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In-Plane Bending and SCF of Tubular Y-Joint

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Abstract

The Y-joint is formed by welded together the brace and chord element at an acute angle. The main feature of this joint is that the brace's external diameter is less than the external diameter of the chord. In this paper, the effects of in-plane bending load acting on the joint were investigated. The results are presented in stress concentration factor (SCF) distribution induced around the joint between chord and brace. There are two in-plane loads considered in this study, namely closing and opening in-plane bending loads. The analysis found that the maximum SCF of 3.002 occurred in the area of crown position (ϕ = 0^o) of the chord under the closing mode of in-plane bending. Thus, the discussion in this paper focused on closing the in-plane load on the joint. The finding also indicates that the chord experienced higher SCF as compared to the brace. The results were compared with previous studies, and it shows a similar trend of SCF distribution around the Y-joint.

Keywords — *Y-joint, joint modeling, in-plane bending, stress analysis, SCF.*

I. INTRODUCTION

There are many types of structures designed and installed for specific uses and functions. The basic requirement in that design is that the structure must withstand the design load it might encounter throughout its service life. External loading acting on the structure would induce maximum stress on some segments of the structure.

As shown in Fig. 1, several joint types are used to form a whole structure on a typical structure. Among others, they are Y-joint, K-joint, T-joint as well as K-T-joint. In this paper, the investigation was focused on the Y-joint to study the effects of in-plane bending acting on the joint. Y-joint is one of the widely used members in the construction of the steel structure. This joint may be exposed to all kinds of loadings such as wind, wave, gravity, live, dead loads, etc., depending on where the structure was installed. Therefore, the structural engineer must consider extreme loading or maximum loading conditions when designing this joint as part of the structure.

A large number of investigations have been undertaken on the analysis and design of structural tubular joints [1], [2], [3], [4]. Information related to stress distribution, stress concentration, and fatigue strength of a wide range of joint types under various loading conditions were also widely published. A comparison between standard parametric equations and experimental results was compared for T/Y joints [4].

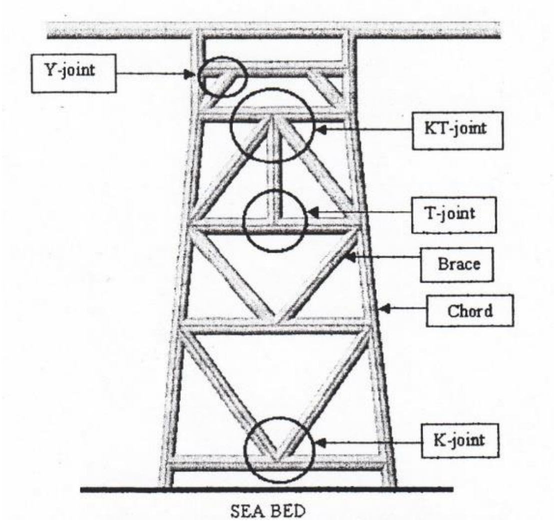

Fig.1. Typical joints on a steel structure.

II. JOINT DESCRIPTION AND PARAMETRIC CONSIDERATION

The Y-joint was modeled using NASTRAN software and was used to simulate loading and response due to an in-plane bending load as details in the following sections. The geometric notation and non-dimensional parameters describing Y-joints are given in Fig. 2. The basic dimension which describes a simple joint is: (1) Chord outside diameter, D, (2) Brace outside diameter, d, (3) Chord wall thickness, T, (4) Brace wall thickness, t, (5) Chord length, (distance between end restraints or points of contra flexure of the chord), L and (6) Length between the brace centreline-chord centreline intersection and the brace centreline-chord surface intersection, WPO.

To facilitate the assessment of simple Y-joint, the above parameters were kept dimensionless. The following non-dimensional geometric parameters are used for the design and assessment of the joint. They are; $\alpha = 2L/D$, $\beta = d/D$, $\gamma = D/2T$ and $\tau = t/T$. Fig. 3 shows a Y-joint under in-plane bending loading in closing mode. The reference angle is $\phi = 0^o$ at the inner side of an acute angle of brace-chord inclination and $\phi = 180^o$ for the outer open inclination side, as shown in Fig. 3. In-plane loading directions are illustrated in Fig. 4 is for opening mode.

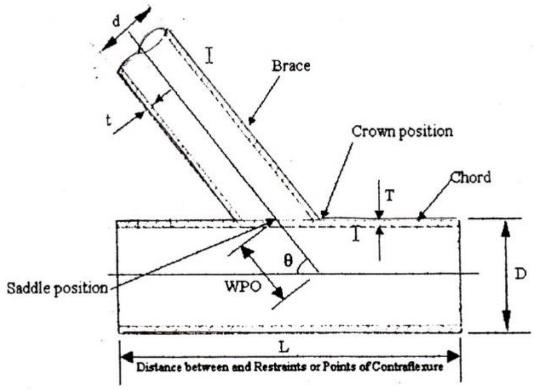

Fig. 2. Y-joint description

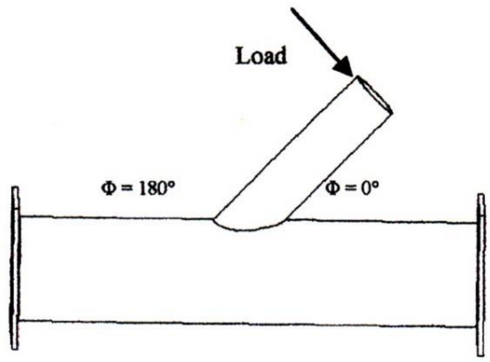

Fig. 3: In-plane bending on Y-joint (closing mode)

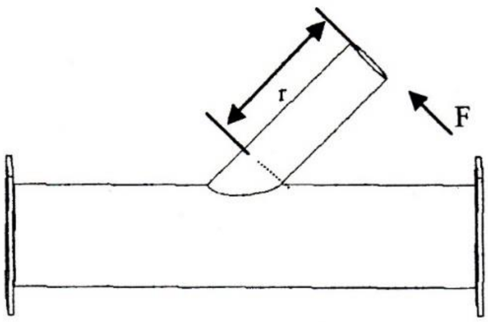

Fig. 4. In-plane bending on Y-joint (opening mode)

Finite element modeling and analysis of the tubular Y-joint were performed to obtain the stress concentration and stress distribution around the joint intersection. Results from numerical simulation were compared with results obtained from previous studies.

Geometrical parameters adopted in this study are;

Chord diameter, D = 1.00 m
Brace diameter, d = 0.66 m
Chord thickness, T = 0.0216 m
Brace thickness, t = 0.0197 m
Chord length, L = 3.6 m
Brace length, l = 2.46 m

III. STRESS FORMULATION

Stress formulation for analysis of Y-joint under in-plane bending loads was adopted from Kuang's [1], Connolly's [2], and Hellier [3] stress equations as presented in this section. Several other equations also being proposed in international standards [5], [6].

The ranges of applicability of the formulae for SCF on chord and brace of the Y-joint according to Kuang are;

$$0.3 \le \beta \le 0.8$$
$$8.3 \le \gamma \le 33.3$$
$$0.2 \le \tau \le 0.8$$
$$30^o \le \theta \le 90^o$$

Kuang's parametric equations for stress concentration factor as a function of joint geometry fitted on both chord and brace sides of the intersection. Combining these two sets of equations, the stress distribution for a Y-joint was predicted from its geometric parameters and loading mode. The following equations denote the stress concentration factor as a joint geometry function for chord and brace [1].

$$SCF_{Chord} = 1.02\beta^{-0.04}\gamma^{0.60}\tau^{0.86}sin^{0.57}\theta$$

$$SCF_{Brace} = 1.301\beta^{-0.38}\gamma^{0.23}\tau^{0.38}sin^{0.21}\theta$$

Connolly [2] has conducted a systematic study of stresses in tubular Y-and T-joints for thin-shell finite element analyses. The analysis covers a wide range of joint geometries under axial loading, in-plane bending, and out-of-plane bending. For each mode of loading, and for both chord and brace sides, this study's results were used in deriving characteristic formulae for the stress distributions around the intersection [2]. The SCF values presented are obtained at the intersection line of the mid-surface between the brace and chord. For all in-plane moment loading cases, the chord end conditions were taken as supported.

The limit of applicability of Connolly's UCL equations are as follows;

$$6.21 \le \alpha$$
$$0.2 \le \beta \le 0.8$$
$$7.6 \le \gamma \le 32.0$$
$$0.2 \le \tau \le 1.0$$
$$35^o \le \theta \le 90^o$$

Chord: for $\phi = 0^o$

$$SCF_C^0 = 2.84\alpha^{-0.0055}\gamma^{0.234}\tau^{(1.21-0.171\theta)} \times exp\left[\left(\frac{0.0021\gamma - 0.0373}{\beta^2}\right) - \left(\frac{0.0179}{sin\theta}\right)\right]$$

Chord: for $\phi = 180^o$

$$SCF_C^{180} = -3.845\alpha^{-0.029}\gamma^{0.407}\tau^{(0.966-0.719\theta)} \times exp\left[\left(\frac{0.00166\gamma - 0.0399}{\beta^2}\right) - \left(\frac{-0.682}{sin\theta}\right)\right]$$

Brace: for $\phi = 0^o$

$$SCF_C^0 = 1.89\alpha^{-0.065}\beta^{0.298}\gamma^{-0.214/\theta^2}\tau^{0.186}$$
$$\times exp\left[\left(\frac{-5.88}{\gamma}\right) - \left(\frac{1.81}{sin\theta}\right) - 0.0534\beta^3\gamma - \left(\frac{0.0848\beta}{\tau}\right)\right]$$

Brace: for $\phi = 180^o$

$$SCF_C^{180} = -7.02\alpha^{-0.045}\beta^{0.141/\theta^2}\gamma^{0.167/\theta^2}\tau^{0.143}$$
$$\times exp\left[\left(\frac{-0.015}{\beta^2}\right) - \left(\frac{164.4}{\gamma^3}\right) - \left(\frac{0.0534}{sin^2\theta}\right) - 0.0254\beta^2\tau\right]$$

The results were found to give good agreement in most cases, and the formulae were also conservative. In Connolly's load cases, the hot-spot SCF equations were generally overestimating the measured SCFs from steel model tests. Thus, it is said that the equations are the most reliable in predicting a conservative value of SCF, which could be used in design [2].

IV. RESULTS AND DISCUSSION

Table 1 shows the distribution of SCF along the chord-brace joint referring to the crown position with $\phi = 0^o$ at the inner inclined angle between brace and chord, as previously defined. The relationship in Table 1 was plotted and shown in Fig. 5.

TABLE 1: SCF distribution along the welded joint under in-plane bending.

Location ϕ (deg)	SCF value	
	Chord	Brace
0	3.002	1.553
10	2.995	1.907
20	2.940	2.251
30	2.811	2.338
40	2.900	2.350
50	2.817	2.243
60	2.769	2.211
70	2.481	2.085
80	1.955	1.360
90	1.504	1.428
100	0.655	0.834
110	0.202	0.353
120	- 0.120	- 0.066
130	- 0.685	- 0.457
140	- 0.854	- 0.612
150	- 1.156	- 0.781
160	- 1.403	- 0.955
170	- 1.522	- 1.053
180	- 1.607	- 1.108

The in-plane loading results give rise to the higher SCF at chord members compared to SCF on the brace. The maximum hot-spot stress value location is at the crown of the joint at angle $\phi = 0^o$. It is as expected the location is where tension (at $\phi = 0^o$) and compression (at $\phi = 180^o$) of elements occurred when closing bending load acts on the brace junction.

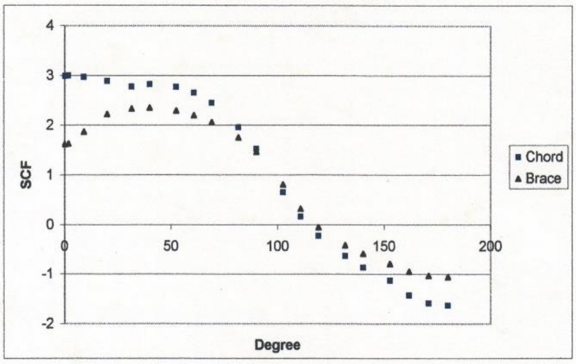

Fig. 5. SCF distribution under in-plane bending

The stress contour diagram for the equivalent stress or Von Mises stress shown in Fig. 6 investigates the Y-joint stress distribution. The diagram shows that the maximum equivalent stresses experienced by elements on crown points of the joint. Under closing in-plane load, it was found that the maximum compressive stress occurred at the point of $\phi = 0^o$ while maximum tensile stress at $\phi = 180^o$, respectively. The maximum stress induced on the element at the crown of the joint under compressive in-plane bending load.

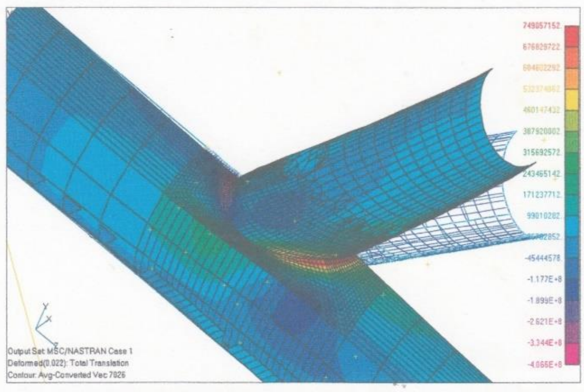

Fig. 6. Stress distribution under in-plane bending

Maximum SCF magnitudes occurred along with the crown point under compressive and tensile loads indicates that the maximum strain also occurred at those locations. Concerning this SCF distribution, elements at the joint intersection were experienced maximum deformation and hence stress level, as shown in Fig. 6. The maximum magnitude of SCF = 3.000 occurred at the crown where $\phi = 0^o$ under closing load.

This study's results were compared with earlier similar works by Connolly et al. for Y-joint's behavior under in-plane bending load. Fig.7 and Fig. 8 show simulated FEM results of the SCF distribution for chord and brace, respectively, from this study compared to Connoly's UCL-equation results. It can be seen that the results show a similar trend of SCF distribution for both chord and brace. The difference in SCF magnitude can be due to assumptions in the modeling and loading considered in the analysis and simulation.

Fig.7 and Fig. 8 show the similarity in the SCF distribution trend between the two-chord and brace results. It was found that the chords' maximum SCF value from this simulation is 3.0 compared to 4.15 from Connolly's UCL equation. On the other hand, this simulation gives a maximum value of SCF = 2.4, and Connolly's UCL equation provides an SCF with a value of 3.5.

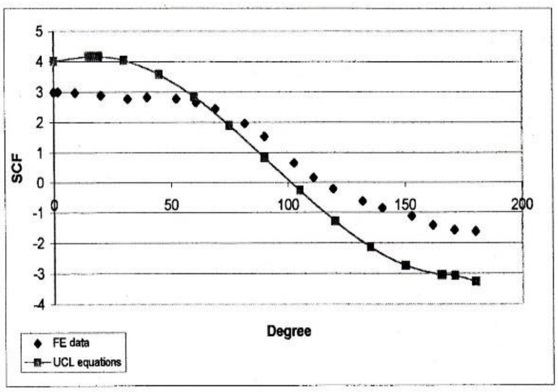

Fig. 7. Comparison between FEM results and Connolly's SCF distribution for a chord.

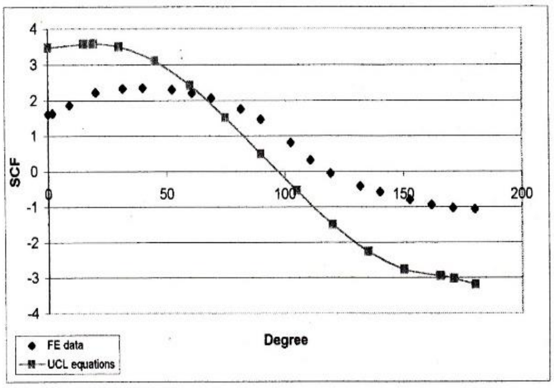

Fig. 8. Comparison between FEM results and Connolly's SCF distribution for the brace.

There are some differences between the results obtained in this study and Connolly's UCL [2] equation results. However, Connolly stressed that their results from the empirical equations used in the analysis are rather overestimated values of SCF at the joint as compared to their experimental values. Since the results by Connolly are overestimated the real values, therefore the difference exhibited in Figs. 7 and 8 for the SCF comparison proved the results of this study are of acceptable magnitudes. The point of maximum SCF occurred at the joint's crown position; hence, the member's elements experiences the maximum induced stress. The maximum deformation of the joint should be expected at the point with maximum stress.

V. CONCLUSIONS

The results obtained from the stress concentration factor study on the Y-joint model can be summarized as the following;

1. The study shows that the local stress adjacent to the Y-joint intersection is much higher than the nominal stress applied to the chord and the brace.
2. Induced stresses were computed, and the maximum stresses occurred on the joint's crown near the intersection weld, $\phi = 0^{o,}$ and $\phi = 180^{o}$.
3. The results also indicate that the maximum elemental deformation occurred at the location of maximum stress.
4. The results obtained from this study were in good agreement with those of theoretical methods.

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