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Strengthening of Reinforced Concrete Beams

Renforcement de poutres en béton armé

Verstärkung von Stahlbetonträgern

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SUMMARY

Results of laboratory tests on bending strengthened reinforced concrete beams are presented. The laboratory tests threw light in the efficacy of different techniques of bending strenghtening.

RÉSUMÉ

Les résultats d'essais sur des poutres en béton armé renforcées sont présentés. Les essais exécutés ont permis de connaître et de comparer l'efficacité des différentes techniques de renforcement.

ZUSAMMENFASSUNG

Es wurden verschiedene Methoden zur Versteifung von Stahlbetonträgern untersucht. Die durchgeführten Versuche lassen die Wirkung der verschiedenen angewandten Verstärkungstechniken auf die Durchbiegung der Balken erkennen.

1. INTRODUCTION

Repair and structural strengthening are matter of great importance today, for they increase safety and durability of structures. Premature deterioration (corrosion, cracking, deformation,etc), design or construction faults, increase in live loads, accidents,etc, are some of the most frequent causes.

Papers and books describing strengthening or repair executed upon existing structures, sometimes with load tests, are frequently obtained (1),(2),as well as papers dealing with laboratory tests on models strengthened using a certain tech nique (1), (3). It is not easy, however, to find papers comparing different strengthening techniques, which motivated the present research.

Reinforced concrete beams, strengthened with additional bending reinforcement were tested, and efficacy compared among different techniques. Later, other re inforced concrete beams were repaired with grout, substituting concrete crushed by bending. These beams were once again loaded, a few days after repair, and the results were analysed. The description of the laboratory tests and the outcome are described as follow.

2. STRENGTHENING OF BENDING REINFORCEMENT

Three different bending strengthening techniques of reinforced concrete beams were compared: shotcrete, glued mortar and glued steel plates.

2.1 Beams and Type of Strengthening

Twelve equal beams, 2,0 m in length each, were poured (fig. 1). Three of them were not strengthened (beams SB), and were used as a lower-bound limit. Three beams were strengthened with shotcrete (beams SH, fig. 2), and other three with glued mortar (beams MB, fig. 2). The remaining three were strengthened with epoxy-glued steel plates. For the beam in fig. 3.a (beam SP1), only epoxy was used to connect plate to concrete. For beam SP2 in fig. 3.c, U plates were used to connect steel plate to the beam, and for beam SP3 (fig. 3.b) bolts were used to assure a better connection between plate and concrete.

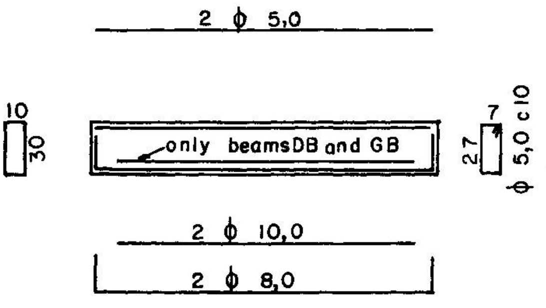

Fig. 1 Beam reinforcement

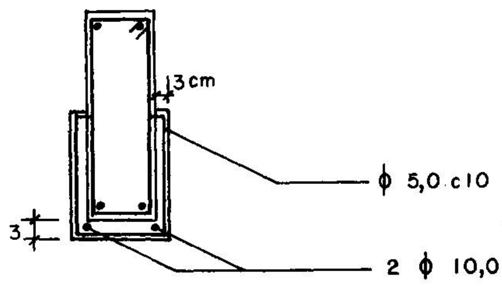

Fig. 2 Shotcrete and glued mortar

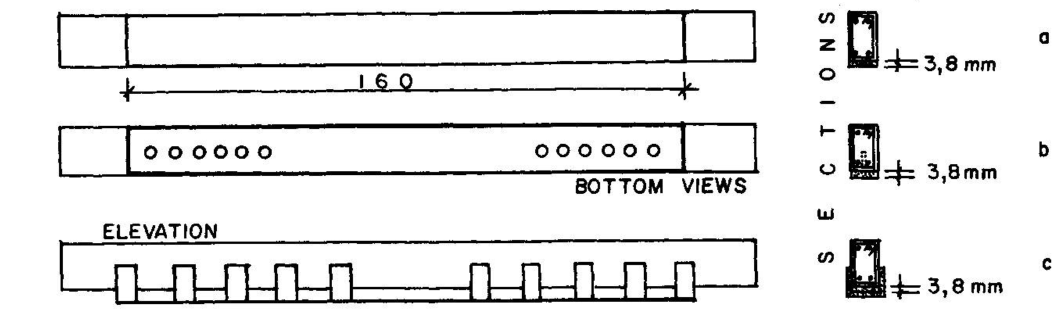

Fig. 3 Epoxy-glued steel plate strengthening

Three other beams received a second reinforcement layer before pouring (beams DB in fig. 1), and were used as an upper-bound limit.

2.2 Executed Tests

All beams were tested for bending, with a 1.85 m span and two equal concentrated loads distant 0.30 m between them. During the tests, vertical displacements, bending and shear crack widths, and specific strains along depth at mid-span, were measured.

Fig. 4 displays "load x curvature" diagrams, and table 1 shows the design loads (Pd), the theoretical (Pu) and the experimental (Pu, exp) collapse loads (4).The listed values are total loads applied to the beam (sum of two concentrated loads).

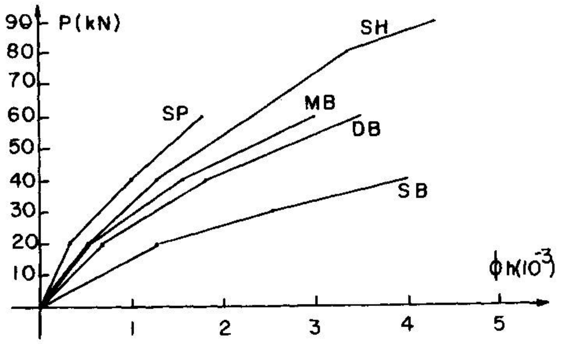

Fig. 4 Load x Curvature diagram

BEAM	P_d	P_u	$P_{u,exp}$
SB 1/2/3	33,6	46,5	51,5
SH 1/2	71,3	115,0	119,5
SH 3	71,3	115,0	101,5
MB 1/2/3	71,3	115,0	91,3
SP 1	51,0	77,0	70,0
SP 2/3	76,0	90,6	99,0
DB	60,0	98,3	106,0

Table 1 Theoretical and (kN) experimental loads

2.3 Tests Results Analysis

The following items were noticeable during the tests:

- All tested beams exceeded the design loads;

- Two beams with glued steel plates and special devices to assure connection to the beam, SP2 and SP3, exceeded theoretical collapse load by 9%;collapse load for beam SP1 (fig. 5) was lower than the theoretical one by 10% (5); all beams have collapsed showing a disconnection of the steel plate from the beam (although this was expected only for beam SP1), and none of them have showed rupture of the steel plate.

- Two shotcrete beams surpassed theoretical collapse load by 4%; the other one failed with 88% of expected load, probably because of an old concrete area with

-out rugous surface (fig. 6);

- Beams strengthened with glued mortar failed with 79% of the expected load;

- Beams strengthened with glued steel plates were the stiffest, followed by shotcrete strengthened beams;

- Beams strengthened with glued steel plates showed the best behaviour for crack width, with no cracks in strengthened region until the design loads were reached; nevertheless, beam SP1 collapsed soon after the first horizontal crack in the concrete cover occurred (fig. 5).

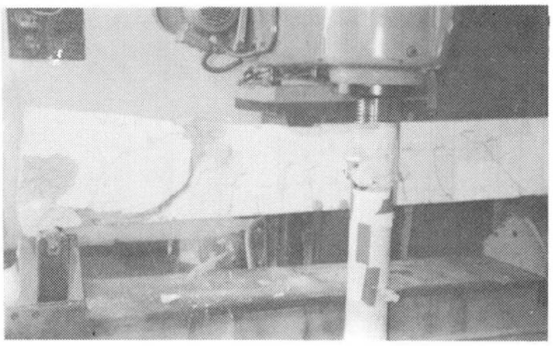

Fig. 5 Steel plate beam

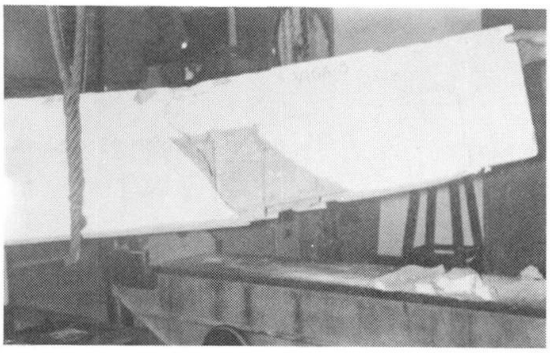

Fig. 6 Shotcrete beam

3.GROUT REPAIR

3.1 Beams and Repair Execution

During the second stage three beams were built (identical to DB beams), and named GB beams. These beams were subjected to test loads until failure, which always occurred crushing compressed concrete without yielding of the tension reinforcement.

These beams were repaired, by pouring grout (high strength expansive mortar) to substitute the damaged concrete.

3.2 Results Analysis

Beams were once more loaded, and fig. 7 shows "load x curvature" diagrams for tests before and after repair. Collapse loads before and after repair are presented at table 2, and a repaired beam before and after failure is showed at figures 8 and 9.

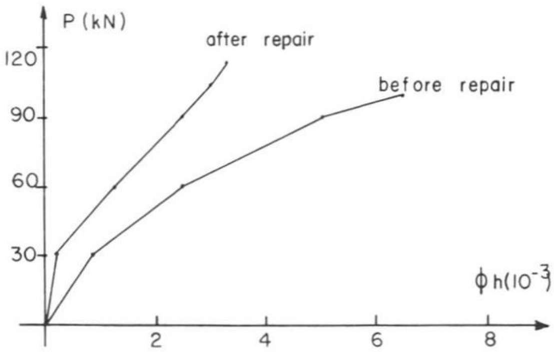

Fig. 7 Load x Curvature diagram

BEAM	$P_{u,exp}$ before	$P_{u,exp}$ after
GB 1	109,0	124,5
GB 2	108,5	130,0
GB 3	106,0	88,0

Table 2 Failure loads before and after repair (kN)

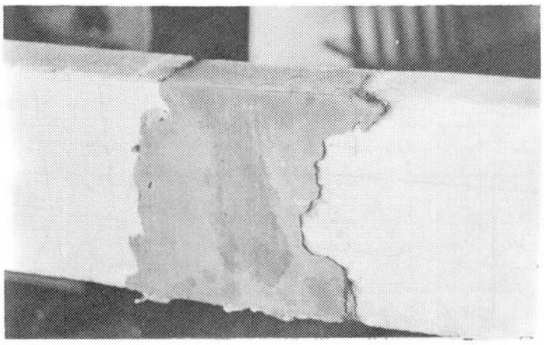

Fig. 8 Grout repaired beam

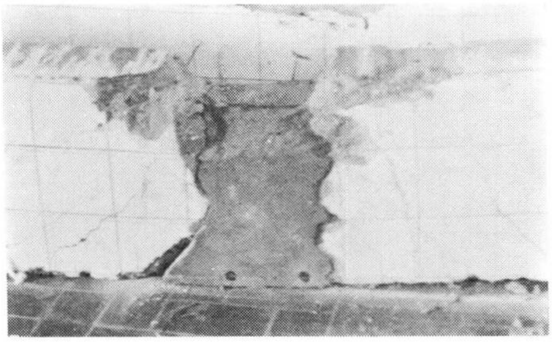

Fig. 9 Grout beam after failure

The following items were noticeable during the tests:

- Two repaired beams, loaded at ages 4 and 8 days, presented increase of collapse loads of 14% and 20%, respectively;
- The other one failed with 83% of initial collapse load, probably because before use, the grout was maintained in an open bag for 40 days, at risk of hydration by the 75% local air humidity; this result was dismissed.
- Although strains measured at the grout (2^{nd}stage of load) were smaller than at the initial concrete (1^{st} stage of load), as displayed at fig. 7, vertical displacements were larger, because a great part of the beam was already cracked.

4.CONCLUSIONS

Some conclusions could be extracted from this research:

- Strengthening with glued steel plates and with shotcrete agree very well with the expected values of failure loads (the expected increase in initial load at about 100% was reached);
- Repair of the damaged concrete area with grout reached very good results, and can be used when it is necessary to load the structure at early ages;
- From the economic point of view, shotcrete would be used to strengthen large areas, where it is possible to obtain great productivity, and the cost of equipment mobilization is attenuated;
- Glued steel plate strengthening is specially indicated for little areas, because large equipments are unnecessary; this technique, however, requires local temperatures below 70º C, and the designing of an efficient connection between steel plate and concrete beam;
- For all repair and strengthening techniques, a rigorous quality control is needed, including materials and execution, in order to warrant safety and durability.

5.ACKNOWLEDGMENTS

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