REINFORCED CONCRETE FLAT ROOFS

by
Dr. A.C. Visvalingam

Abstract

Nine of the most common factors which lead to cracks and leakages in reinforced concrete flat roofs are described briefly with a view to guiding young structural and civil engineers in the art of designing and constructing these building elements more successfully.

1.0 Introduction

The writer, in his capacity as a structural engineer, is often called upon by clients to advise them on problems which beset various types of structures designed and constructed for them by both professionals and non-professionals. One of the more common problems faced by them is in connection with cracked or leaking reinforced concrete flat roofs. This paper is intended to help young engineers from making the types of mistakes which the writer believes can be easily avoided in the design and construction of this class of structural elements.

There are numerous factors which lead to problems in reinforced concrete flat roofs but, of these, in the writer's experience, there are nine which recur over and over again. They are related to -

1. drainage,
2. external/internal level differences,
3. formwork,
4. embedded items and construction debris,
5. waterproofing,
6. insulation,
7. settlement of supports,
8. re-entrant corners and rapid changes of shape, and
9. the shrinkage of concrete.

These factors are dealt with below in brief outline. If, however, there is any point of particular interest to the reader, it may be possible, at some time in the future, to arrange to go into a little more detail regarding it.

2.0 Drainage

In a very large building in Colombo, on which the writers' advice was sought, it was seen that, for a roof area of around 12000m^2, the sum of the cross-sectional areas of the openings in the gully covers at the heads of the rainwater downpipes was only about 120cm^2, i.e. only about 10mm^2 of opening for each square metre of drained roof area whereas it should have been at least four times this amount. It was not surprising, therefore, to learn that rainwater used to pond up on this roof by up to 200mm in depth in heavy rain. This ponding enabled the rainwater to seek out percolation paths which would, otherwise, have been inaccessible to it and, consequently, there was extensive leakage into the building (Figure 1).

When faced with this type of failure, clients, almost invariably, come to the conclusion that the leakages are sure indications of structural weakness due to bad design or construction - and the engineer is forced into a defensive position. Therefore, right from the outset, it is best to work in such a manner as to avoid getting into professionally-embarrassing predicaments of this nature.

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Specifically, even though there may be someone else in charge of the design of the stormwater drainage, the structural engineer should make it his business to see that rainwater will be evacuated quickly and efficiently, with sufficient safety factors to take care of any partial blockages that might arise as a result of poor maintenance. He should also ensure that there are adequate slopes on the upper surface of the flat slab, either in the rendering, or in the slab itself, to discourage ponding to the minimum. He should arrange for properly detailed drops to be provided at all outlets (Figures 2a, 2b and 3).

It is only after these precautions are taken that he should commit himself to definite sizes for the structural members because the provision of these aforesaid features will unquestionably require increases in the dimensions of slabs, beams and columns over those required solely to meet the structural loads (Figure 3).

If the required gradients are to be attained by sloping the roof slab, rather than by resorting to an expensive tapered screed, any beams which are parallel to the gradient of the slab will vary in depth - and the design and detailing should not ignore this.

Failure to take timely action in this regard will result in the architect and the services professionals encroaching, rather late in the day, into the envelope of the load-bearing structure, to accommodate drains and gullies, thus creating innumerable headaches for the structural engineer.

As good drainage is essential to ensure that reinforced concrete roof slabs are not subjected to the adverse effects of temporary or semi-permanent ponding of rainwater, the structural engineer should not leave it to others to design the drainage systems by themselves, without his being provided the earliest possible opportunity of examining the implications of the systems proposed.

3.0 External/internal level differences

Sometimes the roof slab extends over only a part of a floor and the rest is covered by a roof at a higher level. Where this type of situation arises, it is vital to design the exposed roof area to be at a lower level - perhaps, 80-120mm - than the covered area. This will leave enough space to accommodate a tapered rendering. Otherwise, it will be found that, during heavy rain, water will tend to flow into the covered area - as is found to happen in more than one important building in Colombo.

In fact, there is an allied problem in a multi-star hotel in Colombo, where the designers had failed to provide drops for the bathrooms - with the result that there was no way of washing the bathrooms without getting the bedroom carpets soaked. Of course, the bathrooms could be mopped dry but this was not always found to be adequate.

4.0 Formwork

The third aspect to be considered is formwork.

All reinforced concrete specifications state quite clearly that formwork shall be rigidly fixed and shall be leakproof. There is certainly no encouragement in any technical specification to use cheap, freshly-cut timber which will begin to warp badly almost as soon as it is fixed in position or to employ badly-damaged shuttering after multiple uses. If the specifications are not followed closely in erecting formwork, there will be a greatly enhanced risk of grout loss and honeycombed concrete. The structure will not achieve its design strength and any defects in the waterproofing barrier will show up very rapidly.

Despite the importance of rigid, tight shuttering, one all too frequently encounters formwork with joints already open or in the process of opening up even while the reinforcement is being tied. It behoves the structural engineer, therefore, to be very strict in supervising the work of contractors in respect of formwork, particularly in the case of concrete roofs where, if there is any honeycombing, the reinforcement will corrode rapidly and progressive leaching of the cementitious bonding material will cause the structure to degenerate steadily with time.

5.0 Embedded items and construction debris

One of the most common sources of trouble with reinforced concrete roof slabs and even ordinary slabs under toilets and bathrooms is the presence of intentionally and unintentionally embedded items such as electrical conduits, wooden plugs for the suspension of ceilings and service ducts, as well as bits and pieces of wood, brick, plastic, metal etc. which are left in by careless contractors.

Although the writer has, sometimes, at the insistence of cost- sensitive clients, agreed reluctantly to the embedding of electrical conduits in concrete slabs, he tries his best to persuade them to introduce suspended ceilings as a long-term investment so that all the services they require could be accommodated within the ceiling space. Quite apart from the convenience and planning flexibility of this arrangement, the benefits from the point of view of avoiding water leakage and electrical short-circuiting problems are immeasurable.

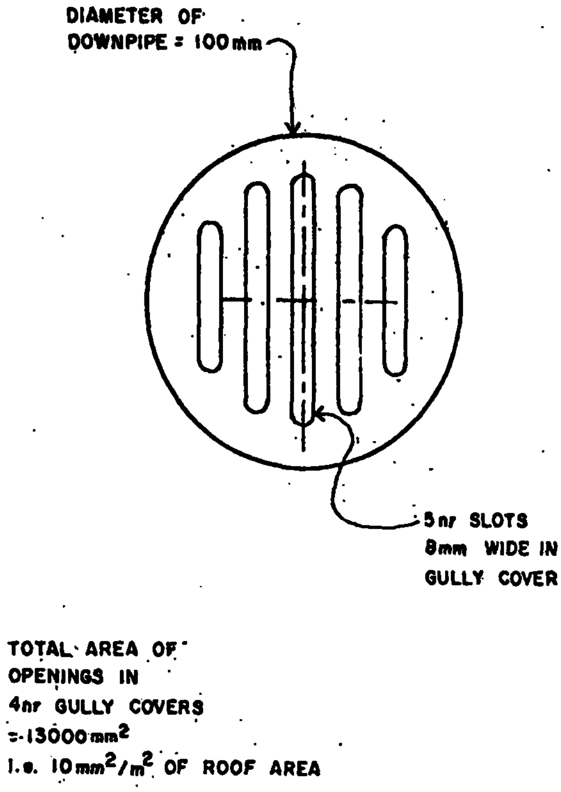


FIG 1

PLAN VIEW OF GULLY COVER

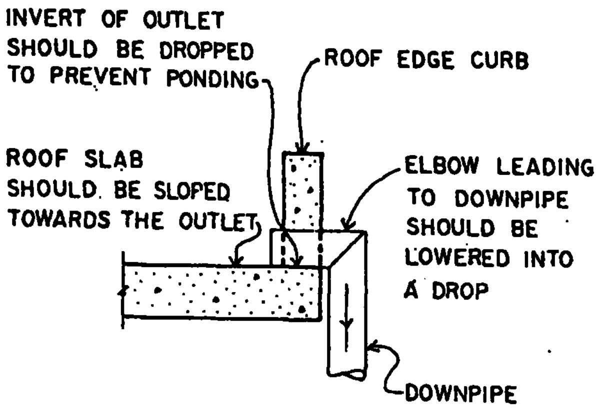


FIG 2a

VERTICAL SECTION THROUGH ENTRANCE TO DOWNPIPE

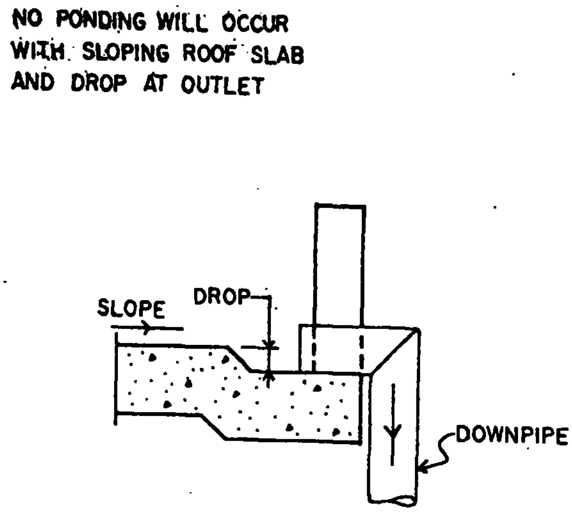


FIG 2b

VERTICAL SECTION THROUGH MODIFIED ENTRANCE TO DOWNPIPE

For years, a certain very important building in the heart of Colombo had over a hundred leaks from the roof. A good number of these were traced to embedded wooden plugs which had been provided for the suspension of air-conditioning ducts. The alternative method of drilling or firing in anchors from the soffit after the completion of the slab is much to be preferred.

In a more recent case, in a building which is something of major landmark, over 30m of 100mm x 50mm timber formwork supports were found to have been buried in the concrete at one particular location. The thoughtless detailing of a concealed drain may have contributed to the contractor forgetting to remove this large quantity of hidden timber. There were also several other instances of substantial lengths of timber left embedded in the various roof slabs. The net result is that there continue to be numerous leaks from the aforesaid drain and at the other locations into the floor spaces below. In fact, hundreds of square metres of very valuable floor space have not been brought into use for several years owing to the engineering and other difficulties associated with sealing these leaks.

6.0 Waterproofing

The next aspect relates to waterproofing.

To take a specific example, the writer's own house has a concrete roof over 270m^2 in area. There is a suspended ceiling. No embedded items whatever were permitted in the roof slab. As a result of careful design and good construction quality control, it had only three pindrop leaks in it, when completed - even before the waterproofing was installed.

These leaks, too, disappeared after the removal of an accidentally-embedded small piece of wood and the application of a 20mm layer of insulation on a coating of emulsified bitumen, followed by a further coating of emulsified bitumen and a protective rendering of asphaltic concrete - which was all the waterproofing and insulation the writer could afford at the time (Figure 4).

Although the aforesaid waterproofing is still performing perfectly, the writer wishes, on hot, windless days, that he had been able to afford a greater thickness of better insulating material.

A year after completing this house, the writer designed a bakery with a flat roof over 1000m^2 in extent. Even though provision had been made in the BOQ for waterproofing and insulating this roof in a manner similar to that which had been used on the writer's house, it was found that neither of these was necessary as there was not one single leak through the bare, sloped, cement-rendered concrete slab. This remarkable performance was due to the careful design, not only of the structure but also the provisions for drainage and dealing with the shrinkage of concrete. And, of course, strict supervision during construction.

Incidentally, the large internal height of the building and the excellent ventillation arrangements have prevented any heat problem inside despite the absence of any insulation.

As a general rule, however, one cannot rely on a concrete roof slab alone to act as the water barrier. Prudence dictates that provision should always be made for the scientific waterproofing of concrete flat roofs.

There are innumerable proprietory systems available for this purpose. Whereas it is true that the better systems generally cost more than the others, it does not follow that the most expensive will turn out to be the best. A very careful study of manufacturers' specifications will be found necessary to select the most cost-effective system for a particular building.

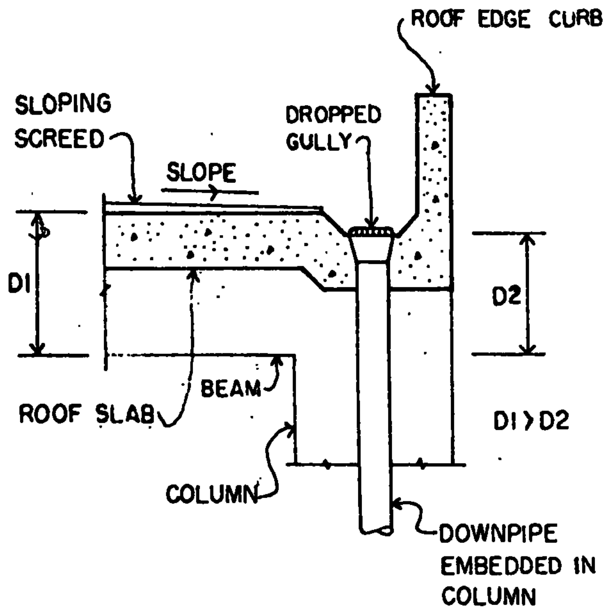
The structural engineer should acquaint himself with the various types of waterproofing systems which are available and ensure that a suitable type is selected which will prevent water passing into or through the slab and corroding the reinforcement or washing out essential salts from the cement. A particularly desirable, but rather expensive feature, would be to include a reinforcing fabric or scrim to help the waterproofing barrier to bridge any cracks which might have a tendency to widen with a substantial drop in temperature or with time. With some expensive types of barrier, however, a separate reinforcing fabric would not be required.

The commonly-proposed solution of providing a corrugated asbestos or profiled sheet metal roofing to deal with a leaking reinforced concrete flat roof is fraught with so many disadvantages - apart from defeating the whole purpose of having designed a flat roof in the first place - that the writer could not recommend it as a solution in all but the rarest of situations. Some of the problems relate to difficulties of anchorage against wind suction, poor access for maintenance, low insulation characteristics, undesirable heat storage, complex edge sealing requirements and drainage details, impracticability of regular inspection, animal intrusions etc.

7.0 Insulation

The sixth aspect relates to insulation.

Insulation of flat roofs is generally provided with a view to decreasing the heat load on air-conditioning plants.



EXTRA BEAM WIDTH AND BEAM DEPTH REQUIRED TO ACCOMMODATE GULLY

FIG 3

DETAIL AT GULLY

1 - ROOF SLAB
2 - 2 COATS OF EMULSIFIED BITUMEN
3 - 20mm EXPANDED POLYSTYRENE
4 - 1 COAT OF EMULSIFIED BITUMEN
5 - 12mm ASPHALTIC CONCRETE

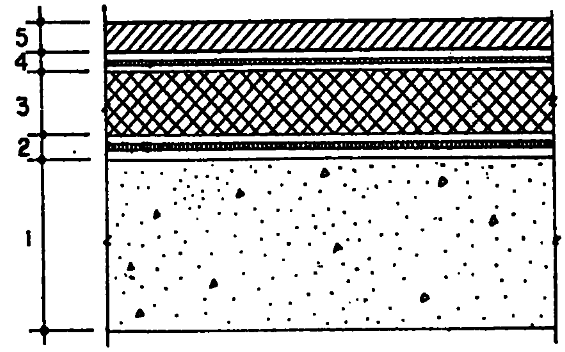


FIG 4

WATERPROOFING & INSULATION LAYERS

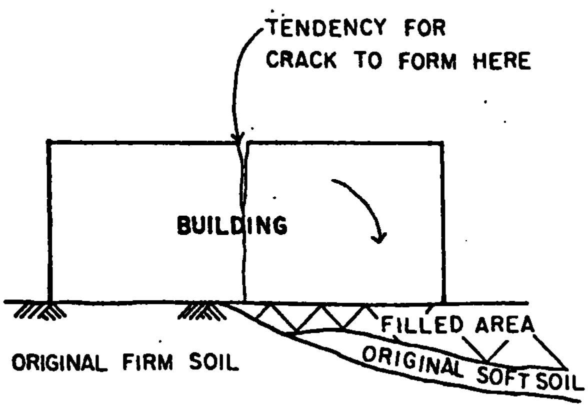


FIG 5a

CRACK CAUSED BY DIFFERENTIAL SETTLEMENT

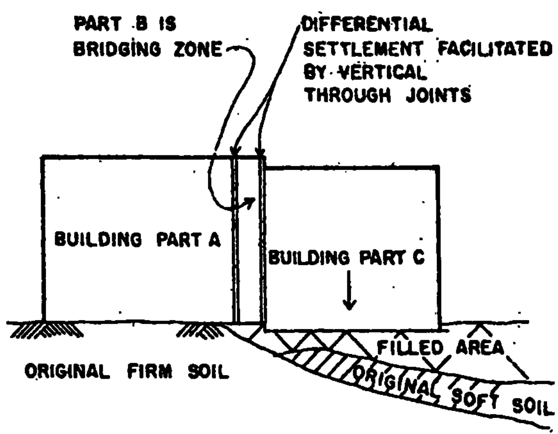


FIG 5b

VERTICAL THROUGH JOINTS TO ACCOMMODATE DIFFERENTIAL SETTLEMENTS

Certainly, the designer of a reinforced concrete roof would not fail to appreciate that such insulation would also greatly assist in keeping thermal expansions and contractions - and the associated stresses - within very much smaller limits than would be the case if there were no insulation.

What is not always appreciated, however, is that there is a third, very important, benefit - namely, that insulation provides long-term protection to the more common types of waterproofing barriers against the damaging effects of heat, vapourising water, ultra-violet radiation, abrasion and so on.

Whatever any manufacturer may say or claim to guarantee, weathering causes most waterproofing barriers to deteriorate within a fraction of the lifetime of the building to which they are applied unless they are protected from heat and other forms of harmful radiation. In any case, even the most expensive exposed types are generally guaranteed for not more than ten years. Moreover, the so-called guarantees themselves are of dubious enforceability. Insulation of the waterproofing layer, other than for the very heavy duty, exposable types is, therefore, virtually obligatory.

All other things being equal, designers would be wise to favour a cheaper waterproofing barrier with insulation rather than a more expensive one without insulation, not only because of the longer life that can be ensured for the waterproofing barrier but also because of the reduction in thermal stresses and heat transfer.

8.0 Settlement of supports

The seventh aspect of importance is differential settlement.

It is not necessary to labour the point to civil and structural engineers that differential settlements should be kept within the limits permitted by the relevant Codes. One must, however, keep in mind that, whereas a crack in an internal beam or slab may often not be a matter to get worried about, even the smallest crack in a reinforced concrete flat roof could be potentially dangerous or, at the very least, extremely inconvenient.

Turning to the question of predicting settlements, how well this can be done is, in the writer's opinion, a matter for the exercise of good judgement based on adequate practical experience.

It is especially important that the structural engineer should visit the site of any building he proposes to design so that he can form a correct idea as to how the report of the soils investigations should be interpreted. The one thing he must not do is to take the bearing capacity figure given in the soils report and blindly adopt it for the purposes of his designs as there are many other important factors to be taken into account, which can only be assessed by direct inspection of the site.

Returning to the matter of roof slabs in this connection, it is vital to ascertain whether, in the case of the structure that is being designed, the foundation conditions would tend to favour uneven settlements. Should there be a possibility of significant differential settlements, it should be remembered that the consequential effect of such settlements would be much more drastic on a roof slab than on many other elements of the structure. In situations where largish differential settlements could be expected, it may be found to be advantageous to divide the building structurally so that the settlements of its various parts could be allowed to take place independently (Figures 5a and 5b).

If a structure is divided into independent sections - either on account of the possibility of excessive differential settlements or for any other reason - the pertinent joints in the roof will need to be provided with flashing - perhaps, on the lines indicated in Figure 6.

9.0 Re-entrant corners

The penultimate factor to be considered is the concentration of stresses which takes place at re-entrant corners and rapid changes in plan shape or depth or cross-section.

Re-entrant corners and sudden changes in the shape of a slab, when viewed in plan or section, are a real problem because they represent a virtually open invitation for the formation of cracks (Figure 7). Corner bars are the most commonly adopted solution at re-entrant corners but may, in some cases, not be enough to limit cracking to acceptable limits.

Wherever architecturally permissible, one should physically isolate the parts of the structure on the two sides of the line at which the change of plan shape is required to occur. This procedure will almost certainly require the introduction of double beams and columns, and similar features (Figure 8).

The design engineer will encounter less difficulty in finding solutions to this kind of problem when dealing with those architects who appreciate that there is merit in allowing structural solutions to dictate the forms of buildings to the

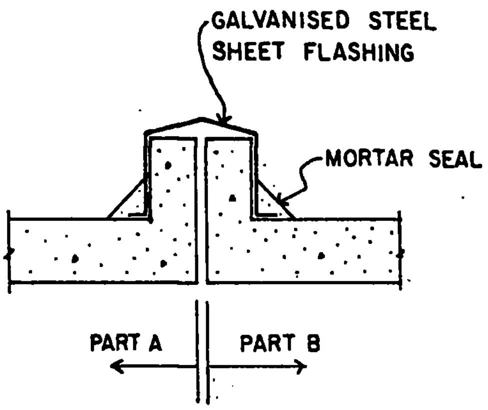


FIG 6

FLASHING DETAIL AT CONTRACTION JOINT IN ROOF SLAB

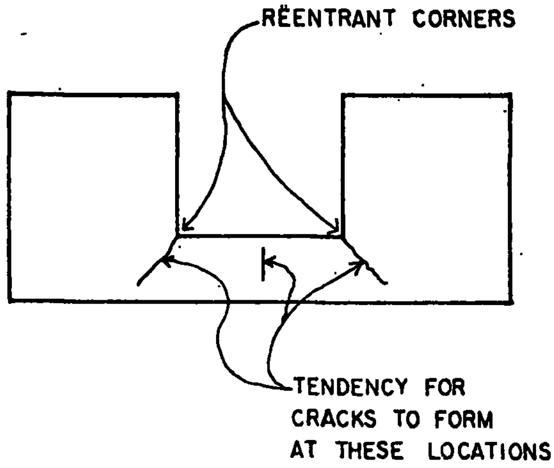
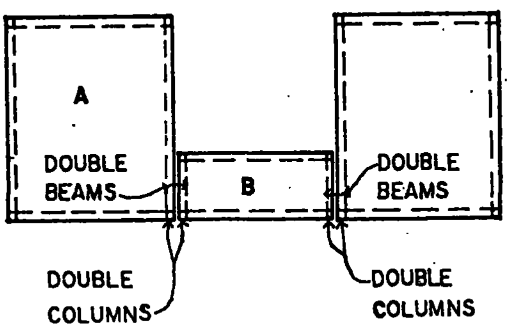


FIG 7

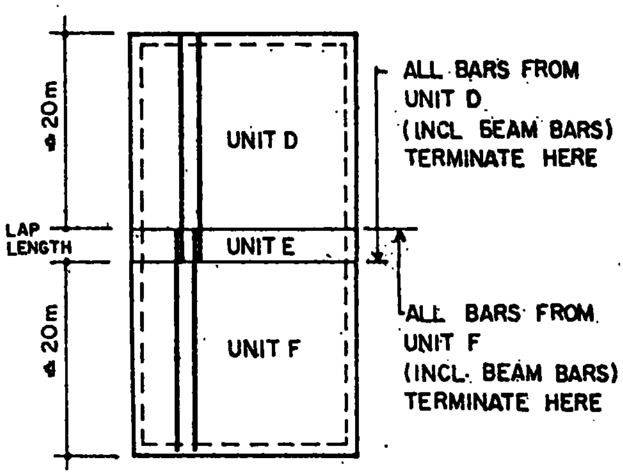
PLAN OF ROOF SLAB SHOWING CRACKS AT REENTRANT CORNERS



STRUCTURES A, B AND C CAN SETTLE OR SHRINK OR EXPAND INDEPENDENTLY OF EACH OTHER

FIG 8

PLAN OF BUILDING SHOWING DOUBLE BEAMS AND DOUBLE COLUMNS AT THROUGH JOINTS



UNITS D AND F SHALL BE COMPLETED FIRST. UNIT E SHALL BE COMPLETED NOT LESS THAN 28 DAYS AFTER UNITS D AND F

FIG 9

PLAN OF SLAB SHOWING "SHRINKAGE GAP"

maximum extent possible, subject, obviously, to any other overwhelming constraints.

10.0 Shrinkage

The writer has kept the most neglected factor of all to the last i.e. shrinkage of concrete.

All structural engineers know that concrete shrinks on setting and continues to shrink for long thereafter at a reducing rate. But how many actually design their structures so as to minimise the adverse effects of shrinkage?

If we consider a continuous concrete structure of, say, 75m in length, a rough assessment of the shrinkage that would take place within 28 days would be around 15-20mm. The long-term figure, particularly in a tropical environment, could reach 35-40mm. Assuming that there is a reinforced concrete roof slab to cover this structure, and that this roof slab is held firmly at its two ends by other parts of the structure, it is inevitable that, after sometime, there will be micro-cracking as well as large cracks, in a transverse direction, aggregating 35-40mm or so in width. If one provides the Code requirements of reinforcement in the appropriate direction, there will, undoubtedly, be a reduced tendency for single large cracks to form. However, weak locations such as construction joints, changes of section at transverse beams, other structural restraints etc. virtually guarantee that there will be at least a few cracks which would be in the range of 1-3mm in width, if not wider. Such cracks could cause problems of a structural nature or lead to difficulties in waterproofing.

In order to minimise cracks of this sort, it was an absolute rule, in the first consulting firm where the writer worked (in London), that any reinforced concrete structure of more than 20m or so in length had to be split into two or more completely independent constructional units with provision made for each unit to shrink for a period of 28 days without any restraint whatever from any other adjacent unit. A shrinkage gap, equal to the stipulated lap length of the largest bar to cross this gap, was required to be provided between the independent constructional units. All bars from one unit would be lapped, at the shrinkage gap, with their corresponding bars in the adjacent unit. Thus, during the initial shrinkage period of 28 days, the lapping bars would, in effect, slide past each other without any transfer of stress from one to the other. It was only after the elapse of 28 days that the shrinkage gap was permitted to be concreted. By this means, shrinkage stresses and shrinkage cracks were greatly reduced (Figure 9).

In contrast to this, the writer is currently dealing with a problem building where the designers had failed to make any kind of provision whatever to deal with shrinkage strains despite the large expanses of reinforced concrete involved. This has led to the formation of innumerable cracks through most of which water in substantial quantities had entered, or continues to enter, the building. When taken in combination with other negligent design features in respect of drainage, waterproofing, insulation and finishes, as well as some constructional shortcomings, this has led to a considerable loss to the owner.

It should always be borne in mind that, inter alia, shrinkage has a profound effect on the performance of concrete slabs under edge and intermediate restraints. Design engineers should, therefore, introduce shrinkage gaps and, if necessary, contraction joints at suitable locations. The details shown in figs 5b, 6 and 7 would be applicable not only to dealing with problems of differential settlement but also large-scale contractions due to shrinkage which cannot be handled even by the provision of shrinkage gaps.

11.0 Conclusion

There are no easy routes to design and construct flawless reinforced concrete flat roofs. As in most endeavours - whether they be in engineering or in other fields - it is the giving of thorough attention to detail which will ensure a successful outcome.