Experimental and Numerical Investigation of Geometric SCFs in Internally Ring-Stiffened Tubular KT-Joints of Offshore Structures

Ahmadi, Hamid*; Lotfollahi-Yaghin, Mohammad Ali

Faculty of Civil Engineering, University of Tabriz, Tabriz, IR Iran

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Abstract
Tubular KT-joints are quite common in offshore structural design and despite the crucial role of stress concentration factors (SCFs) in evaluating the fatigue performance of tubular joints. However, the SCF distribution in internally ring-stiffened KT-joints have not been investigated and no design equation is currently available to determine the SCFs for this type of joint. In the present paper, results of experimental and numerical investigations of the SCF distribution in internally ring-stiffened tubular KT-joints are presented. In this research, experimental study has been followed by a set of parametric stress analyses for 118 steel ring-stiffened KT-joints subjected to balanced axial loads. The analysis results are used to present the general remarks on the effect of geometrical parameters on the SCF distribution along the weld toe and to establish a new set of SCF parametric equations for the fatigue design of internally ring-stiffened KT-joints.

Keywords: Fatigue, Stress concentration factor (SCF), Tubular KT-joint, Internal ring-stiffener, Parametric design equation

1. Introduction

Offshore jacket-type platforms are mainly fabricated from tubular members by welding one end of the branch member (brace) to the undisturbed surface of the main member (chord), resulting in what are known as tubular joints. The static and fatigue strengths of tubular joints are the governing factors in the design of offshore steel structures.

Significant stress concentrations at the vicinity of the welds are considerably detrimental to the fatigue performance of the joints. Since, offshore structures are subjected to cyclic wave loading, it is imperative that these structures be designed for long fatigue life. Hence, it is important to accurately determine the magnitude of stress concentration and to reduce it to a reasonable level. In the design practice, a parameter called the stress concentration factor (SCF) is used to evaluate the magnitude of the stress concentration. The SCF is the ratio of the local surface stress to the nominal direct stress in the brace and its value depends on the joint geometry, loading type, weld size and type and the considered location around the weld.

If the capacity of a joint is found to be inadequate during the design stage proper method for its
correction must be applied. For example, if the chord thickness requirement is beyond the forming limits of fabricators, it can be enhanced by introducing stiffeners to the inside of the chord as this is an efficient method to reduce stress concentration, increase load-carrying capacity and fatigue life of joint, decrease the bending stress in tube walls and avoid attraction of additional wave forces and corrosion attack. These types of joints are called internally ring-stiffened joints (Fig. 1).

The value of SCF along the weld toe of a tubular joint is mainly determined by the joint geometry under any specific loading condition. In order to study the behavior of tubular joints and to relate this behavior easily to the geometrical properties of the joint, a set of dimensionless geometrical parameters were defined. Figure 1 shows an internally ring-

stiffened tubular KT-joint with the geometrical parameters ($\tau$, $\gamma$, $\eta$, $\beta$, $\zeta$, $\alpha$, and $\alpha B$) for chord and brace diameters $D$ and $d$, and their corresponding wall thicknesses $T$ and $t$.

Although, the tubular KT-joints are quite common in practice and despite the crucial role of SCFs in evaluating the fatigue performance of tubular joints, stress distribution in internally ring-stiffened KT-joints has not been investigated so far and no design equation is currently available to determine the SCFs for this type of joint. In the present paper, results of experimental and numerical investigations of the SCF distribution in internally ring-stiffened tubular KT-joints are presented. In this research, experimental study was followed by a set of parametric stress analyses for 118 steel ring-stiffened tubular KT-joints subject to balanced axial loading.

**Fig. 1:** Geometrical notation for an internally ring-stiffened KT-joint under balanced axial loads
The analysis results were used to present general remarks on the effect of geometrical parameters including \( \tau \) (brace-to-chord thickness ratio), \( \gamma \) (chord wall slenderness ratio), \( \eta \) (ring-to-chord width ratio), \( \beta \) (brace-to-chord diameter ratio), and \( \theta \) (outer brace inclination angle) on the SCF distribution along the weld toe. Since the vertical (central) brace SCFs are generally much bigger than the inclined (outer) brace SCFs, the present study was focused only on the SCF distribution along the weld toe of the intersection between the central brace and the chord. Based on the results of ring-stiffened KT-joint finite element (FE) models which were verified against experimental measurements, a comprehensive SCF database was constructed and a new set of SCF parametric equations was established, through nonlinear regression analysis, for the fatigue design of internally ring-stiffened KT-joints. An assessment study of these equations was conducted based on the acceptance criteria proposed by the UK DoE (1983).

Significant effort has been devoted over the past four decades to the study of SCFs in various unstiffened joints. Nevertheless, very few investigations have been reported for stiffened joints due mainly to the geometrical complexity and the vast variety of possible stiffening arrangements.

Dharmavasan and Aaghaakouchak (1988) showed that in the case of axial and Out-of-Plane Bending (OPB) loadings, careful positioning of the stiffeners greatly reduced the stress concentrations and gave a more uniform stress distribution around the intersection. Various stiffener sizes and configurations were analyzed and recommendations made on the optimum design. Aaghaakouchak and Dharmavasan (1990) presented an improved FE technique consisting of 3-D brick and semi-loof shell elements. Ramachandra et al. (1992) investigated the effect of geometrical parameters on the SCFs in ring-stiffened tubular T- and Y-joints. They proposed a set of parametric equations for the prediction of maximum SCFs under axial, In-Plane Bending (IPB), and OPB loadings. Using degenerate shell elements, Nwosu et al. (1995) studied the stress distribution along the intersection of internally ring-
stiffened tubular T-joints, under the action of axial, IPB, and OPB loads. The effects of stiffener size, location and number have been investigated in this study. Ramachandra et al. (2000) investigated the effect of internal ring stiffeners on the fatigue strength of tubular T- and Y-joints. Hoon et al. (2001) studied the SCF distributions along the intersections of a doubler-plate reinforced T-joint subjected to combined loadings. Myers et al. (2001) investigated the effects of three different longitudinal stiffeners on the stress concentration factors in jack-up chords. The constant thickness continuous stiffener returned the best performance when compared to the dual thickness stiffener (rack/rib plate) and the non-continuous stiffener. Woghiren and Brennan (2009) proposed a set of parametric equations to predict the SCFs in multi-planar tubular KK-joints stiffened by rack plates.

2. Experimental Investigation of the SCF Distribution in Ring-Stiffened KT-Joints

2.1. Details of Specimens

Two steel KT-joint specimens were fabricated for the purpose of experimental tests in order to investigate the effect of internal ring-stiffeners on the SCF distribution along the weld toe of tubular KT-joints. Fabricated specimens were of the same size with identical geometrical characteristics. The only difference between the two specimens was the presence of internal ring-stiffeners in the second specimen. Geometrical details of the internally ring-stiffened specimen are presented in Figure 2. As shown in this figure, three ring-stiffeners were used in the present study for each brace. One of them was placed at the saddle position and the other two were welded at the crown positions.

2.2. Test Setup and Loading Scheme

The two fabricated specimens were tested using a hydraulically controlled test rig. Both ends of the chord and upper ends of the outer (inclined) braces...
were welded onto the flat plates and bolted directly to two standing supports as shown in Figure 3. The static loading was applied at the end of the central (vertical) brace. In order to guarantee the accuracy and reliability of recorded data, 6 different magnitudes were chosen for the applied axial load (Table 1) and for each application, output data from strain gauges were recorded 10 times in 5 sec intervals.

![Figure 2: Geometrical details of the internally ring-stiffened KT-joint specimen](image1)

![Figure 3: Test setup](image2)

Table 1: Axial loads applied on the central brace in stiffened and unstiffened specimens

<table>
<thead>
<tr>
<th>Nominal stress, ( \sigma_n ) (MPa)</th>
<th>±5</th>
<th>±10</th>
<th>±15</th>
<th>±20</th>
<th>±25</th>
<th>±30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied load, ( F_a ) (kN)</td>
<td>11.95</td>
<td>23.9</td>
<td>35.85</td>
<td>47.8</td>
<td>59.75</td>
<td>71.7</td>
</tr>
</tbody>
</table>
2.3. Strain Gauge Locations and SCF Extraction Procedure

In the present study, the strain gauges were placed around the entire brace/chord intersection at 30° intervals. As shown in Figure 4a, two strain gauges were used at each location to measure the strain components perpendicular to the weld toe. The arrangement of the two strain gauges followed the linear extrapolation procedure recommended by IIW-XV-E (1999). The first extrapolation point is at a distance of 0.4T from the weld toe, and the second point lies at 1.0T further from the first point (Fig. 4b). The hot-spot strain ($\xi_\perp$) was obtained by linear extrapolation of the results from these two strain gauges to the weld toe. At four typical positions, i.e. two crowns and two saddles, another pair of strain gauges were glued onto the surface of the chord along the direction parallel with the weld toe to measure the parallel components of the strain at the extrapolation points. Again, parallel component ($\xi_n$) of the strain at the weld toe was obtained by linear extrapolation of these two parallel strain gauge results to the weld toe. It must be noted that sufficiently small strain gauges should be used to avoid averaging high and low strains in the regions of steep gradients.

After recording the data from strain gauges, the strain concentration factors (SNCFs) were calculated using the following equation:

$$\text{SNCF} = \frac{\xi_\perp}{\xi_n} \quad (1)$$

Where $\xi_n$ is the nominal strain that is obtained from the measurement of four strain gauges which are glued onto the surface of the loaded brace at the midpoint.

For the four typical positions along the weld toe, SCFs were calculated using the following equation:

$$\text{SCF} = \text{SNCF} \times \frac{1+(V\xi_n/\xi_\perp)}{1-V^2} \quad (2)$$

Where $V$ is Poisson’s ratio. For other positions along the weld toe, SCFs were derived using the SCF/SNCF ratio which was obtained by averaging the SCF/SNCF ratios at the four typical positions. In the present study, average ratios were 1.20 and 1.25 for unstiffened and stiffened specimens, respectively.

![Image](image_url)

**Fig. 4:** (a) Plan view of the strain gauge locations along the weld toe, (b) Extrapolation procedure recommended by IIW-XV-E (1999)

2.4. Results and Discussion

Figure 5 illustrates the SCF distribution along the weld toe on the chord surface of the unstiffened and stiffened KT-joint specimens. In this figure, experimental data and FE results have been compared. Due to the symmetry in the joint geometry and loading, the SCF distribution along the weld toe is symmetric and only one fourth of the whole 360° brace/chord intersection, between the crown and saddle positions, is required to be considered. As shown in Figure 5, there is a good
agreement between the test results and FE predictions in both unstiffened and stiffened joints (Fig. 5). Hence, generated FE models could be considered to be accurate enough to produce valid results. Details of FE analysis are discussed in Section 4. It can be clearly concluded from comparing the SCF distributions in stiffened and unstiffened joints that, internal ring-stiffeners can effectively reduce the stress concentration along the brace/chord intersection and consequently, improve the fatigue performance of the tubular joint. It can also be seen that the presence of stiffeners have resulted in the change of peak SCF location from the saddle position to $\phi = 60^\circ$. This result means that the position from which the fatigue cracks initiate could be different in stiffened and unstiffened KT-joints subjected to axial loading. As depicted in Figure 5, the SCF distribution along the weld toe of the stiffened joint is much more uniform than the distribution in the unstiffened joint. This observation is a result of using the stiffeners at both saddle and crown positions and means that the applied load on the brace transfers to the chord in nearly equal proportions through the intersection. The difference between the SCFs in stiffened and unstiffened joints is larger at locations adjacent to the saddle position. This result implies that the stiffener located at the saddle position is more effective than the stiffeners welded at the crown positions in reducing the SCFs along the weld toe.

### 3. SCF Numerical Analysis of Ring-Stiffened KT-Joints

#### 3.1. Important Modeling Considerations

In the present study, the multi-purpose FEM-based software package, ANSYS was used for the numerical modeling and analysis of internally ring-stiffened tubular KT-joints, subjected to balanced axial loading (Fig. 1a), in order to investigate the SCF distribution along the weld toe. During the FE modeling of an internally ring-stiffened tubular joint, there were two subjects that needed careful attention: (a) accurate simulation of the weld profile and (b) correct modeling of the interaction between the chord and the stiffener, when direct merging should be avoided in order to provide high-quality mesh along the brace/chord intersection.

In this study, the welding size along the brace/chord intersection satisfied the AWS D 1.1 specifications (2002). Modeling of the weld profile according to AWS D 1.1 (2002) has been extensively discussed by Lotfollahi-Yaghin and Ahmadi (2010).

The chord and stiffener were meshed separately and then the ANSYS contact capability was used to define the interaction between them.

Due to the XY-plane symmetry in the joint geometry and loading, only half of the entire ring-stiffened KT-joint is required to be modeled (Fig. 6a).

#### 3.2. Mesh Generation

In the present study, ANSYS element type SOLID95 was used to model the chord, brace, stiffener, and the weld profile. The element is defined by 20 nodes having three degrees of freedom per node and may have any spatial orientation. In order to guarantee the mesh quality, a sub-zone mesh generation method was used during the FE modeling. The mesh generated by this method for an internally ring-stiffened tubular KT-joint is shown in Figure 6.
4. Effects of Geometrical Parameters on the SCF Distribution

4.1. Parametric Study

In order to investigate the stress concentration in internally ring-stiffened tubular KT-joints, 118 models were generated and analyzed using the multi-purpose FEM-based software package, ANSYS. The objective was to study the effect of non-dimensional geometrical parameters on the SCF distribution along the weld toe of the central brace in the joints subjected to balanced axial loading (Fig. 1a). Different values assigned to each dimensionless parameter were as follows: $\eta = 0.1, 0.15, 0.2$; $\beta = 0.4, 0.5, 0.6$; $\gamma = 12, 18, 24$; $\tau = 0.4, 0.7, 1.0$; $\theta = 30^\circ, 45^\circ, 60^\circ$. These values cover the practical ranges of the normalized parameters typically found in ring-stiffened tubular joints of offshore jacket-type structures. Three ring-stiffeners were used for each brace in all models: one at the saddle position and the other two at the crown positions.

The 118 generated models spanned the following ranges of the geometric parameters:

\begin{align*}
0.1 & \leq \eta \leq 0.2 \\
0.4 & \leq \beta \leq 0.6 \\
12 & \leq \gamma \leq 24 \\
0.4 & \leq \tau \leq 1.0 \\
30^\circ & \leq \theta \leq 60^\circ
\end{align*}  \quad (3)

4.2. Effect of internal ring-stiffeners on SCFs

The SCF distribution along the weld toe in two stiffened and unstiffened tubular KT-joints are compared in Figure 7a. The polar angle ($\phi$) along the 360° curve of the weld path is measured from the...
crown position. Hence, values of $\varphi$ are $0^\circ/180^\circ$ at the
crowns and $90^\circ/270^\circ$ at the saddles. It could be
observed that in the unstiffened joint, the peak SCF
is located at the saddle position, while in the
stiffened joint it is located at the crown position. It is
also clear that the shapes of SCF distributions in
stiffened and unstiffened joints are quite different.
These two observations highlight the necessity of
investigating the SCF distribution instead of studying
the SCFs at typical positions, such as the saddle and
crown. As shown in Figure 7b, the SCF in an
unstiffened KT-joint is 4.5 times bigger than the SCF
at the same position in the corresponding ring-
stiffened joint. This result indicated that, if the SCF
design equations developed for the unstiffened KT-
joints were used for the SCF calculation in the
stiffened joints, obtained SCFs could be unrealistic
and highly conservative. Hence, it was necessary to
develop SCF formulae specially designed for ring-
stiffened tubular KT-joints. It can also be seen that the
difference between the SCFs in stiffened and
unstiffened joints was larger at locations adjacent to
the saddle position. This observation was in
agreement with the experimental results (Section 3.4).

4.3. Effect of the $\gamma$ on the SCF Distribution along the
Weld Toe

Since the parameter $\gamma$ is the ratio of radius to
thickness of the chord, the increase of the $\gamma$ in the
models having fixed value of the chord diameter
leads to the decrease of the chord thickness.

The increase of the $\gamma$ leads to an increase in SCFs
at all positions along the weld toe. For small values
of the $\tau$ (say $\tau = 0.4$), the peak SCF is always located
at the saddle position regardless of the value of the $\gamma$.
But for intermediate and big values of the $\tau$ (say $\tau = 0.7, 1.0$), change of the $\gamma$ can result in displacing the
peak SCF position.

4.4. Effect of the $\tau$ on the SCF Distribution along the
Weld Toe

The parameter $\tau$ is the ratio of brace thickness to
chord thickness and the $\gamma$ is the ratio of radius to

4.5. Effect of the $\eta$ on the SCF Distribution along the
Weld Toe

Results of investigating the effect of the $\eta$ on the
SCF distribution along the weld toe are discussed in
the present section. In this study, the interaction of
the $\eta$ with the other geometrical parameters was also investigated. The parameter $\eta$ is the ratio of the stiffener width (height) to the chord diameter. Hence, providing that the value of the chord diameter remains unchanged, the increase of the $\eta$ leads to the increase of the stiffener width. Three charts are presented in Figure 8, as an example, showing the distribution of SCFs along the weld toe for the 9 of analyzed models. These charts illustrate the effect of the $\eta$ and its interaction with the $\tau$. Each chart in Figure 8 shows the SCF distributions for three different values of $\eta$ (0.1, 0.15, and 0.2). Values of the parameters $\beta$, $\gamma$, and $\theta$ are identical in all three presented charts and the value of $\tau$ in Figure 8a-c is 0.4, 0.7, and 1.0, respectively.

For small values of the $\tau$ (say $\tau = 0.4$), the peak SCF is always located at the saddle position regardless of the value of the $\eta$. The increase of the $\eta$, from 0.1 to 0.2, leads to a decrease in SCFs at all positions along the weld toe. This result is independent from values of the other geometrical parameters. Although the increase of the $\eta$ affects the magnitude of SCFs, it usually does not have remarkable influence on the shape of the SCF distribution along the weld toe.

4.6. Effect of the $\beta$ on the SCF Distribution along the Weld Toe

Since the parameter $\beta$ is the ratio of the brace diameter to the chord diameter, the increase of the $\beta$ in a model with fixed value of the chord diameter leads to an increase in the brace diameter. A total of 36 comparative charts were used to study the effect of the $\beta$. These charts are not presented here for the sake of brevity.

The increase of the $\beta$, from 0.4 to 0.6, resulted in the increase of SCFs at all positions along the weld toe. This conclusion was independent from values of the other geometrical parameters. For small values of the $\gamma$ (say $\gamma = 12$), increase of the $\beta$ did not have remarkable influence on the shape of the SCF distribution along the weld toe. But for intermediate and big values of the $\gamma$ (say $\gamma = 18$, 24), the shapes of SCF distributions could be quite different in the joints having different values of the $\beta$.

![Figure 8: Effects of the $\eta$ on the SCF distribution along the weld toe and its interaction with the $\tau$](image)
4.7. Effect of the $\theta$ on the SCF Distribution along the Weld Toe

It can be concluded by investigating the effect of the outer brace inclination angle ($\theta$) on the SCF distribution that, as it was expected, this parameter did not have remarkable influence on either the magnitude or the distribution pattern of SCFs along the weld toe of the central brace. This conclusion was independent from values of the other geometrical parameters.

5. Parametric Design Equations

After performing a large number of nonlinear regression analyses by the statistical software package SPSS, following geometrically parametric equations are proposed for predicting the SCF distribution along the weld toe and the peak weld-toe SCF in internally ring-stiffened tubular KT-joints subjected to balanced axial loading:

**SCF distribution along the weld toe:**

$$SCF = [\xi_1(\tau, \beta) + \xi_2(\gamma, \beta) \xi_3(\beta) \xi_4(\varphi)] \xi_5(\theta) \xi_6(\gamma, \tau, \gamma, \beta) \quad R^2 = 0.915$$

where functions $\xi_1 - \xi_6$ are expressed as follows:

$$\xi_1(\tau, \beta) = 0.198 - 0.009 \tau + 0.310 \beta + 0.920 \tau \beta$$

$$\xi_2(\gamma, \beta) = (1.203 \gamma^{0.001} - 1.202) \cdot (1.146 \gamma^{1.426} - 61.095)$$

$$\xi_3(\beta) = (1.416 \beta^{0.450} + 1.784) \cdot (2.892 \beta^2 + 2.874 \beta + 1.904)$$

$$\xi_4(\varphi) = -0.260 \sqrt{\varphi} + 0.397 \sin(1.218 \varphi) - 4.302 \cos(0.180 \varphi) + 4.577$$

$$\xi_5(\theta) = 1 + 6.559 \theta^{1.303} + 2.402 \cos \theta + 8.022 \sin \theta$$

$$\xi_6(\gamma, \tau, \gamma, \beta) = 1 + 0.841 \gamma^{14.616} - 1.493 \tau \gamma - 0.049 \eta \gamma + 0.320 \eta \beta - 0.291 \eta \theta$$

**Peak SCF along the weld toe:**

$$SCF_{\text{max}} = 0.304 \gamma^{0.768} \eta^{0.993} \beta^{0.244} \eta^{-0.307} \theta^{-0.060} \cdot (1 - 0.954 \eta \tau - 0.096 \eta \gamma + 2.447 \eta \beta + 0.025 \eta \theta) \cdot R^2 = 0.909$$

In Eqs. (4) and (6), $R^2$ denotes the coefficient of correlation and its value is considered to be acceptable for both equations regarding the complex nature of the problem. The parameter $\varphi$ ($0^\circ \leq \varphi \leq 180^\circ$) in Eq. (5.4) and the parameter $\theta$ in Eqs. (5.5) and (6) should be inserted in radians. The validity ranges of dimensionless parameters for the proposed equations have been given in Eq. (3).

The UK Department of Energy (UK DoE) (1983) recommended the following assessment criteria regarding the applicability of the commonly used SCF parametric equations (P/R stands for the ratio of the predicted SCF from a given equation to the recorded SCF from test or analysis):

- If the acceptance criteria were nearly met i.e. $25\% < \% P/R < 30\%$, and/or $5\% < \% P/R < 7.5\%$, then the equation was regarded as borderline and engineering judgment must be used to determine acceptance or rejection.

- Otherwise reject the equation as it is too optimistic.

In view of the fact that for a mean fit equation, there is always a large percentage of under-prediction, the requirement for joint under-prediction, i.e. $P/R < 1.0$, can be completely removed in the assessment of parametric equations (Bomel Consulting Engineers, 1994). Assessment results according to the UK DoE criteria [1] are presented in Table 2.

<table>
<thead>
<tr>
<th>Equation</th>
<th>Conditions</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>$% P/R &lt; 0.8$</td>
<td>$% P/R &gt; 1.5$</td>
<td></td>
</tr>
<tr>
<td>Eq. (4)</td>
<td>$17.4% &gt; 5%$</td>
<td>$2.5% &lt; 50%$ OK. Revise</td>
</tr>
<tr>
<td>Eq. (6)</td>
<td>$2.8% &lt; 5%$ OK</td>
<td>$0% &lt; 50%$ OK. Accept</td>
</tr>
</tbody>
</table>
As can be seen in Table 2, Eq. (6) satisfied the UK DoE criteria, but Eq. (4) required revision. In order to revise the Eq. (4), SCF values obtained from this equation were multiplied by a coefficient in such a way that resulted SCF set would satisfy the UK DoE acceptance criteria. This idea could be expressed as follows:

Design factor = SCF_{Design} / SCF_{Eq. (4)}

where values of SCF_{Eq. (4)} were calculated from the proposed equation and the values of SCF Design were expected to satisfy the UK DoE criteria.

Multiple comparative analyses were carried out to determine the optimum value of design factor. Following equations should be used for design purposes:

\[
SCF_{Design} = 1.32 \times SCF_{Eq. (4)}
\]

\[
SCF_{Design} = 1.00 \times SCF_{Eq. (6)}
\]

6. Conclusions

Results of experimental and numerical investigations of the SCF distribution in internally ring-stiffened tubular KT-joints were presented in this paper. Numerical results from analyzing 118 FE models were used to present general remarks on the effect of geometrical parameters on the SCF distribution along the weld toe of the central brace and to establish parametric SCF equations for the fatigue design. Main conclusions are summarized as follows:

The presence of internal ring-stiffeners, depending on the values of geometrical parameters, might lead to the disposition of the peak SCF along the weld toe. The shapes of SCF distributions in stiffened and unstiffened joints could also be quite different. The SCF distribution along the weld toe of a stiffened joint was usually much more uniform than the distribution in its corresponding unstiffened joint. This behavior was a result of using the stiffeners at both saddle and crown positions. These results highlighted the necessity of investigating the SCF distribution instead of studying the SCFs at typical positions such as the saddle and crown. SCFs in an unstiffened KT-joint are generally much bigger than the SCFs at the same positions in the corresponding ring-stiffened joint. This observation implied that the use of SCF design equations which were developed for the unstiffened KT-joints generally led to over-predicting and highly conservative SCFs for stiffened joints. Hence, it was necessary to develop SCF formulae specially designed for ring-stiffened tubular KT-joints.

The increase in the $\gamma$ and/or $\tau$ and also the increase of the $\beta$ led to the increase of SCFs at all positions along the weld toe. The magnitude of the increase in SCF values due to the increase of the $\tau$ was highly remarkable in comparison with the other geometrical parameters. For small values of the $\tau$, the peak SCF was always located at the saddle position regardless of the value of the $\gamma$. But for intermediate and big values of the $\tau$, change of the $\gamma$ could result in displacing the peak SCF position. For small values of the $\gamma$, increase of the $\beta$ did not have remarkable influence on the shape of the SCF distribution along the weld toe. But for intermediate and big values of the $\gamma$, the shapes of SCF distributions could be quite different in the joints having different values of the $\beta$.

The increase of the $\eta$ led to a decrease in SCFs at all positions along the weld toe. The parameter $\theta$ did not have remarkable influence on either the magnitude or the distribution pattern of SCFs along the weld toe of the central brace.

Relatively high coefficients of correlation and the satisfaction of acceptance criteria recommended by UK DoE guaranteed the accuracy of the proposed equations. Hence, the developed formulae could reliably be used for the fatigue design of offshore jacket-type structures.

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