Experimental Study on the Effect of Certain Repair Materials Applied to Concrete Beams

S.Kalaiselvi
Assistant professor
Department of civil engineering
Sona college of technology
Salem,india

S.Prabhakaran
Assistant professor
Department of civil engineering
Sona college of technology
Salem,india

Abstract- The effectiveness of a repair work for the restoration of spalled reinforced concrete(R.C structures) depends to a great extent, on their ability to restore the structural integrity of the R.C element , to restore its serviceability and to protect the reinforcements from further deterioration. This paper presents the results of an experimental study to investigate the structural performance of eight spalled R.C beams repaired using repair materials (Micro Concrete) namely a free flowing self compacting mortar along with polypropylene and steel fibres with various percentages. The repair technique adopted was that for the repair of spalled concrete in which the bond between the concrete and steel was completely lost due to reinforcement corrosion or effect of fire or impact. The beams used for the experiment were first cast and then hacked at maximum flexure zone before they were repaired except for the control beam . The beam specimens were then loaded to failure under two point loadings. The structural response of each beams was evaluated in terms of first crack load, cracking behaviour , crack pattern , deflection , collapse load and mode of failure. The results of repaired beam are compared with that of control beam and conclusions are reported.

Keywords – Repair, Concrete, Spalling, Crack

I. Introduction

Reinforced concrete is the most frequently applied structural material in the practice of civil engineering. By virtue of its good characteristics such as durability, compressive strength, hardness, fire resistance and workability, it is used in a wide variety of building and construction projects. As durable and strong as it is, the commonly held view that concrete is a maintenance-free construction material has been challenged in recent years. Cracks in buildings are of common occurrence. A building component develops cracks whenever stress in the component exceeds its strength . Poor cover over reinforcement leads to carbonation and chloride attack. When ignored, this can lead to more serious problems with corrosion. As the corrosion proceeds , it not only results in significant loss of cross section of the reinforcement but also cause the concrete cover to spall. While removing corrosion it is necessary to measure the diameter of the bar. Replacement of steel is necessary if it has lost more than 20% of area but many of the researchers specified it require replacement if more than 10% of the area is lost.

Deterioration in the form of spalling is very common in the concrete covers of R.C. structures, especially when they are exposed to aggressive environmental conditions. Spalling occurs most commonly because of corrosion in the reinforcement bars. Such corrosion is often accelerated by a lack of adequate cover. Spalling is also brought about by factors such as alkali-aggregate reactions, abrasion of the concrete surface/cover, the use of high-pressure water jets, damage from fire, and exposure to sulphates, sea-water and acid.

In recent years, with the introduction of structurally effective bonding agents, patching using modified cementitious mortar has been used widely. Studies have been conducted to investigate the mechanical and physical properties of repair materials and fibres to enhance their suitability for patch repairs.

This paper presents a study on the structural performance of R.C beams repaired using Micro concrete with and without fibres . furthermore , this study focuses on the serviceability , strength and ductility performance for each repaired beam compared to control one to study their potential application in spalled reinforced concrete beams.

II. EXPERIMENTAL PROGRAMME

TEST SPECIMENS

A total of nine R.C beams were prepared. All specimens were identical in their dimensions they had rectangular cross sections of 125 x 250 mm concrete covers of 25mm to a length of 2000mm in length.

Details of Test Specimens

S.No	Specimen identification	% of Fibre	
		Steel	polypropylene
1	B1	-	-
TYPE-I Specimen(Depth of spalling 50mm)			
2	RB2	-	-
3	RB3	0.1	0.1
4	RB4	0.3	0.3
5	RB5	0.5	0.5
TYPE-II Specimen(Depth of spalling 75mm)			
6	RB6	-	-
7	RB7	0.1	0.1
8	RB8	0.3	0.3
9	RB9	0.5	0.5

'R' designates Repaired beam

A.Properties of Repair Materials

S.No	Type	Expansion/Shrinkage	Compressive strength N/mm^2		Flexural Strength N/mm^2	Water Absorption
			7days	28days	28days	
1	Micro concrete	10 - 12 x 10 -6 / ^oC	40	50	5	0.45

S.No	Type	Flexural strength	Tensile Strength	Shear strength
		7days	7days	
1	Epoxy bonding agent	34	20	20

S.No	Type	Specific gravity	Thickness of application
1	Zinc Primer	2.10	75microns

B.Properties of Fibre

S.No	Properties	Steel fibre	Polypropylene fibre
1	Length	35mm	20mm
2	Diameter	0.5mm	40micron
3	Aspect ratio	77.78	500
4	Young's modulus	1000mpa	500mpa

Polypropylene fibre

Steel Fibre

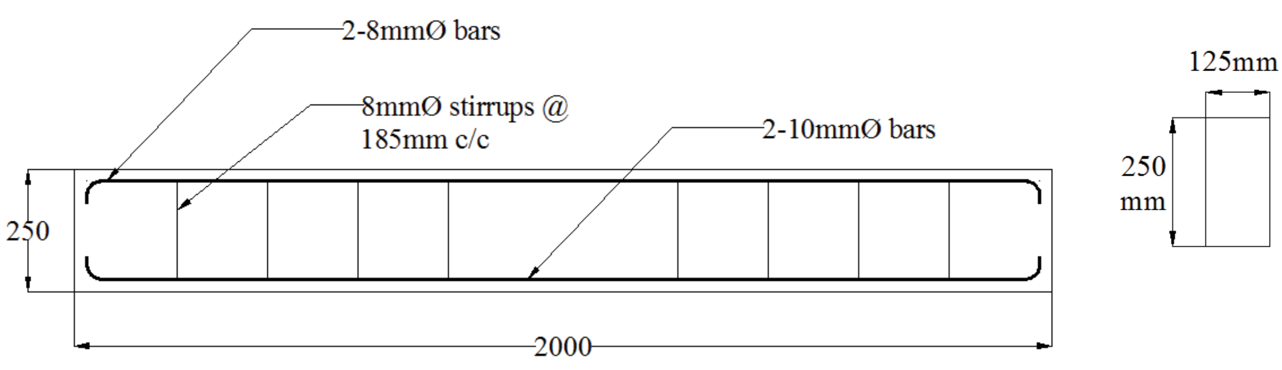
C. Materials

Ordinary Portland cement , sand , coarse aggregate size of 20mm were used in the mix proportion of 1:1.98:3.5. A water cement ratio of 0.55 was used to bring about the concrete's desired strength of 20Mpa. Standard samples of cube , cylinder were used to determine the concrete's compressive strength, split tensile strength of 28days.

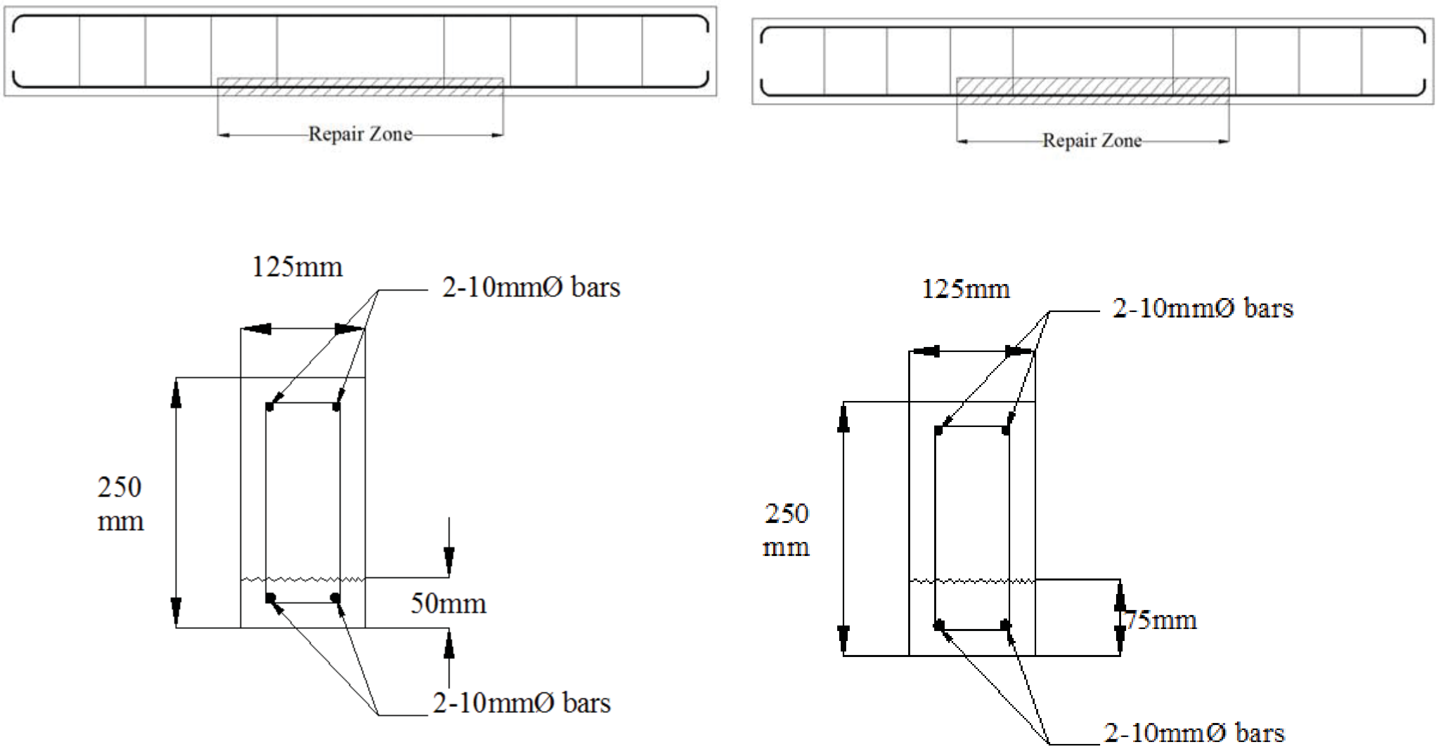
The repair materials chosen for the study are microconcrete shrinkage compensated cementitious mortars that are prepacked , single component system ready for use. Micro concrete is free flowing self compacting mortar containing natural aggregate of a maximum size of 6mm and Epoxy bonding agent was used as a bonding agent on the interface between the concrete substrate and the repairmaterials.

D. Specimen preparation

The test specimens were cast. They were designed in accordance with IScode. The flexural reinforcements consisted of two high yield deformed bars of 10mm in diameter , two 8mm diameter bars were used as hangers and and 8mm diameter bars used as stirrups at a spacing of 185mm c/c as shown in fig. the reinforcements were chosen to ensure a flexural failure mode. The concrete was then placed in steel moulds and properly compacted. The beams were allowed to curing. After the 28th day curing specimens of Type-I and Type-II made to spall in flexural zone by a process of mechanical chipping up to a depth of 50mm and 75mm in flexural zone.



CROSS SECTION OF BEAM



Typical Spalled Sections
Repair of Beam specimens

E. Surface preparation

Loose and unsound concrete in the flexural zone along the length of the reinforcement beam were cut away by means of a steel chisel. The resulting grit and dust were removed by means of a wire brush.

Spalled specimen

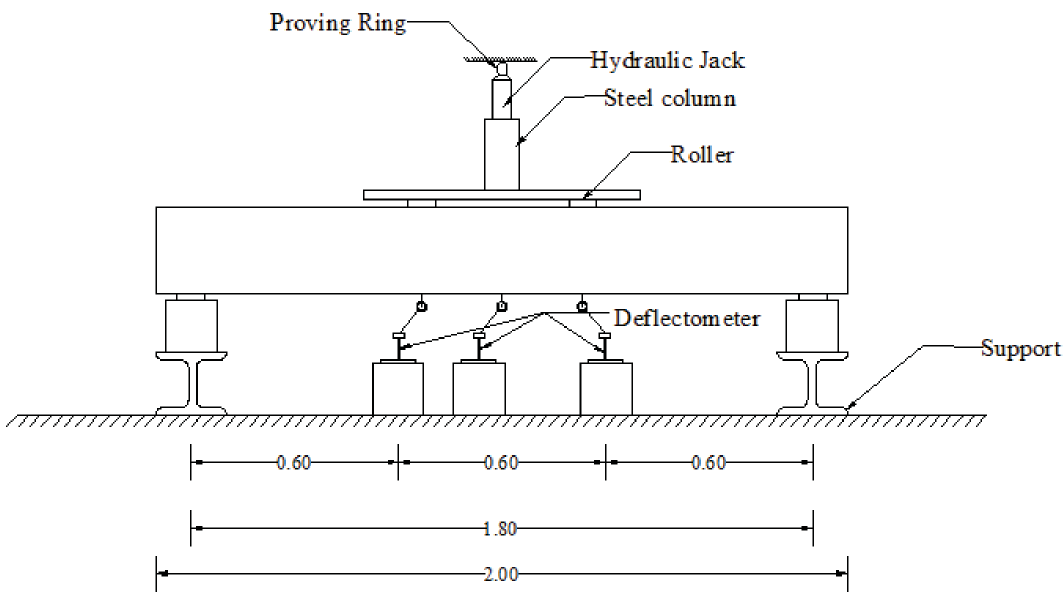
Application of repair materials

F. Application of microconcrete to beam specimens

Steel formworks were used in repair works to give the repaired areas their desired shape. A few hours prior to the repair work the substrate was properly saturated by filling the formwork with clean water. The water was then drained just prior to the commencement of the repair work and the formwork was made leak proof by the free flowing nature of micro concrete. The micro concrete was mixed with clean water to a trowable consistency as recommended by manufacturers. Epoxy bonding agent was then applied on the surface of steel and parent concrete as bonding bridge before the repair material was applied.

Experimental procedure

Tests were conducted using a loading frame. The beam specimens were simply supported and loaded in flexure under a two point loading conditions. The position of the loads and experimental setup shown in figure. The beams were loaded incrementally and the first crack loads , mid span deflections, maximum crack widths , total number of cracks and failure modes were recorded accordingly.



Experimental Setup

III. TEST RESULTS AND DISCUSSIONS

CRACKING LOAD

The first crack of the control beam was 21kN while the first cracking loads for the repaired beam specimens RB2,RB3,RB4,RB5 were observed to be 22kN, 22kN, 24kN, 27kN, respectively. The repaired beams exhibited cracking loads at 20% , 25% , 27% and 31% higher than that of the control beam respectively. The specimen repaired with repair materials with fibres showed higher load as compared to the control specimen. Perfect bonding was achieved between the concrete substrate , steel and repair materials along with polypropylene and steel fibres.

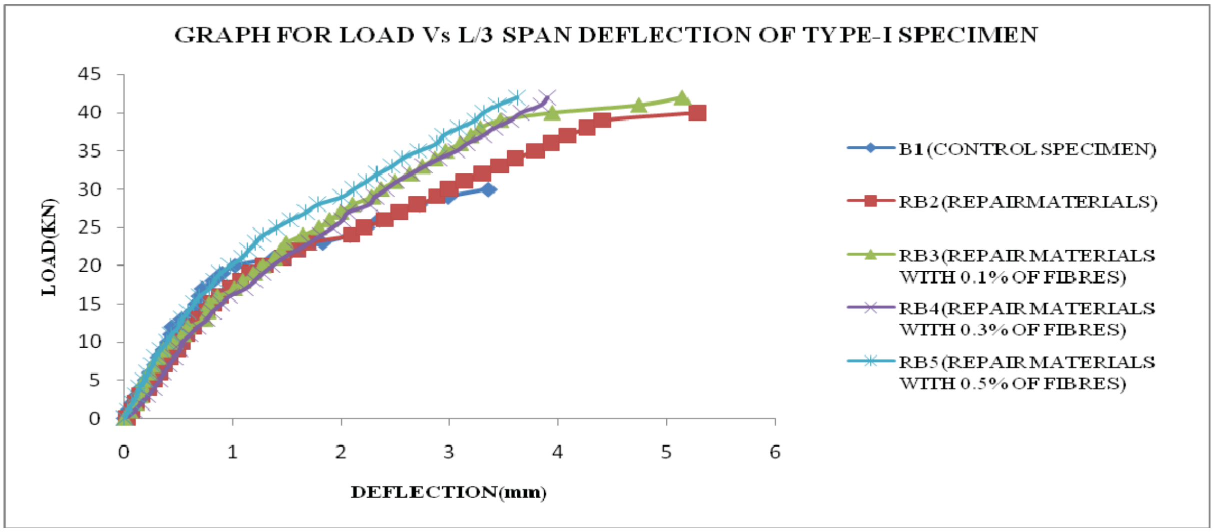
TEST RESULTS

Beam Code	First crack load (kN)	Failure load (kN)	First crack load ratio	Failure load ratio	Crack no at failure	Failure no
B1	21	38	1.00	1.00	22	Flexural Failure
RB2	22	48	1.05	1.26	18	Flexural Failure with no debonding
RB3	22	51	1.05	1.34	16	Flexural Failure with no debonding
RB4	24	52	1.14	1.37	10	Flexural Failure with no debonding
RB5	27	55	1.29	1.45	10	Flexural Failure with no debonding

‘R’ designates repaired beam

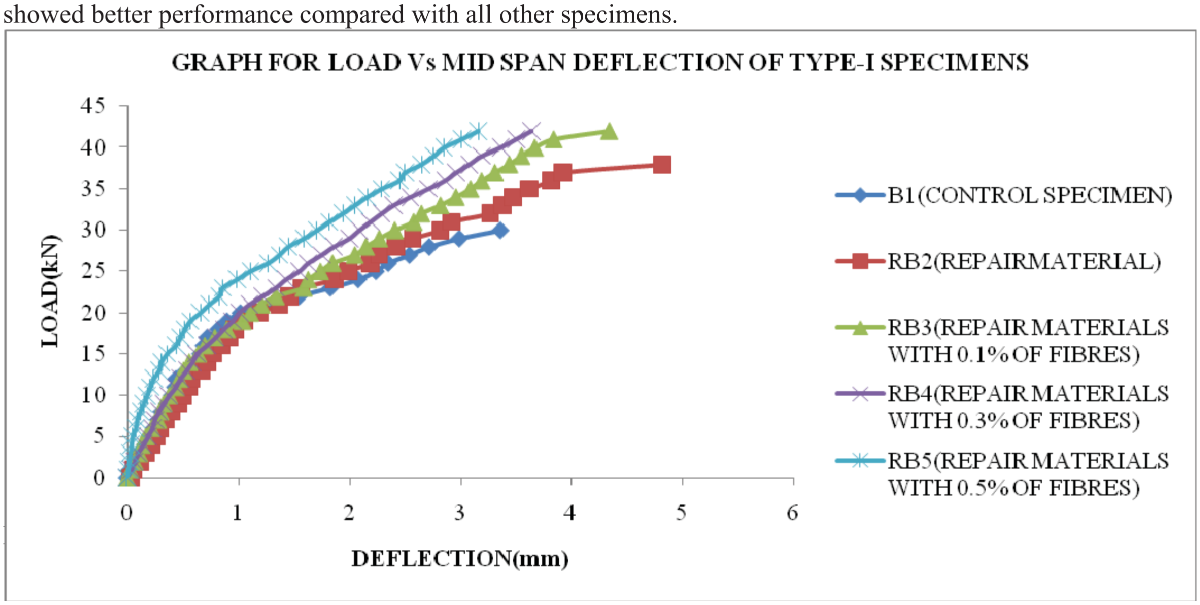
FAILURE LOAD

The above table shows the failure load for all the beam specimens. it can be seen that the ratio of the ultimate load capacity of the beams RB2 , RB3 , RB4 and RB5 repaired using repair materials with polypropylene and steel fibres to that of the control beam are 1.0 , 1.26 , 1.34 , 1.27 and 1.45 respectively. These results indicate that the repair techniques performed by using repair materials along with polypropylene and steel fibres not only restore the beams to their full capacity but also reduces the number of cracks formed compared to the control specimen. The proper surface preparation , unique bonding between the interfaces of concrete substrate and repair materials along with fibres and the good quality of repair materials attributed to the restoration of full capacity of the defective beams.

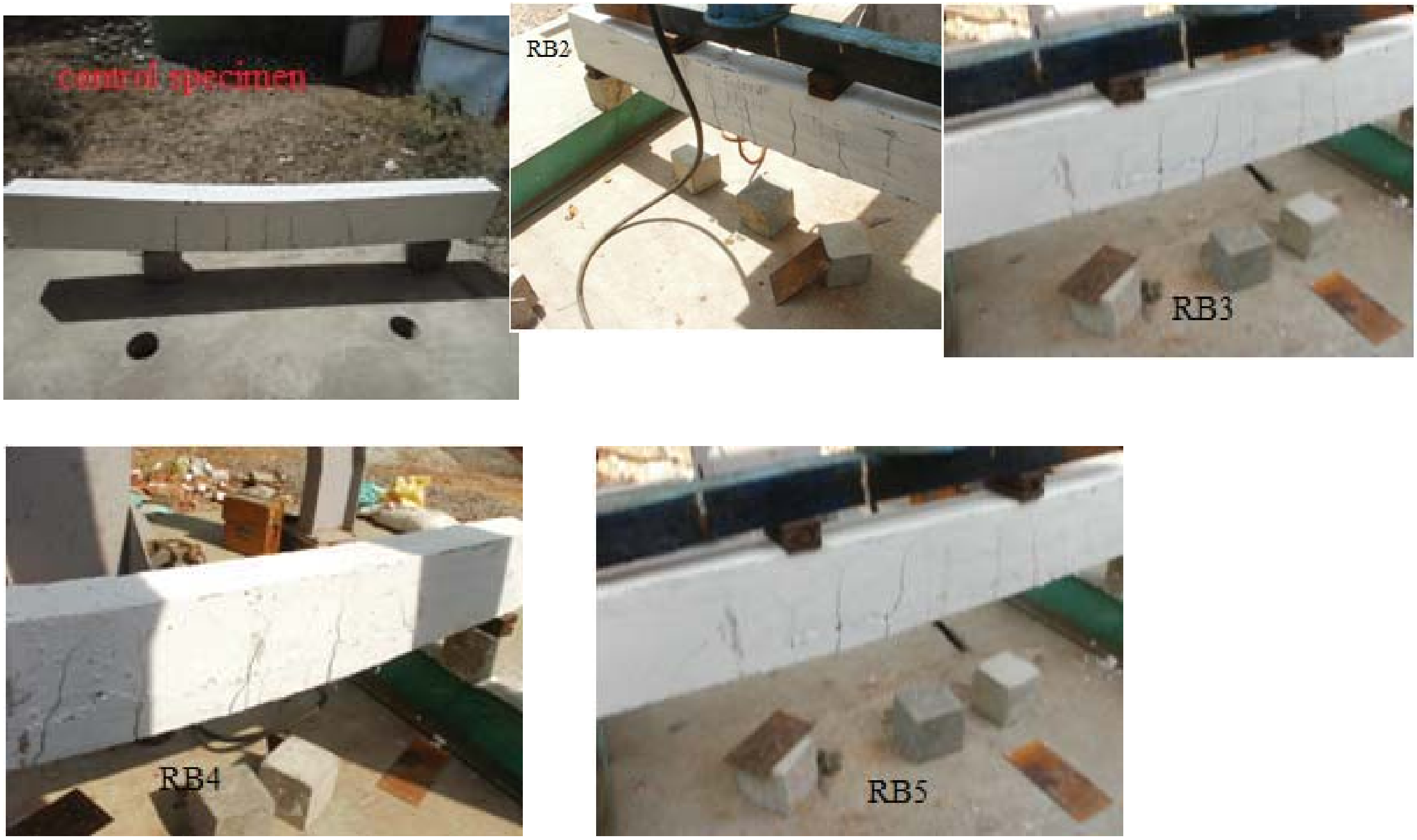


MID SPAN DEFLECTION

The mid span deflection curves for beams repaired with repair materials along with polypropylene and steel fibres as well as for the control specimen were shown in fig. the actual maximum deflections at mid span were measured and plotted against actual loads. The beam specimens repaired by using repair materials along with polypropylene and steel fibre showed almost similar load deflection curves to that of the control beam. Among these RB4 and RB5 showed better performance compared with all other specimens.



The crack pattern and failure modes of the beam specimens was shown in fig. The tests were carried out by increasing the load until failure. Flexural failure was noted for all the repaired beams as well as control specimen. As the load was increased to the point of failure no debonding was observed along horizontal surface of the concrete-repair material interfaces. Proper bonding was observed between parent concrete and the repair material with fibres. The addition of fibres shows the strength improvement and less number of cracks. Similarly on increasing the percentage of fibres with repair materials showed crack width goes on reducing compared control specimen.



Failure Modes and Crack Pattern for all the Beams

IV.CONCLUSION

1. All the repaired beams showed crack patterns similar to that of the control beam. At the service load the repaired specimens showed better performance in terms of strength and less of number of cracks.
2. All the beams including the control showed higher ultimate load values than that expected from theoretical values.
3. There was no debonding along the horizontal surface of the concrete mortar interfaces as the load was increased to the point of failure.
4. The treatment used at the interfaces between the concrete and steel and between the repair materials , fibres , steel and the concrete was satisfactory.
5. On increasing the percentage of fibres the cracks started at slightly higher loads and propagation of cracks occurs at higher loads.
6. The beam specimens repaired using repair materials along with polypropylene and steel fibres showed better performance in terms of strength , stiffness and ductility performance. It follows that the repair materials and techniques used can be safely adopted retrofit reinforced concrete beams that have spalled.

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