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A parametric study on OPB fire response of steel CHS T-joints

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ABSTRACT: The behavior of steel circular hollow section (CHS) T-joints under combined fire load and out-of-plane bending (OPB) is investigated. A review of the literature indicates that the subject has not been previously considered by researchers. The authors carried out the first laboratory experimental study on OPB behavior of simple steel tubular T-joints under standard fire. The results of an experimental and numerical study performed on three small-scale steel tubular T-joint specimens are reported. One specimen was tested at ambient temperature under quasi-static incremental OPB moment in the brace and the other two specimens were tested under OPB moment plus exposure to ISO-834 standard fire. In order to have a deeper insight into the strength and failure mechanism of steel tubular T-joints under fire, their OPB behavior was also studied using coupled mechanical-thermal finite element modeling. The numerical model was validated against the experimental results and reasonable agreements were achieved. A parametric study was then performed on the OPB fire behavior of full-scale steel tubular T-joints. The results showed that the superimposed OPB ratio in the brace and the diameter ratio parameter had more pronounced effects on the fire response of the joint as compared to other geometric and loading parameters. Increasing the diameter ratio parameter from 0.2 to 1, reduced the joint's residual rotation by 56 % and increased the critical temperature by 23 %. By increasing the OPB ratio from 0.2 to 1, the residual rotation increased by 245 % and the critical temperature decreased by 37%.

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1- Introduction

During a fire event, tubular joints play a critical role in maintaining the integrity of the structure. The mechanical performance of steel tubular joints at elevated temperatures or under fire conditions has been the focus of several previous studies. He et al. [1] conducted an experimental study to investigate the behavior of steel tubular K-joints subjected to brace axial loading at elevated temperatures. Fung et al. [2] experimentally and numerically studied the static behavior of CHS T-joints subjected to IPB at elevated temperatures. In an extensive numerical study, Ozyurt et al. [3] described the numerical parametric study on the IPB and OPB strength of circular and square tubular steel T, Y, K, and X joints under constant elevated temperatures. Azari Dodaran et al. [4] numerically investigated the effect of the joint geometry on the ultimate strength and initial stiffness of tubular K-joints under axial brace loading at elevated temperatures. The results showed that the ultimate strength and initial stiffness may decrease drastically by increasing temperature.

The aforementioned short review of the technical literature points out that, despite the significance of the research already conducted on the subject, there is still a lack of knowledge on the OPB of steel tubular joints under fire conditions. The authors carried out the first laboratory experimental study on OPB behavior of simple steel tubular T-joints under ISO-834 standard fire [5]. The fire tests are numerically simulated using a sequentially coupled thermal-stress analysis. After the verification of the numerical model, a comprehensive numerical parametric study was carried out to determine the effects of some key parameters on the OPB structural behavior of tubular steel joints.

2- Experimental study

The tubular specimens considered in the current study were fabricated to ~1:5 scale of a tubular T-joint in an existing steel offshore jacket platform in the South Pars Gas field in the Persian Gulf. The chord and brace members were cut from seamless as-delivered API-5L-X52 steel tubes. The brace was welded at 90° angle on the chord surface to form a tubular T-joint specimen. The geometrical ratios were α =

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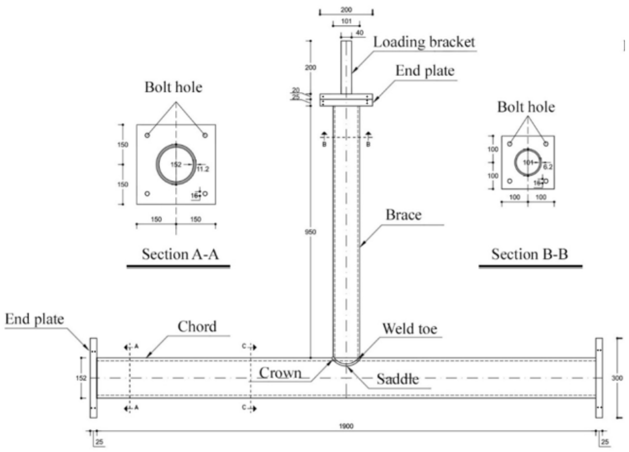

Fig. 1. Overall configuration and dimensions of the steel tubular T-joint specimens (dimensions in mm)

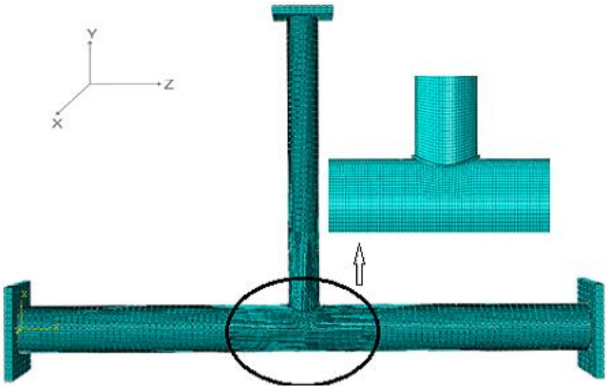

Fig. 2. Mesh details of the numerical model of tubular T-joint in ABAQUS

12.8, γ = 6.8, β = 0.66 and τ = 0.54, which remained within typical ranges in offshore steel structures [6].

The fire tests on the tubular specimens proceeded in three steps: Step 1: a predefined vertical load was superimposed to the free end of the brace, in a force-controlled scheme. This step was carried out entirely at ambient temperature. Step 2: the furnace was ignited and the ISO834 [5] standard fire curve, was introduced to the programmer of the furnace. Step 3: the specimen was unloaded, the furnace was switched off and the specimen was allowed to gradually cool down to room temperature.

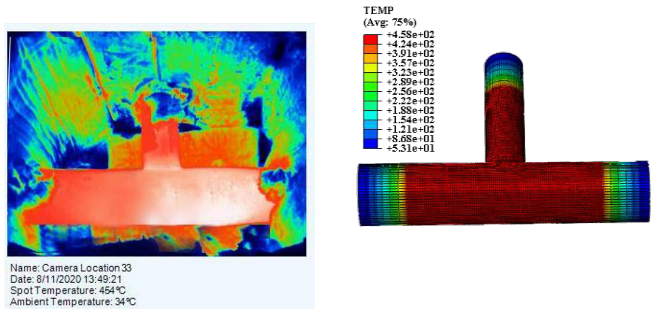

Fig. 3. Comparison of thermal gradient between experimental specimen (left) and numerical model (right)

3- Numerical modeling

The numerical study was conducted using the commercial FE code, ABAQUS [7]. The sequentially coupled thermal-stress analysis modeling approach was used in the current study. A heat transfer analysis was first carried out to obtain the temperature development in the tubular joint. During the subsequent stress analysis, the transient nodal temperature outputs from the previous heat transfer simulation were time wisely imported to the stress model to account for the heat effects on stress development. The mechanical properties of the low-carbon steel material at elevated temperatures were defined using Eurocode 3 [8] equations. For accurate FE modeling of the elastoplastic behavior of a material, the true stress (σ) and strain (ε) were used. The brace and chord members were modeled using three-dimensional (3D) 8-noded DC3D8 solid elements and 8-noded C3D8I solid/incompatible elements for the thermal and stress models, respectively. The size, meshing, and connectivity of the DC3D8 and C3D8I elements remain similar (Figure 2).

Validation of the numerical model was conducted by comparison of the moment-rotation curve, rotation-temperature curve, critical temperature, thermal gradient (Figure 3), and failure mode of simulated models with experimental specimens already conducted by the authors. In general, there was a reasonable correlation between the results of the numerical analysis and those provided by the experimental study.

4- Discussion

A parametric study was then conducted to investigate the influence of geometrical parameters (*α, γ, τ, β*) and the ratio of the applied OPB moment to OPB capacity of the joint (η) on the structural fire performance of steel tubular T-joints. The rotation-temperature response, critical temperature, the residual rotation of the joints, and fire endurance time were investigated. It was found that the chord diameter to thickness ratio (γ), the brace/chord diameters' ratio (β), and the load ratio (η), play remarkable effects on the OPB fire response.

5- Conclusion

The main findings of the study are as follows: The structural fire response was noticeably improved by decreasing γ, increasing β, and decreasing η. The dominant fire-induced failure modes of the T-joint models subjected to OPB were identified as: a) the chord wall plastification, b) the plastic hinge formation in the brace, and c) the punching shear failure in the chord wall. The rotation rate of "1 mili-radian/°C" was introduced as a criterion to define the critical OPB rotation of steel tubular T-joints under fire.

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