Stress Distribution along the Weld Toes of Tubular KT and KDT Joints under Balance Axial Loads and In-Plane-Bending Moments

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Abstract: Jacket offshore structures are constructed from tubular members that consist of several types of multi-planar tubular joints. So far, very few investigations have been performed on stress characteristics of such joints due to their complexity. The present research is focused on the study of stress distribution along the weld toe of brace-chord intersection for most critical brace due to the joint loading. In this paper tubular-KT and KDT joints as elements of an offshore jacket platform are modelled as finite element models. The effect of multi-planarity caused by adding a brace to the stress distribution along the weld toes is investigated under two different loading conditions. To ensure validity of the model, Stress Concentration Factor (SCF) of the KT-joints model was validated by Efthymiou SCF equations. An additional brace has been added within the validated KT-joints models to form a multi-planar KDT joint, and the stress distribution along the weld toes of the joints are investigated under balance axial load and in-plane bending moments. The results showed that under balance axial loading, maximum stress occurred at a point of Crown 1 on the KDT-joints were smaller than maximum stress occurred in the KT-joints as well as the case of in-plane bending moment loading.

1 INTRODUCTION

Jacket offshore platforms that frequently used for oil and gas exploitation in shallow water areas, during their operation life will hold wave forces which introduce variable loading on the structure. This variable loading causes fatigue damage to the structure members which usually initial crack will appears at weld toes region of the tubular joints where maximum stress occurs. Therefore, in the fatigue design it is important to determine the stress distribution along the weld toe of tubular joints.

In this paper, finite element analysis of tubular KT and multi-planar KDT joints will be presented. The results are stress distribution along the weld toe of both type of the tubular joints. Multi-planarity effect to the stress distribution along the weld toe of the tubular KDT joint will be investigated. The multi-planar tubular joint to be analyzed in the present study is depicted in Fig. 1.

Numerous researches have been performed to investigate the stress distribution for various multi-planar tubular joints under several loading conditions. Ahmadi and Zavvar (2016) numerically studied the chord-side SCFs in two- and three-planar tubular KT-joints under in-plane and out-of-plane bending moments. Ahmadi and Nejad (2017) proposed a new parametric formulas to calculate the local joint flexibility of two-planar tubular DK-joints subjected to four types of out-of-plane bending (OPB) loads. Derivation the SCF formula for DT-joints under axial loads was conducted by Jiang et al. (2018). They used two types of error analysis to verify the reliability of the formula. Using another type of tubular joint which is XX-joints, Chiew et al. (2000) investigated stress concentration factors within the joints due to the axial, in-plane-bending (IPB), and out-of-plane bending (OPB) loads. Based on 64 finite element models they proposed general SCF design equations for the joints. Recently Prastianto et al. (2018) have conducted numerical study on stress concentration factor distribution of 60 degrees two-planar DKT tubular joints subjected to axial and in-plane bending loads.

Although several types of multi-planar tubular joints as parts of offshore structures were already been the subject of recent researches, but still no

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research on the multi-planarity effect in the stress distribution at the brace-to-chord intersection areas of the tubular-KDT joint. Therefore, this research will investigate the effect of additional one brace to the KT tubular joint to form a tubular-KDT joint (as shown at Fig. 1) on the stress distribution along the weld toes of the joint.

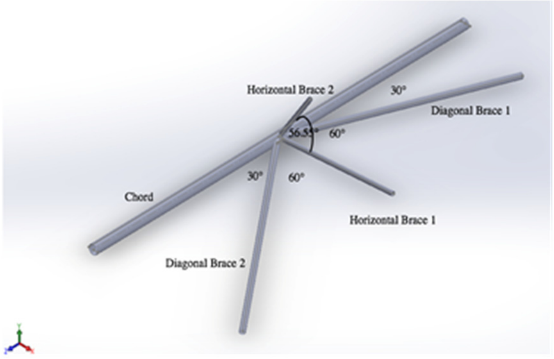


Figure 1: Multiplanar tubular K double T (KDT) joint to be analyzed.

2 FINITE ELEMENT MODELLING

In this research, structure of tubular-KT and KDT joints are modelled using a finite element method-based software with the geometry as presented at Fig. 1 for the KDT joint. Dimensions and material properties of the models can be seen in Table 1 and Table 2. Weld profile along the brace/chord intersection of the model satisfies the AWS D1.1 (AWS, 2002).

Table 1: Geometry of the model of the tubular-KT and KDT joints.

	Thickness (inc)	Outside Diameter (OD)	Intside Diameter (ID)	Length (inc)
Chord	0.688	24	22.62	1032.68
Diagonal Brace 1	0.5	14	13	487.19
Diagonal Brace 2	0.5	14	13	611.55
Horizontal Brace 1	0.364	10.75	16.5	278.22
Horizontal Brace 2	0.364	10.75	16.5	149.80

Table 2: Material properties of the model of the tubular-KT and KDT joints.

	Spec and Grade	Yield Strength (ksi)	Modulus Young (ksi)	Shear Modulus (ksi)	Poisson's Ration
Chord	API 5L Grade 290	290	29007.5 449	11603.01 75	0.3
Brace	API 5L Grade B	241	29007.5 449	11603.01 75	0.3

The finite element model of the tubular joints using element type of solid three-dimensional with a linear element tetrahedron for the model of braces, chord, and weld profiles. The tubular joint models are divided into two different zones according to the computational requirements with sub-zone mesh generation is used to ensure good quality meshing. Meshing size is made smaller on the region around brace-chord intersection rather than meshing size on the areas that far from the brace-chord intersection. The model with the meshing can be seen at Fig. 2.

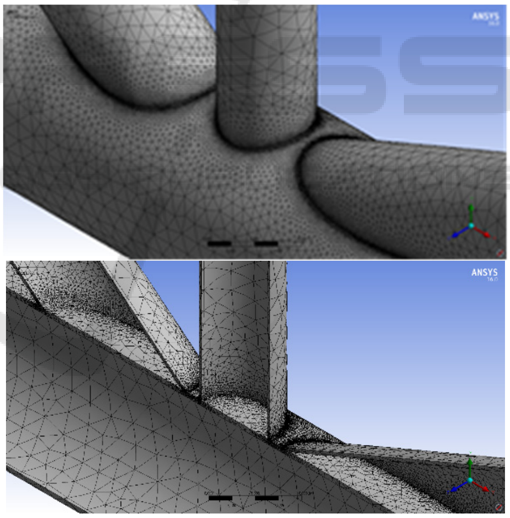
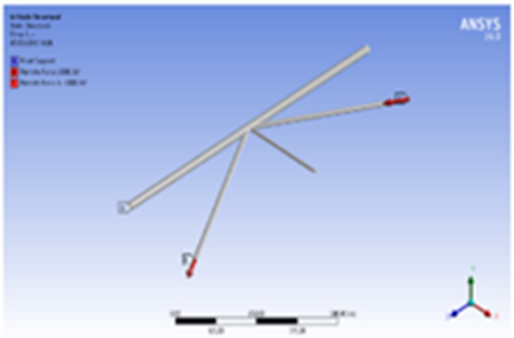
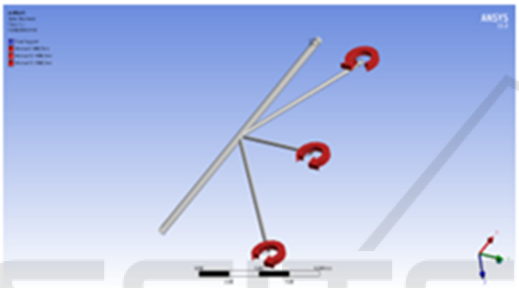


Figure 2: Solid three-dimensional tetrahedron elements used for the model.

According to Efthymiou (1988), fixity condition of the chord ends in tubular joints of offshore structures ranges from almost fixed to almost pinned with generally being closer to almost fixed. For the present study, the chord end fixity condition of the joint models are also set to fixed support on both ends of the chord. The braces of the structures will be loaded with two different types of loading conditions, namely balance axial loading and in-plane bending moment. The loading and boundary condition applied to the models are illustrated at Figs. 3 and 4 for the KT joint model and the KDT joints models, respectively.

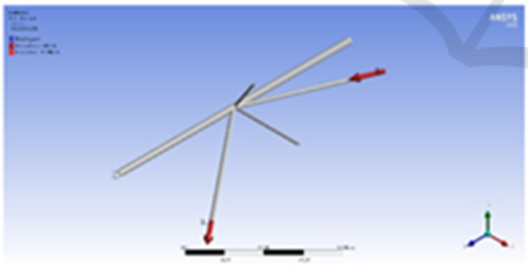


(a) Balance axial load

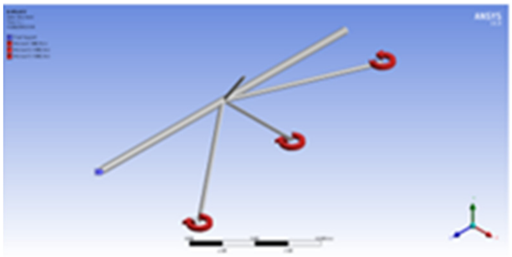


(b) In-plane bending load

Figure 3: Loads and boundary conditions for the KT-joint models.



(a) Balance axial load



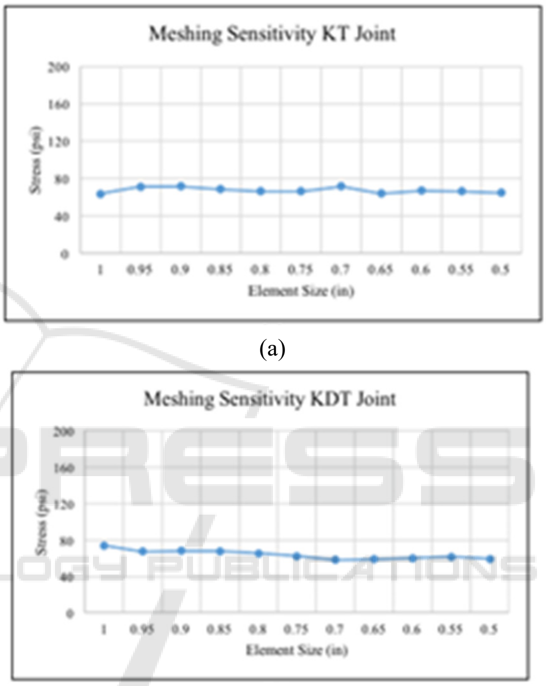
(b) In-plane bending load

Figure 4: Load and boundary conditions for the KDT-joint models.

3 RESULTS AND ANALYSIS

3.1 Meshing Sensitivity Analysis

Meshing sensitivity analysis is performed to ensure the consistency of the output from the finite element analysis. This approach is done by changing element size in the region around brace-chord intersection line from 1.0 inch to 0.5 inch until stress at a particular location reached a constant value as the function of the size change.

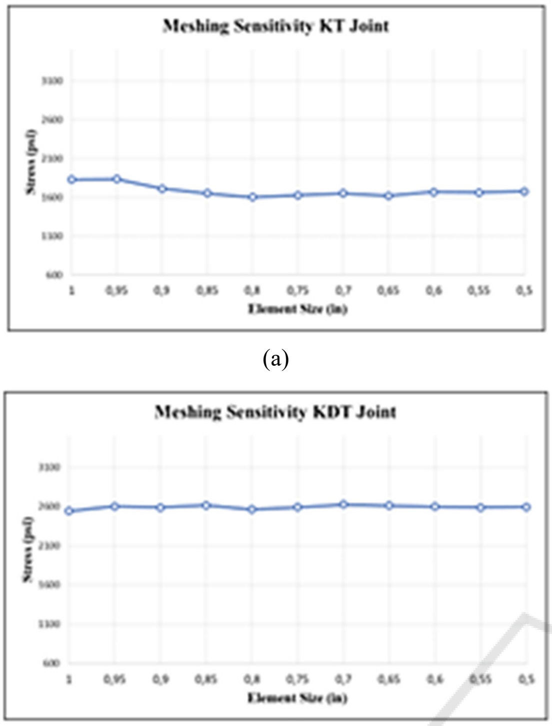


(a)

(b)

Figure 5: Result of meshing sensitivity analysis due to balance axial loading condition on: (a) KT-joint; (b) KDT-joint.

From the results of the meshing sensitivity analysis (see Figs. 5 and 6), for both cases of KT and KDT joints it is found that stress output at particular point nearly constant when element size reached 0.65 inch.



(a)

(b)

Figure 6: Result of meshing sensitivity analysis due to in-plane-bending moment loading condition on: (a) KT-joint; (b) KDT-joint.

3.2 Validation of Stress Concentration Factor (SCF) for KT-joint

Stress Concentration Factor (SCF) is a ratio between hot-spot stress in chord and nominal stress in brace. In this research hot-spot stress calculation is determined using two linear extrapolation points as mentioned in DNVGL-RP-C203 (2001) by using the maximum principal stresses occurred in the joint model.

In this research, nominal stress occurred in brace is obtained by reviewing stresses in 96 elements in the middle of brace length to be analyzed which located far enough from geometrical discontinuity (weld toes area) and will be validated with following equations.

For axial load condition:

$$\sigma_n = \frac{F}{A} \qquad (1)$$

For in-plane-bending moment load condition:

$$\sigma_n = \frac{32dM_i}{\pi[d^4-(d-2t)^4]} \qquad (2)$$

where,

σn : nominal stress for axial load or in-plane-bending moment (MPa)
Mi : in-plane-bending moment (Nm)
d : brace diameter (m)
t : brace wall thickness (m)
F : axial load (N)
A : area (m2)

The obtained nominal stress and hot-spot stress are used to calculate the stress concentration factor of the joints. Prior to analyze stresses of the KDT tubular joint, as a validation step the SCF from finite element analysis for the KT joint will be compared to Efthymiou SCF formula (Efthymiou, 1988) with the results as presented in Table 3.

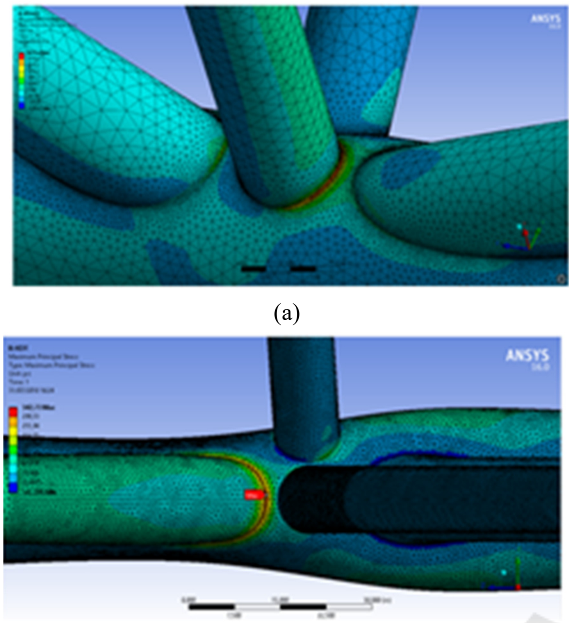
Table 3: Stress Concentration Factor Validation.

Model	FEM		Efthymiou		Error)%)	
	SCF$_c$	SCF$_b$	SCF$_c$	SCF$_b$	SCF$_c$	SCF$_b$
KT-Joint	3.47	2.39	3.44	2.33	0.87	2.58

Both errors of the comparison for the chord and brace stress concentration factor (SCFc and SCFb) are under 5% which are 0.87 and 2.58, respectively. Therefore, KT-joints model was good and can be accepted, then a horizontal brace 2 can be added to the KT-joint to become a KDT tubular joint for later analysis.

3.3 Stress Distribution along Weld Toes of the Tubular-KT and KDT Joints

In this research, the stress in chord side is considered to analyse stress distribution along the weld toes of the joint model. The maximum principal stress was used and the weld toes to be investigated are on joint between the brace with the chord which have the biggest stress among the other braces (see Fig. 7). As shown at Fig. 7, maximum stress due to in-plane-bending moment and balance axial loading occurs at Horizontal Brace 1 and at Diagonal Brace 1, respectively.



(a)

(b)

Figure 7: Location of the maximum stress occurs due to: (a) in-plane-bending moment; (b) balanced axial load.

Description of stresses along the weld toes of the brace-chord intersection line is based on the nomenclature depicted at Fig. 8. There are four main points namely Crown 1, Outer Saddle, Crown 2, and Inner Saddle where are located at 0o, 90o, 180o, and 270°, respectively. Stress distribution along the weld toes of the tubular-KT and KDT joint models are presented at Figs. 9 and 10 for two loading conditions which are balanced axial load and in-plane-bending moment, respectively.

Fig. 9 depicts a comparison of stress distribution along brace-to-chord intersection line between the tubular-KT and KDT joints occurred at diagonal brace 1 due to balance axial loading. Among all points observed, the stress significantly decreased at two points namely Crown 1 and Crown 2 for the KDT joint.

Meanwhile, Fig.10 shows a stress comparison for the two different tubular joints occurred at horizontal brace 1 under in-plane bending moment loading. For this mode of loading, the stress significantly decreased at Crown 1 and two other points at positions of 45O and 315O, respectively. Patterns of the stress distribution are very much different to that for axial loading case.

Generally after the uniplanar KT joint is added by one horizontal brace to the center of the chord to become a multi-planar tubular-KDT joint, stress along brace-to-chord intersection line mostly becomes smaller in all points reviewed (0o to 360o), especially at a point of Crown 1. This results occur for both two cases of loading conditions applied, balance axial load and in-plane bending moment.

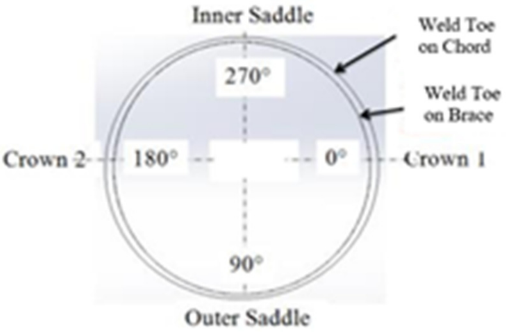


Figure 8: Nomenclature of the observed points along the brace-to-chord intersection line.

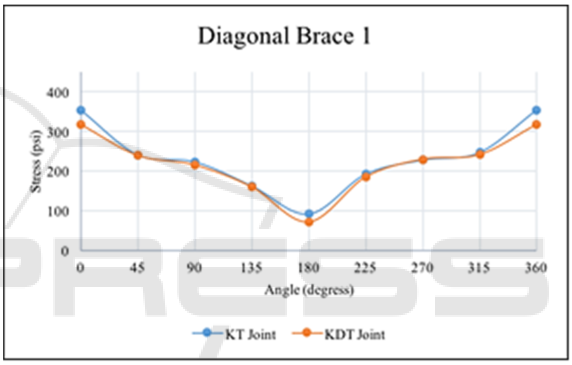


Figure 9: Stress distribution along the weld toes of the joint under balance axial load.

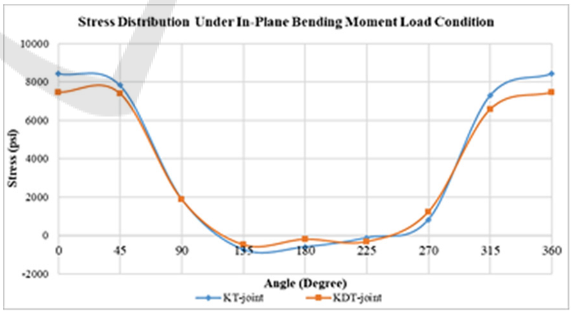


Figure 10: Stress distribution along the weld toes of the joint under in-plane-bending moment.

4 CONCLUSIONS

From the present study, the following conclusions can be drawn:

- The maximum stress along the weld toe of the KT and KDT tubular joints under balance axial load occurs in a member of Diagonal Brace 1 at the Crown 1 point (0o).

- For in-plane-bending moment case, the maximum stress along the weld toe of the KT and KDT tubular joints can be found also at the Crown 1 point (0o), but in critical member of Horizontal Brace 1.
- The multi-planarity caused the KDT-joint has smaller maximum principal stress than the KT-joint under both loading cases of balance axial load and in-plane bending moment. This is due to partly, the occurred stress redistributed onto the additional plane where the new brace laid. In turn, this condition will also make the value of SCF of the KDT-joint smaller than the SCF of the KT-joint.

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