University of Tabriz

Journal of Civil and Environmental Engineering
Volume 53 (2023), Issue 2 (Summer), 189-200

EXTENDED ABSTRACT

Investigation of the Performance of CFRP and GFRP Wraps on Improving the Nonlinear Static Behavior of Tubular X-Joints

Pooya Rezadoost, Hossein Nassiraei, Seyed Ahmad Neshaei *

Department of Civil Engineering, Faculty of Engineering, University of Guilan, Guilan, Iran

Received: 08 September 2021; **Review:** 13 November 2021; **Accepted:** 23 November 2021

Keywords:
Tubular X-joint, Axial compression, FRP wraps, Finite element method, Ultimate strength.

1. Introduction

Tubular structures are made of hollow steel members with circular cross-sections and connecting them is one of the major challenges in their design. So far, some techniques to improve the performance of tubular connections have been proposed. Most of these methods can only be used for structures during the fabrication, but there are only a few techniques that can be applied during both fabrication and operation. Due to the successful experience of using composite materials for the repair and retrofitting of structures, special attention has now been paid to examining the efficacy of these materials in offshore structures.

In this research, the effect of CFRP and GFRP wraps on the ultimate strength and deformation of tubular X-joints under compressive load is investigated. For this purpose, the results of the finite element (FE) models were validated with several available experimental tests. After that, the nonlinear static behavior of tubular X-joints strengthened with FRP was studied. In these FE models, the contact between the FRP layers and the steel members (chord, weld, and braces) was considered. Also, the weld profile in the brace/chord intersection was modeled.

2. Details of FE models

In the present paper, the von Mises yield standard and isotropic plasticity model were applied in the FE modeling. Moreover, both geometric and material nonlinearities were utilized. The weld along was generated according to the A.W.S instructions (2002). The SHELL 281 and SOLID186 elements were used to mesh the steel me members and FRP sheets. The mesh created by this technique is depicted in Fig. 1. Also, the perfect bonding was modeled between the FRP sheets. Also, the contact was modeled between the steel members and FRP sheets. For this aim, the bottom planes of the FRP sheets were selected as the target areas and the external planes of the chord, weld and brace members were selected as the contact areas (Nassiraei and Rezadoost, 2021).

In the present work, the displacement was applied to the brace end. Moreover, a nonlinear static analysis was carried out to analyze the performance of the connections. Also, the arc-length technique was applied to overcome the numerical instability (Nassiraei and Rezadoost, 2021).

3. Validation of FE results

The accuracy of the FE results should be verified. As far as the authors are aware, no experimental database for X-connections retrofitted with the FRP is existent. Therefore, the following experimental data are used to validate the accuracy of the FE model. Three experimental X-joints under compressive load conducted by the

* Corresponding Author
E-mail addresses: pooya.rezadoost@gmail.com (Pooya Rezadoost), h.nassiraei@guilan.ac.ir (Hossein Nassiraei), maln@guilan.ac.ir (Seyed Ahmad Neshaei).

second author' previous study (Nassiraei et al, 2017) and three T/Y-connections with GFRP in brace compressive load (Lesani et al. 2015). Table 1 shows that the FE results are accurate and safe.

4. Results and discussion

4.1. The effects of the orientation of the FRP sheets

43 FE models are generated and analyzed to investigate the effect of the orientation of the FRP sheets on the ultimate strength and deformation of FRP-strengthened X-joints. Changing the orientation of the fibers on the members can modify the behavior of the reinforced joint. For instance, the ultimate strength of a connection with specifications β=0.2 and γ=18 in the unreinforced state is 173.617 kN. Wrapping this connection with 8 FRP sheets increases the ultimate strength by 50% in sketch 1 and by 60% in sketch 2 (Fig. 2). Changing the angle of the fibers on the joint, like the ultimate strength, also affects the modulation of the joint deformations, but this effect is more noticeable in the case of using carbon fibers (CFRP) than in glass (GFRP).

The results of this section showed that the best orientation of the FRP sheet on the chord member is 90 degrees. The angles of the fibers on the brace member do not have a significant effect therefore, the placement of the FRP on the brace member is determined by the ease of execution.

4.2. The effects of the FRP sheet length

Analysis of 25 joints showed that the length of the FRP on the chord member affects the increase of the ultimate strength. Therefore, to achieve a stronger connection, a longer length of the chord member must be wrapped with FRP. The effect of increasing the length of the reinforcement layers on the rate of improvement of the ultimate strength is more noticeable when using 12 FRP layers than 8 and 4 layers.

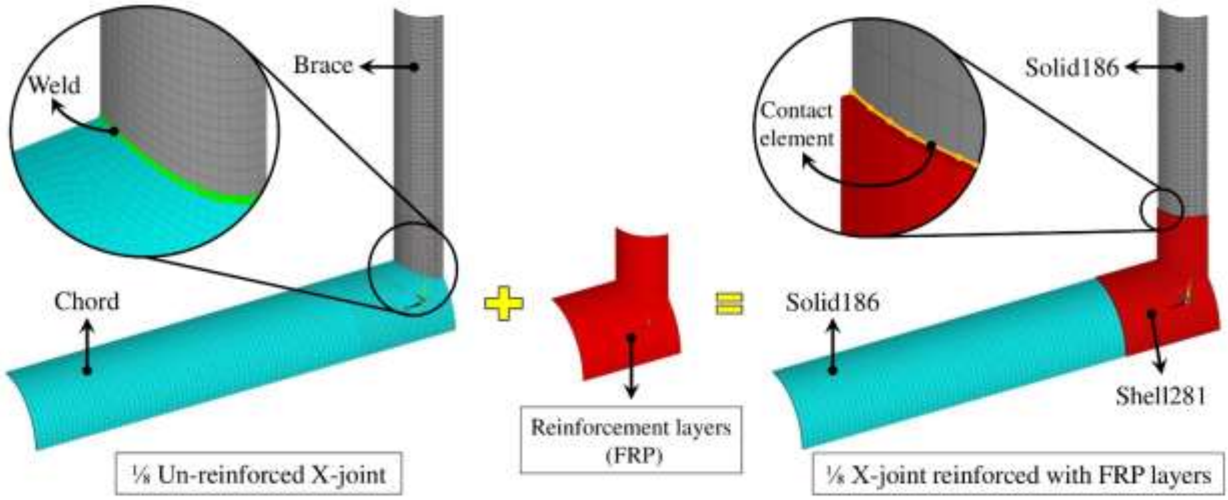

Fig. 1. The mesh generated in an X-joint reinforced with four FRP layers

Table 1. Comparison between numerical and experimental results

Specimen	Joint type	Remarks	$F_{u, Numerical}$ (kN)	$F_{u, Experimental}$ (kN)	R
S1	X	Un-reinforced	171.4	175.1	0.98
S2	X	Un-reinforced	258.6	234.2	1.10
S3	X	Un-reinforced	313.2	320.1	0.98
S4	T	Reinforced with GFRP	197.3	217.8	0.90
S5	Y	Reinforced with GFRP	347.7	327.1	1.06
S6	Y	Reinforced with GFRP	308.6	320.6	0.96

Note: $R = F_{u, Numerical} / F_{u, Experimental}$

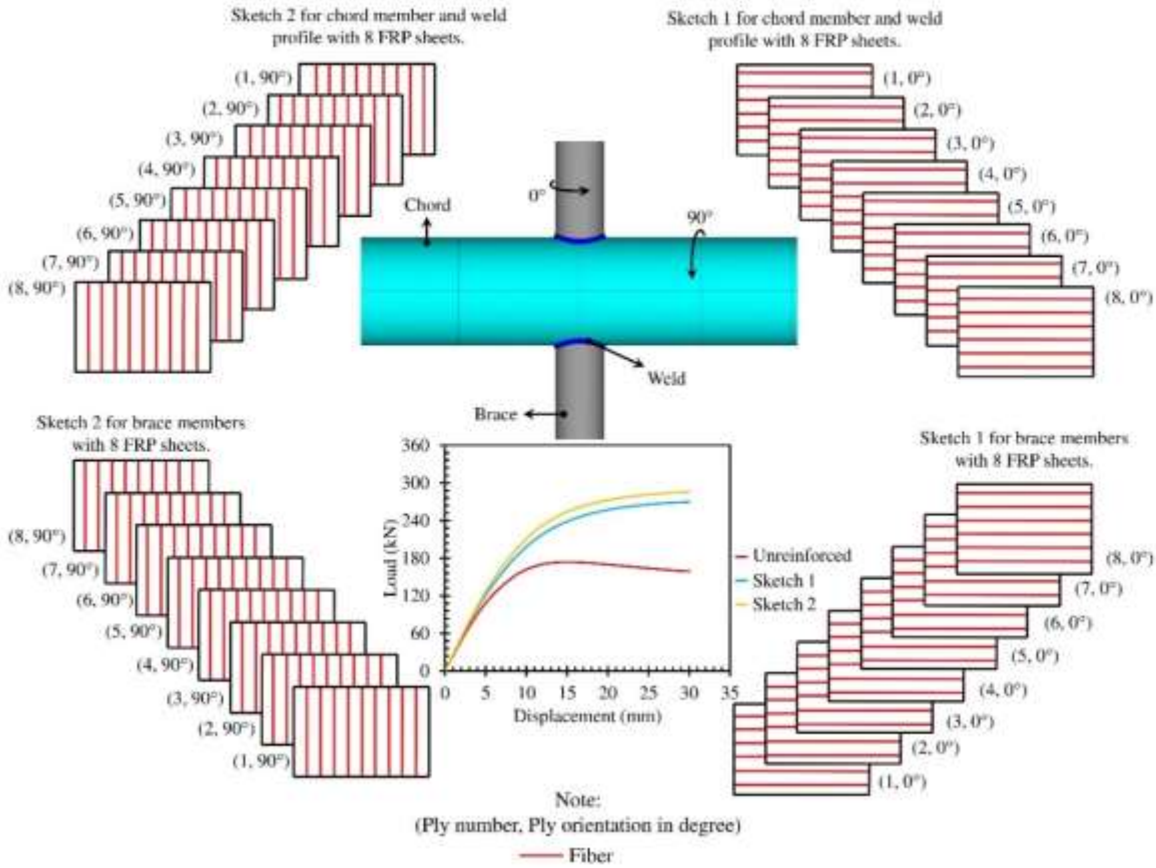

Fig. 2. The effect of the layer orientation on the strength (τ=1.0)

4.3. The effects of the FRP sheet number

As the number of FRP layers on the members increases, so does the ultimate strength. In addition, the displacements of the surface of the chord member along the longitudinal axis of the brace member and its ovalization also improve with increasing the number of layers. The effect of increasing the number of layers on the rate of increase of the ultimate strength in the case of using CFRP is more noticeable than GFRP.

5. Conclusions

Results showed that the orientation of the FRP sheets and their length on the chord member are efficient in enhancing the ultimate strength. Moreover, Carbon Fiber Reinforced Polymer (CFRP) increased the ultimate strength of tubular X-joints more than Glass Fiber Reinforced Polymer (GFRP). Also, the increase of the FRP layer number resulted in the decrease of the deflections and the increase of the ultimate strength. A comparison of the ultimate strength of the reinforced joint with the corresponding unreinforced joint show that FRP layers can increase the ultimate strength of the joint by up to 125% and adjust the displacements by up to 84%. Despite the significant effect of the FRP on the enhance of the static behavior of the X-joints, there was not any study on the X-connections with FRP. According to the obtained results, it can be concluded that the use of FRP layers is a good way to reinforce tubular X-joints in offshore tubular structures.

6. References

American Welding Society, “Structural welding code: AWS D 1.1”, Miami, US, 2002.

Lesani M, Bahaari MR, Shokrieh MM, “FRP wrapping for the rehabilitation of Circular Hollow Section (CHS) tubular steel connections”, Thin-Walled Structures, 2015, 90, 216-234.

Nassiraei H, Rezadoost P, “Static capacity of tubular X-joints reinforced with fiber reinforced polymer subjected to compressive load”, Engineering Structures, 2021, 236, 112041.

Nassiraei H, Zhu L, Lotfollahi-Yaghin MA, Ahmadi H, “Static capacity of tubular X-joints reinforced with collar plate subjected to brace compression”, Thin-Walled Structures, 2017, 119, 256-265.