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SCF Analysis of Tubular K-Joint under Compressive and Tensile Loads

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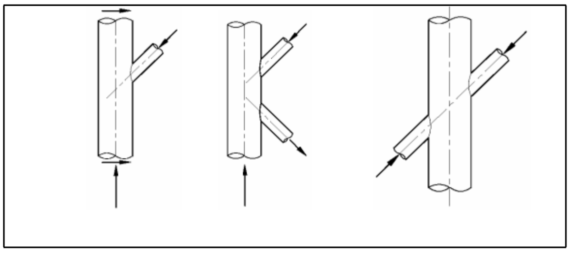
Abstract

Joint connections are widely used in the assembly of two or more structural elements. For a simple tubular K-joint, two main components are there, namely chord and bracing. Local stress in the tubular joint is extremely complex, including punching shear, shell bending, and membrane stress. It is the chord that transfers load from one brace member to another and, at the same time, sustains the severest localized shell bending stresses in the process. In this study, tubular gap K-joint under compressive and tensile loads were investigated. Case study C1 is for compressive loading acting on brace B of the model while Case study CT2 is for the compressive load on brace B and tensile load on brace A. Results shows that the highest value of Stress Concentration Factor (SCF) occurred when the brace-to-chord thickness ratio τ=0.6 and brace-to-chord diameter ratio, β=0.9 with a magnitude of 6.1295. This is an increment of about 24% for the same loading on
K-joint with τ=0.7.

Keywords — *tubular gap K-joint, structural modeling, SCF analysis, compressive and tensile loads.*

I. INTRODUCTION

There are numerous types of joints currently used in industry, and they have been classified according to the configuration and structural size. Mainly, there are three basic planar joint types, being Y-joint, K-joint, and X-joint, as shown in Figure 1 [2]



(a) (b) (c)

Fig. 1. Basic planar joint types: (a) Y-joint (b) K-joint (c) X-joint

K-joint consists of a chord and two braces on the same side of the chord. The axial brace forces' components normal to the chord balance each other, while the components parallel to the chord add and are reacted by an axial force in the chord [2].

The von-Mises stress due to various loading conditions used to determine the Stress Concentration Factor (SCF). The response of tubular K-joint models to external loading acting on different brace-to-chord diameter ratio (β) and brace-to-chord thickness ratio (τ) also will be analysed.

II. LOADING FORMULATION

Applied loads on tubular joints cause stresses at certain points along the intersection weld to be many times the nominal stress acting in the members. This multiplier applied to the nominal stress to reach the peak or maximum stress at the hot spot is called the stress concentration factor (SCF). The SCF is different from a joint geometry to another and is a measure of the joint strength, particularly its fatigue strength [3]. Recent review on SCF on tubular joints used in industry may be found in ref. [5].

The SCF is used to define the effective stress on one point of a structure [6]. When a structural member contains a discontinuity, such as a holes or sudden change in cross section, high localized stresses may also occur near the discontinuity. Such discontinuities are called stress raisers and the regions in which they occur are called areas of stress concentration.

SCF is related to actual maximum stress at the discontinuity to the nominal stress. The factor is defined by the equation below:

$$SCF = \frac{\sigma_{max}}{\sigma_0} \qquad \text{- Equation (1)}$$

where σ_{max} is maximum stress and σ_o is nominal stress.

Two sets of boundary conditions had been used in the analytical study where the chord was simply supported at the end for axial or in- plane moment loads and fixed end condition for out-of-plane moment loading. Equations (2) and (3) are examples for SCF semi-empirical approximations for a K-joint under axial loading given as follows [7];

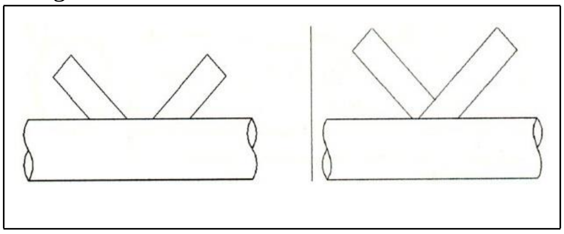
$$SCF_{K\,Chord} = 1.506\beta^{-0.059}\gamma^{0.666}\tau^{1.104}\xi^{0.067}sin^{1.521}\theta$$
- Eq. (2)

$$SCF_{K\,Brace} = 0.92\beta^{-0.441}\gamma^{0.157}\tau^{0.560}\xi^{0.058}e^{1.448\sin\theta}$$
- Eq. (3)

The thickness-to-diameter ratio of the chord (T/D) will influence the radial flexibility of the chord. The brace-to-chord diameter ratio (β) was a governing factor in the stress distribution due to how the load transfer is accomplished. The brace-to-chord thickness ratio (τ) indicates the relative bending stiffness of the brace and chord and, therefore, primarily governs the bending stress in the brace at the intersection. The load transfer mechanism necessitates the inclusion of the angle of inclination of the brace to chord (θ). These four parameters discussed above are applicable to determine SCF for joints referred to in Fig. 1 [7].

III. MODELING OF K-JOINT

There are two types of tubular K-joints usually designed for offshore structures, namely tubular gap K-joint and overlapping K-joint, as illustrated in Fig. 2.



(a) Gap K-joint (b) Overlapped K-joint

Fig. 2: Two types of tubular K-joint

Basic parameters for the model of a K-joint used in this study are given in Table 1.

Table 1: Basic parameters for the Tubular K-joint model.

Fix Parameters	Value
The diameter of the chord, D	0.100 m
The thickness of chord, T	0.002 m
Length of a chord, L	0.600 m
Length of brace, l	0.180 m
Gap distance, g	0.020 m
The angle of inclination of the brace to chord, $\theta A = \theta B$	45°
Chord diameter-to-2 times thickness ratio, $\gamma = D/2T$	25
Chord 2 times length-to-diameter ratio, $\alpha = 2L/D$	12
Gap-to-chord diameter ratio, $\xi = g/D$	0.2
Modulus Young, E	210 GPa
Poisson's ratio, ν	0.3

In this study, the K-joint was modeled using a finite element tool and prepare for analysis. Both ends of the chord set with fixed constraints, as shown in Fig. 3. The loadings model then included as illustrated in the Figure to obtain the Von-Mises Stress on the related hot-spot area.

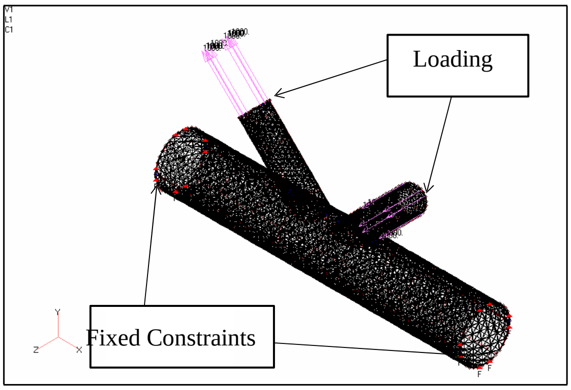


Fig. 3: Tubular K- joint model

K-joint consists of a chord and two braces on the same side of the chord. In load case CT2, the brace forces' components normal to the chord balance each other, while the components parallel to the chord add and are reacted by an axial force in the chord.

IV. RESULTS AND DISCUSSION

According to a scheduled study, external loading was applied on the tubular K-joint model in axial and shear direction to determine the maximum SCF.

In the analysis, brace B was chosen as a reference brace to determine the SCF and the hot-spot locations. Therefore, the nominal stress is only considered to the loading applied on brace B's end surface. The locations of saddle and crown on braces A and B are shown in Fig. 4.

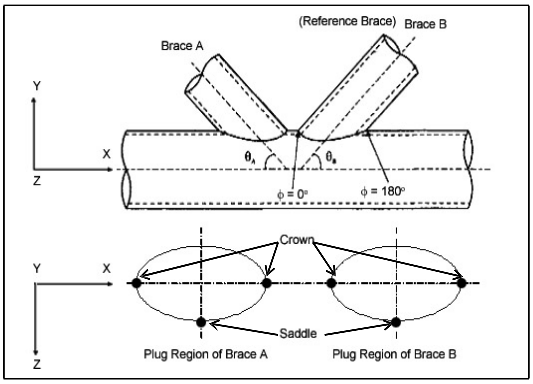


Fig.4: Locations of saddle and crown on Brace A and B

Presentation of solid von Mises stress under axial loading cases on K-joint model are shown in Fig. 5 and Fig. 6. The contour for each model is almost similar while acting with the same types of loading. The hot-spot stress is still maintained at the same location as long as the same type of loading is acting on the FE model. However, the stress value on that critical area is different for various brace diameter and thickness. In Fig. 5 and Fig. 6, critical stress areas usually occurred at either the saddle or crown position. The critical area of load case C1 is located at the saddle point ($\phi = 90^o$) of brace B. Whereas, in load case CT2 the critical area at the crown point ($\phi = 0^o$) of brace B.

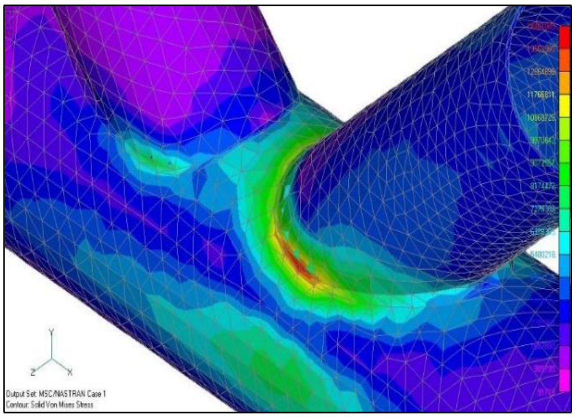


Fig.5: K-Joint (β = 0.7; τ = 0.7) under compression loading on brace B, load case C1

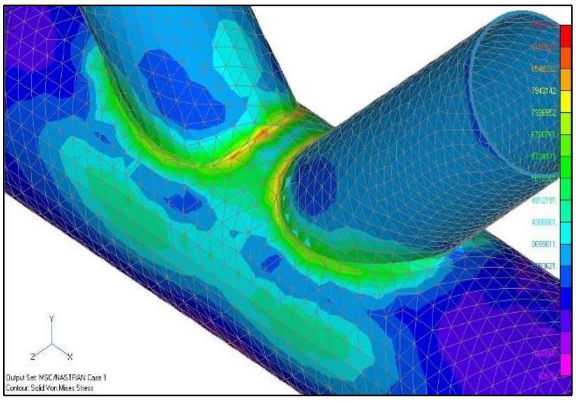


Fig. 6: K-Joint (β = 0.7; τ = 0.7) under compressive loading on brace B and tensile loading on brace A, load case CT2

The response of tubular K-joint models in terms of SCF for certain loading cases was applied on a joint model with geometric parameters given in Table 1. Effect of brace-to-chord diameter ratio (β) on SCF and effect of brace-to-chord thickness ratio (τ) on SCF are analyzed.

Table 2 results from the analysis where the τ value of 0.7 and β the value of 0.7 were adopted, the same values of nominal stress were used where compression loading is acting on brace B. In Table 2, the highest stress factor occurred when the model is acting with compression loading on brace B (load case C1) with an SCF value is 4.363234. This is due to compression loading producing punching shear stress onto the chord surface.

Tables 3 and 4 shows the results of SCF value for β = 0.5, 0.6 and 0.7 under load cases C1, CT2 respectively.

Table 2. Von-Mises Stress, Nominal Stress and SCF for C1 and CT2 load cases

Load Case	Von-Mises Stress, σ_{VM} (MPa)	Nominal stress, σ_0 (MPa)	SCF	Critical Location
C1	14.4611	3.3143	4.363234	Saddle
CT2	7.4563	3.3143	2.249726	Crown

Table 3. SCF value for β = 0.5, 0.6 and 0.7 under load case C1

Brace-to-Chord Dia. Ratio, $\beta=d/D$	0.5	0.6	0.7	Incr. (%)
SCF (τ = 0.7)	4.773671	4.948785	4.363234	9.50
SCF (τ = 0.8)	5.436374	5.563949	4.909145	10.74
SCF (τ = 0.9)	6.064542	6.129503	5.389031	12.53
Increment (%)	27.04	23.80	23.50	

Table 4. SCF value for β = 0.5, 0.6 and 0.7 under load case CT2

Brace-to-Chord Dia. Ratio, $\beta=d/D$	0.5	0.6	0.7	Incr. (%)
SCF (τ = 0.7)	3.094673	2.621575	2.249726	37.56
SCF (τ = 0.8)	3.412844	2.967015	2.537608	34.49
SCF (τ = 0.9)	3.814864	3.274736	2.832414	34.70
Increment (%)	23.27	24.91	25.97	

Fig. 7 and Fig. 8 shows graphs of SFC versus β for related type of loading cases. Figure 7 shows the line τ = 0.7, τ = 0.8 and τ = 0.9 have positive slope from β = 0.5 to β = 0.6 but after that change to negative slope from β = 0.6 to β = 0.7. The SCF value trend increases with increasing values of brace-to-chord diameter ratio (β) until β = 0.6. The SCF value decreases, although the value of brace-to-chord diameter ratio (□) is increasing. This condition occurs due to the eccentricity problem within the model.

Maintaining the gap distance between two braces at 0.02 m and chord diameter at 0.1 m for each FE model, the eccentricity of the joint will be zero when β = 0.5657. Therefore, the slope is positive when β it is less than 0.5657. On the other hand, when β more than 0.5657, the graph shows a negative slope, as shown in Fig. 7. The SCF value increases with an increment in τ value for load case C1.

Fig. 8 shows the line τ = 0.7, τ = 0.8 and τ = 0.9 have negative slope from β = 0.5 to β = 0.7. The SCF value continues to decrease with increment in β ratio. These show that SCF values are not influenced by the eccentricity problem for τ = 0.7, τ= 0.8, and τ = 0.9 when the model is under compressive loading on brace B and tension loading on brace A simultaneously. The SCF value also increases with the increment in τ value for load case CT2.

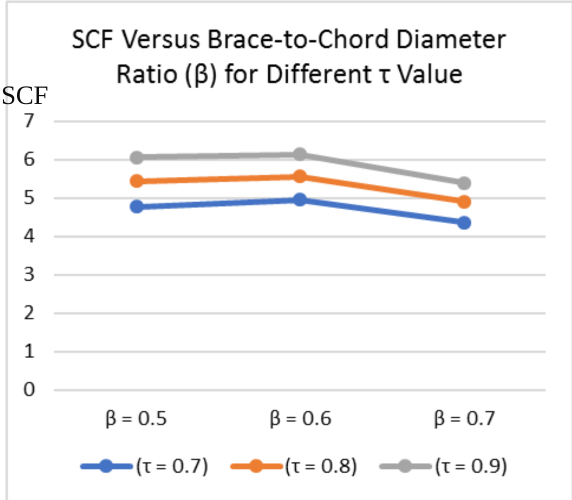


Fig. 7. SCF versus β for different τ value, load case C1

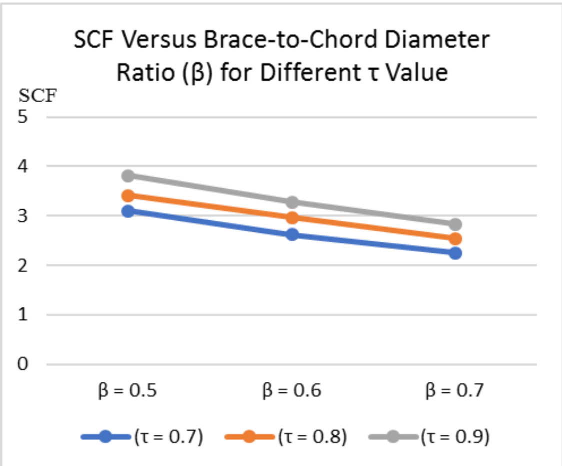


Fig. 8: SCF versus β for different τ value, load case CT2

Analysis of SCF on tubular K-joint modeling and the influence of different geometric parameters on SCF were discussed.

V. CONCLUSIONS

In this study of gapped K-joint, the load case C1 confined to compressive load only on brace B and load case CT2 confined to compressive load on brace B and tensile load on brace A. Main conclusions of the study can be summarized as follows;

1. The selected range □ is between 0.5 to 0.7, and the range used τ is between 0.7 and 0.9.
2. Results show that SCF is more sensitive to the variation in t value for case C1, where the only compressive load was applied on brace B. The variation of 27.04% occurred when τ it varies between 0.7 to 0.9 for β=0.5.
3. For load case CT2, where compressive load acts on brace B and tensile load acts on brace A, the SCF is more sensitive to the variation in β value. The variation of 37.56% occurred when β it varies between 0.7 to 0.9 for τ=0.7.
4. Maximum Von-Mises Stress, σ_{vM} is 14.4611 MPa and located at the saddle position in load case C1.
5. Maximum SCF is 6.129503 and located at the saddle position (β = 0.6; τ = 0.9) under case study C1.

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