Review on Factors Governing Stress Concentration Factor at Tubular Joints

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ABSTRACT

Tubular structures have become so much in use because of their structural performance and attractive appearance. But at the intersections of these tubular structures (i.e., tubular joints), there is stress concentration which adds the fatigue damage in structures which is exposed to cyclic loads. The stress concentration factor plays a crucial role in the computation of fatigue life of tubular structures exposed to cyclic loads. This paper aims to review the factors governing stress concentration factor at tubular joints.

Keywords: Tubular Joints, Stress Concentration Factor, Hot Spot Stress.

1 Introduction

Tubular structures are being commonly used in trusses, offshore constructions, high rise building etc. because of their structural performance and attractive appearance. The intersections of these tubular structures are called tubular joints. Stress concentrations which usually occur at the tubular joints due to the irregularities and geometric discontinuities such as holes, grooves, welds etc. Tubular members exposed to cyclic loads are susceptible to fatigue damages at stress levels lower than the nominal stress. The critical location for the initiation of fatigue failure is at the tubular joints. Stress Concentration Factor (SCF) which is the ratio between hot spot stress and nominal stress, where hot spot stress is the highest stress which occurs at geometric discontinuities like welds, hole, grooves etc. and nominal stress is the stress calculated on the basis of the net cross section of the specimen without considering the geometric discontinuities. By computing SCF, the hot spot stress at the joints could be found out. The SCF is very sensitive in the computation of fatigue life of structures. Hence, it is important to find the factors governing the stress concentration factors at tubular joints.

2 SCF at Tubular Joints

Extensive research has been conducted on the factors affecting the computation and magnitude of SCF. Important factors governing the computation of SCF are method of computation such as empirical, numerical and experimental method, type of loading, non- dimensional geometrical parameters, weld geometry, presence of notch, concrete Filled Chord (CFC) and wrapping the joints with fibre Reinforced Polymer (FRP).

2.1 Method of Computation of SCF

SCF can be computed using Experimental, Numerical and Empirical methods. In the experimental method, strain gauges are attached on every location where the stress is to be calculated. The nominal stress is then calculated by multiplying the modulus of elasticity of the material and the strain calculated. The method gives accurate SCFs but it has practical difficulties. Numerical methods make use of finite element analysis packages such as ANSYS, ABAQUS etc. Empirical methods involve the use of parametric equations to compute SCF. However different methods give differences in SCF.

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Kuang et al. (1977) developed parametric equations for SCFs at T/Y, K and KT joints. The equation specifies only the chord side SCFs and brace side SCFs. No specific location for the SCFs, were proposed. The values estimated for various joints and load cases either over estimated or underestimated the SCF.

Efthymiou and Durkin (1985) developed parametric equations for SCFs at T/Y and K joints using a finite element program (FEA) called PMB SHELL. The tubular joint was welded for the analysis, as the weld profile around the joint was observed to affect the results. Hellier et al. (1990) developed empirical equations for SCFs at Y- and T-joints of a wide range of joint geometries under axial loading, in-plane bending (IPB) and out-of plane bending (OPB). According to the study, the empirical equations normally under predict the SCFs. Lloyd's Register of Shipping for the Health and Safety Executive (1997) did an assessment of simple joint SCF equations. According to their study, the parametric equations generally under predicted around 0% to 40% of the SCFs measured. The under prediction was attributed to the different equations used, joint configurations, different load cases and the locations at which the SCFs were measured.

Ahmadi et al. (2011) developed empirical equations for SCFs at double KT (DKT)- joints under balanced axial loads. When the equations proposed for KT- joints were used to calculate the SCFs of DKT- joints, it was found that there is a considerable under prediction. This suggests that, different equations should be used for the different joints. Haghpanahi and Pirali (2006) did a comparison between SCFs at a T- joint under axial loading and IPB, using empirical equation and numerical study conducted in ANSYS. There was a good agreement between the SCFs computed using empirical and numerical methods. Musa and Mashiri (2019) investigated the variation of the maximum Stress Concentration Factor (SCF_{max}) with the non-dimensional geometrical parameters in steel circular hollow section brace welded to concrete filled circular section chord (CHS-to-CFCHS) T-joints under IPB and OPB in ABAQUS. They developed empirical equations for SCFs from the FEA results using multiple regression analysis and they were verified using the experimental results. The results showed a good agreement between the SCF_{max} computed from the empirical equations, FEA and those determined from the experiments. Matti and Mashiri (2020) did experimental, numerical (ABAQUS) and empirical studies on square hollow section Square Hollow Section (SHS) T-joints subjected to OPB. The studies were done to find the maximum SCFs and there was a good agreement between the results from the 3 methods.

2.2 Effect of loading

The stress variation at a tubular joint is related to load combination of three basic load modes. which are axial loads (AL), in plane moments or in plane bending (IPB) and out of plane moments or out of plane bending (OPB) as shown in Figure 1.

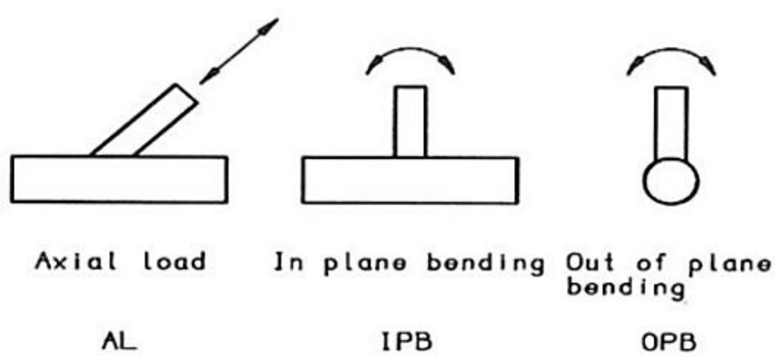

Figure 1. Type of Loading (Source: Haghpanahi and Pirali 2006).

Spyros et al. (2000) did an FEA (I-DEAS) to compute the SCFs at steel gap K-joints subjected to IPB. The location of maximum SCF was found from the 10 locations (5 on chord side and 5 on brace side) identified. It was found that for K-joint under IPB, the critical point is crown toe for chord side and crown heel for brace side. Haghpanahi and Pirali (2006) conducted FEA (ANSYS) to compute SCFs at T-joint subjected to axial loading, IPB and combined axial loading and IPB. The critical points under axial loading and IPB were at saddle point and midway between the crown and the saddle points respectively. It was concluded that the location of the critical points depended on non- dimensional geometrical parameters also. In the case of combined loading, the location of the critical points depended on axial to IPB ratio. Musa and Mashiri (2019) carried out FEA (ANSYS) to compute SCFs at CHS-to-CFCHS T-joints subjected to IPB and OPB. The critical points under IPB and OPB were at the crown tension side and saddle tension side of the intersections respectively.

2.3 Effect of Non- Dimensional Geometrical Parameters

The non- dimensional geometrical parameters (β, τ, γ, α, θ) of a T/Y joint are shown in Figure 2.

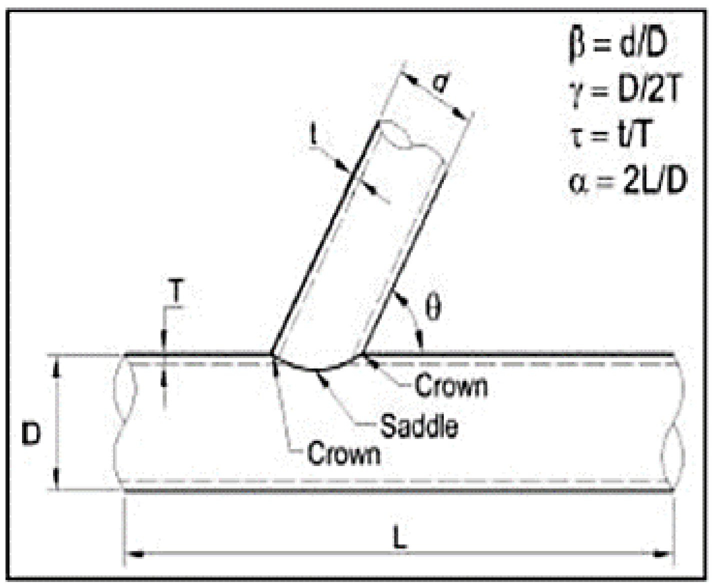

Figure 2. Geometrical Parameters for a Joint (Source: Haghpanahi and Pirali 2006).

The geometric parameters needed to define each joint type, e.g. chord diameter (D), chord thickness (T), brace diameter (d), brace thickness (t), etc. are also defined in Figure 2. Many researches have been carried out to study the effect of non- dimensional geometrical parameters on the distribution of SCFs of tubular joints under different loads. Hellier et al. (1990) presented a paper on SCF to study the effect of non- dimensional geometrical parameters of Y and T-joints subjected to axial loading, IPB and OPB, using 'PAFEC' finite element package and empirical equations such as Kuang's equations, Wordsworth/Smedley equations and Gibstein formulae. With an increase in β, the SCF values increased at first but then decreased for all empirical equations except Kuang equation for which the SCF decreased from the beginning. As τ and γ increased SCF also increased. Ali et al. (2010) contributed a paper on the effect of non- dimensional geometrical parameters of T-joints subjected to balanced axial loading using ANSYS finite element package. It was concluded that as τ or γ increases, SCFs also increased at all locations along the weld toe, and as β increased SCFs decreased at the saddle and crown heel locations. Ahmadi et al. (2011) conducted a research on the effect of non- dimensional

geometrical parameters of DKT and KT- joints subjected to balanced axial loads using ANSYS. The maximum SCF was located near the saddle for most cases. For the the cases with smaller γ, the maximum SCF was between the saddle and crown heel positions. As β increased, the SCFs at the saddle and crown heel decreased and as τ and γ increased the SCFs at all locations around the weld toe increased. Kumar et al. (2019) studied the effect of non- dimensional geometrical parameters of CHS T/Y- joints subjected to IPB using ABAQUS. For β variation, the SCF_{max} on brace increased at first, attained the maximum value but then decreased except for θ = 30°. SCF_{max} on brace increased as τ increased and the maximum SCFs were observed when τ = 1 (when the brace thickness was equal to the chord thickness). For γ variation also, a similar trend as τ was observed.
Musa and Mashiri (2019) published a paper on the effect of non- dimensional geometrical parameters of CHS-to-CFCHS T- joints subjected to IPB and OPB using ANYSYS. The SCFs of concrete filled joints were compared with the empty joints as proposed by CIDECT (Committee for International Development and Education on Construction of Tubular structures). As τ and γ increased, the SCF_{max} also increased for the cases of IPB and OPB for both concrete filled and empty T-joints. As β increased, SCF_{max} increased first and then decreased. It was also concluded that the trend shown by the variation of SCF_{max} with the geometrical parameters were the same for both CFCHS and empty CHS joints. Hosseinia et al. (2020)) investigated the effect of non- dimensional geometrical parameters of CHS Glass Fibre Reinforced Polymer (GFRP) T- joints subjected to axial loading using experimental method. The study was done to evaluate the effect of FRP materials on the non- dimensional geometrical parameters. As β increased the effectiveness of FRP in the reduction of SCF at saddle point also increased, and the reduction was about 45% at the saddle point and at the crown point, the most reduction was around 11% for β=0.5. As τ and γ increased the effectiveness of FRP in reducing SCF was increased at the crown point, but the at the saddle point the reduction in SCF was not very significant.
Matti and Mashiri (2020) studied the effect of non- dimensional geometrical parameters of SHS T-joints subjected to static OPB using experimental, numerical and empirical methods. As β increased, the SCFs first increased and then decreased. The maximum SCFs were generally observed at β equal to 0.5 and 0.75. With the increase in γ and τ, the SCFmax also increased.

2.4 Effect of concrete

Concrete filling in Chord has been used in tubular joints to reduce SCFs as it improves the tube stiffness. Mashiri and Zhao (2010) studied the effect of concrete filling in SHS T- joint under IPB, and it was found that concrete filling can effectively reduce the stress concentration. The average reduction in SCF was found to be around 40%. Jiang et al. (2018) investigated the effect of concrete filling in 90° SHS-to-CFSHS X- joints subjected to axial tensions using ABAQUS. The SCF obtained from FEA were validated using the experimental results. When the results obtained from analysis of concrete filled joints were compared with the SCFs at empty joints, an SCF reduction of about 10–26% was observed, implying a better fatigue life. Musa et al. (2018) conducted a study on the effect of concrete filling in CHS-to-CFCHS T- joints subjected to axial tension, axial compression, IPB and OPB using experimental method. The SCF at the concrete filled joints were compared with SCFs at empty T-joints. The results implied a reduction in SCF at concrete filled joints. The reduction was more prominent under axial tension.
Musa et al. (2018) studied the effect of concrete filling in CHS-to-CFCHS T- joints subjected to axial tension using the ABAQUS software. The SCFs obtained from FEA were validated using the experimental results. The effect of non-dimensional geometrical parameter, β on SCF_{max} was studied. The

results were compared with the SCF of empty joints and observed that concrete filling resulted in reduction of SCF, especially when β travels close to 0.5. Concrete filling showed no significant effect in reducing SCF as β approached unity. The trend in variation of the maximum SCF with parameter β in the CHS-to-CFCHS T-joints subjected to axial load was contradictory to that in empty joint and an empirical equation was derived from the FEA results. Musa and Mashiri (2019) carried out a study to investigate the effect of concrete filling in CHS-to-CFCHS T- joints subjected to IPB and OPB using the ANSYS software. The effect of concrete filling in the tubular member subjected to OPB was more significant than IPB. Musa and Mashiri (2019) conducted a study on the effect of concrete filling in CHS-to-CFCHS uniplanar K-joints subjected to balanced axial loading using the ABAQUS software. The SCFs obtained from FEA were validated using the experimental results. The reduction in SCF due to concrete filling was observed and concluded that the chord SCF is greater than the brace SCF.

2.5 Effect of FRP

Hosseinia et al. (2020) investigated the effect of FRP in CHS T-joints subjected to axial loading using experimental method. The T- joint member was strengthened with Glass/vinyl ester. The schemes consisted of strengthening of chord, strengthening of brace and strengthening of brace and chord. The SCFs at both saddle and crown points on the chord member were computed. The FRP resulted in reduction of SCF and it was found that the FRP on the chord member played a more significant role in the reduction of SCF (with a reduction of 2.5%) rather than the brace (1%). Complete strengthening of the chord and brace members also resulted in a good reduction in SCFs at both crown (28%) and saddle (27%) points. Lesani et al. (2015) conducted experimental and FEA (ABAQUS) on T and Y joints strengthened by FRP wrapping and subjected to axial compression. It was found that there was a good reduction in the stresses on the joint due to FRP strengthening. Hossein Nassiraei and Pooya Rezadoost (2021) investigated the effect of FRP strengthening on T/Y joints under IPB. FRP strengthening resulted in a reduction of SCF of about 40%. As FRP strengthening layer increased, SCFs showed a decreasing trend.

3 Conclusions

From the literature review done regarding the SCF at tubular joints, it can be summarised as there a number of aspects governing the SCFs at tubular joints. The significant factors which affect the SCF at tubular joints are the method of computation of SCF, nature of loading, non- dimensional geometrical parameters, concrete filling in chord and presence of FRP wrapping. The selection of empirical equation depends on the joint type, validity range of non- dimensional geometrical parameters, type of loading and material properties. Hence, not every equation could be used for all the types of joints and load conditions. And hence, a lot of care needs to be taken during the selection of empirical equation. Experimental, numerical and empirical methods show a close agreement between each other in computing the SCF. Different loading conditions give rise to different critical points. Under, axial loading both crown and saddle points are critical but that need not be the case for IPB and OPB. For IPB, crown points are more critical and for OPB, saddle points are more critical. Non-dimensional geometrical parameters also have an influence in the variation of SCF. On a general note, as β increases, maximum SCF increases up to a certain value and then decreases. Also, as γ and τ increase, maximum SCF also increases which suggests that an increase in diameter of chord and thickness of brace result in an increase in SCF. When the effect of β parameters was studied along the weld toe it was seen that an increase in β led to a decrease of SCFs at the saddle and crown. An increase of τ and/or γ resulted in the increase of SCFs at all locations along the weld toe. Other factors which influence the variation of SCF are concrete filling in chord and wrapping of FRP. Concrete filling helps in reducing the SCF at joints. An average reduction of about 10-40% was observed depending upon the loading case and joint type. FRP also helps in reducing the SCF at joints. A reduction of 1-40% was observed depending upon the joint type and FRP scheme.

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