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DESIGN & CONSTRUCTION ISSUES WITH RC ENCASEMENT OF WIDE BEAMS SUBJECTED TO FLEXURE AND TORSION

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ABSTRACT

Retrofitting and rehabilitation are synonymous though they represent two contextual meanings when it comes to strengthening. Former one can be associated with strengthening of the existing structures for gravity loads whereas the later also includes seismic strengthening in addition.

Reinforced Micro-concrete encasement is a well-established technique in the field of strengthening for both gravity loads as well as seismic demands. Well executed retrofit structure using Micro-concrete encasement is expected to behave monolithically with the existing structure.

The present paper deals with specific issues related to design as well as construction of RC encasement of wide and shallow beams subjected to flexure as well as torsion based on a live project. While flexure is easily conceivable, torsion has crept in due to adjoining cantilever slab of 5m.

Paper presents in brief the specific design features adopted for design, specific and innovative measures proposed for moment transfer at column ends of the retrofit beam. In addition, limitations in the present codal provisions are also presented.

Specific construction features, issues in execution are discussed in detail based on the live case. Particular demands such as de-shuttering sequence, post construction behaviour are also presented in detail.

INTRODUCTION :

Retrofit schemes are required for structural elements may be due to distress, inadequate design provisions or due to degradation beams etc. Retrofitting of the building as discussed herein had become essential due to inadequate design provisions. Given the structural location, beams are subjected to flexure, shear as well as torsion as ell s differential deflections.

Solutions adopted for retrofitting (i.e. other than seismic strengthening) are quite different from rehabilitation (seismic strengthening)[1]. For normal cases of retrofitting of frames, measures such as i) beam shear capacity strengthening, ii) shear transfer strengthening between members, iii) stress reduction techniques, iv) column strengthening, v) flexural strengthening, vi) connection stabilization & strengthening, and vii) crack stabilization are common.

For beam members, flexural strengthening is usually the needed area. The conventionally adopted techniques to increase flexural capacity include: a) external post tensioned reinforcement, b) span shortening, c) bonded steel plate reinforcement, d) correction of deflection with bonded steel plate, e) concrete overlay & section enlargement[2,3]. Nowadays, fiber wrap has gained popularity due to ease of execution.

BACKGROUND OF THE PROBLEM

The building under reference is a multi-storied structure and part plan as shown.

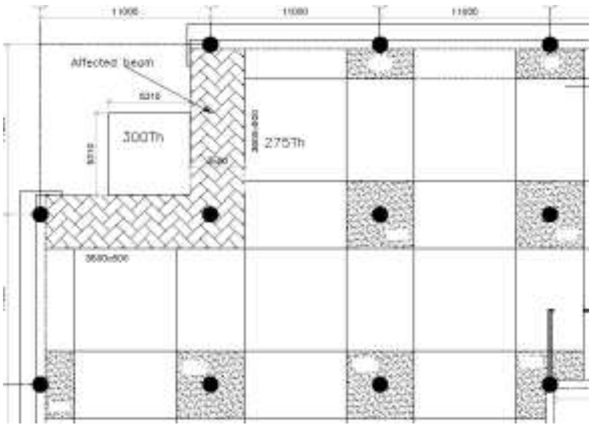

Fig 1: Part of the slab and affected beams

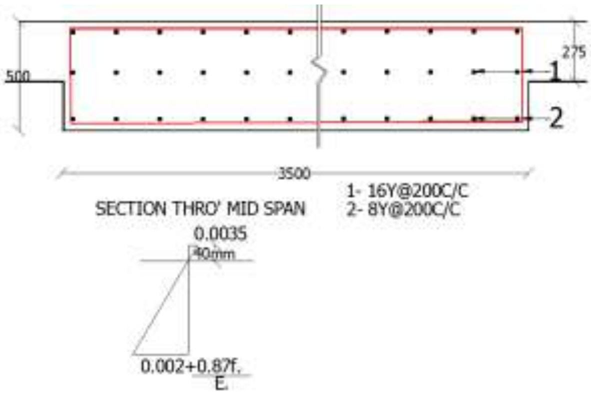

Fig 2: Section through Mid span showing provided steel & corresponding strain diagram

The beams shown as affected are located at four quadrants and provided with 5.5m cantilever slab at each corner shown in Fig 1. Beams are 11m in spans and 3500x500 in cross section and designed with M25 grade concrete and Fe 415 grade steel. Hence the beams under reference are subjected to flexure, shear and torsion.

It is interesting to note that as per designer's intention, beams are adequately designed. The issue with the design was that the steel provided in layers as shown in fig 2. Bottom most layer had 8Y@200 c/c (250 sq.mm /m) while at slab level, it had 16Y@200 c/c (1000 sq.mm/m). Hence large area of steel was available at close to mid depth and not at extreme fiber. Required steel as per design is 2100 sq.mm/m whereas equivalent steel provided was 900 sq.mm/m after due consideration for lower stress for higher level steel as shown [4]. This miscalculation led to instantaneous cracking in beams on de-shuttering. Hence, there was a need to strengthen the wide beams while accounting for flexure, shear and torsion.

Fig 3 shows view of the building and fig 4A&B show cracked beams

Fig. 3. The Structure

Fig 4A : Crack in the beam

Fi 4.B : Typ cracks in mid span

Summary of the design concerns:

a). Strengthening for flexure and shear
b). Specific measures for torsion
c). Measures for moment continuity at support- In this the concern is that good part of the bottom and top steel to be provided is not the column due to circular columns and embedment is limited. Hence, innovative solution was thought of.
d). Measures for differential deflections
e). Appropriate de-shuttering sequence

REVIEW OF EXISTING SCHEMES WITHIN THE FRAME WORK OF THE PROBLEM

Of all the methods available for retrofitting, concrete encasement, steel plate jacketing and fiber wrap were actively considered for final selection. Due to the limitations associated with fiber wrap [1], the same could not be used. Important excerpts from [5] are as given below:

Clause 1.4: "FRP systems work on sound concrete and should not be considered for applications on structural members containing corroded reinforcing steel or deteriorated concrete".

Based on the above, it is clear that fiber wrap is not a viable solution in the present case. In schemes using steel plates, two methods are known, a) steel plate adhesion and b) steel plate jacketing. From [2], it is clear that steel plate jacketing enhances deformation capacity while plate adhesion improves flexural and shear capacity. A word of caution from the literature indicates the need to understand both the short-term and long-term behavior of the adhesive used in steel plate adhesion. Besides the above, due to cost concerns, micro concrete encasement was finalized.

SPECIFC DISCUSSIONS ON DESIGN METHODOLOGY

a). Design for flexure

Typical moment contour based on ETAB analysis is presented in Fig 5. Due to cantilever effect, moments in the beam under reference are much higher than rest of the locations.

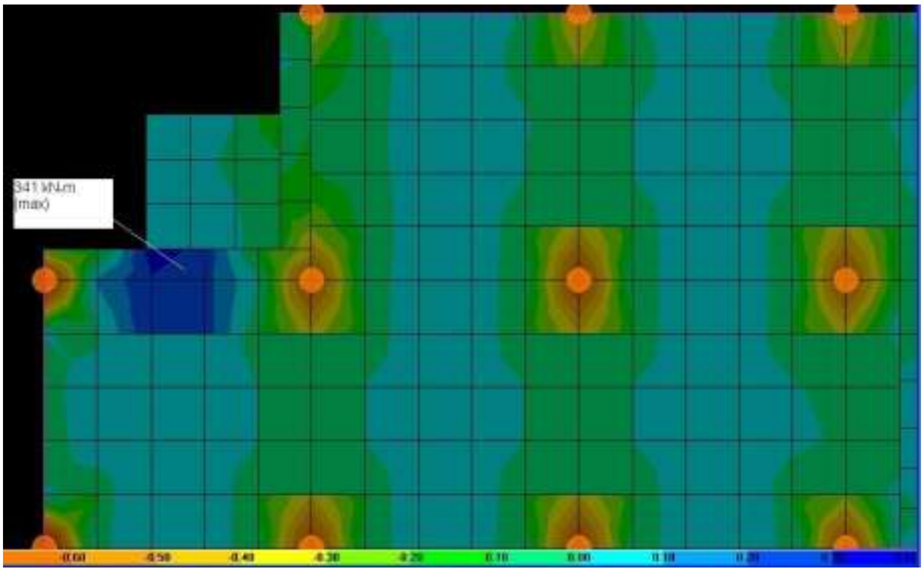

Fig 5 : Moment Contours in Y direction

Since, props were provided, it is a propped construction and steel provided is fully effective as per the corresponding strains.

Overall beam depth and width are increased by 75mm on all sides. Following specific measures were taken in the design calculations

i). Moment gradient : Moment averaging which is a common practice in wide beams is not considered due to partial cantilever. As can be seen from fig 5, steep increase in moments around cantilever edges along main beam and it is a potential source of cracking.

ii). Equivalent effect of long term deflections : Based on the fact that design moment corresponding to short deflections, additional moments are calculated based on long term deflections. This fact is specifically considered as large cantilever is the potential source for enhancing deflections and torsion will enhance beam cracking. Long term deflections are based on full dead load and partial live load. Reduction in deflections due to enhanced section and measures for reducing end deflection of cantilever are duly accounted for in the calculations. Beams are redesigned for 540 kNm as against 341 kNm as per original design.

$$M_f = M_d + M_{ld} \qquad \text{------------------------------(1)}$$

Where M_f is final moment , M_f is original design moment and M_f is moment due to difference between short term and long term deflections, calculated in accordance with ACI 318[6].

iii). Relocation of Neutral axis(NA): As shown in fig 2, NA depth is 40mm from top and in the close range of compression reinforcement. Design moment enhancement for the reasons explained in (ii) required larger steel area which helped in increasing neutral depth to 90mm from top ensuring compression steel is effective.

b). Design for Horizontal Shear

In the case of retrofitting with encasement, interface shear and its resisting mechanisms assume significance. Horizontal shear which arises due to couple being formed by moment need to be resisted by following mechanisms

i). Surface friction
ii). Anchors

The beams are hacked to hammers to get roughening and laitance removed with scrubbers. As per [2], this amounts to intentionally roughened surface and accordingly,

$Vu \leq \phi V_{nh}$ where V_u is factored shear force, ϕ is the strength reduction factor and V_{nh} is Nominal horizontal shear strength $0.55 b_v d$.

Enhanced shear strength is suggested by ACI for groove cut which was not possible due to practical concerns and hence not considered..

For the calculation of anchors, resultant of shears arising out of moment and torsion is considered as explained below.

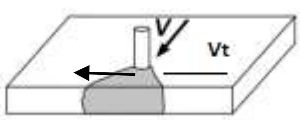

Fig 6: Representation of bi-directional shears due to moment and torsion

Where V is due to horizontal shear in Transverse direction and Vt is due to torsion as a specific case.

Resultant is taken as vector product of shears

Normal reinforcement is used as anchors and fixed with polyester resins. Pull out test was conducted. Ties are calculated as per standard design provisions.

c). Establishment at ends for moment continuity-

One practical concern was on how to ensure moment continuity of additional steel at top and bottom as shown below. To overcome this issue, an innovative approach was adopted as shown in fig 8. Purpose this additional column was to introduce shift slope line to new column so as to ensure fixity. The proposed columns are in structural steel and are to be provided with heads properly fixed at top and bottom. This concept may be akin to span shortening but different from other conventional measures where original column is provided with heads. Hence main difference is in achieving shift in slope away from main column.

These columns would be provided before laying floor finishes and wall construction.

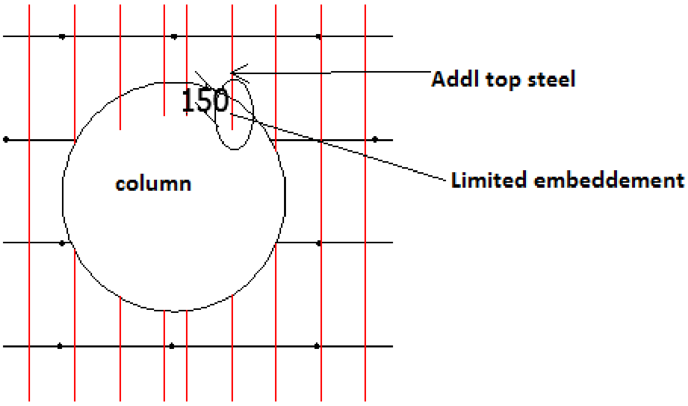

Fig 7: Limited embedment of top and bottom steel at columns

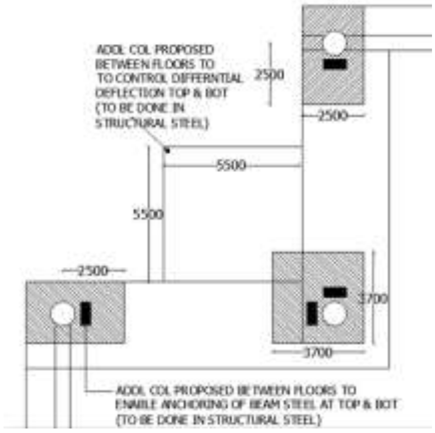

Fig 8: Proposed additional columns with heads

d). Measures for Differential deflection

Large cantilever slab ends are prone to long term deflections and differential deflections. This is a concern when ends are provided with glazing which can cause breaking in glass. To avoid the same, prop is provided at the far end corner as shown in fig.8. Besides reducing torsion, it will also reduce differential deflections. As it is additions to be introduced after short deflections occur, it is not required to be designed for dead loads.

e). De-shuttering sequence

To avoid jerks of load transfer, de-shuttering is done in a sequential manner from cantilever ends and progressed towards spans. Total operation was completed in 2 days. Further, props are marginally loosened and allowed slab to adjust before complete removal.

EXECUTION :

ℜ Supporting the Beam :

The first stage of the execution is supporting and propping the beam before execution, since it is important not to encase the beam in deflected state. At the same time the supporting system should not obstruct the encasement.

Hence truss type beam was fabricated by 2 nos 16 mm plates separated by 16 mm bars as can be seen in fig.9. The gap between the plates is maintained at 75 mm equal to the encasement thickness. Series of trusses were provided at a spacing of 1.0 m c/c. Adjustable props were provided below the trusses.

Fig.9. : Truss Supports to beam

ℜ Surface preparation and fixing of shear connectors.

The complete concrete surface of concrete was hacked, roughened and cleaned. 20 mm dia holes to a depth of 100 mm and 16 mm dia rebar fixed in the drilled hole using Polyester Resin Grout. For testing the efficacy of the shear connector, random shear connector is selected and suspended with weights. The required pullout strength is 500 Kgs, however, on testing it is noted that at 1350 kgs, the rebar has sheared up but the anchor and grout was intact. The same can be seen in fig.10 below:

Fig. 10. : Testing and failure pattern of Shear connector.

ℜ Reinforcement Fabrication :

Reinforcement was fabricated as per design specification to the underside of the beam threading through the trusses and tied to the shear connectors. The reinforcement was anchored into the column by drilling a horizontal hole to a depth of 300 mm and fixing the rebar using polyester resin grout. Fig. 11 Shows the reinforcement details & after fabrication and anchoring of reinforcement into the column.

Fig 11 : Reinforcement Details & after fabrication and anchoring

ℜ Fabrication and fixing of Shuttering :

Once the reinforcement is in place, leak proof ply shuttering was fabricated and fixed in place. At this stage care is taken that the supporting props are removed one row at a time and re-fixed after fixing of shuttering. This activity was carefully carried out so that the beam is not left un-propped. Fig. 12 shows the shuttering after fabrication.

Fig. 12 : After Shuttering fabrication

ℜ Preparations for Micro Concreting :

Proper preparations and planning is the basis for successful application of Micro concreting and execution of the project. Some of the important aspects to be considered for the Micro-concreting to the underside of the beam to a thickness of 75 mm are :

The concrete has to flow to a total length of 24 m and to a width of 3.5 m and with only 75 mm thickness at the underside of the EXTRA WIDE BEAM. To enable this the following were considered :

A) Flow of Micro Concrete : The flow of Micro concrete was fixed and it was ensured that the flow spread was atleast 750 to 800 mm (using a standard Slump Cone). Series of tests were conducted at site and the water content and percentage of aggregate were fixed. Fig 13. Shows the Spread Test.

B) Pouring Head for Micro Concrete : The horizontal flow of the micro concrete should be atleast 2.5 to 3.0 m below the beam. By just providing hole in the beam of 450 mm thick, the head of 450 mm is not sufficient for achieve the flow of 2.5 to 3.0 m that too with a thickness of only 75 mm. In view of the same, it was decided to place the micro concrete from the next floor by core drilling a hole in the next floor also. 100 mm dia core holes have been drilled in the beam (to be encased) and also in the beam in the next floor. The spacing between the core holes was limited to less than 2.0 m. The sketch in fig.14 shows the concrete placement arrangement. The figure also shows the inlet vent fixed in the core drilled hole in the beam.

Fig. 13. : Micro concrete spread test

Fig. 14. Arrangements for concreting

ℜ Encasement of the Beam :

Once the preparations are in place, the Micro concreting to the underside of the beam was carried out. Constant watch was maintained to observe the flow of Micro concrete by looking through the core holes in the beam. It was very important that the concrete flows only from one side to the other slowly displacing the air and ensuring that there is no air locking. Fig. 15 shows the concreting in progress.

Fig 15. : Micro concreting in progress

De-shuttering was carried out after 7 days. The fig.16 shows the beam after the de-shuttering. It can be seen clearly the embedded trusses which are sacrificed in the concrete.

Fig. 16 : Beam after de-shuttering

CONCLUSIONS :

A total of 8 such beams have been encased using Micro concreting. Careful planning, application and execution were the key to success of the project. The sequence of execution was so planned such that one beam was encased every week.

As shown in the paper, conventional approach to designs of strengthening need to be modified duly accounting for combined action such as flexure and shear, shear and torsion etc. Further there is a need to be vigilant to study strains and consequent impact on the element being strengthened. Comprehensive guide lines need to be developed for such designs as principles available for composite are limited for use in these applications.

Paper clearly identified the practical concerns in concreting wide beams which are source of air pockets and improved methodology for proper flow of the grout. Formations of micro cracks due to smooth surface of grout are observed in the first beam but effectively eliminated by sue of sprinkled sand.

As discussed, de-shuttering sequence shall be in accordance with envisaged behaviour of the structure and shall not be as per conventional means

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