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BUILDING RESEARCH NOTE

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WATER-PROOFING OF FLAT IN-SITU RCC ROOFS

Introduction

During recent years considerable trouble has been experienced due to leakage and seepage of rain water through flat concrete roofs. In some cases, the trouble has been so wide-spread, that extensive repairs and renewals have become necessary within a short time after laying. This note discusses the important factors which need to be considered in selecting in-situ flat RCC roof and providing suitable water proofing treatments and ensuring their satisfactory performance under conditions of normal exposure. Water proofing of precast roof slabs has been dealt in CBRI Building Digest No. 125.

Basic Considerations

At the very outset it is necessary to emphasise certain basic considerations which must be taken into account for selecting suitable treatments ensuring their satisfactory performance. These may be set down as under :

(a) Choice of a flat roof in preference to a pent roof.

(b) Choice of reinforced concrete as the material for flat roof.

(c) Permeability of concrete.

(d) Integration of waterproofing treatments with thermal treatments.

(e) Design of roof drainage system.

Choice of Flat roof

By its very nature, a flat roof is more difficult to waterproof than a pent one. The latter also accommodates rapidly movements due to thermal variation. Flat roof is, therefore, advised only where it is functionally necessary; either to provide additional space for certain activities or due to non-availability of suitable cladding materials for pent roof. However the present trend is towards the adopt.on of flat roof even where the rainfall is heavy and concentrated, due to its better appearance. In such cases, it is essential to realise that the flat roof requires relatively heavy and costly treatments. For the sake of convenience a map has been prepared, which shows broad zoning of the country into areas suitable for flat and pent roofs. It would be noted that flat roofs can be provided in most parts of the country, excluding the northern areas subject to snow, eastern areas covering Assam and Nagaland and the Western Coast subjected to heavy rain fall.

Choice of Reinforced Concrete

Since the roof slab is required to behave satisfactorily under normal exposure, its susceptibility to undergo movements on account of variations of moisture, temperature or any other cause and its ability to accommodate these movements may have decisive effect on the performance of a treatment. Most of the traditional flat roofs comprise of small units laid with joints or placed in a large volume of mortar such as tiles or bricks laid on battens or joists reinforced brick slab, Jack arch roof, Madras Terrace, etc. These roofs can readily accommodate the movements within the mortar joints. But reinforced concrete not only undergoes relatively greater movements but cannot accommodate them without suffering cracks. Precautions are therefore necessary to provide for and accommodate movements which would otherwise seriously impair the performance of an otherwise satisfactory treatment.

Permeability of Concrete

Permeability of concrete depends upon a number of factors such as type of materials used, thoroughness of mixing, compacting and curing. While concrete can be made highly impermeable, it cannot withstand indefinitely direct incidence of rainfall. Moreover production of a highly impermeable concrete requires great care and control, which is not justified when it has, in any case, to be covered with a waterproofing treatment. Therefore, it is sufficient to ensure that the concrete is reasonably dense and that its impermeability is not adversely affected by the use of unsuitable or badly graded aggregate, excessive water content, inadequate compaction or curing, badly designed or constructed joints, and inadequate protection against temperature variation. Effectve control on quality of concrete is, therefore, an essential prerequisite for satisfactory performance of the roof as a whole.

Integration of Waterproofing Treatment with Thermal Treatment

In most parts of the country a flat RCC roof has to be provided with an adequate thermal treatment (making up a total of about 230 mm thickness) to provide thermal comfort. It is therefore, necessary to provide two treatments, one for thermel protection and the other for water-proofing or where possible, combine these into one single treatment, such as mud-phuska in areas of low rainfall In severe conditions such a combined treatment is usually not satisfactory and separate treatments for water-proofing and thermal protection have to be provided, which introduce the need of suitable integration of the two treatments. Idealy, the water-proofing treatment should be placed on the exterior to prevent ingress of moisture into the thermal treatment. But it is usualey not possible since the nature of the materials used for waterproofing, such as bitumen or polythylene, often necessitates protection against direct sun rays or wear and tear caused by usage. Alternatively, the waterproofing treatment is covered with a protective layer, thus making up a three-tier arrangement. In both these solutions water may enter in between the two layers which ultimately finds its way into the slab through any local weakness in the waterproofing treatment. This difficulty can be partially got over by providing suitable slope in the final exposed surface of the treatment and permitting the water to escape at selected points. The designer of the waterproofing treatment has, therefore, to fully consider the interaction of the waterproofing and thermal treatments and to devise suitable details so that the roof as a whole functions satisfactorily.

Design of Roof Drainage System

Stagnation of water on the roof surface, due to undulating surface, faulty slope or other causes shou'd be avoided to ward off the failure of an otherwise satisfactory treatment It can be avoided by providing adequate slope, limiting the area served by each outlet and designing of outlets to carry full discharge under normal conditions with a suitable margin for freak conditions. Flat roofs are usually defined as having slopes not greater than 1 in 10, but in practice slopes are often restricted to 1 in 40 to 1 in 80. While the increase in slope to 1 in 10 does not result in a substantial increase in the rate of flow of run off, it certainly eliminates the likelihood of stagnation of water due to undulations or depressions developing due to usage. It is therefore advisable to increase the slope to the steepest practicable, say 1 in 30 to 1 in 40 consistent with the type of materials used and cost. Greater care in achieving proper slopes is necessary when the material used is of a compressible type, such as lime concrete or mudphuska, which may develop uneven surface.

How this slope is to be achieved is equally important. Common practice is to have no slope in RCC slab and vary the thickness of the treatment. Since the minimum thickness of the treatment cannot be reduced to less than 75 mm the slopes are often restricted to that which can be obtained by a fall of 60 to 80 mm often resulting in slopes as flat as 1:60 to 1:80. It is therefore advisable to provide some slope in the slab itself, so that adequate slope can be provided by varying thickness of the thermal protection layers.

Outlets for the drainage of water should be designed so as to avoid their chokage and should be regularly cleaned to avoid stagnation of water. The area of drainage for each outlet is guided by the code IS:3067-1988 according to which no outlet should be less than 100 mm in diameter to serve an area not exceeding 40 sq m or it should not be less than 1/5000 of roof area.

Criteria for Selection

It is a common practice to select the water-proofing treatment on the basis of total rainfall at a particular locality. While this may be an important guiding factor, a more important factor, is the duration of rain and dry spells.

When a dry roof receives rainfall, it tends to absorb the rain water, rather than allow it to flow off the surface till a film of a water is formed over the surface encouraging a run-off in preference to absorption into the roof, The rate and capacity of absorption of rain water depends on the materials used in the treatment, as well as on the pattern of rainfall. A slow rain permits the roof to get saturated while a fast falling rain soon forms a film and the water runs off the surface before saturating the roof.

A slow persistent rain extending over a long period therefore tends to be a greater hazard than a sharp shower. In the former, the water tends to find its way through any joint or crevice which may not show any leakage in the latter.

For a correct evaluation of the rainfall hazard, detailed information relating to rainfall pattern, showing both the varying intensities and the duration of rain spells as well as the wind velocities during the rain-spells, is necessary. Since this information is not readily available, choice can only be made on the basis of total rainfall, and the number of rainy days in any month during the monsoon, data for which are published by the meteorological department.

Following tentative criteria are therefore suggested as a general guide

(a) Poor rainfall

Average annual rainfall not exceeding 500 mm and the number of rainy days in any month not exceeding 10.

(b) Moderate rainfall

Average annual rainfall exceeding 500 mm but not exceeding 1500 mm and the number of rainy days in any month not exceeding 20.

(c) Heavy rainfall

Average annual rainfall exceeding 1500 mm and the number of days in any month exceeding 20.

The selection on the above basis should be supplemented by the data for actual performance of treatments provided in the locality such as a very exposed site on a hill top or a low roof receiving rain water from adjoining roofs. Selection of suitable type of treatment for the above conditions is discussed below.

Types of Treatment

The treatments commonly used in India may broadly be classified as :

(a) Rigid treatments

(b) Elastic treatments and

(c) Composite treatments.

Rigid Treatments

Rigid treatments involve the use of materials which present a rigid surface to external elements. They usually employ material of local origin such as lime concrete, mud-phuska with brick tile etc. which provide adequate thermal protection beside water proofing and are really combined treatments Such treatments are ideally suited for roofs subjected to constant traffic or usage; however they are liable to develop cracks due to temperature variation and the joints with the wall and other vertical features are vulnerable necessitating provision of flashings. These treatments can safely withstand poor rainfall condition defined earlier.

Elastic Treatment

These are commercially manufactured products such as bituminous felt, polyethylene sheet, glass fibre reinforced sheet etc. These treatments are easy to lay or renew. They provide satisfactory protection at junctions with walls and other vertical feature besides providing a good water proofing layer over the roof surface. However, they have limited life span needing periodical renewal.

Being generally black in colour, the surface absorbs lot of heat from solar radiation. They do not provide any thermal protection which has to be taken care of separately. They can withstand moderate to heavy rainfall but require to be protected against direct sunlight.

Composite Treatment

This type of treatment is a combination of elastic and rigid treatments such as felt laid on lime concrete, mud phuska laid on polyethylene etc. This treatment can be designed to withstand any given conditions of rainfall in addition to providing adequate thermal protection.

The map indicates the broad zones where the above types of treatments can be used to advantage. In preparing this map the total rainfall and the number of rainy days in the month as well as the temperature have been taken into account. However, this map is to be regarded as a guide, due to allowance being made for local conditions, and availability of material and economics.

Materials and Specifications

In practice a number of materials and specifications have been employed in waterproofing treatment. These are often adopted without due regard to local condition and often unsuitable materials or specifications are adopted. The discussion that follows brings out important points in respect of these treatments.

(A) Mud-Phuska with Brick Tiles Treatments

This treatment usually consists of the following :

(a) 100 mm thick (average) mud-phuska consisting of puddled clay mixed with chopped straw (bhusa) 8 to 10 kg per cubic meter of soil.

(b) Mud plaster consisting of puddled clay mixed with chopped straw 30 to 35 kg per cubic meter of soil.

(c) One or two coats of 'leeping' consisting of fine clay and cow-dung in equal quantities.

(d) One or two layers of tiles, laid on a bed of mud-mortar and jointed and pointed in cement mortar 1:3.

In moderate rainfall areas the present practice is to provide a coat of hot bitumen @ 1.7 kg/sq. m. or polyethylene below the mud-phuska layer. Details of roof slab with mud-phuska and brick tile treatment are shown in Fig 1.

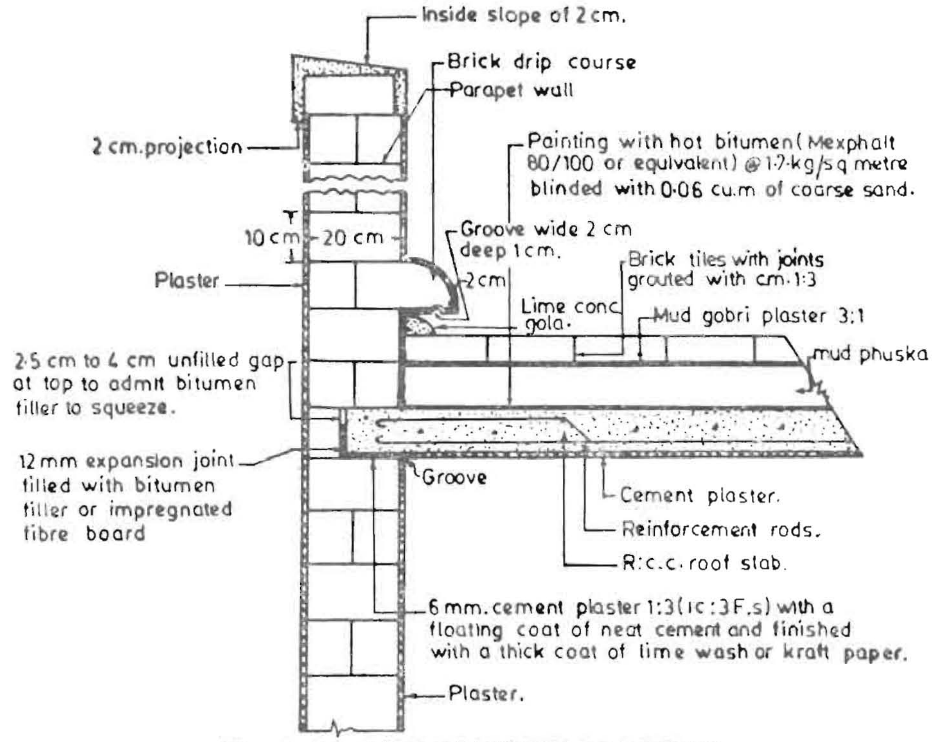


Fig. 1 DETAILS OF WATER PROOFING
(Mud phaska-terracing)

The function of each of these layers needs to be kept in mind while framing specifications. A coat of hot bitumen over the roof slab seals the pores of concrete surface and thus provides a barrier to the seepage of moisture in concrete. Therefore, to make it effective the coating should be applied evenly over the entire surface without any gap and without any blank patches. Bitumen coat is extended over the vertical surfaces meeting with the slab. For this the surface is painted when it is thoroughly dry and after cleaning the surface with wire brushes and cotton etc. Bitumen commonly used is residual type petroleum bitumen penetration 80/100 or hot cut back bitumen. Residual type bitumen (80/100) is heated to a temperature not less than 180°C and not more than 190°C. Cut back bitumen is heated to a temperature of not less than 165°C and not more than 170°C. The quantity of bitumen to be spread per 10 sq. m. of the surface is 17 kg.

The mud-phuska acts as a thermal insulation layer, its thickness varying from 100 to 150 mm. Besides thermal insulation, mud-phuska layer absorbs moisture ingressed through the brick tile surface at top and retains it in its body, thus provides better protection to RCC slabs against moisture. For this reason, the soil for mud-phuska should be clayey. The addition of bhusa for straw to the clay tends to reduce cracking to a minimum. If this purpose can be economically achieved by other means, such as a soil stabiliser e.g. cement, lime or bitumen there is no objection to its use. The mud plaster fills up the cracks which occur in the mud-phuska. This plaster should therefore be less susceptible to shrinkage than mud-phuska. This is achieved by adding more quantity of straw. The purpose of the 'leeping' coats is to protect the mud plaster from cracking and to fill up the pores.

The layer of tiles is required to withstand the driving effect of rain and to serve as a wearing surface if under use. It also assists in shedding off water by providing a smooth surface. Rich cement mortar as 1:3 is susceptible to more shrinkage. Jointing of tiles in rich mortar defeats the purpose of providing a crack-free surface. It is advisable to use gauged mortar of mix 1:1:6 or $1:\frac{1}{2}:4\frac{1}{2}$ (cement:lime : sand). To this mortar, crude oil (5% by weight) of cement can be added to obtain performance under relatively more severe conditions.

Soil for mud-phuska should be selected so as to give maximum density and thus provide better resistance to moisture, Recommendations made in Indian Standard : 2115-1980 are a useful guide in this respect. Usually the local soils suitable for brick making, gives satisfactory results, provided it is properly mixed with straw, matured, laid and compacted at optimum moisture content. A practical way of determining the moisture content of soil suitable for giving good compaction is given here. Take a handful of soil. Add sufficient water so that the soil can be moulded into a ball. Put the ball on a level surface. If the ball does not disintegrate, it contains just sufficient water for good compaction. On the other hand, if the ball is deformed by pressing with hand, the moisture content is on the higher side. There has been some controversy about bedding of tiles. As the tile surface is directly exposed to temperature variations, setting the tiles in cement mortar accentuates the tendency to crack. The tiles should preferably be bedded on a layer of mud mortar after the 'leeping' is dry. Whether the tiles should be laid in one or two layers depends largely on the thickness of tiles available. The purpose of providing two layers of tites is to break joints and reduce the possibility of seepage. Two layers are not feasible if the thickness of tiles is 5 cm or more such as in Punjab and Uttar Pradesh. They not only add to the dead weight but also increase the cost.

(B) Lime Concrete Terracing

Lime concrete acts both as water-proofing and thermal insulation layer. Lime has slow setting property and so permits prolonged beating of lime concrete for better compaction. Lime concrete improves in quality with the passage of time. The strength also increases. Due to these properties, this treatment has been used since time immemorial and its satisfactory performance was long established for flat roofs of traditional type such as tiles or stone slabs on battons and joists, jack arch roof, Madras terrace etc. This fact has encouraged its use on RCC roofs with variable results. The treatment has not been found equally successful in all cases. While the precise reasons for this behaviour need to be established by systematic study, the likely causes may be (i) RCC slabs are relatively rigid as compared to traditional flat roofs and are more susceptible to movements due to variation in temperature.

This causes cracks in lime concrete through which water perculates and finds its way to slab and other places causing dampness in building. At places where temperature variation is less the treatment may be more successful than at places where the variation is more (ii) Variation in the type and quality of lime and the compaction achieved during laying. Performance of the treatment therefore depends upon the quality of the materials and workmanship and varies accordingly. These problems can be mitigated to some extent by providing a flexible separation layer; better control on quality of lime (non-hydraulic or flat lime) and better compaction. Use of surkhi with fat lime is essential for attaining adequate strength. The treatment performs well where these precautions are taken.

Lime concrete is laid in a single layer and spread and rammed with wooden rammers to average thickness of 75 mm to 100 mm and to the required slope. The concrete is further consolidated by beating manually with wooden thappies. Special care is needed to consolidate the concrete properly at junctions with parapet wall. Beating is continued for three to four days, till the mortar is almost set and the wooden thappies rebound from the surface. While beating, the surface is liberally sprinkled with a mixture of gur and boiled solution of bael fruit in the ratio 1.75 kg of Gur to 1 kg of bael fruit boiled in 60 litres of water (CPWD specification). Composition of the mixture for sprinkling, however, varies at other place. Central Building Research Institute has developed a machine for compaction of concrete which can be used instead of manual compaction.

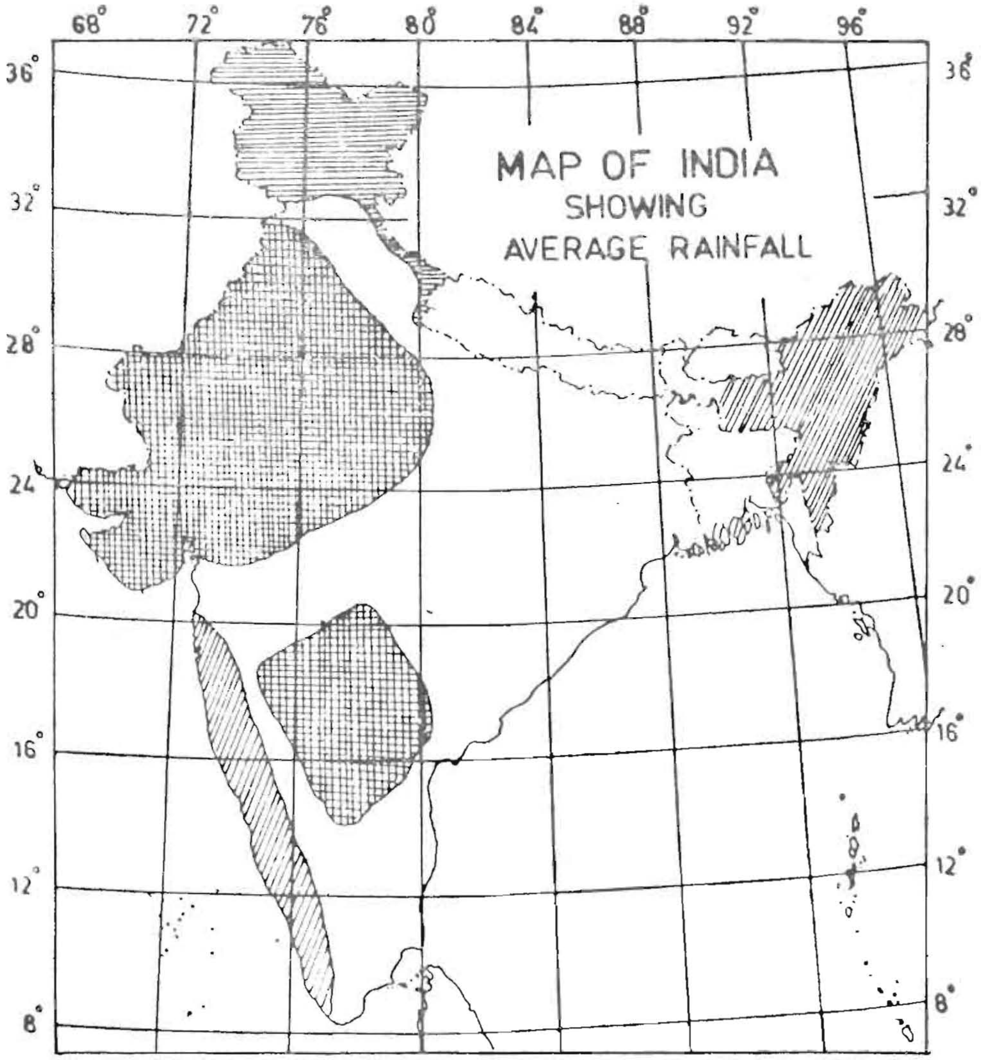
Proportion of lime and other materials used in various regions differ cosiderably. List is given in table-I.

TABLE I

Proportion of Lime and other Materials as adopted for Lime Terracing in various parts of India

Sl. No.	Specification adopted	Region	Remarks
1.	One cubic meter of 20 mm graded brick ballast to 0.4 cu.m. of slaked lime (no sand is added) for 10 sq. m. laid on Madras terracing	Madras	1 Lime ter acing is covered with 3 coarses of flat tiles laid in lime mortar 1 ; 1½. 2. Thickness of terracing after consolidation is 75 mm
2.	One cu.m. of brick ballast (25 mm gauge) to 0.45 cu.m. of lime mortar (1 lime : 1 surkhi : 1 fine sand).	Delhi	
3.	Brick ballast (40 mm gauge) : lime ; surkhi (7:2:2).	West Bengal	
4.	Lime : Surkhi : Brick ballast 6 mm to 25 mm graded (18 : 36 : 100).	U.P.	
5.	Lime : Surkhi : Brick ballast (1:1:3).		Specification adopted by N.E. Rly
6.	1 : 2 (lime : surkhi : mortar 25 mm gauge brick ballast)	Rajasthan	Proportion of lime and surkhi mortar not known. Use of sand in lieu of surkhi has also been reported.

*Based on "Report on Study of method used for water proofing roofs in India" by National Buildings Organisation.



(Printed with the approval of Director, Map Publication, Survey of India)

1. Snowy regions for which pent roofs are recommended. If flat roofs are employed, composite treatments catering for heavier protection against water penetration, thermal insulation and condensation would be required.

2. Regions of heavy rainfall wherein pent roof is recommended. If flat roofs are used, composite treatments having heavier waterproofing treatment on top would be required.

3. Regions with moderate rainfall wherein flat roofs with a composite treatments is recommended.

4. Regions of poor rainfall for which flat roofs with a rigid treatment are recommended.

The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.

"Responsibility for the correctness of internal details shown on the maps rests with the publisher"

No systematic investigation has been carried out to ascertain which proportion is better in performance. From the reports available, it appears that all the mixes referred to in table-I have given satisfactory performance in the areas where they are used. The following conclusions are therefore based on the limited data available in respect of cases where these treatments have not proved satisfactory :

(i) Use of surkhi with fat lime is essential to obtain hydraulicity so that lime concrete attains sufficient strength at the end of 28 days.

(ii) Use of fine sand, coal ash, and stone aggregate does not give satisfactory results.

(iii) Eminently hydraulic or semi-hydraulic lime should not be used as early setting property of these limes, does not allow the concrete to be compacted properly.

(iv) Where the lime is not of good quality or surkhi is not available, the lime concrete should be covered with two courses of flat tiles 10 to 15 mm thick, set in gauged mortar (1:1:6) mixed with 5% crude oil by weight of cement. The joints should be pointed with mortar and finally rubbed with thin iron bar until the pointed surface gets a polish and becomes hard. In case flat tiles are not available, pressed tiles, Shahbad stone slabs etc. can be used.

(v) For better performance RCC slabs should be coated with hot bitumen of 80/100 penetration at the rate of 17 kg per 10 sq. m. and blended with coarse sand before laying lime concrete. as shown in Fig. 2.

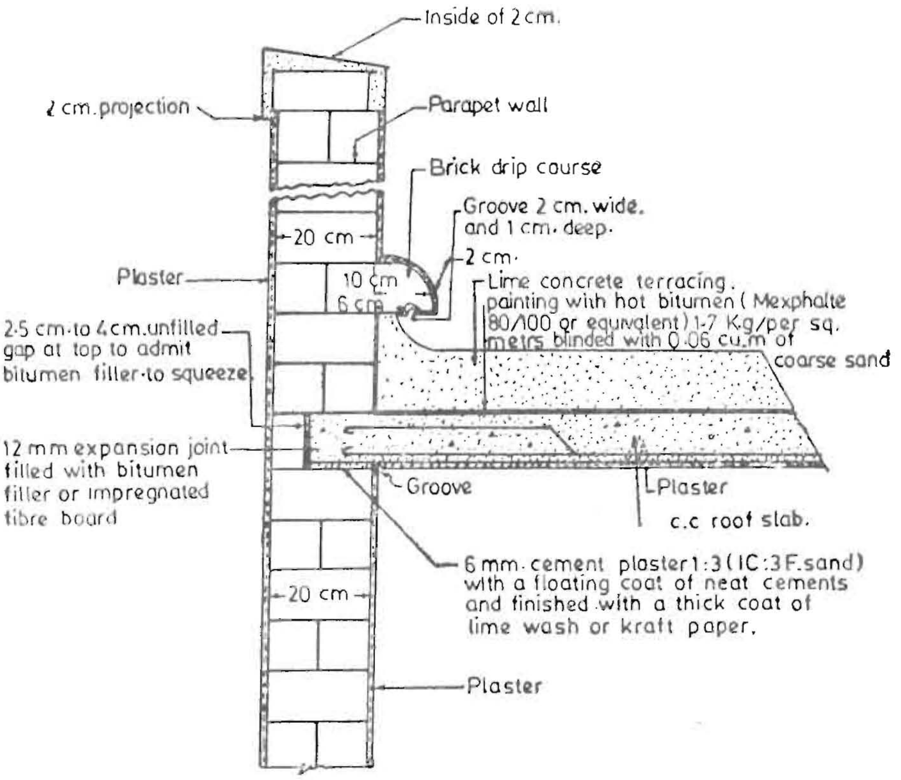
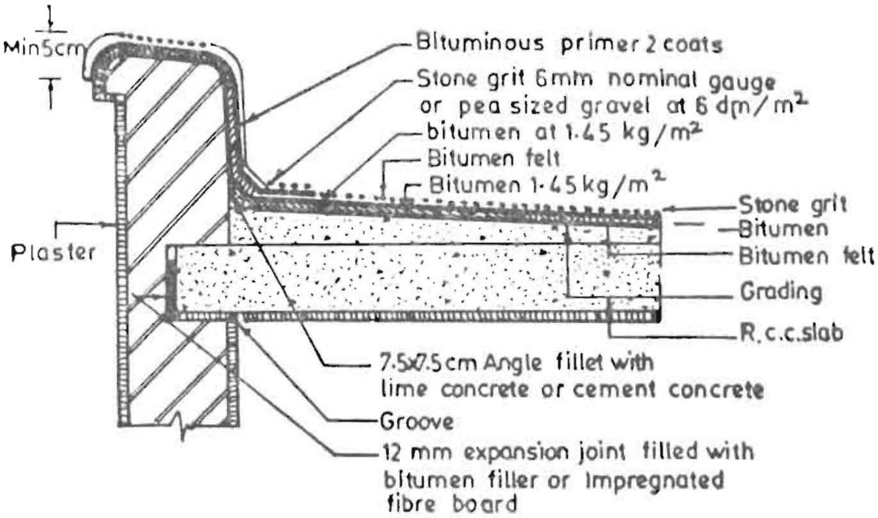


FIG. 2 DETAILS OF WATER PROOFING
(Lime concfete terracing)

(C) **Bitumen Felts**

This treatment is recommended where rainfall is heavy and not interrupted by long dry periods and where the roof is not normally used as terrace. The Code of Practice for water proofing roofs with bitumen felts (IS : 1346-1976) specifies 4 to 8 courses treatment for moderate to very severe conditions. This treatment has limited life and its periodical renewal is essential. Surfacing of the felt with pea gravel and bitumen affords a measure of protection and increases the life of the treatment. Adherence to requirements of ISI standards is essential to obtain good performance. Typical details are shown in Figure-3.



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