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Experimental Studies on RC Beams Strengthened with Epoxy and Polymer Grouting

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ABSTRACT

This study reports the results of rehabilitation study conducted on reinforced concrete beams to assess the structural ability of the repaired beams. Six reinforced concrete beams (RC beam) were cast in the lab and cured for 28 days. The beams were tested for its 90% load carrying capacity. The cracked beams were grouped in to two and the first is rehabilitated with epoxy grouting and second with polymer grouting. The treated beams were again tested for its maximum. By comparing the flexural behaviour of normal and rehabilitated beams, the structural behaviour of the RC beams was assessed. From the experimental results it was found that beams treated with epoxy and polymer were found to be more effective in load carrying capacity and the repaired beams shown higher ductility than the control beams.

Key words: Rehabilitation, grouting, polymer, epoxy resin, cracking, deflection, reinforced concrete

INTRODUCTION

In construction industry, stone masonry is a traditional practiced method for several centuries and later concrete alters that. Because of the cost effectiveness, durability, strength and bendability, concrete plays a major role in construction engineering. For achieving the full life span of the structure it needs periodical maintenance. The structure may experience unacceptable loss in its life span due to adverse environment, changes in use of the structure, construction errors, degradation problems, changes in design code regulations and earth quake. In such cases, total replacement of existing structure may not be advisable and it is too expensive, if there is a possibility for increasing the life span of the structure by retrofitting. Cracks are the main reason for the deterioration of structure and during maintenance this will need special attention. Selection of repair material and method depends largely on the size, depth and area of repair required. Meier (1987) studied the flexural strengthening of concrete beams using thin CFRP sheets as reinforcement. He reported that 25% overall cost savings was achieved with CFRP than using steel. Kaiser reported the application of CFRP composites on tension side of RC beams. He also verified the strain compatibility over the cross section of the beam. He concluded that inclined cracking might lead to premature failure by peeling-off of the strengthening laminate. Saadatmanesh and Ehsani (1990) studied the performance of epoxy bonded FRP laminates on RC beams. They tested with four RC beams simply supported at their ends. They reported that the rehabilitated beam specimens performed better than the control beam and up to 70% of the ultimate load there was no sign of cracks. Al Zoubi and Li (2009) studied the effect of epoxy repairing on shear by experimenting with four reinforced concrete beams. They concluded that the cracks could be effectively restored by epoxy injection and it was strongly recommended for pre-cracked RC beams in shear before shear strengthening by using the CFRP sheets bonded-sides strips.

Singh *et al.* (1995), Czarnecki *et al.* (2000), Surlaker (2001), Vaysburd and Emmons (2001) and Vaysburd *et al.* (2001) reported the application of rehabilitation techniques for the reinforced concrete and masonry structures. Bhikshma *et al.* (2010) did experiments with six beams for M50 grade of concrete by applying two points load by taking 90% of the ultimate load. The failed beams were treated and loaded to its maximum. They found 15% improvement in flexural strength and lesser deflection was observed in the epoxy treated beam. Shash (2005) conducted an investigation on repair materials for damaged concrete beams and reported that epoxy grouted beam behaves well enough in load carrying. Abdel-Zaher and Ambulavanan (1998) discussed about the repair mortars ranged from simple plain cement mortar to complex formulation containing polymer latex, silica fume, methylcellulose, accelerator and carbon or glass fibers. The characteristics study includes compressive, tensile, flexural and flexural bond strengths. The test results showed the superiority of latex modified carbon and glass fiber mortars, followed by polymer latex modified cement mortar. The use of silica fume restricted the advantages gained by the use of polymer latex alone.

Shihada and Oida (2013) reported the performance of four cementitious repair materials such as Ultra high performance concrete, Ultra high performance fiber reinforced concrete, Normal strength concrete and Cement-based repair material on reinforced concrete shallow beams. They tested fifteen reinforced concrete beams under four point-loading and they found that all the four repair materials showed excellent flexural capacities ranging from 97-111% of the control beam. Mailvaganam (2001a, b) studied the performance of polymer based materials in construction industry. He reported the consequent defects and the specific mechanisms of degradation of polymer based material. He concluded that the knowledge about the performance and properties of polymer material used for repairing is very much important for the designer. Rashmin *et al.* (2001) reported a case study of rehabilitation study of a reinforced concrete framed building in South Mumbai constructed in 1950s. The study described the procedure of rehabilitation study conducted. After rehabilitation, NDT tests were conducted to test the strength of the structure. Surlaker (2001) discussed about the selection of repair methods and materials evaluation which is very important in the rehabilitation. They reported that the addition of polymers to cement mortar and concrete improves short-term and long-term properties.

The main aim of the experimental program is to study the flexural behavior of beams repaired with two different resin materials. In addition crack pattern and mid span deflection of the beams before and after rehabilitation are also evaluated.

EXPERIMENTAL PROGRAMS

Materials

Concrete: The beams are cast using the mix proportion 1:1.26:2.81 with a W/C ratio of 0.45 having a 28 days compressive strength of 25 MPa. Then, the beam specimens, used in the study, are wet cured for a 28 days period.

Repair materials: The cracked beams were repaired with epoxy and polymer grouting. The epoxy system used in the study consists of two parts resin and one part hardener; mix in a ratio of 3:1 with low viscosity of 150-300 cps. The resin and the hardener were hand mixed thoroughly using a special mixing tool for at least 5 min. For polymer grouting, Styrene butadiene rubber polymer was used. After strengthening, the specimens were allowed to dry for 2 days before testing in the laboratory temperature (27°C) to make sure that the epoxy had enough time to cure.

Test specimens

Dimensions and reinforcement: In the present study six reinforced concrete beam specimens of size 100 mm wide, 200 mm deep in cross section and 1.4 m long were cast. The cross section and the reinforcement details were shown in Fig. 1. The beams were reinforced with 2 bars of 12 mm diameter at the tension side and two bars of 10 mm diameter on compression side.

Preparations of test specimens for rehabilitation: The beams were loaded for its 90% maximum load carrying capacity. After testing, the cracked beams were separated in to two groups of three in each. In the first group the RC beams were rehabilitated with epoxy grouting and the second group remaining three RC beams were rehabilitated with polymer grouting.

For Grouting, the cracks were cleaned well to remove all dust and loose material by blowing compressed air. Holes of 8 mm diameter were drilled at 35 cm apart for installing entry ports (nipples). Suitable injection nipples were fixed in these ports and the cracks also be sealed using an epoxy sealing putty in order to retain the grouting epoxy. If the cracks were continued on both sides of the beam then nipples were installed on both sides and grouting was done on both sides.

The two components of epoxy injection grout shall be individually stirred, then mixed and injected into the nipples through a suitable injection pump exerting a uniform pressure. The operation shall be carried out from the lowest nipple until the resin comes out. After all the holes are completed, the nipples were capped and removed after drying of the epoxy. Figure 2 shows the epoxy injection during the beam repair. The same procedure was followed for polymer grouting operation also.

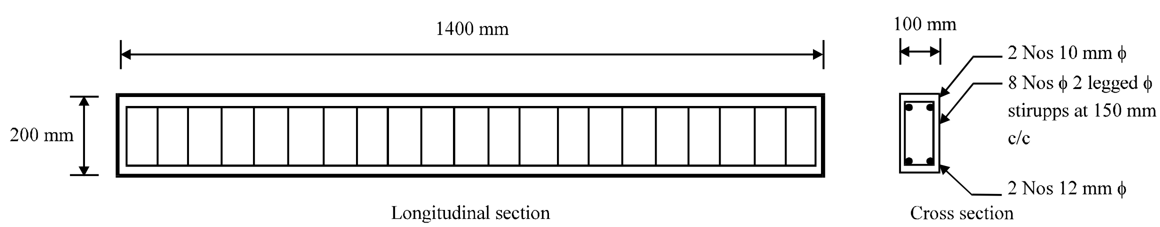

Fig. 1: Beam dimensions and reinforcement details

Fig. 2: Injection of epoxy resin on beams

Test setup and test method: The RC beams were tested in 2000 kN loading frame with 5 kN loading increment. The schematic diagram for the test setup was shown in Fig. 3. The load was applied at two points which are at the one third of the span of the beam. Mid span deflection and deflection under the load were measured using deflectometer having least count of 0.01 mm.

The performance of the beam was observed carefully for each load increment the values were recorded until the beam fails. All the beams were tested upto 90% of its maximum loading and then after grouting treatment they were tested till complete failure takes place.

RESULTS AND DISCUSSION

Load-deflection behavior of beams: A total number of six beams were tested upto 90% of its maximum loading and after distress, three beams were repaired with polymer and the other three were treated with epoxy grouting. The Fig. 4a and 5a show the load deflection behavior of control beams (1, 2 and 3) and the polymer grouted beams, respectively. The Fig. 4b and 5b show the load deflection behavior of control beams (4, 5 and 6) and the epoxy injected beam, respectively.

From the load deflection figures it was observed that the load deflection behaviour of all the beams were very similar before and after rehabilitation. The load carrying capacity of the both epoxy and polymer rehabilitated beam was higher than the control beam. Marthong *et al.* (2011) also reported that the results of epoxy resin grouted reinforced concrete beam specimens and found that rehabilitated beam gave slightly higher load carrying capacity than the beam before repair. In general the rehabilitated beams deflect greater than control beam. Epoxy rehabilitated beam deflects by an average of 13% higher and the polymer rehabilitated beam deflect by an average

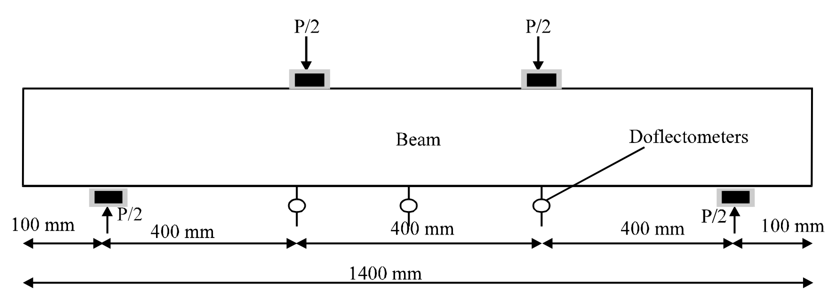

Fig. 3: Schematic diagram for beam test setup

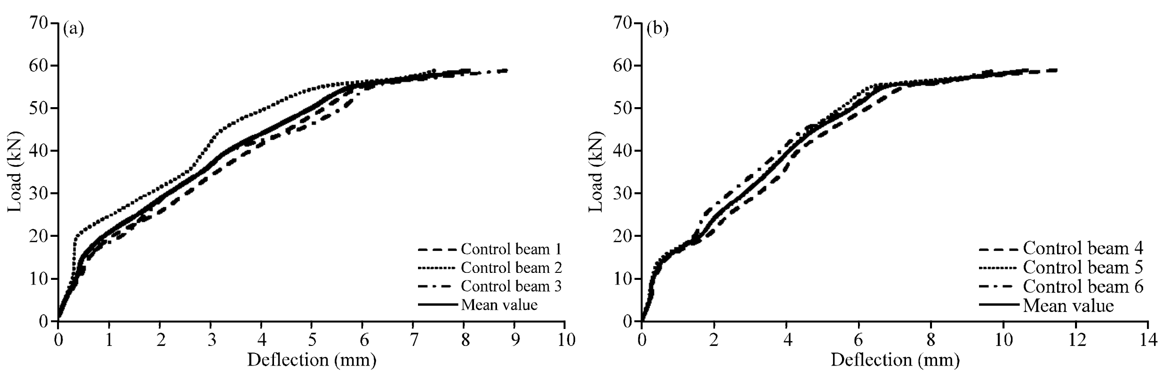

Fig. 4(a-b): (a) Load deflection behaviour of control beams (1, 2 and 3) and (b) Load deflection behaviour of control beam (4, 5 and 6)

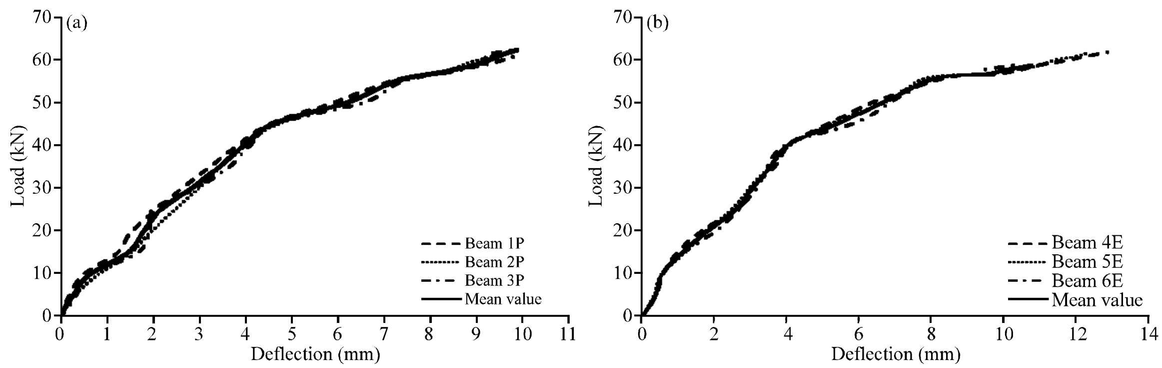

Fig. 5(a-b): (a) Load deflection behaviour of polymer grouted beam and (b) Load deflection behaviour of epoxy grouted beam

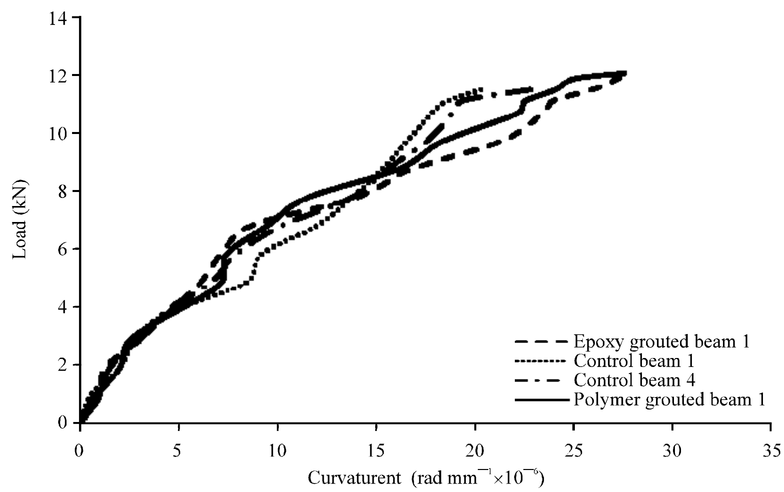

Fig. 6: Moment-curvature behaviour on control and grouted beams

of 12% higher than control beams. The initial crack formation takes place earlier in the rehabilitated beams than the original beams. Table 1 shows the average deflection values of control beams and grouted beams under various loads. From Table 1 it is observed that the ultimate load carrying capacity of epoxy grouted beams are 3% higher than the control beams. Similarly the beams repaired with polymer grouting showed about 5% higher in flexural capacity than the original beam.

Moment-curvature behaviour of beams: The Fig. 6 shows the moment curvature relation between the control beam and the beam repaired with polymer and epoxy grouting. Up to the first crack the curvature shows linear behaviour with moment for both control and treated beams. The repaired beams have low curvatures than control beams up to 75% of maximum loading. After that the repaired beams have curvature higher than the control beam. Bhikshma *et al.* (2010) also observed that the reinforced concrete beams repaired with epoxy resins have low curvatures than original beams. The ultimate load at failure for rehabilitated beams is higher when compared to control beams. Flexural tensile cracks were developed initially in the constant moment region when

Table 1: Load-deflection values for control and rehabilitated beams

	Average mid span deflection (mm)			
Load (kN)	Control beam (1, 2 and 3)	Polymer grouted beam	Control beam (4, 5 and 6)	Epoxy grouted beam
0	0.00	0.00	0.00	0.00
5	0.16	0.28	0.23	0.36
10	0.38	0.65	0.32	0.56
15	0.51	1.48	0.68	1.10
20	0.95	1.83	1.61	1.83
25	1.60	2.19	2.09	2.61
30	2.20	2.86	2.83	3.08
35	2.85	3.47	3.50	3.57
40	3.37	4.00	4.07	4.09
45	4.18	4.64	4.78	5.52
50	4.98	6.26	5.81	6.78
55	5.75	7.32	6.71	8.11
57	6.93	8.35	8.68	10.04
59	8.10	9.10	10.67	11.52
61		9.59		12.57
62		9.91		

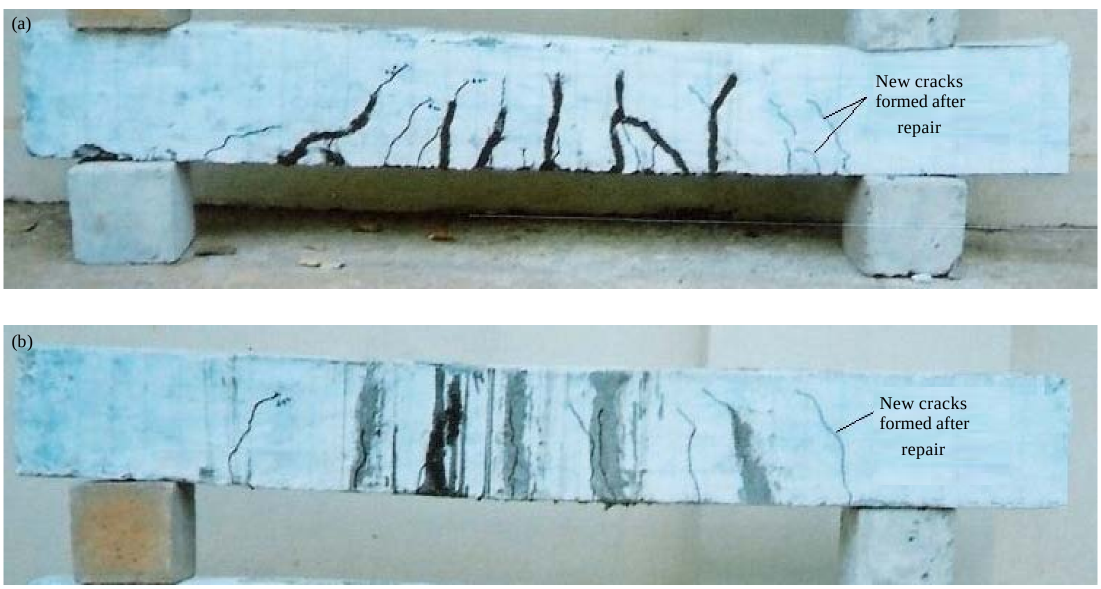

Fig. 7(a-b): (a) Crack pattern of epoxy grouted beam after failure and (b) Crack pattern of polymer grouted beam after failure

the beam was loaded and all the beams were failed due to flexure. From Fig. 6 it was observed that, the ultimate curvature for the all repaired beams was higher than the control beam and therefore the ductility increases after repair.

Crack behavior of rehabilitated beams: During loading on the rehabilitated reinforced concrete beam, the cracks did not developed only at same place and new cracks were also observed. Epoxy resin grouting shows very good adhesion on sound surface and it provides good impermeability on cracked concrete (Jumaat *et al.*, 2006). When we compare the ultimate load carrying capacity of the rehabilitated beams, polymer grouted beam has shown higher value than the epoxy-grouted beam. The initial cracks were appeared at the bottom of the beam and the first crack appears at 15 and 18 kN for epoxy and polymer injected beams respectively. In epoxy-grouted beam, initial crack formation occurs earlier and the maximum deflection value also increases than the polymer grouted beam. Figure 7a and b shows the crack pattern of epoxy and polymer treated beams after failure.

Qureshi *et al.* (2011) reported that for normal strength RC concrete beams, the grouting technique using epoxy resins were very much suitable for repair and showed similar strength and performance as that of control beam. Comparing the nature of failure, epoxy-grouted beam showed good elasticity than the polymer grouted beam. It will take more loads after the initial crack and the deflection capacity also increases to greater amount. Whereas the polymer grouted beam has not shown a good elastic behaviour after the first crack formation. Even though it takes more load than epoxy grouted the maximum deflection value was lesser then the above and results more ductility in nature.

CONCLUSION

Based on the results of the experimental study, the following conclusions are drawn, rehabilitation of reinforced cement concrete beams by repairing and rehabilitating the cracks using Epoxy Resin and Polymers are very effective in restoring the original flexural strength of the beams:

- The load carrying capacity of the beams treated with polymer and epoxy were found to be higher than the original beams
- The similar crack pattern was found in both control and repaired beams
- The beams treated with polymer showed more ductile behaviour than epoxy treated beams

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