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An Experimental Study on the Flexural Retrofitting of the Partial Damaged Reinforced Concrete Beams by using High Performance Fiber Reinforced Cement-Based Composite (HPFRCC)

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***Abstract*— If an individual structure, damages under severe conditions (e.g. earthquake, nearby excavation, etc.), it can't be any more reliable to tolerate designed loads and needs for retrofitting and restoration in structural parts. because of high seismicity, existence of old structures, defects caused by environmental and internal conditions of materials, and also problems in the design phase and implementation of structures, retrofitting and restoration of structures is in a high level of interest. Due to increasing development of building construction, using the novel ideas in design, build and finding the appropriate materials of the building is necessary. Therefore, due to high demand for developing new methods by using high performance materials, the main purpose of this paper is using HPFRCC fiber concrete to recover the damaged beams under loading conditions and also improvement of concrete beams with experimental approaches to increase the ductility and moment capacity and enhance the durability of mentioned member.**

This paper that presents a Retrofitting method using a high performance fiber reinforced cement-based composite (HPFRCC), an experimental research has been performed on three hinged supported beam with the same dimension, same used materials, and with the same reinforcement. First beam which is known as Refrence beam(RC), has been subjected to pure bending until its destruction and two other ones were subjected to a certain amount of load that was according to the final capacity of the first beam. Afterward, two damaged beams have been retrofitted by using HPFRCC in the created grooves under the beam and finally two retrofitted beams were loaded to examine their bending behavior.

Results showed that retrofitting can raise the strength, load of first crack, and yielding load and this retrofitting method increased the ductility and energy absorption of beams.

Keywords*— *Reinforced Concrete Beam, Damaged, Retrofitting, Steel fibers concrete

I. INTRODUCTION

Structures and its components need to be retrofitted for different reasons. General reasons which make the retrofitting necessary are design error, change in application, incorrect Implementation, and damage causes during the usage of the structure or by war or earthquake. Reinforcement of columns, beams, connections, walls, and structural frames called retrofitting. In typical structural systems such as moment frames and dual systems, beams are very important in the seismic capacity of the whole system. These elements need to have high ductility and appropriate strength and intensity related to ductility to behave reasonably in structure. For this purpose, the designer should diagnose the dominant behavior in beams of structure before starting the process of retrofitting and then select the appropriate method to start the retrofitting.

Retrofitting the reinforced concrete beams has been considered by many researchers. In recent years much research has been performed about bending retrofitting of healthful sections of reinforced concrete beams. For instance, laboratory Investigation of reinforced concrete beams with novel technology of HPFRCC concrete by Ahmad Panahi [1], and bending retrofitting RC beams by using HPFRCC and CFRP by Ferrari [2]. In all of the pre-mentioned studies, using the HPFRCC concrete, improve the bending performance of the beam.By considering the previous studies and the great demand for examining the retrofitting the damaged elements, studying the bending behavior of the damaged beam which is retrofitted with HPFRCC has been considered in this research.

Using High performance materials instead of usual materials has long been of interest of researchers which performed many studies about that. As we know, using the novel materials and special composites in the last decade was extremely interested. The first effort for retrofitting the concrete by placing steel fibers has performed by Remold and Boston in the early of 1960 decade [3&4]. After that, lots of studies and industrial application of reinforced concrete with steel fiber have performed.

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bending behavior of HPFRCC influenced by its tensile ductility which many studies have performed about by Maalej, Li, Wang, Rokugo and Kunieda[5,6, and 7]. Multiple Micro-Cracks forms at end of beam because of bending and let the beam have big curvature. The most important advantage of composite is high strength and ductility which can be used for retrofitting the damaged or weak structures and has more application in concrete structures in comparison to steel structures. In this way, the present paper aims at presenting a technique for the flexural strengthening of Damaged RC beams, based on the application of a high performance cement-based composite of steel fibers (HPFRCC) for constructing a more effective transition layer, As shown in Fig 1.

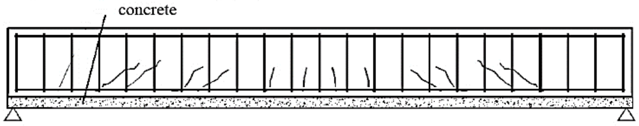

Fig. 1. Scheme of Retrofitting with HPFRCC transition layer

II. MATERIALS PROPERTIES

In this research three hinged supported beams with the same dimension, same materials, and with the same reinforcements has been analyzed. 28-day compressive strength for typical concrete samples was 35.5 MPa and for HPFRCC samples was equal to 65.2 MPa. For bending tensile reinforcement (at the bottom of the beam) reinforcement steel bars with yield stress, which was equal to 338 MPa was used and for Compressive bending reinforcement (at top of the beam) reinforcement steel bars with yield stress equal to 379.9 MPa was used.

The type of fibers used in this research is showed in Fig. 2 and the properties of this steel fibers is showed in table.III.

TABLE I. MIX DETAILS OF THE CONCRETES DEVELOPED

Materials	***Mix Proportions [Kg/m3]***	
	Normal Concrete	***HPFRCC Concrete***
Water	186	325
Cement	429	812
Sand	662	-
Sand(<2.36 mm)	-	609
Gravel	1222	-
Steel Fibers	-	158(2%)
superplasticizer	-	4.06

TABLE II. COMPRESSIVE STRENGTHS OF THE CONCRETES INVESTIGATED

S. no.	***Compressive strength (MPa)-28 day***	
	Normal Concrete	***HPFRCC Concrete***
1	32.8	66.5
2	30.2	70.2
3	37.8	63.3
4	35	60.8
5	34.7	-
6	36.9	-
average	**35.5**	**65.2**

Fig. 2. Steel Fibers

TABLE III. PROPERTIES STEEL FIBERS

Property			
Length (mm)	Diameter (mm)	Length Diameter Ratio	Density (Kg/m^3)
36	0.8	45	7850

III. CHARACTERISTICS OF BEAMS

In this research One of three beams was loaded until its final crack and destruction (P_{max}). In the next step in order to analyze the flexural behavior of a damaged beam, two other beams were loaded with 35 percent of ultimate load (P_{max}). the reason that we select the 35 percent of ultimate load of the refrence specimen was this fact that under this load, the beam behavior is between the elastic point and yielding point of it and has not been subjected to severe loads. The retrofitting performs with forming a layer of HPFRCC by shuttering and concreting in molds at bottom parts of beam in U-shape. In naming of samples, letter B refers to Beam and the two next digits shows the percent of damage (for example, 35 percent) and the next letter indicating the retrofitting material which is HPFRCC and the last letter in the number of damaged sample.

TABLE IV. CHARACTERISTICS OF BEAMS

Beam	***Characteristics***
RC	RC beam. Without strengthening. Control
B35H1	RC beam. loaded at 35 percent ultimate load of RC. retrofitted by HPFRCC layer
B35H2	RC beam. loaded at 35 percent ultimate load of RC. retrofitted by HPFRCC layer

IV. DETAILS OF BEAMS

In order to analyze the bending behavior of beams, selected samples should have the same dimension as real ones in structures in order to gain reliable results. Since, the purpose of performing these analyzes was studying the bending behavior; the two point loading pattern has been selected to create a pure bending part in beams. Supports

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considered as hinged to easily perform the experiment.by considering that the distance between the rigid supports of laboratory was 2600 mm and due to this limit, length of samples considered as 2300 mm to ease the steps of placing the beams and loading them. In two ends of beams, supports build with 2100 mm center to center distance.

The free length of the beam has been divided into 3 parts and two point loads with a distance of 700 mm from each other placed on the beam symmetrically. Placing the stirrups in beams was in such a form which shear crack never governs the crack of the beam and all destruction causes by bending. Dimensions of beam`s Cross-Section was with 200 mm width and 250 mm height as you can see in Fig.3 which all beams have three tensile steel bars with 12 mm diagonal in the bottom and two compressive steel bars with 10 mm diagonal in the top of the beam and 8 mm stirrups placed in each 15 centimeters.

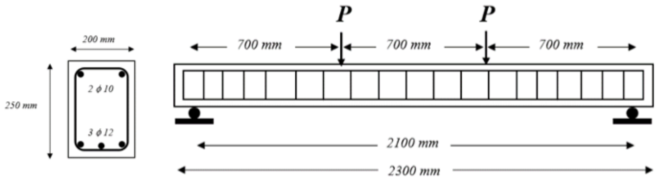

Fig. 3. Beams Details

V. EXPERIMENTAL PROGRAM

A. Test Setup

By considering that the beams are with hinged support, supports constructed with some steel plate and bars as you can see in Fig.4. Beam support was simple hinged and with 2100 mm distance from each other.

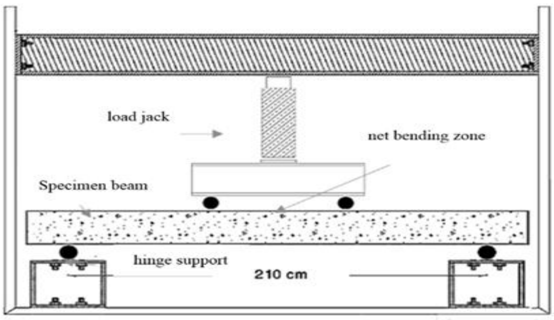

Fig. 4. General setup of the three bending point test of specimens

B. Retrofitting of Damaged Beams

First beam as the reference beam has been subjected to severe load to measure the final crack and two other beams which considered as damaged beams subjected to 35 percent of final load (P_{max}) of the reference beam. In order to be sure of unity and combination treatment of HPFRCC layer and existing concrete in beam (as you can see in Fig.5) some grooves with 3 Cm depth and 4 Cm width has been created by using the electrical Grinder machine.

Fig. 5. Creation grooves in tensile surface

Since steel fibers have unique specification in comparison to other fibers, they have been used for retrofitting the concrete. Accordingly, these steel fibers mix with the concrete with 2 percent of volume ratio (see Fig.2). Two damaged beams have been retrofitted by forming a layer of HPFRCC by shuttering and concreting in molds at bottom parts of the beam in U-shape. It is worth noting that the Thickness of HPFRCC layer in all samples is equal to 2 Cm (the minimum practical thickness)

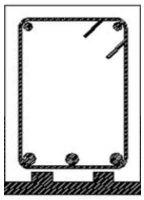

Fig. 6. Schematic of the Retrofitting Layer

VI. TEST RESULTS

A. Load-Deflection Response

The RC beam with rectangular cross-section has been considered as reference beam which its reinforcement is quite similar to other samples. This hinged support beam has been subjected to the 2-point loading pattern. Before starting the test, the equipment installed on sample and by placing the jack on sample, static loading began and loading on beam started which you can see the loading of RC beam in Fig.7 and its Load-Deflection curve in Fig.8.

Fig. 7. Test of RC beam

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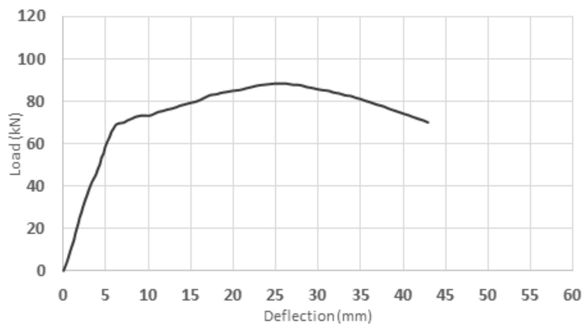

Fig. 8. Load-deflection curve of the RC beam

After loading the reference sample and reaching the maximum loading of reference sample, we start the loading of the two other beams to 35 percent of final load in order to have the damaged beams then we start retrofitting them. Finally, we start loading the retrofitted beams, see Fig.9 . Curve results are available in Fig.10 and Fig.11

Fig. 9. Test of beams B35H1 and B35H2

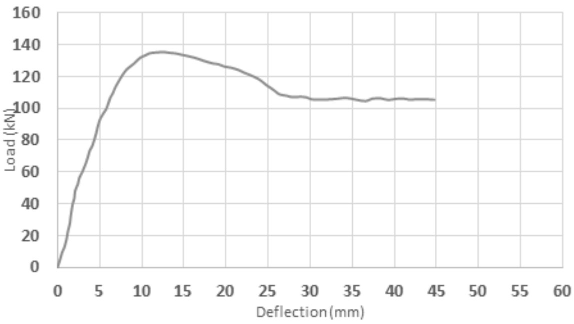

Fig. 10. Load-deflection curve of the B35H1 beam

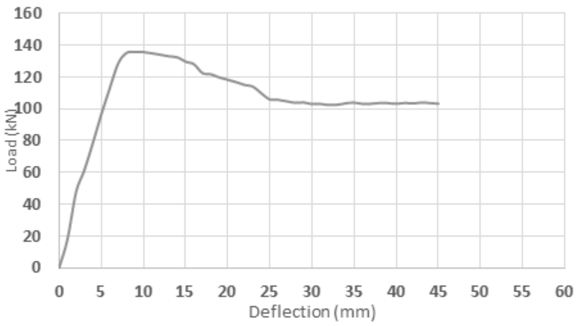

Fig. 11. Load-deflection curve of the B35H2 beam

Values of cracking and yielding loads and displacements related to them are available in table.V and comparison of tested beams with the reference beam has shown in table VI. As you can see, retrofitting with HPFRCC generally leads to increase in all forces of the beam.

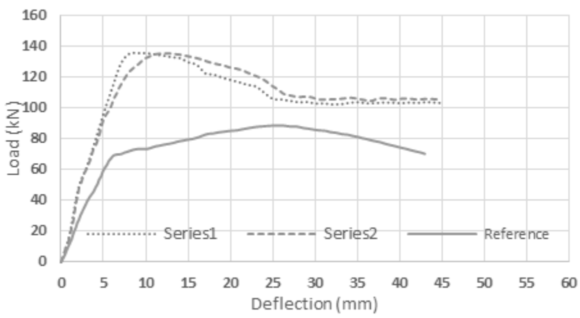

TABLE V. LOADS AND DEFLECTIONS OF BEAMS

Beam	***P_{cr} (kN)***	***Δcr (mm)***	***P_y (kN)***	***Δy (mm)***	***P_u (kN)***	***Δu (mm)***
RC	40	1.58	65.8	5.8	89	39.5
B35H1	52.5	2.1	114.5	6.8	136.28	43
B35H2	51.2	2	118.2	7.6	135	47

TABLE VI. LOADS, FAILURE MODES AND COMPARATIVE OF BEAMS LOAD.

Beam	***P_{cr} (kN)***	***P_y (kN)***	***P_u (kN)***	***P_{cr} / $P_{cr(Rc)}$***	***P_y / $P_{y(Rc)}$***	***P_u / $P_{u(Rc)}$***
RC	40	65.8	89	1.00	1.00	1.00
B35H1	52.5	114.5	136.28	1.31	1.74	1.53
B35H2	51.2	118.2	135	1.28	1.79	1.51

B. ductility of beams

Bending ductility is defined as the ratio of final displacement to the yielding displacement. If the amount of loss is more than 15 percent of final load, value of Δ_u in related load considers as $0.85P_u$. Determination of this value is by considering the condition of compressive concrete and the situation of its smashing and dislodge and the more concrete is unity and strength, we use the more loss for this value. Although researchers suggest different values for this loss, for instance, 20 % loss (displacement corresponding to 80% of maximum load) or sometimes 30% loss (displacement corresponding to 80% of maximum load) has been suggested.

For those concrete with more final compressive strain such as HPFRCC, loss values of 70% and 80% are used and for normal concrete, displacement related to 85% of maximum loading uses as the final displacement and for flexible HPFRCC concrete 70% of maximum force has been used as the Δ_u point. Table.VII shows the calculated values of ductility and the rate of increasing percent.

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TABLE VII. VALOUS OF BEAMS DUCTILITY

Beam	*Δy (mm)*	*Δu (mm)*	*μ (Δu/Δy)*	*μ/ μ(RC)*
RC	5.8	39.5	6.81	1.00
B35H1	6.8	43	6.32	0.93
B35H2	7.6	47	6.18	0.91

C. energy absorption of beams

The amount of energy absorption for each sample is equal to below load-deflection curve until the failure point of sample or the $0.75P_{max}$ which can show the ability of energy dissipation for each sample. Table.VII shows the change ratio in energy dissipation caused by retrofitting.

TABLE VIII. ENERGY ABSORPTION OF BEAMS

Beam	*W (the amount of energy absorption)*	*W/W_{RC}*
RC	2881.92	1.00
B35H1	3269.7	1.13
B35H2	3238.7	1.12

D. path of increased load and initial intensity of samples

As you can see in Fig.12, slope of retrofitted beam`s curve, is more than the slope of the reference beam and the reason of that is increase in intensity of retrofitted sample in comparison to reference sample.

Fig. 12. Load-deflection curves of the beams RC, B35H1 and B35H2

VII. CONCLUSION

Successful application of HPFRCC materials in structures, which is because of their special stress-strain curve (especially in tension), put them to the spotlight of interest of researchers. Because of its hardening behavior of strain under tension which is different with other concrete composite, it becomes a high performance material with high ability for absorption of energy and forming many cracks. In this paper, latest studies about mechanical and structural specifications of HPFRCC materials have been reviewed and behavior of this material in retrofitting the damaged beams has been considered. Results showed that this procedure can be offered as a reliable suggestion for bending retrofitting of partial damaged reinforced concrete.

Based on the experimental results obtained previously,these main conclusions may be drawn:

- In the reference reinforced concrete beam, cracking the beam in addition to softening of the stress-strain curve will lead to reduce the bearing capacity of structure and it is worth noting that this reduce rate is in a direct relation with the number of the cracks. So in order to assure the stability of structure we need to take the steel reinforcements into account, But in those beams which are retrofitted by HPFRCC in the bottom layer, micro-cracks will help the materials to enter the softening level which increases the bearing capacity of the structure.
- In reference reinforced concrete beam, yielding of steel is in the points that steel bars cut the concrete cracks and the destruction caused by the mismatch between the concrete and steel, while in retrofitted beams with HPFRCC, yielding the steel happens in a bigger length and area, which leads to use more capacity of steel reinforcement.
- In all samples, retrofitting increase the load of initial crack. It is obvious that this phenomena can be explained that why the tensile resistance of HPFRCC increase in tensile area. The increase rate in the first load of cracking in our experiments was 30%.
- due to retrofitting, yielding force of tensile reinforcement (steel bars) has been raised about 75%.
- Final force (destruction force) of samples increased about 50% in comparison to reference samples.
- slope of retrofitted beam`s curve is more than the reference beam and the reason of that is increasing in intensity of retrofitted sample in comparison to reference sample.
- By retrofitting the partially damaged beams with HPFRCC method, it`s ductility will reach to about 90% of ductility in reference sample.
- In comparing the energy absorption of samples, it can be resulted that HPFRCC method has increased the energy (energy absorption) of retrofitted samples until the value of 13%.

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