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Experimental investigation on RC beams strengthened with FRP sheets by drilling method

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ABSTRACT: One of the most important applications of FRP sheets is the flexural strengthening of concrete beams by bonding these materials to the beam's tensile surface. The most common problem in this strengthening method is the early de-bonding of the sheet from the surface of the concrete, which results in an early failure before the final strength of the beam is obtained. The most common method for preparing concrete surfaces for proper bonding of composite sheets is the Externally Bonded Reinforcement (EBR) method, which, in addition to environmental pollution, does not completely eliminate the problem of early de-bonding of FRP sheet. This paper examines the possibility of replacing the proposed drilling method with mounting screws instead of EBR method. In this research, ten samples of beam with dimensions of 150 × 300 × 1700 mm3 were tested under 4-point bending. The samples were tested by changing the number of layers and the method of mounting the sheets and in three samples with Simultaneous flexural and shear strengthening. Using the proposed method, the de-bonding problem was completely eliminated in all samples. The greatest increase in flexural strength was related to the sample, which, simultaneously strengthened in shear with FRP bars by NSM method. The effect of removing the bond in the middle part of the FRP sheets was also investigated. The installation without the bond of the sheets in the middle part delayed the rupture of the sheets.

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1. INTRODUCTION

There are many concrete structures around the world that are considered to be unsafe and need to be strengthened. A lot of reasons can be noted for the need for strengthening, which can be summarized as computational errors, weaknesses in implementation, change in the use of the structure, changes in codes and structural deterioration over time. The various advantages of fiber composites have led to the use of these materials for the improvement and strengthening of various structures, including reinforced concrete structures in recent years [1]. The advantages of FRP composites consists of the high ratio of resistance to weight, ease of use, adequate resistance to corrosion, and the slightest changes in geometry and the shape of the reinforced structure [2].

One of the most important applications of fiber composites is the flexural strengthening of RC beams by bonding these materials to the beam's tensile face. The main problem in strengthening RC beams with FRP sheets is the sudden de-bonding of the sheet from the concrete surface, which causes a breakdown before the calculated strength of the beam is obtained [3]. So far, several methods have been devised for better bonding of composite sheets to concrete beams.

In 2010, Mostofinejad and Mahmoudabadi, invented a new method later called the EBROG Method [4]. In this method, grooves are made at a width and depth of several millimeters. Then these grooves are filled with epoxy, and the composite sheet is glued onto it. The result is an increase in the contact surface between concrete and epoxy, as well as the transfer of interlayer tensions and more resistant concrete layers, thereby improving the bond between concrete and FRP sheet. Their research results showed that this method could greatly delay the detachment phenomenon [4]. In 2011, Mostofinejad and Shameli presented a new method called EBRIG. To increase the contact between the reinforcing sheet and the concrete beam and transferring the shear force created between them to the reinforced layers, the composite sheet was directly applied to the surface of the grooves formed in the beam's tensile face [5]. By testing 36 concrete beams of 120 × 140 × 120 mm^3, reinforced in various ways, it was concluded that when using a sheet layer, both methods of EBROG and EBRIG would be effective, but by adding the number of layers of the sheet and increasing the cross-sectional area, the EBRIG method is more effective in postponing the separation than the other method [5].

Another method of installing composite sheets by drilling method was developed by Kamali Zad and Eftekhar in 2012 [6]. In this method, with the idea of transferring stress to the depth of the section, they create holes on the surface of the brick masonry wall sample, and when installing the sheet, these holes are filled with adhesive. Improving the performance of the bricks was enhanced by this method, and the results of the experiments showed that this method is effective in transferring the level of fracture to the depth

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Table 1. Sample Specs.

Sample	Strengthening Technique
B0	No strengthening
B1	One layer, EBR
B2	Two-layer, EBR
B3	Three-layer, EBR
B1-b	One layer, Proposed
B2-b	Two-layer, Proposed
B2-bus	Two-layer, non-glued in the middle, proposed
B3-bus	Three-layer, non-glued in the middle, proposed
B3-bug	Three-layer, non-glued in the middle, shear strengthened, proposed
B3-g	Three-layer, shear strengthened, EBR

Table 2. Summary of Results.

Sample	Disp.(mm)	Load (kN)	Failure mode
B0	25	101	Concrete crush
B1	10.5	113	Debonding
B2	11	115	Debonding
B3	11.3	117	Debonding
B1-b	15.5	115	FRP rupture
B2-b	10.1	122	FRP rupture
B2-bus	39.6	113	FRP rupture
B3-bus	7.9	113	Shear failure
B3-bug	21.9	134	FRP rupture
B3-g	9.2	124	Debonding

of the cross-section, which increases the bearing capacity [6].

In this research, the proposed method of drilling and screw fitting to enhance bonding of fiber composite sheets with concrete surface has been evaluated.

2. TESTING PROGRAM AND RESULTS

The experiments were based on a 4-point test of reinforced concrete beams with a simple span length of 1.5 m. Dimensions, concrete strength, and bending reinforcement of samples were fixed, and the number of FRP sheet layers and the method of joining the sheet to the beam were variable parameters of the tests.

To carry out this experiment, ten reinforced concrete beams of 1700 × 150 × 150mm were made. The flexural reinforcement of the beams was fixed and was 2 rebar No.12 at top and bottom. For shear reinforcement stirrup No.8, with a spacing of 130 and 170 mm, was used. The amount of concrete coating in all cases was 25 mm. Yield strength of flexural and shear reinforcements were 400 and 340 Mpa respectively and concrete compressive strength was 25 Mpa. The Quantum Wrap C200 CFRP sheets were used in these tests and the adhesive used was Quantum EPR 3301. The FRP sheets installed at layers with a width of 90 mm and a length of 1400 mm on the tensile face of the concrete beams.

The method of drilling with screw fitting was proposed as a solution for replacing the surface preparation method (EBR) and for the purpose of better bonding of composite sheets to the concrete surface. The method used to do this was first to mark the points that were used to pierce the tensile face, and then, using a drill machine, 8mm holes were made at a depth of 5 cm. Then the holes and the surface of the concrete was cleaned with water jets to completely eliminate the contamination and fine particles from the hole. After a while, the surface was dried, the glue was injected into the holes through the syringe, and the holes were completely filled with glue. Then the surface of the concrete was impregnated with glue by the spatula and the composite sheet was cut on the concrete surface. In the end, the bolts with a diameter of 7 mm and a length of 5 cm were embedded in the holes

Of the 10 samples, a non-strengthened sample as control, four samples strengthened by the EBR method and five samples strengthened with the proposed method were tested. The summary of the specimens is presented in Table 1.

The summary of observed and measured results is presented in Table 2.

3. CONCLUSION

In this research, which was carried out in the Concrete and Structural Laboratory of Yazd University, the proposed method of drilling with screw fitting to prevent the separation of reinforcing sheets of carbon fiber composites from the tensile face of the beam was evaluated. The summary of the results of this research can be summarized as follows:

1- The failure mode for all samples strengthened by the conventional EBR method was debonding.

2- The increase in the number of FRP sheet layers led to early debonding. The use of the proposed method eliminated debonding mode.

3- The shear cracks, although not the starting point of detachment, but the shear strengthening and control of these cracks could significantly delay the debonding phenomenon.

4- By removing the resin and glue in the middle part of the carbon fiber sheets, the sudden rupture of the FRP sheets changed to a gradual breakdown, and the failure of the sheets was delayed.

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