NUMERICAL INVESTIGATION OF STRENGTHENING THE REINFORCED CONCRETE BEAMS USING CFRP REBAR, STEEL SHEETS AND GFRP

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Abstract

The present study investigates the effect of strengthening the reinforced concrete beams using different methods, including CFRP reinforcement, GFRP and metal sheets. The analytical method used in this section is the finite element using the Abacus simulator. Accordingly, simple double-head beam was modeled and various scenarios were analyzed by applying the appropriate loading and boundary conditions. Results of the uniform loading in bending test in the modes in which the reinforcements are replaced with carbon reinforcements, Mode A3 showed the best behavior and in the case of using Class A GFRP laminates, G3 beam showed the best behavior in the bending test. In the use of steel sheets, it was observed that the steel sheets had more favorable behaviors than all other modes and it decreased compared to GFRP-reinforced modes. Stress and strain diagrams were plotted for the modeling.

Keywords: Strengthening, Reinforced Concrete Beam, Abacus Software, CFRP Rebar, GFRP and Steel Sheets

I. Introduction

FRP composite materials include a variety of materials made of polymers, designed to strengthen and reduce the structure weight. The advantages of the FRP include high strength to weight ratio, corrosion resistance, magnetic and electrical insulation, and ease of installation. Resistant composites are made of carbon fiber and organic polymers have been used successfully in repairing various structures. Repair of concrete structures damaged structurally is necessary because the structural
element can no longer provide sufficient and satisfactory resistance to loads. In recent years, the development of the FRP materials with a high weight resistance ratio and an excellent corrosion resistance has made them be used widely in structural applications. In light of its good performance, the field application of repair by FRP laminates with an epoxy bonding is now considered as an effective and satisfactory method.

Some of the advantages of CFRP sheets are their high strength, lightness and anti-corrosion properties [XV]. The use of CFRP sheet reinforcements reduces structural mass by Karunasena to 15% [XXV, III]. It also results in an optimized design for reinforced concrete structures [IV, XIX]. Many authors [I] are investigating the hardness of reinforced concrete structures with the FRP sheets after cracking [X, XXIII]. In a study conducted by Maheri and Torabi [XXII], the beams were reinforced with CFRP laminates. The results of this research revealed an increase in beam efficiency by up to 170%. In a study carried out by Kachlakev [XI], results revealed a 150% increase in beam connection efficiency when the beams were reinforced in both modes [VII, XX]. Hejabi and zamankabir [XIV], Vijay and Hota [XXI], Malumbela et al [XIII] are among the researchers who conducted extensive studies on the FRP laminates with external joints. Ferreira [II] indicated that when a beam is reinforced with CFRP, its hardness increases and the cracking is delayed. David et al [XII] showed that the CFRP or GFRP bonded composite sheets increase the bearing capacity of the concrete beams. In a study conducted, TalebObaidat et al investigated the composite laminates. In this study, concrete beams were strengthened by using the composite laminates and their bearing capacity was determined [XXVI]. Scorico and Franca investigated the GFRP rebar. Replacing the GFRP rebar and strengthening of the reinforced concrete structures with these rebars, they increased the bending strength of the members [VIII, XVIII]. Al Zand et al also examined the effect of CFRP sheets on the concrete beams. They reinforced the concrete beams with CFRP coating and compared the experimental results with the numerical results [XXIV]. One of the recent studies conducted on the strengthening of the beam-to-column connections is the study conducted by Badawi and Soudki in 2010. They reinforced the beam-to-column connections using CFRP sheets and compared the constructed laboratory model with the numerical results obtained from the software [XVII].

II. Method
Validation

In the verification section, we analyze the paper beam and examines the maximum displacements under the 23KN load.

The figures obtained in this paper are as follows:

The maximum displacement (in mm) is seen in the Mode G2 and the finite element analysis is 3.62 mm (Figure 1).
After modeling the beam used in the study that was conducted by Khalifa and Nanni[5] and applying the boundary conditions in the paper, the maximum displacement was 3.879 mm, as shown in (Figure 2).

Specifications of the Tested Beam

A total of 7 beams were analyzed in the Abacus software. All beams have a square cross-section and the same size: 150 x 200 x 1000 mm.

To investigate the behavior of reinforced concrete beams, we use the following dimensions and specifications and materials and simulate it in the Abacus software (Figure 3).

We will use the solid element for modeling the beam and the wire cross-section for the reinforcements, similar to the study conducted by Suric and Galic.
Specifications of the Concrete and the Steel Used

We will use 17 MPa concrete and AII reinforcement with 300 MPa FY. For strengthening the elements that are plotted as shell according to the Xie and Hu elastic property and elastic area are defined as lamina according to the Xie and Hu research [XVI]. Its elastic and plastic area is also defined in the sections, where it is wire. The CFRP specifications are obtained from the Bazacu et al research [IX].

CFRP Specifications

(Figure 4) illustrates the specifications.

| Property            | Value  |
|---------------------|--------|
| Tensile strength (MPA) | 2600   |
| Elastic Modulus (MPA)  | 165000 |
| Failure Strain       | 1.7    |

*Fig. 4: CFRP specifications*

In another part of the test, we strengthened the test Class A GFRP and obtained the fiber specifications from the kumari et al, [VI] research and match the information to the Afzir site (Figure 5).

| Property            | Value  |
|---------------------|--------|
| Tensile strength (MPA) | 2830   |
| Elastic Modulus (MPA)  | 185000 |
| Failure Strain       | 1.5    |

*Fig. 5: Testing beam with Class A GFRP*

Loading and boundary conditions of the tested beams

We apply the P force in a monotonic way to the center of the beam opening with a magnitude of 23 kN. We use the stress loading this time to apply these loads and to apply the boundary conditions; we will adjust the degrees of freedom of the support according to this mode since the investigated beam is a simple double-head beam.

III. Results and Discussions

**Strengthening of the Tested Beams**

In this study, we aim to investigate the results of the strengthening of the simple double-head concrete beam. Different modes of strengthening are as follows.

Mode A1: We replace the 8-mm-diameter tensile reinforcements with the CFRP reinforcement

Mode A2: We replace the 6-mm-diameter stress reinforcements with the CFRP reinforcement

Mode A3: We replace the 6-cm and 8-cm-diameter stress and tensile reinforcements with the CFRP reinforcement

Similar to the Galic and Suric research [XXVII]:
We strengthen the Mode B of the beam tensile area with a steel plate 850x50x4 with Class ST37.

We consider the G2, G3, G4 modes as the paper and instead of using CFRP; we use the Class C CFRC that has the following geometrical and material properties (Figure 6).

![Fig. 6: Strengthening of the GFRP](image)

**Finite Element Analysis**

An 8-node element (C3D8R) is used for concrete modeling. This type of element can consider plastic deformations and crack in three orthogonal directions at each integration point.

A 2-node rod element (B31) is used to model the steel rebar. The beam element is used for the rebar due to its capability in transmitting the force in the bending, while the truss element does not have this capability.

We will use the static analysis with the 3-D stress element property.

The behavior of the reinforced beam under the 23-kN loading in the bending test in the modes A1, A2 and A3 is as follows:

![Fig. 7: Mode A3 in which the carbon polymer longitudinal reinforcements are in the stress and tensile area](image)
As shown in (Figure 7), less displacement occurred in the Mode A3, in which the carbon polymer longitudinal reinforcements are in the stress and tensile area.

The stress and strain diagrams for the beams A1, A2, A3 are as follows (Figures 8-10):

Fig. 8. Beam A1 stress and strain diagram

Fig. 9: Beam A2 stress and strain diagram

Fig. 10: Beam A3 stress and strain diagram

Investigation of the Mode B strengthening with 4-mm steel sheet (Figure 11):

Fig. 11: Investigation of the Mode B strengthening with 4-mm steel sheet

Stress and strain diagrams of the Beam B are as follows (Figure 12):
Fig. 12: Strain and stress diagram of the Beam B

Investigation of the Mode G2, Mode G3, and Mode G3 is shown in (Figure 13).

Fig. 13: Investigation of the Mode G2, Mode G3, and Mode G3

V. Conclusion

Investigation of the modeled beams and the strain and stress diagrams suggests that in the A1, A2, and A3 beams, in which CFRP has been used as a reinforcement, the A3 beam that has carbon fiber instead of steel reinforcements showed a 3.8-mm displacement that this value has decreased by 0.02 and 1.7 mm, respectively, in the A2 and A1 beams.

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With regard to the G1, G2, and G3 beams, it is observed that the G3 beam had the best performance and its displacement rate decreased by 6% and 18%, respectively, compared to the G1 and G2 beams. The displacement rate of the B beam that steel plate was used in its tensile area showed a 6% decrease, compared to the A3 beam and a 6% increase compared to the G3 beam.

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