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Retrofitting of Reinforced Concrete Beam by Ferrocement Technique

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Abstract

Background/Objectives: The aim of the present study was to examine the performance of reinforced concrete beams strengthened by ferro cement technique. **Methods/Statistical Analysis:** In this experimental investigation five beams of rectangular cross section were cast using M25 (1:1.48:2.52) normal mix and high strength deformed bars as longitudinal and shear reinforcement. The beams were retrofitted for two conditions. In one case, the beams were stressed to 70% of the failure load and than they were retrofitted. In second case, for overloading the unstressed beams were retrofitted. **Findings:** The results obtained indicate that the increase in ultimate load was 70% in overloading case and 45% in stressed beam, also there was reduction in rotation and deflection. **Application/Improvements:** It was concluded from the experimental investigation that the strengthening of reinforced concrete beams by ferro cement technique is practicable and has considerable advantages.

Keywords: Beam, Concrete, Ferro Cement, Reinforced, Retrofitting

1. Introduction

Concrete structures are normally designed to last long some of them do last a great length of time, but some of them became unusable and are in need of restoration or repair[1–4]. Old and ancient structures needing extensive amount of rehabilitation is not a matter of grave concern, however fact that some of the relatively newly constructed structures are also showing signs of decay in their early life spans, sometimes even within a decade or two of their construction is quite disturbing. This may be due to the gross neglect of various well-established aspects during the design and/or construction of the structures. The result is that the number of structures needing rehabilitation has gone up sharply in recent times[5]. Various techniques like; plate bonding technique, concrete replacement technique and injection techniques are used to repair or retrofit these structures. But, ferro cement technique is commonly used for retrofitting due to its lightness and development of finer cracks for the same steel-stress under loading[6].

Ferro cement in American Concrete Institute Committee 549 was defined ferrocement as "a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar, reinforced with closely spaced layers of continuous and relatively small diameter mesh". Various investigations have been done to study the effect of ferro cement technique on different structure members. In some studies it was found that ferro cement technique improves the mechanical properties of concrete and can also used as jacket in reinforced concrete columns[7–9]. Nassif[10] conclude that by adding a thin layer of ferro cement to a concrete it enhances its ductility as well as its cracking strength. All these studies showed that ferro cement technique provide strengthen and crack resistance concrete which is better than other concrete construction[11]. Further to expand the use of ferro cement,

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the present study was carried out to investigate the behavior of the reinforced concrete beam strengthened with ferro cement technique using welded mesh wire of different diameter and spacing.

2. Materials Used

2.1 Cement

Ordinary Portland cement (Aditya Birla 43 grade) was used for the concrete mix. The quality of the cement was checked through various tests and was compared with the specifications given in Bureau of Indian Standard 8112 (1989) for Ordinary Portland cement. The properties of Ordinary Portland cement are given in Table 1.

2.2 Fine and Coarse Aggregates

The crushed coarse sand was obtained from Burjkotia. The physical properties of fine aggregates are listed in Table 2.

Table 1. Physical properties of cement

Sr. No.	Characteristics	Experimental value	Specified value as per Bureau of Indian Standard 8112 (1989)
1.	Consistency of cement	29.5	-
2.	Specific gravity	3.11	3.15
3.	Initial setting time	35 minute	>30 minute
4.	Final setting time	474 minute	<600 minute
6.	Soundness	1.0 mm	<10 mm
7.	Fineness	7.4	<10

Table 2. Physical properties of fine and coarse aggregates

Sr. No.	Characteristics	Fine aggregates	Coarse aggregates
1.	Specific gravity	2.65	2.6
2.	Water absorption	NIL	0.15%
3.	Moisture content	2%	NIL
4.	Fineness modulus	2.38	6.71

Locally available crushed stone aggregates from BurjKotian crusher were used for the present work. Crushed stone aggregate of 20 mm and 10 mm size were mixed in 60:40 proportions to meet the requirements of Bureau of Indian Standard 383 (1970). The physical properties of coarse aggregates are listed in Table 2.

2.3 Water

As per clause 4.3 of Bureau of Indian Standard 456 (2000), the water to be used for both mixing and curing has to be free from any impurities. In present work tap water was used.

2.4 Steel Bars

High Yield Strength Deformed (HYSD) 'TOR' steel bars of 8 mm and 12 mm nominal diameter procured from the local market were used as tension reinforcement in all the test specimens, whereas 6 mm plain steel bars were used as hanger bars; 6 mm diameter bars of the same type were used as nominal shear reinforcement in the form of two-legged closed stirrups in all the specimens at a spacing of 150 mm center to center.

2.5 Welded Wire Mesh

Mild steel welded steel wire mesh of 2.4 mm diameter with square grid size (25 mm x 25 mm) and 3 mm diameter with rectangular grid size (25 mm x 75 mm) mm shown in Figure 1 was used in ferro cement jacket.

2.6 Epoxy

Nitobond EP is used for the purpose of gluing the ferro cement jacket to the beam. The product achieves 50 MPa compressive strength; 20 MPa tensile strength, 35 MPa flexural strength and 25 MPa shear strength. The ratio of epoxy to hardener adopted was 2:1 as recommended by the manufactures Fosroc Parchem, Ltd.

3. Experimental Program

3.1 Mix Proportion

The proportion of cement-sand mortar used for the ferro cement sheets was 1:2 (cement:sand). The water-cement ratio for ferro cement sheets mortar was 0.40. The mix proportions for RCC beam are given in Table 3. The water-cement ratio for RCC beam was 0.40.

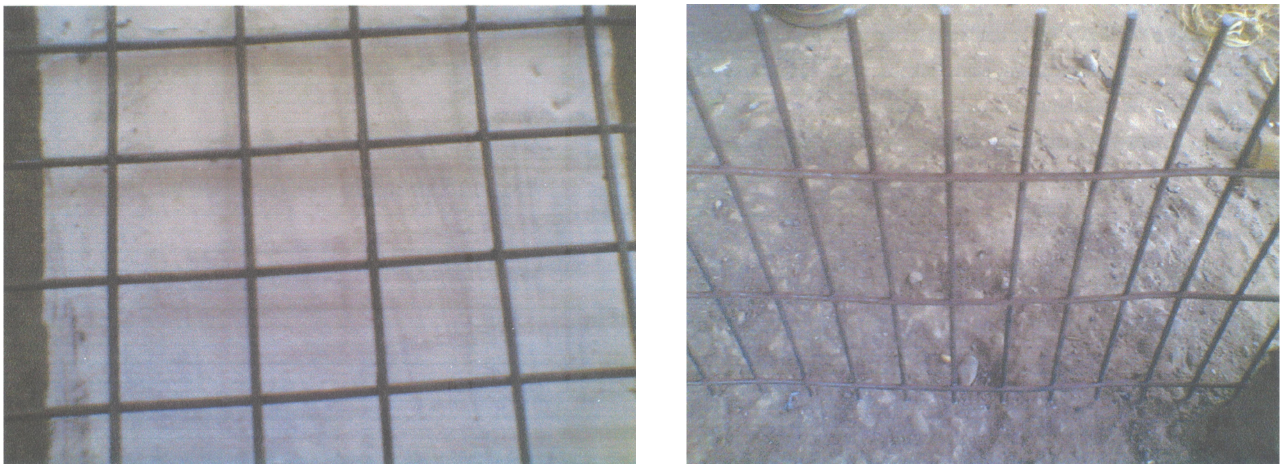

Figure 1. Welded steel wire mesh **(a)** 2.4 mm dia spacing (25 mm x 25 mm). **(b)** 3 mm dia spacing (25 mm x 75 mm).

3.2 RCC Beam Designation, Design and Casting

The experimental program consisted of testing of total five beams and they were classified into three group. Designation of the tested beams is explained in Table 4. In the present study the RCC beam was designed for M25 and Fe415. The beam was designed for given steel i.e. 2 bars of 8 mm at compression face and 3 bars of 12 mm at tension face. The stirrups of 6 mm diameter were provided at spacing of 150 mm. The dimension of the beam was 150 x 250 mm. The beams were cast in mould of size 150 x 250 x 1600 mm as per Bureau of Indian Standard 516 (1959).

Table 3. Mix proportions for RCC beam

Sr. No.	Material	Quantity (Kg/m^3)
1.	Water	185
2.	Cement	422.72
3.	Fine aggregates	627.7
4.	Coarse aggregates (10mm)	640.45
5.	Coarse aggregates (20mm)	640.45

3.3 Testing of RCC Beam

The beam designated as CB (Control Beam) was tested under two point loading system up to ultimate load and two beam designated as RB1 and RB2 was tested under two point loading system up to 70% of the ultimate load of the Control Beam. The effective span of the beam was 1.5 m and the distance between two point loads was 50 cm. The dial gauges was used to observe deflection at the center and under the load position. Two inclinometers were set at the end corner of the beam for knowing the moment curvature relationship. Full scale test set up is shown in Figure 2. Load was applied through a hydraulically operated jack of 600 KN capacity in the increment of 4.5 KN.

3.4 Retrofitting of Beams

Out of five beams casts only two beam (RB1 and RB2) were initially loaded up to 70% of the failure load of

Table 4. Designation of original and rehabilitated beams

Sr. No.	Specimen designation	Dia. Of welded mesh wire	Spacing of grid	Remarks
1.	CB	--		Control beam
2.	RB1	2.4 mm	(25 X 25) mm	Retrofitted beam
3.	RB2	3 mm	(25 X 75) mm	Retrofitted beam
4.	OL1	2.4 mm	(25 X 25) mm	Overloading beam
5.	OL2	3 mm	(25 X 75) mm	Overloading beam

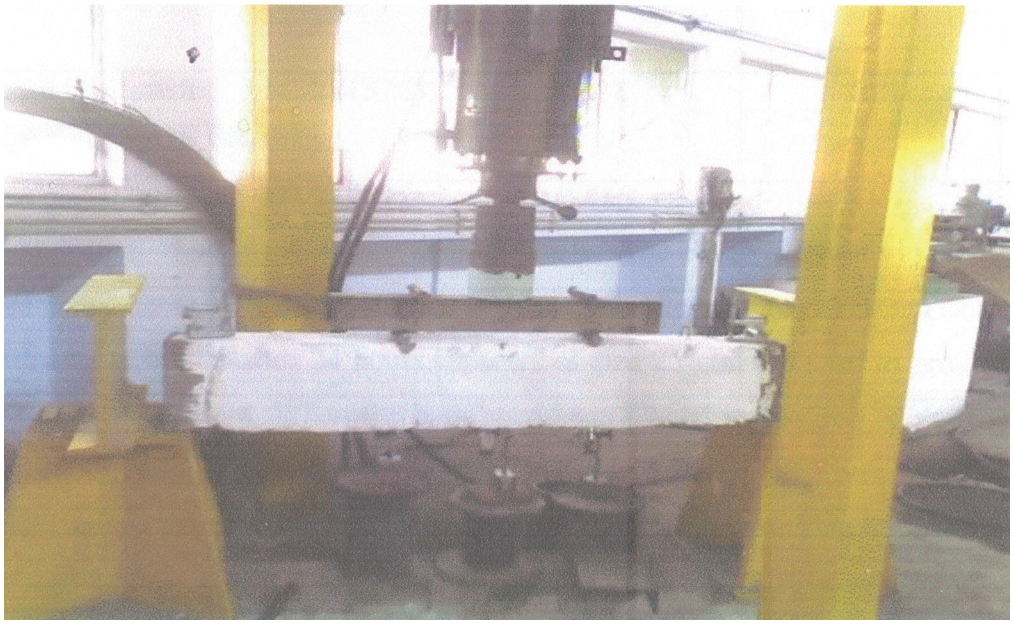

Figure 2. Testing of RCC beam.

control beam and two unstressed beams (OL1 and OL2). Hence repairing and cleaning process of these beams was necessary before strengthening them. Firstly, the surface of the beam is cleaned to apply any of the bonding agents in order to get a perfect bond. Two beams are retrofitted with each of the bonding agent. After this jacketing of the beam with the help of welded wire mesh is done and a 15 mm plaster is applied over three side of the beam. Following this the beam is cured for a period of 28 days. Then with the same procedure as of Control Beam (CB) testing of beam is done in order to determine ultimate load, corresponding deflections and inclinometer reading. In strengthening phase, all four beams (RB1, RB2, OL1, and OL2) were strengthened by gluing welded mesh wire. Sequence of the retrofitting procedure followed is given below:

- For beams RB1 and OL1, the welded mesh wire of size 2.4 mm diameter with grid size of 25 mm x 25 mm was glued on the three sides of the beams (tension side and side face of the beam).
- For beams RB2 and OL2, the welded mesh wire of size 3 mm diameter with grid size of 25 mm x 75 mm was glued on the three sides of the beams (tension side and side face of the beam). All the process which is given above is shown in the Figures 3, 4 and 5.

4. Results and Discussion

4.1 Maximum Load Carrying Capacity

Maximum load carrying capacity for control, stressed retrofitted and overloading retrofitted beams are shown in Figure 6. It was observed that the maximum load carrying capacity of stressed beam RB1 and RB2 was increasedby 35% and 45% respectively than Control Beam. This is because of the enhanced strength imparted by the welded mesh wire to the stressed beam. In over loading case the maximum load carrying capacity of beam OL1 and OL2 was increased by 55% and 70% respectively than Control Beam.

4.2 Moment Rotation Behavior

Moment vs. rotation behavior of the stressed and overloading beams w. r. t. the Control Beam are given in the Figures 7 and 8. In moment rotation curve of the stressed and overloading beam, it can be seen that the moment rotation curve of the stressed beams (RB 1, RB2) was higher than the curve of the Control Beam, shown in Figure 7. In the Figure 7 rotation of the retrofitted beam RB1 and RB2 at a maximum moment was 0.009177 and 0.008778 radian which was less than the rotation of the Control Beam (0.009177). In over loading case, it can be

Figure 3. Application of bonded agent (epoxy).

Figure 4. Application of welded mesh wire.

seen that the moment rotation curve of the overloading beams (OL1, 0L2) was higher than the curve of the Control Beam shown in Figure 8. In the Figure 8 deflection of the retrofitted beam OL1 and 0L2 at a moment of 22.5 KNM was 0.005222 radian and 0.00492 1, which was less than the rotation of the Control Beam (0.009177). While comparing rotation, it was clear that stiffness of the retrofitted beams was improved at all the stage of loading.

4.3 Load Deflection Behavior

Load vs. deflection behavior of the stressed and overloading beams w. r. t. the Control Beam under the load are given in the Figures 9 and 10 respectively.

In load deflection curve of the stressed beam under the load, it can be seen that the load deflection curve of the stressed beams (RB1, RB2) is higher than the curve of the Control Beam shown in Figure 9. The deflection of the retrofitted beam RB1 and RB2 at a load of 90 KN was 5.27

Figure 5. Application of cement mortar (15 mm thick).

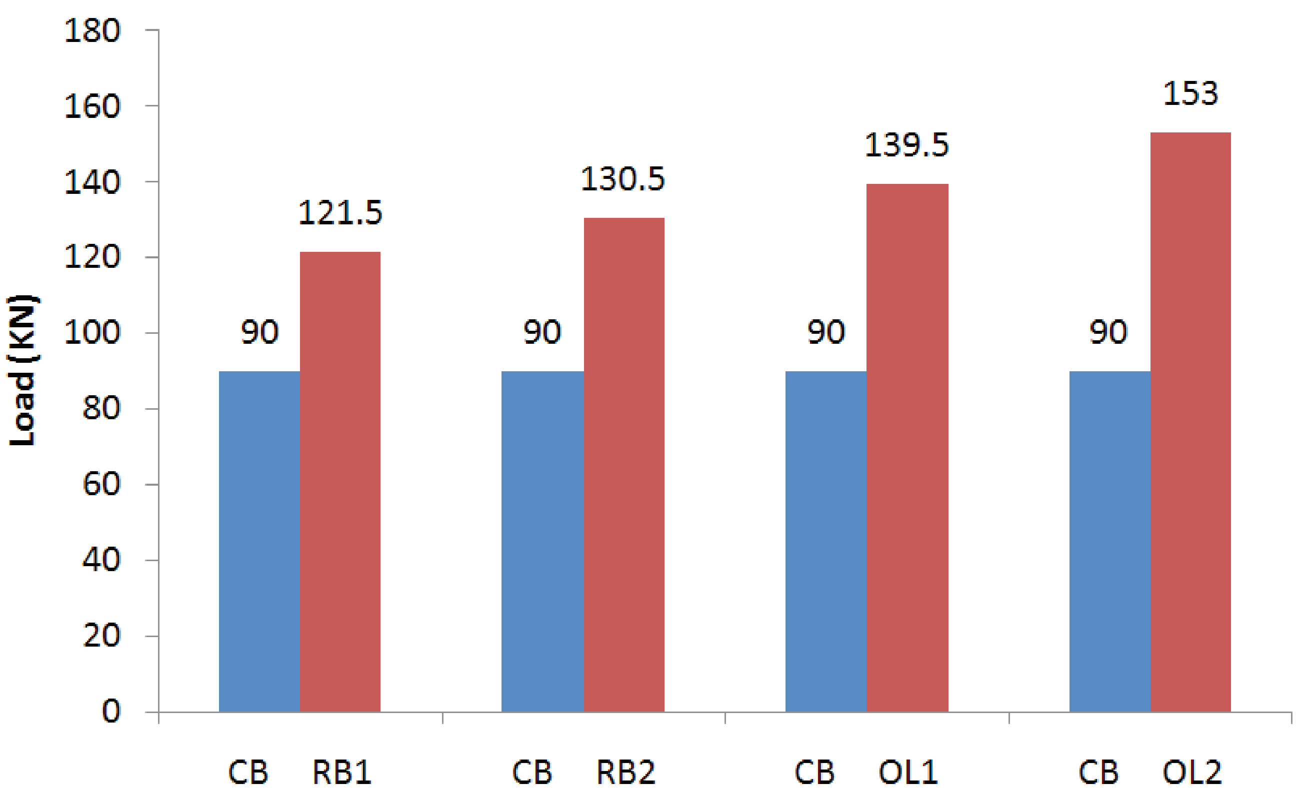

Figure 6. Comparison of failure load of control and retrofitted beams.

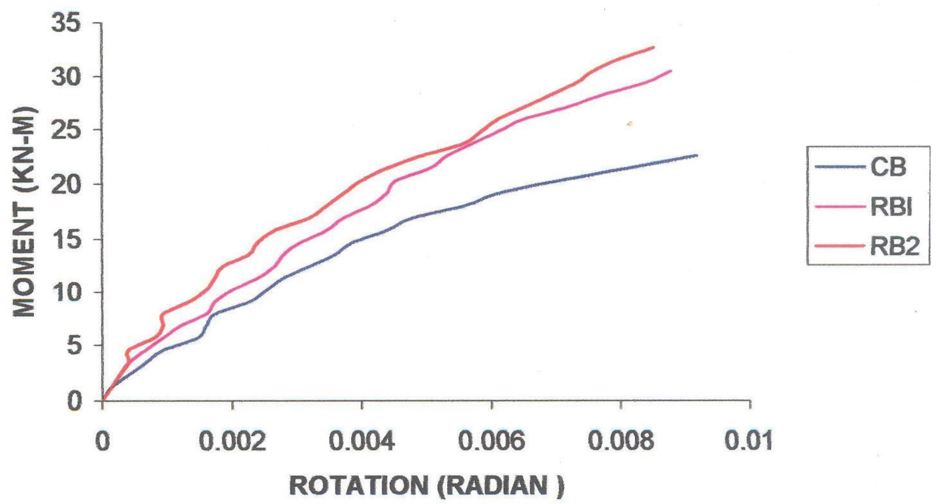

Figure 7. Moment vs rotation behavior of the stressed beams.

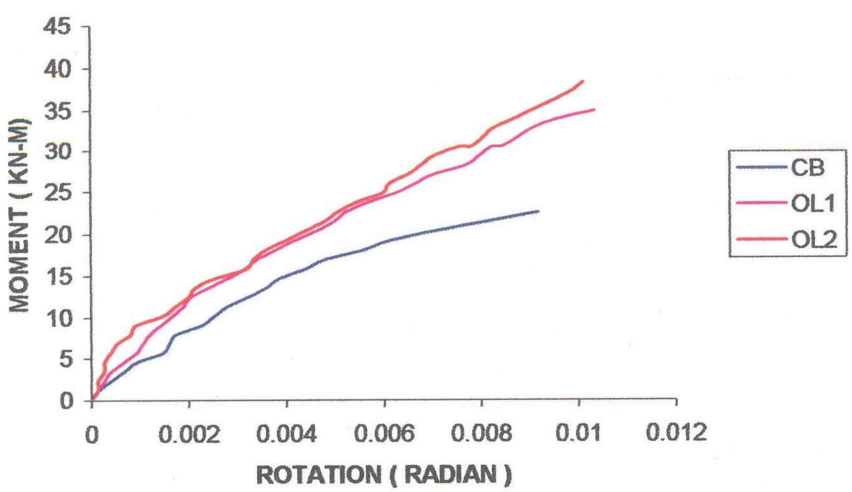

Figure 8. Moment vs rotation behavior of overloading beams.

mm and 4.32 mm which was less than the deflection of the Control Beam (7.55 mm). In over loading case shown in Figure 10, the deflection of the retrofitted beam OL1 and 0L2 at a load of 90 KN was 3.84 mm and 3.05 mm which was less than the deflection of the Control Beam (7.55 mm). While comparing deflection, it was clear that stiffness of the retrofitted beams was improved at all the stage of loading. At each stage of loading deflection were reduced in retrofitted beam.

4.4 Comparison between Welded Mesh Wires

In the present study, mainly two types of welded mesh wire were used for retrofitting technique. One was 2.4 mm diameter having grid size was (25 x 25) mm and other was 3 mm diameter having grid size was (25 x 75) mm. This different type of welded mesh wires effect on the different parameters of the beams like a load carrying capacity, deflection and rotation etc. were studied. The load car-

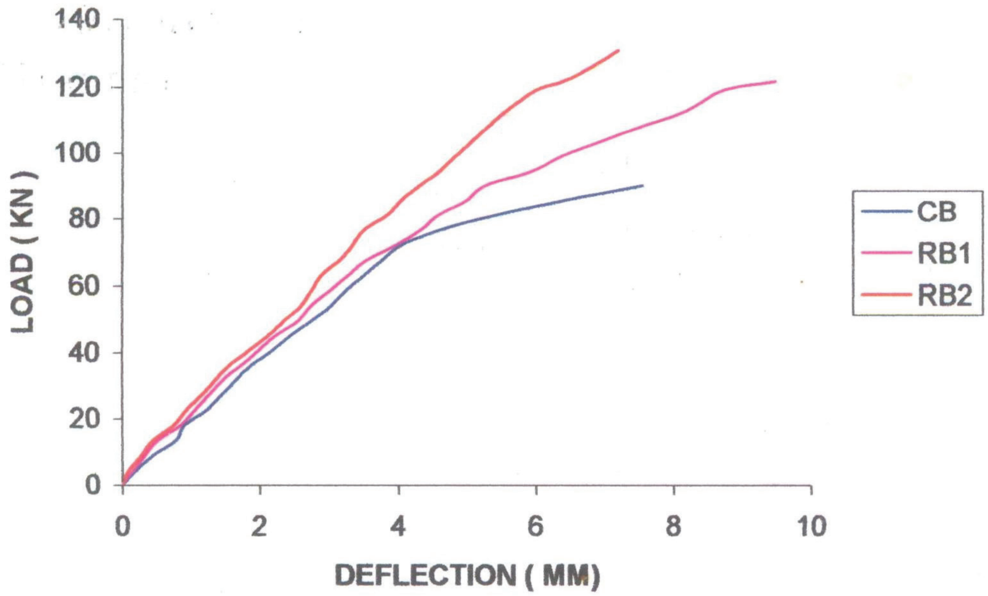

Figure 9. Load vs. deflection behavior of the stressed beams.

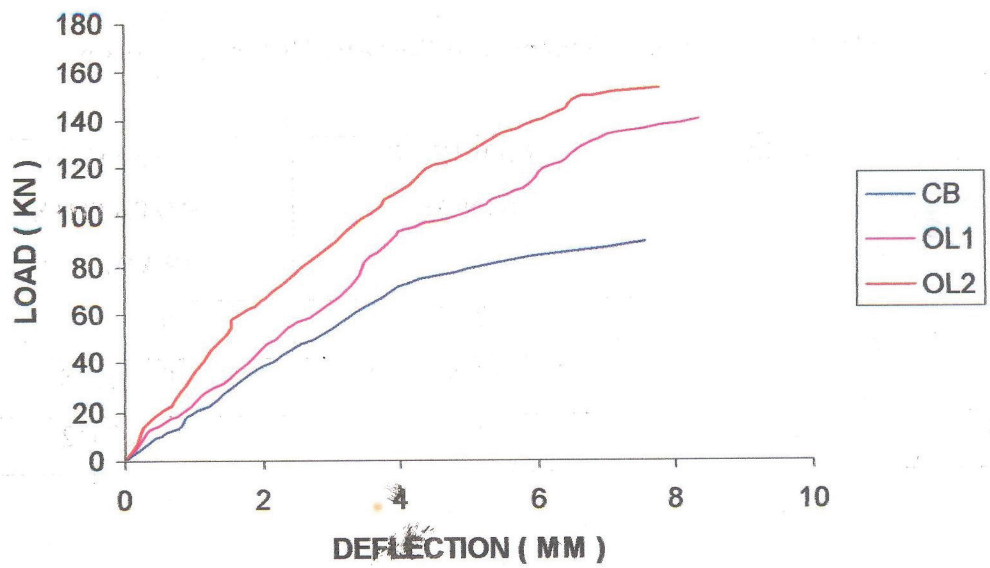

Figure 10. Load vs. deflection behavior of the overloading beams.

rying capacity of the stressed beam (RB2) which was retrofitted with 3 mm dia. welded mesh wire is increased by 7.4% than the stressed beam which was retrofitted by 24 mm dia. welded mesh wire and in overloading case the load carrying capacity of the beam (OL2) is increased by 9.6% then the beam (OLI). Deflection and rotation of the stressed and overloading beams which was retrofitted with 3 mm dia. of welded mesh wire gives the less value in any stage of loading then the beams which are retrofitted with the 2.4 mm welded mesh wire.

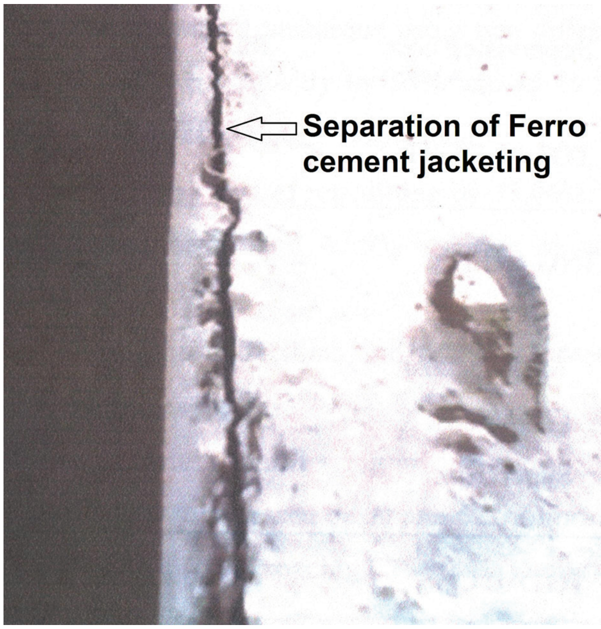

Figure 11. Failure pattern of retrofitted beam.

4.5 Failure Pattern of Specimen

The control specimen failed in bending because it was designed as under reinforced section. But in case of retrofitted beams (both stressed and overloading) failure occurred due to the separation of ferro cement jacketing. This may be due to occurrence of cracks that were developed due to loading. Thus the ferro cement jacketing was subjected to a pull. This pull was more than the bond strength between the welded mesh wire, glue and beam. Once a bond was lost, ferro cement was separated from the beam surface. Failure of the retrofitted beam is shown in the Figure 11.

5. Conclusions

- Retrofitting of the beams by ferro cement technique using two different welded mesh wires increased the load carrying capacity by 35% and 45% for stressed beams and 55% and 70% for overloading beams, respectively.
- Due to retrofitting of the beams, rotation and deflection was decreased, which mean the stiffness of the retrofitting beams increased than Control Beam.
- Retrofitting by 3 mm dia. welded mesh wire having grid spacing (25 mm x 25 mm) gave more strength about 40% for stressed beam and 62.5% for overloading beam than the 2.4 mm diameter having grid spacing (25 mm x75 mm).
- Bond strength between the ferro cement jacketing and original beam was controlling factor. The failure of the retrofitted beams was due to the bond failure.

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