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Repair and/or Strengthening in Function of the Diagnosis on the Structural Failure

Réparation et/ou renforcement de structures en fonction de la prévision de ruine

Reparatur und/oder Verstärkung von Stahlbetonbauwerken aufgrund der Ursache der strukturellen Mängel.

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SUMMARY

Five case studies of structural failures are presented where the successful result of the repairs, in terms of a satisfactory behaviour and an acceptable performance, was based on the correct assessment of the cause of the distress, and on the appropriate decision with regards to relating the kind of repair or structural modification to the actual cause of the structural failure.

RÉSUMÉ

Cinq cas de ruines de structure montrent que le succès des réparations, afin d'obtenir un comportement satisfaisant et un fonctionnement acceptable, est fondé sur une évaluation correcte de la cause du dommage et sur une bonne décision quant au rapport entre le genre de réparation ou modification structurale, et la cause des désordres structuraux.

ZUSAMMENFASSUNG

Fünf Fallstudien von strukturellen Schwächen werden diskutiert, bei denen das erfolgreiche Resultat der Reparatur - zufriedenstellendes Verhalten und akzeptable Brauchbarkeit - auf der Voraussetzung basiert, dass die Ursache korrekt erkannt werden kann und dass eine adäquate Entscheidung gefällt werden kann bezüglich der Art des Reparatur oder der strukturellen Modifikation aufgrund der Ursache der strukturellen Mängel.

1. INTRODUCTION

In our work as professional engineers, we are not always in the enviable position of conceiving and designing entirely new structures. For this latter task we are all able to apply our academic training and we can also make use of computers as tools and structural Codes as general guides.

The problems presented by structural failures are different. In order to diagnose correctly, to be able to identify the cause or causes of structural distress and to propose adequate repairs, (or most often substantial modifications when the causes of failure are conceptual), we can only resort to experience and informed engineering judgement.

2. THE CASE STUDIES

2.1 Stair-Treads Failure

2.1.1 Description of the Structure and Mode of Cracking

In a high-rise building a sizeable number of the precast stair-treads (Fig. 2.1.1) developed flexural cracks in the underside even before the completion of the building. The cracks appeared near mid span: one single major crack on some treads, or two closely spaced cracks on other treads. The width of most cracks exceeded the acceptable upper limit of 0.3mm.

The investigation concluded that no abnormal loading had been applied to the staircase.

2.1.2 Causes of Cracking: The Probable or Real Cause as Opposed to the Assumed One

At first glance it appeared that there was an underestimation in the calculations of the service loads, and by increasing the reinforcement cross-section we could cater for a greater live load or increase the impact resistance.

However it was found that either for simplicity or for practical reasons, the cross-section of the reinforcement was in fact in excess of that required by analysis, while the compressive stress of the concrete as checked by calculations was within acceptable limits.

The sizing and detailing of the treads based on the theory of elasticity and limit state design seemed to be perfect, but unfortunately, only on paper.

We also discarded another possible cause of the failure being as a result of a small misplacement of the welded fabric within acceptable tolerances. In our opinion there are two other aspects which deserve special consideration:

i) The dimensions of the precast treads are such that the reinforcement provided is near or at the neutral axis of the section and is therefore unutilized when the first loading occurs.

   At this stage the treads will behave as precast mass concrete units, where the concrete alone has to withstand the tensile stresses in the underside. As soon as the modulus of rupture is exceeded, cracks appear. In our opinion the assumption that the initial cracks will slowly propagate under repeated loading till they reach the reinforcement, and from then on, the section will behave as a normal cracked section in bending (as shown on calculations), is nothing else but wishful thinking.

It seems that once small cracks appear under the first passing load, they develop with great speed under subsequent loads, causing a sudden excessive permanent deflection or even a complete "V" shape collapse of the tread associated with crushing of the concrete in compression.

It becomes an energy absorption capacity problem rather than one of elastic design.

ii) The mass of the slab is small compared to that of a person. This increases the effect of any sudden load application. It would appear unwise to apply an impact factor appropriate to a much higher dead load to applied load ratio.

2.1.3 Remedial Measures

The existing failed treads were discarded. Being confident of the validity of the diagnosis described in i) and ii) the new precast treads were increased in depth to 60mm in order to improve, even if very little, the ratio between the concrete mass and the live load mass, and also to permit a more rational location of the reinforcement. (Fig. 2.1.3)

Also, in order to have the reinforcement as far as possible from the neutral axis, the mesh was located at only 10mm from the bottom of the precast plank, disregarding the Code recommendation for cover. Being in sheltered conditions we considered that the risk of corrosion was negligible.

The cross section area of the reinforcement was not increased. After more than seven years in service, the new treads, continue to perform satisfactorily.

2.2 The Failure of a Control Joint

2.2.1 Description of the Structure and the Problem

The structure is an extended flat plate for a Shopping Centre.

In view of the size and the irregular plan shape of the structure, a control joint had been wisely introduced in order to minimise the adverse effects of shrinkage and temperature.

But unfortunately all other basic rules for the proper detailing of a control joint were ignored.

Figures 2.2.1 and 2.2.1 (a), show how the joint was originally detailed and the extent of the subsequent damage.

It can be appreciated that the insufficient width of seating, the erroneous detailing of the reinforcement and the total lack of any kind of sliding strip to reduce friction, led inevitably to the result shown on Figure 2.2.1 (a).

2.2.2 Remedial Works

Since to improve the detailing of the reinforcement would have required too much cutting back of the concrete slab, attention was turned to two other aspects: sufficient width of slab seating and much better sliding capability.

As shown on Fig. 2.2.2 the new support was an angle 152 x 152 x 12 with vertical legs of the same size welded to it at 1.0m centres; all, hot dip galvanized, including masonry anchors. This new support was wide enough to allow a good end development length of the slab bottom bars, making unnecessary to worry about improving the detailing of the existing reinforcement.

It was decided to add the vertical legs for two reasons:

i) It was considered unwise for the new support to be bolted to the beam only through the previously damaged area. The additional bolts through the vertical angles were clearly anchored in a perfectly healthy area of the reinforced concrete beam.

ii) With only the horizontal angle providing support, the bolts would be subjected (in addition to shear), to a pull-out action due to the eccentricity of the load. With the vertical legs fixed with two bolts each, this effect should be substantially reduced.

All bolts were long enough to reach the core of the support beam. Before fixing the support to the reinforced concrete beam, the spalled area was duly cleaned of dust and debris and made good with a suitable epoxy.

To ensure adequate stiffness of the supporting flange of the angle, 10mm plate fins were welded at regular centres. To facilitate handling and fixing, the new support was made up in units 2m in length.

A stainless steel on teflon sliding strip was installed between the angle and the slab for the full length of the joint.

From the first inspection of the deteriorated area, propping was recommended in order to prevent more severe damage or even possible total failure, while devising the repair system.

A line of propping to the slab was located close to and parallel to the joint, but at sufficient distance to allow repairs to be carried out.

After more than three years in service the solution appears to be safe, and at the same time permits the relative movement of the two sides of the structure.

2.3 <u>The Column Failure Case</u>

2.3.1 Description of the Structure and the Problem

The structure was a single storey institutional building with an extensive waffle slab.

A control joint had been introduced in a suitable location to reduce shrinkage and temperature effects as well as to prevent a stress concentration where, in plan, the slab has a sudden change in shape.

At one end of the control joint, both sides of the structure were supports by the same massive column, 2500 x 450 in section. (See Fig. 2.3.1)

The problem was that an approximately vertical crack developed in the column. It started at the top of the column in the vicinity of the slab control joint, and extended down for about 2m.

We were commissioned to assess the cause and seriousness of the fault and to devise repairs if considered necessary.

2.3.2 Remedial Works

In this case again the structure was clearly indicating the cause of distress.

The design was inherently faulty: the initially correct introduction of a Control Joint was not carried through to its logical conclusion. It is true that the slabs were not poured monolithically with the column, but no sliding pads were used to allow for movement.

The substantial vertical load combined with the high friction co-efficient concrete to concrete produced an unacceptable restraint to shrinkage.

To make things worse, starter bars connected the column to both slabs, contradicting still more the concept of a control joint.

It was recommended the demolition of part of the column back to the line of the slab joint.

The edge beam supported by the column section to be demolished was propped by two UC's adequate to support the load.

The demolished section was rebuilt as an independent column, with a well formed vertical joint in the plan of the existing slab control joint, down to the top of the footing. (See Fig. 2.3.2.)

Each separate column was checked for the load of the corresponding slab area and results were satisfactory.

Before forming up the new part-column the rough face of the undemolished side of the column was made good and a 10mm polystyrene strip was applied to it to form a permanent joint.

All that had to be done was to provide a well-formed joint where the structure tried to forcibly create one by cracking the column as a protest against the contempt and misunderstanding shown in the design for the natural behaviour of the structure.

3. CONCLUSIONS

The first case illustrates that even apparently very simple structures should not be hastily approached with routine design and uncritical compliance with the code.

Mathematical analysis and computers are of no help either for appraising the causes of failure or for providing the solution for repairs.

The last two cases show that bad detailing, lack of consistency in pursuing a design concept and/or a lack of understanding of structural behaviour inevitably lead to failure.

All cases demonstrate that repairing most often does not mean only patching or strengthening a faulty structure.

We have to resort to experience and informed engineering judgement to find out the real cause of the failure and to devise not merely repairs but total modifications to the structure in order to correct built-in errors of concept.

I should also emphasise that although this field is a somewhat restricted aspect of structural and civil engineering, it is a stimulating and challenging one because there are not all those standards and regulations which have so often impaired clear thinking and reduced many of our engineer colleagues to "book keepers of reinforcement" as somebody once put it.

4. REFERENCES

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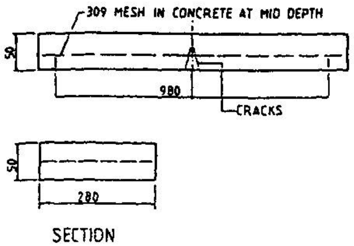

FIGURE 2·1·1

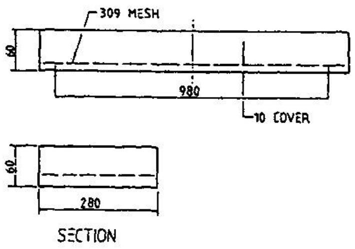

FIGURE 2·1·3

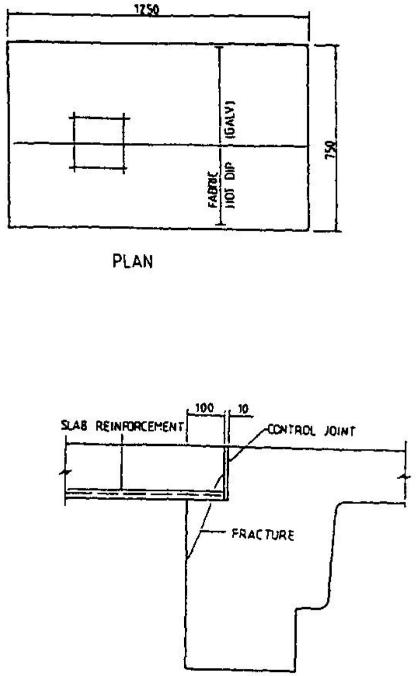

FIGURE 2.2.1

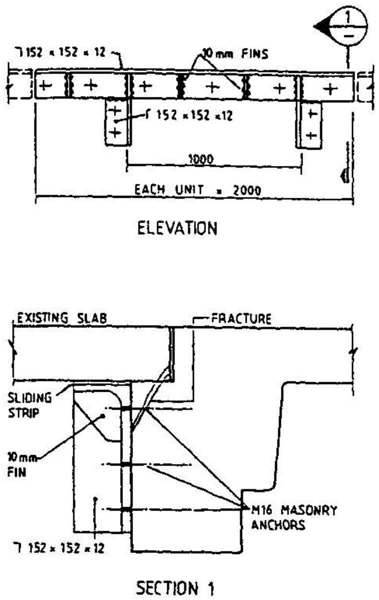

FIGURE 2.2.2

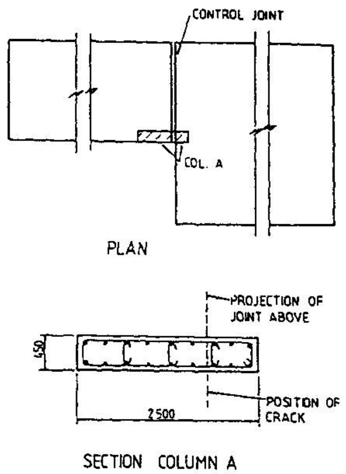

FIGURE 2.3.1

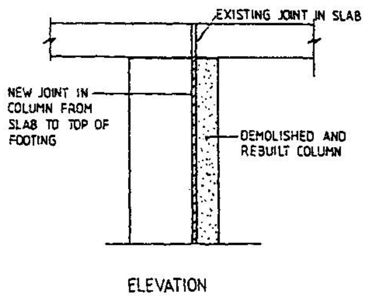

FIGURE 2.3.2

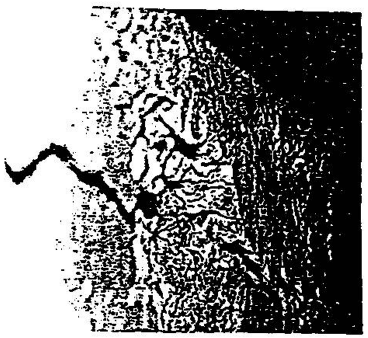

FIGURE 2.2.1(a)