Deterioration of flat roof coverings: Experience from field investigations

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R. HANSON

Civil engineer (Sweden)

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

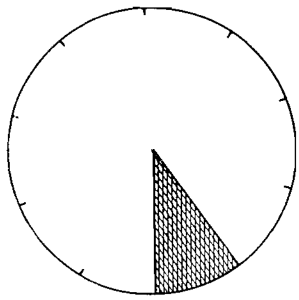


Fig. 1. Method of indicating proportionally the frequency of particular damages (see Figs. 2–17).

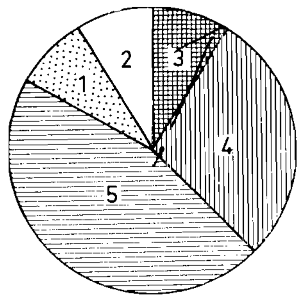


Fig. 2. Frequency of various types of damage. 1 blisters, 2 other injuries, 3 holes and tears, 4 ruptures, 5 wrinkles. Examples of these types of damage are Figs. 3–7.

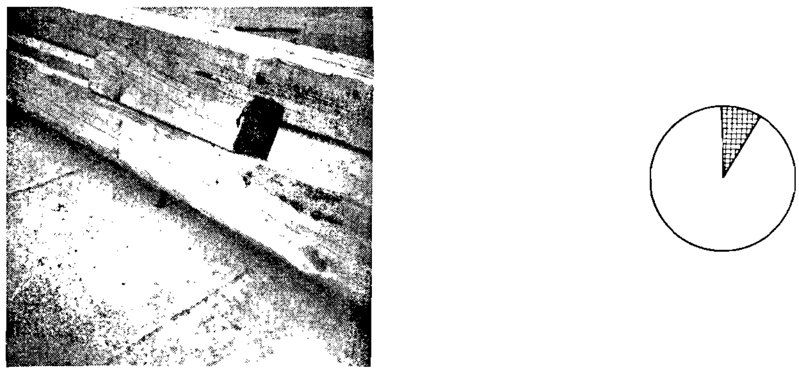


Fig. 3.

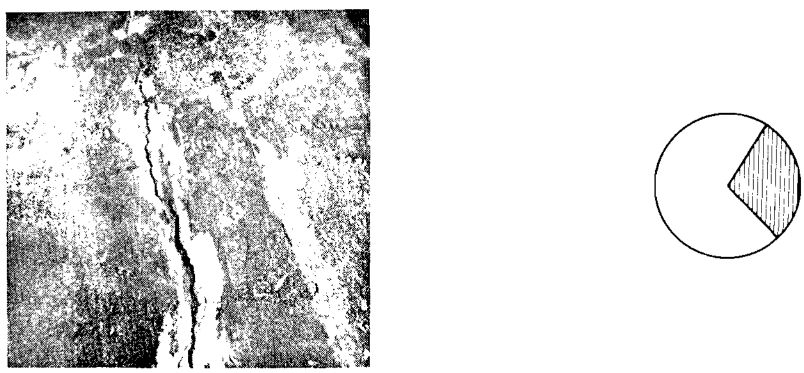
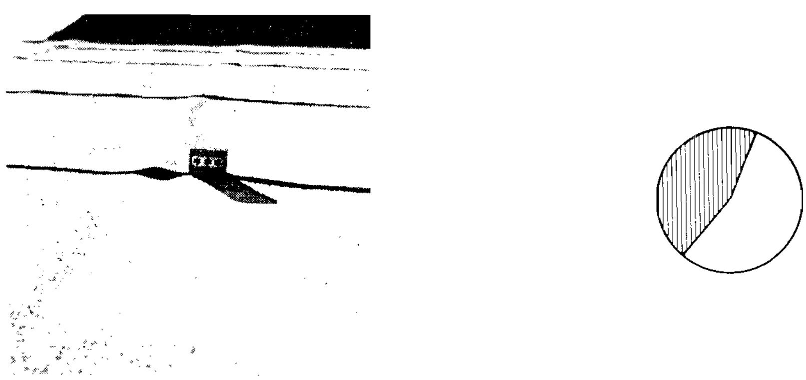


Fig. 4.



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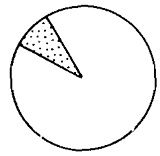

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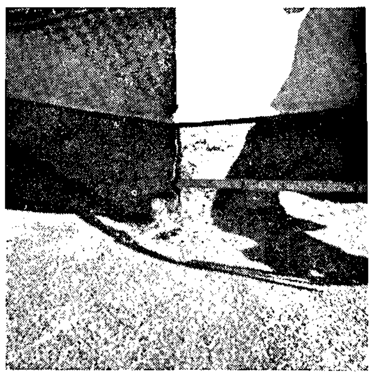

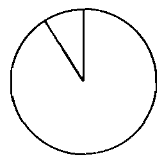

Fig. 7.

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.

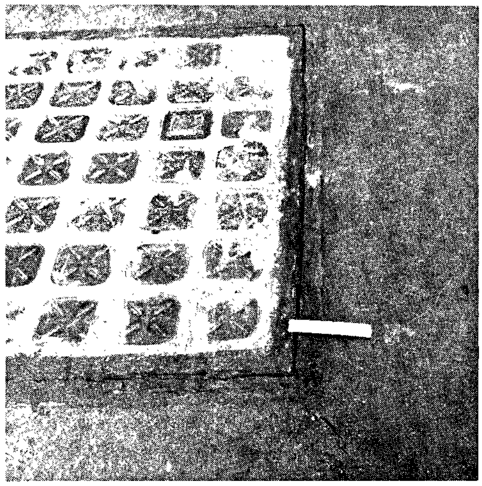

Fig. 8.

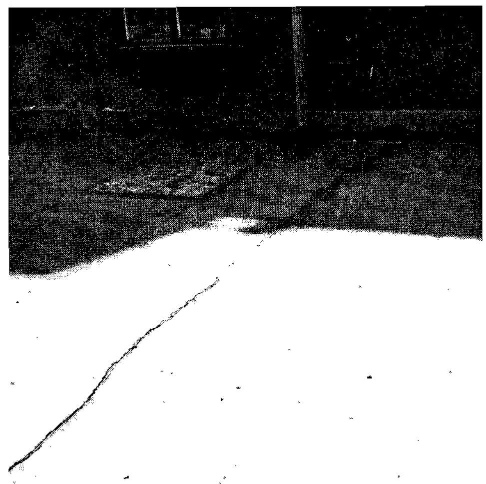

Fig. 9.

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.

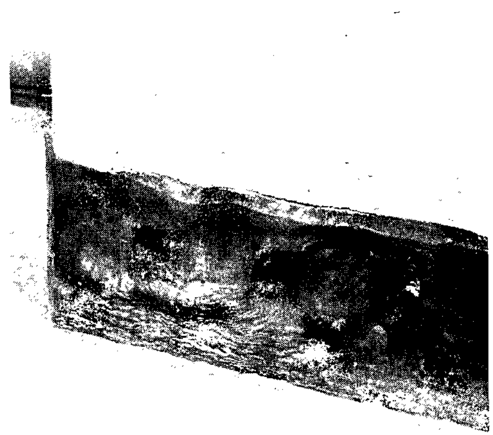

Fig. 11.

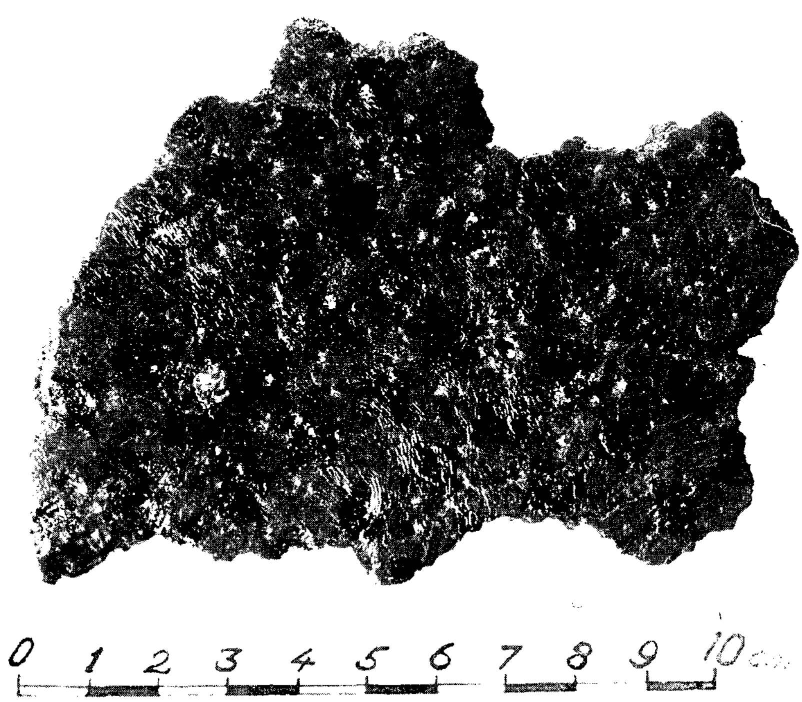

Fig. 12.

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.

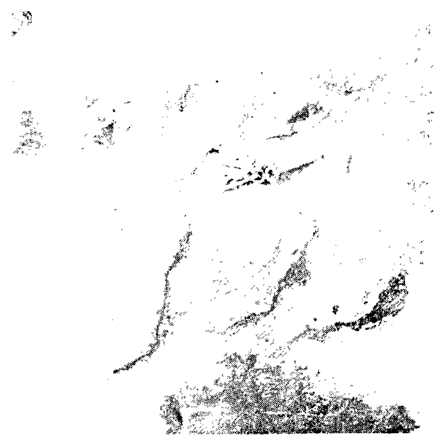

Fig. 14.

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.

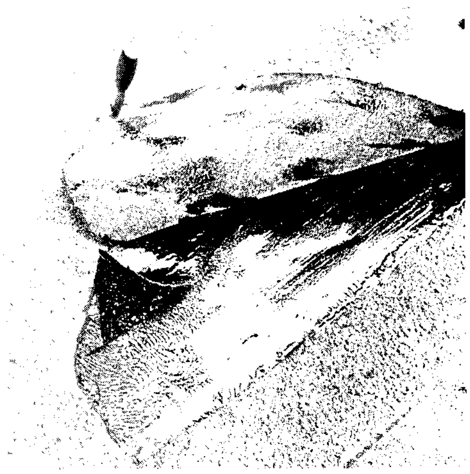

Fig. 15.

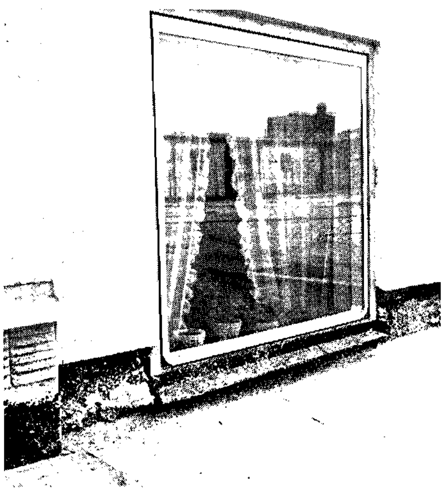

Fig. 16.

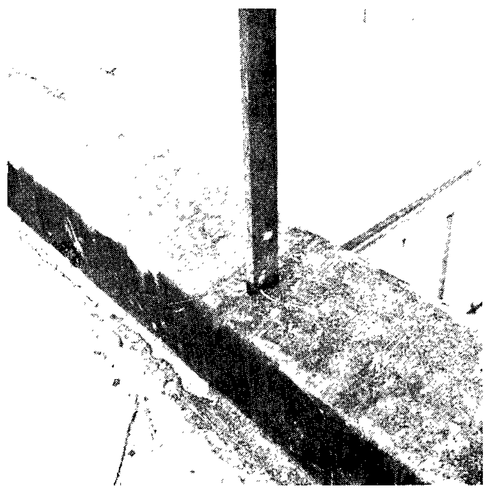

Fig. 17.

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.

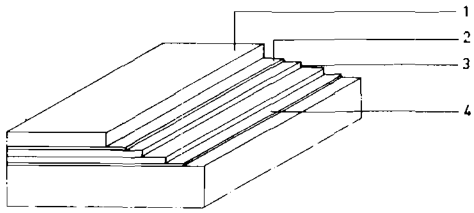

Fig. 18.

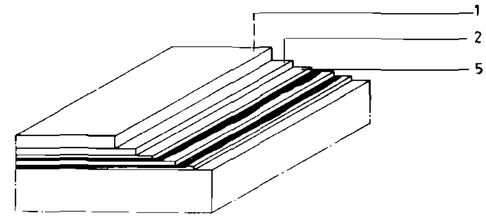

Fig. 19.

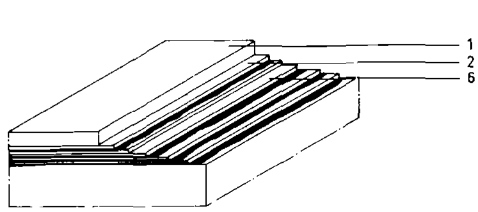

Fig. 20.

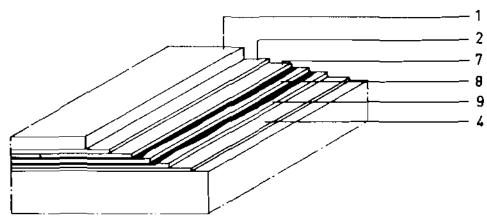

Fig. 21.

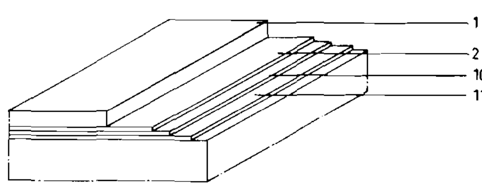

Fig. 22.

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.

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