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Analytical Study of Bending Behavior for Concrete Beams with T-Shaped Cross Section using Composite and Steel Bars

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Abstract: Todays, instead of steel reinforcements, Fiber Reinforced Polymer (FRP) rebars have been using in the reinforced concrete structures. By consideration of different strain-stress behavior between steel and composite material, it is necessary to evaluate the difference of these two materials inside of RC beams. In this research, twelve reinforced concrete T-shape beams were modeled using ABAQUS finite element software. Six of the beams performed as T-shape in which three of them reinforced with FRP rebars and three others were reinforced with steel rebars. As the same as first six beams property, other six beams defined by rectangular performance. The nonlinear static method was used to analysis and load-displacement diagram had been taken to compare the results. The results showed that, the stiffness of T-shape beam is much more than the beams with rectangular performance. Moreover, by comparing FRP and steel rebars, using the FRP rebars reduced stiffness and increased the load capacity.

Keywords: FRP Reinforcement, T-Shape Concrete Section, Finite Element Method, Nonlinear Analysis

Introduction

Generally, strengthening by Fiber Reinforced Polymer (FRP) has been using in order to increase to load capacity and ductility of reinforced concrete structures. In this case, there are two common FRP material include FRP sheets and FRP reinforcements. The FRP rebars has better performance compared with steel rebars like lower density, high strength and etc. So, they are one of the best method to be replaced by regular steel rebars (Mosallam *et al*., 2003; Mirmiran *et al*., 2001). Saadatmanesh and Ehsani (1998) had studied on the RC beams with were reinforced by Glass Fiber Reinforced Polymer (GFRP). In his evaluation, the longitudinal and transvers rebars were used. The results indicated that, the maximum expected theoretical and calculated force was better in beams reinforced by GFRP bars. The longitudinal cracks were normally distributed and the width of tensile crack for beams with GFRP bars was a little bit bigger than beams with steel bars. This was occurred on the grounds of the lower tensile module of elasticity. Dias and Barros (2017) had investigation on shear strengthening of T-cross section RC beam using Near Surface Mounted (NSM) with CFRP laminate. In his experimental research, the result indicated that using this method increased the load capacity and the tensile behavior of beam. Moreover, by increasing the height of the T-shape beam, the effect of CFRP increases. Naseri *et al*. (2009) evaluated the shear and flexural criteria of RC beams retrofitted by GFRP sheets. Their results showed that the ductility of beams retrofitted in shear and flexural area reduced and deflection of retrofitted beams compared with beams without retrofitting was similar. Andrew *et al*. (2017) did analytical study on T-shape reinforced concrete beam which he evaluated the behavior of the beam by different equations base on wave propagation coefficients. Nie *et al*. (2018) had experimental study on RC T-Section beam with FRP web strength opening. His results showed that, the size of web opening can be effective in flexural capacity so that increasing the size of opening decrease the flexural capacity.

Fallahi *et al*. (2018) had numerical study on RC frame with infilled wall under cyclic loading. In their research, they used the CFRP sheets to retrofit the whole system with different retrofitting shapes. The outcomes declared that using CFRP can increase the load capacity of RC frames. Soleimai and Roudsari (2015) and Roudsari *et al*. (2018) had numerical investigation of RC beams under extreme loading as an impact loading with ABAQUS using Dynamic Explicit Analysis. In this study, he evaluated the effect of retrofitting by GFRP sheets and CFRP and GFRP rebars compared to just steel rebars. The results showed, FRP rebars had much more better performance in increasing load capacity and ductility. Also, retrofitting by GFRP sheets could increase the load capacity compared with steel reinforced concrete beam. Tang *et al.* (2006) studied on the flexural behavior of RC beams retrofitted by FRP bars using NSMR method. This result showed that using GFRP bars could increase stiffness and bening loading capacity and reduced ultimate deflection. Gregoria *et al.* (2018) used the failure criteria to predict the shear capacity of reinforced concrete beam. His theoretical studies declare that using the method of predication provided a closer fit to experimental variables. Nayak *et al.* (2018) had experimental test on RC beam externally retrofitted by GFRP. He tested one control beam and nine retrofitted beam which the results showed that the wrapping up the tensile faces of beam had super performance in increasing flexural capacity.

Finite Element Models

In this research the behavior of two different groups of RC beams have been investigated. The first group includes GFRP bars and the second group contains steel bars which in each group the beams have been designed as rectangular and T-shape performance. In order to evaluate the RC beams, ABAQUS software is used.

Geometry and Mechanical Properties

In the term of geometry, the total length of the beams is considered 4 meters with simple support at both ends. Moreover, the T-shape beam has 420 mm height, 300 mm width of flange, 180 mm web width and the thickness of flange is 90 mm. Table 1. showed the geometry parameters of beam which used low steel (called D), intermediate steel (called B) and finally high steel rate (called U). It should be noted that the details of this design based on reference (Hosseini, 2016).

In addition, the details of rectangular-shape beam shown in Table 2 in which the height of the beam is 270 mm, the flange thickness is 375 mm, the web thickness is 180 and flange thickness is assigned 110 mm. It also has low, intermediate and high steel rate based of same design. (Hosseini, 2016).

The mechanical properties of beam can be seen in Table 3. In this research, the longitudinal and transvers bars are in the type of AIII and AII, respectively. The diameter of bar is 10 mm, module of elasticity (E) 2.05×10^5 and poison ratio is 0.3. Moreover, the plastic criteria of the longitudinal and transvers bars are shown in Table 3 and 4. And the mechanical properties of GFRP bars is in the Table 5. The module of elasticity, poison ratio and density are 21N/mm^2, 0.2 and 240 Kgf/m^3. Table 6 is shown the plastic parameter of concrete.

Table 1: The details of reinforcement in T-shape Beam

No	Model	Model Specification	Diameter (mm)	Stretch Rebar
1	S_1	DS32	32	2STEELØ32
2	S_2	BS34	34	2STEELØ34
3	S_3	US36	36	2STEELØ36
4	G_1	DG32	32	2GFRPØ32
5	G_2	BG34	34	2GFRPØ34
6	G_3	UG36	36	2GFRPØ36

Table 2: The details of reinforcement in Rectangular-shape Beam

No	Model	Model Specifications	Diameter (mm)	Stretch Rebar
7	S_4	DS 32	32	2STEELØ32
8	S_5	BS34	34	2STEELØ34
9	S_6	US36	36	2STEELØ36
10	G_4	DG32	32	2GFRPØ32
11	G_5	DG34	34	2GFRPØ34
12	G_6	DG36	36	36 Ø 2GFRP

Table 3: Plastic parameter of longitudinal bars

Yield stress (MPa)	Plastic strain
400	0.0
600	0.1

Table 4: Plastic parameter of transvers bars

Yield stress (MPa)	Plastic strain
300	0.0
500	0.1

Table 5: Mechanical parameter of GFRP bars

Diameter	Tensile strength (MPa)	Tensile modulus of elasticity (GPa)	Ultimate strain
32	551	46	1.19%
34	482	46	1.04%
36	448	46	0.97%

Table 6: Plastic parameter of concrete

Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity parameter
20	0.1	1.16	0	0

Modeling in ABAQUS

By considering 3D modeling in this research, the concrete damage plasticity model is used to define the concrete behavior. In this case, the parametrical study by Roudsari *et al.* (2017: 2018) has been used. He did numerical study using MATLAB toolbox in order to find out the compressive and tensile parameters of concrete and the corresponding damages. In his research, he used this model to validate the RC column with experimental test. The result showed very good accuracy in the maximum outcomes and its trends. Moreover, the beam is defined as solid part with C3D8R meshing family which R indicates the reduce integration method of analyzing.
The Fig. 1 showed the type of element. Also, in order to model of longitudinal and transvers bars, the truss element is used because of the capability of having axial load.

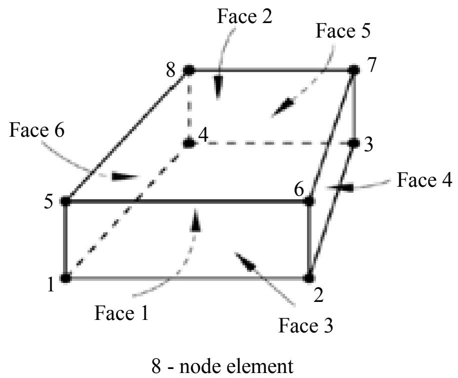

Fig. 1: Element family: C3D8R and the node number coordinate

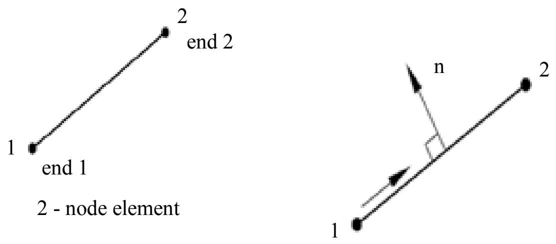

Fig. 2: Truss element and the normal vector

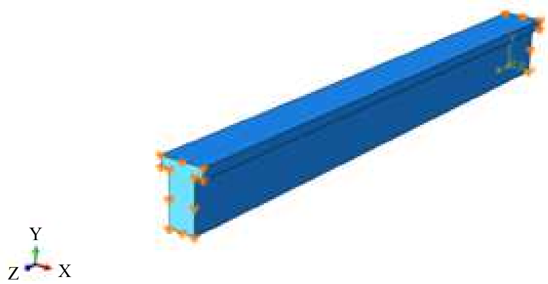

Fig. 3: Loading condition of T-shape beam

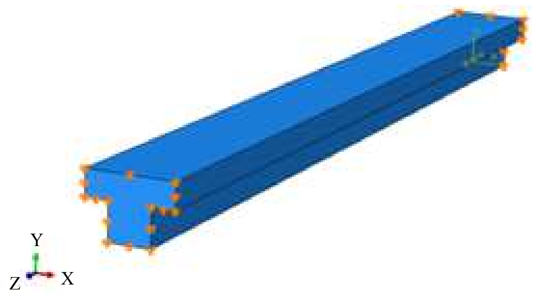

Fig. 4: Loading condition of rectangular-shape beam

Figure 2 indicates the truss element behavior. It should be noted that, Nonlinear static general analysis is used into this research and the boundary condition of both end of the beam is considered as simple support (U1 = U2 = U3 = 0) and the load applied as pressure.

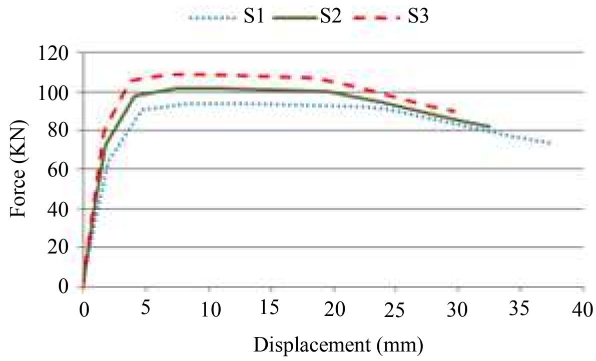

Fig. 5: Loading-displacement of T-shape beam using steel bar

Finally, the displacement is taken from the middle span on the bottom surface of them beam. Figure 3 and 4 are shown the boundary condition of T-shape and Rectangular-shape of the beam, respectively.

T-Shape Result

In the Fig. 5 the result of T-shape beam models as the load-displacement diagram is shown by comparing the S1 (low steel), S2 (intermediate steel) and S3 (high steel). As it is clear, the more bar diameter caused more load capacity in which S3 with 2 longitudinal 36 mm bars had the most load capacity as 108.83 KN. In addition, S1 model by having the low steel rate has the maximum ductility. And the stiffness of S3 is more than two other models. In Fig. 6. is shown the load-displacement diagram of beams with FRP bars. It can be seen that by increasing the cross-section area of GFRP, T-shape beam had more load capacity. G3 model with two 36 mm diameter of GFRP bars had the maximum load capacity in comparison of two other models. The deflection of G1 also with 32 mm diameter GFRP bars was a little bit more than two other beams in this groups.

Rectangular-Shape Result

The load-displacement diagram of rectangular-shape beam models is shown in Fig. 7. In this figure, the maximum load capacity of model S6 is more than other beams in this group and model of S4 has the maximum deflection and S6 also has the maximum stiffness. Moreover, in the Fig. 8. The load capacity of rectangular-shape beam with GFRP bars has been shown. The model of G6 with the maximum cross-section area of GFRP compared to G5 and G4 in which this model (G6) has the maximum load capacity, too. The deflection of G4 with two GFRP bars (32 mm diameter) is smaller than other two models. Eventually, the stiffness of G6 is more than G5 and G4.

The contours of stress distribution for model S2 (T-shape with steel bars) is shown in Fig. 9. Which the maximum compressive stress is 30.8 MPa so that it was more that the compressive strength of concrete. By considering this issue, it can be declared that the support area has some cracks. Furthermore, Fig. 10.

The middle span of the beam has cracks, too. The reason of cracking can be on the wake of the ultimate tensile stress as 3.05 MPa which is more than allowable tensile stress. In model of G2, the beam with T-shape performance and GFRP bars had 36.72 compressive stress (Fig. 11). Also, by looking at the Fig. 12. It can be seen that the maximum strain of the concrete is 0.0098 which is much more than the normal concrete strain (0.003).

In the Fig. 13 and 14 the comparisons between beam with steel and GFRP bars is shown. As it is assent, using FRP bars can increase the load capacity. Also, the stiffness of models with GFRP bars are more than others.

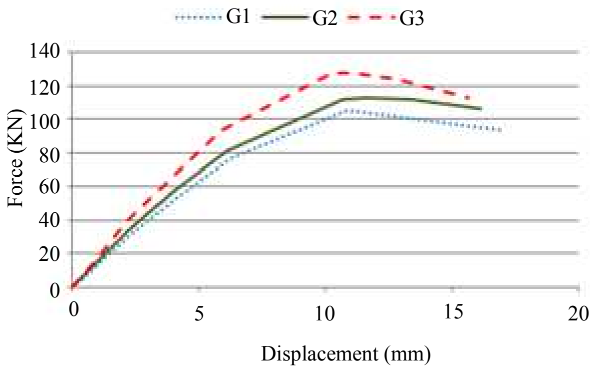

Fig. 6: Loading-displacement of T-shape beam using GFRP bar

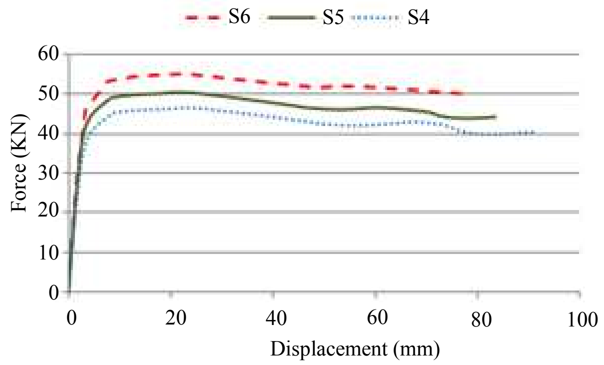

Fig. 7: Loading-displacement of rectangular-shape beam using steel bar

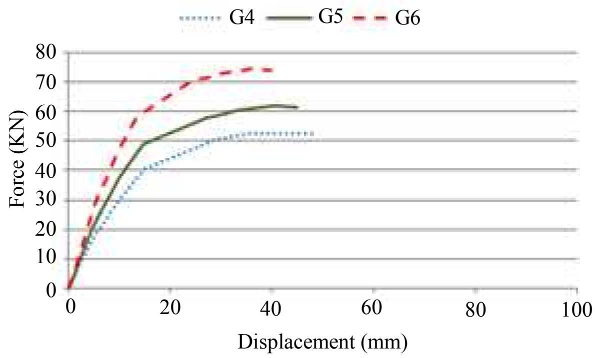

Fig. 8: Loading-displacement of rectangular-shape beam using GFRP bar

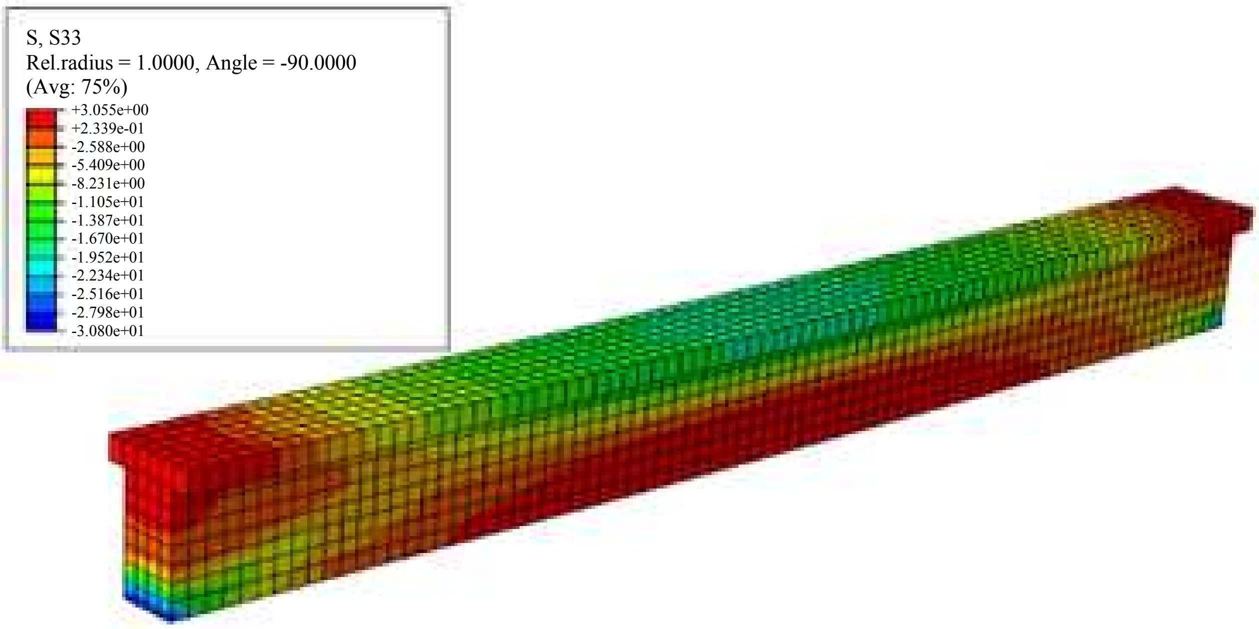

Fig. 9: Stress distribution of S2

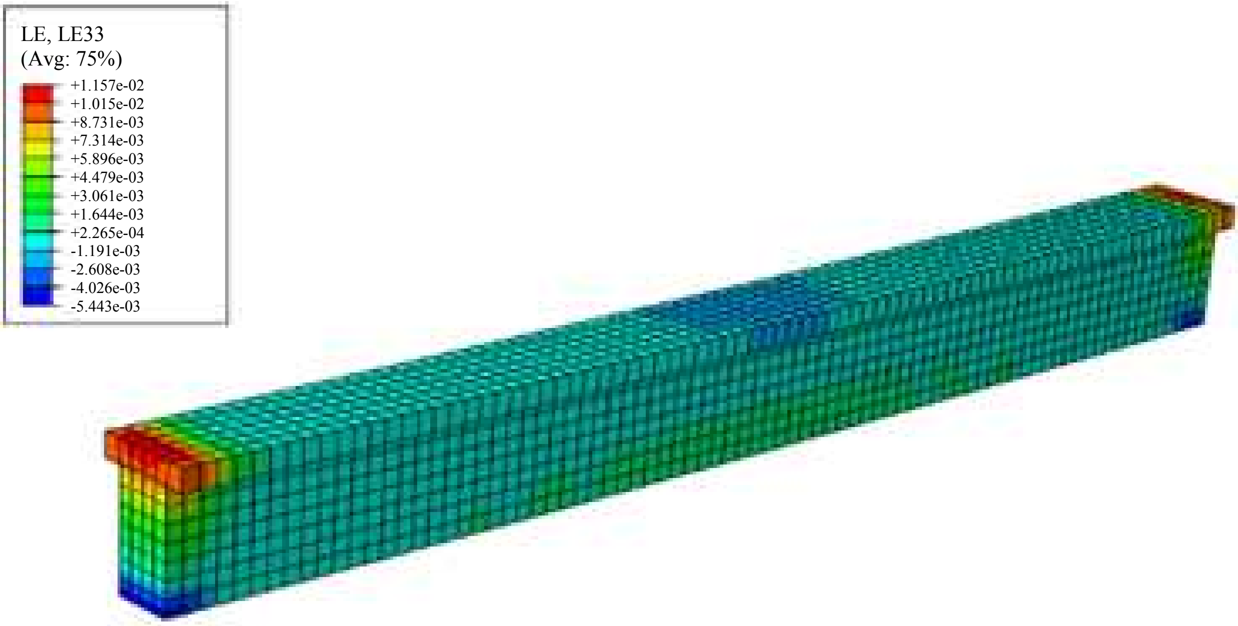

Fig. 10: Strain distribution of S2

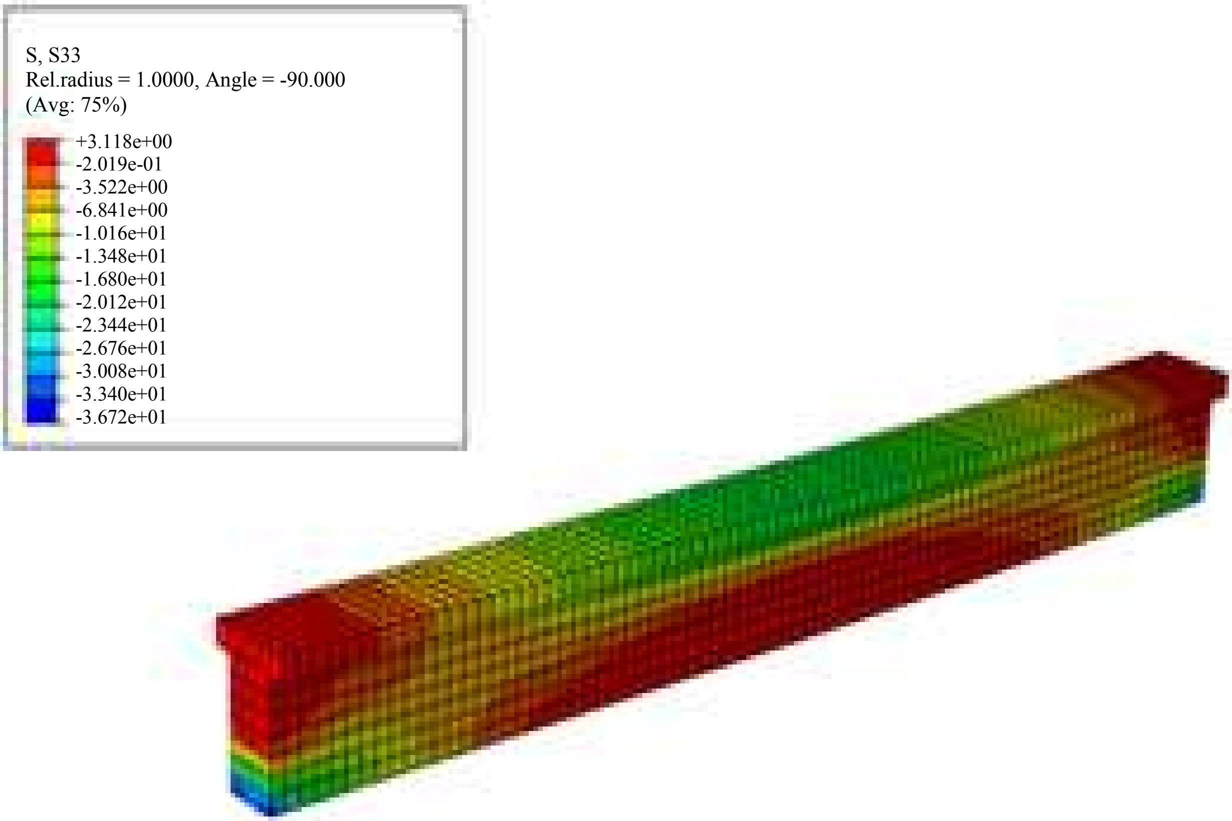

Fig. 11: Stress distribution of G2

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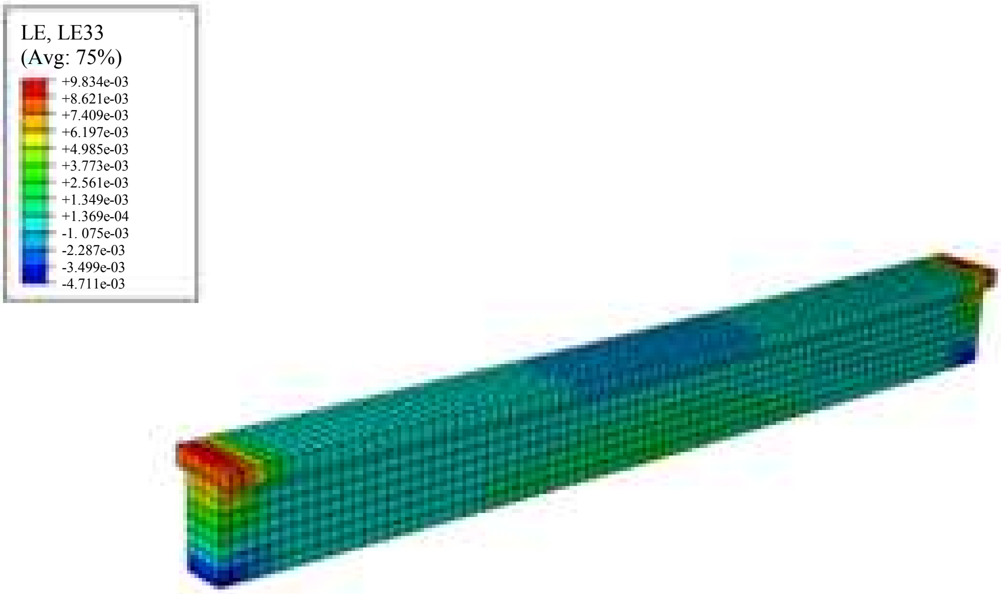

Fig. 12: Strain distribution of G2

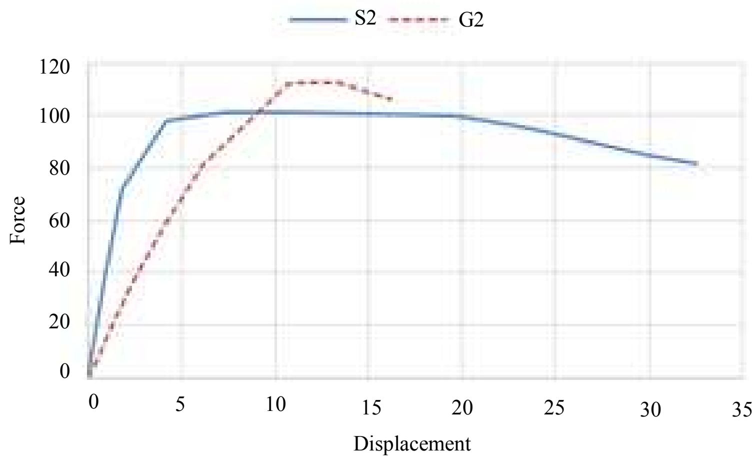

Fig. 13: Load-displacement diagram comparisons for S2 and G2

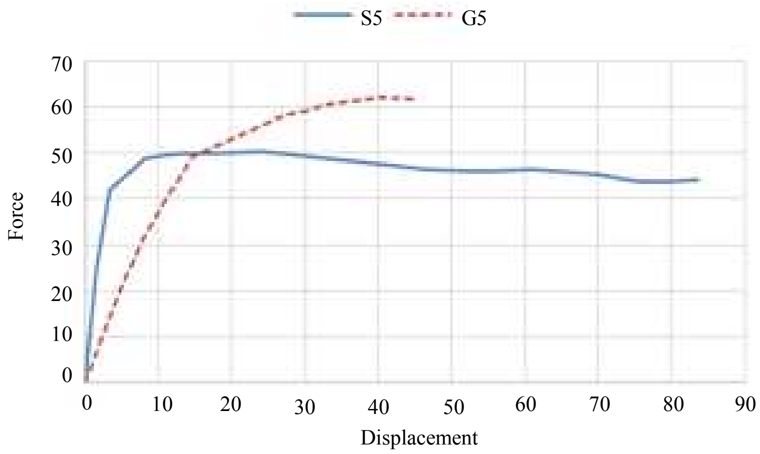

Fig. 14: Load-displacement diagram comparisons for S5 and G5

Conclusion

In this research, the flexural behavior of RC beams using steel and GFRP bars has been assessed:

- Using GFRP bars can increase load capacity from 11.19% to 48.15%
- GFRP bars improve the stiffness of RC beam
- Beams with steel bars have better ductility compared with GFRP
- T-shape beam has better performance in comparison with rectangular-shape beam

Author's Contributions

Seyedeh Zahra Hosseini Ghaziyani: Provided the research topic and guided the research development and modeling. Also, participated in writing the manuscript.

Seyedamin Mostafavian: Provided the research topic and guided the research development and data analysis and modeling. Also, participated in writing the manuscript.

Meysam Azizpour Chirani: Designed the research plan and organized the study. Also, participated in writing the manuscript.

Ethics

This article is an original research paper. There are no ethical issues that may arise after the publication of this manuscript.

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