Characterization of the Effects of Nodal Eccentricity on the Strength of Tubular T-Y Joints

Yang Yifeng*[1], Lu Shuyan[1], Wei HuiWang[2], Hung Chen-Far[3]

1. Undergraduate students, Institute of Naval Architecture and Marine engineering, Ocean College, Zhejiang University, Zhoushancity, Zhejiang, China, 316021
2. Professor, Institute of Naval Architecture and Ocean Engineering, Ocean College,Zhejiang University Professor of Emeritus, Department of Systems Engineering and Naval Architecture, Taiwan Ocean University
3.Professor, Institute of Naval Architecture and Ocean Engineering, Ocean College,Zhejiang University Professor, Department of Engineering Science and Ocean Engineering, Taiwan Ocean University
**Address:No. 1, Zhejiang University Road, Dinghai District, Zhoushan City, Zhejiang Province, Institute of Naval Architecture and Ocean Engineering, Ocean College, Zhejiang University*
*E-mail:3150100213@zju.edu.cn
*Mobile Phone:+86-18357298766

Abstract: Tubular joints are extensively appearing in the tubular offshore platform structures. These joints can be divided into three types according to the eccentricities of the connection nodes, which linked the cylindrical pipe elements together, i.e., those withnegative eccentricity, zero eccentricity and positive eccentricity respectively.Through theoretical analyses it shows that the overall strength of the joint is strongly influenced by such kind eccentricities. Actually, due to construction uncertainties, the nodal eccentricity of tubular joint structurescannot be avoided. This article mainly considered the redistribution of the stress field due to the eccentricity phenomenon, meanwhile thestress concentration factor(SCF) is discussed as well. The FEA software package ANSYS was used for the analyses. Besides eccentricity, other relevant sensitive parameters of tubular joints have had discussed by the systematic simulation analysis results.
Keywords: Tubular joints, Nodal eccentricity, stress concentration factor

1. INTRODUCTION

Owing to the excellent characteristic of high strength-to-weight ratio and smaller outside surface area (less corrosion) of tubular structures, most offshore platforms usually adopted such kind structural configuration. Besides these, tubular structural elements possess the strength irrelevant to the load directions. But inevitably, there are a number of tubular joints appeared at the connections of the tubular structure, which make the accurate assessments of the strength of the structure becoming tremendous difficult[1]. Especially in the evaluations of stress concentration factors (SCFs) at hot spots of the junctions, this would lead the prediction of exclusively uneasy as well.This article proposes systematic analyses of the SCFs of tubular T-Y joints, which encompass typical conventional T-Y joints and combined T-Y joints, and intending to summarize the most sensitive parameter related to SCFs. Hopefully, the results of the study are available for the future applications of detail structural modifications.

Relevant literatures regarding to this topic in the past decades have been found. Simplified mechanical models are proposedin [2], [3]to cope with the mechanical behavior of tubular joints and the stress distribution within the elastic rangeis obtained. FEA have been used to study the SCFs of T, Y and K joints when subjected to axial loads, in-plane bending moment and out-of-planebending moment, such as [4], [5],[6], [7], [8], [9].

2. Parameters Related to T-YJoints

Basically, the T-Y tubular joints consist of a course chord and two smaller diameter braces, the positions of these jointsare shown in the Fig.1 below. The distance between two centerline intersections (i.e., T-brace to chord and T-brace to Y-brace) of the structure is called the nodal eccentricity. Thus, the T-Y joints can be divided into three categories according to the value of eccentricities, i.e., joints with positive eccentricity, zero eccentricity and negative eccentricity respectively. This parameter the nodal eccentricity,was mainly selected to represent the positions of the weld passes, as a consequence, which has a close relation with the stress concentration factor of the joint.

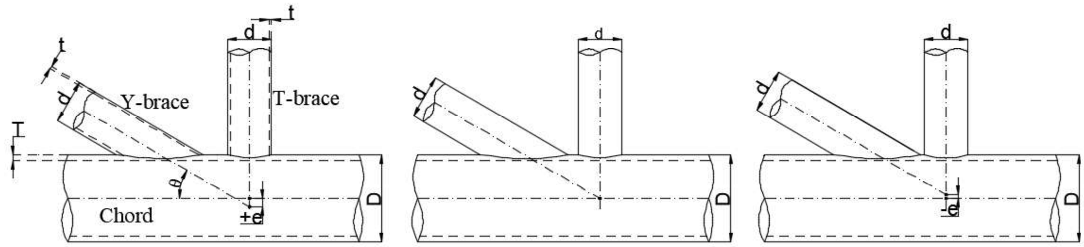


Fig.1 *Categorization of T-Y tubular joints*

2.1 Definition of Relevant Parameters

Besides the nodal eccentricity$e$, the stress concentration factor (SCF) of the T-Y tubular joints could be also affected by a number of other parameters. They are:

Diameter ratioβ : the ratio of the brace diameter (*d*) to the chord diameter (*D*), which is used to describes the compactness of the joints.

$$\beta = \frac{d}{D} \quad (1)$$

Chord thickness ratioγ: the ratio of the chord radius to the chord wall thickness (*T*)which represents the radical stiffness of the chord.

$$\gamma = \frac{D}{2T} or \alpha = \frac{1}{\gamma} = \frac{2T}{D} \quad (2)$$

Wall thickness ratioτ: the ratio of the wall thickness of brace (*t*) to that of the chord(T).

$$\tau = \frac{t}{T} \quad (3)$$

Which represent the strength ratio of brace to the chord.

Angle between the centerlines of chord and braceθ: although $\theta$is determined by the actual layout of the structure, but it is assumed to be constant, $\theta = 30^{\circ}$, in this article.

All the parameters, which are selected to be in relation to the SCFs of the T-Y joints, and its variations in value are summarized in Table 1.

Table1 *Variations of the parameters in relation to SCF*

Type	$D(mm)$	$d(mm)$	$T(mm)$	$t(mm)$	θ(deg)	β	γ	τ	$e(mm)$
T-Y	3000	1548	50	24	30	0.516	30	0.48	-120
T-Y	3000	1548	50	24	30	0.516	30	0.48	-100
T-Y	3000	1548	50	24	30	0.516	30	0.48	-80
T-Y	3000	1548	50	24	30	0.516	30	0.48	-40
T-Y	3000	1548	50	24	30	0.516	30	0.48	0
T-Y	3000	1548	50	24	30	0.516	30	0.48	100
T-Y	3000	1548	50	24	30	0.516	30	0.48	200
T-Y	3000	1548	50	24	30	0.516	30	0.48	400
T-Y	3000	1548	50	24	30	0.516	30	0.48	800
T-Y	3000	1648	50	24	30	0.549	30	0.48	0
T-Y	3000	1348	50	24	30	0.449	30	0.48	0
T-Y	3000	1048	50	24	30	0.349	30	0.48	0
T-Y	3000	648	50	24	30	0.216	30	0.48	0
T-Y	3000	1548	60	28.8	30	0.516	25	0.48	0
T-Y	3000	1548	80	38.4	30	0.516	18.75	0.48	0
T-Y	3000	1548	100	48	30	0.516	15	0.48	0
T-Y	3000	1548	120	57.6	30	0.516	12.5	0.48	0
T-Y	3000	1548	50	28	30	0.516	30	0.56	0
T-Y	3000	1548	50	32	30	0.516	30	0.64	0
T-Y	3000	1548	50	40	30	0.516	30	0.8	0
T-Y	3000	1548	50	48	30	0.516	30	0.96	0

Besides the angleθkeeps constant the other three parameters, i.e., the length of the chord and brace are also taken to be constant 20m and 8m respectively. These lengths are long enough to obey the Saint Venant's principle under the loading conditions of pure bending. The last one of the parameters, which is the weld size (*a*) of the weld pass, is kept to be:

$$a = T \quad (4)$$

That is complied with the requirement of the Material and Welding Specification of CCS. The analysis model of the weld pass is shown as Fig.2.

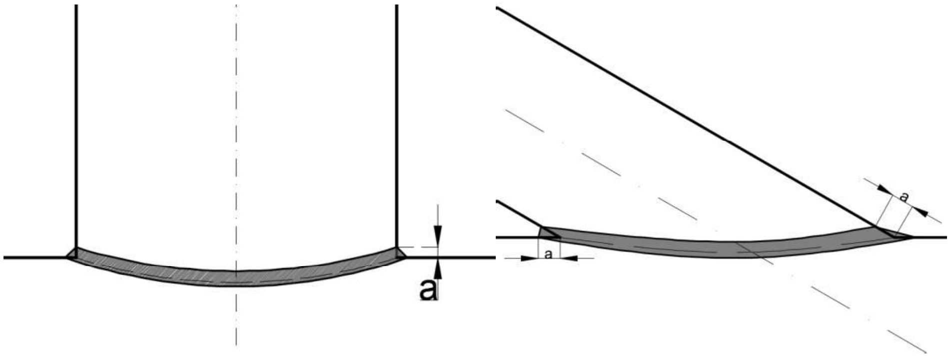


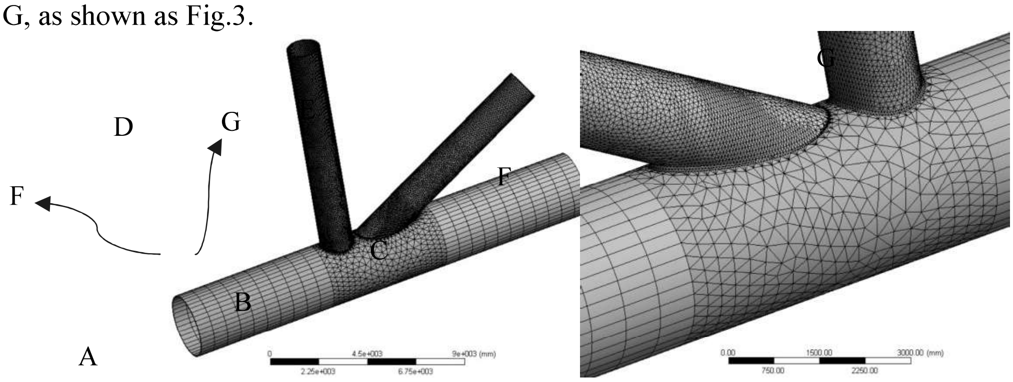
Fig.2 Weld pass model of T-Y tubular joints

3. FEA Modelling and Convergence Testing

To discuss the circumstance of the stress concentration at the hot spots around the T-Y joints of a tubular structure, the finite element analysis (FEA) method was used and conducted by applying the software package ANSYS. Before carrying out the systematically parametric studies, the convergence testing of the selected element types and the corresponding mesh sizes should be ascertained.

3.1 FEAModel

To aim at minimizing the number of elements and so as to reduce the computing time, and to ensure the accuracy of the stress distributions as well, the FEA model of the tubular K-T joint is partitioned into seven zones, each of which is modelled by different mesh sizes individually. Among which, zones A, B, C are located on the chord pipe, D and E are on the braces respectively, and G, F along the weld passes. The mesh sizes are divided in to four hierarchies, i.e., the course mesh zones A and C; the fine mesh zone B; the finer mesh zones D,E and the finest mesh zones F, G, as shown as Fig.3.



(a) Partitioned zones (b) Mesh sizes in different zones

Fig.3 FE model of the T-Y tubular joint and mesh sizes in different zones

From the topolpgy of the T-Y tubular joint, the quadrilateral solid element and the traigular solid elements are used in the mesh generation process while a couple of mesh sizes are adjusted in different analysis phases. In all analysis processes, as the stress levels are controlled withthe elastic range of the material. Besides mesh sizes and element types used, the other geometrical data used is shown as in Table. 1, and the material constants are: Young's modulus of 200Gpa and Poisson's ratio of 0.3. Table. 2 listed the element type used in each patitioned zone and the corresponding mesh sizes in the FEA model.

Table2 Element type and mesh size in different zones of the T-Y tubular joint

Zone	Element type	Mesh size(*mm*)
A	quadrilateral solid	700
B	triangular solid	300
C	quadrilateral solid	700
D	triangular solid	100
E	triangular solid	100
F	triangular solid	50
G	triangular solid	50

3.2 Static and Kinematic Boundary Conditions

Basically, if analyses are concentrated on the stress concentration of the T-Y tubular joint, then it is reasonable to isolate the joint structure by four section L, M, N and O for consideration. Among which, sections L and M are used to isolate the T-brace and Y-brace respectively, sections N and O are used to isolate thechord. Owing to the bending loads (both in-plane and out-of-plane) would predominate the stress concentration phenomenon occurring at the hotspots in the weld passes of the joint, the following four static and kinematic boundary conditions are taken into consideration.

BC (1): Section O subject to an in-plane bending moment, and the sections L, M, N are fixed, as shown in Fig.4.(a).

BC (2): Section M subject to an in-plane bending moment, and the sections L, N, O are fixed, as shown in Fig.4.(b).

BC (3): Section O subject to an out-of-plane bending moment, and the sections L, M, N are fixed, as shown in Fig.4.(c).

BC (3): Section M subject to an out-of-plane bending moment, and the sections L, N, O are fixed, as shown in Fig.4.(d).

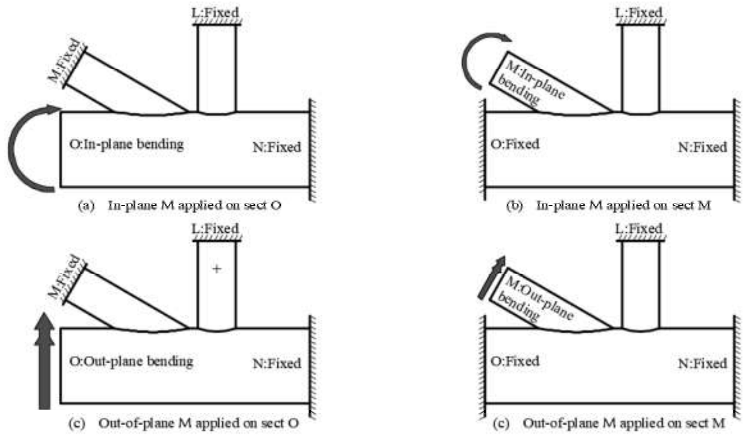
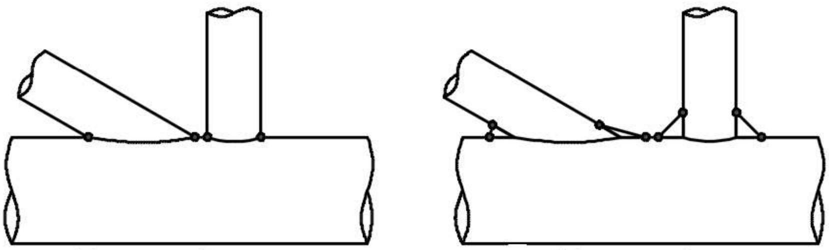


Fig.4 *Static and Kinematic boundary conditions of an isolated T-Y tubular joint structure*

3.3 Convergence Testing of SCF Related to Mesh Size

In principle, the hot spots of a structure in high stress region are normally locate at the discontinuities of the structure. There are two types of hot spots occurring in the T- Y joints. The first type is locating at the positions having re-entrant angle (Fig.5.(a)), the second one locates at the positions of weld toes (Fig.5.(b)).



(a) Type 1 hotspots (b) Type 2 hotspots

Fig.5 *Types of hotspots*

Once the positions of hotspots are determined, the stress concentration factors (SCF) are calculated by:

$$SCF = \frac{\sigma_{hs}}{\sigma_0} \qquad (5)$$

Where σ_{hs} is the equivalent stress atthe hotspot of the weld toe, as defined by Fig.6, and calculated by FEA software,$\sigma_0$is the maximum equivalent stress occurring in the related chord section as if the brace do not exist.

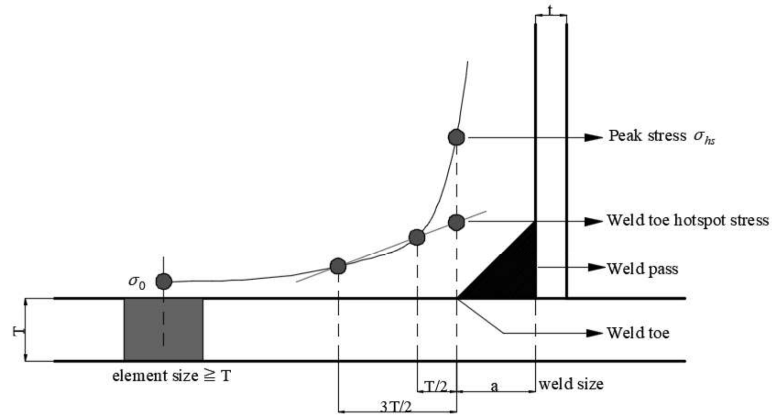


Fig.6 *Definition of the weld toe hotspot stress*

$\sigma_0$is expressed as:

$$\sigma_0 = \frac{M}{Z} = \frac{32M}{\pi D^3[1-(1-\alpha)^4]} \quad (6)$$

$\alpha$is the reciprocal of the chord thickness ratio as defined by Eq.(2).

Convergence testing and the ascertainment of mesh sizes is the premise of FEA. In order to determine the optimal mesh sizesin different zones as described in Table.2 for the purposes of reducing computing time and attaining the same level of accuracy simultaneously, the results of σ_0 and $\sigma_{hs}$are shown in Fig.6 as an example. Through the mesh sizes in different zones A, B and C of the chord member shown in Fig.3.(a). But the mesh sizes adopted in the meshing scheme for zones F and G are fixed to be 50*mm*, and 100*mm* for the zones D and E. These mesh sizes are determined according to the rule shown in Fig.6. Fig.7 (a) and 7 (b) show the results of convergence testing of the SCF related to the mesh sizes in zones A and C, and zone B respectively. The optimal mesh size in zones A, C is 700*mm*, while in zone B is 300*mm*, as shown in Table.2.

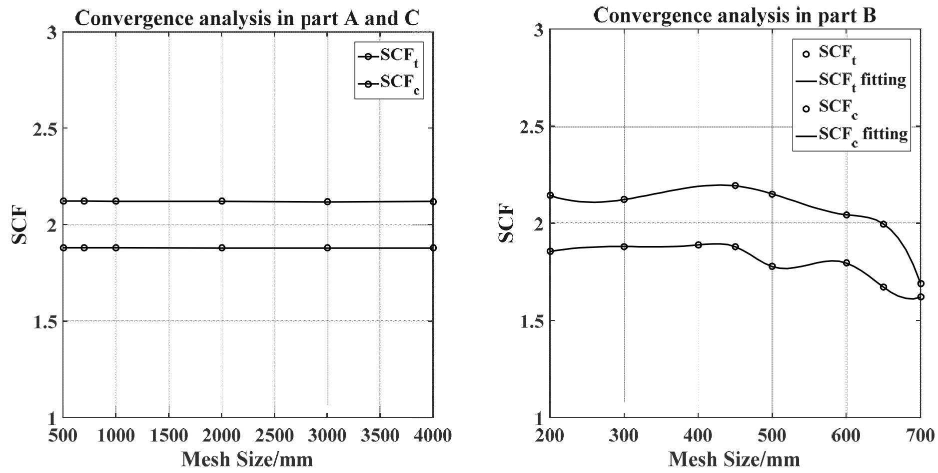


Fig.7 *Convergence analysis in part A, B and C*

4. Parametric Study

Forthe purpose of the demand for designing applications, SCFs at the hotspots of a T-Y joint should be taken into considerations to evaluate both the ultimate strength and the fatigue strength of the joint structure more accurately. Thus a series of systematically parametric analyses are performed so as to recognize whether parameter dominating the SCF in the structural configuration. Four parameters are selected to study and discuss in this article. They are the eccentricity (e),the diameter ratio (β), the chord thickness ratio (γorα) and the brace thickness ratio (τ).

4.1 The Variations of SCFs Versus Eccentricity

Nodal eccentricity denotes the relative positions of the braces linking to chord. How is the variation of eccentricity to influence the SCFs in the joint would be discussed by FEA under the above mentioned four boundary conditions.

4.1.1 BC(1) —Chord Subjected to In-Plane Bending Moment

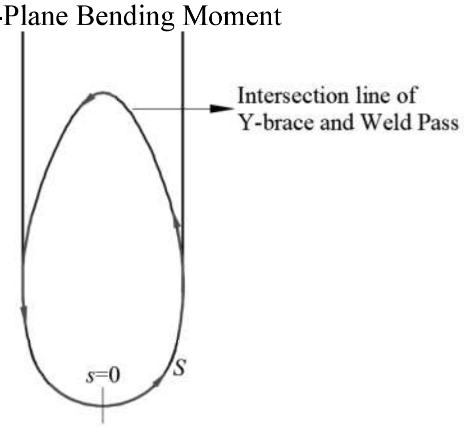


Fig.8 *Definition of coordinate s*

By using the FEA, the equivalent stress distribution around the weld pass of the Y-brace with different eccentricities can be attained, as shown in Fig.9. It can be seen that there exists four peaks around the weld pass, which locate at $s_1 = 2.0m$, $s_2 = 3.2m$, $s_3 = 4.7m$and $s_4 = 6.0m$ respectively (the *s* coordinate is shown in Fig.8, the same below). These peak equivalent stress are also named as the maximum equivalent stress.

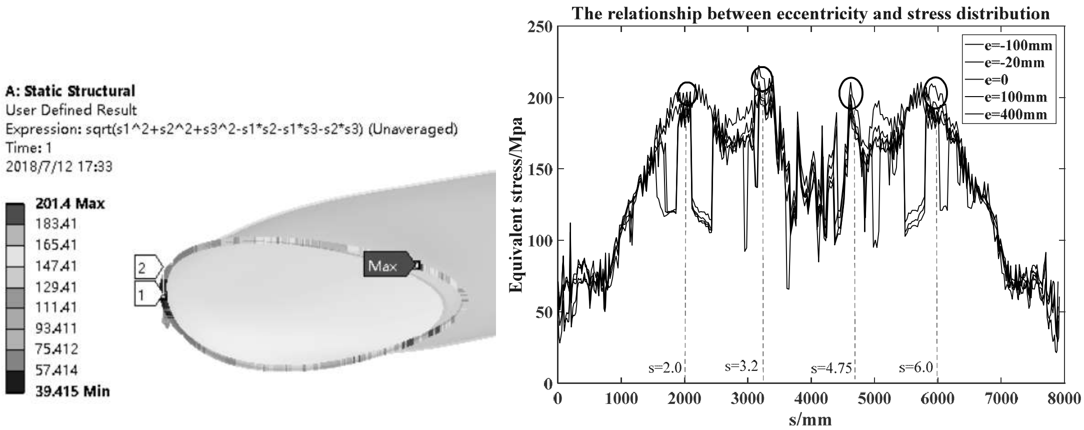


Fig.9 *Equivalent stress distribution around the weld pass*

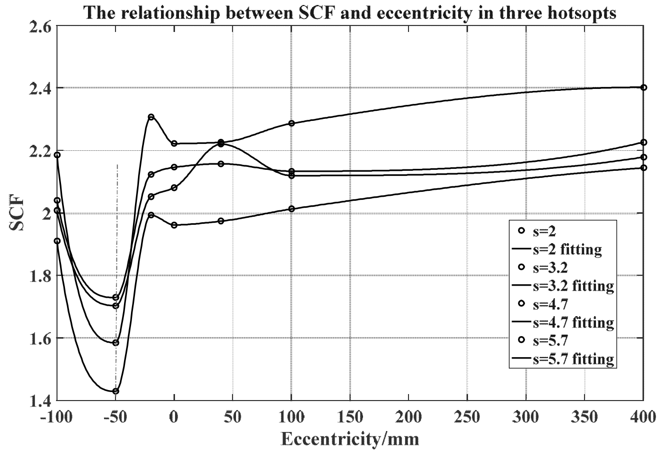


Fig.10 *Variations of hotspots' SCFs versus eccentricity*

Using these peak equivalent stresses, the variations of the hotspot SCFs versus eccentricity can be plotted as Fig.10. It is interesting to note that there is a series of hollow points located at the eccentricity around -50*mm*. These kind layout are worthy of the design application for reducing the stress concentration at Y-joint subjected to in-plane bending.

4.1.2 BC(2)—Y-BraceSubjected to In-Plane Bending Moment

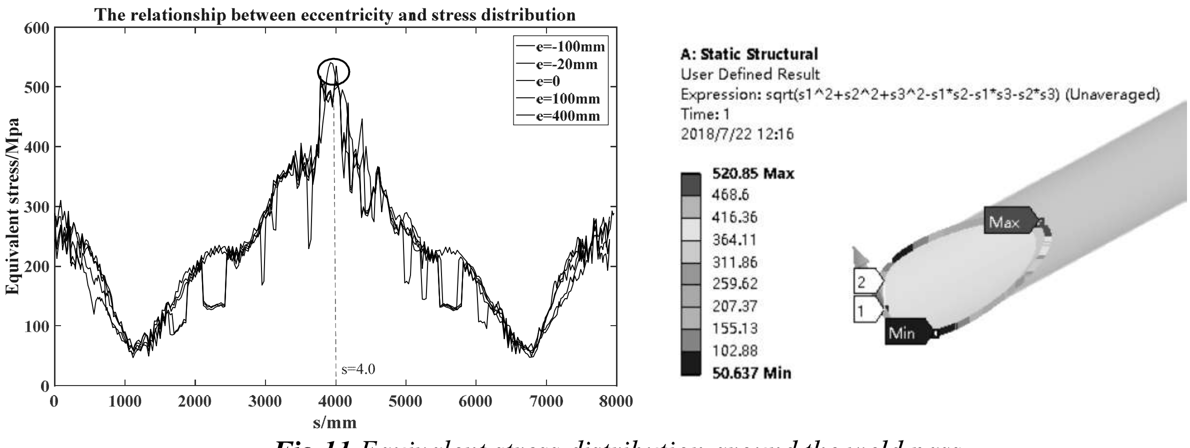


Fig.11 *Equivalent stress distribution around the weld pass*

The equivalent stress distribution around the weld pass of the Y-brace with different eccentricities can be attained by FEA, as shown in Fig.11. It also can be seen that there exists one peak around the weld pass, which locate at $s_1 = 4.0m$. This peak equivalent stress are also determined as the hotspot's equivalent stress.

Using this peak equivalent stresses, the variations of the hotspot SCFs versus eccentricity can be plotted as Fig.12. In general, the SCF does not change a lot with the variation of eccentricity. However, it is interesting to note that when the eccentricity of the T-Y joints is zero, the SCFs is a little larger than that the eccentricity is non-zero by an amount of 5%.

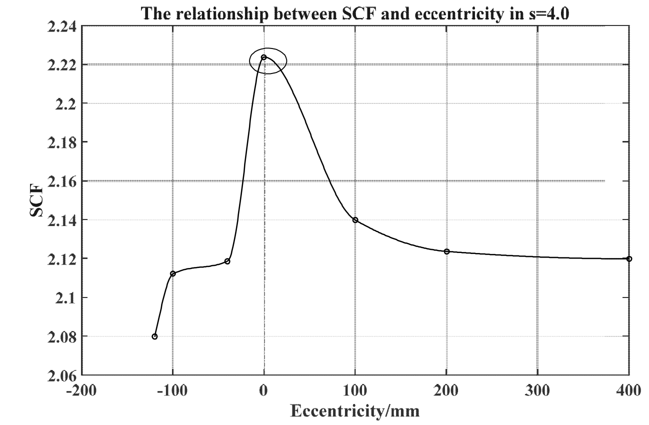


Fig.12 *Variations of hotspots' SCFs versus eccentricity*

4.1.3 BC(3)—Chord Subjected to Out-of-Plane Bending Moment

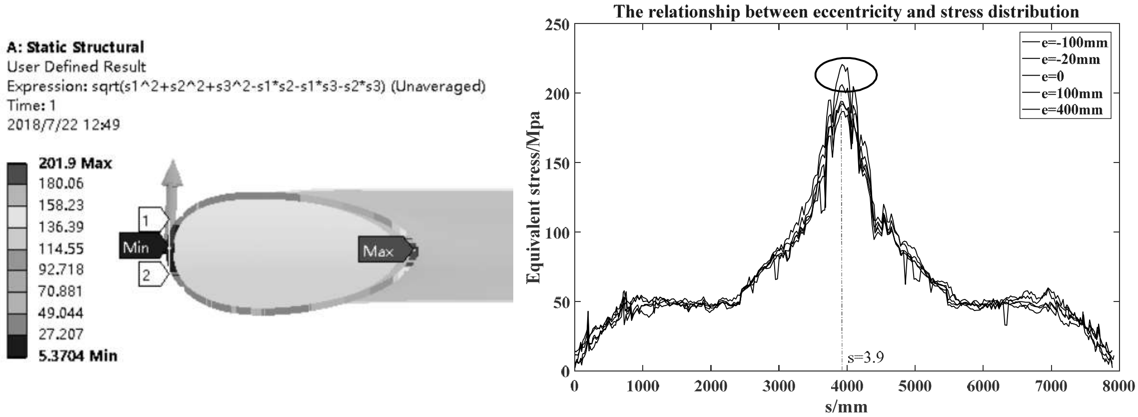


Fig.13 *Equivalent stress distribution around the weld pass*

From FEA, the equivalent stress distributions around the weld pass of the Y-brace with different eccentricities are attainedas shown in Fig.13. It also can be seen that there exists one peak around the weld pass, which locate at $s_1 = 3.9m$. This peak equivalent stress are also determined as the hotspot's equivalent stress.

Using these peak equivalent stresses, the variations of the hotspot SCFs versus eccentricity can be plotted as Fig.14. It is interesting to note that there is a hollow point located at the eccentricity around -50mm. This layout is worthy of the design application for reducing the stress concentration at Y-joint subjected to out-of-plane bending. In addition, when the distance between two weld passesis too large, the SCFs will increase rapidly, which is also worthy of the design for T-Y tubular joints.

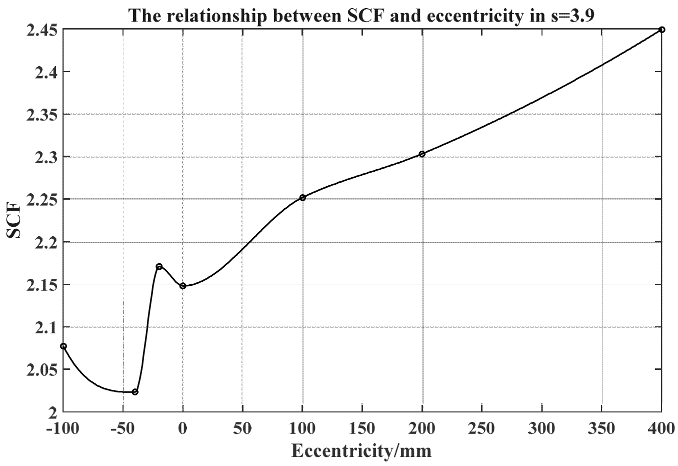


Fig.14 *Variations of hotspots' SCFs versus eccentricity*

4.1.4 BC(4)—Brace Subjected to Out-of-Plane Bending Moment

The equivalent stress distributions around the weld pass of the Y-brace with different eccentricities are attained as shown in Fig.15. It also can be seen that there exists two peaks around the weld pass, which locate at $s_1 = 1.525m$.and $s_2 = 6.64m$. These peak equivalent stress are also named as the maximum equivalent stress.

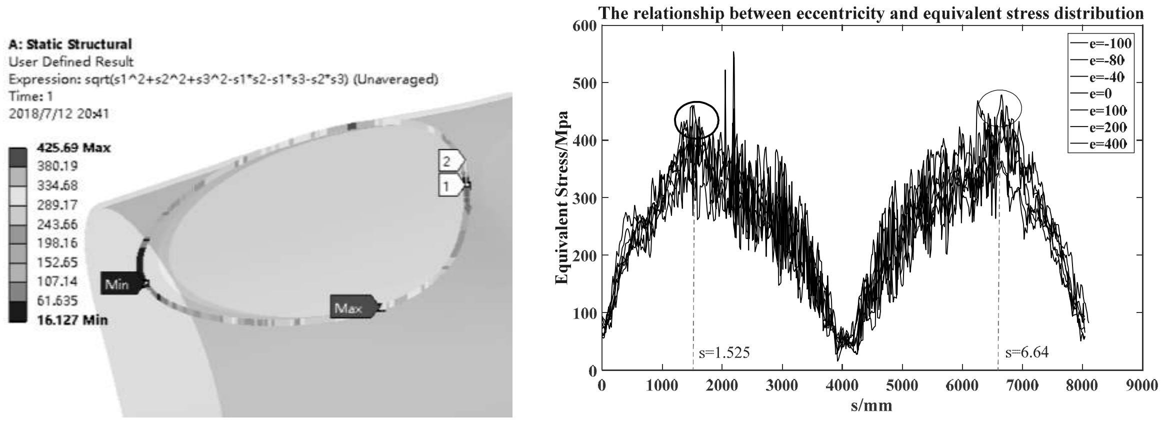


Fig.15 *Equivalent stress distribution around the weld pass*

Using these peak equivalent stresses, the variations of the hotspot SCFs versus eccentricity can be plotted as Fig.16, which points out that the SCFs of negative eccentricity T-Y tubular are smaller, and it is interesting to note that when the eccentricity of the T-Y joints is zero, the SCFs is larger than that the eccentricity is non-zero. These layout are worthy of the design application for reducing the stress concentration effect at Y-joint when Y-brace subjected to out-of-plane bending.

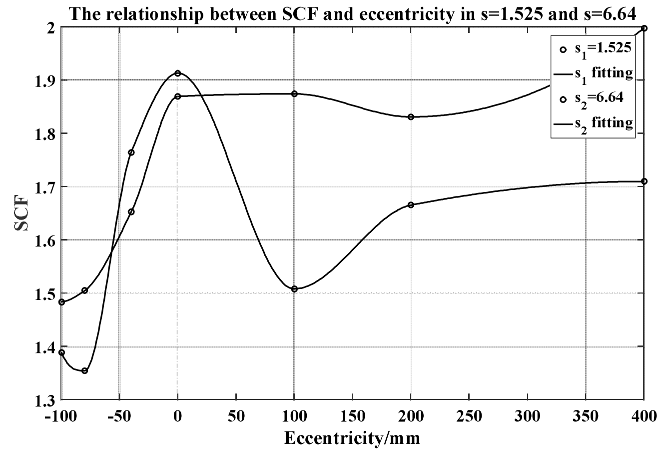


Fig.16 *Variations of hotspots' SCFs versus eccentricity*

4.2 The Variations of SCFs Versus Other Related Parameters

Other relevant sensitive parameters of tubular joints have also been discussed in order to assess the effect of eccentricity on stress concentration. When comparing the influence of different sensitive parameters on SCFs, the most sensitive parameters can be obtained. In this chapter, although the geometric parameters have changed, the stress distribution is basically the same as the 4.1.1 and 4.1.3 because of the same load condition as 4.1.1 and 4.1.3. Therefore, it is reasonable to choose the stress at similar positions as hotspot stress.

4.2.1 The Variations of SCFs Versus Diameter Ratio

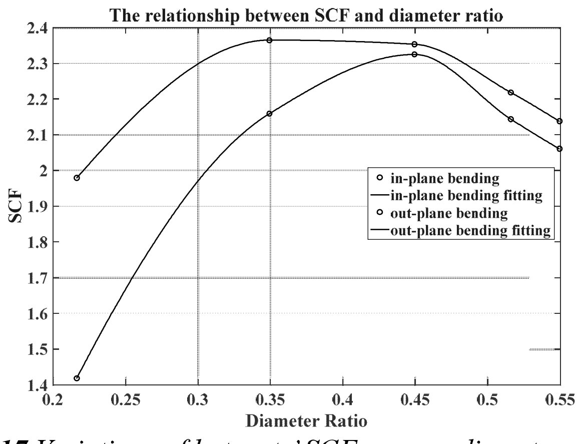


Fig.17 *Variations of hotspots' SCFs versus diameter ratio*

Using the peak equivalent stresses when the chord is subjected to in-plane and out-of-plane bending moment, the variations of the hotspot SCFs versus diameter ratiocan be plotted as Fig.17. It is interesting to note that the SCFs are much larger when the diameter ratio is within 0.35 to 0.5. These layout are worthy of the design application for reducing the stress concentration at Y-joint subjected to in-plane and out-of-plane bending.

4.2.2 The Variations of SCFs Versus Chord Thinness Ratio

Chord thinness ratio is another parameter that affects the SCFs. Using the peak equivalent stresses when the chord is subjected to in-plane and out-of- plane bending moment, the variations of the hotspot SCFs versus chord thinness ratio can be plotted as Fig.18, which noted that the SCFs is negatively correlated with chord thinness ratio within a certain range and the SCFs can be effectively reduced when the chord thinness ratio is large enough, which is worthy of the design application for reducing the stress concentration at Y-joint.

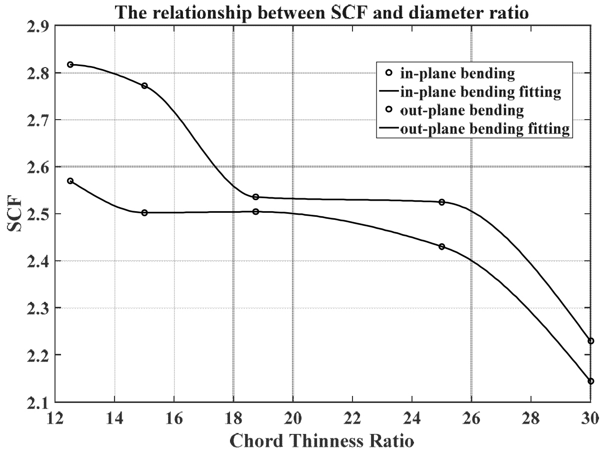


Fig.18 Variations of hotspots' SCFs versus chord thinness ratio

4.2.3 The Variations of SCFs Versus Wall Thickness Ratio

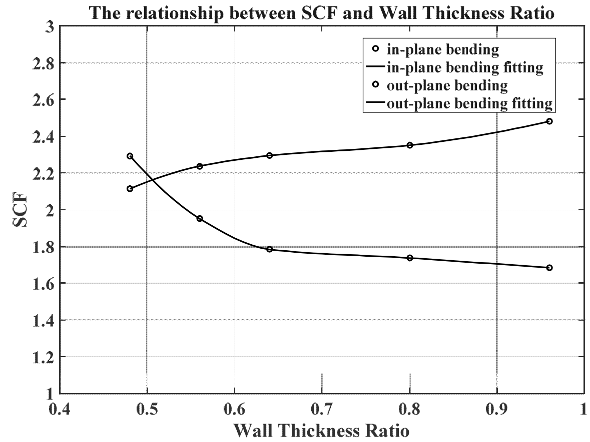


Fig.19 Variations of hotspots' SCFs versus wall thickness ratio

The wall thickness ratio will affect the load carrying capacity, weight and SCFs of the structure. Using the peak equivalent stresses, the variations of the hotspot SCFs versus Wall thickness ratio can be plotted as Fig.19, which indicates that SCFs are positively correlated with wall thickness ratio when the chord is subjected to out-of-plane bending moment, the SCFs are negatively correlated with wall thickness ratio when the chord is subjected to in-plane bending moment.

5. Conclusionand Discussion

In this study the stress concentration factors around the hotspots of weld passes of T-Y tubular joints was analyzed and characterized. The establishment of algorithm and procedure of the analyses can enhance one to understand in depth that regarding the variations of SCFs versus different design parameters. Among the four parameters regarding the SCFs of the T-Y joints considered, it is found that: each of eccentricity, or diameter ratio, or chord thinness ratio or wall thickness ratio, has some extent of influence. This emerges an opportunity to optimize the joint configuration design by using the established algorithm of analyses.

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