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1. Object of the research work

The German building industry, in general, has not yet gathered too much of an experience regarding reinforced masonry as the German standard DIN 1053, Page 1, being valid at present, hitherto allowed economic constructions of reinforced masonry by way of exception only.

It has been the purpose of this study to show some possibilities of rationalization adhereing simultaneously to the rules and regulations of construction and design of the new standard DIN 1053 part 3.

Another target of this study has been to demonstrate certain constraints and contradictions included in the standards which prove to be a hindrance to rationalization. This ist taken as a basis for suggestions how to proceed in this research work which, on account of comparable experience in reinforced concrete construction - has good prospects of success.

2. Implementation

2.1. State of art

Meanwhile, experience has been gathered throug approx. 100 years regarding construction, design and execution of reinforced masonry, and predominantly abroad. As example from earlier times (the nineties of the last century) we should mention the reinforcement of vertical coring bricks by means of reinforcing steel of approx. 3 mm which had been inserted axially into mortar (grout) channels of a square cross-section of approx. 25 m^2. The mortar was mixed at a ratio of cement: sand = 1:2. In this way and manner, not only walls frequently were made as fair-faced masonry work, but also individual piers or wall piers, with the reinforcing steels being provided with binders (links) - please also refer in this respect to /1/.

During the last decades, a multitude of varieties has been developed for the design of reinforced wall- and column constructions. Partly, the reinforcement is installed only horizontally or only vertically or both combined, in case of pillars or wall piers these are generally provided with an additional lateral reinforcement.

In order to be more independent regarding reinforcement layout, double-leaf wall constructions with core concrete or core mortar were developed. The varieties of design shown in DIN 1053 part 3 (basic illustrations fig. 1 - 7) correspond to the experience hitherto gathered if you add the mixed varieties derived from the seven basic varieties.

The good experience gathered with above-ground masonry, already more than 50 years before gave rise to the design and execution of iclined wall constructions and - in borderline cases - horizontally reinforced masonry - nowadays standardized by DIN 1045 as so-called "reinforced block floors".

In many countries, reinforced masonry has been widely used also for civil engineering works, like e.g. shells of double curvature /2-5/. A European directive /6/ includes essential design data. Of annex 1. Depending on the shape of shell, spans of 50 to 60 m have been achieved with a shell thickness of approx. 25 m.

Last not least, it should be mentioned that, abroad, reinforced masonry frequently has been applied also as beam- or plate-type bearing member for holding high loads originating from several storeys.

To the corrosion behavior, there is a comparably scarce literature only on corresponding tests and inspections of reinforced masonry. Anyhow, there are a few studies, and in particular it may be taken from /1/ that the reinforced and bearing fair-faced masonry of a thickness of 11.5 cm, with bracing by means of reinforced fair-faced masonry supports, did not reveal any damage in case of several inspected buildings. The author, however, draws the attention to individual cases in which an unfavourable design lead to an extremo ponding on cornices and masonry projections which again entailed damage by corrosion. In /7/, another author gives a similar report on inspections performed in Great Britain. The studies /8 and 9/ carried through in Germany, are unsuitable for an appreciation of reinforced masonry as in this case types of design were studied which according to the standard DIN 1053 part 3 or even according to other standards cannot be realized at all.

In view of the comprehensive inspections of structures and laboratory tests regarding the protection against corrosion of the reinforcement in case of reinforced concrete, the corrosion behaviour of unprotected steel in masonry was examined, too, using small laboratory test specimen /10/.

Whilst the individual authors /e.g. 11, 12, 13/, who have dealt with the question of corrosion in case of reinforced concrete, in spite of the frequent corrosion damage found at structures, have come to the conclusion that the standard regulations nowadays valid with regard to the concrete cover on the reinforcement of external structural members will, also for the long term, offer an adequate protection against corrosion, the author of /10/ negates such adequate protection against corrosion for masonry with embedding of the reinforcement in mortar of group III or IIIa; even additional measures like e.g. external painting on the masonry will scarcely mean an improvement.

Basing on the experience gathered abroad through many, many years /1, 6, 14/, the requirements regarding protection against corrosion seem to be excessive. The comprehensive examinations which for external walls consisting of brick masonry work yielded a substantial moisture content u_y of 1.5 % by vol. only (stipulated by standard DIN 4108), give rise to the expectations that in very rare exceptional cases only a corrosion-promoting humid environment will occur in external walls.

2.2. Important standard specifications

For the design regarding function and forces acting on comparable structural parts considerably more considerations and deliberations are necessary for reinforced masonry in order to come to an economic design adapted to the respective site, than would be necessary in case of reinforced concrete. There are different reasons for it:

- In case of reinforced masonry, the planning engineer may choose between a multitude of types of masonry featuring a wide range of compression strengths and the arithmetic valuess β_R, derived therefrom - cf. annex 1 -

- For a certain grade of masonry strength, the arithmetic values β_R are not constant in case of cored blocks. With regard to bending load it must be taken into consideration whether the compression stress is acting parallel or orthogonal to the direction of the hole/core in which latter case the β_R-values are divided in two.

- The type of the applied filling mortar for embedding of the reinforcement may also influence the β_R-value of the respective strength grade of masonry.

- Contrary to reinforced concrete, it must be differed between plate- and slab-thrust. Different conceptions of design will apply. In case of the plate thrust it must additionally be taken into consideration whether the cross joints are fully mortared or not.

  In case of slab thrust (load acting vertically on masonry level) it is irrelevant whether the compressive stresses due to bending existing simultaneously within the masonry, are acting in parallel or vertically to the direction of the block core.

- Only when using concrete for embedding of unprotected reinforcements, the covering dimensions acc. to DIN 1045 shall apply.

  When using cement mortar of groups III or IIIa it is true that an overall covering thickness of 3 cm is required (except for reinforcement in larger horizontal (bed) joints) but this does not mean an efficient protection against corrosion.
  Therefore, a protected reinforcement must frequently be used.

2.3. A summary of costs for various types of masonry

Independent of the exploitability of certain grades of masonry strenght and types of design as far as statics are concerned, of the thermal and sound insulation perhaps additionally required, as well as of requirements regarding fire protection, the knowledge of the costs for 1 m^2 of masonry represents an important basic information for the planning engineer.

It must be metioned that the costs have been determined on a uniform basis; this applies to the solid masonry as well as to the situation regarding wages and prices for materials indicated by builders' merchants in the area of Essen and valid in summer 1990. Working time and material requirement are more or less constant whilst the hourly wage rates, the specific extras on standard wages (overhead expenses, profit and risk..) as well as prices for material in general will change every year. Furthermore, prices will depend on the scope/size of the building, the degree of difficulty of the construction, the distance between supplier of building materials and the site. For further details please refer to the main report.

Some of the results of the cost summary for the various types of masonry have been shown in a graph in annex 2.1 and 2.2. For wall thicknesses of 11.5, 17.5, 24.0, 36.5 and 49 cm in case of brick masonry as well as d = 10.0, 11.5; 17.5 and 24 cm in case of reinforced concrete walls several variants have been taken into consideration respectively.

This leads to a series of essential conclusions regarding rationalization on basis of production costs as well as specific rules and principles of design associated with the respective type of wall:

- Also with a low percentage of reinforcement, costs increase significantly as compared to constructions without reinforcement. With increasing wall thickness, the portion of costs caused by the reinforcement alone, is reduced in accordance with the higher basic costs for the unreinforced masonry of a greater thickness.

- The employment of a protected reinforcement and in particular of prefabricated reinforcements, again will mean an increase of costs as compared to unprotected reinforcements. Even if the difference is significant, it is not so serious because the costs of laying remain the same so that only the materials will have an effect on the costs.

- The differences in sizes also strongly influence the production costs - and particularly in case of masonry types of greater thicknesses. By selecting favourable brick formats, the total costs including a light unprotected reinforcement can be lower than in case of an unprotected masonry of small formats.

- For masonry made of small-sized bricks all classes of stone strength are available and from the structural point of view, it simultaneously offers more options for the layout of reinforcement subject to an appropiate selection of the masonry bond. All small-sized bricks are readily available near sites and all over the Federal Republic, including facing bricks. As a rule, the costs are significantly higher than in case of the larger and more conventional sizes.

2.4. Criteria for application

Some further aspects have to be taken into consideration when deciding on the applicability of reinforced masonry:

- aspects of structural physics, like thermal insulation, sound insulation, fire protection, comfort, environmetnal compatibility,

- optical and aesthetic effects,

- structural and static aspects, like e.g. time/money required for planning, availability of experienced and reliable construction firms, static expoitability of the wall cross-section (often a moderate thrust/shearing force only will be opposed to a high bending load rating) taking into consideration the type of the stuctural element concerned (parallel or vertical load on the wall level), ratio between reinforced structural elements and unreinforced masonry, size of building and period of construction.

2.5. Adivce for application

Considering the preceding paragraphs, a reinforced masonry will be economically applicable for numerous types of masonry constructions.

- External cellar walls, predominantly with vertical reinforcement, because the storey height and consequently the span are clearly less than in horizontal direction (distance of the crosswalls).

- Free-standing masonry walls, perhaps also with wall pillars, which also have to fulfil highest requirements regarding architectural features.

- Infill walls in fair-faces masonry work featuring greater bay widths than permissible without reinforcement. Depending on the dimensions of the bays the reinforcement may be of horizontal, vertical or "cross-wise" design, perhaps also with reinforced masonry cross members of larger dimensions or lesenes/pilaster strips for division of bays.

- Design of self-supporting fair-faced masonry facades with or without strong division (lesenes, wall pillars) so that expensive high-grade steel supports with brackets/shoulders and expensive anchors can be dispensed with.

- Supporting walls of smaller builidngs and of not too great heights.

- Shear walls for the reinforcement of normal rising sturctures in the field of residential and business buildings.

- Supports and smaller wall sections with eccentric load.

- Constructive and/or static measures for ensuring earthquake resistance.

In some areas of the Federal Republic of Germany there is a moderate seismic activity. Contrary to wind stress which normally can be assigned arithmetically to a few structural elements of corresponding dimensions, the stress caused by earthquakes will act upon each structural element in horizontal direction only.

The protection against earthquakes is to design individual structural elements and the whole building as "though/impactresistant" work. If an exact and mostly very expensive evidence is not required, a slight constructive horizontal and vertical reinforcement each in the marginal areas of individual masonry walls may increase such "thoughness" considerably.

In case of longer walls, an additional vertical and intermediate reinforcement at certain distances is recommende. In order to cope with influences coming directly from the subsoil or building ground, the reinforcement of the basement storey in connection with the foundations and the raft foundation is of special importance.

3. Summary

Basing on the general conditions of the new standard DIN 1053 part 3, a reinforced masonry will in many cases be a more economic solution than reinforced concrete alone. In spite of the higher requirements to be fulfilled regarding corrosion protection (as compared to reinforced concrete), a reinforced masonry will offer clear economic advantages for many types of wall designs. Further aspects like a better thermal insulation of the masonry or requirements regarding design, like fair-faced masonry, will improve additionally the effect of rationalization in favour of a reinforced masonry.

During an initial phase after the introduction of DIN 1053 part 3 by the competent authorities a greater restraint will have to be expected regarding the employment of reinforced masonry work. Planning, static calculations and execution of work are still new grounds in the Federal Republic of Germany, even if some of the respective companies already have gathered experience through many years basing on DIN 1053 part 4 "Buildings made of prefabricated brickwork" and "Reinforced block floors according to DIN 1045". Add to this that a reinforced masonry, as compared to reinforced concrete, is not to be regarded as isotropic (at least when using cored blocks, and that a great number of partly very different types of masonry must be taken into consideration in planning and also later when executing the works.

There are further possibilities of rationalization if, basing on adequate results of research, you succeed in reducing the requirements regarding corrosion protection which at present are very high compared to reinforced concrete (the costs of the protected reinforcement are three times higer than for normal reinforcing steel rods).

There are good chances for a more economic dimensioning of reinforced masonry by improving the shear rating in consideration of an adequate shear reinforcement. In case of several types of masonry it must be expected with all probability that, with the respective results of research in hands, the permissible shearing stresses with an adequate reinforcement and in connection with a sufficient mortaring will be increased significantly as compared to the present valid permissible shearing stress (which also apply to unreinforced masonry).

May we avail ourselves of this occasion to extend our thanks to BM Bau for the financial backing of the research project.

Essen, this 13th day of November, 1990
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