Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Repair and strengthening of reinforced concrete beams

D.P.Singh
Hudco, New Delhi

ABSTRACT: The paper deals with the repair and strengthening of damaged reinforced cement concrete beam element in a structure by means of epoxy injection and epoxy bonded steel plate/strip. Experimental results of load-deflection and stress-strain variation in original beams that is before damage and repaired or strengthened beam after failure are given. From study of original beams and repaired beams the epoxy injection by injecting pump and epoxy bonded steel plate/strip are quite effective measures for such damages. On dynamic testing of beams it was concluded that at low amplitude the repaired beams were slightly less stiff than origional beams. However at large deflections associated with sever damage the stiffness of the repaired beams did not degrade as much as that of orginal beams and cracking in beams was less sever in the repaired beam after the test than in the original beam. Epoxy based repair/strengthening is considered to be an appropriate method for earthquake damaged structures.

1. INTRODUCTION

The repairing, retrofitting and strengthening of reinforced concrete structures, damaged by earthquake, requires largest number of possible repairing techniques, from which most effective one will be chosen in each particular repairing case. In some cases even newly built structures require, repair and strengthening, so as to eliminate defects due to mistake in design or construction. The repairing of a concrete structure or its element has always been very difficult, and adequate solutions have often entailed extensive works. Specialised techniques of strengthening, stiffining and repair are needed to deal with damaged produced by unusual events such as fire, earthquake, foundation movement, impact and overload. Even when a reconstruction and rehabilitation are now days often preferred to demolition and redevelopment, because of cost advantages. The development of wide variety of artificial resins, specially epoxy based adhesives, has given rise to new and extensive possibilities of repairing concrete constructions. Research on this subject was started by R.L. Hermite and J. Bresson (1971). Epoxy injection techniques were used extensively to repair crack of highway bridges, buildings and other reinforced concrete structures damaged by 1964 Alaska, 1969 Santa Rosa California, and 1971 San Fernando California, Earthquake, among others.

This paper deals with the study conducted on the reinforced cement concrete beams designed to fail deliberately in a required mode that is in flexure (Compression or tension) and shear. These damaged beams were then repaired/strengthened by injecting epoxy resin or by gluing steel strip/plate at the required location. These repaired beams were again tested to a failure load. In both the cases that is orginal and repaired beams stress-strain and load-deflection were recorded. The data were analaysised and plotted. A comparative study was conducted on stress strain behaviour in case of original and repaired beams. The strength of the repaired beams were quite comparable with original beams. The results of the study revealed that epoxy repaired beams were quite effective and can be restored to original design stength level.

2. SPECIMEN AND EXPERIMENTAL SET UP:-

About 30 specimens were prefabricated from the concrete of grade M 15 with crushed stone aggregate of 20 mm and graded size. The average crushing strength of concrete was 15 N/sq.mm. All longitudnal and transverse reinforcement was plain mild steel bars of grade Fe 250. In case of the beams tested for shear failure and repair no shear reinforcement was provided. The beam cross section and length adopted for study under flexural and shear failure are shown in

Fig.1. Reinforcement details for beams tested, failed and repaired in flexure tension/compression and shear are also shown in Fig.1. The length of beams for study under flexural was 3000mm and that for shear was 1500 mm only. The casting of beams was done under a strict quality control in suitable form work. After a curing for about 3 months these specimen were tested.

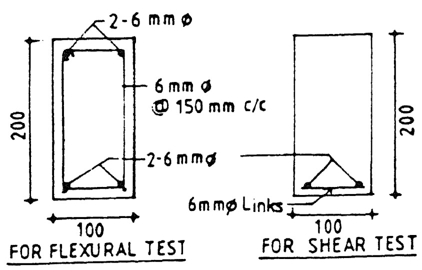

Fig. 1. BEAM X SEC

Under the test, load predetermined for ultimate failure for each beam was applied in the form of two point loads at middle third of the span. The load was applied to ultimate failure or to an extent so as to develop extensive cracks. The load-deflection record was maintained by using mechanical dial gauges at the centre and under the point loads. For measuring strain, studs in tension and compression zone of beam were fixed at suitable spacings. The strains were measured with mechanical extensometer. Test set up for beam under flexure and shear study is shown in fig.2

Fig. 2. FLEXURAL TEST

3. EXPERIMENTAL TEST AND ANALYSIS

3.1 Flexural Test: Under this test two types of the beams under reinforced and over reinforced were designed and used for testing and study. The load deflection curve for some of the original beams alongwith the repaired beams are shown in Fig.3.

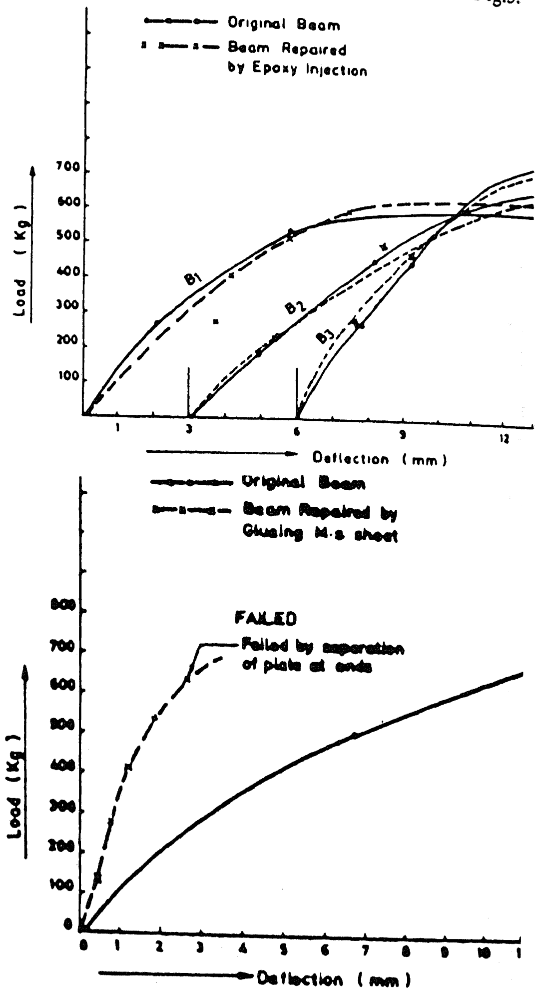

Fig. 3 LOAD DEFLECTION CURVE

The stress-strain variation as recorded at different level in compression and tension zone of the beam cross section are shown in Fig.4.

From the recorded data and result it was observed that the strength of the epoxy repaired beams failed in different mode like in compression, yielding of reinforcement was very well comparable with the original design strength level. In case of beams repaired by epoxy injection the cracks pattern developed were of the same nature as that of orig-

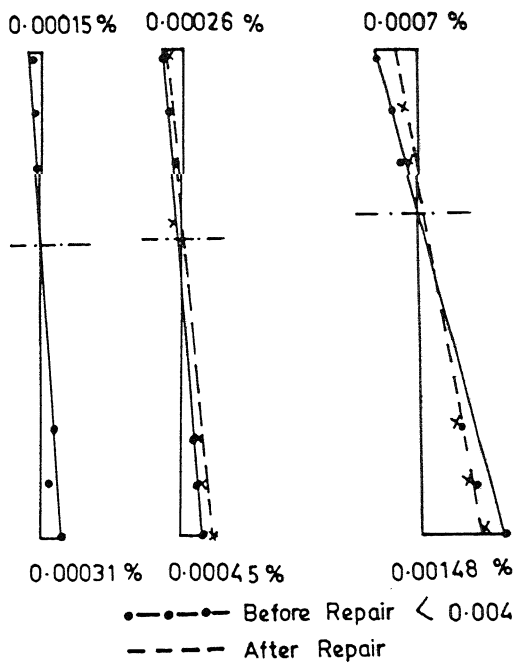

Fig. 4. STRAIN DIAGRAMS

ional beam but the location was different. Beams repaired by bonding equivalent steel area plate in tension zone, failed by separation of bond between plate and concrete surface at higher load than that of the origional beam. Deflection in case of such repaired beam was also much less in comparision to origional beam as in Fig.3.

3.2 SHEAR TEST: Beams tested for shear were not provided any shear reinforcement. The test set up and testing of specimen is shown in Fig.5 Load deflection

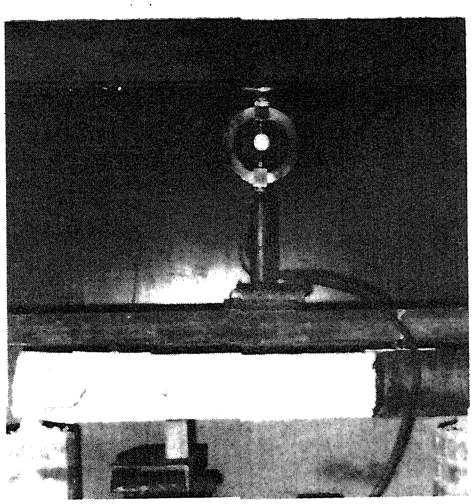

Fig. 5. SHEAR TEST

curves for original and repaired beams are shown in Fig.6. It was observed that the repaired end of beam did not failed but it failed at the other end as shown in Fig. 5. It shows that there is a perfect connection between the external steel and the concrete element without any shifting.

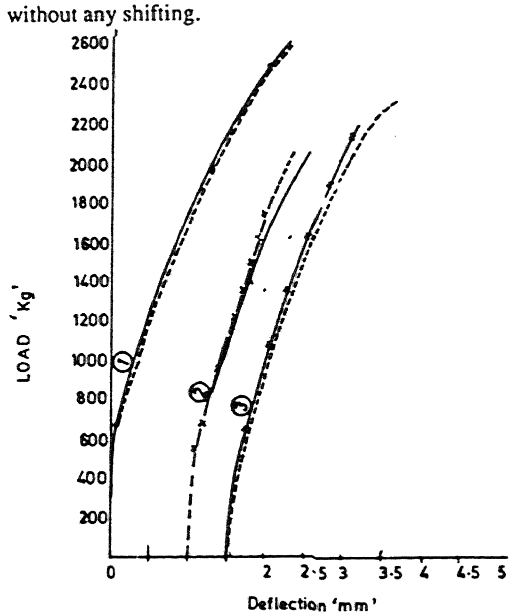

FIG. 6. LOAD DEFLECTION CURVE (SHEAR TEST)

4. METHODOLOGY FOR STRENGTHENING:

Based on type and extent of failure the strengthening methodology was followed. Beams over reinforced in cross section developed cracks in concrete only. These were repaired by injecting epoxy under a pressure of 0.85 N/sqmm. in case of narrow cracks. For injecting the epoxy the cracks were just sealed with epoxy putty leaving the portion just below the nozzel hole. Nozzeles were fixed at a lower level on one face and at a higher level on the other face of the beam crack. Epoxy was injected through the lower level nozzel till it start comming out from the nozzel at the higher level on other face of the beam.

In case of under reinforced section the failure was mainly due to yielding of reinforcement. These beams were strengthened by gluing equivalent steel area plate in the tension surface of the beam. In addition to bonding of steel plate the narrow cracks developed were repaired by injecting the epoxy. The calculation of the area of the externally bounded steel plate/strip in pure bending is on the basis of Van Gemert D., etal (1982).

Shear failure of beams was characterized by the occurence of inclind cracks. In some cases inclind cracking was immediately followed by member failure and in other cases, the inclined cracks stabilize and substantially more shear force may be applied before the member fails. In addition to the primary cracks (flexural and the two types of inlcined cracks), secondary cracks often results from splitting force developed by the bars when slip between concrete and reinforcement occures or from dowel action forces in the longitudnal bars transfering shear across the cracks.

Fig.5, shows the failed and repaired beams. It was observed that the repaired end of the beam was intact and it failed at the other end in a similar mode.

5. DYNAMICT TESTING AND PROPERTIES:

To study the influence of epoxy repaired beams failed in flexure, free vibration study before damage and after repair of damage was also conducted. Fig.7, shows the free vibration record of the original and repaired beams. It was observed that the repaired beam are less stiff in comparision to original beams. It was noted that reduction was of the order of about 30 percent.

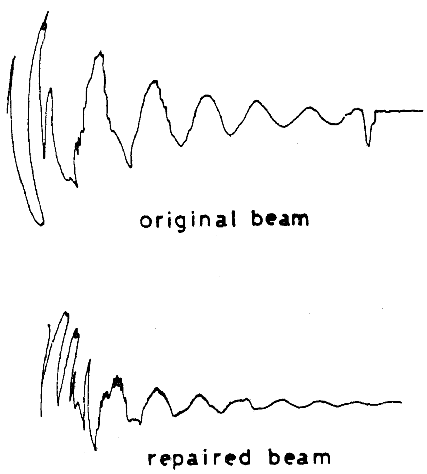

Fig. 7 FREE VIBRATION RECORD

6. DISCUSSION AND CONCLUSION:

Epoxy-bounded external steel reinforcement in the form of steel plates or strips have proved to be reliable structural elements not in laboratory tests but also in many practical applications. The design of the section may be done in a usual manner as there is no slip or shifting between external steel and the concrete element. In the field of restoration and retrofitting the system is competitive, time saving and economical for reinforcing damaged structures. Also this technique is quite satisfactory for repairing earthquake-damaged structures (1983, 1986)

ACKNOWLEDGEMENTS:

The test programm and the evaluation of the resulting test data was the regular research and development work of the Central Building Research Institute, Roorkee (India). The work given here is a part of the work carried out byauther at the Institute. The paper is being published with kind permission of the Executive Director Design and Development Wing, HUDCO, NEW DELHI.

REFERENCES:

Bresson 1971 Nouvelles rechercheset et aplications concernant l' utilisation des collages dans less structures. Annalesde l'ITBTP, serie BBA/116, France.

Joseph M. Plecnik, John M. 1986. Behaviour of epoxy repaired beams underfire. ASCE, structure division Vol. 112, No.4.

Lathika Jaisingh, M.P. Jaisingh 1986. Repair and strengthening of reinforced concrete members. Proceedings of 8th symposium on Earthquake Engineering, Roorkee, Vol. I, pp 371-378.

Van Gemert D. 1983 Execution and control of epoxy bounded external reinforcements. S&A-publication nr.5 'Repair of concerte Construction'. Belonvereniging Zoetermeer, The Netherlands.

Van Gemert D., Vanden Bosch M. Design of externally bonded steel plate reinforcements for elements, loaded in bending.