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. Nasir 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 ABAQUUS 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 binging 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, ABAQUUS 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/mm², 0.2 and 240 Kg/m³. Table 6 is shown the plastic parameter of concrete.

**Modeling in ABAQUUS**

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.
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.
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. 10:** Strain distribution of S2

**Fig. 11:** Stress distribution of G2
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.

Meyans 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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