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Empirical Modeling of Stress Concentration Factors Using Artificial Neural Networks for Fatigue Design of Tubular T-joint Under In-Plane and Out-of-Plane Bending Moments

Abstract:

Purpose – Stress concentration factors (SCFs) are commonly used to assess the fatigue life of tubular T-joints in offshore structures. SCFs are usually estimated from parametric equations derived from experimental data and finite element analysis (FEA). However, these equations provide the SCF at the crown and saddle points of tubular T-joints only, while peak SCF might occur anywhere along the brace. Using the SCF at the crown and saddle can lead to inaccurate hotspot stress and fatigue life estimates. There are no equations available for calculating the SCF along the T-joint's brace axis under in-plane and out-of-plane bending moments.

Design/methodology/approach –In this work, parametric equations for estimating SCFs are developed based on the training weights and biases of an artificial neural network (ANN), as ANNs are capable of representing complex correlations. 1250 finite element simulations for tubular T-joints with varying dimensions subjected to in-plane bending moments and out-of-plane bending moments were conducted to obtain the corresponding SCFs for training the ANN.

Findings – The ANN was subsequently used to obtain equations to calculate the SCFs based on dimensionless parameters (α, β, γ and τ). The equations can predict the SCF around the T-joint's brace axis with an error of less than 8% and a root mean square error (RMSE) of less than 0.05.

Originality/value – Accurate SCF estimation for determining the fatigue life of offshore structures reduces the risks associated with fatigue failure while ensuring their durability and dependability. The current study provides a systematic approach for calculating the stress distribution at the weld toe and SCF in T-joints using FEA and ANN, as ANNs are better at approximating complex phenomena than typical data fitting techniques. Having a database of parametric equations enables fast estimation of SCFs, as opposed to costly testing and time-consuming FEA.

Keywords: T-joint; Artificial neural network; stress concentration factor; fatigue design; finite element analysis; In-plane bending; Out-of-plane bending

Nomenclature: D = chord diameter; d = brace diameter; T = chord thickness; t = brace thickness; θ = angle between the brace and the chord; L = chord length; ℓ =brace length; β = ratio of the diameter of brace and chord; γ = ratio of chord's diameter and twice chord's thickness; τ= ratio of brace thickness to chord thickness; α = ratio of twice the length of the chord to the diameter of the chord; α_b = ratio of twice the length of brace to the diameter of the brace; r= brace radius; t= brace thickness; SCF = stress concentration factors; ANN= Artificial neural network; FEA= Finite element analysis; DOE= Design of experiments; R^2 = Coefficient of determination; IPB= In-Plane bending, OPB= Out-of-Plane bending; i_{max} = maximum of original input data; i_{min} = minimum of original input data; o_{max} = maximum of SCF data used for training; o_{min} = minimum SCF training data; F=force applied on the top of the brace; AWS = The American Welding Society; IIW = International Institute of Welding; API= American Petroleum Institute; GA= genetic algorithm; $\sigma_{nominal\ stress} =$ Nominal brace stress applied on brace; $\sigma_{hotspot\ stress} =$ Maximum stress along the weld toe; FFNN = feed-forward neural network design; DNV= Det Norske Veritas; UEG = Underwater engineering group; HSS= Hotspot stress; CHS= Circular hollow sections; N= Fatigue load cycles; σ_1 , σ_2 = Stresses at extrapolation points; Bx; bias value; A(x)= activation function; hnx= Neurons in the hidden layer ipx=input parameters; WWx= ANN weights

1. INTRODUCTION

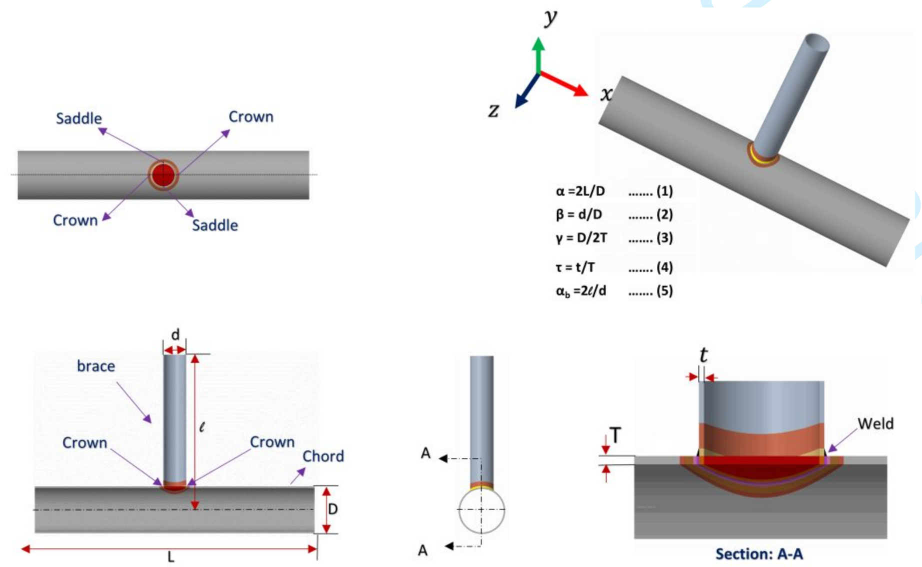
Offshore platforms are subjected to cyclic wave loads, which may lead to fatigue failure after a specific number of cycles [1]. Therefore, accurately assessing the fatigue life of offshore tubular joints is critical to ensure structural durability and safe operation [2]–[4]. These platforms are usually formed with circular hollow sections tubular segments.

Branching components, or braces, are welded to the main structure or chord, creating tubular joints, with the T-joint among the most used tubular joints. Figure 1 shows a T-joint with a circular brace welded at 90° to a main chord. Fatigue failure is the most prevalent form of failure in engineering structures [5], and the fatigue life assessment of each structural component of an offshore structure is part of the fatigue design process. As joints are the most critical components of offshore structures, their fatigue life has a significant impact on the fatigue life of the entire structure [2].

Additional hollow sections include hybrid CHS-SHS, CHS-RHS, and SHS-RHS hollow sections [6]–[10], as well as rectangular hollow sections (RHS) and square hollow sections (SHS). Because of their high bending strength, high strength-to-weight ratio, non-directional buckling, and low wave resistance, circular hollow sections are frequently used in offshore structures [11], [12].

The hotspot stress (HSS) refers to the highest stress around the weld toe and is an essential measure for calculating the fatigue life of offshore structures [13]–[15]. The HSS can be calculated using the stress concentration factor (SCF) and the nominal brace load. Once the HSS is determined, the number of load cycles (N) for the fatigue life can be calculated using the S-N curves specified in the design codes [16], [17]. Accurate SCF prediction leads to accurate HSS calculations. Several factors influence the SCF, including joint shape, applied load, weld size and type, and distance from the weld. Over the last fifty years, significant research efforts have been made to develop accurate parametric equations for SCF [18]–[24]. Calculating the accurate SCF for determining the fatigue life of offshore structures reduces the risks associated with fatigue failure while ensuring their durability and dependability.

Tubular joint fatigue performance is generally evaluated through experimentation and finite element analysis (FEA). Costly experimentation is typically conducted to verify the numerical model. Further analysis is performed using the FEA. Additionally, numerical equations derived from FEA are utilized. Mathematical equation modeling has seen improvements. However, incorporating complex nonlinear patterns into the SCF equations of tubular joints is uncommon. Although equations obtained from regression of FEA datasets based on statistical methods are simple, they produce imprecise SCF. Some research has brought attention to this matter; however, the efficiency of empirical modeling techniques has led to the development of inefficient empirical models [25], [26]. ANN outperforms statistical methods that rely on simple assumptions and can accurately estimate the SCF in offshore joints ~~and~~. The benefits of ANN include its capability to efficiently approximate universal functions, process data in parallel, and effectively handle nonlinearity [2]. The ANN model's dependability and accuracy are demonstrated by achieving the highest coefficient of determination (R^2) throughout the training, validation, and testing subsets [2]. The challenges faced by artificial neural networks (ANN) include the quality and accessibility of data, optimizing the ANN architecture for best performance, and the necessary processing resources [2]. ANN should be examined to improve the correlation between input variables and SCF.



Where, D= Chord diameter, d= brace diameter, T= Chord thickness, t= brace thickness, L=chord length, ℓ = brace length

Figure 1: A typical Tubular T joint (Source: figure created by authors)

Offshore structures are subjected to multiaxial loading, a combination of axial and bending moments, because of the multidirectional character of sea states. As a result, the HSS can be situated anywhere around the intersection [27]. Following an examination of the impacts of member and load interaction, Gulati et al. [28] recommended that the HSS be derived by superimposing the stress distributions of all uni-axis load modes. The UEG [23] and the American Petroleum Institute (API) [29] recommend this method because it is the most precise and complete way to determine the stress distribution around the outer edge of the intersection [27]. However, this is rarely employed for T-joints due to limitations in existing parametric equations. The available models can only calculate SCFs at the crown and saddle position, while the maximum SCF may occur around the weld toe between the crown and saddle positions, which may result in an imprecise estimate of the HSS and the corresponding fatigue life [30].

Over the last 35 years, various parametric equations have been created to predict SCFs for tubular joints [18]–[24]. The UK Health and Safety Executive [20] report, released by Lloyd's Register, thoroughly evaluated the existing parametric equations for fundamental tubular junctions. These parametric equations were created by experimental study of specimens with tubular joints made of acrylic and steel. The Lloyd's Register (LR) equations [20] were derived by fitting the extracted SCF data to minimize the difference between the recorded and estimated SCF values at the saddle and crown points [4].

Smedley and Fisher [18] created parametric equations for single-plane joints (KT, Y, X, T, and K). These equations cannot be used to calculate the SCF along the weld line [4]. The Hellier, Connolly, and Dover (HCD) equations [19] were created to improve the precision of estimating the remaining lifespan of T/Y joints based on fracture mechanics concepts [3]. Nevertheless, they cannot account for the effects of every geometric parameter and may not provide sufficiently accurate findings for specific joints, as the equations were derived from a limited sample [27].

Efthymiou [24] provided a comprehensive mathematical formulae detailing KT, X, T, Y, and K joint designs. These formulae calculate the SCF at the crown and saddle points. They represent the average fit, leading to frequent underpredictions [20]. The equations created by Efthymiou [24] are currently used in ISO-19902 [31], as well as in the guidelines from DNV [32] and the API [29]. Linear regression equations usually give the SCF values at the saddle and crown positions. However, they might undervalue SCF if it is located between these positions. The Wordsworth/Smedley (W/S) equations [22] were developed using acrylic model test data for tubular junctions modeled without a weld fillet. Wordsworth's parametric equations focus on the saddle and crown positions. It is unclear whether intermediate positions were considered, particularly when the hot-spot stress is close to the saddle and crown [20]. Kaung et al. [21] developed parametric equations for SCF of KT, K, T, and Y joints using a finite element program. The Kuang equations were derived by statistical analysis of data collected from the examination of FE joints. The exact location of the hot-spot stress around the weld is not identified; instead, it is categorized as chord-side or brace-side. The equations fail to account for the impact of the chord length on the saddle caused by the constraints at the ends of the chord. Thus, it is probable that the SCFs for longer chord lengths (α) are underestimated due to Kuang's use of joints, mostly with shorter chord lengths [20].

The UEG [23] equations are based on the W/S and Wordsworth equations but include an adjustment for configurations with high γ (>20) and β (>0.6) values. Vinas-Pich [27] found that the UEG [23] stress distribution equations are not precise enough for the entire brace-chord junction. Haghpanahi et al. [33] numerically analyzed the T-joint under combined loading and found that the HSS is at the saddle position for axial loading and in the middle of the saddle and crown positions for combined loading; however, no mathematical equations were presented by the authors.

While stress distribution along the weld path is crucial [2], [25], [34]–[36], most research has been devoted to estimating the SCF at the saddle and crown positions. Given that ANNs have proven to be an effective approximator of complex phenomena [37], [38], their application in the mathematical modeling of SCF at a T-joint weld line under in-plane bending moments (IPB) and out-of-plane bending moments (OPB) is examined in this paper. The FEA was verified based on published results. Once the validity of the numerical model was verified, ANSYS Workbench 2021 R1 [39] was utilized to simulate a dataset intended for the Design of Experiment (DoE). The resulting DoE dataset was then exported to MATLAB [40]. In MATLAB, a neural network was constructed utilizing the nntool program with dimensionless parameters (α, β, ɣ, τ) as input and the SCF as output. The trained model's weights and biases were used to generate mathematical equations to calculate the SCF of the T-joint. The SCF is computed by this model at each 15° angle about the brace axis.

2. Methodology

In the process of ANN-based mathematical modeling, input parameter bounds are first established, and design configurations are then created, followed by finite element analysis. Lastly, the equations are developed using the ANN's weights and biases. Figure 2 depicts a flowchart that illustrates this methodology. The design dataset was created by defining design variables commonly used in the offshore industry. The datasets were analyzed using FEA, and the outcomes were stored. The data was transferred to MATLAB [40] for neural network modeling. The empirical model was developed using the ANN weights and biases from MATLAB [40]. The following subsections provide a detailed explanation of these steps.

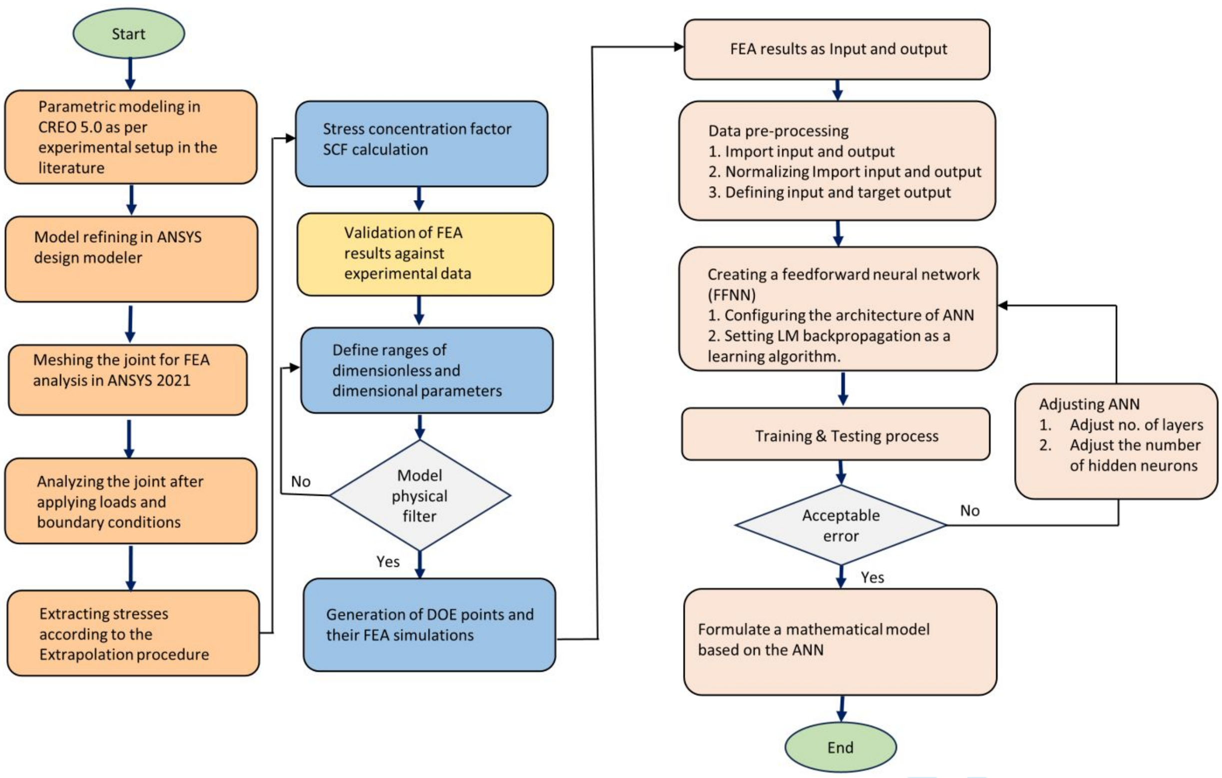


Figure 2: Methodology flowchart for ANN-based modeling of SCF (Source: figure created by authors)

2.1 **Finite element modeling**: CREO 5.0 [41] and ANSYS 2021 [39] were used for the finite element modeling of T-joints with dimensionless and dimensional parameters. DOE-based models were built using CREO 5.0 software [41] and refined in the ANSYS design modeler [39]. Linear elastic static analysis was performed in ANSYS 2021R1 [39], which is suitable for calculating SCFs in tubular joints [42].

2.1.1 **Parametric modeling in CREO 5.0.** The tubular T-joint was created in CREO 5.0 [41]. The model, as shown in Figure 1, was created using parametric equations, which utilized dimensionless and dimensional parameters outlined in Table 2 as variables. The parametric modeling allowed the fast and efficient update of the model to meet DOE requirements in seconds. Individual components were modeled and then joined, allowing sub-zone meshing, as seen in Figure 3**.**

2.1.2 **Weld profile:** The welding profile was examined to obtain an accurate SCF. The dimensions at the brace and chord connections are defined by the AWS D 1.1 standards [43], whereas the weld profile is designed as per the complete joint penetration (CJP) weld profiles [44] ~~as~~ in accordance with AWS D 1.1 [43], as detailed by Lotfollahi et al. [25]. Residual stresses were not considered as welded tubular connections in offshore constructions are post-heated after fabrication to reduce residual stresses caused by the welding process [45].

2.1.3 **Model refinement in Design Modeler**: The model was then imported into Design Modeler, where name selections were added, followed by model refinement.

2.1.4 **Material model:** The experimental coupon test results of the steel material by Ragupathi et al. [46] were the source of the material parameters for the brace and chord. The steel has a yield stress of 300 MPa, an ultimate stress of 415 MPa, Young's modulus of 207.9 GPa, and the Poisson's ratio of 0.29.

2.1.5 **Meshing:** Sub-zone meshing was selected for the parts at the brace and chord intersection. The coarser mesh was selected for brace and chord regions that are away from the brace and chord intersections. As shown in Figure 5, the extrapolation region was meshed to obtain nodes at 15˚ around the brace and to get nodes at extrapolation points (0.4T and 1.4T). As seen in Figure 3, the chord and brace were meshed separately, and ANSYS [39] contacts were used for their connections.

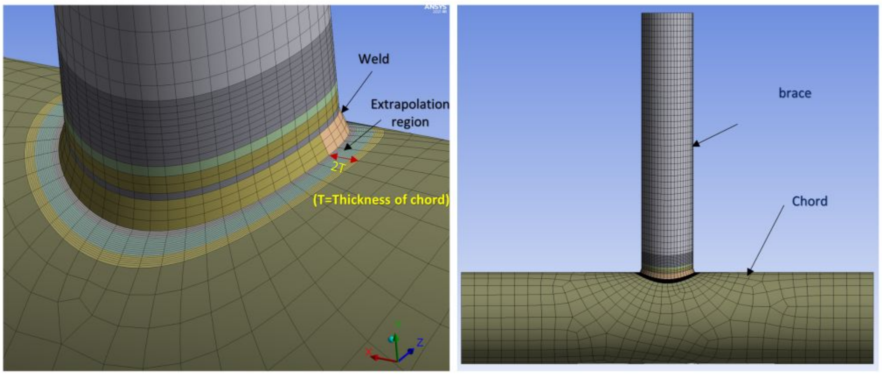


Figure 3: Mesh generated for FEA analysis of a T-joint in ANSYS 2021 [39] (Source: figure created by authors)

Before creating the FE models for the parametric analysis, a sensitivity assessment using various mesh densities was carried out to confirm the convergence of the FE data. Table 1 shows the results of sensitivity assessment. The FEA results of the sensitivity assessment was compared with the experimental results provided in Table 4. The sensitivity assessment led to the finalization of a mesh of 17728 elements.

Table 1: Mesh sensitivity assessment (Source: table created by authors)

Sr.No.	No. of elements	SCF_{crown} (FEA)	SCF_{saddle} (FEA)	SCF_{crown} FEA/ SCF_{crown} (Exp)	SCF_{saddle} FEA/ SCF_{saddle} (Exp)
1	11673	3.58	9.93	0.92	0.81
2	17728	3.67	10.69	0.94	0.88
3	22041	3.67	10.72	0.94	0.88

1.1.1 **Boundary conditions and Loads:** The load magnitudes were carefully selected to keep the deformation linearly elastic [47]. The ends of the chord were fixed, and a moment equivalent to 3 MPa stress was exerted at the top of the central brace. A moment equivalent to 3 MPa stress was chosen to ensure that the stresses in the weakest joint in the DoE remain under the elastic limit. The loads and boundary conditions are shown in the Figure 4.

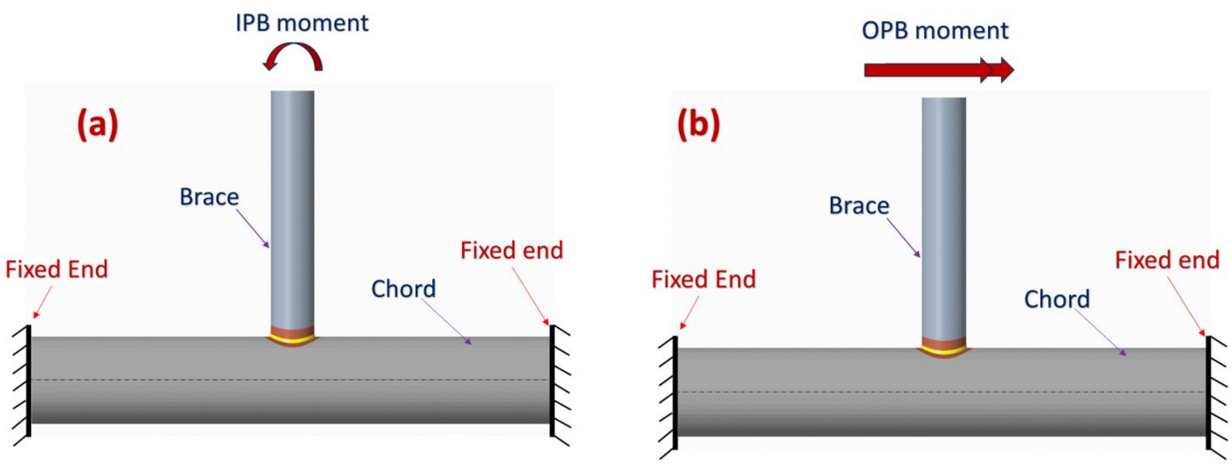


Figure 4: Loads and boundary conditions under (a) IPB moment (b) OPB moment (Source: figure created by authors)

1.1.2 **Extraction of stresses, extrapolation procedure and SCF calculation:** The SCF was determined using the IIW-XVE methodology developed by the International Institute of Welding [48]. The linear extrapolation of von Mises stresses was performed at two specific locations, 0.4T and 1.4T, from the weld toe, where T denotes the chord's thickness. Ahmadi et al. [34] and Hosseini et al. [49], [50] calculated the SCF using the von Mises stress. Due to the complex geometry of the weld toe, the SCF zone was divided into a separate mesh. The length of the SCF zone was set to twice the chord thickness so that the stress of the node at 1.4T from the weld toe was not affected by the coarser mesh beyond the extrapolation region and to obtain nodes at a distance of 0.1T from the weld toe. The area for extrapolation points near the brace was divided into 48 equal parts between 0˚ and 360˚ to measure stresses at 15˚ angle around the brace axis, as shown in Figure 5. The von Mises stresses were calculated for the fourth and fourteenth elements, and the hotspot stress at the weld toe was extrapolated accordingly. The SCF was calculated by dividing the stress at the hotspot by the nominal stress of the brace.

$$SCF = {\sigma_{hotspot\ stress}}/{\sigma_{nominal\ stress}} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

where,

$$\sigma_{hotspot\ stress} = 1.4\sigma_1 - 0.4\sigma_2 \quad \ldots\ldots\ldots\ldots\ldots (7)$$

σ_1 and σ_2 are the stresses on the first and the second extrapolation points, respectively. The first and second extrapolation points are at 0.4*T and 1.4*T from the weld toe, respectively. The nominal stress, $\sigma_{nominal}$ can be calculated as follows.

$$\sigma_{nominal} = \frac{32dM}{\pi(d^4 - (\mathrm{d} - 2t)^4)} \quad \ldots\ldots\ldots\ldots\ldots (8)$$

where M is the moment applied on the brace, d and t are the diameter and thickness of the brace (Figure 1), respectively.

The extrapolation points around the central brace, as recommended by the International Institute of Welding [48], are shown in Figure 5 below.

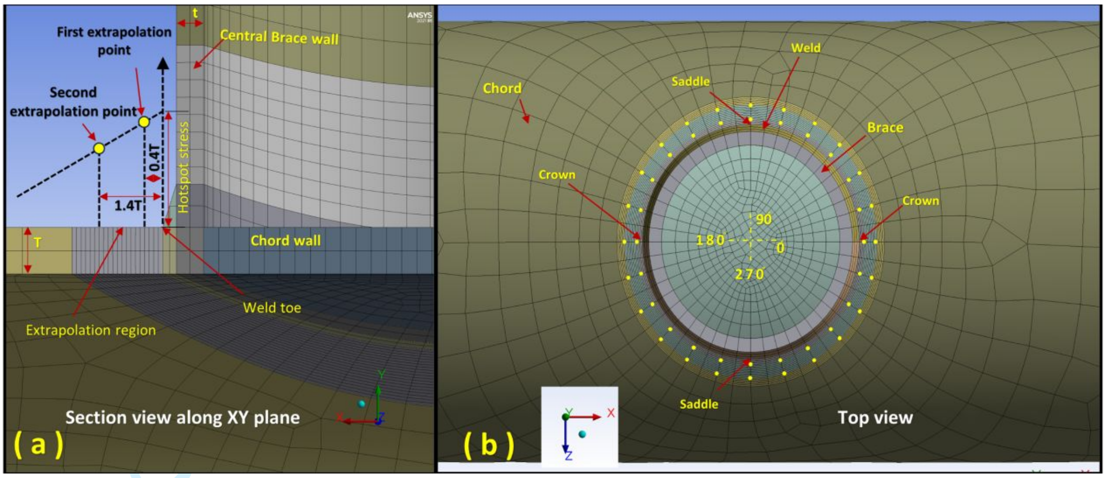


Figure 5: Extrapolation procedure as established by the International Institute of Welding IIW-XV-E-(1999) [48] (Source: figure created by authors)

Chang et al. [27] found that the brace length does not affect SCF when the ratio α_b (α_b =2 ℓ/d) exceeds a critical limit. Therefore, a brace length of ℓ=1000mm was chosen for all simulations.

1.1.3 **Determination of the specific values for the design parameters.** The design variables act as a function in the SCF equation. The ranges for design variables were chosen from their corresponding ranges commonly used in the offshore industry.

1.1.4 **Creation of the design's dataset.** The design dataset development was done in two stages. Initially, the entire range of geometric factors was considered in creating a set of design points. The dataset was then filtered based on the dimensionless parameters listed in Table 2. Because of its large size, the dataset was reduced for further study. A partial factorial design was used to limit the number of simulations, with five different values for each parameter.

2.2 Utilizing the MATLAB nntool for modeling with ANN. ANN is based on the universal approximation theory, which states that a basic neural network can approximate continuous functions based on given inputs [51]. The current study focused on creating an ANN model using FEA. The goal was to create new empirical formulas to determine the SCF of T-joints under IPB and OPB moment loads. The input data for MATLAB [40] comprised dimensionless parameters, with SCF as the output. The input and output data were imported into MATLAB's nntool module, and then a neural network was established. The Levenberg–Marquardt backpropagation algorithm was employed to implement supervised learning. This approach demonstrates increased efficiency due to its second-order convergence rate [2], [51]–[53] Figure 6 depicts a standard ANN model with an input layer containing two inputs, a hidden layer containing three neurons, and an output layer with two outputs.

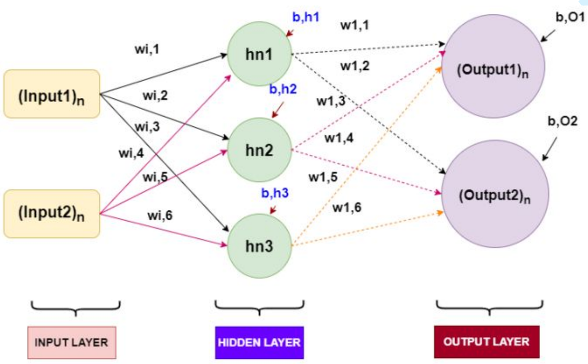


Figure 6: A typical feed-forward neural network (Source: figure created by authors)

The ANN underwent training using the specified input and output data. The hidden layers utilized tan-sigmoid, and the input and output layers utilized linear transfer functions, as described by Equations 9 and 10. The model's coefficient of determination (R^2) was used to assess the ANN's ability to create results that closely resembled the training data. The R^2 value, which represents the degree of correlation between the regression line of the ANN plot and the training data points, ranges from 0.0 to 1.0; a greater R^2 value implies a better fit.

$$a(x) = \frac{2}{(1+e^{-2x})-1} \quad \text{.......................... (9)}$$

$$f(x) = x \quad \text{.......................... (10)}$$

2.2.1 Creation of an empirical model. The mathematical expressions of the trained ANN weights and biases were used to construct the equations. Equations 11 and 12 present the matrix representation of an ANN. Every neuron in the surrounding hidden layer (hnx) is linked to the inputs (ipx) with weights (WWx). The values are added after being multiplied by their respective weights. The sum of the products undergoes an activation function A(x), and the resulting output is then combined with a bias value (Bx). The neuron in the subsequent hidden layer takes input from the accumulated sum until the output layer.

$$\begin{bmatrix} hn1 \\ hn2 \end{bmatrix} = \begin{bmatrix} W1 & W3 & W5 \\ W2 & W4 & W6 \end{bmatrix} \begin{bmatrix} ip1 \\ ip2 \\ ip3 \end{bmatrix} + \begin{bmatrix} B1 \\ B2 \end{bmatrix} \quad \text{.......................... (11)}$$

$$[op] = [W7 \quad W8] \begin{bmatrix} hn1 \\ hn2 \end{bmatrix} + [B3] \quad \text{.......................... (12)}$$

2. Results and Discussion

Determination of the specific values for the design parameters. The T-joint's geometry is defined by dimensionless and dimensional features shown in Figure 1. The set of dimensionless and dimensional parameters and their ranges were selected to build a dataset for the DoE according to the established criteria in the offshore sector [3], [4], [20], [26], [54], [55]. Table 2 displays the range of these variables. 1250 design points were utilized in the simulation dataset.

Table 2: Parameters and their ranges (Source: Table created by authors).

Sr.No.	Type of parameter	Parameter	Range	References
1	Dimensionless	α	8-40	[3], [4], [20], [26], [54], [55]
2		β	0.3-0.7	
3		γ	12-28	
4		τ	0.4-1	
5	Dimensional	Ө	90˚	
6		D	300mm	
7		ℓ	1000mm	

Validation of FEA results against experimental data. The T-joint JISSP 1.13 was chosen from the experimental test results in the HSE OTH 354 report [20] to validate the accuracy of the finite element analysis. The parameters associated with the geometry of the validation joint were identical to those of the experimental models and are presented in

Table *3*. Figure 1 contains the relevant notations and definitions (Equations 1-5).

Table 3: Chord diameter and the other geometrical parameters of the validation joint (Source: table created by authors)

Reference joint	D (mm)	α	β	γ	τ
JISSP joint 1.13 [20]	508	6.2	0.8	20.3	1.07

The accuracy of the FEA findings was verified through a direct comparison with the experimental data published in JISSP1.13 tubular T-joints [20].

Table **4** summarizes the validation process by comparing the FEA results with the experimental results [20], API [29] and LR equations [20] at the saddle and crown positions. The values %error1, %error2 and %error3 in

Table **4** indicates the percentage discrepancy between the experimental results and the results obtained from the present study, API equations [29], and LR equations [20], respectively. The percentage error of present study was -5.90% for IPB moment and -12.46% for OPB moment load cases, demonstrating that the finite element model effectively predicts the SCF at the crown and saddle, and the SCF predictions are consistent with the test results.

Table 4: Validation of FEA results against experimental test results [20], API [29] and LR equations [20] (Source: table created by authors)

Joint	Position	Test results	Present study	API	LR	% Error1	% Error2	% Error3
JSIIP1.13	IPB (Crown)	3.90	3.67	4.85	4.07	-5.90	24.36	4.36
	OPB (Saddle)	12.20	10.68	15.29	14.11	-12.46	25.41	15.66

Creation of the design's dataset. After the FE model was validated, the design dataset simulations were carried out with CREO 5.0 [41], ANSYS [39], a Python script, and MATLAB [40]. Stress values were obtained at 15° around the brace's axis using a Python script in ANSYS Mechanical [39], and von Mises stresses at 0.4T and 1.4T were calculated. These stresses were then extrapolated to calculate the hot-spot stress at the weld toe. Linear stress extrapolation was chosen over nonlinear extrapolation due to the minimal difference in stress variation, which was less than 10% [20]. The hot-spot stress at the weld toe was extrapolated using the approach outlined in the International Institute of Welding IIW-XV-E-(1999) [48]. The SCFs were derived from the hotspot stress values using Equation 6 and then utilized to train the ANN. 1250 design configurations were successfully processed to provide outputs. Each cycle defined twenty-four output parameters, namely the SCF, at every 15° interval for a total of 360°.

Utilizing the MATLAB nntool for modeling with ANN. ANN training was conducted with a dataset comprising 1250 simulated design points. IPB and OPB have 625 design points each. An ANN model was created with dimensionless parameters (α, β, γ, τ) as input and SCF at a 15° offset as output. A feed-forward neural network (FFNN) design was used, consisting of an input layer, one or more hidden layers, and an output layer. During the training process, 70% of the design dataset was allotted to training, with validation and testing each receiving 15%.

Figure 7 (a & b) shows the architecture of the created ANN models for IPB and OPB, respectively. The neural network's ideal configuration was determined iteratively by altering the total number of hidden layers and hidden neurons through trial and error [37]. An ANN was built using one input layer, one hidden layer, and one output layer. The hidden layer consists of eight neurons for IPB and ten neurons for OPB load cases.

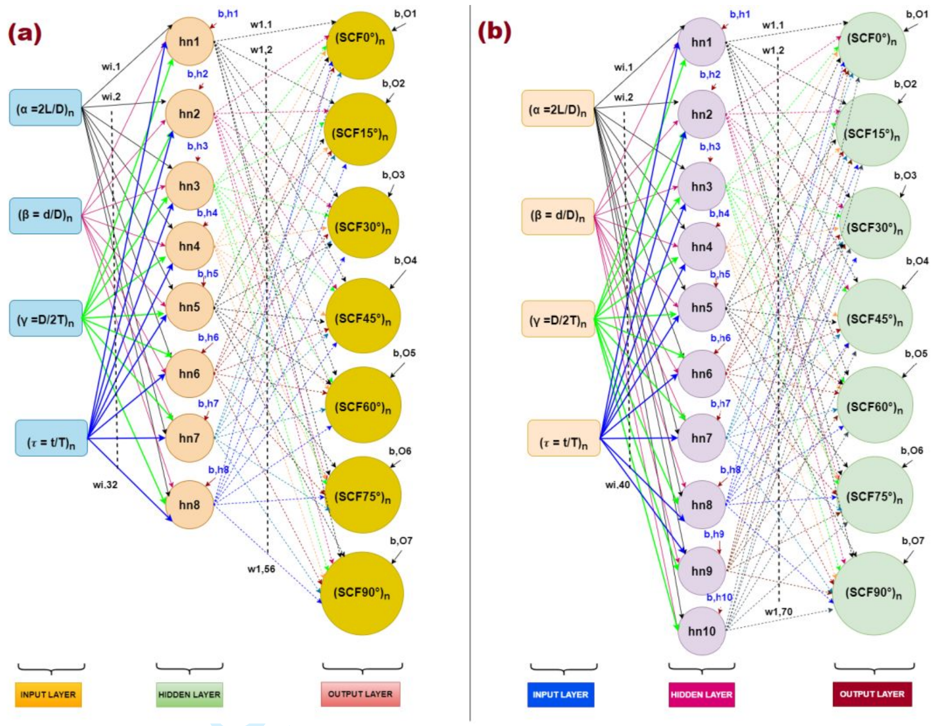


Figure 7: (a) The developed ANN (IPB) (b) The developed ANN (OPB) (Source: figure created by authors)

Figure 8(a&b) shows the regression plots generated by MATLAB R2021 [40] for the ANN. Both diagrams comprise four plots, one each for training, validation, and testing, and three combined plots. The plots show the linear regression line of best fit, which depicts the relationship between the ANN output and the desired output value. The solid lines represent the line of best fit, whereas the dashed lines represent the ideal or perfect results. Figure 8(a&b) shows that the solid and dotted lines in each plot have virtually perfect overlap, indicating that the ANN can provide outputs similar to the training data. The ANN demonstrated great accuracy by achieving R^2 values of 0.999 for IPB and OPB moment load scenarios (Figure 8). This high R^2 value of 0.999 for IPB and OPB moment load cases indicates a strong correlation between the ANN SCF predictions and the SCF derived from FEA.

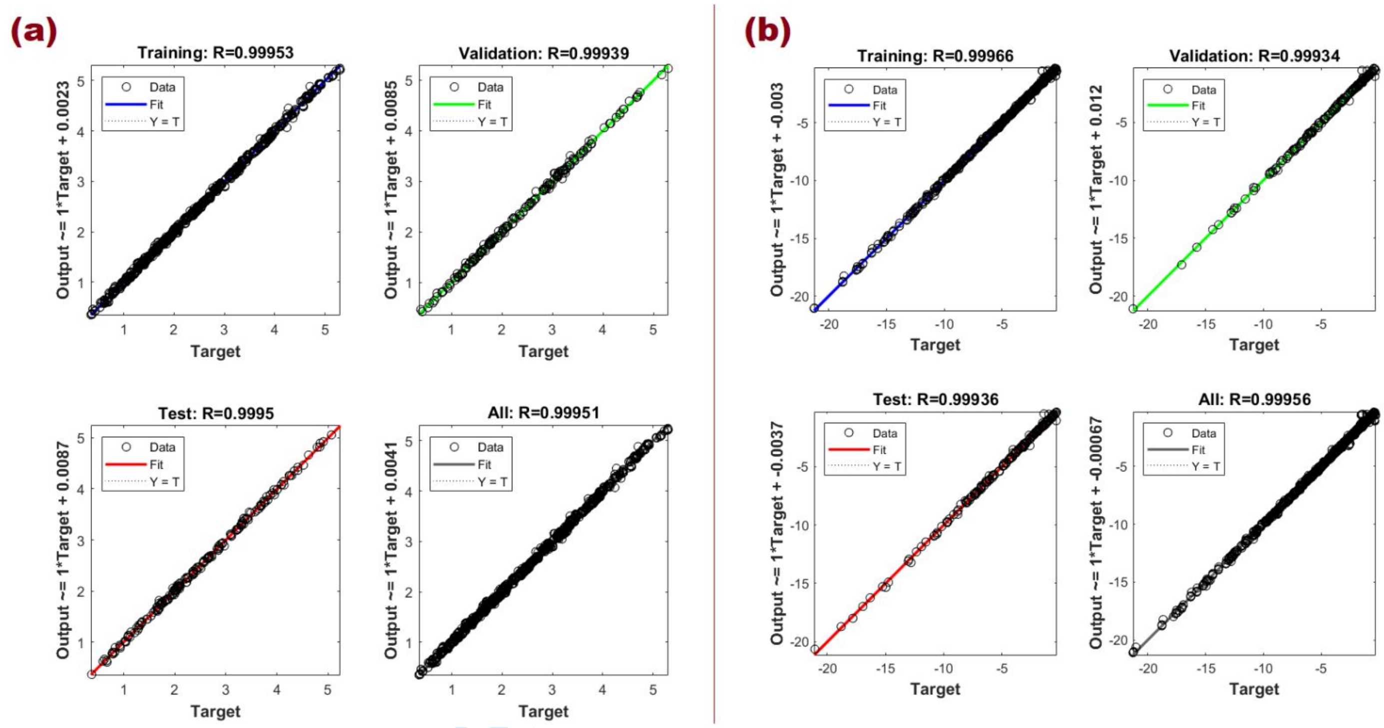


Figure 8: (a) Regression plot of trained ANN (IPB) (b) Regression plot of trained ANN (OPB) (Source: figure created by authors)

Figure 9(a&b) shows the performance graphs of the trained ANN during the validation process for IPB and OPB load cases, respectively. The best epoch yielded the weights for each neuron and biases for each layer, which were used for empirical modeling.

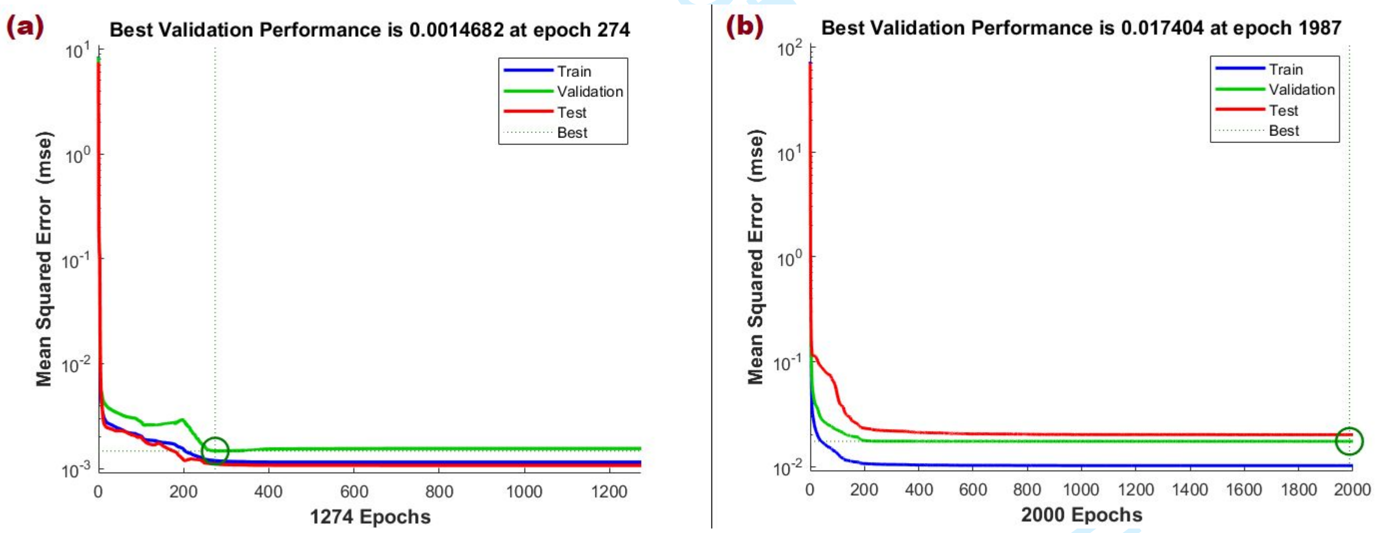


Figure 9: Performance validation of trained ANN (IPB) (b) Performance validation of trained ANN (OPB) (Source: figure created by authors)

Creation of an empirical model. The ANN's weights and biases were exported as a matrix. The inputs were normalized to prevent particular variables from dominating the result, and the outputs were denormalized. Normalization and denormalization can be achieved using Equations 11 and 12. Empirical formulas for SCFs are provided in Equations 13 and 14 for the IPB moment load case and in Equations 15 and 16 for the OPB moment load case.

$$i_{normalized} = i_{n,min} + \frac{(i_{n,max} - i_{n,min})(i - i_{min})}{(i_{max} - i_{min})}$$ ……………………………………………..….. Equation 11

$$o_{denormalized} = o_{min} + \frac{(o_n - o_{n,min})(o_{max} - o_{min})}{(o_{n,max} - o_{n,min})} \qquad \text{Equation 12}$$

where, $i_{n,max} = 1$ $\quad i_{max}$ = max of original input data

$i_{n,min} = -1$ $\quad i_{min}$ = min of original input data

$o_{n,max} = 1$ $\quad o_{max}$ = max of SCF data used for training

$o_{n,min} = -1$ $\quad o_{min}$ = min of SCF data used for training

$$\begin{bmatrix} h1 \\ h2 \\ h3 \\ h4 \\ h5 \\ h6 \\ h7 \\ h8 \end{bmatrix} = \begin{bmatrix} 0.03 & 0.92 & 1.86 & -0.004 \\ -0.04 & -1.13 & -2.3 & -0.02 \\ -0.01 & 0.43 & 0.15 & -0.10 \\ 0.005 & 0.01 & 0.26 & 1.24 \\ -0.002 & 0.20 & 0.22 & 0.05 \\ 0.02 & 6.23 & 16.71 & 2.06 \\ 0.02 & -1.15 & 0.64 & 0.35 \\ 0 & 0.01 & 0.26 & -2.94 \end{bmatrix} \begin{bmatrix} \alpha_n \\ \beta_n \\ \gamma_n \\ \tau_n \end{bmatrix} + \begin{bmatrix} -0.45 \\ 0.43 \\ -0.10 \\ 1.28 \\ 0.16 \\ -13.67 \\ -1.86 \\ -0.90 \end{bmatrix} \qquad \text{Equation 13}$$

$$\begin{bmatrix} SCF\ 0^\circ \\ SCF\ 15^\circ \\ SCF\ 30^\circ \\ SCF\ 45^\circ \\ SCF\ 60^\circ \\ SCF\ 75^\circ \end{bmatrix} = \begin{bmatrix} -2.02 & -1.58 & -2.20 & -1.30 & 5.08 & 0.14 & 0.06 & -0.70 \\ -1.69 & -1.31 & -2.27 & -1.39 & 5.18 & 0.11 & 0.01 & -0.74 \\ -0.83 & -0.63 & -2.40 & -1.62 & 5.28 & 0.03 & -0.12 & -0.84 \\ 0.25 & 0.21 & -2.39 & -1.79 & 5.03 & -0.03 & -0.26 & -0.91 \\ 1.44 & 1.14 & -2.41 & -2.02 & 4.73 & -0.09 & -0.38 & -1.02 \\ 2.50 & 1.99 & -2.38 & -2.15 & 4.35 & -0.13 & -0.49 & -1.07 \end{bmatrix} \begin{bmatrix} h1 \\ h2 \\ h3 \\ h4 \\ h5 \\ h6 \\ h7 \\ h8 \end{bmatrix} + \begin{bmatrix} -0.54 \\ -0.54 \\ -0.54 \\ -0.52 \\ -0.46 \\ -0.42 \end{bmatrix} \qquad \text{Equation 14}$$

$$\begin{bmatrix} h1 \\ h2 \\ h3 \\ h4 \\ h5 \\ h6 \\ h7 \\ h8 \\ h9 \\ h10 \end{bmatrix} = \begin{bmatrix} 0.02 & -0.01 & 0.52 & 0.33 \\ -0.004 & 1 & 0.004 & -0.18 \\ 0.005 & 0.43 & 0.35 & 0.01 \\ 0.03 & 3.06 & 6.69 & 2.65 \\ -0.02 & -0.39 & -0.13 & -0.35 \\ -0.01 & -0.32 & -0.33 & -0.35 \\ -0.03 & 0.39 & 1.76 & 6.13 \\ -0.001 & -0.17 & -0.65 & 1.21 \\ 0.01 & 0.56 & 0.43 & -0.06 \\ 2.98 & -0.60 & -0.48 & -0.34 \end{bmatrix} \begin{bmatrix} \alpha_n \\ \beta_n \\ \gamma_n \\ \tau_n \end{bmatrix} + \begin{bmatrix} -1.11 \\ -0.34 \\ 0.16 \\ -6.21 \\ 1.58 \\ 1.22 \\ -4.78 \\ 1.28 \\ -0.03 \\ 4.46 \end{bmatrix} \qquad \text{Equation 15}$$

$$\begin{bmatrix} SCF\ 15^\circ \\ SCF\ 30 \\ SCF\ 45^\circ \\ SCF\ 60^\circ \\ SCF\ 75^\circ \\ SCF\ 90^\circ \end{bmatrix} = \begin{bmatrix} 0.21 & 0.62 & -2.17 & -0.07 & -2.06 & 0.84 & -0.18 & -0.50 & 0.73 & 0.21 \\ -1.35 & 0.08 & -3.69 & 0.10 & 0.53 & -1.11 & -0.05 & -0.18 & 3.14 & 0.58 \\ -0.80 & 0.67 & -3.03 & -0.09 & 3.53 & -3.9 & -0.17 & -0.49 & 1.32 & 0.31 \\ 0.05 & 0.77 & -2.31 & -0.08 & 0.62 & -0.80 & -0.17 & -0.54 & 0.41 & -0.10 \\ 0.63 & 0.53 & -1.49 & -0.003 & -2.99 & 3.03 & -0.08 & -0.36 & 0.19 & -0.36 \\ 0.75 & 0.39 & -1.28 & 0.02 & -4.15 & 4.17 & -0.04 & -0.27 & 0.28 & -0.40 \end{bmatrix} \begin{bmatrix} h1 \\ h2 \\ h3 \\ h4 \\ h5 \\ h6 \\ h7 \\ h8 \\ h9 \\ h10 \end{bmatrix} + \begin{bmatrix} 2.09 \\ -0.27 \\ -0.18 \\ 1.11 \\ 1.87 \\ 2.13 \end{bmatrix} \qquad \text{Equation 16}$$

A dataset not part of the training, validation, or test data set was used to validate the empirical model. Table 5 displays six verification design points with their respective maximum absolute difference values, percentage differences, and Root Mean Square Errors (RMSE). Figure 10 (a&b) compares the SCF calculated using FEA in ANSYS Workbench [39] and ANN from the proposed empirical model.

Table 5: Verification results of the empirical model (Source: table created by authors)

Sr. No	α	β	γ	τ	Max. absolute difference		Maximum % Error		RMSE (Route mean square error)	
					IPB	OPB	IPB	OPB	IPB	OPB
1	8.40	0.56	12.90	0.72	0.04	0.14	4.86	3.37	0.00	0.01
2	15.90	0.31	19.80	0.68	0.12	0.10	5.21	5.65	0.01	0.00
3	8.10	0.49	15.60	0.95	0.05	0.30	1.71	5.09	0.00	0.03
4	32.50	0.66	23.80	0.75	0.12	0.26	6.99	5.03	0.02	0.03
5	39.70	0.52	15.50	0.89	0.03	0.42	1.29	7.20	0.00	0.05
6	15.70	0.68	27.50	0.95	0.09	0.36	1.87	6.72	0.00	0.03

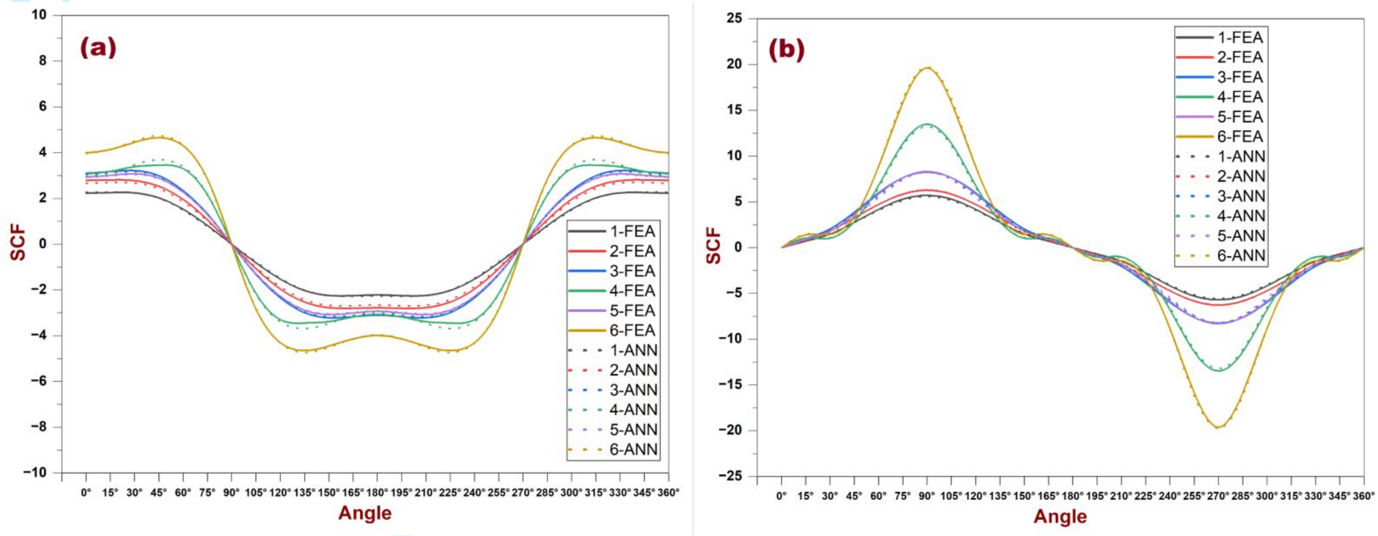


Figure 10: Comparison of ANN and FEA results for (a) IPB load cases and (b) OPB load cases (Source: figure created by authors)

The derived equations provide a precise estimation of the SCF quickly, with an error percentage of under 8% and an RMSE of less than 0.05 when compared to the SCF calculated via FEA. Hence, these equations can be utilized to calculate the SCF along the axis of the brace in a T-joint under IPB and OPB moment load conditions.

CONCLUSIONS

1. The equations established using ANN are efficient for estimating SCF in tubular joints. The integration of FEA and ANN has proven to be effective in estimating SCF. The equations can estimate the SCF around the T-joint's weld toe under IPB and OPB moment load cases with a percentage error of less than 8% and a root mean square error (RMSE) of less than 0.05. These equations remain applicable even when the maximum SCF position changes from the saddle or crown position.

2. Engineers in practice can utilize the equations (Equations 13-16) to calculate hotspot stress precisely and quickly, reducing the hazards associated with fatigue failure of offshore structures and ensuring their longevity and reliability. Our study helps to improve the safety and reliability of offshore structures by allowing for more exact estimates of stress distribution.

3. A similar approach can be used to compute SCF on the tubular joint's inclined braces. This approach can also be extended to other types of joints under different loading conditions to generate a set of equations for efficient SCF computations.

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Reviewer #1:

Comment #1

In this work, parametric equations for estimating stress concentration factors (SCFs) are developed based on the training weights and biases of an artificial neural network (ANN), as ANNs are capable of representing complex correlations. 1250 finite element simulations for tubular T-joints with varying dimensions subjected to in-plane bending moments and out-of-plane bending moments were conducted to obtain the corresponding SCFs for training the ANN. The current study provides a systematic approach for calculating the stress distribution at the weld toe and SCF in T-joints using FEA and ANN, as ANNs are better at approximating complex phenomena than typical data fitting techniques. Having a database of parametric equations enables fast estimation of SCFs, as opposed to costly testing and time-consuming FEA.

This paper is well-organized and written well. Despite a few remarks, the article presents interesting and valuable results. The strength of the work is that ANN was used to create mathematical formulas for determining the stress concentration factor (SCF) and the application nature of this research. Therefore, after making the appropriate changes, the article may be considered for publication in the INTERNATIONAL JOURNAL OF STRUCTURAL INTEGRITY.

Response: Thank you for recommending the manuscript for publication. However, efforts have been made to further improve the quality and content of the manuscript in view of the reviewers' comments.

Comment #2 Abstract: Abstract state's the main aim clearly with a preamble, findings and the originality of this work.

1. Introduction: The section must be rewritten based on the following comments.

A separate paragraph should be added to the below comments.

a) Explain the concept of stress concentration factors and their significance in fatigue design? What are the challenges associated with determining stress concentration factors in tubular T-joints under compressive loads?

b) How does an artificial neural network model assist in predicting stress concentration factors compared to traditional methods? What parameters and data inputs are typically utilized in the development of an artificial neural network model for this purpose?

c) The authors need to state the reason to carry out this study using an ANN to predict the SCF in tubular T-joint subjected to bending.

d) How do the authors validate the accuracy and reliability of the neural network model in predicting stress concentration factors? What are the advantages and limitations of using artificial neural networks in predicting stress concentration factors compared to other numerical methods?

Understanding Stress Concentration Factors:

e) Explain what stress concentration factors (SCFs) are and why they are critical for the fatigue design of tubular structures? How do SCFs in tubular T-joints differ under in-plane and out-of-plane bending moments?

Fatigue Design and Challenges:

f) What makes fatigue design in tubular T-joints challenging, and how does empirical modeling address these challenges? How do in-plane and out-of-plane bending moments affect the fatigue life of tubular T-joints?

Methodological Approach:

g) Could you describe the process of collecting data for training the ANN models? What are the key parameters and variables considered in the ANN model for predicting SCFs?

Results and Validation:

h) How do the ANN models compare with traditional methods in predicting SCFs for fatigue design? What validation techniques were used to ensure the accuracy of the ANN predictions?

i) Please conduct an extensive literature review. Some of the most relevant references that need to be cited in the literature review section are:

- Stress concentration factors in tubular T/Y-joints strengthened with FRP subjected to compressive load in offshore structures
- Structural behaviour of cold-formed steel T-Stub connections with HRC and screws subjected to tension force
- An experimental study on stress concentration factors of stainless steel hybrid tubular K-joints
- A numerical study and proposed design rules for stress concentration factors of stainless steel hybrid tubular K-joints
- A State of the Art Review of Fillet Welded Joints
- Stress concentration factor analysis for notched welded tubular T-joints

Response: Thank you for your insightful comments. We have carefully addressed each of your concerns and made significant improvements to the introduction section of the manuscript.

In the revised introduction, we have elaborated on the concept of stress concentration factors (SCFs) and their critical role in fatigue design, particularly in tubular T-joints subjected to IPB and OPB loading conditions. We have also discussed the challenges associated with determining SCFs in such joints, especially under IPB and OPB loads, highlighting the importance of accurate SCF estimation for reliable fatigue life assessment.

Furthermore, we have provided a comprehensive explanation of how artificial neural network (ANN) models assist in predicting SCFs compared to traditional methods. The parameters and data inputs utilized in developing ANN models for this purpose have been delineated, emphasizing the superiority of ANN in capturing complex relationships and improving prediction accuracy.

Moreover, in the last paragraph of the introduction, we have clarified the rationale behind conducting this study using an ANN approach, underscoring the need for accurate SCF prediction to enhance the estimation of fatigue life in offshore structures. The manuscript elucidates the validation process of the ANN model against finite element analysis (FEA) results, demonstrating its reliability and accuracy in predicting SCFs.

Additionally, we have expanded on the challenges of fatigue design in tubular T-joints, particularly under in-plane and out-of-plane bending moments, and how empirical modeling addresses these challenges. The manuscript now provides insights into the methodological approach for collecting data and training ANN models, emphasizing the key parameters considered in the prediction of SCFs.

Our manuscript underscores the importance of considering in-plane and out-of-plane bending moments, which are common load scenarios encountered by offshore structures in marine environments. These two types of loading induce varying stress distributions in tubular joints, necessitating accurate calculation of stress concentration factors (SCFs) to ensure reliable fatigue design. By focusing on calculating SCFs under both loading conditions, our study aims to contribute to a comprehensive understanding of how SCFs influence the fatigue behaviour and structural integrity of tubular structures in offshore installations.

Lastly, the results and validation section includes a thorough comparison between ANN and FEA results of SCFs. The validation techniques employed to ensure the accuracy of ANN predictions have been elaborated, showcasing the excellent performance of ANN models with error percentages of less than 8% and RMSE of less than 0.05 when compared to FEA results of unseen data which were not part of Design of experiments.

We have also conducted an extensive literature review, including the relevant references you provided, such as stress concentration factors in tubular T/Y-joints, cold-formed steel T-Stub connections, stainless steel hybrid tubular K-joints, fillet welded joints, and notched welded tubular T-joints.

Overall, we believe these revisions have significantly improved the clarity and completeness of the introduction section. Thank you once again for your valuable feedback, and we look forward to hearing your thoughts on the revised manuscript.

Comment #3 Methodology:

a) The methodology of the entire work flow must be a separate session

b) Add a new session FEA titled FE modelling (Material nonlinearity; Weld modelling; Mesh generation; Loading and boundary conditions; Analysis).

c) 2.1.3 Model refinement in Design Modeler: Present with neat and clear pictures from the numerical analysis.

d) Present the Material model of steel (notes — Fy: yield stress; εe: yield strain; E: Young's modulus).

e) Provide The mesh generated using the sub-zone method to understand the weld profile, solid elements and shell elements.

f) Why a collar plate not provided in the brace and chord joint?

g) Provide load versus displacement graphs from the FE analysis.

3. Results and Discussion:

a) With changing parameters like β, τ, and γ what is the influence in terms of SCF's.?

b) A nomenclature table can be added for better understanding of the readers.

c) Figs.5 & 6 is not in a readable format.

d) State the clearly the different criteria in Fig.9 comparing the ANN with the FEA.

Response: Thank you for your detailed comments regarding the methodology section of our manuscript. We have made significant revisions to address your suggestions and improve the clarity and comprehensiveness of the methodology.

Firstly, we have added a new separate section titled "FE Modeling" to provide a detailed description of the finite element analysis (FEA) methodology used in our study. This section includes information on material nonlinearity, weld modeling, mesh generation techniques, loading and boundary conditions, as well as the analysis procedure.

Additionally, we have ensured that proper citations for CREO 5.0 and ANSYS 2021 are included in the manuscript as requested. The material model of steel, including parameters such as yield stress (Fy), yield strain (εe), and Young's modulus (E), has been presented in the methodology section.

We have further elaborated on the mesh generation process, specifically mentioning the sub-zone method used to understand the weld profile and the incorporation of both solid and shell elements in the mesh.

Regarding the absence of a collar plate in the brace and chord joint, we want to clarify that the scope of our study is motivated by the analysis of unstiffened joints. While collar plates have been used in the literature for strength enhancement, our focus is specifically on stress concentration factors (SCFs) for fatigue design. Therefore, the collar plate was not included in the analysis as it was not relevant to our research objectives.

We appreciate your suggestion to include load versus displacement graphs from the FE analysis. However, as mentioned in the paper, our analysis was conducted within the elastic limit to ensure that the stresses in the weakest joint of the design of experiments (DOE) remained within elastic limit. Therefore, load-displacement graphs typically associated with nonlinear analyses for ultimate strength calculations were not included in this study.

Thank you for your valuable feedback on the Results and Discussion section of our manuscript. We have carefully addressed each of your points to improve the clarity and quality of our presentation.

a) The dimensionless parameters other than α, have a significant impact on HSS and SCF. Increasing the parameters (γ and τ) increase the HSS and SCF while increasing the parameter β has a parabolic effect. Increasing β from 0.3 to 0.5 increases the HSS and SCF, while increasing the β from 0.5 to 0.7 decreases HSS and SCF. This includes discussing how variations in these parameters impact the SCFs and their implications for the design and analysis of tubular joints.

b) A nomenclature table has been added to the manuscript to aid readers in better understanding the terminology and symbols used in the Results and Discussion section.

c) We have replaced Figs. 6 and 7 with higher quality images to ensure readability and clarity for the readers.

e) The percentage error was used as a criteria for comparing the results of ANN and FEA. A percentage error of less than 8% and RMSE of less than 0.05, was found in the ANN results as compared to FEA results.

Overall, we believe these revisions have significantly enhanced the methodology section of our manuscript, providing a comprehensive overview of the FE modeling approach used in our research. Thank you once again for your valuable feedback.

Comment #4. Conclusion: Well presented. Add a paragraph stating the future recommendations of this study.

Response: Thank you for your positive feedback on the Conclusion section. We have incorporated a paragraph outlining the future recommendations of this study. SCF of tubular joints with inclined braces can also be calculated using an identical approach. Likewise, the same procedure can be used for the T-joint subjected to IPB, OPB, or mixed-stress situations. This approach can be applied to different types of joints to derive a set of equations that can be used for efficient computations of the SCF. The estimation of SCF (Stress Concentration Factor) can be improved by considering the parameters associated with the defects. Research on optimizing ANN, including genetic algorithms, can potentially streamline the empirical model.

General Comment:

a) Explain the training procedure used to create the neural network model for this particular use case? To what extent does the neural network model adapt to changes in loading conditions and input parameters?

Response: Thank you for your inquiry regarding the training procedure used to develop the neural network model for this specific use case. Our training procedure involves several steps. Firstly, we create a Design of Experiments (DOE) to generate a comprehensive dataset covering input parameters. Subsequently, we utilize the NNTOOL in MATLAB for Artificial Neural Network (ANN) modeling. The input parameters are dimensionless, while the Stress Concentration Factor (SCF) serves as the output. During the modeling process, we experiment with different configurations of layers and neurons within the neural network, aiming to maximize the coefficient of determination ((R^2)) value, which indicates the model's accuracy. Once we achieve the highest accuracy with the maximum (R^2) value, we export the weights and biases from the trained neural network for mathematical modeling purposes. The Artificial Neural Network (ANN) developed for this study exhibits robustness in its response to variations in input parameters. Through rigorous testing, we've observed that the ANN demonstrates insensitivity to changes in input values. This resilience underscores the reliability of the model across different scenarios and loading conditions, enhancing its applicability and effectiveness in predictive tasks.

b) Does the neural network model require any special considerations or modifications when it comes to various geometries or materials?
Response: The neural network model presented in this study is tailored specifically for T-joints subjected to two distinct loadings: In-plane bending loading (IPB) and Out-of-Plane Bending Loading (OPB). While the model is optimized for these particular loading conditions, It's important to note that before utilizing the presented equations, input normalization is necessary, and following model output, denormalization is required. The manuscript provides

the requisite equations for both normalization and denormalization processes, ensuring the accurate application of the model.

Applications and Implications:

c) How can the findings from this study be applied in the real-world design and maintenance of tubular structures? What are the potential implications of using ANNs for structural engineering design, particularly in the context of fatigue analysis?
Response: The findings from this study hold significant implications for the real-world design and maintenance of tubular structures, particularly in offshore engineering. Engineers in practice can utilize the equations derived from this study to accurately predict the fatigue life of T-joints in offshore structures. By accurately predicting fatigue life, engineers can make informed decisions regarding design modifications, maintenance schedules, and operational practices, thereby enhancing the durability and longevity of offshore structures. The application of Artificial Neural Networks (ANNs) in structural engineering design, particularly in the context of fatigue analysis, offers numerous advantages. ANNs have the capability to process large amounts of data and identify complex patterns, allowing for more accurate predictions compared to traditional analytical methods

Future Research and Developments:

d) What are the limitations of the current study, and how could future research address these challenges? How might advances in artificial intelligence and computational methods further improve the modeling of SCFs in tubular structures?
Response: The current study is limited to T-joints under specific loading conditions. Future research could explore different joint geometries and loading conditions to broaden applicability of ANN in offshore structures. Advances in artificial intelligence and computational methods could enhance SCF modeling, offering more accurate predictions. Advancements in ANN have the potential to greatly improve SCF modeling in tubular structures, enhancing safety and efficiency in offshore engineering applications.

Comparative Analysis:

e) How does the performance of ANNs in modeling SCFs compare to other machine learning techniques? Are there specific advantages of using ANNs over traditional finite element methods for this type of analysis?

Response: The performance of Artificial Neural Networks (ANNs) in modeling Stress Concentration Factors (SCFs) is notable for its reliability and accuracy. ANNs demonstrate superiority over traditional statistical methods by achieving the highest coefficient of determination (R^2) across training, validation, and testing subsets. Unlike statistical methods, which often rely on simplistic assumptions, ANNs can capture complex relationships within the data and accurately estimate SCFs in offshore joints. Additionally, ANNs offer advantages over traditional finite element methods (FEM) by providing efficient and accurate predictions without the computational burden associated with FEM. Once a database of FEM is available, The engineers can rapidly assess SCFs using the ANN model and make informed decisions in the design and analysis of tubular structures.

Additional Questions:

1. Originality: Does the paper contain new and significant information adequate to justify publication? Please respond in no less than a paragraph.: Yes

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any highly cited work ignored?: No needs improvement

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed (analytical, computational, experimental) appropriate?: Yes

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: Yes

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: Yes

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Yes

Response:

Thank you for your comments.

Reviewer #2:

Comment #1

The topic of this paper is within the scope of International Journal of Structural Integrity. The authors proposed Empirical Modeling of Stress Concentration Factors Using Artificial Neural Networks for Fatigue Design of Tubular T-joint Under In-Plane and Out-of-Plane Bending Moments. However, this paper needs a thorough revision. There are some notable issues which should first be addressed in the following comments:

There is too much description of the existing research content in the introduction, but the contribution to their own work is insufficient.

Response: Thank you for your feedback. We've reworked the introduction to center more prominently on our contributions regarding Artificial Neural Networks (ANNs). We believe this adjustment better highlights the relevance and uniqueness of our study within the field.

Comment #2

In the literature review, please note the following recent paper:

Fatigue & Fracture of Engineering Materials & Structures 46(3):1031-1044.

INT J STRUCT INTEGR, 2022,13(6): 985-998.

INT J STRUCT INTEGR, 2023,14(5): 629-662.

Response:

Thank you for your review. We have incorporated the mentioned research paper into the revised version of our manuscript as a citation. We appreciate your guidance in ensuring the completeness of our references.

Comment #3

The picture in Figure 7 is not clear. The picture is too small and not clear enough. The points are too dense, please improve the quality.

Response:

We have replaced Fig. 7 with a higher-quality image to ensure readability and clarity for the readers.

Comment #4

Some parameters in the formula are not explained.

Response:

Thank you for your feedback. We have carefully reviewed the formula and ensured that all parameters are adequately explained in the revised manuscript. We appreciate your attention to detail and are committed to clarity in our presentation.

Comment #5

The lines in Figure 8 and 9 need to be adjusted, the lines are too dense to see clearly. Please improve quality of them.

Response:

We have replaced Figs. 8 and 9 with higher-quality images to ensure readability and clarity for the readers.

Comment #6

The conclusion section needs to be refined and written more clearly in separate points.

Response:

Thank you for your valuable feedback. We have refined the conclusion section as per your suggestion, presenting the key points in a clear and concise manner, each delineated as separate points. We believe this revision enhances the clarity and readability of the conclusion, ensuring that our findings are effectively summarized for the reader.

Comment #7

There are some grammatical errors in this manuscript. Please improve the language.

Response:

Thank you for your feedback regarding the grammatical errors in the manuscript. We have carefully reviewed and revised the language throughout the document to ensure clarity and correctness. We appreciate your attention to detail and are committed to delivering a polished and professional manuscript.

Comment #8

Please check the whole reference list to correct possible typos.

Response:

Thank you for bringing attention to the reference list. We have meticulously reviewed it to correct any potential typos or errors. We appreciate your thoroughness in ensuring the accuracy of our references.

Additional Questions:
1. Originality: Does the paper contain new and significant information adequate to justify publication? Please respond in no less than a paragraph.: Yes

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any highly cited work ignored?: Yes

3. Methodology: Is the paper’s argument built on an appropriate base of theory, concepts or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed (analytical, computational, experimental) appropriate?: Yes

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: Yes

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: Yes

6. Quality of Communication: Does the paper clearly express its case, measured against the

technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Yes

Response:

Thank you for your comments.

Reviewer #3:

Comment #1

It is suggested to change the manuscript title as:

"Empirical Modeling of Stress Concentration Factors Using Artificial Neural Networks for Tubular T-joint Under In-Plane and Out-of-Plane Bending Moments."

Since there is no fatigue analysis in the manuscript (although the SCFs can be used for fatigue analysis).

Response:

Thank you for the suggestion regarding the title. We understand the absence of explicit fatigue analysis in the manuscript. However, we've chosen to include "Fatigue" for two reasons: 1) S-N methodology allows fatigue life estimation solely based on hotspot stress, obtainable through SCF formulas. 2) Reflecting common practice, most existing literature on this topic incorporates "Fatigue" in titles despite focusing on SCF calculations. We believe this clarifies the application of our SCF modeling towards fatigue analysis.

Comment #2

The authors should discuss the following reference in the Introduction part of their manuscript.

M. Haghpanahi and H. Pirali, Hot Spot Stress Determination for a Tubular T-Joint under Combined Axial and Bending Loading, IUST International Journal of Engineering Science, Vol. 17, No.3-4, 2006, Page 21-28.

Response:

Thank you for your suggestion regarding the inclusion of the reference by M. Haghpanahi and H. Pirali in the Introduction section of our manuscript. We want to inform you that this reference has been cited and discussed in the revised version of our manuscript. We appreciate your attention to detail and ensuring the completeness of our references.

Comment #3

Since according to AWS there are different classes (types) of welds that can be used for welding steel pipes, the authors must discuss the type of weld used in their analysis. They should also provide enough information and reason on the selected type of weld used during the modeling process.

Response:

Thank you for your insightful comment regarding the type of weld used in our analysis. In our manuscript, we have referred readers to Lotfollahi et al. [24], where detailed discussions on the modeling process, including the complete graphs of profiles used with the standard AWS D1.1, are provided. As highlighted in the referenced pages, Complete Joint Penetration (CJP) welds are employed due to their higher strength and fatigue resistance, making them suitable for tubular members. Additionally, for the convenience of our readers, we have included detailed information on AWS profiles with page numbers from the standard in our reference list, ensuring accessibility to complete information on weld profiles. We appreciate your attention to this aspect of our methodology.

Comment #4

Does the type weld used in their analysis matches the same model presented in the experimental investigation used by other authors?

Response:

The reference is added in the revised manuscript for use of CJP weld profiles used in the current study. In offshore structures, tubular members are commonly subjected to fatigue loading. To optimize performance against fatigue and achieve higher strength, Complete Joint Penetration (CJP) welds are extensively utilized in offshore structures. Additionally, in the literature, CJP welds are consistently employed due to their superior fatigue resistance and strength characteristics. Furthermore, the consistency observed between Finite Element Analysis (FEA) results and experimental findings indicates that the same CJP welds were used in the experimental setup. This alignment underscores the validity and relevance of employing CJP welds in both experimental investigations and numerical simulations for tubular members in offshore structures.

Comment #5

The type of boundary conditions used to create the final element model should be clearly defied.

Response:

Thank you for your comment regarding the boundary conditions used in creating the finite element model. As detailed in the manuscript, the ends of the chord were fixed, and a moment equivalent to 3 MPa stress was applied at the top of the central brace. This specific moment value was chosen to ensure that the stresses in the weakest joint in the Design of Experiments (DoE) remain below the elastic limit. Furthermore, in response to your suggestion, we have included a new figure to provide better clarity and understanding of the boundary conditions employed in our analysis. We believe these additions enhance the comprehensibility and completeness of our methodology description.

Comment #6

The authors must present a table according to which their results have converged to the final values used for design analysis. As a substitute, a plot of converged results based on the number of elements might be presented.

Response:

We've integrated a mesh sensitivity assessment table into the manuscript as per your suggestion. This table illustrates the convergence of our results to the final values utilized for design analysis, contingent on the number of elements. This addition enriches the thoroughness of our study and promotes transparency in our approach. Thank you for your valuable input.

Comment #7

Comparison of the finite element results with those of experimental findings in Ref. [9] are very vague. The authors claim that they have compared their results against the experimental values for a T-joint already available in Ref. [9]. They must give a concise information on the Tables (data) and/or equations that were used from this book regarding the type loading used in their analysis for comparison of their results. Have they applied superposition? If yes, please state why and what equations were used? Since there are a few number of equations, please outline the equations (if any) for verification of the finite element results?

Response:

Thank you for your thorough evaluation of our manuscript. We appreciate your insightful comments regarding the comparison of our finite element analysis (FEA) results with experimental findings and established equations.

To address your concerns, we would like to clarify that in our study, the FEA results have indeed been compared with published experimental results of the T-joint,. The published literature provides complete information about the specific joint JISSP 1.13 geometry, load applied and the calculated SCF. Additionally, to provide a comprehensive analysis, we have compared our FEA results with equations available in the API standard and LR equations. This comparison has been summarized in a dedicated table within the manuscript. We believe that this approach ensures transparency and allows for thorough verification of our findings against both experimental data and established equations.

Comment #8

What are the parentage difference based on other equations available in literature.

Response:

Thank you for your insightful feedback. We have taken your suggestion seriously and expanded our analysis to include a comparison with established equations found in the literature, specifically the API and LR equations. In addition to comparing our results with experimental data, we have incorporated the comparison results into a dedicated table within the manuscript. This comprehensive approach not only validates the findings of our study but also provides a broader context for understanding the significance of our results within the existing body of knowledge. We believe that by incorporating this additional analysis, we have addressed your concerns and strengthened the robustness of our research. Thank you for guiding us in enhancing the quality of our work.

Comment #9

What does Table 3 represent? Is it a comparison of SCFs? Please complete the Table's caption. Authors must also present the references of the test results used for comparison in this Table.

Response:

Thank you for your inquiry regarding Table 4 (Previously Table 3). As outlined in the manuscript, Table 4 summarizes the validation process by comparing the FEA results with the experimental results [19], API [28] and LR equations [19] at the saddle and crown positions. The values %error1, %error2 and %error3 in Table 4 indicate the percentage discrepancy between the experimental results and the results obtained from the present study, API equations [28], and LR equations [19], respectively. Regarding the references of the test results used for comparison in this table, they are listed in the table's caption for readers' convenience. We appreciate your attention to detail and ensuring clarity in our presentation.

Comment #10

On page 8, line 12, what does this sentence mean “Table 3 summarizes the validation process at the saddle and crown. The error in”?

Response:

Thank you for bringing this to our attention. The sentence has been revised as follows: "Table 3 summarizes the validation process by comparing the FEA results with the experimental results [19] at the saddle and crown positions." We appreciate your diligence in ensuring clarity and accuracy in our manuscript.

Additional Questions:

1. Originality: Does the paper contain new and significant information adequate to justify publication? Please respond in no less than a paragraph.: Yed it does.

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any highly cited work ignored?: Yes it does, but there are some other relevant references that the authors have ignored. They are advised to have a better search in the available literature.

3. Methodology: Is the paper’s argument built on an appropriate base of theory, concepts or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed (analytical, computational, experimental) appropriate?: Yes, but the finite element method (numerical method) lacks some key issues.

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: No. They are not. The authors must perform a comprehensive investigation into their numerical results and present a valid comparison with the existing experimental findings.

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: Yes, it almost does. Application of the finite element results can eliminate the cost of doing experiments.

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal’s readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Yes, it almost does.

Response:

Thank you for your comments. The relevant points have been discussed in the relevant questions .