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RETROFITTING OF RC BEAMS USING ULTRA HIGH PERFORMANCE FIBER REINFORCED CONCRETE

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Shear deficient structures have been strengthened or repaired by using various methods, e.g., external pre-stressing, shotcreting, steel plate bonding, polymer impregnation, fiber reinforced polymers (FRPs). But there were problems with each of the above techniques as the use of FRP gives sudden failure due to de-bonding, steel plates got corroded after some time and several losses in the case of external pre-stressing. To overcome all the above problems faced in different retrofitting techniques, a new cementitious material with ultra high performance characteristics like very high compressive strength (above 110 MPa), high tensile and flexural strength due to the addition of fibers, very less permeable and high workability i.e. UHP-FRC came into existence. In the present study, shear deficient RC beams initially stressed to a prefixed percentage, i.e. 60% of the ultimate failure load are retrofitted using UHP-FRC. Retrofitting is done using side face retrofitting. From the study it is seen that the ultimate load carrying capacity of RC beams retrofitted with UHP-FRC is significantly increased with side face retrofitting. Moreover, this technique also increased the ductility and energy absorption of RC beams which resulted in the usefulness of UHP-FRC as a retrofitted material.

Keywords: Shear deficient beam, Initially stressed RC beams, De-bonding, Under reinforced concrete beam, Over reinforced concrete beam.

1 INTRODUCTION

There are two primary modes of failure in reinforced concrete (RC) beams, flexural failure and shear failure. Flexural failure of a beam is ductile in nature, whereas shear failure is brittle in nature and does not allow substantial redistribution of loads. Thus, shear failure occurs without any prior warning and is often catastrophic. Shear failure of RC structures may be due to many factors, e.g., insufficient shear reinforcement, reduction of the steel area due to corrosion and spalling of concrete caused by aggressive environmental conditions, increased service load due to change-in-usage of the structure, and any detailing, design, and/or construction error. Various materials and techniques such as shotcreting, steel plate, polymers, FRP and pre-stressed FRP, anchor bolt being used to retrofit the shear deficient structure. But the limitation of each material forced the researchers to develop the new retrofit material. The last four decade's efforts have now established a new cementitious material with ultra high performance characteristics i.e. UHP-FRC.

UHP-FRC is the outcome of a demand that began in the 1930s to seek for approaches to increase the mechanical properties of concrete, in particular its compressive strength. UHP-FRC can be successfully used when durable and strong but light members are required, or in cases where a considerable liberty with regard to form is desirable. Aïtcin (1998) reported that the world's first engineering structure designed with UHPC was the Sherbrooke footbridge in Sherbrooke, Quebec, built in 1997. Brühwiler and Denarié (2008) evaluate the behavior of 30 mm thick UHP-FRC overlay for the rehabilitation of short span road bridge with heavy traffic. The protective function of the UHP-FRC overlay was verified by air permeability tests which confirmed the extremely low permeability; approximately 30 times lower than normal concrete. Tayeh *et al.* (2012) experimentally evaluated the relationship between concrete substrate roughness and the bonding performance of UHP-FRC used as a repair material. The results showed the significant influence of substrate surface preparation method on bonding strength between UHP-FRC and the concrete substrate. The composite with sand blasted surface behaved closely as a monolithic structure.

In the present study shear deficient RC beams initially stressed to a prefixed percentage, i.e. 60% of the ultimate failure load are retrofitted using UHP-FRC. The side face retrofitting is used to retrofit the shear deficient beam. From the study, it is seen that the ultimate load carrying capacity of RC beams retrofitted with UHP-FRC is significantly increased with side face retrofitting. Moreover, this technique also increased the ductility, energy absorption and initial stiffness of RC beams which resulted in the usefulness of UHP-FRC as a retrofitted material.

2 MATERIAL CHARACTERIZATION

The ordinary Portland 43 grade cement is used in this study. The specific gravity, initial and final setting time of cement is 3.04, 40 min and 320 min respectively. The standard consistency is 33% and 28 day compressive strength is 44.5 MPa. The specific gravity and fineness modulus of 20 mm aggregates are 2.61 and 6.87 respectively. The specific gravity and fineness modulus (F.M) of 10 mm aggregates were 2.68 and 6.37 respectively. The specific gravity, F.M and water absorption of sand are 2.46, 2.56 and 0.83% respectively. Silica fume is obtained from KGR Agro Fusions (P) Ltd., Ludhiana, Punjab. To develop UHPC mixes, polycarboxylic ether based MASTERGLENIUM SKY 8866 Superplasticizer was obtained from BASF solutions, Chandigarh. The crimped steel fiber and hooked steel fiber (SHAKTIMAN ® Steel Fibers) are used which were obtained from Stewols India (P) Ltd., Nagpur. The metakaolin and epoxy were also used in the experimental study. HYSD steel of grade Fe-500 D (Tata Tiscon) of 16 mm, 12 mm and 8 mm diameters were used as reinforcement. The yield strength and ultimate strength of the reinforcement are 540 N/mm^2 and 600 N/mm^2 respectively. In the current study potable water available in the material testing laboratory was used for making concrete.

2.1 Concrete Mix Design

The M25 concrete mix was designed by using the properties of cement, fine aggregate and crushed stone coarse aggregates as per are: IS 10262 (2009) guidelines. The mix proportions are given in Table 1. The cubes were prepared with this mix proportions and were tested at the age of 7 days and 28 days. The average compressive strength of cubes at 7 days and 28 days was 20.9 MPa and 34.40 MPa respectively. The cement, fine aggregate, coarse aggregate and water in M 25 grade concrete are 417.9 kg, 544.38 kg, 1190 kg and 192 kg respectively. UHP-FRC was used for retrofitting of the beams. For the development of UHP-FRC, various trials were done, out of which three best trials were taken by varying amount of superplasticizer, metakaolin and use of different sand particle sizes to densify the matrix to achieve the target compressive strength of 120 MPa. These are shown in Table 1.

Table 1. Mix Trials for the Development of UHP-FRC.

	Trial Mix 1	Trial Mix 2	Trial Mix 3
Items	Quantity(Kg/m^3)	Quantity(Kg/m^3)	Quantity(Kg/m^3)
Cement	875	875	1000
Sand (<300μm)	-	-	270
Sand (<600μm)	270	270	-
Sand (<300μm-	-	-	750
Sand(1.18-2.26mm)	1055	1055	-
Silica fume	300	300	150
Metakaoline	-	-	150
Superplasticizer	45	35	45
Fibers (hooked)	1.5% by vol. of concrete	1.5% by vol. of concrete	1.5% by vol. of concrete
Fibers (crimmed)	0.5% by vol. of concrete	0.5% by vol. of concrete	0.5% by vol. of concrete
Water	200	200	230
7 Day Strength(MPa)	48	52	75.8
28 Day Strength(MPa)	75	79	118

3 EXPERIMENTAL PROGRAM

3.1 Casting of Beams

RCC beams of size 700 x 150 x 150 mm are designed and cast using M25 grade concrete and Fe 500D grade steel. The RCC beam is designed using the limit state method and both under-reinforced and over-reinforced sections are designed. The beam is designed having 2 steel bars of 8 mm diameter at compression face and 2 bars of 16 mm diameter at tension face for over-reinforced section; 2 bars of 12 mm diameter at tension face for under-reinforced section and the stirrups used are of 8 mm diameter and at the spacing of 85 mm for under-reinforced section and at 75 mm for the over-reinforced section.

3.2 Testing Arrangement

The beams were tested after 28 days from the date of casting. All the specimens were tested as simply supported beams subject to a two-point loading with loads applied at a distance of L/3 from each end; where L is the effective span i.e. 600 mm. The shear span to effective depth ratio (a/d) was equal to 1.6. The testing of beams was carried out in the Universal testing machine (UTM) of 1000 kN load capacity.

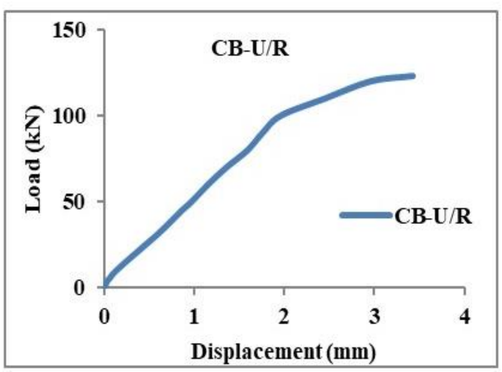
3.3 Process of Retrofitting

Firstly, all beams are initially stressed to 60% of its ultimate load carrying capacity and then retrofitted with UHP-FRC using epoxy as a bonding agent between old concrete and UHP-FRC. Retrofitting of beams is done in three stages- chipping off side cover to expose stirrups, the epoxy layer applied and then finally retrofitting with the new UHP-FRC layer. Inside face retrofitting, all the three stages are shown in the Figure 1. The section is retrofitted till it is restored to its original dimensions of 150x150 mm with UHP-FRC.

Figure 1. a) Side face chipped off beam (Stage 1); b) Epoxy layer applied after chipping off (Stage 2); c) Beam retrofitted with UHP-FRC (Stage 3).

4 RESULTS AND DISCUSSION

The beams are tested to failure and deflection at the center of the span is recorded using dial gauges. The results of the beams CB1 and CB2 are then averaged to obtain a single set of results (designated as beam CB-U/R) for under-reinforced section control beam and (designated as beam CB-O/R) for over-reinforced section control beam. The load-deflection curves for both beams (CB-U/R and CB-O/R) are presented in Figure 2 and Figure 3. The first flexural crack in beams CB-U/R and CB-O/R was observed at a load of 32 kN and 48 kN respectively, and it occurred between the left point load and the center of the beam respectively.



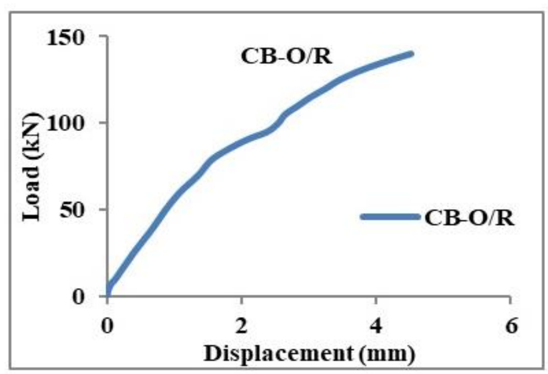


Figure 2. Load v/s mid-span deflection of CB-O/R. Figure 3. Load v/s mid-span deflection of CB-U/R.

The shear cracks started appearing on the beam in shear span at a load of 70 kN and 84 kN for CB-U/R and CB-O/R beams respectively. On increasing the load further, shear cracks started to widen and propagate upward toward the point at which loads are applied to the beam and finally beam failed in shear with a maximum deflection at the center 3.42 mm and 4.52 mm for beams CB-U/R and CB-O/R respectively.

4.1 Effect of Retrofitting of Strength of Beam

The beams were initially stressed to 60 % of their corresponding ultimate load i.e.73.8 kN for U/R section and 84 kN for O/R section beams and then retrofitted using UHP-FRC by side face retrofitting techniques. The retrofitted beams were then tested to failure and result of each beam was recorded. It has been observed that after retrofitting the first crack load, yield load, initial stiffness, and maximum load carrying capacity increased. After retrofitting the maximum load carrying capacity was increased to 147.9 kN for SF-U/R from 123 kN (CB-U/R) in side face retrofitting technique whereas for O/R side face retrofitted beam the load carrying capacity increased to 160.75 kN for SF-O/R from 140 kN (CB-O/R). In addition to that, the first crack load of CB-U/R shifted from 32 kN to 36.75 kN respectively, whereas, the yield load shifted from 115 kN to 121.6 kN. The first crack load of CB-O/R shifted from 140 kN to 160.75 kN whereas the yield load shifted from 140 kN to 160.75 kN.

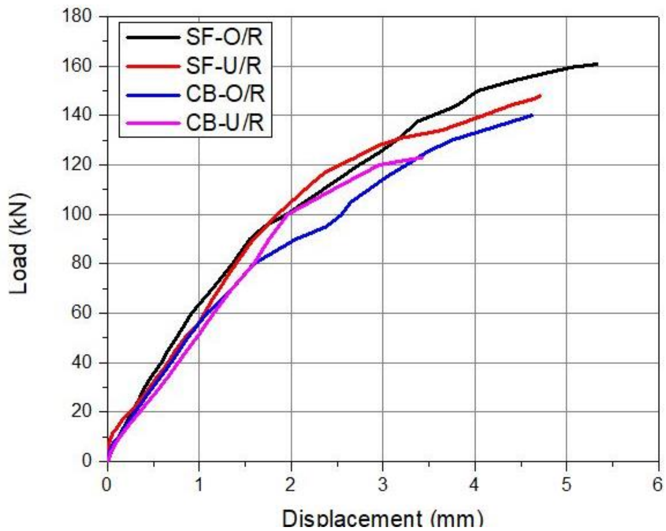


Figure 4. Load vs mid-span deflection for all control and retrofitted specimen.

Retrofitting of beams (SF-U/R) and (SF-O/R) resulted in 20.24% and 14.82% improvement in load carrying capacity respectively. It has been observed that the mid-span deflection of the retrofitted beams increased. The possible reasons for the above results are (a) UHP-FRC has a higher compressive strength as compared to control concrete (118 MPa v/s 25 MPa). In addition, the higher modulus of elasticity of UHP-FRC confined the initial damaged beam from the side faces (b) The hybrid fibers able to retard and delay the crack propagation so that the load carrying capacity of side face retrofitted initially stressed beam is increased.

4.2 Effect of Retrofitting on Ductility and Energy Dissipation for Control U/R, Control O/R and Side Face Retrofitted Specimen

To measure ductility, it is generally accepted to use ductility factor (μ) which represents the ratio of deflection (Δ) at the ultimate load to corresponding property when the reinforcement starts yielding (Afefy and Mahmoud 2014). It is observed that the ductility increased when the beams are retrofitted by Side Face for U/R section beams. For over-reinforced section, beams failed in shear before the steel yields so the ultimate load and the yield load are same. It can also be noted that the ductility values are 1 for O/R section beams, whereas, the ductility of control section increased from 1.266 to 1.708. The energy absorption of CB-U/R is 266.14 jouls and increases 77% after side face retrofitting. Likewise, CB-O/R the energy absorption is 401.96 jouls and 44.23% increment is observed after side face retrofitting. Initial stiffness is calculated from the initial slope of the load-deflection curve. The initial stiffness of CB-U/R and CB-O/R is 42.53 kN/mm and 51.5 kN/mm respectively. The 21.09% and 15.84% increment in initial stiffness of SF-U/R and SF-O/R is observed.

5 CONCLUSIONS

Based on the results of an experimental study carried out the following conclusions can be drawn;

- The yield load, first crack load, and load carrying capacity increases when the initially stressed (60%) beams are retrofitted with UHP-FRC.
- Retrofitting of initially damaged beams by replacing side face concrete cover with UHP-FRC in the shear span increases the ultimate load carrying capacity and yield load of under-reinforced (U/R) section beams by 20.24% and 5.74% respectively.
- The deflection at the failure load increased when beams are retrofitted with UHP-FRC in the side face retrofitting configurations.
- Maximum ductility and energy absorption capacity have been observed for side face retrofitting. The corresponding value of ductility factor (μ) is 1.70 and increment in energy absorption is 77.05% for U/R section beam and 44.23% for O/R section beams. The initial stiffness of the retrofitted beams also increased as compared to control beams.

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