ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

International Journal of Mechanical Engineering

Shear behavior of RC beams strengthened with CFRP Rod using Embedded Through-Section technique EST

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Abstract

This paper presents the experimental investigation results obtained on reinforced concrete beams using a modified fiber reinforced polymer (ETS) (FRP) reinforcement technique. To raise the shear strength of RC beams, the ETS FRP rod technique shows potential lifting of load capacity, since ETS reinforcement is a recently developed technique to avoid failures in concrete structures, the strategy allows for more confinement and leads to better results. Tests include seven rectangular RC beams having 1500 mm span. The parameter of this study adopted the effect of the angle of the CFRP bars the parameters of this study. The method of shear strengthening using fiber-reinforced polymer (ETS) technology has proven to be an effective method for shear strengthening in the implanted areas by reducing cracks in these areas, in addition to strengthening these areas and confining the failure area away from the area that has been reinforced with these bars, as well as increasing the rigidity of the beams.

1. Introduction

Since Near Surface Mounted technology is useful in enhancing bending and shearing in concrete structures, the technique of using FRP installed near the surface as concrete reinforcement is innovative and promising in the rehabilitation of structural concrete members [1]. Near-surface fibers (NSM) reinforced with carbon rods are a promising technique for boosting bending and shear strength in concrete components that are weak, since this technique has become appealing in strengthening the curvature in the negative moments that concrete endures [2] , [3]. An additional Steel plate bonded by epoxy or fiber-reinforced plastic (FRP) to its face tense is a regularly utilized approach for strengthening and recovering Existing reinforced concrete elements. This procedure appears to be a valuable choice for increasing the previous structure's strength and stiffness. The advantages of this technology can be linked to the availability of dependable and high-quality epoxy resin, as well as a low-cost and low-manpower demand [4]. RC structures are made of externally bonded fiber-reinforced polymers (EB-FRP). A roll of columns, side slits, and longitudinal reinforcement, as well as transverse packet reinforcement, is common uses for Unidirectional EB-FRP Sheets. The utilization of EB-FRP for bending reinforcement and repair of RC beams will be the emphasis of this paper. Bending package strengthening is one of the more challenging applications. Due to the need for protection against junk failure types and considerable deflection capacity, EB-FRP was chosen, while yet retaining the intended advantage of greater power [5]. In past years, a significant research effort has been done to understand the behavior of externally enslaved EB fiber reinforced polymer, which has proven to be an effective and successful way of strengthening and rehabilitating concrete structures [6]. Many buildings and bridges on North American highways have reached or beyond their service life, and as a result, they are deteriorating rapidly. Given the large budget and logistics involved, rebuilding these structures is pointless. As a result, reinforcing these structures to extend their service life is a viable and cost-effective option.

The use of EB-FRP composites to strengthen deficient reinforced concrete (RC) structures is cutting-edge and cost-effective technique research using EB-FRP to test the efficiency of various shear reinforcing systems and configurations has been done. When RC beams fail, the effect of volume tends to reduce the attributed shear strength of concrete as beam size grows [7]. The use of CFRP for the repair and reinforcement of reinforced concrete structures (R/C) is widely established. However, there has been some investigation into using CFRP to reinforce and repair the impact of broken P/C bridge girders. Methods for mending P/C. beams that are currently acceptable Steel jackets, tendon connections, external stress, and replacement damaged symptoms are all examples. These systems have some drawbacks, including relatively expensive costs, performance exhaustion, and long periods of turbulence. Reduced installation time, wear resistance, and ease of application are all advantages of CFRP.

Laboratory and field studies were conducted to establish the efficacy of CFRP as a repair procedure for P/C bridge girders [8]. Due to the high direct cost of repairing and rebuilding corroded RC bridges, alternative treatment methods using FRP were required. FRPs have numerous advantages over traditional reinforcement procedures, including (1) design flexibility, (2) convenience of use, and (3) wear resistance [9]. The origin of these issues can be related to the age of the concrete structure, a defect in design or implementation, or environmental exposure to the environment surrounding the concrete structure. Carbon Fiber Reinforced Polymer (FRP) reinforcement is useful in strengthening concrete sections under shear and bending due to its high tolerances [10]. RC beams fail in one of the two modes either in flexural failures or shear failures and shear failures can occur suddenly or the failure is due to corrosion of the internal steel shear joints, overloading, and therefore it is important to prevent this failure from occurring by strengthening using carbon polymer fibers (FRP) where it bears high stresses in addition to its lightweight and resistance to corrosion [11].

2. Experimental Program

The experimental program includes 7 samples of RC beams divided into three groups, all of them were poured using a self-pressing concrete mix, where the first group consists of a control beam and a beam without stirrups, and the second group consists of four beams reinforced with carbon fiber reinforced polymer and carbon fiber reinforced polymer 10 mm in diameter designated B200-E10-V, B200-2E10-V, B200-3E10-V, B200-E10-I, and the third group consists of a 13 mm CFRP-reinforced beam carbon fiber reinforced polymer with a diameter of 13 mm and is designated B200 -3E10-V where CFRP is added across the cross-section and at a distance of d/2 from the beam face, the distance is 81 mm for vertical CFRP bars, but for inclined bars, the distance from the beam face is at a distance of d, the distance is 162 mm.

2.1. Description of Specimens

The samples used in this study are rectangular beams and they were poured simultaneously using a self-compacting concrete punch. All beams were 1500 mm long, the clear span was 1300 mm, the beam width was 160 mm and depth 200 mm, compressive strength for 28 days was 52.02 Mpa and the longitudinal steel reinforcement at the bottom consisted of two layers with a diameter of 16 mm (Its area is 201.06 mm) and the distance between the two layers is 5 mm, and the longitudinal rebar on top was with a diameter of 12 (area 113.09 mm) mm, and the stirrups used were 10 (area 78.53 mm) mm and the distance between the stirrups was 200 mm as shown in (Fig. 1). The first had a diameter of 10 mm (area of 71.26 mm) and the second was of a diameter of 13 mm (area of 126.7 mm).

To fix the CFRP used in the EST method, the following steps are carried out: (1) making blind holes in the cross-section with a diameter greater than 2 mm than the diameter of the CFRP, and also making inclined holes at an angle of 45 degrees. (2) Holes are cleaned using compressed air and water, (3) Epoxy is put through the holes using an injection gun and the holes are filled with epoxy, (4) A small amount of adhesive is placed around the CFRP rods, (5) CFRP rods are inserted and fixed through the holes and insertion It is either from above or below (Fig. 2) shows the locations of the CFRP rods in the RC beam.

2.2. Material properties

The local supplier used commercially available concrete in the laboratory. All samples were poured simultaneously. The concrete used was self-compacting concrete without the use of a vibrator. The average compressive strength of concrete for 28 days was 52.02 MPa. The yield strength of the longitudinal rebar φ10 was 612.98 Mpa and the break elong was 16.61%, the yield strength of the rebar φ16 was 534.41 Mpa and the break elong was 14.97%, and the yield strength of the stirrups φ10 was 579.15 Mpa and the break elong was 20.93%. Carbon fiber-reinforced polymer rods were used to strengthen the RC packages. The CFRP rods used in this study are 10 mm and 13 mm in diameter. The stress strength of both diameters was 2068 MPa and 2172 MPa, respectively, and the modulus of elasticity of the two diameters was 124 GPa where the carbon fiber reinforced plastic rods were connected. Pre-drilled with adhesive made of resin and hardener, the properties of the adhesive used were 1.68 Kg/m³, tensile strength 11N/mm², compressive strength 60 N/mm², and temperature resistant up to 80°.

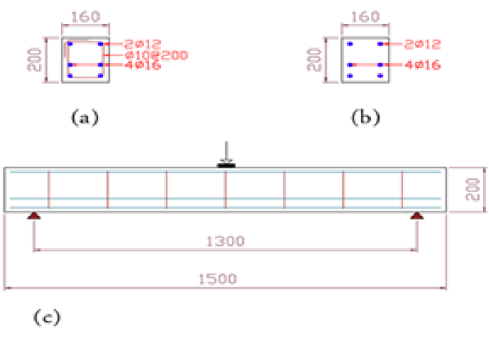
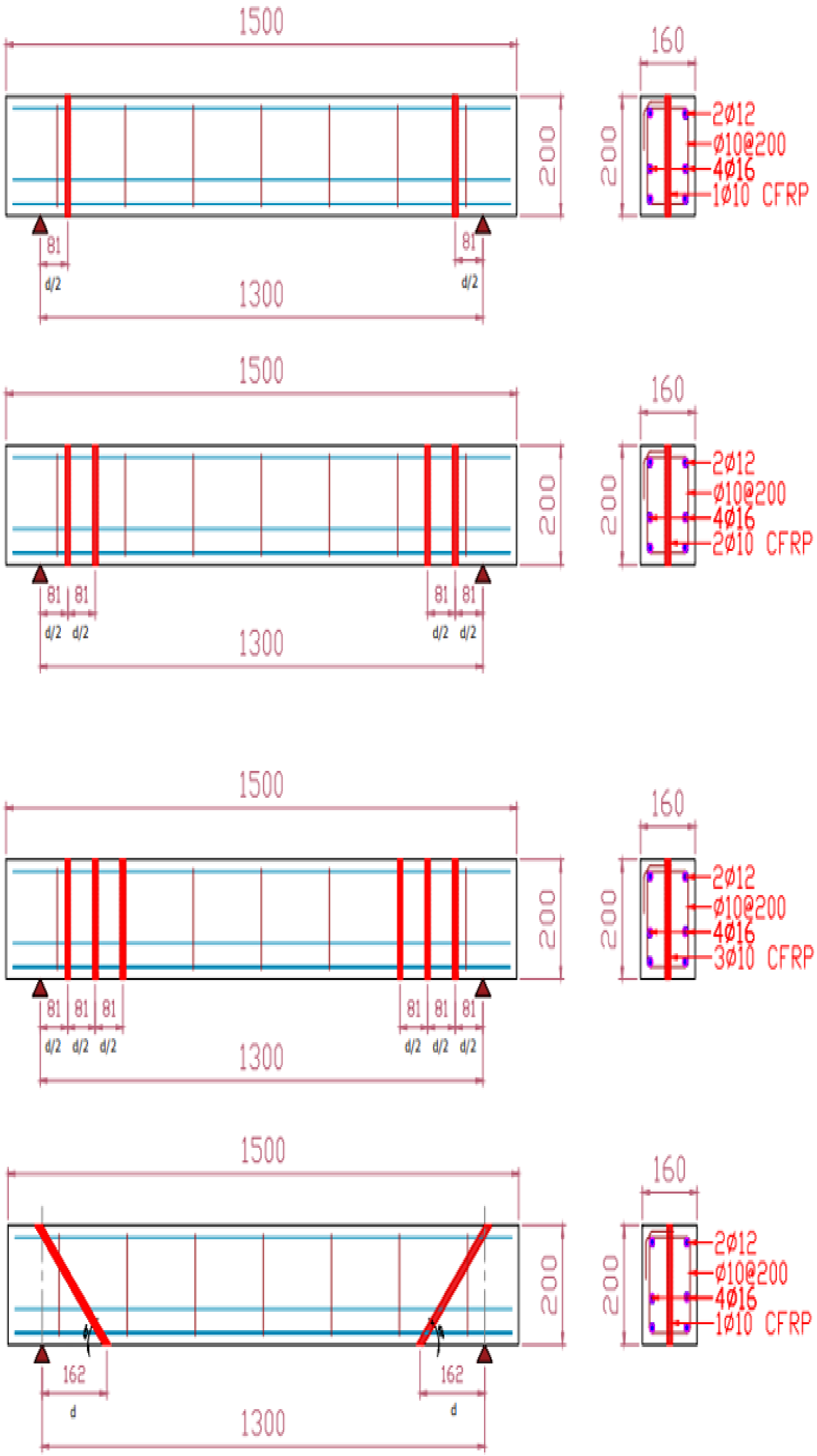


Fig. 1. Details of concrete beam: (a) cross section with transverse steel, (b) cross section with no transverse steel, (c) elevation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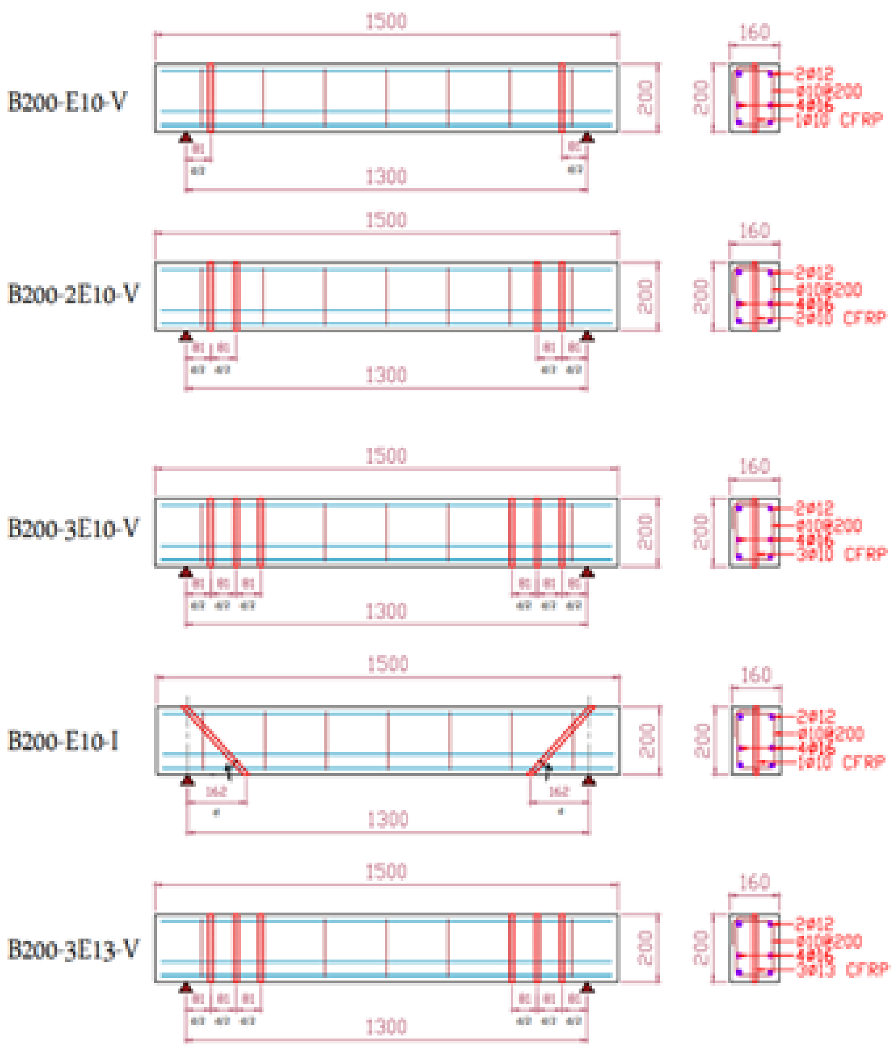


Fig. 2. Reinforced concrete beam with CFRP rod.

3. Instrumentation

The vertical displacement was measured at the position under the load in the mid-beam region using linear differential transformers (LVDT) 150 mm in length. A strain gauge was placed in the middle of the beam on the bottom and a strain gauge was also placed on the longitudinal rebar in areas expected for shear failure. In CFRP a strain gauge was placed on the CFRP bars before attaching the bars with epoxy adhesive in the holes. The hydraulic load applied by the device was 1000 KN.

4. Discussion of Experimental Results

(Table 3) shows the maximum loads that were achieved in the experimental test when the beams were ruptured and the increase in the loading capacity was due to the presence of CFRP rods that increased the resistance of the samples. The purpose of having a beam without stirrups is to compare it with a control beam in the amount of total load as well as in cracks and failure speed. The beam, named B200-E10-V, which contains two vertical 10mm diameter CFRP rods, exhibits a higher failure tolerance than the control beam because the CFRP implanted inside the beam helped with the stirrups close to it to bear part of the load applied to the beam. Also, the presence of CFRP reduced the cracks in the implanted area as shown in (Fig. 4), in the beam that contains four vertical CFRP rods with a diameter of 10 mm, which are named B200-2E10-V, which appear in (Table 3) bearing the final beam at The failure was higher than the tolerance of the control beam and also higher than that of the beam containing two CFRP bars, which indicates that the increase in the load increases when the increase of the CFRP rods working with the stirrups close to it to withstand part of the applied load, the beam containing six CFRP bars The 10 mm diameter vertical beam named B200-3E10-V showed a final load at failure higher than the control beam due to the presence of CFRP rods that contributed to increasing the bearing of the beam. The beam containing CFRP vertical rods six diameters 13mm named B200-3E13-V Contribute to the work of strengthening the beam and thus an increase in the final load of the wind Shell is higher than the control beam, but for the beam that contains two CFRP inclined bars at an angle of 45 degrees with a diameter of 10 mm named B200-E10-I, the final load of failure was higher than all beams because the CFRP inclined bars implanted took more space inside

Concrete from the rest of the cases, and in addition to the fact that the angle of inclination of the implants of these rods was opposite to the direction of the shear, and thus gave a higher resistance to the beam than the rest of the cases, as shown in (Table 3). (Fig. 3) shows the relationship between the applied load curves versus the maximum displacement for all beams, as the curves appear at the beginning of the bearing, all of them are similar before the concrete begins to crack and with continued loading, the cracks begin to appear and spread as in (Fig. 11) until reaching The beams to a downward curved failure are an indication of a loss of firmness to the firmness due to the spread of cracks. The decrease of stiffness caused internal stresses to redistribute, triggering the contribution of the transverse steel.

5. Cracking and Failure Mode

The failure of the control beam and without stirrups was a shear failure. Samples B200-E10-V, B200-2E10-V, B200-3E10-V, B200-E10-I had flexure failures and sample B200-3E13-V had a shear-flexure failure. There are no signs of the collapse of the CFRP rods, as the cracks in the flexure area in all samples at the beginning of the loading were close to (40-56) KN. As for the diagonal cracks, they started to appear in the samples ranging (126-160) KN, and the cracks were close in all samples as shown in (Fig. 11). In the control sample, B200-2E10-V, B200-3E13-V, and B200-E10-V failure occurred in compressive concrete in the area immediately under loading as in (Fig. 11) the beam without stirrups failed at load 142.41 KN where it failed after the appearance of the diagonal cracks and the stiffness decreased and it began to expand and extend until the area of the load. The control beam failed to cut at a load of 154.56 KN higher than the failure load that occurred in the beam without stirrups due to the presence of stirrups in the beam, which made it bear more load as these stirrups resist shear, for samples B200-E10-V, B200-2E10- V, B200-3E10-V, B200-E10-I that failed to a flexure that the CFRP implanted inside the beams increased the hardness of the beams in the area in which it was implanted, which strengthened in the shear area as the presence of CFRP with the stirrups prevented the occurrence of shear failure, which Limiting the failure area under load and thus all these beams failed in flexure. As for the B200-3E10-V beam, it is a shear-flexure failure. Also, it can be said that CFRP rods increased the hardness of the beam in the area where CFRP rods are implanted, which limited the failure area under load, and in general it can Say that the first cracks in the flexure region all began to appear before the first diagonal cracks.

Table 1 Properties of CFRP

Diameter (mm)	Area (mm)	Ultimate tensile load (KN)	Tensile strength (Mpa)	Modulus of elasticity (Gpa)
13	126.7	262	2172	124
10	71.26	154	2068	124

Table 2 Properties for epoxy (Lokfix DUR adhesive)

Density	Tensile strength	Compressive strength	Temperature resistant up to
1.68 Kg/m³	11 N/mm² (24hr)	60 N/mm² (25hr)	80° C

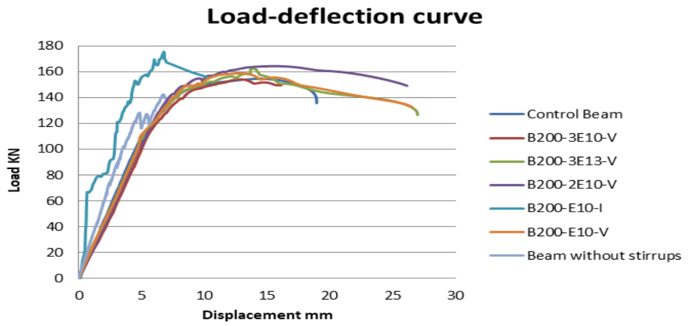


Fig. 3. Load-deflection curve for all experimental beams

Table 3
Experimental
Results

Specimen	NO.CFRP	angle	diameter	Ultimate load (KN)	Vc (KN)	Vu (KN)	Deflection at ultimate load (mm)	Failure
Beam without stirrup	-	-	-	142.41	126	71.21	6.7	Shear
Control Beam	-	-	-	154.56	121	77.28	14.52	Shear
B200-E10-V	2	90	10	158.72	150	79.36	12.81	Flexure
B200-2E10-V	4	90	10	164.25	150	82.13	15.44	Flexure
B200-3E10-V	6	90	10	158.28	130	79.12	13.15	Flexure
B200-3E13-V	6	90	13	162.24	123	81.12	13.3	Shear-flexure
B200-E10-I	2	45	10	175	160	87.5	6.8	Flexure

6. Finite element model develop

To investigate the behavior of the RC beams treated with carbon fiber reinforced polymer, a finite element model was created using ABAQUS software.

6.1. Concrete

Concrete is created in the ABAQUS program to form a sample model. It is assumed that the concrete component is a homogeneous material and 8 knots and 3 degrees of freedom (C3D8R) were used in this concrete component. This element is also used to model nonlinear characteristics in compression and tension. The properties of the concrete used in the study of the finite element method

6.2. Steel reinforcement

Longitudinal bars and stirrups are modeled in ABAQUS using 2 node and 3 degrees of freedom (T3D2) and are designed to take the compression and uniaxial tension that has the potential over the deformation of the elastomer. Steel reinforcement was modeled on the assumption that this has non-linear elasticity and is a really plastic material. The yield strength of the rebar used below is 534 Mpa, the yield strength of the higher rebar is 579 Mpa, the yield strength of stirrups is 612 Mpa, and the modulus of elasticity is 200 Gpa Poisson’s ratio 0.3. The materials mentioned above were also used to model support members.

6.3. CFRP rod

Two CFRP rods with diameters 10 mm and 13 mm were used in ABAQUS software, where 2 node and 3 degrees of freedom (T3D2) and are designed to take the compression and uniaxial tension that has the potential over the deformation of the elastomer were used in both diameters. The isotropic properties of CFRP rods were given. The properties of CFRP were provided in Table 1.

6.4. Geometric details

All the information that was entered into the ABAQUS program when analyzing the beams is the same as in the experimental study. Figure 3 shows the control beam. Fig. 5 and Fig. 6 show the beams that were reinforced using carbon fiber reinforced polymer at an angle of 90 and 45, respectively.

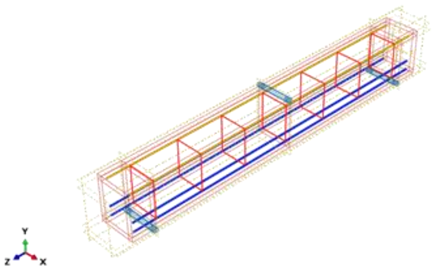


Fig. 4. Reinforced concrete for control beam

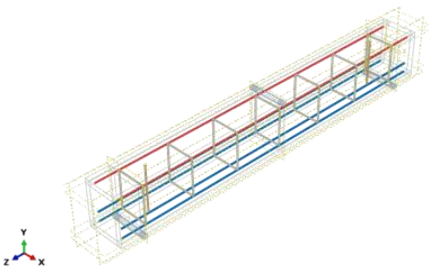


Fig. 5. Reinforced concrete for strengthening beam with 2 CFRP (B200-E10-V)

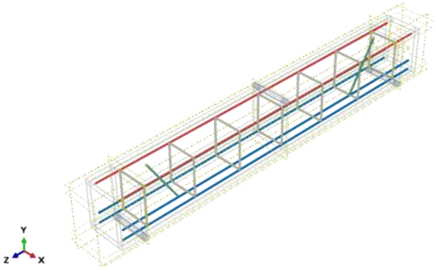


Fig. 6. Reinforced concrete for strengthening beam with 2 CFRP inclined (B200-E10-I)

6.5. Mesh size

All beams analyzed in ABAQUS program were used mesh size 0.02 mm where finite element models were used with beam elements with 8 node and 6 degrees of freedom as shown in Fig. 7.

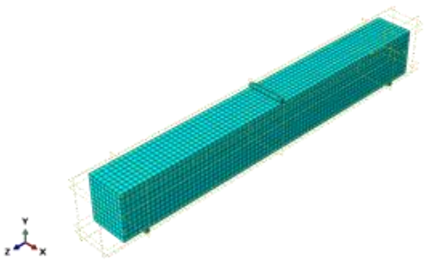


Fig. 7. The mesh size for all beams

7. The purpose of creating finite element models

7 RC beams were created in the ABAQUS program as in the experimental study in order to understand and verify between the numerical study and the experimental study for the beams that were strengthened using carbon fiber reinforced polymer as well as in order to make a comparison between both studies. The FEM models studied in the ABAQUS program, the results of which are available in the table, where the convergence between the two studies was 90% as shown in table.

8. Comparison of numerical and experimental results

The comparison in the results will be through the curve of load with displacement, where in the control beam, where the relationship between the curves of load and displacement in the FEM and the experimental study shows a good convergence in terms of response, but the stiffness in the FEM curves is higher than the experimental curves, this is because the numerical analyzes assume The existence of an ideal bond between the materials, which has an effect on the behavior of the curves in the numerical study FEM, which makes it more rigid, and also that the decrease in the stiffness of the experimental beams after the beginning of the first cracks as shown in the Fig. 8, Fig. 9 and Fig. 10 comparison figure for the control beam in both studies

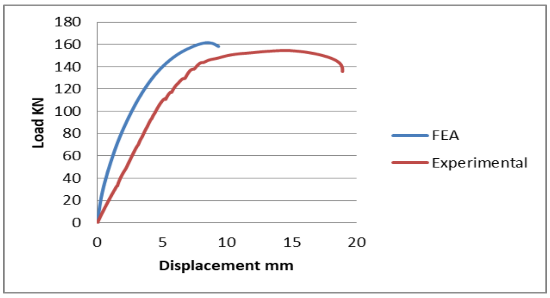


Fig. 8. Load-deflection curve for control beam

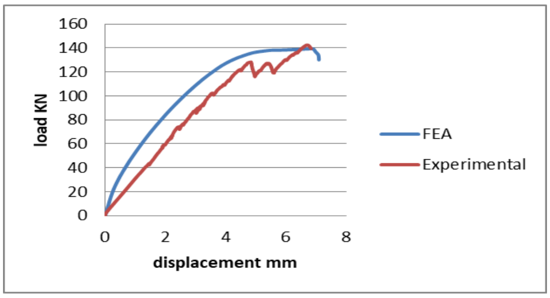


Fig. 9. Load-deflection curve for beam without stirrups

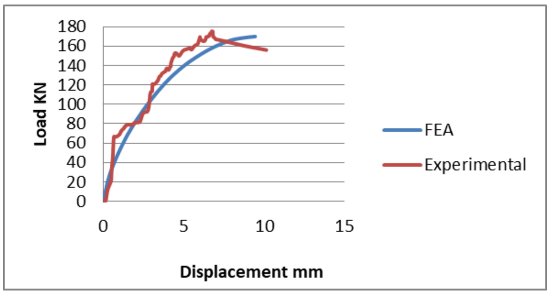
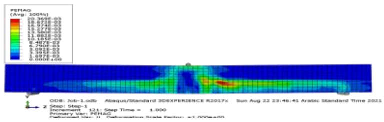


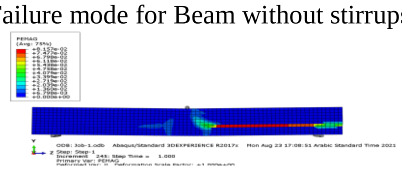
Fig. 10. Load-deflection curve for B200-E10-I

Failure mode for Control beam



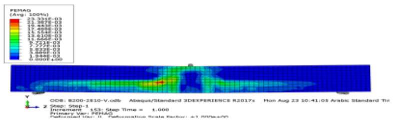
Failure mode in FEA for control beam

Failure mode for Beam without stirrups



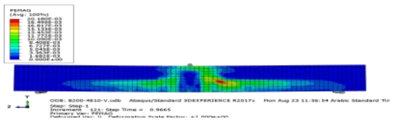
Failure mode in FEA for beam without stirrups

Failure mode for B200-E10-V



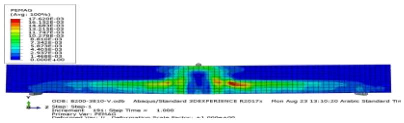
Failure mode in FEA for B200-E10-V

Failure mode for B200-2E10-V



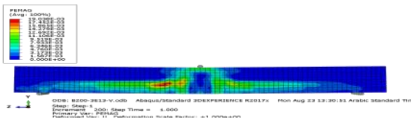
Failure mode in FEA for B200-2E10-V

Failure mode for B200-3E10-V



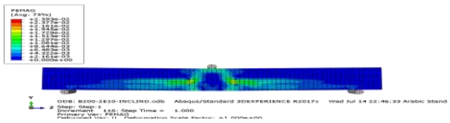
Failure mode in FEA for B200-3E10-V

Failure mode for B200-3E13-V



Failure mode in FEA for B200-3E13-V

Failure mode for B200-E10-I



Failure mode in FEA for B200-E10-I

Fig. 11. Failures of all beams in ABAQUS and experimental study

Table.4 Results of experimental beams and FE model beams.

Specimen	FE load (KN)	Experimental ultimate load (KN)	$\left\|\frac{(Pu)_{EXp} - (Pu)_{FE}}{(Pu)_{EXp}}\right\| \times 100\%$	Failure Mode
Beam without stirrup	145.705	142.41	2.34	Shear
Control Beam	158.19	154.56	2.31	Shear
B200-E10-V	154.299	158.72	2.78	Flexure
B200-2E10-V	169.228	164.25	3.03	Flexure
B200-3E10-V	164.819	158.28	4.13	Flexure
B200-3E13-V	164.724	162.24	1.53	Shear-flexure
B200-E10-I	169.942	175	2.89	Flexure

Table.5 Results of experimental beams and FE model beams.

Specimen	FE Deflection (mm)	Experimental Deflection (mm)	$\left\|\frac{(\Delta u)_{EXp} - (\Delta u)_{FE}}{(\Delta u)_{EXp}}\right\| \times 100\%$
Beam without stirrup	9.44	6.7	4.47

Control Beam	7	14.52	34.98
B200-E10-V	9.33	12.81	27.16
B200-2E10-V	9.44	15.44	38.86
B200-3E10-V	9.32	13.15	29.12
B200-3E13-V	9.34	13.3	29.77
B200-E10-I	9.44	6.8	38.82

9. Parametric study

In this paragraph, one variable is studied on the models, which is the angle of the carbon fiber reinforced polymer implanted inside the RC beams.

9.1. Effect of CFRP Rod Inclination Angle

One of the reasons for this study was to find out how the angle of the CFRP rod affected the strength of shears reinforced beams using the ETS method. Samples B200-E10-V, B200-2E10-V and B200-3E10-V were all reinforced with 10 mm diameter FRP bars implanted at a vertical angle, all with equal spacing of 81 mm, as the implanted CFRP increased the rigidity of the beams and thus increased its resistance to loading, reaching The increase in shearing was 23.96%, 23.96% and 7.43%, respectively, as for the sample B200-E10-I that was reinforced with FRP rods inclined at an angle of 45 degrees with a diameter of 10 mm and the distance d from the face of the beam equal to 162 mm as this sample gave An increase in the endurance is higher than the rest of the samples, the maximum load amounted to 175 KN due to the increase in the hardness of the sample, and the amount of increase in shear reached 32.2% due to the fact that these rods were planted with an inclination angle opposite to the expected shearing direction, in addition to their inclination within the sample as occupying an area of more than Vertical CFRP It can be said that the tilted CFRP in the opposite direction of the shear is more effective than the vertical CFRP.

10. Conclusions

The results of an experimental examination encompassing seven tests on reinforced RC beams utilizing the shear ETS method are presented in this paper. The ETS approach is used to improve FRP for RC packages. The accuracy of the proposed method was confirmed utilizing the current study's experimental results. Suggested the experimental data and the model have a reasonable correlation. In addition, the following are the key findings of this study:

(a) The ETS FRP strengthening approach has been shown to improve the shear capacity of RC beams, as the shear increase was 23.96%, 23.96%, and 7.43% for samples B200-2E10-V, B200-2E10-V, and B200-3E10-V respectively.

(b) CFRP rods implanted inside RC beams have been shown to increase cross-sectional rigidity by withstanding EST FRP-reinforced beams with higher loads than unreinforced beams.

(c) It was proved that the method of cultivating inclined CFRP rods is more effective than vertical CFRP rods, as the shear increase amounted to 32.2% for sample B200-E10-I because the inclined rods are in a direction opposite to the direction of shear.

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