{\delta\theta}{\delta \ln t} = \frac{c}{4\pi\lambda}$$

whilst for $t \rightarrow \infty$ they approximate to a straight line parallel to

$$\frac{\delta\theta}{\delta \ln t} = \frac{q}{8\pi\lambda}$$

This is shown qualitatively in Fig. 3.

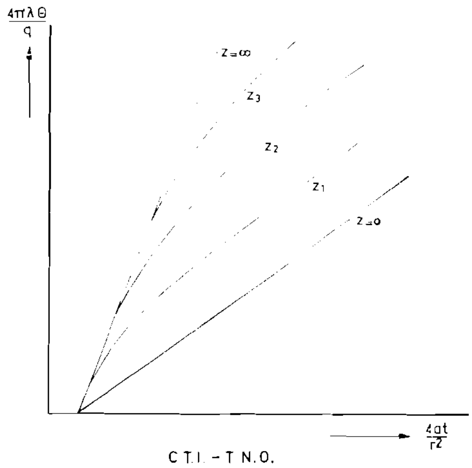

Fig. 3. Relation between time and temperature for different values of the distance z from the top of the heater.

In order to calculate the λ value from the measuring curve the following procedure is adopted.

Draw the tangent at, say, three points of the curve and calculate from this an apparent λ' value according to

$$\frac{4\pi\lambda'\theta}{q} = -C + \ln\frac{4at}{r^2} \qquad (7)$$

From this λ can be calculated according to

$$\lambda = \frac{\lambda'}{2}\,\mathrm{erfc}\left(-\frac{z}{\sqrt{4at}}\right) \qquad (8)$$

In order to apply equation (8) the a-value must be known. As the a-values differ little from one another on the whole, a justified estimate is always possible.

APPLICATION

Measurements were made in Ytong, a kind of gas concrete with the following characteristics:

thermal conductivity: 0.187 kcal/mh °C (dry)
apparent density: 800 kg/cm³
specific heat: 0.20 kcal/kg °C.

From this follows the thermal diffusivity

$$a = 12.10^{-4}\ m^2/h$$

The measurements were effected with a double-folded heater 0.1 mm thick and a movable thermo-couple 0.1 mm thick. The results are summarized in Table I, in which z is the distance from the top of the heater in mm and the indices 100, 300 and 1000 represent the time (in seconds) to which the λ (λ') value (in kcal/mh °C) relates. Lastly, the average $\bar{\lambda}$ value is calculated.

TABLE I

z (mm)	λ' 100	λ' 300	λ' 1000	λ 100	λ 300	λ 1000	$\bar{\lambda}$
60	0.188	0.191	0.191	0.188	0.191	0.189	0.189
60	0.188	0.188	0.194	0.188	0.188	0.192	0.189
50	0.186	0.191	0.195	0.186	0.191	0.186	0.188
50	0.188	0.188	0.188	0.188	0.188	0.183	0.186
40	0.196	0.204	—	0.196	0.204	—	0.200
40	0.192	0.196	0.210	0.192	0.196	0.197	0.195
30	0.186	0.189	0.192	0.186	0.187	0.169	0.181
30	0.186	0.196	0.204	0.186	0.194	0.180	0.187
20	0.193	0.207	0.230	0.190	0.190	0.182	0.184
20	0.196	0.206	0.219	0.194	0.187	0.173	0.185
15	0.179	0.206	0.234	0.174	0.178	0.169	0.174
15	0.184	0.206	0.238	0.178	0.178	0.171	0.176
10	0.214	0.240	0.282	0.190	0.182	0.184	0.185
6	0.235	0.261	0.302	0.181	0.174	0.175	0.177
4	0.271	0.303	0.328	0.184	0.183	0.184	0.184
4	0.245	0.279	0.332	0.167	0.168	0.181	0.172
2	0.283	0.300	0.319	0.170	0.168	0.175	0.171
1	0.336	0.343	0.365	0.185	0.182	0.190	0.186
0.1	0.361	0.361	0.388	0.184	0.180	0.195	0.186
0.1	0.353	0.368	0.368	0.180	0.188	0.185	0.184
Average				0.184	0.184	0.183	0.184

By way of illustration, a measuring curve is drawn in Fig. 4 which was recorded at 10 mm from the top; a is the tangent for $t = 1000$, b for $t = 300$ and c for $t = 100$ sec.

Lastly, Fig. 5 shows the course of λ' as a function of the distance in the specimen for $t = 100$, 300 and 1000 sec. The λ' values given in the table are also drawn in the figure.

From these experiments it may be concluded that theory and practice are in good agreement.

THE TWIN PROBE

One of the drawbacks of probe measurements is the fact that under non-steady boundary conditions, *e.g.* if the sun is shining on a wall, measurements cannot be effected.

In order to overcome this difficulty a twin probe was constructed (see Fig. 6). One of the "legs" is the probe proper; the other comprises the cold junctions of the first. In this way an apparently stationary state is created in which there are no obstacles to measurement.

FOOT OF THE PROBE

A study of the phenomena occurring on the outer side (at the foot) of the probe is one of the items on the programme of the A.W. The I.G. has worked on this. This study is still in the initial stages, so that little can yet be said on the subject.

MOISTURE IN WALLS

Thick, homogeneous, damp walls can already be tested with the long probe for their moisture content.

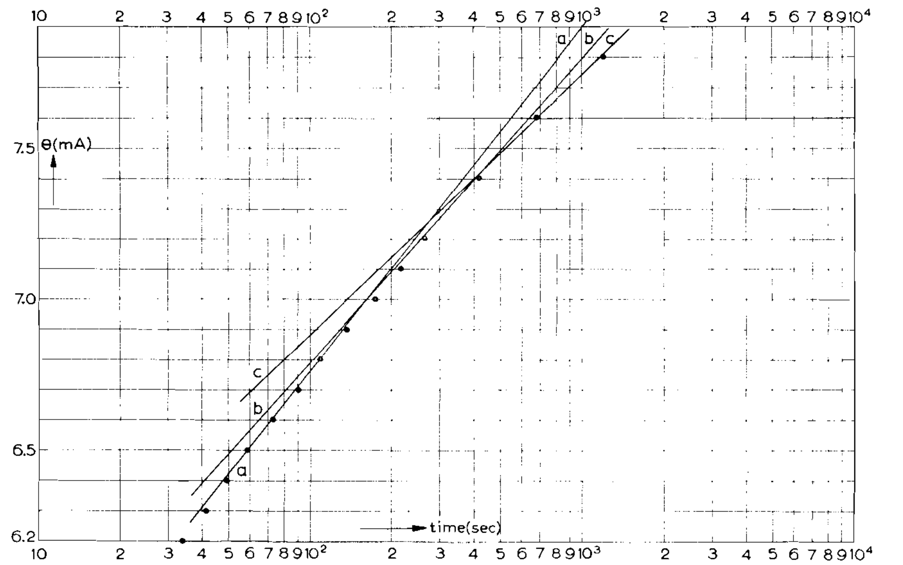

Fig. 4. Measuring curve for the relation between t and θ (see text).

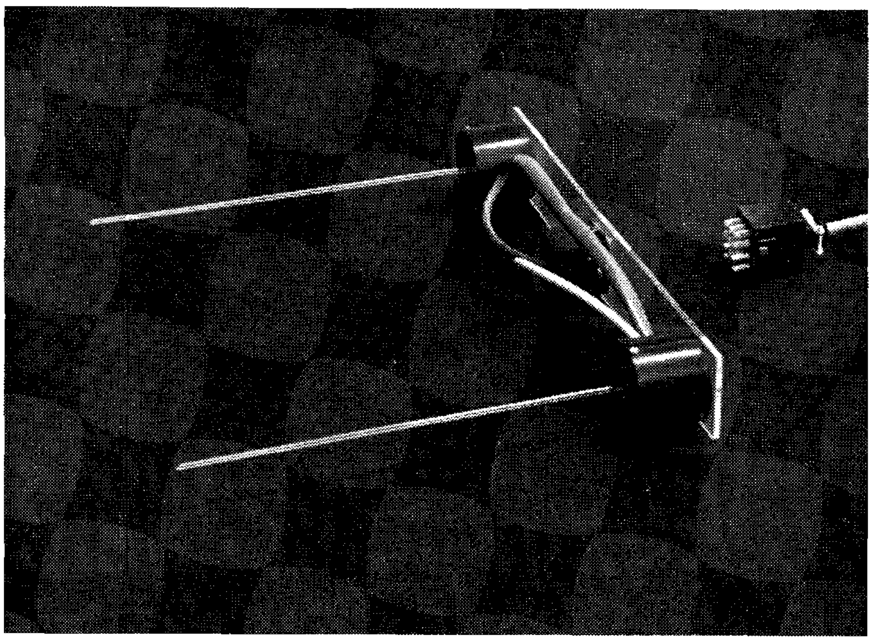

Fig. 6. A twin probe for thermal conductivity measurements.

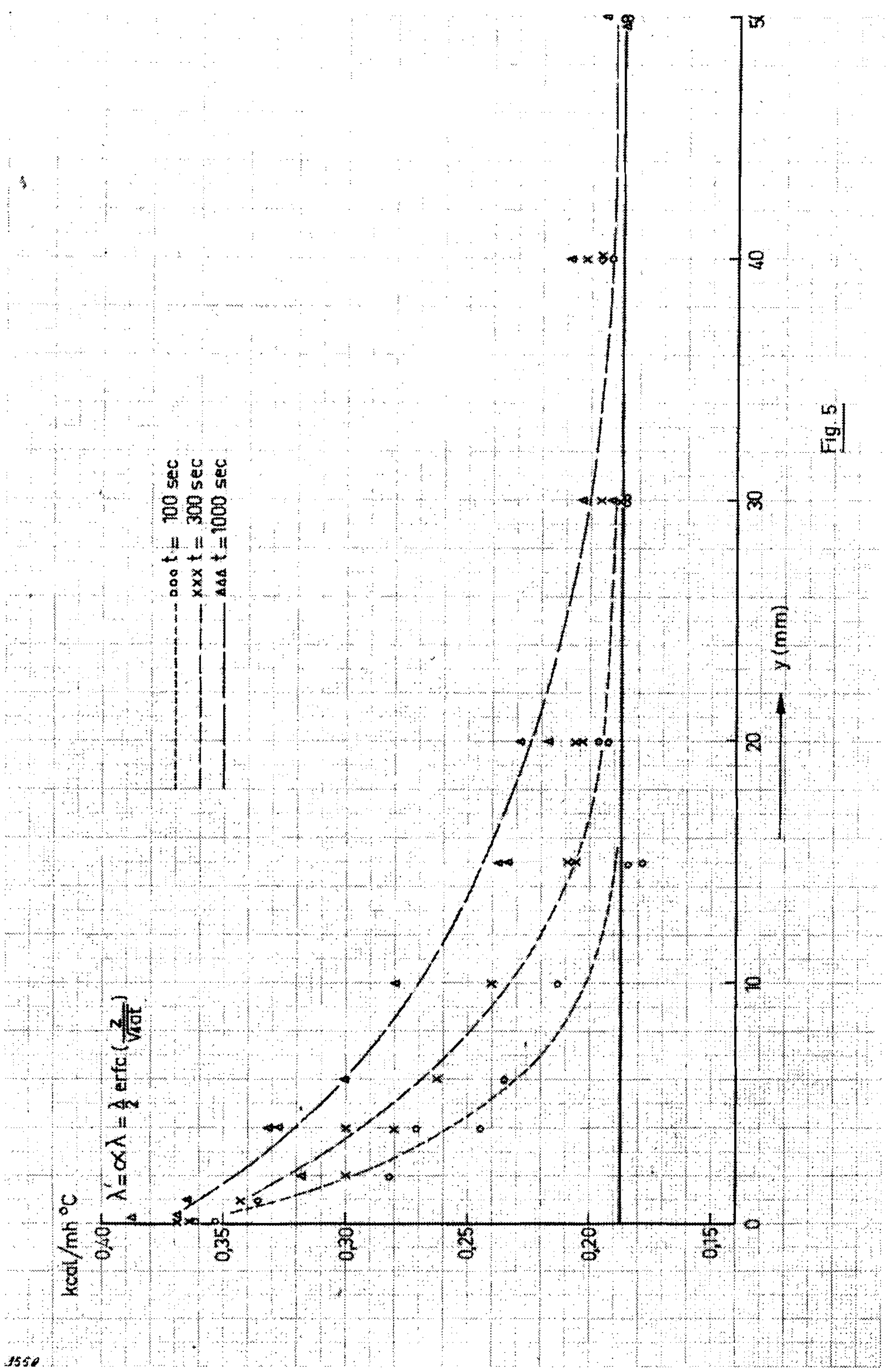

Fig. 5. Relation between distance y and heat conductivity coefficient λ' (see text).

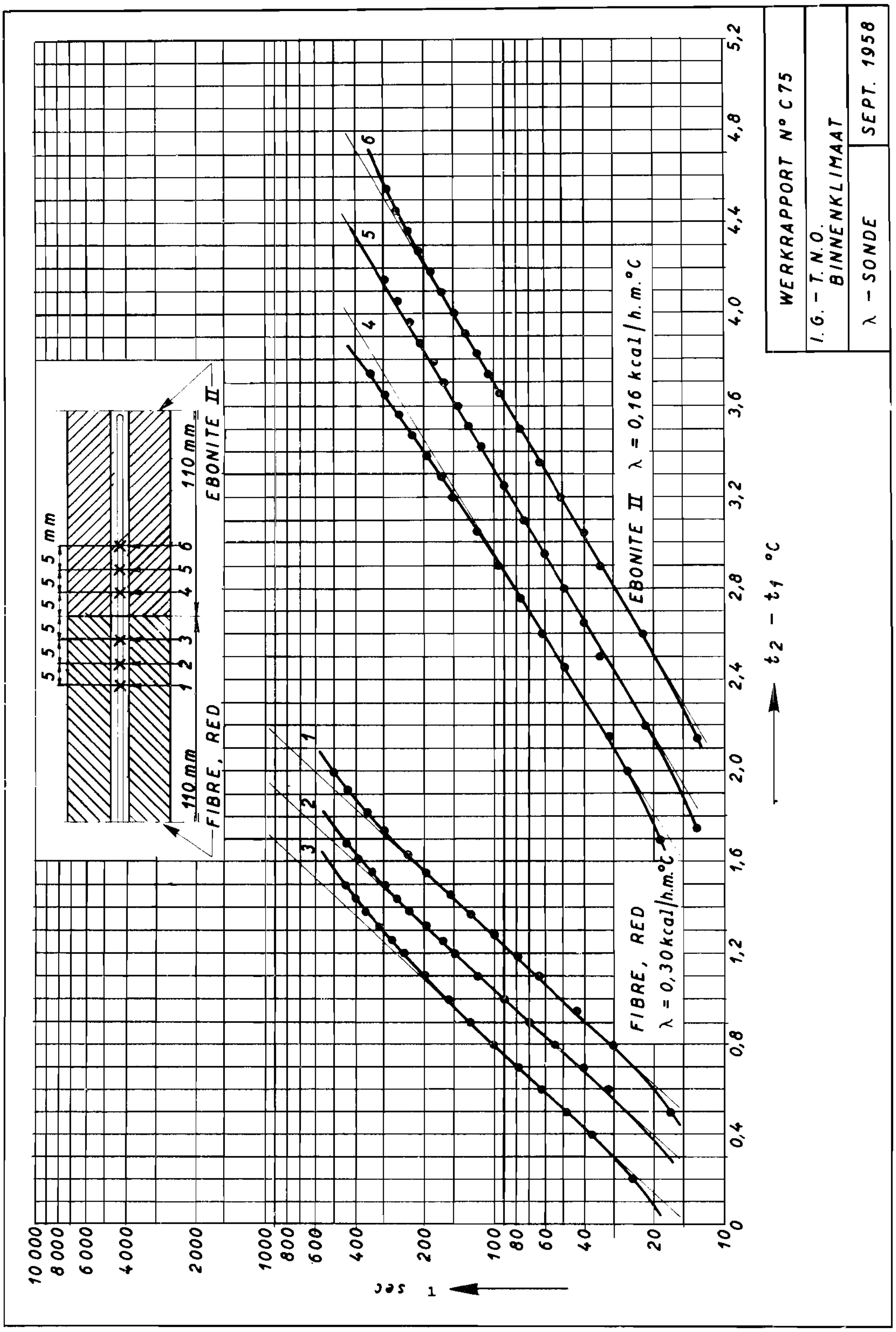

Fig. 7. Measurements in the vicinity of the interfacial boundary between two materials ($\lambda_1 : \lambda_2$ 2 : 1).

The testing of non-homogeneous damp walls is still in the initial stages. Thus, the I.G. has carried out thermal conduction measurements by the probe method in samples consisting of two different materials, *e.g.* with equal $c\rho$ but different λ (Fig. 7).

Mathematically this problem is so complicated that the solution is unserviceable for practical purposes. It will therefore be necessary to scan the test field with a number of λ_1/λ_2 and $c_1\rho_1/c_2\rho_2$ combinations.

Samples in which heat conduction is a continuous function of position, *e.g.* damp walls, make the mathematical problems still more complicated. We hope that the investigation of samples composed of two materials gives a sufficient start to the solution of these problems as well.

REFERENCES

1 H. C. Carslaw and J. C. Jaeger, *Conduction of Heat in Solids*, Oxford, 1947, p. 284.

2 E. F. M. van der Held, J. Hardebol and J. Kalshoven, *Physica*, 19 (1953) 208. Problem IV.

3 B. H. Vos and H. J. Erkelens, Ermittlung des Feuchtgehaltes in Baukonstruktionen. *Allgem. Wärmetech.* (appearing shortly).

4 E. van Gunst, Onderzoek naar de vochtigheidstoestand van een aantal woningen, *Bouw*, September 24, 1955.

Thermal insulation and the question of establishing common building regulations in Scandinavia UDC 699.86 : 35(48)

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INTRODUCTION

A few years ago housing authorities in the Scandinavian countries formed a committee for the coordination of building regulations on thermal insulation in Sweden, Norway, Finland, Denmark and Iceland.

This work, which is now nearly completed, was started at a time when

Sweden had a system of building regulations demanding a certain minimum thermal insulation. These regulations dated back to 1934 for the city of Stockholm, and to 1950 for the country as a whole [1].

Denmark had no regulations on thermal insulation, except for the city of Copenhagen, but most of the residential houses were financed by the state and for those a complete set of regulations on thermal insulation had existed since 1947 [2].

Norway had building regulations on thermal insulation since 1950 [3].

Finland more or less followed the Swedish rules.

Iceland had no regulations.

There was, however, an essential difference between these regulations. In principle, the Norwegian regulations were the most complete. They not only gave maximum values for the coefficients of transmission, k kcal/m^{2}h °C ($\sim$ U B. Th. U. (h) (sq.ft) (deg. F), but they also contained a list of the coefficients of thermal conductivity, λ kcal/mh °C, ($\sim$ k B. Th. U./(h) (sq.ft.) (deg. F per ft)), for the building materials, and they formed a complete basis for the calculation of heat loss from a house.

The Swedish regulations did not consider windows, and thus gave no possibility for calculating the total heat loss.

In Denmark the regulations comprised only the maximum coefficients of transmission, but the Danish Society of Civil Engineers in 1953 published a complete set of rules for the calculation of heat loss from houses [4], and these rules were upheld for all residential houses financed by the State.

These differences made coordination more complicated. At first only the maximum coefficients of transmission were considered, but it soon proved necessary to take into account also the coefficients of thermal conductivity, in order to be sure that the usual wall types were still allowed.

The last step, *i.e.* giving the complete basis for calculating the heat loss, has not been taken as yet, but it is my personal opinion that this ought to be incorporated in the coordinated material.

The system of administration is different in the various countries and, probably, the regulations will always be differently formed. However, this has no real importance, as long as the subject matter is the same.

After these mainly administrative considerations we shall now pass to problems of a more technical kind.

BUILDING TRADITIONS

In primitive buildings the question of thermal insulation is hardly recognized as a separate problem. The walls generally consist of only one material used in rather great thickness. In Norway and in Sweden this material was usually wood as in the log houses, in Denmark it was partly timber, partly brick.

Only when it became necessary to economize in building materials as well as in fuel, was it recognized that the function of a wall was

(1) supporting,

(2) heat-insulating,

(3) weather-screening,

and that each of these functions might be carried out by a separate element or layer in the wall.

In the various parts of Scandinavia the starting points were different and thus the development followed a different trend. Therefore the building regulations in the various Scandinavian countries were different not only because of their different authorship, but also because the buildings themselves were different. For example, a villa in Denmark usually has a cavity brick wall. In Norway and Sweden the brick wall is usually solid with separate insulation on the inside and often with a covering of boards on the outside.

In Norway houses are still largely built as a framework of timber with insulation in the gaps and a covering of boards or wall-board on both sides.

It is obvious that these varying building practices presented a difficulty when common building regulations were considered, as the qualities of any material depend to a certain degree on its use in the building. In Denmark, with cavity brick walls, we wanted a separate, rather big λ-value for the outer part of the wall, while in the other countries this was considered unnecessary. In Norway air-infiltration into the insulation or through the wall was a problem of much greater moment then in Denmark on account of the timber constructions.

CLIMATIC CONDITIONS

The climatic conditions are very different in the Scandinavian countries. Norway, Sweden and Finland are each divided into four zones, while Denmark and Iceland have only one zone each, corresponding to the warmest of these four zones.

The zones mainly correspond to a certain minimum winter temperature, but especially in Norway the wind and precipitation (rain and snow) differ greatly at the coast and in the mountains, and the local climate for the individual site has a very great influence especially in the valleys.

In Norway the minimum winter temperature from the point of view of regulations should be fixed not only from the geographical position but also from the height, and even then major local variations are possible.

Of course, corresponding differences occur in any country, and when they are felt extra strongly in Scandinavia it may be partly due to the colder climate in the north and partly to the widespread use of central heating with correspondingly higher demands for a constant temperature throughout the winter.

MATERIALS AND λ-VALUES

In order to compare the coefficients of thermal conductivity (the λ-values) from the various countries it is necessary to make sure not only that the material in question is considered to contain the same moisture percentage in each country, but also that it is virtually the same material.

The moisture percentage considered normal may very well be different, partly because of the climatic differences and partly because we know very little about moisture percentages in building materials in practice. This point is, however, at least open to discussion.

It is far more difficult to decide whether there is a virtual difference between what is nominally the same material in two countries. At first sight you might say that a brick from Sweden and a Danish brick must be more or less identical, if they had the same specific weight. They are, however, not only of a slightly different size – thus making the joints carry more weight in the Danish masonry – but they are of different sorts of clay, which may well give different hygroscopicity. As far as I know, this has never been effectively controlled. The word "letbeton", which means lightweight concrete, in Denmark and Norway comprises not only aerated concrete, etc., but also clinker concrete, clinker bricks, etc. This is not the case in Sweden, where clinker concrete is less frequently used. Moler bricks (moler consists of diatomite) are used quite often in Denmark, but are practically unknown in the other countries.

Wood wool slabs form a very heterogeneous group in all the countries, and so the difficulty in fixing a common λ-value is hardly greater than for each country to fix a value. For most materials it proved rather easy to agree upon a λ-value. For lightweight concretes several values were fixed: some corresponded to concrete walls insulated on the inside with lightweight concrete, some to walls insulated on the outside and some to walls built exclusively of lightweight concrete. For materials in use in only one of the countries, no common λ-value was fixed.

There were, however, several materials for which nobody deemed it possible to fix a practical λ-value although these materials were in common use. Firstly, to a minor degree, this was the case for mineral wool, where the Norwegian practice with timber framework made air infiltration a very serious problem, and where we agreed upon a range of λ-values so that the smaller values could be used under good conditions and the bigger values under less satisfactory conditions.

Then there was expanded mica, a material which is apt to settle in certain cases up to 40–50%. In Denmark mica is used rather extensively for filling the air gap in hollow brick walls, and it was agreed that no λ-value, however great, could satisfactorily compensate for the settling of the material.

Lastly, there was plastic foam based on urea formaldehyde, which is made on site and pressed into cavities and air gaps in the construction, *e.g.* into the air gaps in cavity brick walls. This material is of a very heterogeneous character, as it is made on site under little or no control. It is often impossible to ascertain if the cavities have been completely filled, and the material shrinks considerably. By the shrinking of the foam it may be possible to get rather effective air circulation inside the wall, and nobody really knows what the heat loss through the wall may eventually be. Plastic foam is, unfortunately, the filling material most commonly used for hollow brick walls in existing houses in Denmark, and as rule it must be admitted that it reduces the heat loss – but nobody knows to what extent, and there is hardly any doubt that the gain is often very much less than anticipated.

FLOORS DIRECTLY UPON THE GROUND

In many modern dwellings there is no basement and the floor is cast directly upon the ground. This construction may give – and has given – very serious moisture problems.

There is still a long way to go before these problems can be really solved and conclusions can be drawn by architects and consulting engineers. However, the Danish National Institute of Building Research has published a booklet [5] specifying certain constructions which ought to work under normal conditions.

Quite outside the problem of making a good floor, we were confronted also by the problem of specifying a minimum thermal insulation of the floor and in order to do this we must first be able to estimate the heat loss through the floor. This in itself is a very difficult problem.

In the middle of a very wide floor there is little heat loss through the floor unless there is water moving in the ground and not too far down. In other words: one has to know a great deal in order to calculate the heat loss accurately and usually one knows very little.

The Danish booklet [5] mentions an approximate method for a floor of concrete on a bed of drained cinders. For the inner zone the coefficient of transmission to the outer air is $k = 0.9$, for the perimeter zone (up to 1 m from the walls) $k = 1.2$. Any extra insulation, which is protected against moisture, reduces the k-value in the normal way.

This approximate calculation is based upon research in Sweden by Jansson, Holmqvist and Hendriksson [6]. Presumably we shall agree to use this method for the calculation of heat losses through floors directly upon the ground simply for want of better methods.

RESULTING MAXIMUM COEFFICIENTS OF TRANSMISSION

The main trend of the coming inter-Scandinavian regulations will be apparent from Table I.

THE PURPOSE OF THESE REGULATIONS

The building regulations on thermal insulation have several purposes.

Firstly, for reasons of health a certain thermal insulation is appropriate, but the requirement is not very stringent.

Secondly, a consideration of private economy shows that it is cheaper to insulate your house properly than to use a lot of fuel. This consideration may be opposed by difficulties in raising the necessary funds. Such a problem of private economy should rather be a case for propaganda than for building regulations.

Thirdly, from the point of view of national economy it is preferable that the houses are well insulated, so that the fuel consumption – and fuel import – is reduced. This consideration, however, is not adequately met solely by demands on the coefficients of transmission but should really be a demand on the maximum overall heat loss per square metre of floor. If a house is built with an excess of window area or with quite a lot of bays, the total heat loss may very well be great, although the coefficients of transmission for the walls are low.

The logical thing would be to prescribe a certain maximum heat loss per square metre of the house, as in the U.S.A., where the calculated heat loss must not exceed 55 B. Th. U. per square foot of floor area, or 150 kcal/m^2.

For normal Danish conditions this value will be ample. From considerations of national economy the maximum heat loss should be quite a lot lower, but this would seriously encroach on the right to build your own house just as you like it, *e.g.* with big french doors opening on to the garden, etc. Therefore, it is not advisable to carry the demands on the overall heat loss too far.

"THE QUALIFIED GUESS"

In several cases it has been extremely difficult to decide on a coefficient of thermal conductivity for use in practice, as we know too little about the moisture content and as the moisture content may vary greatly. For most of these cases we have formed a catch-phrase: "the qualified guess".

Most architects and consulting engineers have no possibility at all of estimating what the

TABLE I

MAXIMUM COEFFICIENTS OF HEAT TRANSMISSION

Zone	*Exterior walls or walls to unheated rooms*			*Decks to outside air or to unheated rooms*			*Heated rooms*			*Exterior walls in frostfree basements*
							Floors			
	Subsidiary requirements for walls exclusively of brick	*Normal requirements*	*Subsidiary requirements for light walls < 100 kg/m²*	*Subsidiary requirements*	*Normal requirements*	*Subsidiary requirements for roofs of wood*	*Against partly heated rooms*	*Against unheated rooms*	*Against the outside air*	
1	2	3	4	5	6	7	8	9	10	11
1	0.80	0.60	0.40	0.50	0.40	0.35	0.60	0.40	0.35	1.10
2	0.90	0.70	0.40	0.50	0.40	0.35	0.60	0.40	0.35	1.40
3	1.00	0.80	0.50		0.50	0.40	0.70	0.50	0.40	1.70
4	1.10	0.80	0.50		0.50	0.40	0.70	0.50	0.40	2.00

Column 2 is necessary in order to provide for wall types now in use, but in time the requirements should be raised so that all walls correspond to columns 3 or 4.
In Denmark, which is zone 4, the requirement in column 11 will not be applicable.

moisture content will be but are reduced to guessing. Even if we know far too little, we have much more material than they and thus our guess will be more qualified and therefore generally better. We have felt that when seriously in doubt, we simply had to fix a λ-value. There are only very few exceptions to this rule, and they have been mentioned above.

REFERENCES

1 Anvisningar till byggnadsstadgan, *kgl. byggnadsstyrelsens publikationer,* 1950 : 1.
2 *Tekniske Krav og Vejledning,* Indenrigs- og boligministeriet, Copenhagen, March, 1953.
3 *Byggeforskrifter av. 15. Desember,* 1949, Forsynings- og Gjenreisningsdepartmentet, Oslo, 1950.
4 *Regler for Beregning af Varmetab fra Byggninger,* Teknisk Forlag, Copenhagen, 1953.
5 *Gulve direkte paa Jord,* Statens Byggeforskningsinstitut, Anvisning Nr. 40, Copenhagen, 1958.
6 I. JANSSON, N. HOLMQVIST AND P. HENDRIKSSON, *Isolering av gulv och liggplatser i djurstaller,* Meddelande 38 from Statens Forskningsanstalt för lantmannabyggnader, Lund, 1957.

Recommendations for the use of lightweight masonry, with a view to its useful thermal characteristics

UDC 699.86 : 693.2

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The present recommendations were published in November, 1958, in practically identical form in Cahier No. 34 of the CSTB, section 277, accompanied by a report consisting mainly of a detailed account of the research carried out by the CSTB in the course of a number of years on the actual thermal characteristics and the behaviour with respect to damp of lightweight masonry, *i.e.* of walls constructed of hollow and perforated clay blocks, of expanded clay aggregate concrete and hollow blocks, of heavy and lightweight concrete and of autoclaved cellular concrete blocks.

The reader is, therefore, invited to refer to this Cahier if he wishes to find the basis of some point in the "Recommendations", as the present document has been compiled solely for the purpose of making available to users a summary entirely devoid of scientific explanation.

RECOMMENDATIONS

The Centre Scientifique et Technique du Bâtiment recommends that the rules given in Tables I and II should be observed in the application of lightweight masonry in consideration of its effective hygrothermal characteristics.

Table I shows the hygrothermal properties (effective *K*, dry weight equivalent, presence of an absorbent rendering) which a wall must have under various climatic conditions in the European territory of France, dependent on whether it is a frontage wall or an end wall and dependent on the type of dwelling. Table II shows, as a function of the same parameters, the thickness of the finished wall and the number of rows of cavities, dependent on the nature of the principal material of the wall.

The directions contained in these two tables have the following significance: if they are not observed, the housing quality will generally be mediocre and often bad, occupation conditions being on the whole what they are for each category of dwelling. Even if they are observed, there will still not be any guarantee against disorder, especially when the occupation conditions are bad.

Table IV gives the values of the intrinsic thermal characteristics (effective *K* and dry weight equivalent) of optimum walls of lightweight masonry which make it possible to pass from the first to the second table. Table VI and Fig. 1 define and indicate the climatic zones used in the first and second tables.

DEFINITIONS OF EFFECTIVE HYGROTHERMAL CHARACTERISTICS (TABLE I)

Coefficient effective K

The coefficient effective *K* is the overall transmission coefficient from one side of the finished wall to the other, thus including joints and rendering, the materials being in a moderate state of humidity for walls of housing in France.

The effect of humidity on the coefficient *K* is important. Hence, the value "effective *K*" is clearly different from that which one could call "theoretical *K* dry" of the wall supposed to be entirely dry. In the case of lightweight masonry the former is from 15 to 60% higher than the latter.

Only the value effective K is significant and must be used for both the calculation of losses and of possible condensation.

Dry weight equivalent

The dry weight equivalent is equal to the sum of the dry weight of the wall and the weight of water content $\times$ 1/0.22. It is only a more pronounced form of the thermal mass and together with the coefficient effective K it enables the thermal inertia of the wall to be specified.

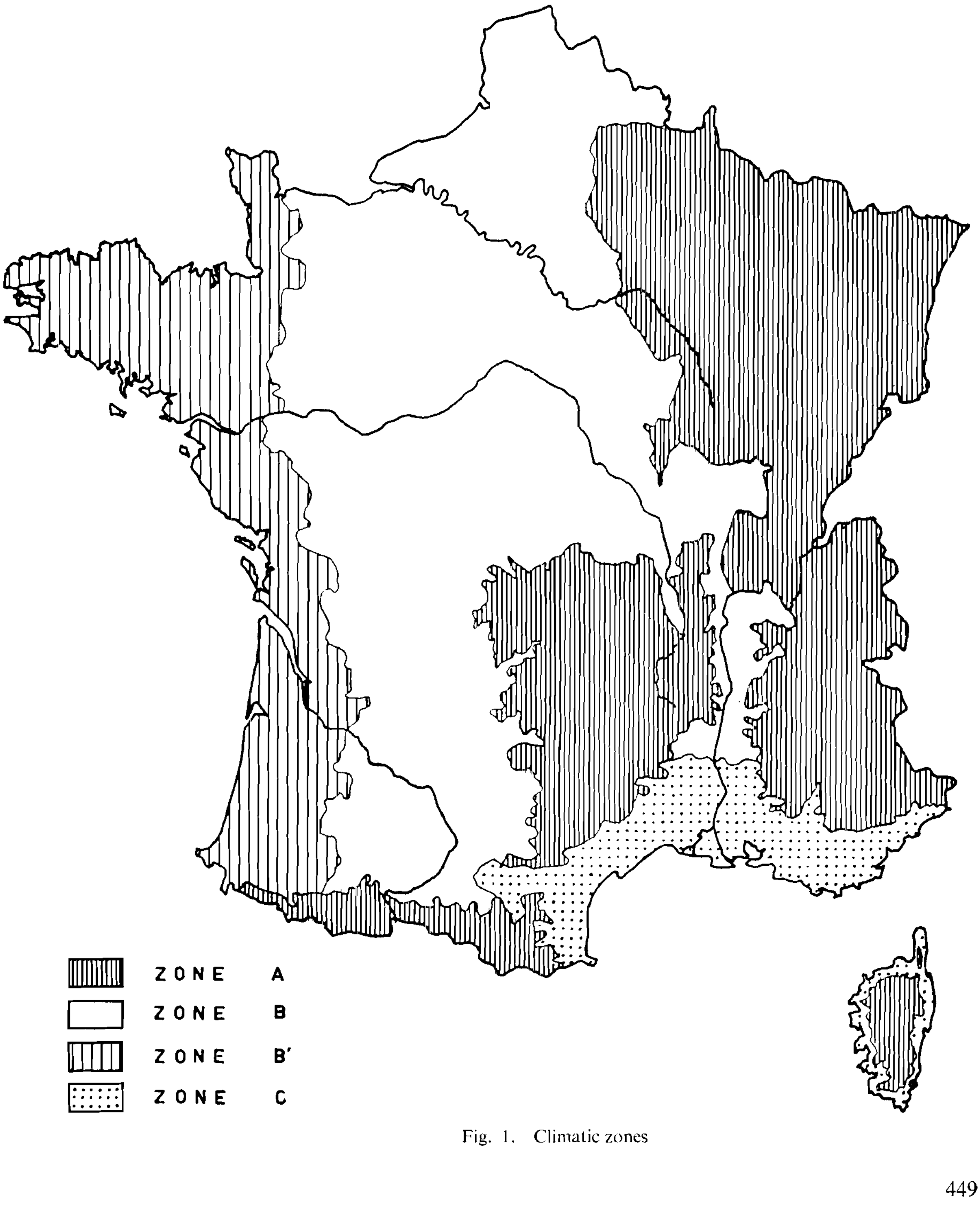


Fig. 1. Climatic zones

TABLE I

RECOMMENDED HYGROTHERMAL PROPERTIES FOR MASONRY WALLS IN FRANCE

(maximum coefficient effective K in cal/m^{2}h °C)

"Superior" dwellings	*Zone A*		*Zone B*	*Zone B′*	*Zone C*
"Medium" dwellings	*Zone A*	*Zone B*		*Zone B′*	*Zone C*
Third-class dwellings (not recommended in Zone A)	*Zone B*	*Zone B′*			*Zone C*
	Interior absorbent rendering				
Heavy masonry > 600 kg	1.5(1.5)	1.7(1.5)	1.9(1.7)		2.0(1.9)
Lightweight masonry 450–600 kg	1.4(1.4)	1.6(1.4)	1.8(1.6)		1.8(1.7)
350–450 kg	1.3(1.3)	1.5(1.3)	1.7(1.5)	1.8(1.6)	1.6(1.4)
250–350 kg	1.2(1.2)	1.4(1.2)	1.6(1.4)	1.7(1.5)	1.4 [1]
200–250 kg	1.1(1.1)	1.3(1.1)	1.5(1.3)	1.7(1.5)	1.2 [1]

Figures refer to frontage walls, figures in parentheses to end walls.

[1] Walls of less than 350 kg are not recommended for end walls.

In the walls of housing and in the French climate the thermal inertia is a property from which it is evident that the coefficient K is less affected as the wall becomes heavier, the lack of insulation being compensated to a certain extent by the additional weight.

It is important to note that the notion of dry weight equivalent is only valid for walls that are relatively homogeneous throughout their thickness. Hence it cannot be applied to certain composite walls.

Interior absorbent rendering

The interior absorbent rendering cannot be defined by a quantitative expression at our present state of knowledge. Its qualitative definition is as follows: it is rendering which, due to its thickness and its behaviour with respect to damp, enables condensation water to be absorbed and subsequently to be given off without damage or inconvenience to the occupant.

The mention in Table I of the term "interior absorbent rendering" means that this is required wherever dampness or moisture on the wall surface is inadmissible. This is generally the case with all spaces other than kitchens and bathrooms, the only spaces where the wall furniture, plinths and floor covering are treated to withstand the effects of condensation and moisture.

CLIMATIC ZONES

These are the zones defined in Table VI. This table gives a list of the Departments and indicates the zone in which they have been classified. Some are divided into two parts according to altitude (above or below 500 m), each part being classified in a different zone. The map on Fig. 1 presents an overall picture.

According to regulations now in force in France, three zones are distinguished.

Zone A, with a "hard climate" (east of France and mountainous zones), in winter is very cold, in summer hot, and strong daily temperature fluctuations occur from winter to summer. Hence, in this zone provisions are made for heavy insulation (low K) and this insulation is made heavier as the weight becomes lower.

Zone B, intermediate, with a "moderate climate", we have divided into two sub-zones with a view to separating in some cases the zone B′ of the Atlantic coastal area with a mild climate and with very little variation, for which the inertia of the wall is of less importance.

In Zone C, with a "hot and varied climate" (Mediterranean coastal area), the resistance to heat in summer demands a high thermal inertia and thus a marked increase in insulation (decreasing K) for lightweight walls.

CATEGORIES OF DWELLINGS

With regard to the problem in which we are interested a dwelling is characterized at once by its intrinsic qualities, which together can be defined as its comfort, and by the occupation conditions: underpopulated or overpopulated, well or badly ventilated, washing and drying inside or outside the dwelling, well or badly heated (this concerns the conduction of heat, not the installation, of which the quality forms part of the comfort).

It would appear possible for our purposes to make a unique classification on the basis of two parameters, intrinsic comfort and occupation quality, which means that in our opinion the two parameters are related in the majority of cases. In this way we have arrived at three categories of dwellings: superior, moderate and third-class dwellings.

The superior dwellings are defined as follows:

As regards comfort: by adequate floor space, separate exits for service space and housing space, central heating;

As regards occupation: by the absence of overpopulation, good quality heating, proper ventilation facilities for washing and drying clothes.

This category can be considered to include the non-subsidized dwellings, the subsidized dwellings at 600 F, the "H.L.M. en accession", the majority of the "H.L.M.B. locatifs", certain "LOGECO" particularly well occupied.

The moderate dwellings are defined as follows:

As regards comfort: by just sufficient floor space, a central heating which more or less ensures a uniform temperature throughout the various rooms.

As regards occupation: by absence of serious overpopulation, moderate quality of heating, a certain amount of ventilation, facilities for washing and drying clothes.

This category can be considered to include the "LOGECO" and "H.L.M.A. bis", certain "LOPOFA (H.L.M.A.)", particularly well built (having in particular collective or individual central heating) and well occupied.

The third-class dwellings are defined as follows:

As regards comfort: by insufficient floor space, the absence of central heating.

As regards occupation: by overpopulation; bad heating; absence of ventilation and facilities for washing and drying clothes.

This category can be considered to include a large number of the "H.L.M.A.". In this category it is evident that the requirement of a good quality wall is not sufficient to effect any real amelioration of habitability. The tables clearly show that the lower the category of the dwelling the better the wall should be, which amounts to saying that it is necessary to spend on improvement of the wall all or part of what one has economized on the other elements of comfort, especially floor space and heating. This would lead to the conclusion that it is not advisable to provide third-class dwellings in a hard climate.

On the other hand, in the hot regions, where the heat of summer and the cold of winter must both be considered, while airconditioning is not practised, all the categories of dwellings, equally devoid of artificial cooling, are equivalent.

THE FUNCTION OF PARTITION WALLS

We distinguish "frontage walls" and "end walls", a notion which is self-explanatory in the case of the conventional blocks of flats and dwellings built in rows. The choice of higher thermal characteristics for end walls satisfies the need to compensate as far as possible the disadvantages of the end dwellings, both as regards comfort in winter (losses and condensation) and comfort in summer (insulation and thermal inertia). We are concerned here with a requirement which is identical to that which has led to more severe insulation measures for terraces being prescribed in certain regulations.

In the case of tower flats and detached and semi-detached houses it would be advisable in our opinion to consider all exterior walls as end walls. The consequences of this are, however, less severe than would appear at first sight, because the houses concerned hardly ever belong to the third category.

Table of intrinsic thermal characteristics of optimum lightweight masonry (Table IV)

This table contains the values of the coefficient effective K and of the dry weight equivalent of walls constructed essentially of lightweight masonry:

hollow and perforated clay blocks;

hollow blocks of concrete, with heavy aggregates, *i.e.* sand and ordinary gravel;

expanded clay aggregate concrete and hollow blocks of concrete with light aggregates, *viz.* pozzolano and expanded slag;

autoclaved cellular concrete blocks, *viz.* concrete with a nominal density of 0.6.

By way of documentation and without claiming exactness, the values for a number of heavy walls are given in the tables:

solid bricks;

porous concrete with heavy aggregates, *i.e.* ordinary fine gravel.

The thicknesses indicated are those of the finished wall, with an external rendering of mortar and an internal rendering of plaster, the sum of the thicknesses of the two layers being approximately 2.5 cm. The thermal characteristics of the lightweight masonry given in this table are not valid for any brick or block; only products designed for optimum characteristics are considered here. It may be assumed that in the majority of cases the other products would have an inferior coefficient K.

The form, the dimensions and the composition of the optimum products were fixed on the strength of extensive research carried out by the CSTB in collaboration with the manufacturers; the requirements for production constituted an important criterion and it can be said that these products can only be obtained by carefully designed industrial processes which, however, would not be regarded as exceptional.

From now on heavy and lightweight concrete blocks corresponding to the types presented in the table are eligible to receive the designation N.F. (Norme Française). The rules governing the granting of this designation can be found in Cahier No. 284 of the CSTB. Similar documents will shortly be published for hollow clay blocks. Finally, the autoclaved cellular concrete blocks of which the characteristics are found satisfactory are subject to approval.

Summarizing, what are the qualities required in respect of optimum materials? Two categories may be distinguished:

Heavy materials, clay and heavy concrete, in respect of which the following characteristics must be observed: essentially, the form, *i.e.*

the number of rows of cavities;

the proportion of void:

55% minimum for hollow clay blocks,

30% minimum for perforated clay blocks,

45% minimum for heavy blocks for thin partition walls,

35% minimum for heavy blocks for thick partition walls;

for some, the staggered design of the transverse joints.

Additionally, the dimensions, because they determine the frequency of the joints (lower insulating quality than the rest of the wall): the nominal dimensions (including joints) of the standard heavy blocks are 40 cm long and 20 cm high; the nominal dimensions of standard hollow clay blocks will be the same, but will continue to be acceptable with a length of 30 cm and provisionally with a height of 16.5 cm.

Lightweight materials: lightweight concrete and cellular concrete, for which the following should be observed:

Essentially, the composition, so as to obtain at once a low density and a low hygroscopy, with a view to limiting the moisture balance or the effective humidity.

For lightweight concrete this results in a reduction of the proportion of fines. Table II lists the proportions which we recommend.

TABLE II

	Expanded clay aggregate concrete	*Hollow blocks*
Pozzolano 0/7	20% maximum	33% maximum
Pozzolano 0/15	80% minimum	67% minimum
Expanded slag 0/3	5% maximum	10% maximum
3/12	15% maximum	23% maximum
12/20	80% minimum	67% minimum

This, therefore, relates to concrete without fines, a characteristic which must be considered as essential.

Additionally, the dimensions should be observed for the same reasons as mentioned above: the nominal dimensions of the standard lightweight concrete blocks are 40 (or 50) cm long and 20 cm high; those of the approved cellular concrete blocks are 50 cm long and 25 (or 20) cm high.

The effective moisture values arrived at on the strength of our investigations, expressed in % by volume, are given in Table III.

TABLE III

Principal material		*Joints and rendering*	
Clay		Joints of ordinary mortar	4
Hollow blocks	1		
Perforated blocks	1	Exterior rendering of ordinary mortar	3
Solid bricks	0.5		
Heavy concrete		Interior rendering of plaster	10
All blocks	3		
Porous concrete	2		
Lightweight concrete			
Expanded clay aggregate concrete	4		
Blocks	4		
Cellular concrete			
Blocks	6		

PERMISSIBLE TYPES AND MINIMUM THICKNESSES OF FINISHED WALL (TABLE V)

This table is a synthesis of the preceding tables and the explanations given for the latter are equally valid for the present table. However, a few remarks should be added:

1. The transition from the preceding table to the present table is not rigorous as regards the smallest thicknesses. In certain cases 15 cm thick walls of lightweight expanded clay aggregate concrete or cellular concrete would be acceptable. However, for reasons of stability and resistance to cracks – very important for exterior walls exposed to rain – we consider this thickness dangerous and we have not gone below 20 cm.

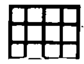
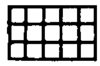
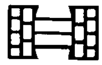
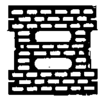
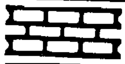
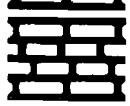
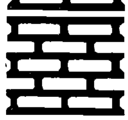
2. As in the preceding table, the thicknesses of the finished wall are those of a wall with an exterior mortar rendering and an internal plaster rendering, the total thickness of the two layers being about 2.5 cm.

3. The range of thicknesses could be extended by choosing figures in multiples of 2.5 cm.

TABLE IV

INTRINSIC THERMAL CHARACTERISTICS OF OPTIMUM LIGHTWEIGHT MASONRY

(*i.e.* those obtainable with efficient but not exceptional production processes. For each wall the table indicates the coefficient effective K and the equivalent dry weight between brackets [1])

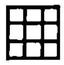
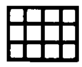
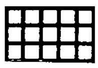
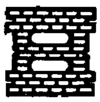
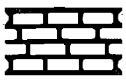
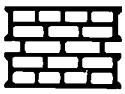
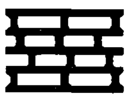
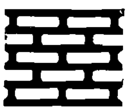
Thickness of finished wall, rendering on both sides (cm):		*20*	*22.5*	*25*	*27.5*	*30*	*32.5*	*35*
Thickness of blocks or of wall without rendering (cm):		*17.5*	*20*	*22.5*	*25*	*27.5*	*30*	*32.5*
Clay Hollow blocks density: 1.8–2.0 void: 55–65 %		1.7 (205)	1.6 (225)					
		1.6 (215)	1.5 (235)	1.45 (260)	1.35 (280)			
				1.35 (265)	1.25 (285)	1.2 (300)		
				1.3 (270)	1.2 (290)	1.15 (315)		
Perforated blocks density: 1.7–1.9 void: 30–40 %		1.5 (250)	1.4 (280)	1.3 (310)	1.2 (335)	1.15 (365)		
Heavy aggregate concrete (sand and fine gravel) hollow blocks, thin partition walls (10–20 mm) density: 2.0–2.2 void: 45–55 %		2.05 (250)	1.95 (265)					
		1.95 (260)	1.85 (275)	1.75 (295)	1.65 (325)			
				1.65 (310)	1.55 (330)	1.5 (355)	1.4 (385)	
						1.4 (370)	1.35 (400)	1.3 (430)
Hollow blocks thick partition walls (25–35 mm) density: 2.0–2.2 void: 35–45 %		2.45 (295)	2.3 (320)					
		2.35 (305)	2.15 (330)	2.0 (360)				
			2.0 (340)	1.9 (370)	1.8 (395)	1.75 (420)		
						1.65 (430)	1.55 (465)	1.5 (495)
								1.4 (515)
Lightweight aggregate concrete (pozzolano or expanded slag) Expanded clay aggregate concrete of porous structure density: 1.1–1.3		1.2 (275)	1.1 (310)	1.0 (345)				
Hollow blocks thick partition walls (30–40 mm) density: 1.2–1.4 void: 30–40 %		1.45 (250)	1.35 (265)	1.3 (275)				
				1.25 (295)	1.2 (320)	1.15 (345)		
Autoclaved cellular concrete Blocks, density: 0.6–0.7		1.2 (210)	1.1 (240)	1.0 (270)				

SOME HEAVY WALLS

Thickness of finished wall	25	30	35	40	45	50	55
Solid bricks density: 1.7–1.9	1.9–2.25 (445–460)		1.65–1.95 (660–670)		1.3–1.6 (855–905)		
Heavy aggregate porous concrete density: 1.7–1.9	2.25 (440)	2.1 (560)	1.95 (655)	1.8 (750)	1.65 (845)	1.55 (935)	1.45 (1030)

[1] The maximum permissible loads are not only dependent on the strength category of the principal material, but also on the strength of the mortar and on the quality of workmanship.

TABLE V

		Permissible types and minimum thicknesses of the finished wall										Maximum permissible loads in tons per linear metre (basis for calculation in preliminary stage of project)				
"Superior" dwellings		Zone A				Zone B		Zone B′		Zone C		Strength cat. in kg/sq. cm	Thickness of finished wall			
"Moderate" dwellings		Zone A		Zone B				Zone B′		Zone C						
Third-class dwellings (not recommended for Zone A)		Zone B		Zone B′						Zone C			20	25	30	35
		Interior absorbent rendering														
								**20**								
Clay Hollow blocks density: 1.8–2.0 void: 55–65 %						**25**			25			25	**5**	**7**	**9**	
												40	**9**	**11**	**14**	
												60[1]	**13**	**17**	**21**	
												80[1]	**17**	**22**	**27**	
		**30**	30	**25**	30		25			**25**	30	exceptional				
Perforated blocks density: 1.7–1.9 void: 30–40 %		**30**	30	**25**	30	**20**	25	**20**	20	**25**	30	≥ 60	**15** **20**	**19** **26**	**24** **31**	
Heavy concrete (sand and fine gravel) hollow blocks for thin partition walls (10–20 mm) density: 2.0–2.2 void: 45–55 %				**30**		**30**	30	**25**	30	**30**						
		**35**	35		35						30					
Hollow blocks for thick partition walls (20–30 mm) density: 2.0–2.2 void: 35–45 %								**30**				40 60 80[1]		**13** **19** **20**	**16** **24** **26**	**19** **28** **31**
				**35**		**30**	35		35	**35**	35					
		**35**	35		35											
Lightweight concrete (pozzolano or expanded slag) concrete of porous structure, density: 1.1–1.3		**20**	20	**20**	20	**20**	20	**20**	20	**20**	25	25 40	**7** **12**	**9** **15**		
Hollow blocks for thick partition walls (30–40 mm) density: 1.2–1.4 void: 30–40 %				**25**		**20**	25	**20**	20	**25**		25 40	**6** **10**	**8** **13**	**10** **16**	
		**30**	30		30						30					
Autoclaved cellular concrete blocks, density: 0.6–0.7		**25**	25	**20**	25	**20**	20	**20**	20	**20**	30	45	**10**	**13**	**15**	
SOME HEAVY WALLS																
Solid bricks: density 1.7–1.9		**45**—45		**35**—45		**35**—35		**35**—35		**35**—35		≥ 60	**24–33**	**32–43**		
Heavy aggregate porous concrete density: 1.7–1.9		**55**—55		**45**—55		**35**—45		**35**—45		**35**—35		50	**23**	**30**		**38**

The figures in bold type refer to frontage walls, those in roman type to end walls.

TABLE VI

DEFINITION OF THE CLIMATIC ZONES

	Zone A	Zone B: B	Zone B: B′	Zone C
Ain	×	....	....	....
Aisne	×	....	....	....
Allier	above 500 m	below 500 m	....	....
Basses-Alpes	× > 500	× < 500	....	....
Hautes-Alpes	×	....	....	....
Alpes-Maritimes	× > 500	....	....	× < 500
Ardèche	× > 500	× < 500	....	....
Ardennes	×	....	....	....
Ariège	× > 500	× < 500	....	....
Aube	×	....	....	....
Aude	× > 500	....	....	× < 500
Aveyron	× > 500	× < 500	....	....
Belfort	×	....	....	....
Bouches-du-Rhône	....	....	....	×
Calvados	....	×	....	....
Cantal	×	....	....	....
Charente	....	×	....	....
Charente-Maritime	....	....	×	....
Cher	....	×	....	....
Corrèze	× > 500	× < 500	....	....
Corsica	× > 500	....	....	× < 500
Côte-d'Or	×	....	....	....
Côtes-du-Nord	....	....	×	....
Creuse	× > 500	× < 500	....	....
Deux-Sèvres	....	×	....	....
Doubs	×	....	....	....
Dordogne	....	×	....	....
Drôme	× > 500	× < 500	....	....
Eure	....	×	....	....
Eure-et-Loire	....	×	....	....
Finistère	....	....	×	....
Gard	× > 500	....	....	× < 500
Haute-Garonne	× > 500	× < 500	....	....
Gers	....	×	....	....
Gironde	....	....	×	....
Hérault	× > 500	....	....	× < 500
Ile-et-Vilaine	....	....	×	....
Indre	....	×	....	....
Indre-et-Loire	....	×	....	....
Isère	× > 500	× < 500	....	....
Jura	×	....	....	....
Landes	....	....	×	....
Loire	× > 500	× < 500	....	....
Haute-Loire	×	....	....	....
Loire-Atlantique	....	....	×	....
Loiret	....	×	....	....
Loir-et-Cher	....	×	....	....
Lot	× > 500	× < 500	....	....
Lot-et-Garonne	....	×	....	....
Lozère	×	....	....	....
Maine-et-Loire	....	×	....	....
Manche	....	....	....	....
Marne	×	....	×	....
Haute-Marne	×	....	....	....
Mayenne	....	×	....	....
Meurthe-et-Moselle	×	....	....	....
Meuse	×	....	....	....
Morbihan	....	....	×	....
Moselle	×	....	....	....

	Zone A	*Zone B*		*Zone C*
		B	*B′*	
Nièvre	× > 500	× < 500	....	....
Nord	....	×	....	....
Oise	....	×	....	....
Orne	....	×	....	....
Straits of Dover	....	×	....	....
Puy-de-Dôme	×	....	....	....
Lower Pyrenees	× > 500	....	× < 500	....
Eastern Pyrenees	× > 500	....	....	× < 500
Upper Pyrenees	× > 500	× < 500	....	....
Lower Rhine	×	....	....	....
Upper Rhine	×	....	....	....
Rhône	× > 500	× < 500	....	....
Upper Saône	×	....	....	....
Saône-et-Loire	....	×	....	....
Sarthe	....	×	....	....
Savoy	×	....	....	....
Upper Savoy	×	....	....	....
Seine	....	×	....	....
Seine-et-Marne	....	×	....	....
Seine-et-Oise	....	×	....	....
Seine-Maritime	....	×	....	....
Somme	....	×	....	....
Tarn	× > 500	× < 500	....	....
Tarn-et-Garonne	....	×	....	....
Var	× > 500	....	....	× < 500
Vaucluse	....	....	....	×
Vendée	....	....	×	....
Vienne	....	×	....	....
Haute-Vienne	× > 500	× < 500	....	....
Vosges	×	....	....	....
Yonne	....	×	....	....

However, we consider this discrimination of little value in the interests of standardization, hence a limitation of thicknesses to multiples of 5 cm. These are, therefore, the only thicknesses permissible for standard concrete blocks and homologous hollow blocks of clay.

Permissible maximum loads

The mechanical strength of walls does not come within the scope of these recommendations. However, seeing that the choice of a type of material is made at once for strength and insulation, it would seem practical to place these two characteristics side by side.

It will be appreciated that the maximum permissible load of masonry is equal to the compressive strength of the materials divided by a coefficient of safety, of which the value depends on the way the wall is loaded: eccentric load or otherwise. In each individual case this leads to calculations which are generally not made until the production stage of the project. However, an approximate figure for the maximum permissible load of the wall is necessary in the preliminary stage of the project. This is the figure which has been given.

The categories of material strengths are those fixed in the different load tables of the CSTB.

Discussion

TECHNICAL AND PHYSICAL ASPECTS

The discussion reveals that the complexity of the technical and physical aspects that are involved in heat transmission and its measurement necessitates the collection of much basic information that is often not available as yet.

Mr. I. JANSSON (Sweden) raises, as a first problem, the question of non-steady heat flow through walls. Water and vapour in walls are not uniformly distributed. They will assemble in the colder part of the structure during the cold season. Apart from this there is the influence from freezing and thawing of water in the structure on its insulating capacity.

Mr. R. HANSON (Sweden) advocates more investigation into the variation with time of water content in exposed walls. Reference is made to the important work of Prof. KRISCHEV (Darmstadt Technical Union) on capillary movement and vapour diffusion of moisture in porous solids. Mr. HANSON's own studies and experiments on capillary movements have led him to a theory that gives agreement with practical results.

Mr. G. BÅVE (Sweden), speaking of the work carried out in several countries on lightweight concrete (Siporex), reports a moisture content of 17% in a 22 cm thick exposed wall of a small house. The amount decreased in one year to 10% and in another four months to 6%.

Mr. A. W. PRATT (United Kingdom), referring to Mr. A. TVEIT's experiments on exposed walls, asks for information on the effect of ventilation of cavities on the air-to-air transmission coefficient, and what effect of solar radiation on heat exchange has been noticed. He also draws attention to the importance of determining the functional relationship between conductivity and moisture content as a design basis for correcting calculated *U*-values to practical values.

In reply to a question by Mr. PRATT, the rapporteur Dr. MARKE makes it clear that there is, in fact, very little technical evidence about moisture effects on wall insulation in Scandinavia. The actual basis for regulations is and should be a qualified guess until further evidence is collected.

BUILDING REGULATIONS ON INSULATION

Another specific matter revealed by the discussion is that there are at least two different schools of thought on the setting of insulation standards and of measures for moisture prevention.

The main paper of Prof. H. REIHER anticipates regulations that may include certain requirements for habitation. In Scandinavia, on the other hand, economic considerations prevail in the establishment of insulation requirements.

Mr. E. STROKIRK (Sweden) gives information on what he calls the "Swedish Government's way to favour a better fuel economy". The cold winters and the necessity to import nearly all fuel make the costs for heating and hot water provision such an important part of the rent of a house that a better insulation than that according to medical and minimum government requirements is warranted.

The financing of the greater part of the newly-built residential houses in Sweden is based on a combination of private and state mortgage loans. First and second mortgage loans are provided in the capital market (*e.g.* by savings banks and insurance companies), and the State offers a third mortgage loan. The size of the different loans is determined in relation to the so-called loan value of the house (and the site). This value – both of blocks of flats (multifamily houses) and of small houses – has been maximized by the Government. For blocks of flats this maximum value ("the loan ceiling") is at present 610 Sw. crowns per square metre of dwelling space; more exactly, this refers to a particular house in a town in the middle of Sweden. Consequently the maximum value varies in relation to 610 Sw. k. per sq. m according to all relevant deviations of a house from the basic one, first of all according to the geographical dispersion of building costs in the country and to variations with regard to the size of the house and the different types of dwelling units within it. But also many other factors are considered. One of them is the quality of the thermal insulation.

If the quality of the thermal insulation of outside walls, attic floor structures and windows is higher than this, it is taken into consideration by increasing the maximum loan value (making the loan ceiling higher) as shown in Table I.

TABLE I

INCREASE OF LOAN VALUE FOR HIGHER QUALITY OF THERMAL INSULATION OF OUTSIDE WALLS (ALL KINDS OF CONSTRUCTION)

Transmission coefficient (K)	*Sw. k. per sq.m dwelling space* *Zone I*	*Zone II + III + IV*
< 0.25	14	14
0.26 – 0.30	11	12
0.31 – 0.35	8	10
0.36 – 0.40	5	8
0.41 – 0.45	2	6
0.46 – 0.50	—	4
0.51 – 0.55	—	2

For attic floor structures, if $K < 0.25$, the loan value is increased by 4 Sw.k. per square metre dwelling space. When three-pane windows are used instead of two-pane ones, the loan value is increased by 9 Sw. k. per square metre dwelling space in zones I and II and by 6 Sw. k. in zones III and IV.

The present terms in this respect have been in force since July 1, 1959, but some corresponding although somewhat different terms were introduced as early as January 1, 1956. As is shown in Table II, the quality of the thermal insulation of outside walls in newly built houses was higher than the minimum requirements in earlier years. Since the beginning of 1956 still further progress has been made.

TABLE II

MINIMUM REQUIREMENTS FOR THERMAL INSULATION OF OUTSIDE WALLS MEASURED BY THE HIGHEST ACCEPTED TRANSMISSION COEFFICIENTS, K, (kcal/m^2 h°C), AND ACTUAL TRANSMISSION COEFFICIENTS (AVERAGE VALUES) FOR RESIDENTIAL HOUSES COMPLETED IN THE YEARS 1953, 1956, 1957 (ONE-FAMILY HOUSES) AND 1959 IN DIFFERENT PARTS OF SWEDEN

	Transmission coefficients (K) in zone [1]: *I*	*II*	*III*	*IV*	*I–IV*
Minimum requirements					
Solid brick walls	0.85	0.95	1.05	1.15	—
Light concrete walls	0.65	0.75	0.85	0.95	—
Wood walls	0.45	0.55	0.65	0.75	—
Average values					
Multifamily houses 1953	0.57	0.59	0.66	0.84	0.67
Multifamily houses 1956	0.56	0.62	0.68	0.73	0.68
Multifamily houses 1959	0.36	0.44	0.46	0.48	0.45
One-family houses 1957	—	—	—	—	0.50

[1] The country is divided into four zones with regard to the climatic conditions. Zone I represents the northern part of Sweden.

The terms taking into consideration the quality of the thermal insulation related in Table II refer only to blocks of flats (multifamily houses).

It might seem peculiar that the small houses are not considered at all in this respect, especially as we know that, for instance, the average dwelling space of the one-family houses is 90 sq. m, the average area of their outside walls 100 sq. m and of their attic floor structure 80 sq. m, while the corresponding average numbers for multifamily houses are, respectively, 65, 40 and 15 sq. m. This means, of course, that it must be still more important to improve the thermal insulation of the small houses – and as a consequence their economy – than that of the others.

One of the reasons why until now not all houses are included in the measures taken to further a better fuel economy is said to be the following. The small houses – at any rate the detached ones – are built by their future owners, and it is in their own interest to invest money in their houses in such a way that the yearly fuel costs will become as low as possible. The builders of multifamily houses, on the other hand, as a rule have the ambition to arrive at the lowest possible building costs. The question whether the yearly fuel costs do not become as low as possible is irrelevant, as the future tenants will have to pay these costs, whatever they may be.

In any case, it is a fact, as shown in Table I, that all kinds of houses are well insulated.

According to the opinion of Mr. STROKIRK, the thermal insulation of the small houses ought also to be considered, but in an administratively simpler way. In this connection the fact is mentioned that in Norway the small houses are supported by the State in this respect but not the multifamily houses.

The question has been raised why the attempts to improve the fuel economy are limited to taking into consideration the thermal insulation of the outside walls, the attic floor structures and the windows, while, on the other hand, nothing is done to further a better efficiency of the furnace. If the loss of heat from the furnace, which now as a rule amounts to 40–50%, could be brought down to 30%, this would mean an important improvement of the fuel economy.

The relative importance of the efficiency of the furnace can be illustrated by the following distribution of the total loss of heat in a fairly well insulated small house:

Outside walls	8%
Attic floor structure	6%
Bottom structure	8%
Windows and doors	12%
Ventilation	16%
Hot water	10%
Furnace loss	40%
	100%

Subject 9

INDUSTRIALIZATION OF BUILDING

UDC 658.2/5 : 69.002

REPORTS

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Industrialization of construction in the U.S.S.R.

UDC 658.2/5 : 69(47)

V. I. OVSYANKIN
Vice-President of the Academy of Building and Architecture (U.S.S.R.)

GENERAL PROBLEMS OF INDUSTRIALIZED CONSTRUCTION

To realize an ambitious programme of rapid development of the entire U.S.S.R. national economy, the total State capital outlay for 1959–1965 has been fixed at about two billion roubles, exceeding investment over the preceding seven years by 1.8 times. Of the total, some 75% will be invested in industrial development and about 20–22% in housing, municipal, cultural and welfare construction. Dwellings are to be constructed with a total of 650–660 million m^2 of floor space, as against 240 million m^2 in 1951–1957, and another 7 million houses will be erected in rural areas by collective farmers and rural intelligentsia.

A specific increase is planned for the Urals, Central Asia, Siberia and the Far East, where 40% of the total investment will go. All this necessitates the speeding up of construction, an increase in labour productivity and a reduction of costs, together with the improvement of quality and hence technical progress and a higher level of organization and engineering based on extensive industrialization.

This problem has become real only because of the progress of U.S.S.R. heavy industry and since indispensable conditions for industrialization – training of many specialists and establishment of industrial facilities – have been fulfilled.

Industrialization means factory production and the mechanization of transport and site operations, introducing mass production followed by assembly operations. Its economic effect depends foremost on the introduction of new techniques and also on such matters as organization of the building industry; degree of specialization and cooperation of producing, assembling and auxiliary organizations; extent of application and technological suitability of prefabricated products, their unification, degree of factory completion, weight, dimensions, etc.; extent of mechanization and automation especially of arduous and labour-consuming operations; perfection of plant and equipment; quality of design; development prospects for industrial construction facilities and acceleration of technical progress by means of planning, financing, incentives, etc.

Possibilities within reach for 1965 as compared with today, calculated by the Institute of Construction Economics of the U.S.S.R. Academy of Building and Architecture, are: reduction of labour costs of 12–13% by better organization, of 15–16% by mechanization and of 11–12% by prefabrication and use of effective new materials, adding up to 38–41%, which corresponds with a 61–69% increase in labour productivity; reduction of costs of operations of 6% by increased labour productivity, economy in materials, reduced transport costs and lower overhead charges.

Faster construction, ensuring a rapid start of operation of industries and hence an increase in national income and living standard, is very important. Examples are: completion of seven blast furnaces in the Donetz coal basin in 1958 within 7–9 months as compared with 13–18 months required 10–15 years ago and completion of five-storey large-panel residential buildings at the Cherepovete Metallurgical Works within 60 days, labour amounting to 0.3–0.5 man-day per m^2 of building.

Mechanization increased more than 3.5 times in 1940–1957. Averages per 100 million roubles of construction work were, in 1940, 6 excavators and 3.3 cranes; in 1957, 20 excavators and 20 cranes; and they will double in the coming seven years.

The essential material is precast reinforced concrete. Production was 18 million m^3 in 1958, and will be 42–45 million m^3 in 1965, putting the U.S.S.R. ahead of the rest of the world; the 1957 figures were 10 million m^3 for the U.S.A., 3 for United Kingdom, 1 for the German Federal Republic and 0.6 for France. Prestressed components were 8% of the total in 1958, will be 25% in 1965. Use of prefabricated elements raised the percentage of completed buildings – *i.e.* by 70% as against 41% in 1953 with Glavmosstroi – by elimination of seasonal variations and doubling labour productivity.

The degree of industrialization is highest in housing, is well advanced in construction of industrial buildings, bridges, etc., and is to be increased soon in all branches.

MECHANIZED PRODUCTION OF PRECAST AND PRESTRESSED COMPONENTS

NATURE OF PRODUCTS AND SCOPE OF PRODUCTION

Large quantities are required. In housing: hollow deck panels with round or oval voids occupying 47% or 57% of the volume; vacuum panels with welded or prestressed reinforcement; ribbed ceiling panels produced by a rolling method at special mills, ribs facing upward or double ribs facing one another; large panels for walls and partitions. Large panel production in the seven-year plan will cover 25 million m^2 of dwelling space per year, entailing establishment of factories with a 30 million m^2 floor space total capacity.

In roofing: recent use of prefabricated concrete rectangular cross section rafters, large panels resting on walls and ridge beams; until recently metal trusses and girders to span 12–15 m; now concrete girders of 12–18 m and prestressed trusses of 18–36 m; girders have I-beam sections, upper flanges 40–80 cm wide and 8–15 cm thick, lower flanges with prestressed reinforcement; trusses are often arch trusses with loose trussing and prestressed lower girders; ribbed panels with conventional welded or prestressed reinforcement and spans of 6, 3 or 1.5 m wide.

Column prefabrication was initially delayed due to the excessive variety in standard dimensions, now cut down by 50%. I-beam and angle columns are used. Bearing elements of industrial buildings are prefabricated. Filing is done with ribbed panels, *e.g.* in the Cherepovete Krivoi Rog rolling mill (Fig. 1). Quality aspects are also considered, and very economic thin-walled prestressed elements are introduced.

NEW TECHNOLOGICAL METHODS AND PLANTS

New methods and plants are required to increase the production by 2.5 times in the next

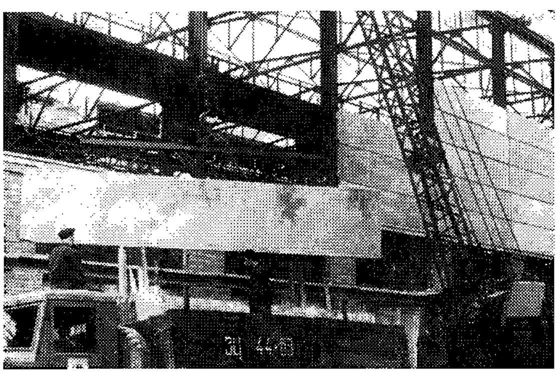

Fig. 1. The erection of wall slabs in the rolling shop.

seven years. In the last five years new plants, each having a 180,000–260,000 m^3 capacity and applying conveyor or unit line technology, have been built.

THE CONVEYOR METHOD

The Stalingrad plant is designed for a 190,000 m^3 output. Fillers, delivered by rail to a warehouse, proceed by belt conveyors to the mixing department; cement goes by air chutes and a horizontal screw conveyor to four tower silos of 500 tons each; the mixing plant has three mixers of 7 m^3 per hour each (10 batches) and automatic batches. The mixture goes to moulds by belt conveyors, the main building houses reinforcement and moulding shops; the reinforcement shop has automatic welding machines, suspension welding tongs, butt devices and shearing tools serving a wide-grid automatic welding line, reinforcement being supplied from the store to the conveyor by crane; the moulding shop has four conveyors with 15 positions each for removing the finished article, cleaning moulds, lubrication, etc. Moulding is done by special machines on rails; conveyors 1 and 4 are for ceiling panels with oval voids and up to 6.4 m long; conveyor 2 is for ceiling panels with round voids; conveyor 3 is for landings, flights, road slabs, etc. Packing is effected for multi-void ceiling panels by vibrating void-forming devices, for flights by vibrating stamping dies, for other articles by vibrating platforms. By roller bed and lift, the moulding trucks go to their storied autoclaves, where simultaneously a truck with the finished article leaves the other side and goes by lift and roller bed to the beginning of a conveyor, where it is removed by crane to an inspection platform and then to an open-air stock, from where 10-ton cranes load them on transport vehicles.

THE UNIT LINE METHOD

The unit line method is simple and flexible and does not require the complex machinery or rigid rhythm of operations of the conveyor method. Overhauling the bay for production of different articles can be done without stopping. The method requires a moulding unit or vibration platforms, and a travelling hoist to move moulds from one unit to another and to the autoclaves.

Factory 5 of Mosglavpromstroimaterialy in Moscow – capacity 132,000 m^3/year– is a pioneer of this method and has two moulding shops.

Moulding shop 1 in a building of 56×32 m has four bays, three of 8 m and one of 5 m, each equipped with a line of vibrating platforms and self-propelled concrete placers. The mixture goes from the mixing department by a system of stationary and shuttle belt conveyors; the remaining space contains hole chambers on the lids of which all preparatory work – striking, cleaning, etc. – is done; at the other end articles are inspected, minor repairs made, transport to store on self-propelled trucks arranged. The reinforcement department, parallel to moulding, supplies frames on narrow-gauge rail trucks.

In moulding shop 2 the mixture is transported by cable on a monorail from an outside mixing department and the reinforcement department is also outside; production includes ceiling panels 6.4×1.2 and 6.4×0.8 m, with round and oval voids and prestressed multi deckings with oval voids; autoclaves 7.5×3.25 m and 7 m deep have steam through perforated pipes on the floor along the perimeter; stressing of rods is done simultaneously by a special machine; yearly output per worker: 221.4 m^3, or, per sq. m of factory floor space, 27.7 m^3.

An advanced standardization in production and design tends to eliminate the deficiencies concomitant with manual labour.

CONTINUOUS HIGH-TENSILE REINFORCEMENT BY REELING MACHINES

One-man machines reinforce complicated elements. A recent improvement is the heating by electric current up to 250° C of the mechanically stressed wire. The outside coating is burnt, improving the adhesion, and better plastic properties and additional stress by cooling are obtained.

Vibration stamping

Vibration stamping, permitting vigorous vibration, greater specific pressure and the use of hard concrete with a water/cement ratio of 0.35 or less, is becoming the main packing method.

Rolling method

The rolling method, suggested by N. Y. Kozlov (Fig. 2), is used for large thin-walled elements. The mill, with its continuously moving metal strip, is multi-purpose. Rolled products have constant properties, high frost resistance, precise dimensions and a high-quality surface. Though light, they are strong and rigid, *e.g.* ribbed panels up to 25 m long, 3.3 m wide and at least 10 mm thick. Shape and bearing capacity can be varied and ducts inserted during production. A rolled panel house weighs 2–2.5 times less, is 15–18 % cheaper and requires 5–6 times less labour than a brick house.

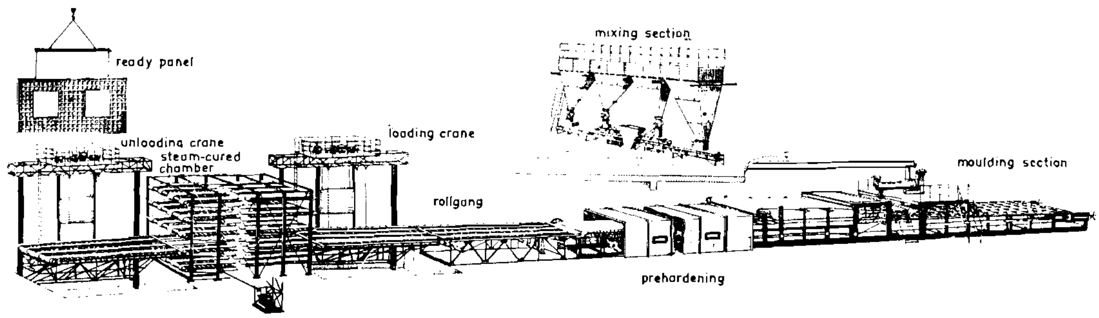

Fig. 2. Production line scheme of the manufacture of rolled large-sized reinforced concrete wall panels.

Rolling with a continuous line permits semi-automatic operation: a hard mixture – water/cement ratio 0.28–0.32 – supplied by a continuously working mixer to the moulding strip with the reinforcement is distributed by a worm vibrating placer; packing is continued by a vibrating girder underneath; and a cutter forms the article in approximate thickness, allowing for subsequent cogging. The moulded units then move under rollers that apply pressure up to 50 kg/cm^2 through an endless rubberized belt, and are calibrated with a smooth surface. Next they pass into a 50 m heat treatment section and for 2 hours are heated to 95–98 °C by live steam; then the belt is automatically stripped and the units have 70 % of the rated strength. Being tipped into a vertical position, they are transported in sets by crane to the store.

One rolling plant serviced by six operators per shift has a capacity for 60,000 m^2 of dwelling floor space per year. For 1959–1965 some 260 plants are to be built and standard dwelling designs have been made for plants of 35,000, 70,000 and 140,000 m^2 of floor space capacity, permitting complex housing production with outer walls providing insulation only and inner walls carrying the load.

Cassette method

The cassette method (Fig. 3) is used for 10 cm thick ceiling panels, 12 cm inner wall panels (all-room size), staircases, etc., accounting for 70 % of all products per building. Special swinging stands produce 22–25 cm outer wall panels of three layers, *viz.* two outside of 50 mm concrete and one inner of 120–150 mm semi-rigid mineral insulation.

This production was started in 1958 in Ochkovo, Gorky and elsewhere. The method permits reduced factory floor space and yields products with maximum factory finish and minimum dimensional allowances. The unit can simultaneously produce eight panels, ribbed or solid. It consists of a bed, movable and stationary cassettes, pans, hydraulic, electric and steam systems, and a control panel. The process includes drawing apart, cleaning, lubricating of cassette surfaces, inserting reinforcement, etc., mounting stops, bringing surfaces together, installing vibration head pieces, filling moulds, vibrating, removal of vibrators, putting on covers, steam treatment for two hours, seasoning for four hours, drawing surfaces apart, removal of finished article. Concrete, sand (coarse-grained of 200 kg/cm^2 or with 6–8 cm slump) and up to 30% fine gravel is used. New plants are to be built and existing ones will be adapted for production of electrical transmission line supports, lighting systems, railway sleepers, mine supports, etc.

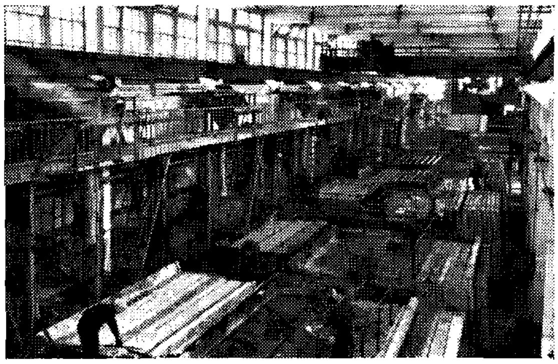

Fig. 3. Cassette method of manufacturing precast reinforced concrete elements (house building plant, Moscow).

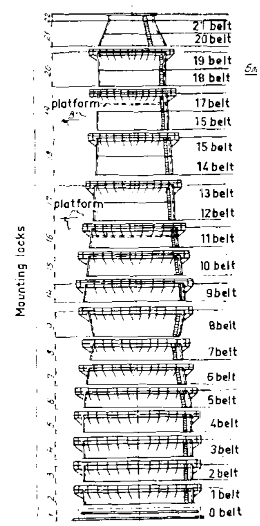

Fig. 4. The splitting of a blast furnace shell into erection units.

IMPROVING THE ERECTION OF PREFABRICATED BUILDINGS

Large units are required. For example, steel parts formerly used for blast furnace shafts have been replaced by crane-mounted concrete units of up to 25–30 tons, reducing construction time (Fig. 4). Thus blast furnace installations at Ghelyabinsk were built in 1958 in 8 months, twice as fast as earlier structures of the same sort.

Examples are the precast reinforced concrete units of up to 55 tons for ore bridges, foundation form slabs which serve as part of the structure of five blast furnaces in 1955–1957 and three others in 1958 in the Donetz coal basin.

Fig. 5 gives the bunker trestle of the Krivorozstal works. Large units were also used for mechanical, sanitary and electrical equipment and all such units accounted for 70% of the total material costs. Another successful example is a major 650 mm rolling mill at Nizhny Tagil works in 1958, where 16,000 tons of steel units and 8900 m^3 of reinforced concrete units were assembled.

The latter, going by crane directly to their ultimate location by vehicle, gave an output per worker of 315%, as compared with 160% for steel parts, of the planned target. For power stations the same advantages were obtained.

Powerful cranes have been developed, *e.g.* the G.K. 1425 tower crane used at Nizhny Tagil blast furnace 5 (capacity 75 tons, lift 92 m) (Fig. 6).

As cranes in housing are used to only 10–40% of capacity, uniformity of weights must be striven at as well as direct mounting from the vehicle (Fig. 7). This helped reduce labour consumption in 1958 in Novye Cheremusky from 3600 to 2600 man-days per house and construction time from 82 to 52 days.

Light prefabricated masonry of ceramic blocks and panels, reducing the weight of walls by 48% and brick consumption by 25-45%, must be used since bricklaying will remain in the coming seven years. Experiences in Kiev, Leningrad, Novo Kuibyshevsk, etc., show that with brick blocks, as compared with conventional bricks, labour expenses are 15–35% lower in total and 2.5–3 times lower at the site.

CRANE PRODUCTION

Large-scale crane production has started: new mobile tower cranes (6K-215, C-390, MCK-3-5/20, 6K-370) transported without being dismantled; caterpillar cranes Э-1254 with 20 tons capacity and Э-2006 with 50 tons capacity; K-123 12-ton pneumatic tyre cranes and K-104 10-ton automobile cranes. However, current demand is not yet met.

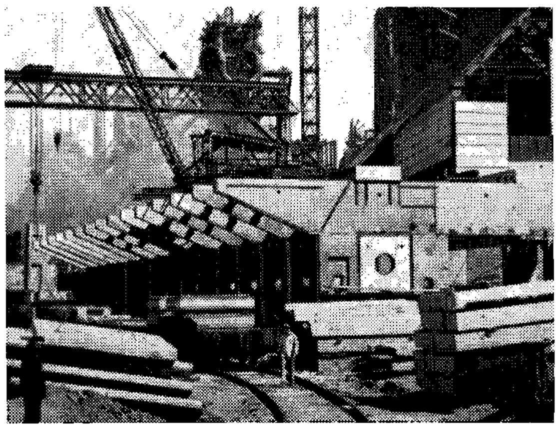

Fig. 5. The blast furnace bunker trestle of precast reinforced concrete units.

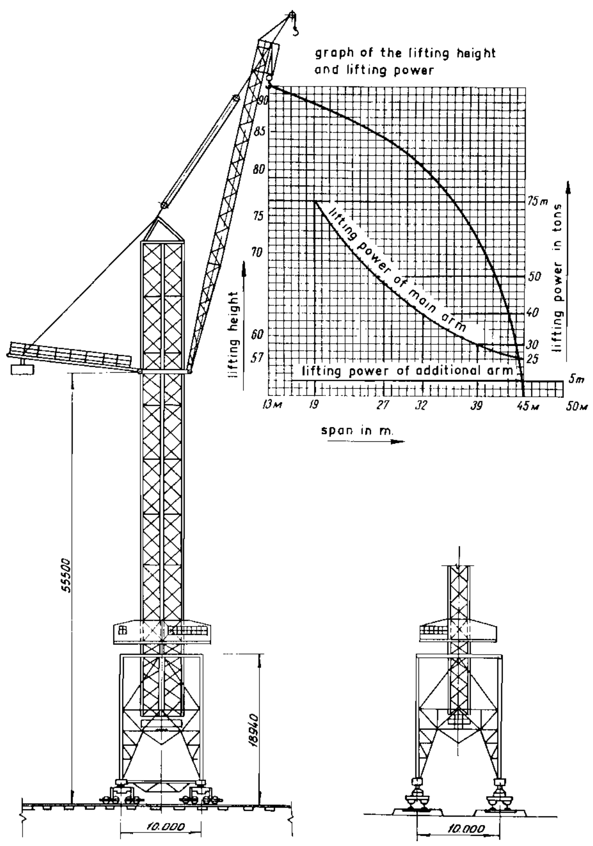

Fig. 6. The tower crane of 75-ton lifting capacity.

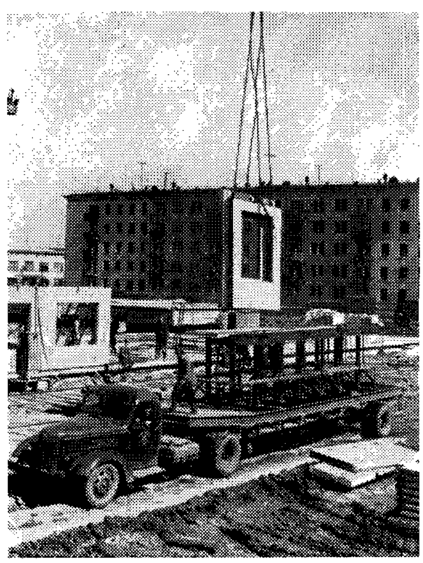

Fig. 7. The erection of large-sized units from the vehicle.

A special 5-ton pneumatic tyre crane for large-panel 4- and 5-storey housing is being developed by the Institute of Organization, Mechanization and Technical Aid of the Academy together with the Leningrad Streimash Designing Office. Measures planned for the future are production of 5-ton mobile tower cranes for housing and increase of output of special 30–40 ton tower cranes and gantry cranes for industrial building; increased production of 10- and 25-ton pneumatic tyre cranes and 20–25 ton caterpillar cranes; development of special 5-ton pneumatic tyre cranes for housing; production of 0.5–1.5 ton mobile cranes, the C-391 type and the KTC-3 type 3-ton automobile cranes for one- and two-storey housing. Foreign experience with 50-ton pneumatic tyre and 100-ton caterpillar cranes will be taken into account. Harmonized production is aimed at in order to obtain complete basic sets; 10–75 ton caterpillar cranes, 10–50 ton pneumatic tyre cranes and 5–25 ton automobile cranes.

AUTOMATION

Automation is equally important. At least partial automation may be reached by devices such as crane hoisting capacity, stop pieces, load meters, remote control facilities for crane operation and television sets, automatic load-gripping facilities, etc.

MECHANIZED STREAMLINE CONSTRUCTION AND ERECTION WITH LARGE UNITS

In housing this process is no novelty (it was applied in the U.S.S.R. in the thirties for one- and two-storey housing), but the historic development came with the 23 six-storey houses of the Lenin Prospect in Moscow in 1939, influencing development all over the country.

Analysis of the now considerable experience with this process by the Institute of Organization, Mechanization and Technical Aid of the Academy shows that it effects a reduction of 20% in the average construction time and of 4.5-5% in costs, and an increase of 8–10% in labour productivity and an improvement in quality are obtained.

Favourable examples of the mechanized streamline process can be cited for various places and various types of construction elements. In Barnaul, for four- and five-storey brick houses, the foundations and superstructure of each house took 24 and 86 days respectively, two houses per month being completed. In Cherepovete, for large-panel five-storey houses of 1,762 m^2 floor space each, results were: one house per month; erection time per house 60 days, of which 25 for erecting the precast units; strict correlation of timing of production, transport and mounting led to 0.45 man-day per m^3 only and to a reduction of cost per m^2 of floor space by 8%. The more long-term the project, the smaller the influence of "starting" operations and the greater the advantages of the method.

For example, the Moscow housing programme would, when executed by the methods of the twenties, require a labour force of 1.3 million in 1958, as compared with 9–10 times less with the modern method.

Excavation and foundation work in housing has also fully been mechanized by means of new mobile excavators and automobile or caterpillar cranes. For one- and two-storey houses these may also be used to mount superstructures, otherwise done by tower cranes (Fig. 8). Mortar supply and finishing is also mechanized by use of mortar pumps, pneumatic bunkers, etc.

OTHER CONSTRUCTIONS

In 1957 the Magnitostroi Building Trust applied the streamline method to construct a 500 m long four-span, thin-sheet hot rolling department, divided during construction into eight equal sections for equal amounts of labour. Special teams successively carried out the various operations, passing on from section to section.

Experience with one-storey industrial buildings led to full-size prefabrication of structures, dismantled only in parts if transport necessitated it. Erection is done directly from the transporting vehicle. Unlike the complex mounting of small sections with steel structures, concrete structures are mounted step by step separately, *viz.* first columns, checked and fastened, then girders and ceilings. Thus continuity of work and simultaneous carrying out of different operations becomes possible, as other operations can go on where the structure is completed. Stressing reinforcement on site is done after assembly of large units. Concreting the underlying floor precedes erection of overlying structures to smooth the operations.

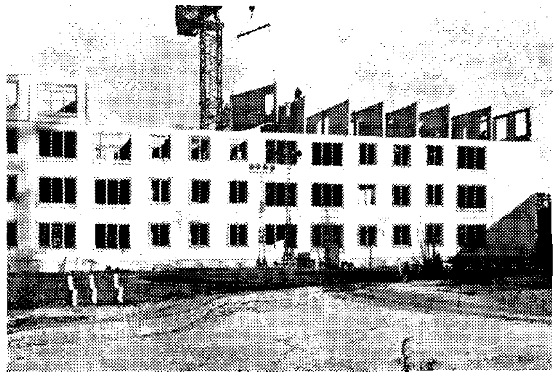

Fig. 8. The erection of panels fabricated by the cassette method.

A typical example of the method is given by the mechanical assembly department at a Dniepropetrovsk works, using some 3770 m^3 of precast concrete. On-site labour averaged 3.2 man-days per m^2 floor space. Erection of double T-section columns of 2.4 tons required 0.3 man-day and the crane operation 0.0953 crane shift. Erection of the complete ceiling required 0.42 man-day per m^3, the crane operating at a rate of 28.5 m^3 per shift.

As the mechanized streamline method has been checked in practice and proved its value it may well become applied all over the country in the near future. It is particularly effective in areas of intensive housing construction and industrial building, where all the required facilities exist.

Erection directly from the transport vehicles reduces costs by 8–10% and is consequently very important. The factory stock should directly serve the job by well harmonized planning. But for real development individual plans must become a part of long-term overall planning, in which mechanized streamline construction plays a predominant role. Standardization of the process by means of elaboration of technological charts is also required and these should be the subject of an index and catalogues to be published.

CONCLUDING REMARK

The above brief analysis may interest foreign specialists. There is substantial progress in the U.S.S.R., though the methods are not devoid of deficiencies. A discussion on the matters raised may, therefore, result in further improvement by industrialized construction.

Industrialization of building

UDC 658.2/5 : 69(43)

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"INDUSTRIALIZATION AND RATIONALIZATION"

The expression "industrialization of building" is interpreted in different ways by European experts. Some understand it to have the limited meaning of construction with large elements prefabricated industrially and merely assembled at the site. The greater part of the work that otherwise would have been done at site will, according to this process, be done in factories.

Others give a wider meaning to the word "industrialization": the rational development of construction in accordance with the principles known and tried in stationary industry. The first explanation of the definition is, moreover, that used by the German experts and the "Institut für Bauforschung". The theme of the CIB Congress should, however, be understood in the sense of the second explanation of the definition, similar to the word "rationalization".

AIM AND DIRECTION OF DEVELOPMENT

Efforts towards industrialization and rationalization of building must make it possible to be able to build more or better structures at the same cost or to be able to build the same qualities and quantities as at present at less cost. According to the extent that we achieve this aim we shall be able to build more dwellings, better dwellings or less expensive dwellings.

To rationalize building thoroughly we must start by giving the most rational form to the buildings and to the details of their fittings. This is the first condition and also the most important one for rational building. We must find the most rational materials and building techniques for all the elements of the dwelling and we must apply them.

Giving an economic form to housing and using favourable materials and working techniques begin to show a profit from the time when work on site is organized according to the principles that have already been shown to be rational in stationary industry.

It does not matter whether the buildings are constructed in accordance with revised traditional processes or according to new processes. Whatever the case, rational organization will show us that plant standing idle, production errors and obstacles can be avoided and that in this way productive work can be attained.

THE RATIONAL CONSTRUCTION OF BUILDINGS

The means for rational construction of buildings may be given by four examples:

- the practical sequence of work,
- rational use of mechanical plant,
- site planning, and
- doing the same work in series.

THE PRACTICAL SEQUENCE OF WORK

It has been proved that in a practical sequence of building operations the gas, water and electricity mains, etc., and the streets must be completed before building of the houses starts. This sequence is generally followed in a number of countries, for example, in Holland and in Sweden, but other countries do not adhere to it. Thanks to this sequence the supplementary costs occurring when work above ground has to be interrupted by the simultaneous performance of work at or below ground level are first of all avoided. Furthermore, a road leading to the site and passable, whatever the weather, is available. Finally, the additional costs for a temporary road or for the transportation of materials on impassable roads are avoided.

In many countries houses are built in the following way: the excavation is made, the foundations, the walls of the cellar, the ceiling of the cellar, etc., are made, and later the mains are installed in the cellar, followed by the floor of the cellar. This work is hampered by the narrowness of the cellar. For some time a different procedure has been followed in other countries: first the excavation is dug, and then the mains are laid in the open excavation. Next come the foundations and the floor of the cellar, its ceiling, etc. In this way the horizontal mains and the floor of the cellar can be made without difficulty owing to the larger work site with shorter supply routes. Installing the mains and making the foundations and the floor of the cellar in accordance with the second technique require only half of the working hours needed for the first technique in the same circumstances (Figs. 1 and 2).

Installing the staircase and the plumbing during rough construction – perhaps even before the floor has been made – has proved more rational than installation after construc-

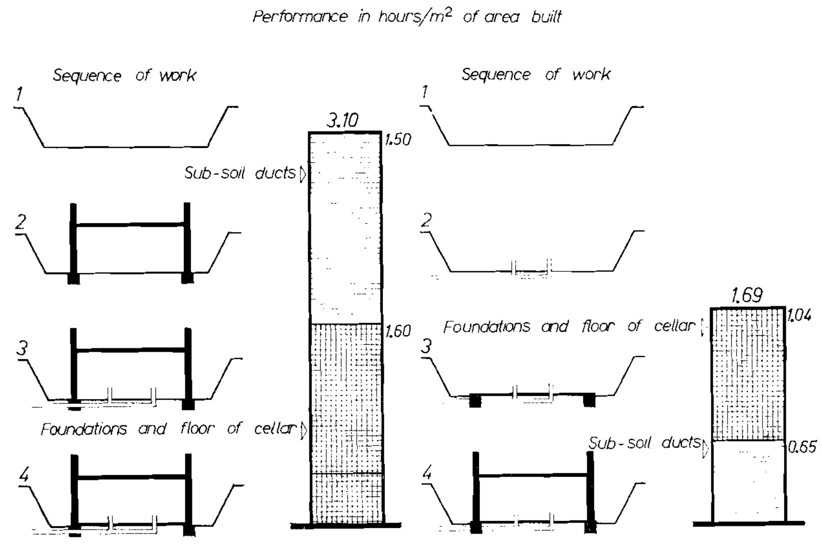

Fig. 1. Old and new methods for the construction of piping and foundations.

Fig. 2. Foundations, basement floor and piping being laid before construction of the cellar.

tion has been finished. The drainage pipes for waste water were installed with a saving of 30 to 35 per cent.

RATIONAL USE OF MECHANICAL PLANT

Another means for rational construction in the various countries is the use of mechanical plant for building, which is permanently on the increase from year to year as a substitute for human labour. Moreover, plant is needed for the assembly of large prefabricated elements. In improved masonry techniques, too, building can be performed more rationally with the aid of plant. This relates in particular to excavation, mixing concrete and mortar, and transporting materials.

The profit from working with plant instead of manpower depends on the choice made. It is a matter of selecting from the large number of types of plant now available the one that will best suit the rational work expected.

Fig. 3, for instance, shows a few light hoists for the transportation of materials. The capacity of these hoists is not very great, but the prime cost and the cost of installation are low. The lower part of the figure shows a number of high-speed hoists. They have a much greater capacity than that of the light hoists, but the purchase price and the cost of installation are higher. Fig. 4 shows several types of cranes. They are of much greater capacity, but are also more expensive.

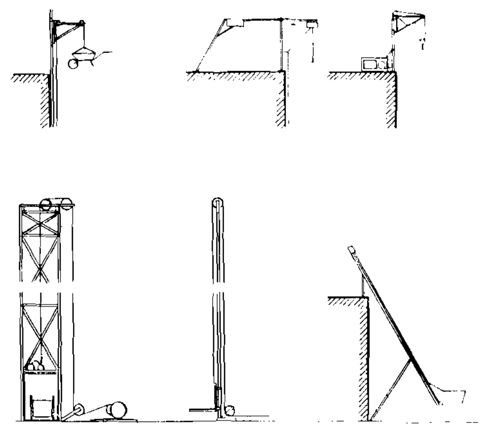

Fig. 3. Rapid goods elevators and lightweight goods elevators.

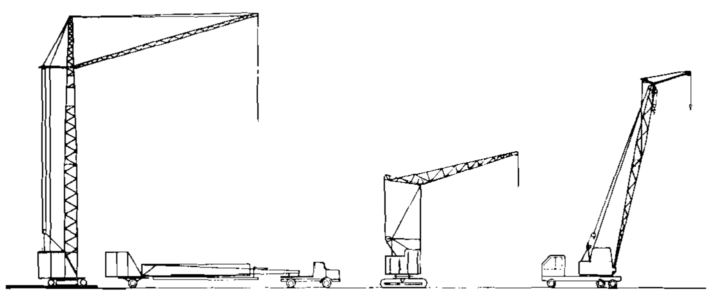

Fig. 4. Different types of cranes for the transportation of building materials.

An investigation made by the Institut für Bauforschung provides the following information on this matter.

Under certain conditions prevailing in Western Germany the first group of less productive but less expensive hoists works more rationally for minor building requirements up to about 10 dwellings. The second group – the high-speed hoists which are dearer but more productive – works most economically for average requirements of approximately

10 to 19 dwellings. Cranes of a still greater capacity and even more expensive are advantageous only for greater needs. Fig. 5, based on several investigations, shows the cost of transporting a ton of rubble stone with different types of equipment. It gives these costs for houses of different sizes, needing from 10 to 10,000 tons of the quantity transported. It is interesting

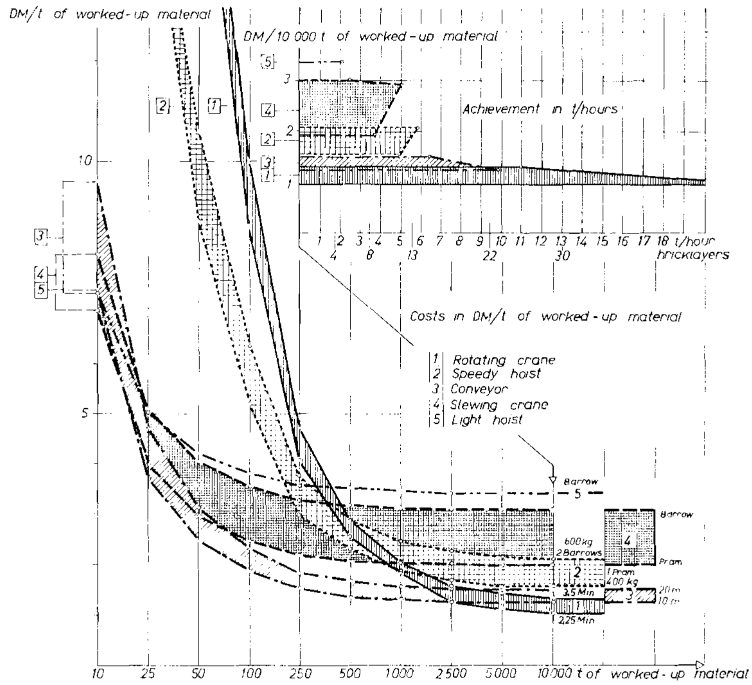

Fig. 5. Costs of transporting 1000 kg of bricks with different types of equipment and for building projects of various sizes.

to note from this diagram that a heavy piece of equipment, a crane, for instance, works in a much more expensive fashion for a small building than the appropriate lighter piece of equipment. A lighter piece of equipment, *e.g.* a hoist, works in a more expensive manner than a crane when the building on which it is used is too large, but the additional expense is not very high in this case.

SITE PLANNING

Site planning and work organization are particularly important for more rational construction. A small example taken from practice may show the effect of the form of site planning. On a large site in Frankfurt two identical rows of houses were commissioned from two different firms. One of the firms planned its site rationally. The materials of construction were transported over a distance of 20 m from the place where they were stacked to the place where they were used. The other firm's planning was not rational. A distance of 50 m had to be covered. Bricklaying required 3.6 hours per cubic metre for each site. The transportation of the materials required 0.9 hours per cubic metre on one site, and 1.9 hours on the other, thus bringing the totals to 4.5 hours per cubic metre and 5.5 hours per cubic metre, a difference of 20%.

This is a difference caused only by site planning. There is no fixed pattern for a perfect site. The buildings themselves, their location and the sites differ too much for that. On the other hand, there are clear rules that can be followed everywhere. The site must have a well-built road that can be used whatever the weather. It must be wide enough to allow two vehicles to pass without difficulty. The road must run past the buildings being constructed

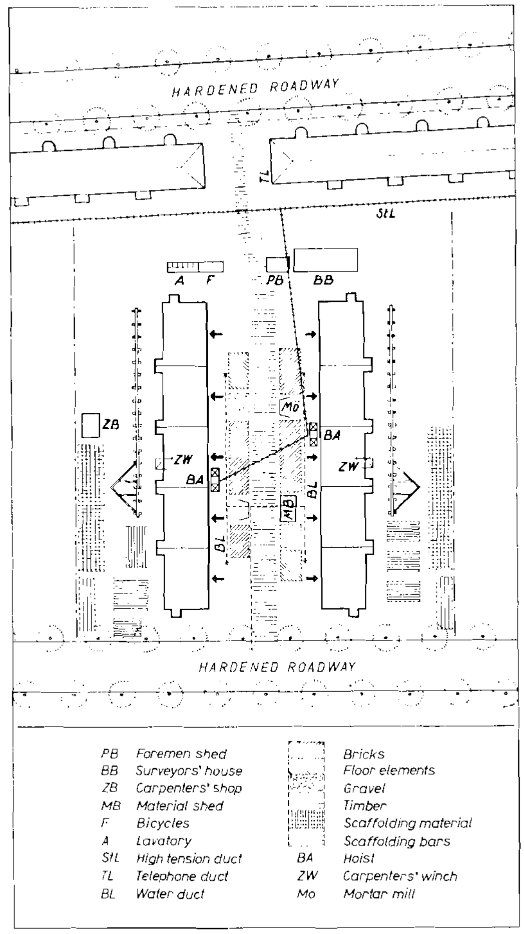

Fig. 6. Hardened roadway on the site along the building.

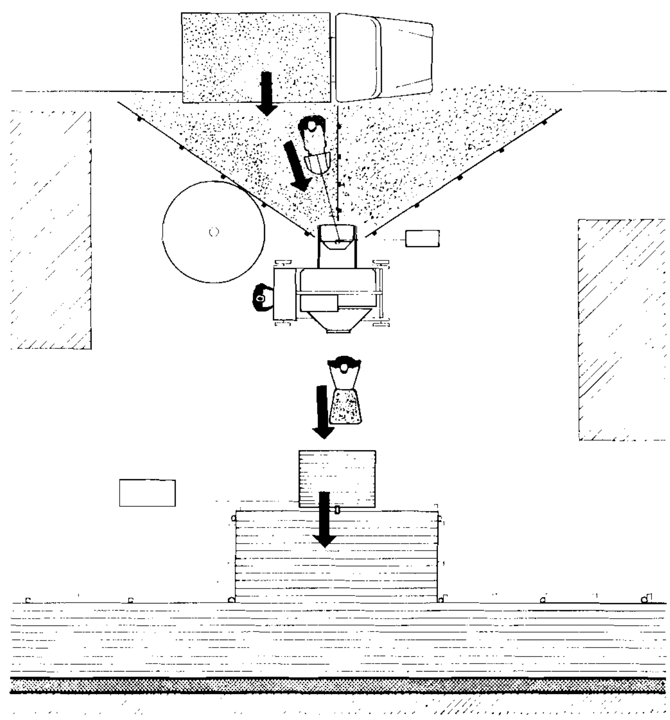

Fig. 7. Example showing a method for the production of concrete on the site.

so that the building can be easily reached and so as to avoid any manual transport (Fig. 6). Between this road and the building there must be a space large enough to take materials and the more important plant. Work must always proceed in the same direction, *i.e.* the truck is unloaded in the direction of the building. The gravel is thrown into the concrete mixer in the direction of the building. The concrete mixer pours the concrete into the wheelbarrow in the direction of the building. The wheelbarrow goes on to the hoist in the direction of the building, etc. (Fig. 7). In this way supply routes are shortened and work routes are prevented from crossing. Fig. 8 shows a bad example with a mode of operation in the wrong direction and long routes.

Every kind of plant necessitates different site planning. If the materials are transported by hoist, they all pass through the same point, *i.e.* the hoist. All the materials and the concrete-mixing plant must be arranged in a tight circle around the hoist (Fig. 9). If the

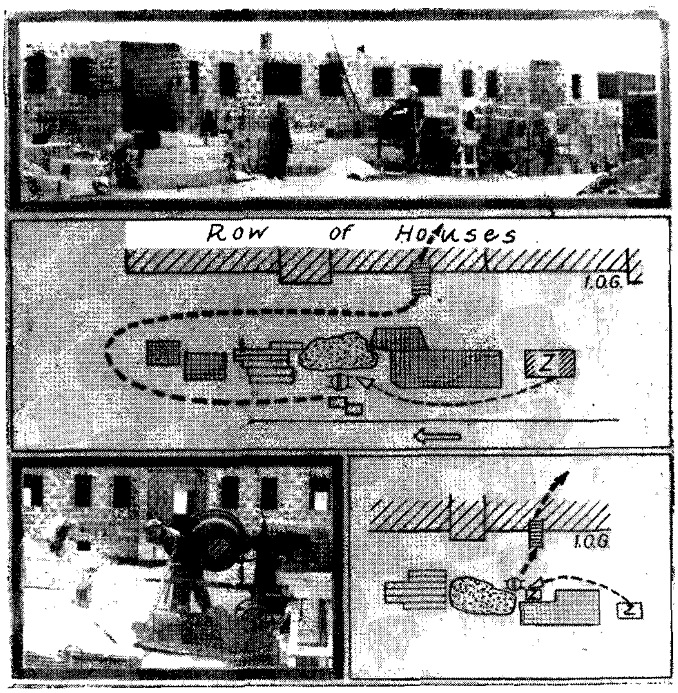

Fig. 8. Work on the site proceeding in different directions.

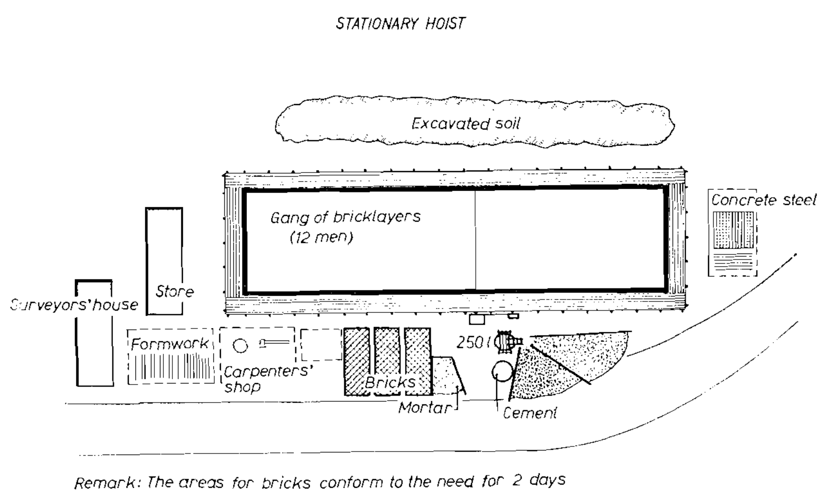

Fig. 9. Typical arrangement of a site provided with a stationary goods elevator.

materials are carried by a conveyor belt there must be a space near the house large enough to move the conveyor belt in easily. The materials must be stacked along this space (Fig. 10). But if the materials are transported by crane the rails must be laid along the long side of the building and in its immediate vicinity. On the opposite side to the rails the materials must be stacked and the concrete-mixing plant installed. Finally comes the road serving the site. The crane must be able to reach the building on one side and on the other the piles of material and also the road, in order to be able to unload trucks (Fig. 11).

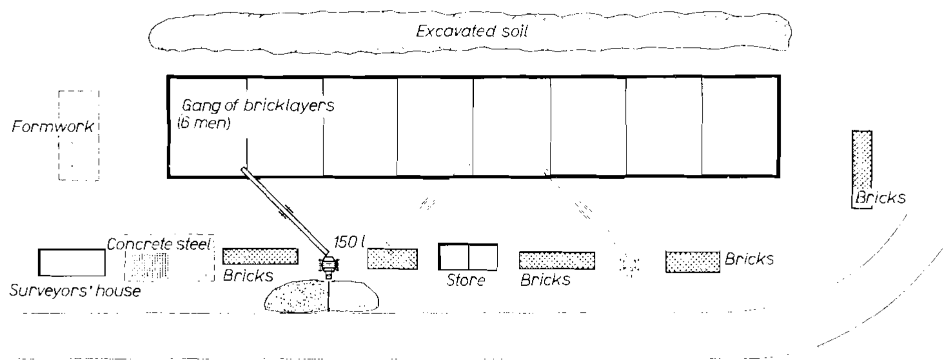

Fig. 10. Typical arrangement of a site provided with a conveyor belt.

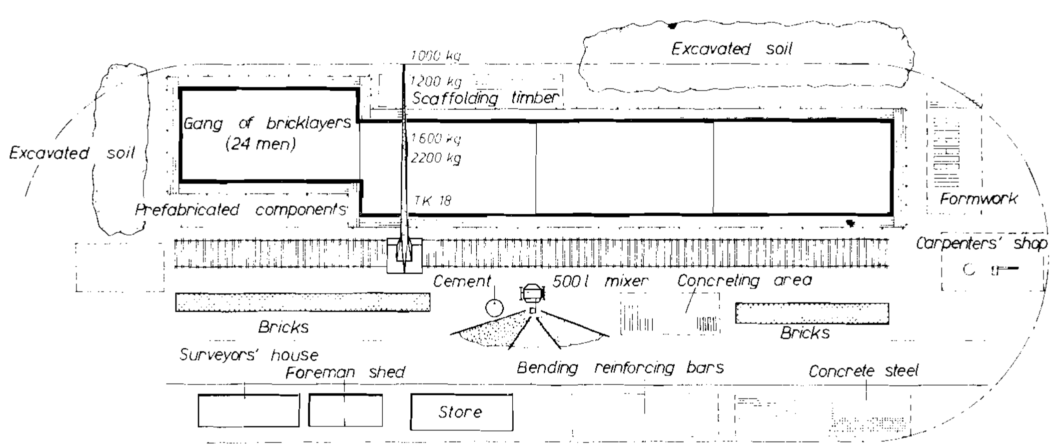

Fig. 11. Typical arrangement of a site provided with a crane.

The importance and the effect of rational selection of the equipment, of rational installation and of site organization may be illustrated by a practical example. During building on one of the experimental sites of the West German Ministry of Housing, two firms had to build in the same time the same row of 48 houses. The plans, the location and the building time were the same. Only the planning and organization of the concrete sites differed for the two firms. One used a crane, the other a crane and a concrete pump. In this way it increased the costs by the utilization of two expensive machines. One firm installed its crane in a favourable position, enabling all the necessary transportation. The other installed its crane unfavourably, and was obliged to fall back on additional means of transport. One firm transported certain materials, *e.g.* the elements for the ceilings, direct from the truck to the scaffolding. The other stacked them once again before use. One prefabricated certain elements – staircases, columns, etc. – at the site and assembled them afterwards. The other failed to do this. Whereas one worked in series, the other did not. The total working hours of one firm were 18,000. The other totalled 22,000 hours for the same amount of work; more than 20% longer. This is merely the result of a few minor measures of rationalization concerning the installation of the site and the organization of the work.

DOING THE SAME WORK IN SERIES

Finally, doing the same work in series is a means of building more rationally. By work in series we mean the repeated performance by the same team of workers of the same operations successively.

When a number of the same buildings have to be constructed on the same site, several or all the buildings are usually started at the same time. A team of workers is put on to each building. These teams work in practically the same fashion side by side with each other. But if the buildings are constructed in series only one team will be put to work in all cases, and this team will always do the same work in each of these buildings one after the other. For instance, the first team will go from building to building and will only lay the foundations. It will be followed by a team that will only build the walls of the cellar. The third team will make the floors one after the other in each house, etc. By means of these repetitions in series of the same work the working capacity will, as a rule, increase considerably. The extent to which this happens depends on the number of repetitions and is also determined by the form of the work.

Work in series has proved more successful for complicated operations than for elementary ones. It has more success with manual labour than with mechanical labour. For instance, the costs of constructing brick walls are reduced by 25% after the fifth wall. The costs of making reinforced concrete floors are even reduced by 45% after a fifth repetition. The effect is less for other jobs. Nevertheless, the total costs for rough construction work and finishing work have decreased by 17% after the eighth repetition and in another case by 20% after the twentieth repetition.

THE PRACTICAL SUCCESS OF RATIONALIZATION

To conclude, it may be best to illustrate by a practical example what the effect was of a number of measures aiming at economic construction on operating costs and the cost of new buildings, and the degree to which the buildings have actually been made less expensive by these measures. In 1952 the Housing Ministry had groups of 50 dwellings built in accordance with identical plans in ten different towns in the Federal Republic. The choice of the materials and the form that the construction was to take was left to the local authorities.

The table in Fig. 12 shows in the ten white columns the costs of construction of these ten groups. Although the plans were identical, the costs of construction are different. This was the result of the difference in materials used and in organization. Our institute followed the implementation of the projects very closely. The results were analysed and passed on to the participants in all the towns. Two years later, in 1954, the same groups of dwellings were built again in accordance with the same plans, using the same architects, firms and job superintendents. The experience gained in the first construction period was then applied. The ruled columns show that in most cases identical dwellings were built at less cost, with one exception – the second column from the left. In that case other circumstances prevailed. The greatest saving was achieved in the third example from the left, with nearly 30 per cent. The total of working hours differs from town to town. However, for rough construction the same number of working hours has already been achieved in all cases. It must therefore be presumed that in this respect a peak of rationalization has already been reached.

These few examples selected from among a large number of results of scrupulous research have clearly illustrated that both traditional construction procedures and non-traditional

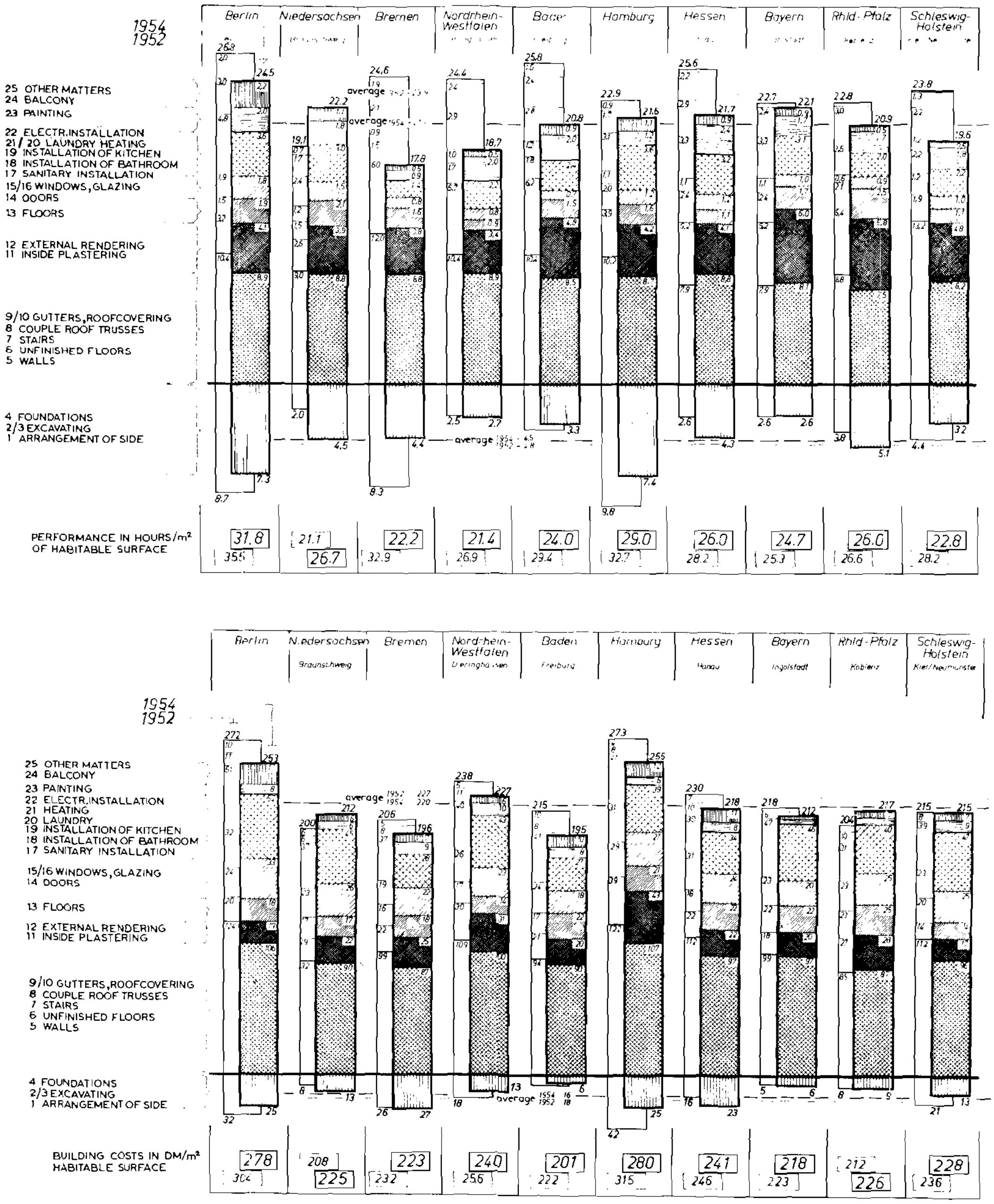

Fig. 12. White columns: operatives top and costs bottom for the construction of 10 groups of houses built in 1952 in ten towns in West Germany. Shaded columns: the same indications for 10 groups of similar houses built in the same towns in 1954 on the basis of the experience gained during the first execution.

techniques can be developed even more rationally. The examples have also shown the methods that have already proved themselves in this case and what results can be achieved in practice. Finally, the examples are intended to illustrate that endeavours to achieve rationalization and industrialization in building are definitely crowned with success and that we can continue confidently to follow the path that we have begun to take.

Report on industrialization

UDC 658.2/5 : 69(44)

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The purpose of this report is to examine, according to a scheme common to the three Russian, German and French reports, the French conception of the industrialization of building (which in France is confined to house building).

Industrialization in the sense in which it is used in this report means the endeavour to increase productivity by using the methods of other industries to bring productivity in building closer to productivity in these other industries. The three objectives that are hoped to be attained by this increase of productivity or industrialization are: the reduction of costs, the shortening of building time and the reduction of working hours devoted to the construction of a dwelling.

As regards price, in France (and we assume all over the world), the client is interested in a reduction. The person who does the building, the contractor, is equally interested, since such a reduction strengthens his position in the market *vis-à-vis* his competitors. This criterion of the reduction of costs is thus very important and doubtless the easiest to establish of the criteria of the improvement of productivity.

Shortening building time has only one inherent virtue, *viz.* that it reduces the length of time for which capital is tied up unproductively. It is, in fact, one of the elements of the cost of the transaction for the person who has the dwelling built. But when a construction job lasts longer than necessary, it is certain that this involves loss of working hours and waste of materials, and, on the whole, a higher cost. Cutting time to the minimum therefore means improving the cost; on the other hand, cutting the time in an absolute sense means reducing the unproductive period during which capital is tied up.

Reducing the labour force employed on the construction of a building is a consideration that should not be entertained separately; here again a distinction should be made between the elimination of lost or badly spent hours, which has, of course, to be attempted whatever the circumstances, and the replacement of man-hours by machine-hours and the consumption of energy. Whether this substitution will be possible depends on the general situation of a country's economy; in an underdeveloped country with a surplus of labour and a shortage of energy and plant, a saving will have to be made on the latter and not on labour.

In France it is labour that is scarce, and consequently the country has reached the stage where an attempt has to be made to economize on it to increase production.

On the other hand, labour is expensive and can only become proportionally dearer at the cost of energy and plant; as a result, it is necessary to economize on it to reduce costs.

Economizing on labour and replacing it by plant and energy does not mean reducing the total costs of this labour whilst retaining the same number of workers, *i.e.* replacing specialists by labourers. On the contrary, it means reducing the number of hours by calling in a small number of well-paid workers (well-paid because they will have benefited by part of the increase in productivity). It is in the interests of the country's economy to replace indifferently paid labour, *i.e.* poor consumers, as much as possible by better paid labour, *i.e.* good consumers. On the whole, the objective of reducing the number of hours devoted to a construction project is for the Government just as important an objective as that of cutting costs, and for the contractor it is also an important objective because he knows that it is a means for him to reduce his costs to an increasing extent in the course of time.

The scheme jointly adopted for these reports provides for the successive analysis of five major means of improving productivity or industrialization:

(1) prefabrication using large elements;
(2) organization of building sites;
(3) mechanization;
(4) increasing the output of labour;
(5) organization of the market.

We shall see that these five means have been employed in France, but that some of them have been especially utilized.

PREFABRICATION USING LARGE ELEMENTS

Prefabrication using large elements is a method of construction by which the contractor assembles on site elements manufactured in a factory, the length and height or the length and the breadth of these elements being at least equal to the dimensions of the rooms of the dwelling. It is what was at first called heavy prefabrication, not because weight was being sought after, but because the manufacturers wanted to show that they were not afraid of tackling the prefabrication of large elements, *i.e.* heavier than medium-sized or small elements. This expression "heavy prefabrication" caught on, perhaps because it was reminiscent of heavy industry, and it may have influenced the development of the processes.

The starting point for the supporters of heavy prefabrication was the idea that the fabrication of large elements in the works and the reduction of operations on the building site to simple assembly should lead to a great saving in labour and, more particularly, specialist labour, and in that way ought to reduce costs. Since the fabricated elements were made from solid concrete, which allowed them to be used as load-bearing elements and which also ensured heat insulation, these panels were in actual fact heavy panels, weighing several tons.

On the other hand, since the elements are made in moulds that have to allow baking in view of rapid withdrawal from the mould, and since the number of these expensive moulds is necessarily limited, the process is an inflexible one, *i.e.* changing the plan entails considerable expense and it is necessary to conceive of every type of dwelling having to form the subject of a series of several thousands.

Prefabrication using large, heavy elements has not revolutionized the building business. This is essentially the result of the following factors:

First of all the inflexibility, which many prospective owners and their architects have used as an argument for rejecting this process.

Then there is the fact that assembly on site has not proved quite as simple as was imagined: the problems of the tightness of the joints, aggravated by the size of the elements and the amount of water trickling, those of the precise adjustment of the elements and those involved in getting the height just right – all these present difficulties which can only be solved at the cost either of labour on site or of precautions supplementary to fabrication.

The installation of secondary fittings is not facilitated *ipso facto* by the use of large elements and in the first applications difficulties were encountered with this.

Finally, it has been realized that casting concrete in moulds was an operation that could certainly be rationalized in the factory, with the advantage of working under cover though at the cost of additional limitations bound up with transport, but that it could also be rationalized on site thanks to ingenious shuttering, to a well-organized site, and to the mechanization of handling, and experience has proved that, in fact, construction methods using concrete cast on site in wall moulds, especially concrete made from light aggregates and hollow concrete cast in open-work shuttering, cut labour requirements at least as much as heavy prefabrication in the works.

In short, the essential advantage of heavy prefabrication, of which the more traditional techniques have also been able to avail themselves, has been the rationalization of projects and the organization of sites, *i.e.* abolition of wastage of labour.

It appears today that if it is desired to revolutionize building by prefabrication using large elements and assembly techniques, other paths have to be followed – this is the trend that we are witnessing in France – than the reproduction in the factory of what can be done on site: we may mention first a new path which, although it is hardly more revolutionary than heavy concrete panels, offers certain specific advantages, *viz.* large panels on a terra cotta base. These panels have the advantage of being light (they weigh about one ton) and they are much more flexible to construct, for the moulds are much smaller. This technique is undergoing considerable development at present, particularly in the south of France, and we believe it to be the method of the future, without, as we have said, there being any hope of a revolution.

Another path to be followed is making load-bearing elements lighter than the usual panels from concrete, which remains the best inexpensive material. These elements not only have a load-bearing function but can also perform other functions, such as that of a multi-purpose shaft: rubbish chute, ventilation, chimney stack. These elements, which can hardly be envisaged as being made *in situ*, and which are therefore a typically "workshop" concrete technique, form the first step in a direction which offers interesting prospects, that of the integration of functions.

At a time when in the traditional techniques we see the separate trades successively doing the different jobs required to fulfil the various functions demanded of a dwelling, it would seem that a lot could be gained by devising elements which fulfil various functions and which are fabricated at one and the same time. We believe that it is this path that must be followed by prefabrication using large elements and assembly.

A technique at present being developed in France is that of the curtain wall. These are light elements constructed from wood, metal or plastics for the outside and from wood, metal, plaster or plastics for the inside, with a layer of insulation in between. These elements are, therefore, outside walls without a bearing function. It seems to us that these elements have a definite future in a new distribution and integration of functions; if great competition is still to be expected from the traditional wall, it is because this wall itself represents the integration of quite a large number of functions: it is a load-bearing element, resistant to shocks, it has a thermal mass and thermal insulation; it presents good insulation against noise.

The aim of prefabrication using large elements ought to be to regroup functions in a small number of large elements: floors, outside walls, load-bearing elements, which can be made in the factory and which merely have to be assembled on site.

In any case, since the technique of the assembly of large elements has made it necessary to organize work in such a way as to stop wastage of labour, but since this advantage has also been gained in normal construction on the site, the technique of large elements must today concentrate on finding new techniques which are more typically industrial and which make it possible to reduce labour not by putting a stop to wastage but as a consequence of the very nature of the product and of the way in which it is made.

ORGANIZATION OF BUILDING SITES

The necessity of organizing building sites so as to reduce losses of material and labour has long been recognized and in France, as elsewhere, this organization is rendered difficult by various circumstances: first of all, the professional practices of the various trades which have been slowly developing for centuries; then the fact that numerous trades participate successively or simultaneously in the construction of the same structure; and, finally, the fact that a building operation is always a unique operation that in any case will never be recommenced at the same place and which is hardly ever recommenced in identical fashion because site requirements, the necessities of the building programme or the whims of the architect or the builder change the substance and the very technique of the operation.

In the traditional conception of construction, the responsibility for organizing the site is divided between the architect, who has the task of coordinating the work of the various trades, and the contractor or contractors, who organize their own activities to perform that part of the work which is their task. Experience has shown that this solution is no longer sufficient, and new ones have been sought using different means.

One means is prefabrication which, by reducing all or part of the operations on site to simple assembly, facilitates organization of the site. Another means is to specify which of the participants in construction is responsible for the whole of coordination and organization. The most usual current practices are to call on the services of the general contractor, to appoint a pilot organization from among the various enterprises engaged in the project, to create a coordinating or advisory office among the enterprises, or to call in engineering offices and entrust to them this task of coordination, the engineering office being responsible to the contractors, the clerk of the works or the architect.

A final means of improving the organization of the sites is to extend the preliminary studies of the operation and the organization of the site: the lay-out of materials and installations should no longer be improvised, but studied fully in advance. The various job sites must also be studied in detail so as to get the maximum out of them. Plans have to be drawn up in such a way that they will be followed in two phases: general planning followed by detailed planning relating to each contractor.

It is beginning to be clearly realized nowadays that as soon as one is concerned with an important operation bringing into play enterprises that have at their disposal means of study, the organization of the site and planning cannot be envisaged without the participation of those enterprises. To put it another way, the enterprises must be associated with the working-out of part of the project, in particular everything concerning the organization of the site and planning.

This is the lesson of a large series of construction projects, known as "Secteur Industrialisé" (12000 dwellings a year since 1952), for which an extended study of the files was made by engineering research offices. Many of the difficulties would have been removed if these offices had been able to help with the perfecting of the project side by side with the contractors in charge of construction.

These efforts to improve the organization of building sites have led to very interesting results in France. However, since in general these organizational endeavours are associated with an attempt at mechanization and also an improvement of the design of structures, it is difficult to calculate the part played by them in improving productivity.

Nevertheless, it may be stated that on building sites using processes which do not include prefabrication, labour consumptions of less than 1200 hours are being achieved for a three-room dwelling of 50 useful square metres, and that it is probable that certain outstanding applications have reduced this figure to less than 1000 hours (*i.e.* 20 hours per useful square metre).

MECHANIZATION

Mechanizing a building operation means having machines do work formerly done by human labour. Since the stress has been put in France on the reduction of working hours consumed in building, the mechanization of building sites has been developed. First of all, it is the justification and the advantage of prefabrication that it enables the mechanization of operations performed manually in traditional processes. Moreover, prefabrication using large elements is inconceivable without mechanical handling equipment on site for the installation of the elements.

But traditional building has also been considerably mechanized. Of course, the making of concrete in concrete mixers is the rule, as is mechanical excavation: mechanical shovels and sometimes scrapers are used in the construction of large buildings, in which case the excavation work can hardly be distinguished from general earth-moving and road-building operations. The two important trends in recent years have been the development of central concrete-mixing plant and the general use on building sites of service cranes which are used to handle shuttering, to carry and to pour concrete, to install masonry and to carry pieces of woodwork and fittings to their place of installation.

Finally, mention should be made of small mechanical equipment, such as mechanical mortar boards, plugging guns and shovels for handling medium-sized quantities of aggregate.

As we have already stated in connection with the organization of sites, it is difficult to distinguish between the considerable gains in productivity obtained by this mechanization and those obtained by improving the organization of sites, with which mechanization is almost inevitably associated.

The development of this equipment renders necessary an exact study of the equipment suited to a particular site, so that an acceptable return may be obtained from what is chosen. It is mainly in this field that efforts should be made: care should be taken not to tie up powerful machines on minor tasks, and endeavours should be made to achieve a coefficient of utilization as close as possible to 1 for the various devices.

IMPROVING INDIVIDUAL OUTPUT

The improvement of the individual output of labour has not formed the subject of systematic study in France, and endeavours should definitely be made in this field. At present reference should be made to the studies on concrete work sites and the studies by the Tile and Brick Federation on the handling of bricks and on keeping the place where bricks are being laid supplied.

But, in the absence of theoretical studies, quite numerous experiments have been made in practice towards getting the workers interested in improving productivity. While this offers great prospects, it has to be handled with great caution, for the danger of abusing piecework is ever present. Excellent results have been obtained in some firms at the expense of special book-keeping and letting the workers have the whole of the gain accruing directly from the increased productivity, the firm contenting itself with the indirect gains resulting from deadlines being met and then building times being shortened.

ORGANIZATION OF THE MARKET

It has become more and more evident in France in recent years that the efforts to achieve industrialization and increase productivity in the building trade would be greatly facilitated and their efficacy considerably enhanced if far-reaching modifications were made to the structure of the construction market. This market is at present characterized by its extraordinary dispersion.

Every year tens of thousands of independent operations are conducted under new projects and often under new techniques for the purpose of constructing the bulk of some 300,000 dwellings built in France. This variety, the heritage of a past in which techniques and the economy were different from those today, is kept alive by the way in which prospective owners behave. When they give an architect a programme that is generally incomplete in its details, when the architect devises a new plan on the strength of this programme, when this new plan is put out to tender among contractors each of whom uses his own special technical processes, it is inevitable that the results are those arrived at in practice.

However, this means that when the client decides on a construction project and commissions his architect, he is engaging in the construction of something he does not know for a price of which he is not aware.

If the prospective owner could be persuaded preferably to commission the repetition of constructions already made, merely improving details, which means that he would be commissioning a known thing for a known price, these uncertainties would be solved and at the same time the building trade would be given a continuity that at present it is lacking. Now this lack of continuity means that the study of organization of building sites must be entirely written off against one single operation, and that consequently it is either expensive or done imperfectly, that labour which is constantly switching from one technical process to another does not attain the output made possible by repetition and the complete perfecting of a system, that the material which has to satisfy varied requirements resulting from plans and processes that are always different cannot be an absolutely suitable material, and, finally, that perpetual improvisation prevents the making of correct planning forecasts and consequently prevents the reduction of building time and the coordination of the various enterprises without loss of time.

It would, therefore, seem to be an essential objective of the improvement of building productivity and of the development of industrialization to ensure the continuity of plans and techniques, which can be achieved most easily by repetition. Failing complete repetition, or the reproduction of the same plan with the same technique of construction, technical continuity, *i.e.* the standardization of processes, will already offer some of the advantages quoted above.

It may appear strange to want to restrict the variety of processes, *i.e.* creativity, when the building trade is an industry which is often accused of being too attached to its traditions. It so happens that since 1945 innumerable technical processes have blossomed forth in France at the prompting of the civil services and also on account of the efforts of engineering research offices, which are naturally keen on offering new processes of their own, and because of a certain degree of competition between architects. This large number of processes has made great progress possible, and has led to the exploration of new fields, but the time has come to apply a certain selection and to concentrate efforts on improving and perfecting definite processes.

Research into new processes may no longer set itself the objective of equalling the results already obtained by different processes; it must attain results entirely superior to present results, which presupposes long-term research, working on processes not to be applied immediately but in several years' time or even in the next decade. Technical efforts should, therefore, be directed towards perfecting existing processes that deserve to be retained and long-term research into processes that will revolutionize productivity.

What is being done in France to change the conditions of the market and to create continuity? In 1953 design/construction competitions were initiated. These required the submission of a project drafted by a team of architects and engineers. This formula, which made it possible to organize the building site efficiently, the plan being adapted to the firm's means, was also the beginning of continuity, since the team of contractor and architect was not dissociated in successive applications.

At present efforts are being directed towards immediate privileges granted by the State to repetitive constructions, the chief of these being priority of financing given to such constructions. In order to allow the prospective owner to become sufficiently aware of the value of the constructions among which he has to choose the model to be repeated, a classification system is established for certain qualities of the dwellings: acoustical properties, cost of heating, quality of the appointments and the finish.

It is thought that this classification of the actual qualities of the dwellings and the privileges accorded to repetition ought to lead to a commercialization of the building market, the buyer, *i.e.* the prospective owner, ordering an object that he sees and whose qualities he has been able to evaluate and, furthermore, ordering this object at a fixed price in advance. It is also thought that this commercialization, by leading to good designs, will ensure that these designs are abundantly repeated, thus bringing continuity, and will discourage scattered experiments in favour of the pursuit and perfecting of the best techniques.

Subject 10

OPERATIONS RESEARCH

UDC 658.01 :311 : 69/72

REPORTS

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Operational research in building

UDC 658.01 : 69.001.5

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INTRODUCTION

Research into building topics on a national basis was commenced in the United Kingdom nearly 40 years ago when the Building Research Station was formed in 1921. In the early years the research work was primarily carried out in the laboratory and quickly spread over a fairly wide field; the study of the properties of materials led into the field of chemistry, crystallography and the general properties of porous bodies; the consideration of the functional requirements of building involved studying problems of heat, light and sound; while the structural side involved incursions into the fields of structural and civil engineering.

As the background information in these fields was collected, the Building Research Station partook more and more in helping the builder overcome his difficulties, and the relation between him and the Research Station became closer and closer. The result was that the work widened in scope and the laboratory work learnt to walk hand in hand with an increasing amount of field work. This was the position when the very considerable problems of the postwar period arrived. Since the end of the last war, investigations in heating, sound insulation, structural performance, soil mechanics and so on, have involved more and more field trials. In parallel with this development the research field was considerably widened to include the application of scientific methods to the study of the whole field of building operations; in other words, the application of what has now been termed "operational research" or "operations research" techniques to problems of design, construction and materials production within the building industry. It is this particular aspect of building research in Britain which will be discussed here.

Before reviewing the work which has been carried out over the last ten years, it may not be inappropriate first to consider what is usually meant by operational or operations research. These terms were first used during the last war when scientists were called upon to solve some of the problems which faced the executive side of the Armed Forces. The results were startling and since the war operational research has been applied to many peace-time problems. It has been defined in many ways but a commonly accepted definition is that it is the application of scientific method to the study of problems which normally face an executive authority. At the Building Research Station the aim has been to obtain factual data on the operations and processes involved in building in order to provide a reasonably sound basis for the necessary decisions for improving efficiency, increasing productivity and thereby reducing cost. This, of course, is at one with the primary aim of all the work of the Building Research Station: namely, to provide the building owner with a building which represents the optimum compromise between appearance, function and cost. To achieve this aim it is important to realise that decisions are made at national level by the top management of firms as well as by those who have to deal with the day-to-day problems of a particular building site.

In studying a wide variety of problems there can obviously be no unique method of approach and, because this is a relatively new field of research activity, reference is being made to the methods which have been adopted at the Building Operations Research Unit of the Building Research Station.

DISCIPLINES REQUIRED

By and large in this kind of research the laboratory is the building site and the design office. On many scientific problems a single discipline is used, say, chemistry, physics or mathematics, although, of course, possibly with different degrees of specialization.

In operations research the solution of any problem depends more upon a team involving a number of disciplines and it is thus not surprising to see the wide variety of professions which have been found necessary; namely, scientists (physicists, chemists, mathematicians and economists), members of the professions (architects, quantity surveyors, engineers) and builders. The team engaged on any particular problem is usually made up from different disciplines since few of the problems are amenable to solution by one discipline.

THE PATTERN OF RESEARCH

When discussing the pattern of operational research it is necessary to realize the conditions existing in a traditional industry such as building. It is an industry based on craft and consequently existing customs and methods tend to loom large in its thinking. The building industry has always been conservative and cautious of introducing changes. This is not unexpected when it is realized that its work is fully exposed to the vagaries of the climate. Again, in building, the product remains where it is produced and labour is mobile, production cannot be centralised, there is a very high turnover in labour, and thus a considerable number of variables not found in many industries are introduced. In addition to these peculiarities, the industry has to deal with a wide variety of work, ranging from large constructional projects to small maintenance items.

Such circumstances must, of necessity, give difficulties in bringing problems to the surface and the operational research worker must be prepared to assist in isolating problems and defining them clearly in terms of building practice. This may involve him in extended studies on building sites or within building firms or organizations for which he has to obtain the wholehearted support of those working in the industry. In fact, to obtain the right data, the research man has to understand the ways of the industry, know its general outlook and realise the day-to-day difficulties which have to be overcome when transforming drawings into actual buildings.

Once the problem has been clearly defined, the research then follows a fairly standard pattern. A solution which would apply under the conditions prevailing is sought. This usually entails the analysis of data which are subject to considerable variations from firm to firm and from site to site. However, even when a seemingly satisfactory solution has been found, the third step in the research may be to develop the tools to enable the industry to apply it in practice. When this has to be done with plant it is best carried out in conjunction with a progressive manufacturer.

When this hurdle has been successfully negotiated the next phase is to demonstrate to the industry that the solution is a beneficial one. The builder's product has to stand the test of time in the open and under the watchful eye of all future clients.

It is not surprising, therefore, to find that builders are conservative and will not readily accept anything new without adequate proof that it will be successful. It is, therefore, advisable to test the solution in the field under the same conditions as the builder has to work. This phase can have quite a salutary effect on the research.

The final stage, following the successful demonstration of the solution, is to ensure that all the information is presented to the industry in a suitably digested form. This is most important and the goal must always be to present the results so that each builder or building organization can determine for himself or itself the benefits which can be derived from this application. This is not an easy task in an industry which consists of a multiplicity of firms of varying size and in which there is a dearth of men trained in analytical methods.

The way the above pattern of research has been applied in Great Britain may best be illustrated by discussing some examples of the investigations which have been and are being carried out at the Building Research Station.

PRODUCTIVITY

One of the early investigations which has formed the background to much subsequent work was the study of productivity in the house-building industry. This was done as a survey of the performance of about 170 firms and the aim was not only to obtain information on the general level of labour productivity, but also to determine the causes of the variation known to exist between one firm and another. Data were extracted from the records of each firm on the labour expenditure per house (in man-hours) for each trade, such as bricklayer, plasterer, etc. A specification of the houses built was also obtained.

The data collected were, of course, extensive and required the use of punched card machines for analysis. A notable feature was the wide range in performance from one firm to another, the worst firms taking three times as many man-hours to build a house as the best. To obtain information on the possible causes of this variation, the data were subjected to analysis using normal statistical techniques and it was possible to show the effect of such things as incentive schemes, the use of subcontracting or the size of the contract on productivity.

Not only did this survey provide specific information on such matters, but it also demonstrated the importance of inherent variations of productivity in any comparisons which may be made between one form of construction and another. Thus, in the survey the coefficient of variation for a particular trade between firms was 22 per cent and for different sites operated by the same firm it was 10 per cent. Even between different houses on the same site there was a variance of 5 per cent. Clearly these figures set limits to the detail with which site comparisons can be made and emphasize the importance whenever possible of making comparisons between methods on the same site.

MANAGEMENT PROBLEMS

The productivity survey showed, *inter alia*, the important part incentive schemes can play, since projects which had an incentive scheme were, on an average, 15 per cent above the mean in productivity. Such a survey could not, however, identify the features of a well run scheme. A case study was, therefore, made of 25 firms who were known to be operating effective incentive schemes. The nature of the scheme, its application in practice and the problems involved in its use were studied by interviews lasting about a week and covering most branches of the firms' activities. From this it was possible to determine the characteristic features which were required for the successful operation of an incentive scheme. At the same time the work showed the important part that the incentive scheme can play in the general organization of the firm, since it can provide a link which is often lacking between the departments concerned with site production and those involved in estimating for the purposes of tendering.

Another important aspect of studies in the management field arose originally during our investigations into the mechanization of certain building operations. It soon became apparent that success depended largely on the proper organization of the whole of the work on the site. Techniques were therefore developed for the programming of building work and these were applied not only in connection with mechanization but more generally over a wide range of building work. These investigations involved the preparation, in collaboration with the individual contractor, of a programme for the work; a study of how far it was practicable to keep within the limits set by the programme and, by comparison with the performance of earlier work by the same contractor, assessing the effect of a programme on productivity. Reductions of labour expenditure of 10 to 15 per cent consequent on the introduction of programmes was not unusual.

The subject of site organization was being studied when the European Productivity Agency asked the Building Research Station to undertake a survey of the organization of building sites in Europe. This study, which has now been completed, involved an officer from the Station visiting nine countries in Europe and having discussions lasting several days both on site and at head office with 23 firms. The report, which has now been published, provides a comprehensive review of the whole of the activities involved in site operations and the related head office functions.

MECHANIZATION

In the study of mechanization it is necessary, on the one hand, to study equipment from the point of view of its mechanical performance and its ability to operate satisfactorily under normal site conditions, while, on the other hand, there is its effect on the whole of the site process into which it is introduced. The Station's work has, therefore, been characterized first by its study of the particular building operation involved, in order to assess the possibilities of introducing mechanization. This is followed by a search for suitable machines which may involve a period of development of plant and also of ancillary equipment for use with it. Finally the plant is used under normal site conditions and its effect on the building work assessed.

In this way it is possible not only to demonstrate the economic advantages which can arise from the introduction of mechanical plant but also the organizational requirements necessary to obtain the fullest advantage. Because the Station has often been concerned itself with the development of the mechanical equipment, it is in a position to assist both the builder and the designer of mechanical plant for the industry. The introduction both of powered barrows and of the tower crane from Europe into the British building industry is a direct consequence of the Station's pioneering work.

Bricks and blocks may be handled five or six times from leaving the works to being placed in position and a technique has been developed for reducing and simplifying this handling. Basically it involves the use of a steel band to produce a pack of 50 bricks which can be handled as a unit. The Station has developed a range of equipment for handling such packs on the site either by crane or barrow while simultaneously studying the problems of producing the packs at the brickworks. Site trials have shown the advantages of such packed bricks, particularly on restricted sites in the middle of cities, where they facilitate handling direct from the lorry by crane to the position at which they are to be built in. The use of packed bricks is now growing fairly rapidly and about a million a week are being delivered to sites.

Concrete forms an important building material in most countries and the production problems involved in its use have been engaging increasing attention recently.

The use of ready-mixed concrete is growing rapidly in Great Britain and the Station has investigated, both on site and at the concrete plant, the problems involved in its use and the circumstances necessary for its most advantageous employment. It is now clear that the straightforward substitution of ready-mixed for site-mixed concrete, without due consideration of the implications of the newer method, does not take full advantage of it. The effect of the design of formwork and of the mix-design itself on the cost of placing concrete is also being considered.

The widespread interest in mechanization in the industry has revealed the need for comparative data on the true costs of different types of plant. This needed to cover not only the first cost of the plant but its maintenance and replacement costs, the use that can be expected of it and the output which can be obtained when in use. This problem requires for its solution data on a wide range of plant under diverse conditions of use and clearly cannot be obtained from the records of an individual contractor. A survey of a considerable number of contractors operating large plant pools was, therefore, made and, from the information obtained, a basis has been provided for the economic assessment of the value of mechanical plant in any particular set of circumstances.

DESIGN ECONOMICS

Although initially the research into building efficiency and costs was primarily concerned with site operations, increasing attention has been given to the contribution which designers can make to building economy.

An early investigation on the design side was concerned with the question of maintenance costs of housing. Decisions on alternative methods of construction are often taken on first costs alone and the consequences over the life of the building are ignored. Clearly this is unsatisfactory and information was therefore sought on the maintenance costs of housing in relation to particular design features. An approach was made to many Local Authorities and a considerable volume of data was obtained. This showed that the capitalized value of the maintenance costs was equivalent to about a quarter of the capital cost, but it was made up of a large number of relatively small items. In fact, external painting was the only substantial item in which it appeared that greater expenditure in the first instance would be justified if thereby the recurrent need for painting could be reduced or eliminated. Unfortunately, the houses did not differ sufficiently in design to obtain decisive information of the interplay of design and maintenance costs. Because of this limitation further information is now being collected both on a variety of non-traditional housing for which data were not available at the time of the earlier survey, and also on other types of building. Because few building owners record their maintenance expenditure in a form suitable for analysis, arrangements are being made with a number of authorities for them to keep special records of groups of buildings of similar design. This will be done over a period of two or three years. In this way it is hoped ultimately to provide comparative data on both the capital and the maintenance costs of a variety of forms of construction.

A separation between design and production is imposed by the structure of the building industry but in operational research it becomes vital to avoid separating these two aspects and to view the problem as a whole. This is well illustrated by the work being done in connection with the economics of multi-storey flats. In Great Britain the price of accommodation in multi-storey blocks of flats, say, 10 storeys high, is 70 or 80 per cent. greater than that of equivalent accommodation in two-storey housing. In view of the current widespread concern with the redevelopment of the central areas of cities, when high blocks are often required to achieve the necessary housing densities, this difference in cost is clearly of considerable importance.

Initially a survey was made of the costs of more than 70 blocks of flats more than five storeys in height in different parts of the country. The priced bills of quantities which are prepared for tendering purposes in Great Britain were broken down to give the costs not only of the building as a whole, but also the individual components, walls, floors, heating, lighting, etc. These showed that there was a very wide range in the cost of items performing similar functions. By the study of the price variations of the individual components it was possible to suggest targets for each which could be achieved without the need of new methods or new designs, so that prices could be reduced on average by around 20 per cent.

Complementary to this work data have been collected during construction on 20 blocks of flats of different structural designs. Observation on the expenditure on labour, material and plant for each operation was made over a period of several months in each case. The amount of data obtained is necessarily extensive but its analysis should provide a sound basis for suggesting ways in which the present high costs of multi-storey flats can be further reduced. At the same time it provides useful examples of how comparatively trivial design details can interfere with the smooth flow of site production and so increase costs.

The costs of the flats themselves are, of course, only a part of the costs of new housing developments. There are, in addition, the costs of roads, services, public buildings and all the necessary amenities of a housing area. Many cities in Great Britain are faced with serious redevelopment problems in their central areas and with the consequent difficulties of "overspill" of surplus population to new housing estates on the periphery of the town or in new towns. The choice between alternative solutions involves many factors which cannot be expressed in terms of money, but the provision of a clear statement of the various economic factors can be of considerable assistance to the planners who face these difficult decisions. The Building Research Station has therefore collected from many sources information on the costs of the whole complex of urban facilities and has been able to give an indication of the relative importance of the many economic factors which need to be taken into account.

NEW METHODS OF CONSTRUCTION

The traditional methods of building have been to bring the raw materials onto the site and there fashion the different parts and put them into position. Although over the years there has been a definite trend to bring to the site more and more of the units in a finished state, even today housebuilding is, on the whole, in Britain, the assembly on site of a large number of small components. It would appear to be common sense to endeavour to remove a large proportion of the site work to the more congenial environment of the factory, and after both world wars there was, in Great Britain, considerable development of new methods of construction, some of which incorporated a high degree of factory fabrication. As circumstances have become more normal, however, the new methods have been unable to compete with the traditional and thus only a small number of the new designs have survived.

There is a dearth of reliable data on the relative economics of factory and site production, and to fill this gap in our knowledge and to obtain a better understanding of the direction in which factory-made components must develop if they are to be more widely employed, a large production experiment was carried out. This involved the design by the Building Research Station of four house types of the same plan but incorporating a wide range of factory-made components ranging from those which are now normally used in traditional building, such as door frames, windows, etc., up to highly prefabricated systems.

In all, more than 400 houses were built in collaboration with five local authorities in different parts of the country. Detailed observation was made over the whole period of construction by observers stationed on each site for the duration of each of the contracts.

There is a consistent pattern in the results. In general, the savings in site labour resulting from the use of factory-made components are generally insufficient to offset their higher material costs compared with those of the traditional items which they replace.

This is particularly so where the introduction of factory-made components leaves discontinuous items of traditional work which require a disproportionate amount of labour to execute on the site. Successful development in the future must be based on the complete substitution of the traditional by the factory-made component and, in its use, to simplify or eliminate rather than complicate building operations.

This conception of simplification of the building operation has stimulated interest in the type of large-panel construction which has been used recently in both France and Sweden and which is now being used on an increasing scale in Czechoslovakia and the Soviet Union. The work involves a dual approach; on the one hand, there is the study of the technical problems of producing these large units and of providing joints which are structurally adequate and weatherproof under the conditions prevailing in Britain; on the other hand, there is the economic assessment of the possibilities of this radical departure from building methods which involves studying the factory processes involved in the manufacture of the panels, their transport and site erection.

In this brief review it will have become clear that a variety of techniques has been found necessary in this work. There are the large-scale surveys yielding mass data which are analysed by normal statistical techniques; case studies requiring interviews often over a period of several days; observation of work on sites; and the engineering development of new plant and methods. In fact, it is characteristic of this type of work that the method is subservient to the problem; often the problem itself creates a requirement for the development of entirely new methods. For instance, the study of site operations over protracted periods on a scale which is required in order to obtain valid results would require a team of observers which would be prohibitively large unless suitable methods could be found.

The same problem has been faced in other industries, and techniques such as work sampling have been developed. By this method, instead of making a continuous observation of a particular worker or machine, observations are made only at intervals. In this way one observer can cover a number of workers or machines. In the manufacturing industry, however, the processes repeat at short intervals and such work sampling has usually been carried out with an interval of a few minutes between one observation and the next. In building, however, the processes repeat only after intervals of several days or often weeks and it seemed possible therefore that work sampling at relatively infrequent intervals, say every two hours, would be capable of yielding data of sufficient accuracy for many purposes.

The implications of this technique have been fully studied and it has been successfully applied, notably on the large production experiment into alternative forms of house construction.

Although any final decision on the merits of different forms of construction can validly only be decided on the basis of full-scale trials under normal site conditions, there are severe limitations to the method and there is a need in the development stages of a new material or form of construction for a means of assessing the position more quickly. While, obviously, production studies on a small scale are not capable of reflecting completely all the diverse situations which arise on actual building sites, they are capable of providing valuable pointers during development.

A particular example of a technique which seems to meet the requirements is provided by the current study of the production implications of a new design of perforated clay block which the Building Research Station is developing. This block replaces the traditional wall of brick-cavity clinker block by a wall which is laid in one operation. The technique which has been adopted for the production trials is to build "test walls" which involve only about a tenth of the labour involved in the erection of a normal house but at the same time incorporate all the essential features, namely, returns, doors and window openings, air bricks, etc., which interrupt the steady sequence of straight walling. Such trials as have already been carried out indicate that this method correlates well with the full scale and enables the production consequences of comparatively small changes in the design of the block to be studied quickly. They have the further advantage that, because of their size, the test walls can be erected under cover.

The more formal techniques of operational research, such as inventory control, linear programming, queue theory or simulation, have so far found little application in the building field. However, it seems likely that their success in other industries might be repeated in building. A particular field which looks fruitful from this point of view is programming. While the basic principles of programming can be laid down empirically, it is difficult, in practice, to compare with sufficient accuracy the relative merits of alternative methods or to decide, for example, on the best way of dealing with the inevitable interruptions to the work which occur in building sites. Consideration of the building operation in the light of queue theory has already been started and it seems likely that, while the mathematical development of the "loop queues" which are involved would be formidable, it is possible to get important results from the application of this model under certain simplifying assumptions. Indeed, such work as has already been carried out suggests that the conception of balanced gangs which has been inherent hitherto in the empirical approach to programming may lead to far from optimum solutions on small sites.

Because of the difficulties of the mathematics of loop queues, it seems likely that the technique of simulation may be useful in studying programming. A model of the system is made either on paper or physically into which a series of typical values of the input variables are inserted and the effect on the system as a whole is observed. This technique has a very wide application in many fields of science and, indeed, has been claimed to be the central technique of operational research. By this method it is possible to study such problems as the effect of variability in work cycles on the time taken to complete the work and to develop appropriate rules for the time interval which might be left between the completion of one operation and the start of another, to minimize interference between gangs. This work is still in its early stages, but the method which is being developed using Hollerith cards to represent the "model" seems promising.

The purpose of operational research and, indeed, of any applied research is not the provision of a research report but the stimulation of change in the industry. It is generally recognised that the period between obtaining the knowledge of an innovation by a research organisation or one of the more progressive firms in the industry and its adoption in general, is long. There are many reasons which contribute to this and a start is now being made to gain a better understanding of some of them. As a preliminary to this, a survey is being made of the ways in which information reaches the contracting side of the industry. A pilot sample survey has been carried out of about 30 firms and information has been obtained on the technical information which is received at different levels in the firm through articles in technical journals, broadcasts, exhibitions, lectures, etc. This type of information is clearly of importance not only from the point of view of the general study of the introduction of new methods but also from that of the immediate aim of presenting the results of research so that they reach those able to apply it in a readily acceptable form.

CONCLUSION

In this brief review it has only been possible to indicate broadly the lines along which research into building operations has developed in Britain during the last decade. The field is wide, both from the point of view of subject matter and techniques of study, but it is clear from the experience gained so far that operational studies can yield information of immediate practical value to all branches of the industry and they have now established a definite and continuing position within the general field of building research.

Operational research: "decisionics" in building

UDC 658.01 : 311 : 69/72

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BUILDING, A PLAY OF MANY DECISIONS

Building is a play of many acts in which decisions are to be taken repeatedly to determine to a greater or lesser extent the usefulness of the future building in question. If sufficient capital is available, it boils down to taking the decisions in such a way that the all-in costs of the building in operation will be kept down to a minimum. These costs are adversely affected both by too high and by too low an investment.

Although any individual building will be affected by good and bad decisions taken in the phases of development planning and physical planning for the town or region in question, the present paper will deal only with the problems associated with the planning and construction of the individual building. Here we can distinguish among four phases:

(1) The phase of initial decisions on the question of whether or not the building will be constructed, on its location, capacity, etc. (basic decisions).

(2) The planning phase, in which, in the light of the primary decisions, a detailed programme of requirements is drawn up which the building should meet in order to perform its functions to an optimum degree (functional decisions).

(3) The design phase, in which the decisions made by the designer are laid down in drawings and specifications to suit the programme of requirements (design decisions).

(4) The construction phase, in which the building is constructed according to the design and specifications (production decisions).

As more and more decisions are taken, freedom is restricted so that, on the one hand, the extent of possible errors decreases (most errors have been made already or good decisions have been taken) and, on the other hand, the possibilities of favourably affecting the final result are reduced.

The running of a hotel whose number of beds is twice as high as the optimum number cannot be materially affected by means of appropriate detailed architectural design. A contractor works, in one sense, on a lost cause, however efficient his organization on the building site may be, if serious errors have been made in selecting the location. Fig. 1 gives an estimate of percentages of errors that might be made within each of the four groups of decisions.

In the group of basic decisions, the decision not to build at all leads to an investment zero, whereas, for instance, the selection of the wrong capacity may easily result in twice the optimum investment (200%).

In the group of functional decisions the percentage ranges approximately between 50 and 150, subject to the programme quality.

In designing, a variation between 75 and 125 per cent. may be assumed, depending on the design quality, whilst in the production group this figure ranges between 90 and 110 (the optimum investment being set at 100% for each group). When the decision to undertake the construction has been made, a superimposition of errors may result in an investment 3 to 4 times as high as, or only half, the optimum amount.

Correct decisions in any phase, which often are interdependent, will have to be backed by a combination of intuition and calculation. Errors made in one phase may sometimes be retrieved by proper decisions in another phase, but one has, of course, to strive at taking good decisions in every phase of planning and construction. The interdependence of the many acts should be considered under all circumstances.

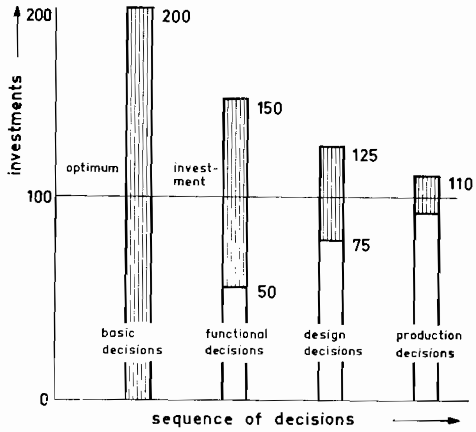

Fig. 1. Estimation of percentage of errors possible within the four groups of decisions.

OPERATIONAL[1] RESEARCH = "DECISIONICS"

The long life of a building, the high capital investment involved and the great influence it exerts on society are all factors that call for systematically putting into practice the proverb "look before you leap". This not only applies to building construction, but to numerous other aspects of society. In general, the consequences of the decisions made are becoming increasingly important, since our society is becoming more and more complex with steadily expanding institutions of growing interdependence, and since everything is subject to fast changes. The responsibility of the managers of these organizations is becoming heavier because they more frequently have to take decisions on problems of such an intricate nature that the consequences of a given solution are almost immeasurable and an intuitive approach to find the optimum solution has become almost impossible.

A typical example of such a problem is that with which the staff of the British Forces was faced in the historic Battle of Britain in 1940. In what way had the comparatively poor means of defence (consisting of a number of aircraft and pilots backed by detection and communication facilities) to be deployed against the superior German assault so as to ensure the greatest possible effect? It was realized that the experience and intuition of the great strategists and tacticians could not provide the proper solution to such a complex problem which was so vital to the fate of the world. Therefore the cooperation of a number of scientists from non-military circles was called in, who solved this problem by purely scientific means and who were so successful that an official team was created with a view to making studies of other similar problems. Since in this case research on military operations was involved, it was called "Operational Research".

During World War II many other "Operational Research" problems were successfully solved, such as:

How should a ship navigate to run the least possible risk of being hit by an enemy aircraft?

How many ships should be combined within a convoy?

After the war, many O.R. workers in England returned to civil jobs where they applied the methods to the solution of industrial and transport problems. American industry has

[1] The term most frequently used in Great Britain is Operational Research, in the U.S. Operations Research.

followed the British example only since 1952, and in recent years West European industry has also begun to use operational research, although on a limited scale.

Operational research, therefore, is a comparatively new line and no agreement has yet been achieved on a waterproof definition. The definition suggested by A. W. Ross might be given as a typical example: "Operations research is the scientific study of the problems of an organization to provide by an objective and preferably quantitative analysis, clear-cut recommendations as to policy".

Instead of making an attempt at giving an exact definition we prefer to summarize a number of characteristic features of operational research:

(a) On the nature of the problem: as a rule it has to deal with fairly complex systems in which human beings, materials and equipment are involved; the performance of the system depends on a large number of factors, which often counteract each other; the pattern of performance cannot be immediately viewed.

(b) On the research method: after the essential variables have been selected, the necessary observations must be made; in the subsequent quantitative analysis, probability theory often plays an important part.

(c) It is the object of O.R. to attain with the available means maximum efficiency by making optimum usage of these means. The manager should decide what is to be understood by "efficiency" in a particular situation.

When the investigation is completed, the O.R. worker should provide sufficient quantitative insight into the performance pattern of the system to enable the manager to take a decision.

In view of the nature of the work, the term "decisionics" has become popular, because it concerns a scientific method of providing data for decision making. Since these data cost time and money this method can be employed only where important problems are concerned, which is often the case with building construction.

We shall now give some examples to illustrate how decisionics may be applied in building construction.

SOME APPLICATIONS OF DECISIONICS IN BUILDING CONSTRUCTION

THE CAPACITY OF A MORTUARY

In a hospital the number of patients that die per day is not constant but is governed by statistical laws. By making the number of cooling cells greater than would on the average be required, the risk of an incidental shortage can be reduced to an acceptable minimum. For calculating the number of cooling cells required, the following data were collected:

average rate of occupation, b (90 per cent.);
mortality rate of the number of patients received s (3.5 per cent.);
average nursing time v (20.75 days).

Since the number of deaths in the hospital in question did not show any seasonal pattern, it was assumed that this number is generally spread over the year in a statistical way (*i.e.* possible epidemics, catastrophes, etc., have not been taken into account). In all cases the corpses should be cooled for 48 hours.

Calculation

It proved that the number of deaths per day varied according to Poisson's law, so that the chance of x patients dying on a given day could be calculated from the formula

$$p_x = e^{-\mu} \cdot \frac{\mu^x}{x!}$$

where the parameter μ represents the number of deaths per day.

$$\mu = \frac{sb}{v} \cdot B = \frac{1}{659} \cdot B$$

where B = total number of beds.

The results of this calculation are shown in Fig. 2, where the required number of cooling cells is plotted against the number of beds. The graph provided the management with the quantitative insight required to arrive at the proper decision; intuition had to make out what chance of shortage could be tolerated.

This graph applies to hospitals with a mortality rate (s) of 3.5, an average nursing time (v) of 20.75 days and a rate of occupation (b) of 90 per cent. If we want to use the same graph for other situations, a reading should be taken at a number of beds B', where

$$B' = 659 \cdot \frac{s'b'}{v'} \cdot B$$

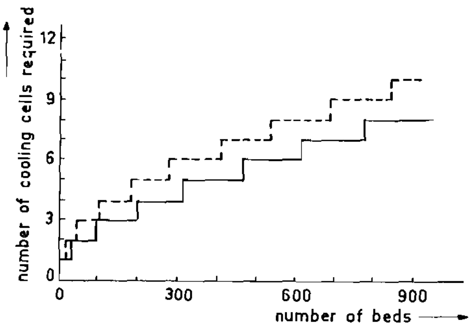

Fig. 2. Required number of mortuary cooling cells for various numbers of hospital beds. ——— shortage occurring on the average once a year, - - - - - - shortage occurring on the average once in ten years.

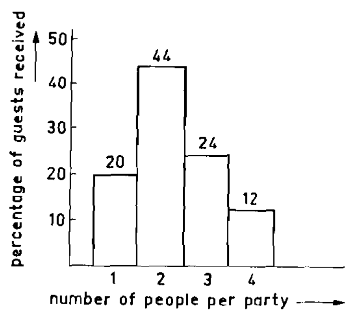

Fig. 3. Distribution of guests over parties of various numbers in a restaurant.

SAVING SPACE BY BETTER ARRANGEMENT

A restaurant is to be planned in which 100 people can have dinner simultaneously when all tables are engaged, no strangers having to be placed at the same table. When making studies in a similar restaurant, it was found that a distribution of the guests over parties of different numbers could be expected as shown on Fig. 3. In the light of this expected build-up of the public, the following two solutions were considered:

(a) Hall furnished with four-person tables (53 tables required);

(b) Hall furnished with four- and two-person tables (42 two-person and 11 four-person tables required).

Furthermore, the following data were known: a four-person table takes a floor area of 4.50 square metres and costs, inclusive of chairs, Dfl. 100 + 4 × Dfl. 50 = Dfl. 300; a two-person table takes 3.00 square metres of floor area and costs Dfl. 80 + 2 × Dfl. 50 = Dfl. 180.

The yearly costs of the furnished hall are set at Dfl. 60 per square metre of floor area plus 10 per cent. of the purchase price of the furniture.

Calculation gives:

Utilisation of space	*Costs of space per annum at Dfl. 60/sq.m. (in Dfl.)*	*Furniture costs per annum at 10% depreciation (in Dfl.)*
(a) 53 × 4.50 m² = 238.5 m²	14,310	1590
(b) 42 × 3.00 m² + 11 × 4.50 m² = 175.5 m²	10,530	1086

Hence, for a combination of 11 four-person tables and 42 two-person tables the total cost per annum will be about Dfl. 4300 lower than in the case of four-person tables only (which is frequently put into practice). This means a saving of 30 per cent. on these yearly recurring costs by saving more that 25 per cent. on space and more than 30 per cent. on furniture.

THE RIGHT COMBINATION TURNS TO ADVANTAGE

Someone wants to build a hotel consisting of a bedroom section with 100 beds and a restaurant section which will be run separately.

A market analysis shows the expected average demand for single and double rooms during the different months of the year. The results of this analysis are plotted on Fig. 4.

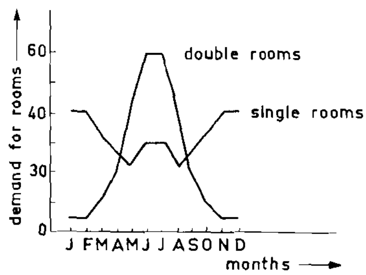

Fig. 4. Expected demand for single and double rooms in a hotel during one year.

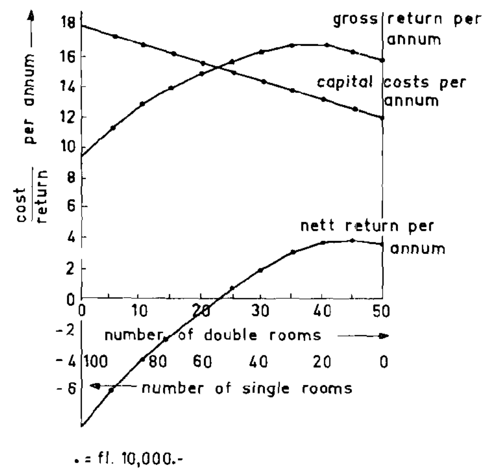

Fig. 5. Choice of the most profitable combination of single and double rooms in a hotel.

From a calculation of building costs for the bedroom section it follows that these will amount to Dfl. 15,000 for a single room and Dfl. 20,000 for a double room, equipment and furniture included.

To cover the sole investment costs, the returns should amount to 12 per cent. of the capital invested. The market analysis also showed that an average rate of occupation of 70 per cent. may be expected.

Next an estimate of the running costs per room was drawn up, which showed that from the lodging prices to be charged, the following amounts would be left to cover the investment costs:

Dfl. 8 per single room occupied,

Dfl. 12 per double room occupied,

Dfl. 7 per double room if used by one person only (who in this case would pay for a single room).

The problem is how to select a combination of single and double rooms (totalling 100 beds) for which the profit will be maximum.

The calculation of the various combinations considered feasible are shown in Fig. 5. From the calculation it is found that there are three combinations, *i.e.* 50 double rooms and no single rooms, 45 double rooms and 10 single rooms, or 40 double rooms and 20 single rooms, which yield approximately the same nett return per annum, *viz.* Dfl. 39,000, Dfl. 40,500 and Dfl. 39,000, respectively.

However, no account has been taken so far of a possible "discomfort" for a person being lodged alone in a double room. In view of this, the solution of 50 double rooms is definitely to be abandoned in favour of 45 double rooms and 10 single rooms, because the former not only yields Dfl. 1500 less annually but also involves 2700 additional "discomfort cases" yearly.

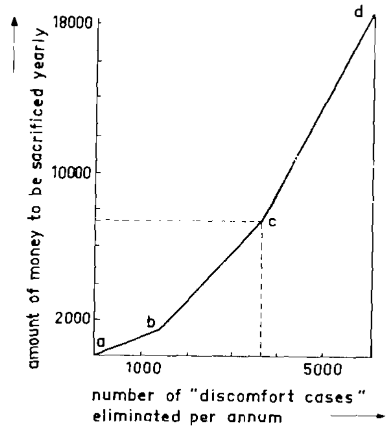

Fig. 6. Amounts of money to be spent on reducing the number of "discomfort cases" in a hotel, *i.e.* cases of one person being lodged in a double room. Combinations of double to single rooms are: (a) 45 to 10, (b) 40 to 20, (c) 35 to 30, and (d) 30 to 40.

In Fig. 6 the amount of money is plotted which has to be sacrificed yearly to eliminate partially or completely all discomfort per annum. The definite choice between solutions a, b, c or d must be made on the basis of intuition, in which an appreciation of the individual client plays an important part. If, for instance, solution c (35 double rooms and 30 single rooms) were chosen, this would mean that the manager in the end is willing to sacrifice approx. Dfl. 7500 per annum in order to eliminate approx. 3750 discomfort cases, or

$\frac{7500}{3750}$ = Dfl. 2 for each discomfort case.

COLLECTIVE MEASURES ARE NOT ALWAYS ECONOMICALLY JUSTIFIED

In many countries it is either prohibited by law to use unlined steel structures in multi-storey construction or their use is limited by certain regulations. Actually, in the opinion of experts, such structures are much sooner destroyed by fire than when they are covered with concrete.

It is not certain, however, whether such prohibitive measures are economically justified, provided that a change in the relevant regulations would not entail greater risks to human life in case of fire.

The following method may be used to calculate whether it is economically justified to line a given steel structure in order to reduce fire hazard:

p = probability per year of the occurrence of a fire with the bearing walls reaching the critical temperature,
B = construction cost of the building without lining,
I = value of inventory,
R = costs incurred by loss on operations when the building is entirely destroyed,
dB = increase in building costs due to lining,
a = proportion of total value ($B + I + R + dB$) lost in case of fire in a building with lined steel structure,
a = 1, for a building with unlined steel structure (total loss when bearing walls reach critical temperature).

For both cases the expected yearly damage as a result of fire can be calculated, *viz.*

$$E_1 = p(B + I + R) \quad \text{for unlined structures}$$
$$E_2 = pa(B + I + R + dB) \quad \text{for lined structures}$$

Hence the increase in risk of damage by fire is

$$dE = E_1 - E_2 = p(1 - a)(B + I + R) - padB$$

When dE is capitalized to A at the moment of construction, $dB - A$ represents the saving that may be effected by omitting the lining.

The relatively high costs of the covering ought to induce authorities to investigate whether it is economically justified to impose a collective obligation to apply a lining to steel structures in general or only to certain types of building in particular.

By means of some examples the meaning of "decisionics" in building has been illustrated. A number of other problems are now enumerated that can be dealt with in an exact way and where decisions are involved that warrant a scientific way of dealing with them.

BASIC DECISIONS

The level of the quality of housing in relation to the production capacity in a given country and in a given period.

Problems of capacity of stores (problems of optimal stock). Choice of location of industrial buildings and problems of centralization and decentralization.

FUNCTIONAL DECISIONS

Distribution of capacity over the different departments of a general hospital (nursing units).

Centralization and decentralization of kitchens in a hotel of a given capacity.

Multi-storey and/or low construction of an office building with a view to internal transport (problems of waiting times).

The choice of a number of units in relation to the degree of occupation.

DESIGN DECISIONS

Safety factors of construction.

Single or double glazing with a view to economy of heating and reduction of noise.

Degree of standardization in the case of series construction: consideration of the functional requirements of the width of a dwelling in relation to the costs of land and of construction.

PRODUCTION DECISIONS

Choice of the degree of mechanization of the execution of a large construction job (cranes, etc.).

Location of the stock of building materials on the site.

Determination of the speed of execution with a view to the loss of interest during the execution.

Optimal stocks on the site in relation to the speed of construction and the loss of interest.

Although the conditions for exact study (time, data and expert knowledge) are not always completely fulfilled so as to allow for a concrete solution of the problem, such a further study always gives the advantage of a better insight into the mutual interdependence of various influences and the factors that mutually counteract one another. In this way the decisions to be taken will increasingly be based on facts and the dangerous basis of opinions, mostly influenced too heavily by recent events and relatively small personal experience, is minimized.