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Tubular K-Joint under Out-of-plane Bending

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Abstract

Joints on a typical structural assembly would experience localized stresses. The area that gives rise to these types of stresses called areas of stress concentration. This paper investigates the effect of out-of-plane bending on stress distribution on the K-joint. Finite element model for a gapped K-joint was created followed with out-of-plane load application and joint response analysis thus obtaining stress distribution as presented. The value of stress was increase in the vicinity of the joint due to its discontinuity. This condition give rise to the hot-spot stress within the structure. In this study the effect of out-of-plane loading on variation of Stress Concentration Factor (SCF) for different brace-to-chord diameter ratio, β, and brace-to-chord thickness ratio, τ, for a simple tubular gapped K-joint were investigated. Load case OPB1 is for out-of-plane bending load acting on brace B of the model while load-case OPB2 is for out-of-plane bending load acting simultaneously on braces B and A. Results shows that the highest value of SCF occurred when the brace-to-chord thickness ratio τ=0.9 and brace-to-chord diameter ratio, β=0.6 with a magnitude of 4.5468. This is an increment of 78.24% for the same loading parameter on K- joint with τ= 0.7. Maximum von-Mises stress experienced by the joint is 86.2318 MPa located at the saddle of the joint under load case OPB1.

Keywords - Tubular K-joint, chord-brace diameter ratio, out-of-plane bending, structural modelling, SCF analysis

I. INTRODUCTION

A tubular connection is a localized portion of the structure where the interaction between chord and brace takes place. This physical interface created by two or more intersecting members and surfaces that produced a strong and important part of the structure. There are several types of joint that may be found on a typical offshore structure where the gapped tubular K-joint is one of the most commonly considered in structural design. This selection usually due to its lighter weight and excellent strength ratio. Stress concentration factor in tubular joints were investigated rigorously by earlier researchers [1, 2]. In this study, the resulting SCF were determined based on magnitude of von-Mises stress and related nominal stress. The main focus of this study is to investigate the response of the joint to the application of out-plane bending loads on the brace. This study is a continuation to the previous works on the response tubular K-joint due to in-plane bending loads as well as the joint under compressive and tensile loads [3, 4]. Analysis has been done on the effects of external loads on brace-to-chord diameter ratio as well as brace-to-chord thickness ratio. The SCF for particular loading conditions were determined based on the resulting value of von-Mises stress.

II. LOADING CONSIDERATION

When the structure under external loading acting on its member, this load will be supported by that particular member under action as well as transferred to the adjacent members. This load distribution is a usual transferred load and very important to the general safety of whole structure. Higher stresses developed at welded intersection of structural members must be carefully addressed at the earlier design stages [3]. Stresses within the joint may linearly increases until the reaching of yield stress beyond which the joints are considered as fall into failed category.

The SCF for the K-joint were calculated based on the maximum stress over nominal stress at the location. The SCF is different from one joint geometry to another and is a measure of the joint strength, particularly its fatigue strength [5]. Recent review on SCF on tubular joints used in industry may be referred as in [6].

In this study, the out-of-plane bending loads are illustrated in Fig. 1 shows the source of bending load applied at the end of braces that would induce stresses at the joint. In load case OPB1, clockwise out-of-plane bending load acts on brace B while in load case OPB2, two bending loads acting on the braces, clockwise out-of-plane bending loads acts on brace B and counter-clockwise out-of-plane bending acts on brace A. Orientation of braces A and B may be referred to in Fig. 2.

Two sets of boundary conditions had been used in the analytical study where the chord was simply supported at the end for out-of-plane moment loads. 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 the manner in which the load transfer is accomplished. The brace-to-chord thickness ratio (τ) is an indication of the relative bending stiffness of the brace and chord and therefore, primarily governs the bending stress in the brace at the intersection. The inclusion of the angle of inclination of the brace to chord (θ) is necessitated by the mechanism of the load transfer. These four parameters discussed above are applicable to each of the three joint types in SCF determination [2]. SCF is a relationship of actual maximum stress at the discontinuity to the nominal stress.

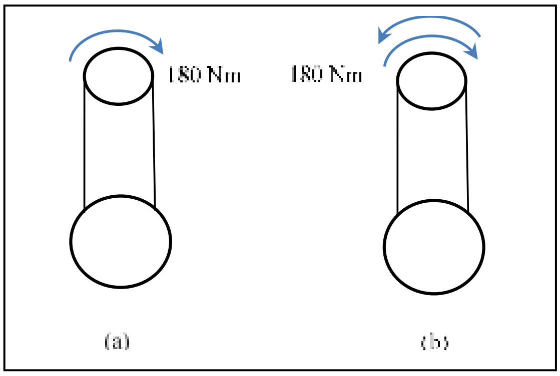


Fig. 1: Out-of-plane bending loading: (a) load case OPB1, (b) load case OPB2

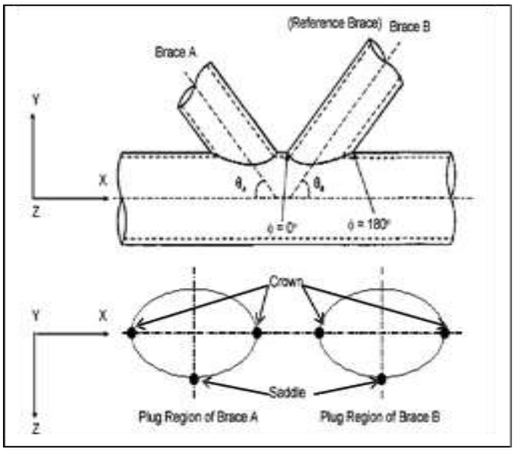


Fig. 2: Saddles and crowns on braces A and B [7]

Parametric equations suggested for the SCFs on the chord and the brace side derived from joint with $\alpha = 12$ under balanced axial loading are given as follows [7];

$$SCF_{Chord} = \gamma^{0.91}(0.22 - \beta^2 + 1.92\beta)\sin^{2.51}\theta$$
$$\times \left[\beta_{max}\left(\frac{-0.81}{\beta_{min}^3} + \frac{5.67}{\beta_{min}^2} - \frac{8.09}{\beta_{min}} + \frac{4.08}{\beta_{max}}\right)\right]$$
$$\times \tau^{1.26}[0.13 + 0.12\beta^{-0.41}\arctan(\zeta)]$$
$$+\{\beta^{0.27}\gamma^{0.32}(-12.42\tau - 0.02)$$
$$\times [-0.1(\theta_{max} + \theta_{min})^{0.59\beta}]f(\alpha)\}$$

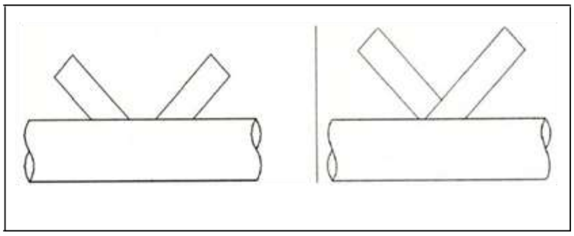
$$SCF_{Brace} = 0.26\tau(-0.18 - \beta^2 + 2.23\beta)\sin^{3.12}\theta$$
$$\times \left[\beta_{max}\left(\frac{-0.17}{\beta_{min}^3} + \frac{1.76}{\beta_{min}^2} - \frac{3.19}{\beta_{min}} + \frac{2.27}{\beta_{max}}\right)\right]$$
$$\times [0.33 + 0.26\beta^{-0.90}\arctan(\zeta)]$$
$$+\{(2 + 0.58^{\theta\tau})\tau^{0.01}\gamma^{0.88}$$
$$+2.31\,(\theta_{max} + \theta_{min})^{-0.03\beta}\ \}$$

with;

$$f(\alpha) = 1 + [0.06\beta\alpha\tau^{50.62}\exp(-14.55\gamma^{0.83}\alpha^{0.35})] \quad \text{for } \alpha > 12$$
$$f(\alpha) = 1.0 \quad \text{for } \alpha \le 12$$

III. MODELLING OF K-JOINT

Fig. 3 shows typical types of tubular K-joints which comprises chord and two braces welded at certain angle of interaction with the chord. The arrangement of the brace either gap or overlap has a certain bearing on the performance of the joint. Generally, lapped tubular joint is known to be stronger than the gapped joint. However, for the ease of construction and fabrication it is not always possible to have a braced joint throughout the structure.



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

Fig. 3: Types of tubular K-joint.

In Table 1, basic parameters used to model the gapped tubular K-joint used in this study is presented. Mechanical properties of the material of the tubular as well as related loading magnitude were also given.

TABLE 1: Parameters for tubular K-joint model [1].

Parameters	**Value**
Chord Diameter, *D*	0.100 m
Chord Thickness, *T*	0.002 m
Chord Length, *L*	0.600 m
Brace Length, *l*	0.180 m
Gap distance, *g*	0.020 m
Inclination Angle of brace to chord, θ*A* = θ*B*	45°
Chord diameter-to-2 times thickness ratio, γ = *D/2T*	25
Chord 2 times length-to-diameter ratio, α = 2*L/D*	12
Gap-to-chord diameter ratio, ξ = *g/D*	0.2
Young's Modulus, *E*	210 GPa
Poisson's ratio, ν	0.3

The gapped K-joint was modeled using a finite-element software. Then the out-of-plane loads were applied on braces A and B as illustrated in Fig. 1 and Fig. 2 to obtain the distribution of von-Mises stress at the joint.

IV. RESULTS AND DISCUSSION

Responses of tubular gap K-joint due to out-of-plane bending loads were investigated and the results are presented in form of SCF contours at the joint. The load case and joint parameters are presented in Table 1. Two load cases were adopted in this study where the out-of-plane loads applied on braces A and B as illustrated in Fig. 1 and Fig. 2. These loads will cause in deflection and deformation and results in the increase of stresses at the joint between the chord and braces. Two main locations of stress hot spot are the crowns and the saddles as shown in Fig. 2. The magnitude of SCF at these locations may easily be estimated.

Von-Mises stress distribution for a gap K-joint under out-of-plane bending loads are shown in Fig. 4 and Fig. 5. Fig. 4 is showing the stress contour at the joint between brace B and the chord due to out-of-plane bending load acting on brace B (load case OPB1). Fig. 5 shows the stress response contour due to load case OPB2 where two out-of-plane bending loads acting on brace A and brace B. As anticipated, the result shows that higher stresses occur at the vicinity to the welded joint between the chord and braces. In load case OPB1 the raised stress magnitude can be observed appeared near the joint of brace B and the chord and it is in agreement that the out-of-plane load only act on brace B. 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 magnitude on that critical area is totally of different level for various brace diameter and thickness in used. In Fig. 4 and Fig. 5, critical stress occurred at saddle positions due to the direction of loads. The critical area of load case OPB1 is located at the saddle point (ϕ = 90^{O}) of brace B. Whereas, in load case OPB2 the critical area occurred at the saddle point (ϕ = 90^{O}) both braces A and B.

Table 2 shows the result for SCF analysis on the joint where the parametric values are τ is 0.7 and β is 0.7. These values were adopted in both load cases to determine nominal stress and von-Mises stress at the joint. Result shows that highest SCF value is 2.6598 occurred due to out-of-plane bending on brace B in load case OPB1. The stress was induced on the chord surface at the saddle point 90º refer to the longitudinal axis. Tables 3 and 4 shows the results of SCF value for β = 0.5, 0.6 and 0.7 under load cases OPB1 and OPB2 respectively.

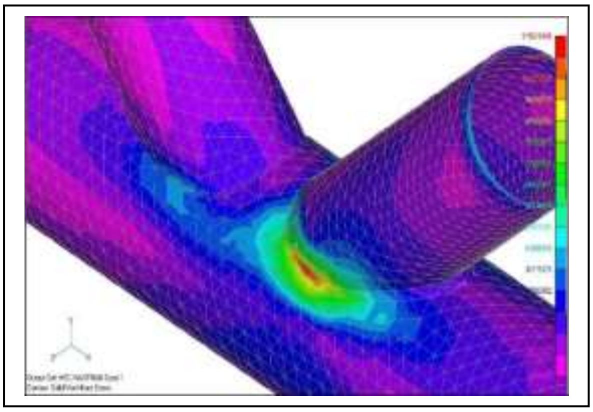


Fig. 4. K-joint (β=0.7, τ=0.7) – load case OPB1.

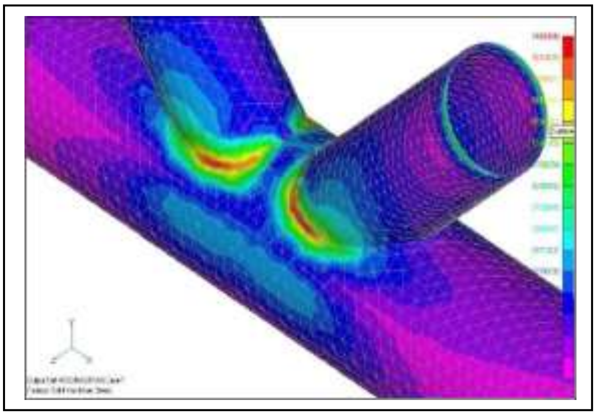


Fig. 5. K-joint (β=0.7, τ=0.7) – load case OPB2.

TABLE 2. Von-Mises stress, nominal stress and SCF for OPB1 and OPB2 load cases.

Types of Loading	Von Mises Stress, σ_{vM} (MPa)	Nominal Stress, σ_0 (MPa)	SCF	Critical Location
OPB1	86.2318	32.4204	2.6598	Saddle
OPB2	58.1571	32.4204	1.7938	Saddle

TABLE 3. SCF value for β = 0.5, 0.6, 0.7 under load case OPB1.

Brace-to-Chord Dia. Ratio, β=*d/D*	0.5	0.6	0.7	Incr. (%)
SCF (τ = 0.7)	2.504174	2.550917	2.659800	6.215
SCF (τ = 0.8)	3.850847	3.975424	3.631482	5.697
SCF (τ = 0.9)	4.187970	4.546789	3.892411	8.568
Increment (%)	67.240	78.241	46.342	

TABLE 4. SCF value for β = 0.5, 0.6, 0.7 under load case OPB2.

Brace-to-Chord Dia. Ratio, β=*d/D*	0.5	0.6	0.7	Incr. (%)
SCF (τ = 0.7)	1.688985	2.316172	1.793843	37.133
SCF (τ = 0.8)	2.698268	2.571639	2.445499	9.367
SCF (τ = 0.9)	2.973960	2.966176	2.660711	10.533
Increment (%)	76.080	28.064	48.325	

The results also show that for out-of-plane bending load cases the stress responses are more sensitive to variation in τ values. In OPB1 load case, the variation of 78.24% occurred when τ varies between 0.7 to 0.9 for β=0.6. For load case OPB2, where out-of-plane bending load acts on both braces, the SCF is more sensitive to the variation in τ value at β = 0.5. The increment of 76.08% occurred for the variation of τ between 0.7 and 0.9. Maximum von-Mises stress, σ_{vM} is found to be 86.2318 MPa and located at the crown position in load case OPB1. Variation in brace-to-chord diameter ratio, β, has a lesser influence on SCF as shown both in Table 3 and Table 4. In load case OPB1 variation in SCF of 8.568% appear for variation in brace-to-chord diameter ratio, β, from 0.5 to 0.7. Highest percentage variation in SCF due to variation in β is found to be 37.133 % as shown in Table 4.

Fig. 6 and Fig. 7 shows graphs of the relationship between SCF and brace-to-chord diameter ratio (β) values for a K-joint under out-of-plane bending loads. Stress response due to load case OPB1 is presented in Figure 6 and stress response due to load case OPB2 is presented in Fig. 7.

In load case OPB1, the results gave highest value of SCF related to τ value of 0.9 and β value of 0.6 located at the saddle of brace B. Generally, the results are more sensitive to the variation in τ-value. The trend of the response is that SCF is also increase with the increment in β values from β = 0.5 through β = 0.6. This indicates that bigger brace diameter will induce higher stress at the joint with the chord. The result also shows that SCF values does influenced by eccentricity problem for τ = 0.7, τ = 0.8 and τ = 0.9 when the model is under out-of-plane loading on brace B in load case OPB1 and loading on both braces A and B in load case OPB2.

In Fig.7, the graph shows the non-linear behavior between the SCF and the brace-to-chord ratio, β under out-of-plane loading condition in load case OPB2 where both braces were loaded. The line τ = 0.7 has a positive slope from β = 0.5 to β = 0.6 and then follows with a negative trend to β = 0.7. Under the same load case, graphs for τ = 0.8 and τ = 0.9 have negative slope from β = 0.5 to β = 0.7. This condition occurs due to eccentricity within the model. The effect of eccentricity does affect the smaller ratio of τ-values and higher ratio of β-value. Both of these conditions were observed and presented in Fig. 6 and Fig. 7.

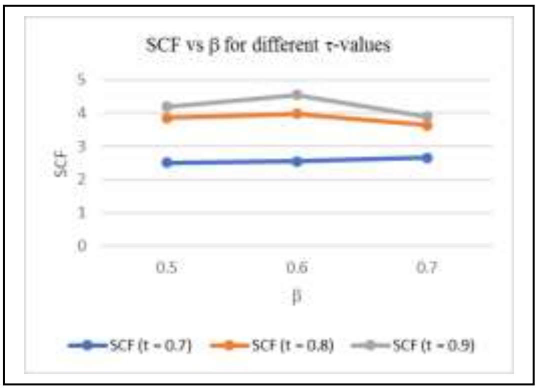


Fig. 6. SCF versus β for different τ values -load case OPB1.

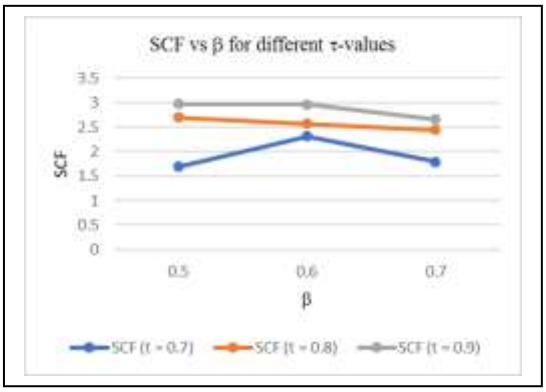


Fig. 7. SCF versus β for different τ values -load case OPB2

V. CONCLUSIONS

The outcome of the study for a tubular gap K-joint under out-plane loading cases were discussed. The value of brace-to-chord thickness ratio, τ, is found to have more influence of the variation of stress concentration factor within the joint under out-of-plane bending. In this study, nominal stress at the joint under both load cases (OPB1 and OPB2) is 32.4204 MPa. In OPB1 load case, the variation of 78.24% occurred when τ varies between 0.7 to 0.9 for β=0.6. For load case OPB2, where out-of-plane bending load acts on both braces, the SCF is also sensitive to the variation in τ value at smaller β ratio where the variation of 76.08% occurred when τ varies between 0.7 to 0.9 for β=0.5. Maximum von-Mises stress, σ_{vM} is 86.2318 MPa located at the saddle position in load case OPB1. Maximum SCF is 2.6598 and located at the saddle position.

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