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Experimental Investigations on retrofitting of RC beams using SFRC plates

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Introduction

Retrofitting is a technical intervention in structural system of a building that improve resistance to earthquake by optimizing strength and ductility. Strength of a building is generated from its structural dimensions, materials, shape and number of structural elements, etc. Durability of a building is generated from good detailing, materials used, degree of seismic resistance, etc. Earthquake load is generated from the site seismicity, mass of structures, degree of seismic resistance etc. Due to the variety of structural conditions of building, it is hard to develop typical rules for Retrofitting. Each building has different approaches, depending on the structural deficiencies. Hence, engineers are required, to prepare and design the retrofitting approaches. In the design of retrofitting approach, the engineer must fulfill the minimum requirements of the building codes, such as deformation, detailing strength, etc. Retrofitting of flexural concrete elements is traditionally accomplished by externally bonding steel plates to concrete. Although this technique has proved to be effective in increasing strength and stiffness of reinforced concrete elements, it has the disadvantages of being susceptible to corrosion and difficulty in installation. Recent development in the field of composite materials, together with their inherent properties, which include high specific tensile strength, good fatigue strength, corrosion resistance and ease of use, make them an attractive alternative to steel plates in the field of repair and strengthening of concrete elements. Reinforced concrete structures often have to face modification and improvement of their performance during their service life. The main contributing factors are change in their use, new design standards, deterioration due to corrosion in the steel caused by exposure to an aggressive environment and accident events such as earthquakes. In such circumstances there are two possible solutions: replacement or retrofitting. Full structure replacement might have determine disadvantage such as high costs for material and labour, a stronger environmental impact and inconvenience due to interruption of the function of the structure e.g traffic problems. When possible, it is often better to repair or upgrade the structure by retrofitting. In the last decade, the development of strong epoxy glue has led to a technique which has great potential in the field of upgrading structures. Basically the technique involves gluing steel plates or SFRC plates to the surface of the concrete. The plates then act compositely with the concrete and help to carry the loads. FRP can be convenient compared to steel for a number of reasons. These materials have higher ultimate strength and lower density than steel. The installation is easier and temporary support until the adhesive gains its strength in not required due to the low weight. They can be formed on site into required due to the low weight. They can be formed on site into compiled shapes and can also be easily cut to length on site. Retrofitting reduces the vulnerability of damage of an exiting structure during a future earthquake. It aims to strengthen a structure to satisfy the requirements of the current codes for seismic design. The performance of present techniques of retrofitting and strengthening of structures using externally bonded steel plates and CFRP, GFRP plates with epoxy resins has been extensively investigated . (Swamy RN, Jones R, Bloxham JW 1987), (Zhang, S., M. Raoof and L. Saadatmanesh, H., Mohammad, R.E. 1991). This technique of retrofitting has gained more popularity in a construction field, being fast, causing minimal site disruption and producing small change in section dimensions. (Grace, N.F., Sayed, G.A., Soliman, A.K., Saleh, K.R. 1999). Strengthened by epoxy plated beams bonded to RC beams using epoxy injections (D.P.Singh 1992, Buyukozturk, O. and B. Hearing 1998), (Teng, J.G, et al.2001), (Kim, S. and R.S. Aboutaha 2004), (Farshid Jandaghi, et al 2003). Earlier research has demonstrated that GFRP plates were bonded to the beams in both horizontal and vertical directions on the sides and bottom of the beams. The factor of safety was raised for the strengthened beams and these beams were resistant to diagonal cracks. In another study (Farshid Jandaghi, et al 2003) (HPFRCC) designated as CARDIFRC plates used for retrofitting of existing concrete structures to predict the moment resistance and load-deflection response of the beams. (Cheng-Chih Chen and Chung-Yan Li 2005) Strengthened a slab-column with GFRP and (H. Wang and A. Belarbi, 2005) in this strengthened with CFRP and GFRP. An analytical model,(S.T.Smith S.J.Kim 2009) which is based on the ultimate moment of resistance about critical crack lines was made to correlate with the experimental results. The techniques (Obaidat, Y.T., S. Heyden, and O. Dahlblom, 2011), (Namasivayam Aravind, Amiya K. Samanta, D. K. Singha Roy and Joseph V.Thanikal 2013) involved by gluing steel plates or SFRC plates to the surface of the concrete gained more strength. The retrofitting process shall start with investigation and diagnosis of cracks and then applying suitable retrofitting technique and compatible materials. There are several techniques which are used to retrofit structural members such as section enlargement, external plate bonding, external post-tensioning, grouting and fibre reinforced polymer composites. Based on the severity of the damage and required capacity to be regained, a proper retrofitting technique is specified and implemented. The load carrying capacity, load-deflection, the flexural strength behavior of shear deficient beams and flexural deficient beams by retrofitting with SFRP plates reinforced with steel bars, SFRP plates reinforced with glass bars and steel plates.

Materials and Methods

Ordinary Portland cement of 53 Grade, conforming to IS: 12269-1987 was used in this investigation. The cement used has been tested for various properties as per IS: 4031-1988 and are reported in Table.1.

Table.1 Physical Properties of OPC (53 Grade)

Sl No	Properties	Test Results	Requirements as per IS:12269-1987
1	Normal Consistency	31%	--
2	Specific gravity	3.10	--
3	Initial setting time	53 min	Not less than 30 min.
4	Final setting time	250 min	Not more than 600 min
5	Soundness (LeChatelier)	1.7 mm	Not more than 10 min
6	Fineness	3200 cm^2/gm	Should not be less than 2250 cm^2/gm
7	Compressive Strength	62.6 MPa	53 MPa

Aggregates

Ennore Sand: Indian standard sand as per IS: 650 – 1991 is used or testing of cement. Fine Aggregate: Locally available clean, well-graded, natural river sand having fineness modulus of 2.89 conforming to Zone II of IS 383-1970 was used as fine aggregate. Various properties of fine aggregate are evaluated in accordance with IS: 2386-1963 Part I to VIII and tabulated in

Course Aggregate

Crushed granite angular aggregate of Size 20mm and 10mm size from local source with specific gravity of 2.75 was used as coarse aggregate. The Physical characteristics of coarse aggregate are tested in accordance with IS: 2386 – 1963 Parts I to VIII and are tabulated in Table 3.2

Table.2 Properties of Fine and Coarse Aggregates

Property	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.50	2.56 (20mm)
		2.55 (10mm)
Type	natural	Crushed
Total Water absorption	1.0%	1.6% (10mm)
		3.6% (20mm)
Moisture content	0.15%	0.8% (10mm)
		0.7% (20mm)
Bulk Density (Loose)	1423 kg/m^3	1429 kg/m^3
Bulk Density (Compacted)	1612 kg/m^3	1617 kg/m^3
Fineness Modulus	2.85 (Zone II)	7.35 (20mm)
		6.29 (10mm)

Table.3 Details of Test Beams

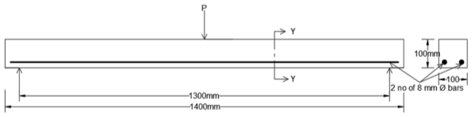
Type of Beam	Grade of Mix	Reinforcement	Shear Reinforcement	Dimensions, mm
Shear Deficient Beam (SDB)	M20	2 – Ø 12 mm	Nil	1400× 100 × 100
Flexure Deficient Beam (FDB)	M20	2 – Ø 12 mm	Ø 6 mm, 2 legged stirrups at 150 mm c/c	1400× 100 × 100

Table.4 Details of Retrofitting Plates

Retrofitting Plate ID	Grade of Mix	% of Crimped Fibers	Reinforcement	Plate length mm	Plate Width mm
RP1	M40	0.5	Ø6 mm, 3 Number of Mild Steel Bars	700	100
RP2	M40	0.5	6 mm × 7 mm, 3 Number of Glass Fiber Bars	700	100
RP3	Glass Fiber Plates			700	80

Table.5 Specifications of Control Beam

Type of Beam	Grade of Mix	Reinforcement	Shear Reinforcement	Length mm	Cross section mm
Shear Deficient Beam (SDB)	M20	2 – Ø 12 mm	Nil	1400	100 × 100
Flexure Deficient Beam (FDB)	M20	2 – Ø 12 mm	Ø 6 mm, 2 legged stirrups at 150 mm c/c	1400	100 × 100



DETAILED LONGITUDINAL OF RCC CONTROL BEAM FOR SHEAR DEFICIENT (SDB) SECTION AT - YY

Fig.1 2D view of three-point load Shear Deficient beam with reinforcement

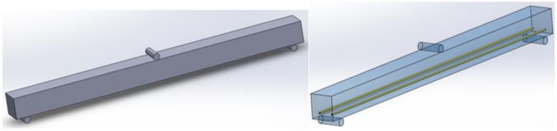


Fig.2 3D view of three-point load Shear Deficient beam

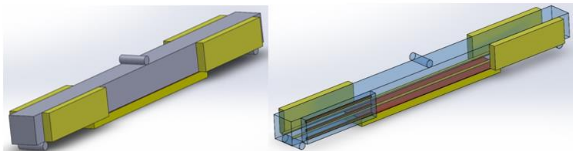


Fig.3 3D Model of Shear Deficient Beam retrofitted with RP1

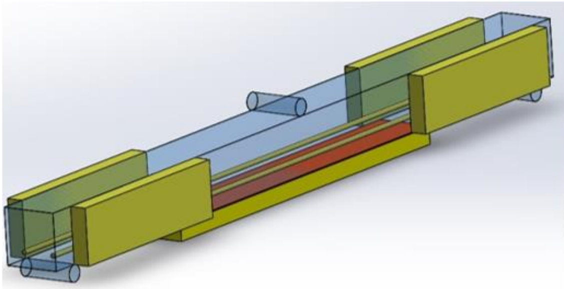


Fig.4 3D Model of Shear Deficient Beam retrofitted with RP2

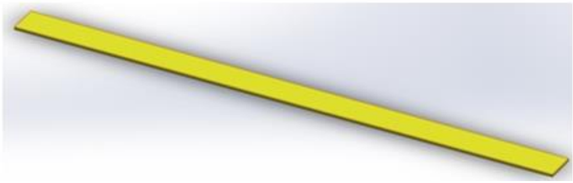


Fig.5 3D Glass strip of 3 mm thickness

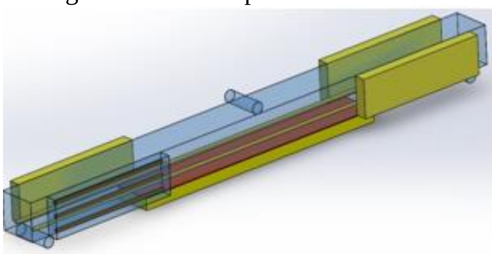


Fig.6 3D Model of SDB retrofitted with RP3

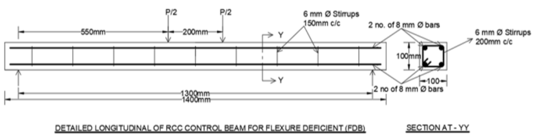


Fig.7 FDB, Flexure Deficient Beam

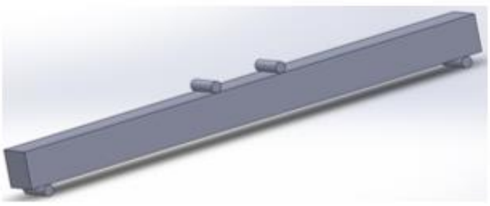


Fig.8 3D Model of four-point load FDB

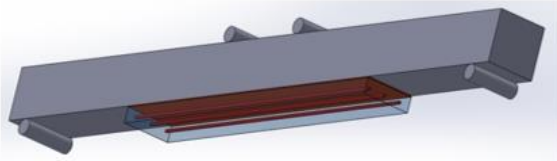


Fig.9 3D Model of FDB retrofitted with RP1

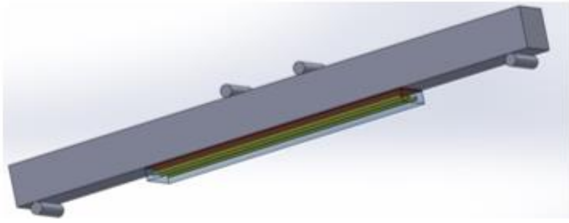


Fig.10 3D Model of FDB retrofitted with RP2

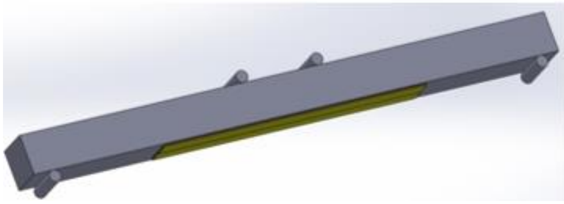


Fig.11 3D Model of FDB retrofitted with RP3

Fig.14 Molds for SFRC plates Glass fiber bars of size 700 mm length and 6mm × 7mm cross section, Casting of SFRC plated including 3 numbers of glass fiber bars, curing of beams and plated in a water tank, Various thickness of SFRC plates including steel bars and glass bars.

Fig.15 Setting UTM machine for flexure test of beam samples, beam sample for three-point load with dial gauge

Fig.16 Tested sample of Shear Deficient Control Beam

Fig.17 Four point loaded beam sample for flexure test (FDB)

Sample ID	Ultimate Load (kN)	Average Load P_u	Deflection (mm)	Failure Mode
SDB 1	12		12.1	Flexure Failure
SDB 2	11.6	12.0	9.86	Shear Failure
SDB 3	12.4		10.38	Shear Failure
SDB 1 – P1	13.6		12.6	Flexure Failure
SDB 2 – P1	14.1	13.83	11.1	Shear Failure
SDB 3 – P1	13.8		10.5	Flexure Failure
SDB 1 – P2	16.2		11.51	Shear Failure
SDB 2 – P2	16.6	16.53	10.64	Flexure Failure
SDB 3 – P2	16.8		9.35	Shear Failure
SDB 1 – P3	20.2		10.6	Shear Failure
SDB 2 – P3	19.6	19.93	10.0	Shear Failure
SDB 3 – P3	20.0		9.15	Shear Failure
SDB 1 – P4	15.8		12.22	Shear Failure
SDB 2 – P4	16.4	16.26	11.56	Shear Failure
SDB 3 – P4	16.6		12.5	Shear Failure
SDB 1 – P5	19.6		10.2	Shear Failure
SDB 2 – P5	19.4	19.4	10.61	Shear Failure
SDB 3 – P5	19.2		9.58	Flexure Failure
SDB 1 – P6	20		4.41	Debonding Failure
SDB 2 – P6	18	22	3.32	Debonding Failure
SDB 3 – P6	22		9.12	Shear Failure
SDB 1 – P7	12.5		10.3	Debonding Failure
SDB 2 – P7	12.6	12.7	9.56	Shear Failure
SDB 3 – P7	12.7		9.1	Shear Failure

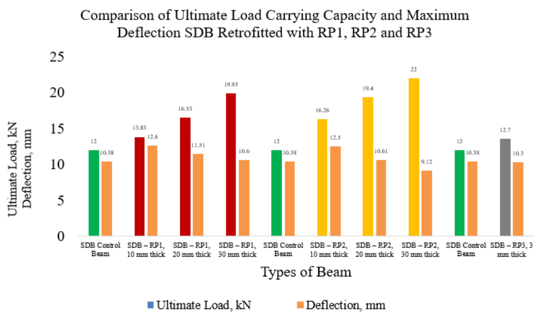


Fig.18 Comparison of Ultimate Load Carrying Capacity and Maximum Deflection of SDB

Sample ID	Ultimate Load (kN)	Average Load P_u	Deflection (mm)	Failure Mode
FDB 1	12.6	12.33	10.51	Flexure Failure
FDB 2	12.2		9.6	Flexure Failure
FDB 3	12.2		10.23	Flexure Failure
FDB 1 – P1	14.8	14.7	8.12	Flexure Failure
FDB 2 - P1	14.2		9.12	Flexure Failure
FDB 3 – P1	15.2		9.8	Flexure Failure
FDB 1 – P2	17.4	17.26	8.4	Flexure Failure
FDB 2 - P2	17.6		8.1	Flexure Failure
FDB 3 – P2	16.8		8	Flexure Failure
FDB 1 – P3	21	21	8.6	Flexure Failure
FDB 2 - P3	20		8	Flexure Failure
FDB 3 – P3	22		7.9	Flexure Failure
FDB 1 – P4	17.6	17.6	8.5	Flexure Failure
FDB 2 - P4	17.8		8.9	Flexure Failure
FDB 3 – P4	17.4		8.1	Flexure Failure
FDB 1 – P5	20.4	20.46	7.9	Shear Failure
FDB 2 - P5	20.6		8.1	Flexure Failure
FDB 3 – P5	20.4		8.5	Flexure Failure
FDB 1 – P6	22	24.1	4.3	Debonding failure
FDB 2 - P6	18		2.75	Debonding Failure
FDB 3 – P6	16		2.18	Debonding Failure
FDB 1 – P7	13.2	13.1	9.1	Debonding Failure
FDB 2 - P7	13.1		9.8	Debonding Failure
FDB 3 – P7	13.3		8.9	Debonding Failure

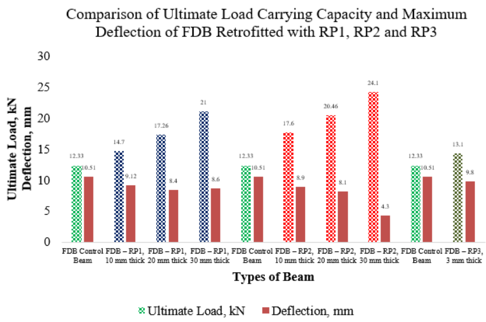


Fig.19 Comparison of Ultimate Load Carrying Capacity and Maximum Deflection of FDB

Conclusions

1. Retrofitting of shear deficient beams with 10mm and 20mm thick concrete plates reinforced with steel bars shows improvement in load carrying capacity.
2. Beams retrofitted with 10 mm and 20 mm thick SFRC plates displayed improvement in load carrying capacity. Initial stiffness is observed to be high. Better bonding between plate and concrete beam is observed. Beams retrofitted with 30 mm thick SFRC plates displayed better load carrying capacity eventually failed in debonding.
3. Beams retrofitted with 3 mm thick glass fiber plates exhibited very less improvement in load carrying capacity and poor deflection control as compared to beams to retrofitted with SFRC plates.
4. Flexural capacity and Improvement in stiffness of beams retrofitted with SFRC plates reinforced with glass fiber bars (RP2) exhibits better performance over beams retrofitted with SFRC plates reinforced with steel fiber bars (RP1) and glass fiber plates (RP3). Improved stiffness

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