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Z.W. Zhu*, T. Qin, X.W. Chen
Preface

These proceedings contain the papers presented at the TENTH INTERNATIONAL CONFERENCE ON ADVANCES IN STEEL STRUCTURES (ICASS 2020) held in Chengdu, China, from 21 to 23 August 2022. The international conference series on Advances in Steel Structures was initiated in 1996 under the support of The Hong Kong Polytechnic University, which remains very active in fostering its continuation—joined a few years later by the Hong Kong Institute of Steel Construction.

These proceedings bring together most recent findings in numerical, theoretical and experimental research, as well as its practical implementation in design practice in the areas of Assembled Structure, Bridge, Cold-formed Steel, Composite, Connections, Corrosion, Fracture & Collapse, Design & Analysis, Direct Analysis, Fatigue, Fire, High-Strength Steel, Impact and Protection, Intelligent Construction, New Material, Seismic Resistance, Stability, Stainless Steel, Structure Systems, Testing & Monitoring. The papers presented in these proceedings come from a wide range of countries/regions and will be a great reference source.

Specially, the subject matter has been categorized under the broad heading of:

**Volume I:** Keynotes Lectures, Assembled Structure, Bridge, Cold-Formed, Composite, Connections, Corrosion, Fracture & Collapse, Design & Analysis, Direct Analysis, Fatigue


Each of the papers was subjected to stringent review by a panel of experts in the respective area. This peer review began with an assessment of the submitted abstracts and following this, authors were invited to submit their full manuscripts. Each manuscript was then carefully reviewed by relevant experts, and their recommendations on accepting, rejecting or modifying the submissions were strictly adhered to, before inclusion in the conference proceedings.
PARAMETRIC STUDIES ON SCF DISTRIBUTION OF THREE-PLANAR TUBULAR Y-JOINTS UNDER IN-PLANE BENDING MOMENT

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Abstract: The three-planar tubular Y-joint is normally multiplanar loaded with severe multiplanar interaction effect, which may cause the hot spot stress (HSS) to occur other than crown or saddle points of the weld seam. Thus, the distributions of stress concentration factor (SCF) along weld seam are needed to calculate HSS rather than formulas that only care about values of crown or saddle points. To find the distribution patterns, a numerical database is established using the validated finite element (FE) analysis method. Sensitivity analyses for five geometric parameters affecting distribution along weld toe curves of SCF are conducted.

Keywords: Three-planar tubular Y-joint; Hot spot stress; Stress concentration factor; In-plane bending moment

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1 INTRODUCTION

The development of ocean energy carries a massive weight in the area of clean energy resources. Many marine structures are welded by steel tubular components which make lots of tubular joints. Fatigue evaluation is inevitable in the structure design of marine engineering as it has to resist long-term cyclic loading caused by harsh environmental and machine operation loads. Geometric discontinuities in the intersection of chord and brace members lead to high stress concentration making tubular joints critical for fatigue design. As tripod substructures of offshore wind turbine (OWT), shown in Fig. 1, are broadly adopted in the offshore wind farms in the intertidal zone of China, the three-planar tubular Y-joint incorporating multiplanar interaction between braces is focused in this study.

The hot spot stress (HSS) method, approved by codes such as DNV [1], API [2], AWS [3], CIDECT [4], IIW [5], Lloyd's Register [6, 7], is currently the most mainstream among many methods for a fatigue assessment of welded tubular joints due to its high accuracy and good applicability. This method calculates amplitudes of HSS by extrapolation considering effects of both cross-section and geometric sizes of the joint. The HSS is thus be taken as the evaluation index to calculate fatigue life combined with S-N curves according to the cumulative damage criterion.

As an essential parameter in fatigue analysis, the HSS is commonly obtained by multiplying stress concentration factor (SCF) with nominal stress which evenly distributes on the cross-section of braces far away from the weld area and can be calculated by von Mises stress...
definition. The SCF is defined as the ratio of HSS and nominal stress. Some codes recommend SCF formulas for simple tubular joints, such as T-, Y-, K- and X-joints.

However, the above formulas all only give attention to the SCF of the crown or saddle points, or at most the peak value with unknown location, which is not applicable to calculating HSS of tubular joints under combined load conditions of several basic loads applied together. Directly superposing peak values of SCF under each basic load to acquire HSS of a tubular joint is not in line with the actual situation, as the locations of peak value vary considerably with load type. Even the improved method is given in DNV [1] emphasizing eight points along a weld toe curve has room for improvement in the accuracy. Because the SCF value of points other than crown and saddle points are extracted through interpolation instead of independent formula.

Bao et al. [8, 9, 10] already offered the HSS formula of multiplanar tubular joints under conditions of combined loads applied on multiplanes, however, the premise of applying the formula is to know SCF distribution along weld toe curves of intersections of chord and braces of multiplanar tubular joints under conditions of basic load applied on a single plane.

Compared to formulas for SCF on crown or saddle points, the amount of formulas for predicting SCF distribution is much less, though, some valuable research are published. Morgan and Lee [11, 12, 13] provided SCF distribution formulas for K-joints under three basic loads (axial force, in-plane bending moment and out-of-plane bending moment) according to simulating results using thin-walled shell elements. Rahmanli and Becque [14] proposed SCF distribution formulas for DKT-joints under balanced axial forces based on numerical studies.

Formulas in these papers can only be used to calculate SCF of 8 points with 45° separation each on weld toe curves rather than a full distribution curve equation suitable for any point of weld toe curve. Herein lies obstacles when executing superposing. Nonetheless, to the author's knowledge, there are no published SCF distribution formulas for three-planar Y-joints yet.

Three-planar tubular Y-joints are taken as the object in this paper considering the wide application of tripod substructure of OWT. A numerical database is established using the validated finite element (FE) analysis method. SCF distributions of three-planar tubular Y-joints under the load condition of in-plane bending moment applied on a single plane are thus obtained and used to conduct sensitivity analyses for five geometric parameters. Based on the information of sensitivity analyses, the SCF distribution patterns are observed and concluded, which can offer some support in the HSS method for fatigue assessment in offshore structures design.
2 NUMERICAL SIMULATION

2.1 Calculation of SCF

Fig. 2 depicts a typical three-planar tubular Y-joint with definitions of geometric sizes: \( L \) is the length of the chord; \( D \) is the outer diameter of the chord; \( T \) is the thickness of the chord’s wall; \( l \) is the length of the brace; \( d \) is the outer diameter of the brace; \( t \) is the thickness of the brace’s wall. \( \theta \) is the brace-to-chord inclination angle; \( \phi \) is the pole angle. Five crucial geometric parameters affecting SCF distributions are: the length-to-outer radius ratio of the chord \( \alpha \) (Eq. (1)), the brace-to-chord diameter ratio \( \beta \) (Eq. (2)), the chord outer diameter-to-chord thickness ratio \( \gamma \) (Eq. (3)), the brace-to-chord wall thickness ratio \( \tau \) (Eq. (4)), and \( \theta \). Formulas of SCF in current codes and literature normally take the above dimensionless geometric parameters as independent variables regardless of the absolute value of geometric sizes of tubular joints. Moreover, it is necessary to draw the pole angle \( \phi \) into one of the independent variables to study the distribution of SCF, in which counterclockwise is positive, \( \phi = 0^\circ \) and \( 180^\circ \) are crown points, and \( \phi = 90^\circ \) and \( 270^\circ \) are saddle points.

\[
\alpha = \frac{2L}{D} \tag{1}
\]
\[
\beta = \frac{d}{D} \tag{2}
\]
\[
\gamma = \frac{D}{2T} \tag{3}
\]
\[
\tau = \frac{t}{T} \tag{4}
\]
In a known load condition, the nominal stress is determined by the section characteristics of
the brace member, taking no account of effects from structural discontinuity and local notch.
For a three-planar tubular Y-joint, basic loads on each brace are extracted from the results of
force analysis of the whole OWT substructure. Then, the nominal stress of each brace can be
calculated using simple beam theory and superposing method, which in in-plane bending
moment loaded condition is expressed as:

\[ \sigma_{n,1} = \frac{32M_1}{\pi d^3 \left[ 1 - \left( \frac{d - 2t}{d} \right)^4 \right]} \]  

where \( M_1 \) is the value of in-plane bending moment applied on a brace; \( \sigma_{n,1} \) is the nominal stress
of a brace under an in-plane bending moment.

For a particular point on a weld toe curve of a tubular joint, the stress composition is shown
in Fig. 3. The HSS \( \sigma_{hs} \), defined as the stress perpendicular to the weld toe curve, is determined
by the geometric dimension of welded components and can thus be called geometric stress or
structural stress. As the weld of a tubular joint is a spatial curve, it can be considered that
countless HSS points distribute along the weld toe curve. In the fatigue evaluation of a tubular
joint, the peak HSS value on the weld toe curve is often taken as the HSS for design. In this
paper, the HSS at each point of the weld toe curve is defined as the geometric stress \( \sigma_{gs} \), and the
peak geometric stress along weld toe curves is defined as HSS.

The stress directly measured or extracted from the weld toe through either experimental or
numerical work is the local notch stress without eliminating the influence of nonlinear stress.
The geometric stress at the weld toe can instead be calculated through extrapolation methods.
For circular tubular joints, the two-point linear extrapolation is accurate enough. The positions
of the two extrapolation points are shown in Fig. 3 where \( L_{r,\min} \) is the distance from the first
extrapolation point (near extrapolation point) to the weld, and \( L_{r,\max} \) is the distance from the
second interpolation point (far extrapolation point) to the weld. The range of extrapolation
regions has also been studied by many researchers suggesting that the near extrapolation point
should be \( 0.4t \) outside the weld toe (\( t \) is the wall thickness of the steel component) based on FE
analyses and experimental results, respectively. The extrapolation points positions specified in
IIW [5] are selected in this study.

According to Fig. 3, the geometric stress at the weld toe can be written as:
\[ \sigma_{\perp W} = L_r, \max \sigma_{\perp E1} - L_r, \min \sigma_{\perp E2} \] (6)

where \( \sigma_{\perp E1} \) and \( \sigma_{\perp E2} \) are stresses in the direction perpendicular to the weld toe curve at the first and second extrapolation points, respectively. These two stresses can be calculated by the following equation:

\[ \sigma_{\perp E} = \sigma_x l^2 + \sigma_y m^2 + \sigma_z n^2 + 2(\tau_{xy}lm + \tau_{yz}mn + \tau_{zx}nl) \] (7)

where \( \sigma_a \) and \( \tau_{ab} \) \((a, b = x, y, z)\) are the normal and shear stress components in the direction of three coordinate axes of the global coordinate system; \( l, m \) and \( n \) are direction cosines of three coordinate axes and can be obtained from:

\[
\begin{align*}
  l &= \cos(X_{\perp}, x) = \frac{x_W - x_E}{\delta} \\
  n &= \cos(X_{\perp}, z) = \frac{z_W - z_E}{\delta} \\
  m &= \cos(X_{\perp}, y) = \frac{y_W - y_E}{\delta} \\
  \delta &= \sqrt{(x_W - x_E)^2 + (y_W - y_E)^2 + (z_W - z_E)^2}
\end{align*}
\] (8)

where \((x_W, y_W, z_W)\) are the global coordinates of the weld toe point; \((x_E, y_E, z_E)\) are the global coordinates of extrapolation points.

### 2.2 Finite element modeling

As a key part of the OWT substructure, the three-planar tubular Y-joint focused in this study is usually fabricated by steel plates with a large thickness of 40 ~ 100 mm. Complete joint penetration (CJP) groove weld is asked by codes of many countries enlarging the contact area between members. The shape and size of the groove specified in AWS code [3] depend on the dihedral angle between the surfaces of the components to be connected. For tubular joints, the dihedral angle of the outer surface of chord and brace members changes along the circumferential direction of weld seams making the simulation of CJP groove weld much more complex than that of fillet weld.

Cao et al. [15] derived equations of intersection curve of chord and brace members via projecting twice. Thereafter, Lie et al. [16] established a method to simulate the CJP groove weld, which not only meets the minimum weld size specified by AWS code [3] but also offers a smooth weld curve through rigorous mathematical derivation. This method can truly reflect the effect of weld in numerical analysis and thus be adopted by many investigations including this study. The main idea and process are demonstrated in their papers and omitted here.

It can be seen from Fig. 1 that the upper part of the chord of the three-planar tubular Y-joint is connecting to a tower with a length larger than the chord length via the flange, while the lower part of the chord is jointed with three horizontal braces centrosymmetric about the axis of the chord. Herein the stiffness of constraints at both ends of the chord is considerable. Previous studies verified that the ends of a chord can be deemed as fixed when it works in an elastic state which is also one of the requirements for OWT structures. Furthermore, it is also found in the pre-study that the influence of boundary conditions on distribution and absolute values of HSS is much weaker than geometric parameters and load types. Therefore, this paper assumes that the boundary condition of both ends of the chord is fixed.

The modeling, calculation and post-processing of three-planar tubular Y-joints are all based on the software ANSYS by developing subprograms using ANSYS Parametric Design...
Language (APDL). The SOLID186 element with 20 nodes is adopted to build FE models of three-planar tubular Y-joints with weld seams.

Mesh scheme may greatly affect the accuracy of numerical simulation. Due to the existence of welds, the intersection of chord and braces, as the core area of stress concentration, is irregular and becomes the main concern. In view of this, the present study gives priority to ensuring the mapping mesh generation at weld seams and then advances to the chord and strut tube layer by layer, making the grid density gradually reduced with the decrease of stress gradient to reduce calculation cost on the premise of ensuring sufficient accuracy. Fig. 4 shows details of weld seams of a FE model. The accuracy and reliability of the FE model have been validated by a model test by Bao et al. [9, 10]).

![Fig. 4 An FE model of three-planar tubular Y-joints](image)

### 2.3 Numerical analysis database

To establish a FE model base, ranges of Efthymiou [1] and LR [6, 7] formulas and practical sizes of tripod substructures are referenced to set the ranges of three-planar tubular Y-joints in this study as shown in Table 1. The amount of FE models in the base is 1920. The following should be expounded:

1. As the length-to-outer radius ratio of the chord, $\alpha$ reflects the strength of the constraints of chord ends. The strong constraint occurring with a small $\alpha$ will have a great impact on SCF values at the intersection of chord and brace. Some codes, such as DNV [1] and API [2], stipulated that the short chord correction factor shall be taken into account if $\alpha < 12$. For three-planar tubular Y-joints, $\alpha$ is commonly less than 12 in practice, so this paper directly considers its influence by setting a range of 6 ~ 15 rather than using the short chord correction factor.

2. Hellier’s research [17] indicates that the length-to-outer radius ratio of the brace $\alpha_B$ has rare effects on SCF when it is greater than 8. Considering $\alpha_B > 8$ can be easily met by three-planar tubular Y-joints, $\alpha_B = 10$ is assigned to all FE models in the base.

3. The brace-to-chord diameter ratio $\beta$ reflects the relative size of brace and chord. The upper limit of the value of $\beta$ is 0.75 determined by the spatial geometric configuration of three-planar tubular Y-joints, as extrapolation regions of each plane even weld seams will overlap if $\beta > 0.75$. In like wise, when $\beta$ is less than 0.4, the braces will lose the function of support and cause large punching pressure on the chord making the lower limit of $\beta$ is 0.4.

4. The brace-to-chord wall thickness ratio $\tau$ is closely related to $\beta$ with a positive correlation: a large value of $\tau$ happens when $\beta$ is large and vice versa. For each value of $\beta$, only five corresponding values of $\tau$ are taken.
(5) The chord outer diameter-to-chord thickness ratio $\gamma$ with a negative correlation about the radial stiffness of the chord reflects the ability to bear the load transmitted by braces. The typical value of $\gamma$ of three-planar tubular Y-joints is $25 \sim 40$ from the statistics of engineering.

(6) The uniplanar Y- and T-joints are often classified into one category in some codes meaning the T-joint is deemed as a special case with $\theta = 90^\circ$ of the Y-joint. However, it can be seen from Fig. 1 that there are apparent differences between three-planar tubular Y-joints and three-planar tubular T-joints in configuration, load condition, force transmission, and so on. In the practical design of OWTs, the typical range of values of $\theta$ is $30^\circ \sim 60^\circ$.

<table>
<thead>
<tr>
<th>Formula</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\gamma$</th>
<th>$\tau$</th>
<th>$\theta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efthymiou</td>
<td>[4, 40]</td>
<td>[0.2, 1.0]</td>
<td>[7.5, 32]</td>
<td>[0.2, 1.0]</td>
<td>[30°, 90°]</td>
</tr>
<tr>
<td>Lloyd’s Register</td>
<td>[4, $-\infty$]</td>
<td>[0.13, 1.0]</td>
<td>[10, 35]</td>
<td>[0.25, 1.0]</td>
<td>[30°, 90°]</td>
</tr>
<tr>
<td>This study</td>
<td>[6, 15]</td>
<td>[0.4, 0.75]</td>
<td>[25, 40]</td>
<td>[0.5, 0.9]</td>
<td>[30°, 60°]</td>
</tr>
</tbody>
</table>

### 3 PARAMETERS STUDY

#### 3.1 Effects of the length-to-outer radius ratio of the chord $\alpha$

The influences of $\alpha$ on SCF distribution of three-planar tubular Y-joints under in-plane bending moment loaded on T1 plane ($\beta = 0.65$, $\gamma = 30$, $\tau = 0.75$, $\theta = 60^\circ$) are shown in Fig. 5, in which (a) and (b) depict SCF distribution on chord and brace sides of T1 plane respectively. Some features can be concluded:

(1) The shape of the SCF distribution curve on the T1 plane is similar to a one-period cosine curve with symmetric to $\phi = 180^\circ$ since the applied in-plane bending moment is symmetric about the T1 plane, however, the left and right half curves of $180^\circ$ are antisymmetric about $\phi = 90^\circ$ and $\phi = 270^\circ$ respectively as the normal stress direction on the cross section of the brace is antisymmetric about the plane of $90^\circ - 270^\circ$ under in-plane bending moment. The peak value of the curve is between $120^\circ - 135^\circ$.

(2) The increase of $\alpha$ has a limited effect on the shape and value of SCF distribution but may cause the uneven distribution to a higher degree. When $\alpha$ changes from 6 to 15, the changes peak and valley value of SCF on the chord side are within 3% and 4% respectively.

(3) The reason for the changing pattern of SCF distribution responding to $\alpha$ can be understood as that a longer chord member has limited effect on the loaded brace since the in-plane bending moment main influence only on the applied plane. The changing pattern of SCF distribution on the brace side is the same as that on the chord side.

![Fig. 5 Effects of $\alpha$ on distributions of SCF](image-url)
3.2 Effects of the brace-to chord diameter ratio \( \beta \)

The influences of \( \beta \) on SCF distribution of three-planar tubular Y-joints under in-plane bending moment loaded on T1 plane \((\alpha = 12, \gamma = 25, \theta = 45^\circ, \tau \text{ changing with } \beta)\) are shown in Fig. 6, in which (a) and (b) depict SCF distribution on chord and brace sides of T1 plane respectively. Some features can be concluded:

1. With the increase in \( \beta \), the shape of the SCF distribution curve on the T1 plane keeps constant, whereas the peak and valley values decrease slightly. Besides, the location of peak value occurs closer to \( \phi = 45^\circ \) accompanied by a small \( \beta \). When \( \beta \) changes from 0.4 to 0.75, the peak and valley value of SCF on the chord side change from 3.2 to 2.7 and 3.0 to 2.5 with a decrease of 16% and 17% respectively.

2. The reason for the changing pattern of SCF distribution responding to \( \beta \) can be understood as that the brace with a larger diameter will cause severer multiplanar interaction making the unloaded braces share more load from loaded braces, thus, leading to a decrease in SCF. The changing pattern on the brace side is the same as that on the chord side.

![Fig. 6 Effects of \( \beta \) on distributions of SCF](image)

### 3.3 Effects of the chord outer diameter-to-thickness ratio \( \gamma \)

The influences of \( \gamma \) on SCF distribution of three-planar tubular Y-joints under in-plane bending moment loaded on T1 plane \((\alpha = 12, \beta = 0.75, \tau = 0.85, \theta = 60^\circ)\) are shown in Fig. 7, in which (a) and (b) depict SCF distribution on chord and brace sides of T1 plane respectively. Some features can be concluded:

1. The increase of \( \gamma \) has a limited effect on the shape of SCF distribution but may cause the distribution more uneven with an almost linear increase in valley and peak value the location of which will be closer to \( \phi = 120^\circ \). When \( \gamma \) changes from 25 to 40, the peak and valley value of SCF on the chord side change from 3.0 to 5.0 and 2.5 to 3.3 with an increase of 70% and 32% respectively.

2. The reason for the changing pattern of SCF distribution responding to \( \gamma \) can be understood as that a chord member with a thinner wall comes with a smaller radial stiffness and can only transmit less load to the constraints of member ends, i.e., the joint and braces will share more load thus provoking increases in SCF. The slenderness affected by \( \alpha \) and the radial stiffness affected by \( \gamma \) is both related to the ability of the chord member to convey loads and produce the same effects on SCF distribution.
3.4 Effects of the brace-to-chord wall thickness ratio \( \tau \)

The influences of \( \tau \) on SCF distribution of three-planar tubular Y-joints under in-plane bending moment loaded on T1 plane \((\alpha = 9, \beta = 0.7, \gamma = 30, \theta = 45^\circ)\) are shown in Fig. 8, in which (a) and (b) depict SCF distribution on chord and brace sides of T1 plane respectively. Some features can be concluded:

1. With the increase of \( \tau \), the shape of SCF distribution is not sensitive, however, the peak and valley values of SCF increase linearly on the chord side and keep stable on the brace side. The location of peak value will be closer to \( \phi = 45^\circ \) along with the growth of \( \tau \). When \( \tau \) changes from 0.7 to 0.9, the peak value of SCF on the chord side change from 2.8 to 3.8 with an increase of 35%. The change of SCF on the brace side is within 5%.

2. The reason for the changing pattern of SCF distribution responding to \( \tau \) can be understood as that a brace member with a thicker wall comes with greater axial stiffness and can transmit more load to the chord member thus provoking SCF peak value increases.

3.5 Effects of the brace-to-chord inclination angle \( \theta \)

The influences of \( \theta \) on SCF distribution of three-planar tubular Y-joints under in-plane bending moment loaded on T1 plane \((\alpha = 9, \beta = 0.6, \gamma = 25, \tau = 0.7)\) are shown in Fig. 9, in which (a) and (b) depict SCF distribution on chord and brace sides of T1 plane respectively. Some features can be concluded:

1. Corresponding to the variation of \( \theta \) from 30° to 60°, the shape of the SCF distribution curve keep stable, however, the peak value of SCF on the chord side increases linearly from 1.8
to 3.6 with an increase of 100% and occurs closer to $\phi = 90^\circ$, while that on the brace side increases from 1.0 to 2.1 with an increase of 110%.

(2) The reason for the changing pattern of SCF distribution responding to $\theta$ can be understood as that the force transmitted from brace to chord increases in a sinusoidal proportion with the increase of $\theta$, i.e., the radial load bearing by chord will increase although the external load is unchanged. Naturally, the value of SCF on chord and brace sides will increase too. The loaded and unloaded braces have the same response to the change of $\theta$.

![Charts showing SCF distributions](image)

Fig. 9 Effects of $\theta$ on distributions of SCF

3.6 Overview of parametric analysis

The summary of the influence of geometric parameters on SCF distribution is presented in Table 2. The sensitivity of SCF to geometric parameters ranked with a reduced sequence is $\theta$, $\gamma$, $\tau$, $\beta$ and $\alpha$. The increase in $\gamma$, $\tau$ and $\theta$ will lead to an increase in SCF. The increase in $\tau$ will increase SCF on the chord side but no obvious change on the brace side.

<table>
<thead>
<tr>
<th>Location</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\gamma$</th>
<th>$\tau$</th>
<th>$\theta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chord side</td>
<td>$\rightarrow$</td>
<td>$\rightarrow$</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
</tr>
<tr>
<td>Brace side</td>
<td>$\rightarrow$</td>
<td>$\rightarrow$</td>
<td>$\uparrow$</td>
<td>$\rightarrow$</td>
<td>$\uparrow$</td>
</tr>
</tbody>
</table>

*'$\uparrow'$ means increase; '$\downarrow'$ means decrease; '$\rightarrow'$ means maintain.

4 CONCLUSIONS

This study investigates the SCF distribution along weld toe curves to calculate HSS of three-planar tubular Y-joints under multiplanar combined loaded conditions. The main conclusions of this study can be summarized:

(1) FE model base is built via a verified numerical method. Sensitive analyses of five geometric parameters affecting the shape and value of SCF distribution are carried out.

(2) In the condition of in-plane bending moment applied on a single brace of a three-planar tubular Y-joint, the sensitivity of SCF to geometric parameters ranked from high to low is $\theta$, $\gamma$, $\tau$, $\beta$ and $\alpha$. This can be used in further work of deduce the SCF distribution formula.

(3) The shape of the SCF distribution curve on the T1 plane is similar to a one-period cosine curve with symmetric to $\phi = 180^\circ$ since the applied in-plane bending moment is symmetric about the T1 plane.
5 ACKNOWLEDGEMENTS

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6 REFERENCES

These proceedings contain the papers at the TENTH INTERNATIONAL CONFERENCE ON ADVANCES IN STEEL STRUCTURES (ICASS 2020) held in Chengdu, China, from 21 to 23 August 2022. The international conference series on Advances in Steel Structures was initiated in 1996 under the support of The Hong Kong Polytechnic University, which remains very active in fostering its continuation - joined a few years later by the Hong Kong Institute of Steel Construction.

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