Experimental Evaluation of strength of Damaged RCC Beam Repaired using Steel Mesh at 45° and Modified mortar

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Abstract - Repair and rehabitation of structures in case of structural damages and partial collapse are of great importance. The estimation of structural adequacy of repaired / retrofitted structural elements (which also display the efficiency of the repair performed) is an important step in the repair and rehabitation process. Many theoretical and experimental methods are reported in the literature for the structural performance evaluation in the case of beams repaired The present study address the experimental method of estimation of the efficiency of full length repair conducted on the beam elements modeled with cover spalling type of damage, using epoxy based bonding agent and steel mesh. The bonding agent and repair materials have been chosen based on a series of standard and non-standard tests conducted in laboratory in the past. The flexural strengths deflection and crack pattern of control beam and repaired beam are controlled to arrive at efficiency of the repairs conducted.

Key Words: flexural, flexural-Shear cracks, control beam with reduced area of tension reinforcement (CBRA), Modelled damaged beam

1.INTRODUCTION

Reinforced Concrete is the most widely used and versatile construction material possessing several advantages over steel and other construction materials. However very often one come across some defects in concrete. The defects may manifest themselves in the form of cracks, spalling of concrete, exposure of reinforcement, excessive deflections or other signs of distress. On many occasions, corrosion of reinforcement may trigger off cracking and spalling of concrete, coupled with deterioration in the strength of the structure. Such situations call for repairs of affected zones and sometimes for the replacement of the entire structure.

A correct diagnosis establishing the cause, nature and extent of damage, and the weakness or deterioration caused in the structure is very essential, since a faulty diagnosis may lead to improper selection of materials and repair techniques leading to the failure of the repaired zone again. It may also be necessary that the serviceability of the structure is checked after carrying out the necessary repairs. The technique to be adopted for repair or restoration of the structure depends on the cause, extent and nature of damage, the function and importance of the structure, availability of suitable materials and facilities for carrying out repair, and a thorough knowledge of the long-term behavior of the materials used for the repair work. Depending upon the requirement, the repairing technique may be of a superficial (cosmetic) nature or, in some cases, may involve the replacement of part or whole of the structure Replacement of steel is necessary if it has lost more than 20 percent of area but many specifies require replacement if more than 10 percent of the area is lost.

Repair of such deteriorated reinforced concrete structures are normally carried out to restore the structural integrity, to reshape the defective structures and also to protect the reinforcement from further severe weather conditions. Several types of new advanced repair materials as well as techniques have been successfully developed to reinstate the spalled cover of R.C structures. One such method is patch repair. Patching is normally done by applying mortar or concrete by hand, recasting with mortar or concrete, by using sprayed concrete, or by using ferrocement with mortar or concrete. Generally, the modified cementitious mortar or concrete are preferred in this field because the properties of these materials are similar to that of the parent concrete. In recent years, with the introduction of structurally effective bonding agents, patching repair using modified cementitious mortar has been used widely. Studies have been conducted to investigate the mechanical and physical properties of repair materials and to enhance their suitability for patch repairs. These studies have also shown that the use of a suitable durable material improves the function and performance of corroded structures, restores and increases their strength and stiffness, enhances their surface appearance, provides water-tightness and prevents the ingress of aggressive species at the steel surface

2. SPECIMEN DETAILS

The 4 control beams and 4 modeled damaged beams specimens of size 2000 x 200 x 150mm and were casted.

For the control beam (CB) 2 numbers of 12 mm diameter and one 8 mm diameter were provided at tension zone and 2 hanger bars of 8 mm diameter were provided at compression zone as reinforcement.

For the control beam with reduced area of tension reinforcement (CBRA) 3 numbers of 8 mm diameter were provided at tension zone and 2 hanger bars of 8 mm diameter were provided at compression zone as reinforcement.

For the modeled damage beams (MDB) 3 numbers of 8 mm diameter were provided at tension zone and 2 hanger bars of 8 mm diameter were provided at compression zone as reinforcement

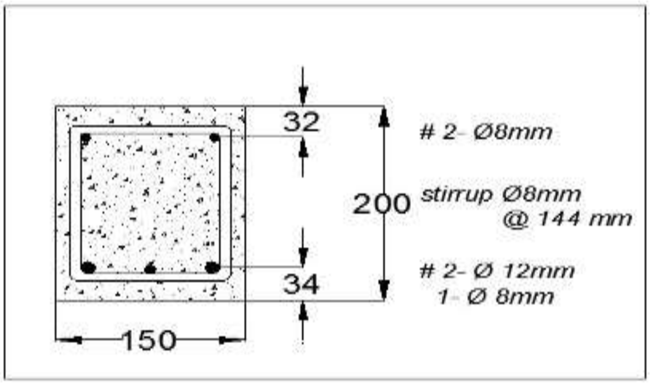

Fig-1 Details of Control Beams (CB**)**

M20 concrete and Fe 415 steel were used. The concrete mix was designed as per IS 10262-2009. The concrete was placed in the formwork in layers, vibrated thoroughly and finished at top neatly to have uniform top surface. Side form work was removed after 24 hours and the specimen was cured for 28 days

Beam specimens having damage of spalled off cover with reduced tension reinforcement were also prepared. The spalled off cover was rebuilt using epoxy bonding agent and modified concrete. Flexural Tests were done on the control beams.

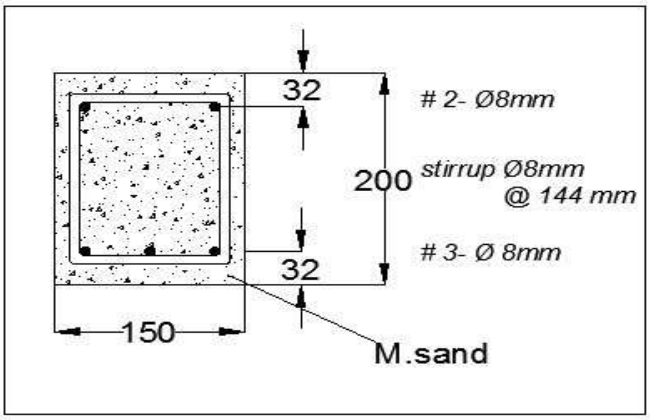

Fig-2 Details of Control Beams (CBRA)

Spalling of cover concrete was modeled by keeping sand filled up to the level of tension reinforcements in beam mould for its full length, before concreting. After 28 days of curing, beams without cover concrete were taken out. The exposed reinforcements were cleaned with wire brush, the surface of substrate concrete cleaned by brushing, and roughened by sand paper. Repair was conducted by application of bonding agent (two parts epoxy) followed by providing compensation for lost area by means of steel mesh and building up of cover using repair concrete to provide cover with adequate thickness to the tension reinforcing bars. The reduced area of steel was modeled by providing three numbers of 8 mm diameter bars instead of the previous case. Test specimens are similar to the previous case but while repairing 5 layers of welded steel mesh were provided on tension side to compensate the reduction in steel area. Instead of steel mesh equal layer geogrid is also used as repair reinforcement for a comparative study with steel mesh.

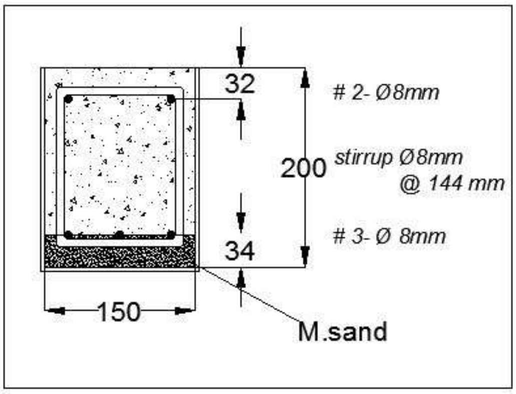

Fig -3 Details of Damaged Beam

Repairing of damage modelled specimen

Among the 4 damaged modelled beams 2 were repaired using steel mesh at 45^0 and repaired using steel mesh at 90^0 . After the curing period, the interface surface is thoroughly cleaned using a wire brush and sand paper to remove sand and other loose particles. The surface is made as dry as possible. Steel pieces having 5mm height were welded vertically above each stirrup as shear keys. Bonding agent two-part-epoxy coating is applied at the interface using a brush. modified concrete is prepared

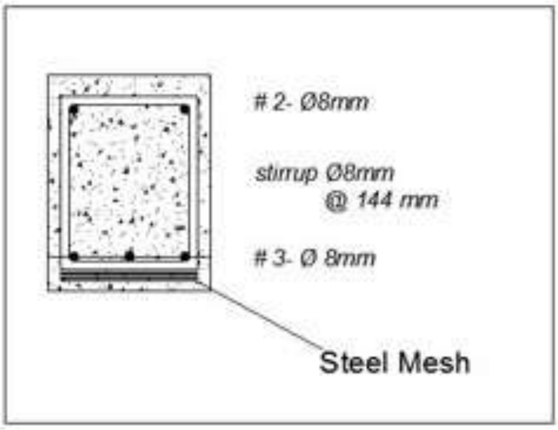

Fig -4 Details of Repaired Damaged Beam

Fig -5 Repaired Damaged Beam (steel mesh at 45^0)

Fig -6 Repaired Damaged Beam (steel mesh at 90^0)

Then the 5 layer of GI mesh tied to the reinforcing bars after which the repair concrete is applied at the top. In between each layer 110 mm length steel pieces are provided in transverse direction to maintain uniform spacing. The finished depth of repaired beam is 250 mm. Kept for curing for 28 days by immersing in water.

Fig -7 Repaired Damaged Beam

3. EXPERIMENTAL SETUP

The present study concentrates on evaluating the efficiency of full length repair on beams with spalled cover to reinforcement. The beam was loaded under two point loading in order to keep the BM constant and predominating at the middle one third region. Further, shear force is zero due to applied loads in this region except shear due to self-weight exists. The zones near supports with 1/3 span length will have predominating shear with less influence of flexure. So the pure flexure behaviour can be studied.

Two steel columns were erected over a girder placed on rigid footing. The column head placed with an arrangement on one side is roller and another side as hinge with two plates and a pin at the centre. The beam was placed on those supports with exactly 1800 mm distance from the centre of roller to centre of pin. At 1/3 points two round rods of 10mm were placed over them a steel girder was placed. Exactly at the centre between two round rods on the girder a hydraulic jack was placed. The top of the hydraulic jack was fixed with a proving ring with dial gauge of capacity of 100 KN. The arrangement facilitates to transfer reactive loading from jack exactly at 1/3 of span as point loads

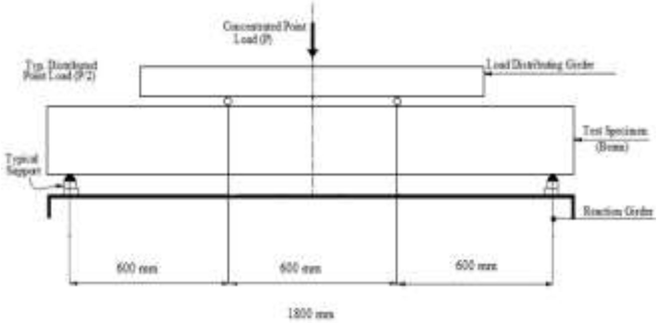

Fig -8 experimental setup

4. RESULTS AND DISCUSSIONS

4.1 CONTROL BEAMS (CB)

Vertical flexural cracks were first observed in the middle portion of the beam at 25kN and the beam failed at 60 kN in flexure. The deflection on one side is found to be slightly higher than that of other side i.e. at dial gauge positions 1 and 3, and maximum deflection was observed at mid-point i.e. at dial gauge position 2 as expected.

The flexural cracks were evenly distributed in the pure bending zone. Flexural cracks were found to be started from bottom of the beam and extended near to the top almost vertically. Flexural-Shear cracks were visible in the shear affected areas (middle thirds near supports). Flexural-Shear cracks also started from the bottom vertically but turned to diagonal directions near shifted neutral axis. Beam failed by crushing of concrete in compression after yielding of tension reinforcement as expected for under reinforced flexural failure.

Fig -9 Crack pattern of Control Beam- CB

4.2 CONTROL BEAMS OF REDUCED AREA OF TENSION REINFORCEMENT (CBRA)

The 28 day cube strength of concrete used for control beam was obtained as 32.45N/mm². From the obtained result the expected failure load is calculated as 38 kN with P = 18.83kN. The control beam with reduced area of tension reinforcement started showing visible cracks at 15kN and failed at 50 kN though the expected value was 38 kN. We had reduced the area of tension steel in this beam compared to original control beam by 45% to simulate loss due to corrosion.

Fig-10 Crack pattern of Control Beam with Reduced Area reinforcement- CBRA

DAMAGE MODELLED BEAM WITH STEEL MESH 45^0

Both repaired beams (RB1 &RB2) using steel mesh vertical cracking were observed to start at a load of 25kN. In RB1 flexural and shear cracking were well developed by the load reaching 60 kN and the beam failed at 75 kN load and RB2 failed at 70 kN load. The repaired cover concrete did not spall off till the full strength of beam was developed. This shows the adequacy of repair. The failure load is greater than that of control beam showing complete successful repair.

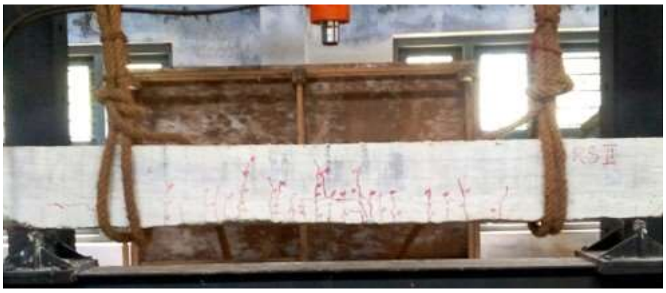

Fig -11 Crack pattern of Repaired Beam (RB @ 45)

5.4 DAMAGE MODELLED BEAM WITH STEEL MESH

Both repaired beams (RB4 &RB5) using steel mesh vertical cracking were observed to start at a load of 25kN. In RB 4 flexural and shear cracking were well developed by the load reaching 50 kN and the beam failed at 60 kN load and RB 5 failed at 65 kN load. The repaired cover concrete did not spall off till the full strength of beam was developed. This shows the adequacy of repair. The failure load is greater than that of control beam showing complete successful repair.

Table 1. Load Vs Deflection Observation of Al the specimens

Sl.No	Load (kN)	(CB12)	(CBRA)	(RB)	(RB-45)
1	0	0	0	0	0
2	5	0.25	0.143	.076	0.11
3	10	0.596	0.35	0.28	0.21
4	15	1.196	0.643	0.466	0.333
5	20	1.79	1.363	.776	0.536
6	25	2.553	2.486	1.273	0.84
7	30	3.426	3.796	1.866	1.226
8	35	4.3	5.836	2.453	1.76
9	40	5.25	7.73	3.113	2.366
10	45	6.293	10.27	3.833	2.973
11	50	7.3		4.416	3.726
12	55	8.40		5.356	4.523
13	60	9.82			5.3
14	65				6.106

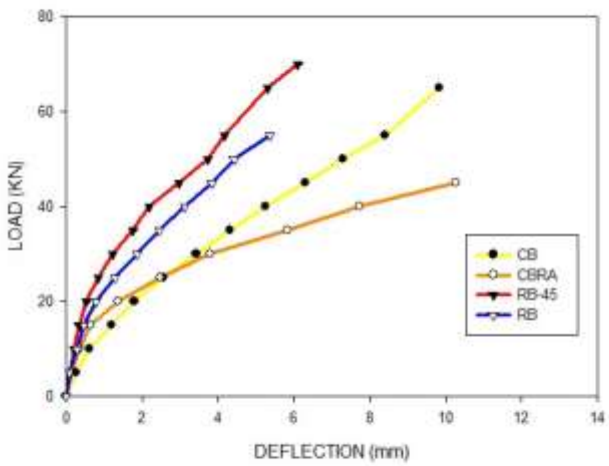

Fig-129 Load Vs Deflection Graph of Control Beams and Damage Modeled Beam with Steel mesh oriented at 45^o and 90^o

All the results are analyzed on the basis of performance of control beam C12. The control beam C8 is with reduced area tension steel; hence very under reinforced and hence failed at a lower load with large deflection. The repaired beam with geogrids could attain comparable load carrying capacities against their control beam. Beam repaired with geogrids showed strength similar to control beam c12 showing their ability to compensate for reinforcement lost by corrosion. But they could not provide additional flexural strengths. Beams repaired with steel mesh at 45° and modified mortar showed excess strength than control beams and shows better ductility in failure than beam repaired with steel mesh at 90°. Hence spalling repair using epoxy, steel mesh at 45° and modified mortar can be proposed as an effective method. All the beams have shown crack patterns displaying the integrity of structural action without failures other than flexure; ie shear, pullout etc.

5. CONCLUSIONS

The crack patterns repair modeled beams were seen to be same as that of control beam specimen. flexural cracks were evenly distributed in the pure bending zone. Flexural cracks were found to be started from bottom of the beam and extended near to the top almost vertically. Flexural-Shear cracks were visible in the shear affected areas (middle thirds near supports). Flexural-Shear cracks also started from the bottom vertically but turned to diagonal directions near shifted neutral axis. Beam failed by crushing of concrete in compression after yielding of tension reinforcement

Beams repaired with steel mesh at 45° and modified mortar (RB1&RB2) could display excess strength than control beams and beams repaired with steel mesh and modified mortar (RB3, RB4) Hence spalling repair using epoxy, steel mesh at 45° and modified mortar can be proposed as an effective method

6. RECOMENTATIONS AND FUTURE WORKS

Following works might be taken up in future as a continuation of the present study:

- Comparison of properties of various kinds of steel meshes in beam
- Repair using combinations of steel mesh and locally available materials

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