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Flexural Performance of Reinforced Concrete Beams Repaired with Mortar Based Repair Materials

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***Abstract*—Repair and retrofitting of existing structures have become a major part of the construction activity. The most common form of repair for a deteriorated structure is through patching. The objective of this experiment is to investigate the performance of different types of repair materials used to strengthen the beams. Five RCC beams of size 1500mm×150mm×200mm were casted which include one beam as control specimen and four beams were casted by providing a trapezoidal notch at bottom surface of the beam and cured for 28 days. Beams were then patched with mortar based repair materials, membrane cured and tested for flexure.**

***Index Terms*—Repair, Flexural Strength, Mix design.**

I. Introduction

Repair and rehabilitation of concrete infrastructure is an important aspect of maintenance activities of a building structure, pavement, or a bridge in the world. The annual cost to the owners for repair, protection and strengthening is increasing day by day. Recent investigations of repairs to bridge decks and other structures have indicated an over-whelming incidence of premature failures resulting from a variety of factors. It is generally observed that a repair section in the concrete structure is mostly performed at the joints or in the tension area. Tension is induced in the concrete by bending of the structure due to loading or due to environmental conditions. Therefore, the flexural test method would be an appropriate method to study performance of different repair materials. Here it is aimed to study the flexural performance of different repair materials to strengthen or repair reinforced concrete beams. The performance of each repair material was assessed through flexural behaviour of different specimens.

Five RCC beams of size 1500mm×150mm×200mm were casted. These specimens include one concrete beam as control specimen (no repair). Four beams were casted by providing a wide mouthed trapezoidal notch at the bottom surface of the beam and all beams were cured for 28 days. Beams with notches were then patched with four selected types of repair materials in which one is repaired with normal concrete and the other three are mortar based repair materials and membrane cured for 28 days. All these beams were tested for flexural strength using two point loading in loading frame. Results were compared with control beam (no repair) and beam repaired with normal concrete (R_{NC}).

II. Materials and Methods

The materials used in this investigation were cement, fine aggregate, coarse aggregate, conventional steel, water, super plasticizer (Conplast SP-430), silica fume, fly ash and Roff concrete bond (bonding agent).The physical properties of the materials are listed in the tables below.

Table 1: Properties of ordinary Portland cement

Sl.No	Properties		Test Results	Standard specifications as Per IS 12269-1987
1	Normal consistency		31%	30%
2	Initial setting time		75 min	Not less than 30 min
3	Final setting time		143 min	Not more than 600 min
4	Specific gravity		2.9	3.0-3.15
5	Compressive strength			
	3 days of curing		29.25	Not less than 27 MPa
	7 days of curing		38.85	Not less than 37 MPa
	28 days of curing		54.15	Not less than 53 MPa
6	Fineness of cement		3%	10%

Table 2: Properties of Fine Aggregate

Sl.No	Test	Results	Specifications as per IS 383-1970
1	Specific gravity	2.56	2.6-2.9
2	Moisture content	2%	0.5%-2%
3	Water absorption	1.2%	0.5%- 1.4%
4	Grading	Zone II	Zone II
5	Fineness modulus	2.64	2.8-3.2

Table 3: Properties of coarse aggregate

Sl.No	Test	Results	Specifications as per IS 383-1970
1	Specific gravity	2.73	2.6-2.9
2	Moisture content	0.5%	0.5%
3	Water absorption	0.6%	0.6%
4	Fineness modulus	6.65	6.5-8.5

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Table 4: Properties of steel

Sl.No	Type	Dia (mm)	Yield strength (MPa)	Ultimate strength (MPa)	Elongation (%)
1	High yield strength deformed bars	10	610	776.68	14.6
2		8	640	835.56	15.2
3		6	760	1007.98	17.4

Table 5: Properties of Superplasticizer

Sl.No	Properties	Range
1	Specific Gravity	1.220 to1.225@35 ^{o}C
2	Chloride Appearance	Min. 85%
3	Appearance	Max. 1.0%

Table 6: Properties of silica fume

Sl.No	Properties	Range
1	Chemical composition	
	SiO_2 (silicon dioxide, amorphous)	Min. 85%
	H_2O (moisture)	Max. 1.0%
	C (carbon)	Max.2.5%
	LOI (loss on ignition)	Max. 4%
2	Physical properties	
	Bulk density D (kg/m3)	600-700
	Bulk density D (kg/m3)	200-350

Table 7: Properties of Fly Ash

Sl No	Properties	Results
1	Specific gravity	3.00
2	Chemical compositions characteristics	Fly ash (% wt)
	Silica	55 to60
	Iron oxide	5 to7
	Aluminium oxide	22 to 25
	Calcium oxide	5 to 7
	Magnesium oxide	<1
	Titanium oxide	<1
	Phosphorous	<1
	Sulphate	0.1
	Alkali oxide	<1
	Loss on ignition	1 to 1.5

The water used in this investigation is potable tap water for both casting and curing. High range water-reducing admixture from Fosroc Chemicals Limited, Bangalore of type Conplast SP-430 has been used.

III. EXPERIMENTAL PROGRAM

The experimental study consists of casting of five RCC beams of dimensions 1500mm× 150mm×200mm. Out of five beams one beam was used as control specimen (no repair), and four beams were casted in such a way that a wide mouthed trapezoidal notch is created at the bottom surface of the beam which represents the damaged or deteriorated area that needs to be repaired using the repair materials. This notch was created at the middle third region of the beam. Beams with notches were patched with four selected types of repair materials using suitable bonding agent.

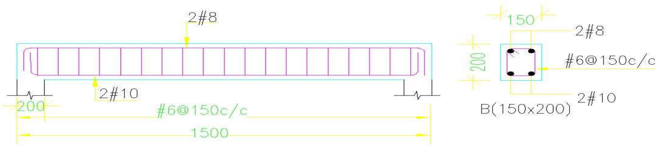

Figure 1: Reinforcement details of the beam

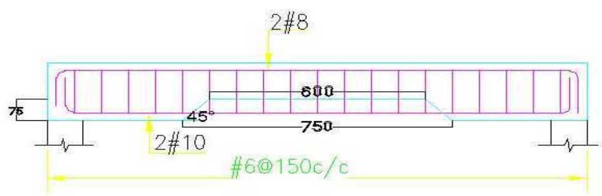

Figure 2: Details of the beam before repair

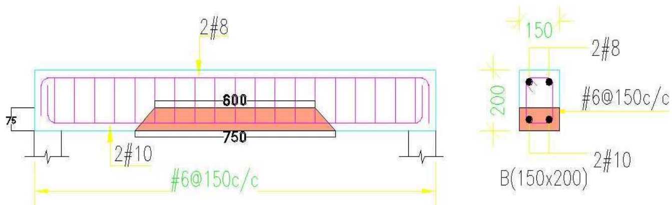

Figure 3: Details of the beam after repair

All beams have same flexural (longitudinal) reinforcement of two #10mm diameter deformed steel reinforcing bars as bottom reinforcement and two #8mm diameter deformed steel reinforcing bars as top reinforcement .The flexural reinforcement is chosen to provide an under reinforced section with a flexural dominating behaviour. The shear reinforcement consists of #6mm diameter deformed steel reinforcing bars as closed stirrups spaced at 150mm along the beam longitudinal axis as shown in Fig 1.

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IV. MIX DESIGN

The mix proportion of M20 grade concrete designed as per IS 10262-1982 is 0.52:1:1.596:3.370.

V. CASTING

Casting of cubes

Cube moulds of 70mm were used for casting mortar cubes to determine the compressive strength of repair materials at 7 days and 28 days.

Casting of control beam

Plywood mould of size 1500mm×150mm×200mm were used for casting of beams. The internal surface of the mould is cleaned and a coat of oil is applied. The reinforcement cage prepared earlier is kept in the mould. To obtain the required clear cover mortar blocks of 25mm thickness are kept at each end. The mould is filled with concrete in three layers with height of each layer equal to 1/3rd height of the mould and compacted uniformly with tamping rods. The top surface is smoothened and the mould is kept for drying to about 24 hours.

Casting of repair beams

Repair beams were casted with the same procedure as that of control beam expect that a trapezoidal notch is created in the flexure zone. The dimensions of the trapezoidal notch is shown in the Fig 2

VI. CURING OF SPECIMENS

Pond curing method is adopted. All the test specimens are removed after 24 hours of casting from the moulds and placed in the tank for 28 days. After 28 days all the specimens are taken out from the tank and kept for air drying.

VII. REPAIR OF BEAMS

After 28 days of curing the beams are kept for air drying. Prior to patching of the repair materials the surface of the substrate concrete has to be prepared. The surface of the substrate concrete is chipped off using a hammer and chisel so that weak concrete is removed. Then all the loose particles, dust and debris are removed. The mixed material of bonding agent (Roff concrete bond) is evenly applied over the prepared and cleaned surface with a brush. The notches are to be filled with the following repair materials as shown in the Fig 3

VIII. TESTING PROCEDURE

Compression test

Cube specimens are used for determining characteristic compressive strength. The load at which cube specimen fails is recorded. The compressive strength is calculated by dividing the ultimate load by cross sectional area of the specimen.

Cube compressive strength = ultimate load / c/s area of the cube.

Testing of beams

After the completion of air drying (24 hours) the specimen are cleaned to remove grit and dirt with the sand paper. White washing was done on all the sides of the beam and were kept ready for testing. White washing was done to facilitate easy detection of crack propagation. The testing is carried on structural loading frame. The loading reaction frame of 1000KN capacity consists of two movable steel I-sections. These I-sections were adjusted to have an effective span of 1300mm. The beam to be tested is placed over these two supports. Steel rollers with grooved steel plates are placed between the beam and the I-section to provide two point loading system . By using plumb bob the centre line of the beam and the hydraulic jack were made to coincide with each other in order to prevent eccentric loading on beam. Proving ring of capacity 500KN was placed in its position to record the load values. Dial gauge was placed exactly beneath the mid-span of the beam to record deflection. The test set up is shown in the Fig 4.The load was applied at a regular interval of 0.725 KN. The load and corresponding deflection values are recorded and tested till the failure of the beam. The load deflection graph are shown in the Figure 5,6,7,8&9.The test results of all the beam are shown in the Table 9.

Figure 4: Test Setup of beam

Table 4.1: Compressive strength of repair materials

Repair material	Curing period	
	7 days	28 days
	Average compressive Strength (N/mm^2)	Average compressive Strength (N/mm^2)
Normal concrete	18	30
SF mortar	34.218	47.221
FA mortar	28.775	41.565
(SF+FA) mortar	35.714	53.13

Table 9: Test results of all beams

Repair material group	Material Designa tion	Ultimate Load, Pu (KN)	% decrease in load compared to control beam	% increase in load compared of normal concrete
Referen ce	Control	39.995	-	-
RN_C	Normal concrete	34.195	14.5	-
RG_1	R_1	34.92	12.69	2.12
	R_2	34.195	16.32	2.12
	R_3	35.645	10.88	4.24

Table 9: Test results of all beams (continued)

Repair material Group	Maximum deflection (mm)	% of Control beam	Pu/ Pu-control	Approx. Cost (Rs)
Reference	18.543	-	1.000	-
RN_C	19.812	106.85	0.855	45
	22.454	121.09	0.873	35
RG_1(Mortar based repair materials)	18.085	97.5	0.855	30
	17.932	96.7	0.891	40

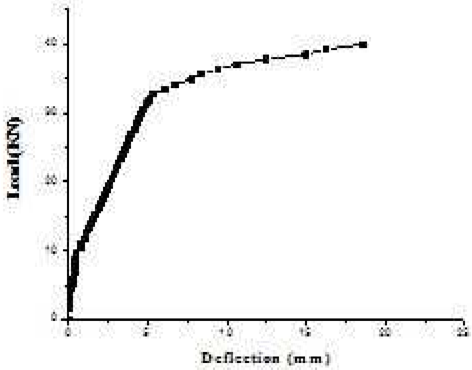

Figure 5: Load v/s deflection curve of control beam

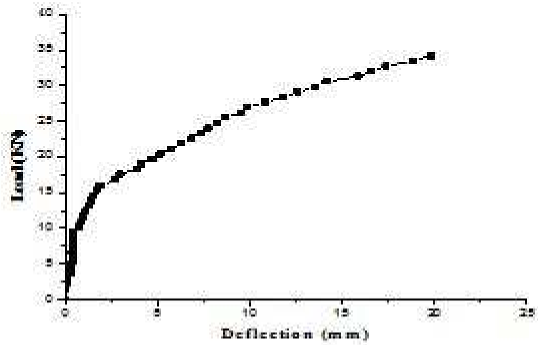

Figure 6: Load v/s deflection curve of R_{NC} beam

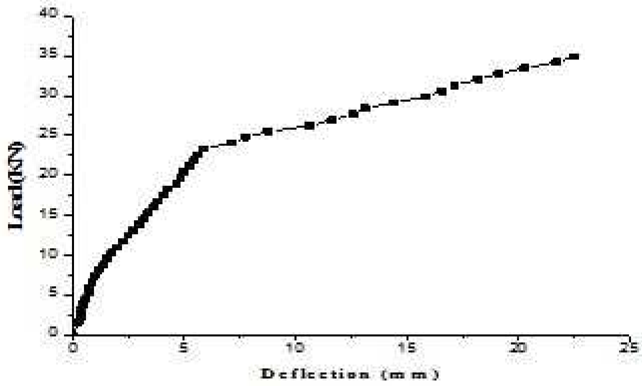

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Figure 7: Load v/s deflection curve of R_1 beam

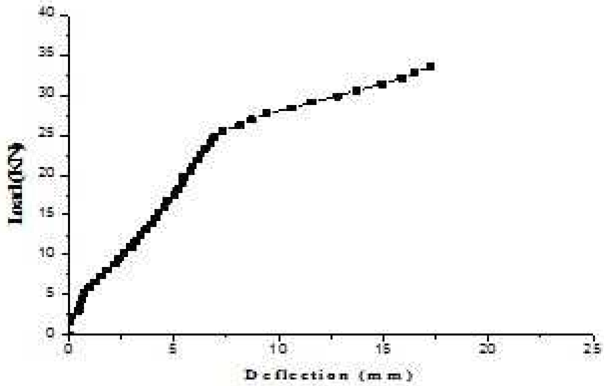

Figure 8: Load v/s deflection curve of R_2 beam

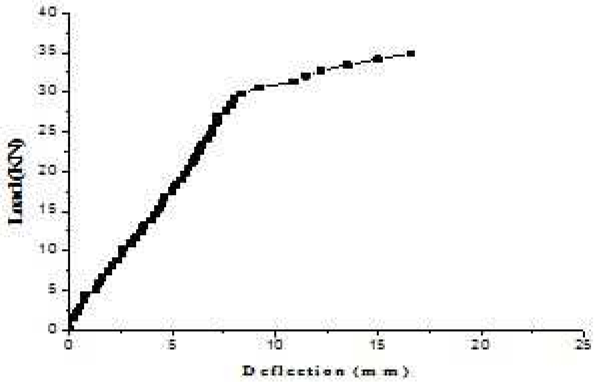

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Figure 9: Load v/s deflection curve of R_3 beam

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IX. CONCLUSION

[1] The flexural strength of the beams repaired in tension with selected repair materials i.e. R_1 to R_3 were increased in comparison with beam repaired with normal concrete (R_{NC}). The increase in flexural strength is in the range of 2.12% to 4.24%.
[2] From the repair materials of same group RG_1 (mortar based materials), it is seen that the beam repaired with R_3[SF(10%)+FA(20%)] materials exhibits better performance.
[3] From the study of modes of failure of the beams it is observed that beams repaired with materials R_1 and R_2 failed due to bonding and with R_3 failed in flexural cracks.
[4] From this study it can be concluded that damaged parts subjected to tensile flexural stresses can be repaired using mortar based repair materials by retaining the capacity of the beam nearer to its original capacity.
[5] The results of this investigation provide a certain confidence level in using these materials to repair reinforced concrete beams.

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