FEM on the SIFs of Cracked Tubular T-Joints

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Abstract: **Due to the complex geometrical of tubular T-joints and the loading condition in offshore tubular structures, fatigue damage is the most common failure mode in offshore tubular structures. The fatigue cracks usually occur at the brace to chord intersection. And fraction mechanism methods is the most common method to estimate the fatigue life of tubular T-joints. Thus, this paper focuses on the stress intensity factors of cracked Circular Hollow Sections (CHSs) tubular T-joints. FEM is produced to calculate the stress intensity factors along the crack front. Based on the FEM of tubular T-joint, the stress intensity factors of a cracked CHS T-joint subjected to brace end axial loads are calculated. The FEM are analysed on ABAQUS software and compared with existing experimental results. It is found that the SIF computed from the FEM is agreed with the experimental results of T-joints. After that, a parametric study is conducted on the geometrical parameter of the tubular T-joints.**

Keyword: **Fatigue; Cracks; ABAQUS; T-joints; SIF.**

I. INTRODUCTION

Circular hollow section (CHS) joints are widely used in offshore and onshore structures. In the past decades, several numerical finite element analysis on tubular CHS joints had been carried out on cracked CHS T/Y/K/X-joints [1-12]. The fatigue cracks in CHS joints can be classified into two categories, a through-thickness crack and a surface crack. The through-thickness crack is the crack which penetrates the whole chord thickness, while the surface crack is the crack which penetrates part of the chord thickness. In this study the focus is on the surface crack. In the earlier days, researchers preferred to use shell elements to construct the FE mesh models of cracked CHS joints due to the limited capabilities of computer processing at that time. Later on, researchers turned to use brick solid elements to construct FE mesh models of cracked CHS joints. The mesh generation approach proposed by [13] was developed to calculate the linear elastic stress intensity factor (SIF) of a cracked CHS joint for elastic analysis. In contrast to the previous researcher work, [3, 9, 14] developed a more flexible mesh generator of cracked CHS T-joint, Y-joint and K-joint for estimating the SIF of cracked CHS joints. In their mesh generation approach, the location of the surface crack. Lie et al. [15, 16] developed a new mesh modeling approach for constructing the elastic-plastic analysis of CHS tubular joints.

In the present study, the focus is on the analysis of surface cracked CHS tubular T-joint. A mesh model of a cracked tubular CHS T-joint containing semi-elliptical surface cracks is analysed by using ABAQUS 6.12-1 software. The FEM are analysed on ABAQUS software and compared with existing experimental results. After that, a parametric study is conducted on the geometrical parameter of the tubular T-joints.

II. ELEMENT TYPE AND BOUNDARY CONDITION

A. *Elements type:*

Finite element method is adopted in this study to model several tubular T-joint with a semi-elliptical crack at the chord weld toe. The type of elements are used. Namely, 20-node hexahedron element and 15-node collapsed prism element. Fig. 1 shows the 20-node hexahedron element which is used to simulate the whole mesh elements of the tubular T-joints except the crack front elements. While 15-node collapsed prism element is used to simulate the element at the crack front. To measure more accurate SIF along the crack front, the elements along the crack front are designed to produce a (1/r)1/2 strain singularity by transferring its mid-side nodes to the 1/4-point position as shown in Fig. 2.

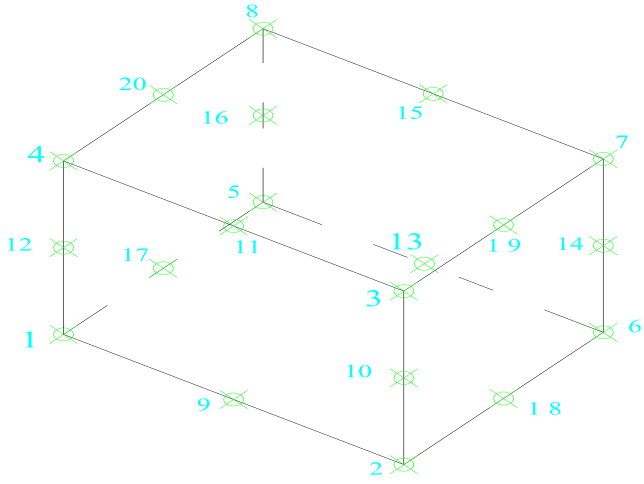

Fig 1: 20-node hexahedron element

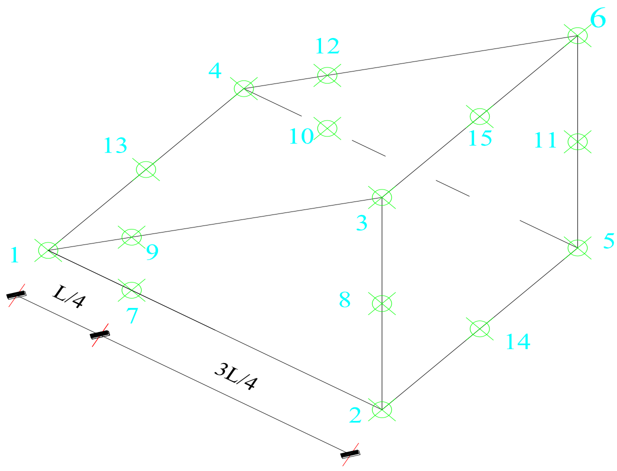

Fig 2: 15-node collapsed prism element

B. Loading and Boundary Condition:

Due to the complexity of the geometry of tubular joints, the stress distribution in tubular joints varies at different locations and the stress far away from the intersection is usually easier to be determined by applied load. On the other hand, the high-stress gradient at the weld toe is harder to be estimated in practice. Hence, the nominal stress is defined as the basic stress caused by applied load at the brace end.

The nominal stress can be obtained by dividing the applied load by the cross-sectional area of the brace. The general form of the nominal stress, σ_n, of CHS T-joint under axial loading can be expressed in Equation (1).

$$\sigma_n = \frac{4F}{\pi(d^2 - (d-2t)^2)} \tag{1}$$

where F in the axial load at the brace end, d is the brace diameter and t is the brace thickness.

In practice, both ends of the chord are connected with adjacent members. Therefore, the boundary condition is that two chord ends are restrained rigidly in all direction against displacement, whereas the brace end is free of lateral constraint.

C. Tubular t-joint geometric parameter:

This section describes T-joint geometry and the crack shape in the finite element modeling. The finite element models created are based on cracked circular hollow section T-joints as shown in Fig. 3. While Fig. 4 shows mesh model of the cracked joint.

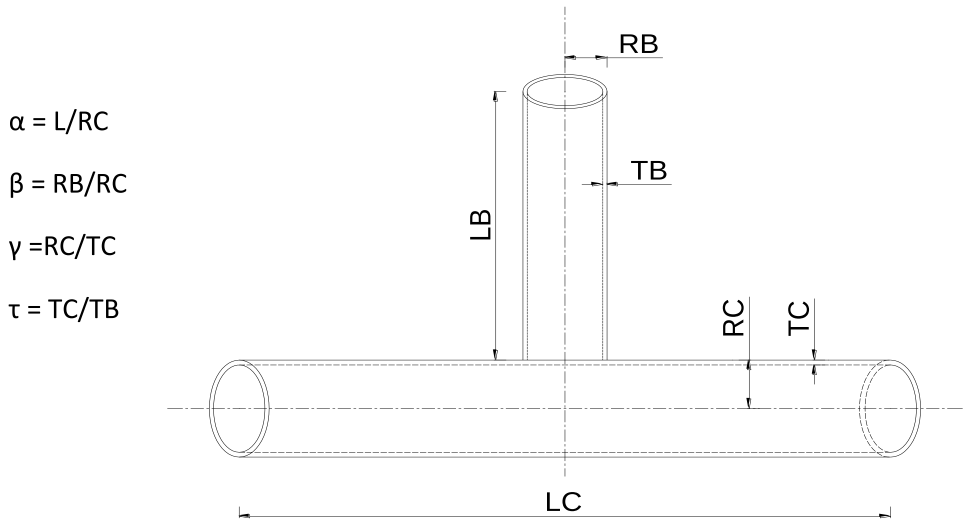

Fig 3: The geometry of a CHS T-joint.

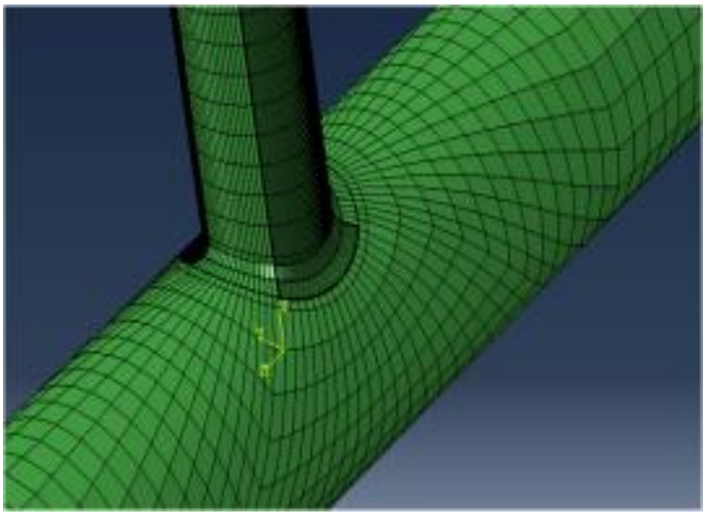

Fig 4: Mesh model of the cracked tubular T-joint

III. VERIFICATION STUDY

For the propose of verifying the SIF obtained by the new mesh generator proposed in this paper, a T-joint used by Huijskens [17] is analysed by using the FE models analysed by ABAQUS. Fatigue crack growth prediction follows the Paris crack propagation law,

$$\frac{da}{dN} = C(\Delta K_{eff})^m \qquad (1)$$

where da/dN refers to the crack propagation rate, C and m are material parameters and ΔK_{eff} refers to the stress intensity factor range calculated from mixed-mode stress-intensity factors as follows,

$$K_{eff} = [K_I^{\,2} + K_{II}^{\,2} + K_{III}^{\,2} / (1-\upsilon)]^{0.5}$$

where K_I, K_{II} and K_{III} refer to the modes I, II and III stress-intensity factor, respectively and υ denotes the Poisson's ratio of the material.

The joint geometrical parameter and the cracks details are tabulated in Table 1. The fatigue crack was located at the weld toe on the chord close to saddle point. Fig. 5 shows the comparison between the SIF at the deepest point derived by Huijskens [17] and the K_I, K_{II}, K_{III} and K_{eff} from the FEM model proposed in this study.

The SIFs results obtained by the proposed new mesh generator are close compared to that obtained from Huijskens [17] experimental results. Hence, the techniques used in the proposed mesh generation can be deemed to be accurate.

Table 1: Geometric parameter and crack details

Chord	*RC*	914
	TC	32
	LB	3900
Brace	*RC*	457
	TC	16
	LB	1250
Crack	*a*	14.3
	c	91

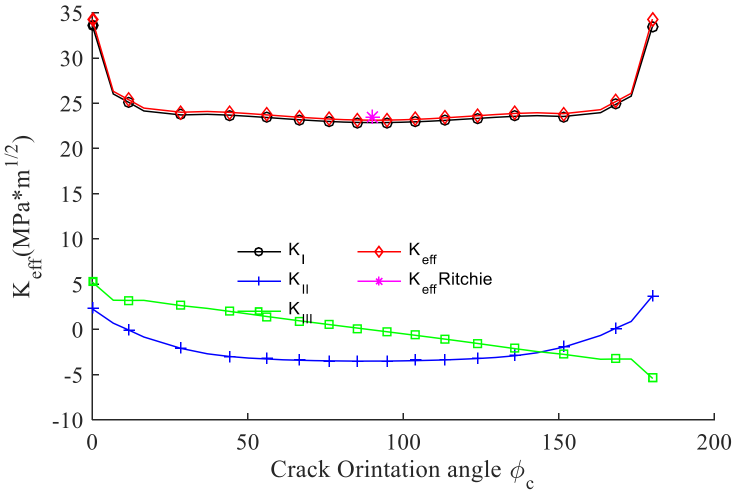

Fig 5: Comparison between the SIF at the deepest

IV. PARAMETRIC STUDY

This section aims to estimate the effects of tubular joints geometrical parameters (α, β, γ and τ) on K_{eff} taking into account the effects of the crack propagation angle. The definitions of the geometrical parameters are shown in Fig. 3.The effects on the SIF of tubular T-joints is studied by varying the parameters α (5, 10, 15, 20 and 25), γ (10, 14, 18, 22 and 26), β (0.4, 0.5, 0.6, 0.7 and 0.8) and τ (0.6, 0.7, 0.8, 0.9 and 1.0).

D. Effect of α on K_{eff}

Fig. 6 show the effect of the geometrical parameter α on K_{eff} for various cases of crack propagation angle along the crack front. In Fig.6 α varies from 5 to 25 and the other geometrical are kept constant. At low values of α , K_{eff} increase as α increases up to β = 5. Later on, the K_{eff} kept constant when β is further increased.

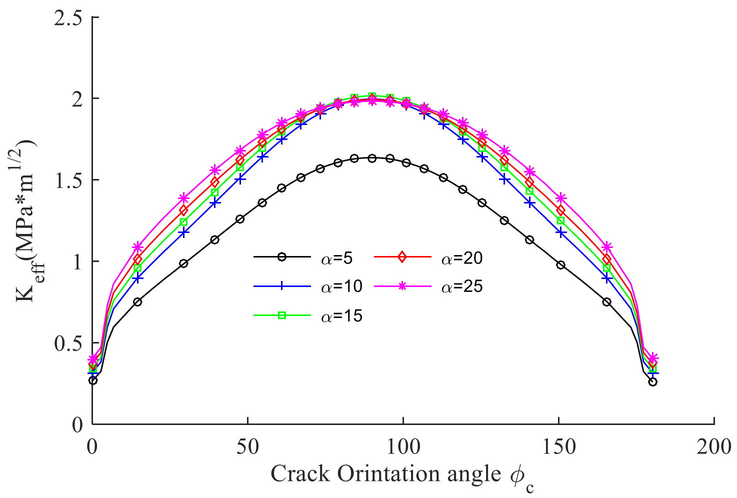

Fig 6: Effect of α on K_{eff}

E. Effect of β on K_{eff}

Fig. 7 show the effect of the geometrical parameter β on K_{eff} for various cases of crack propagation angle along the crack front. In Fig.7, β varies from 0.4 to 0.8 and the other geometrical are kept constant. At low values of α , K_{eff} increases rapidly as α increases up to $\beta = 0.5$. Later on, the K_{eff} decreases rapidly when β is further increased.

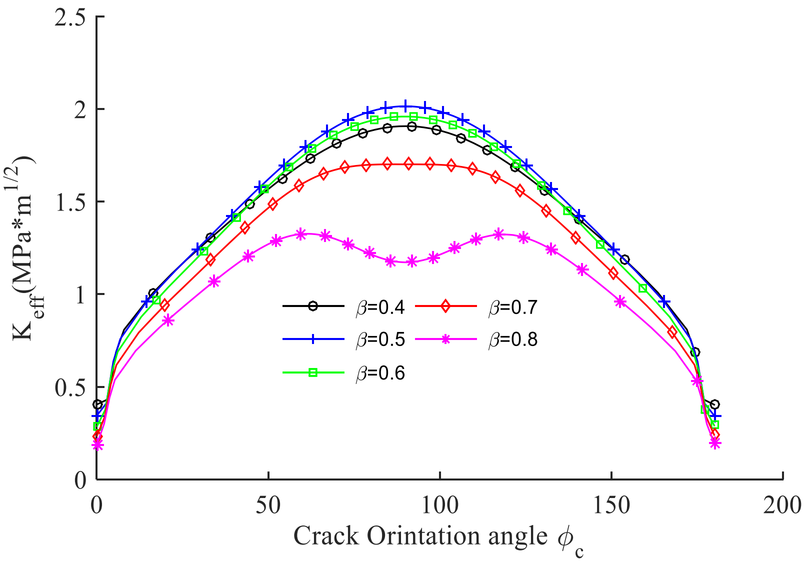

Fig 7: Effect of β on K_{eff}

F. Effect of γ on K_{eff}

Fig. 8 show the effect of the geometrical parameter γ on K_{eff} for various cases of crack propagation angle along the crack front. In Fig.8 γ varies from 14 to 26 and the other geometrical are kept constant. α is in a linear relationship with K_{eff} . As γ increases K_{eff} increases.

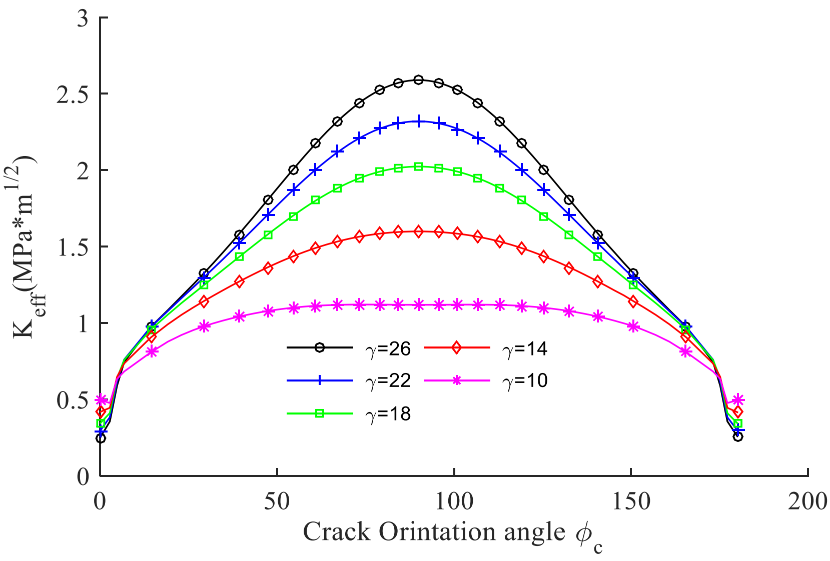

Fig 8: Effect of γ on K_{eff}

G. Effect of τ on K_{eff}:

Fig. 9 show the effect of the geometrical parameter γ on K_{eff} for various cases of crack propagation angle along the crack front. In Fig.9 τ varies from 0.6 to 1 and the other geometrical are kept constant. α is in a linear relationship with K_{eff} . As γ increases K_{eff} increases.

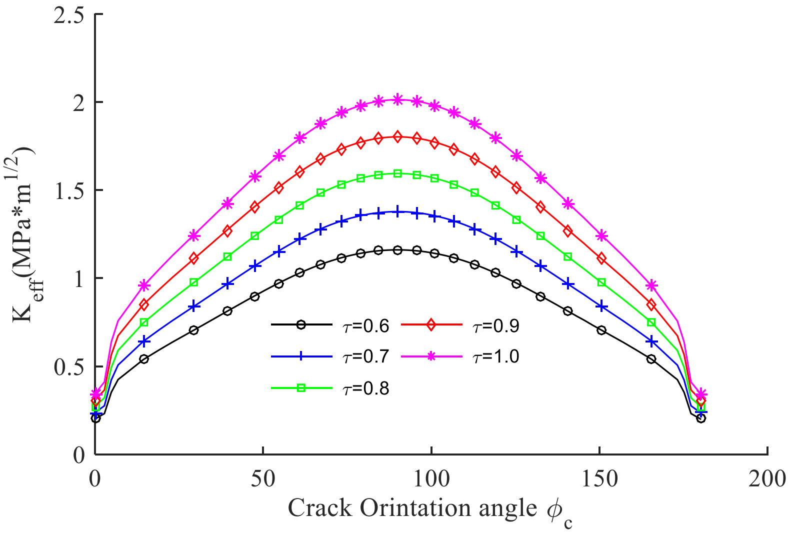

Fig 9: Effect of τ on K_{eff}

V. CONCLUSION

The adaptive finite element program has been developed to simulate cracked tubular T-joints. The stress intensity factors (SIFs) in terms of K_I, K_{II} and K_{III} were predicted by using ABAQUS software. The predicted values of SIFs were compared with the experimental result by Huijskens [17]. The SIFs results obtained by the proposed new mesh generator are close compared to that obtained from Huijskens [17] experimental results. The parametric study in dictates that, the joint geometrical parameter have sufficient effect on the stress in intensity factors at the crack front

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