

# Stress concentration factor distribution of inclined brace in multiplanar offshore tubular double kt joints

**Rudi Walujo Prastianto, Yoyok Setyo Hadiwidodo, Ibnu Fasyin Fuadi, Mhd Bonar Yudha Prawira Naibaho and Prasetyo Nugroho Rahardianto**

Department of Ocean Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia.

E-mail: [rudiwp@oe.its.ac.id](mailto:rudiwp@oe.its.ac.id)

**Abstract.** The majority of tubular joints commonly found in offshore structures are in the form of multi-planar tubular joints, but very few investigations have been reported due to the complexity and high cost involved. The majority of research have been focused on the study of stress distribution at certain position such as saddle and crown points, and the hot spot stress (HSS) at other position along the weld toe of brace/chord intersection have been ignored. In this paper a 60° two-planar double KT (DKT) tubular joint is modelled as a finite element model from an offshore jacket platform. The effect of dimensionless geometrical parameters on the geometrically stress distribution and SCF distribution along the weld toe of inclined brace in axially loaded on the joint are investigated. Non-dimensional parameters that are varied include  $\beta$ ,  $\tau$ ,  $\gamma$  and  $\theta$ . Validation of the finite element model shown a good agreement to the global structural analysis results. The results of parametric studies show that the increase of the  $\beta$  leads to decrease of SCF. While the increase of the  $\tau$ ,  $\gamma$  and  $\theta$  leads to increase of SCF. The peak SCF mostly occurs at the outer saddle point. The effect of parameters  $\beta$ ,  $\gamma$  and  $\theta$  on the SCF are greater than the effect of parameters  $\tau$ .

## 1. Introduction

Jacket platform is an offshore structure often used for oil and gas exploitation of offshore hydrocarbon reservoirs in shallow water areas, which have main structure consists of tubular members welded between braces and chords [1]. Stresses occurring at intersection line brace-chord of the tubular joint is unevenly distributed. The ratio between the maximum stress at the intersection line and the nominal stress in the brace is called Stress Concentration Factor (SCF). The SCF is one of the important parameters in the calculation of fatigue damage [2]. Therefore, more accurate prediction of the SCF is necessary in the calculation of fatigue life of offshore structures.

The majority of tubular joints commonly found in offshore structures are in the form of multi-planar tubular joints. The multi-planar effect plays an important role in the stress distribution at the brace-to-chord intersection areas of the tubular joints as well as stresses in the intersection line are distributed very complex. The fact shows that very few investigations have been reported due to the complexity and high cost involved. For such multi-planar joints, the parametric stress formulae of simple uni-planar tubular joints are not applicable in SCF prediction.

Due to the above situations, the significance of this study is to obtain proper SCF specific for a multi-planar double KT tubular joint. From design point of view this specific SCF would increase accuracy in fatigue life prediction for the joint itself. This research will study the effect of dimensionless geometrical



parameters ( $\beta$ ,  $\tau$ ,  $\gamma$  and  $\theta$ ) on the stress distribution along the weld toe in the intersection region between brace-to-chord and SCF of a multi-planar double KT tubular joint with several variations of the geometrical parameters subjected to axial loading at the braces. Finite element models of the tubular joint are used for local stress analysis to obtain stress distribution in the intersection region which is the accuracy obtained is strongly influenced by the numerical model to be analyzed [3].

## 2. Literature review

The understanding of the behaviour of completely multiplanar joints is very limited. During the past thirty years, a significant number of scientific papers and reports have been published on the study of SCFs in various uni-planar tubular joints. As a result, many parametric study in terms of the joint geometrical parameters have been proposed, providing SCF values at certain locations adjacent to the weld for several loading conditions. Two following paragraphs review the research papers on the determination of SCF distribution along the brace-to-chord intersection of uni-planar joints and on the calculation of SCFs in the multi-planar tubular joints, respectively.

Seng-Keat Yeoh, Ai-Kah Soh and Chee-Kiong Soh [4] presented about behavior of tubular T-joints subjected to combined loadings. Ai-Kah Soh and Chee-Kiong Soh [5] researched about hot spot stress of K tubular joints subjected to combined loadings. Pang and Lee [6] presented three-dimensional finite element analysis of a tubular T-joint under combined axial and bending loading. Chang and Dover [7] predicted of stress distributions along intersection of tubular Y-joints and T-joints. Shao [8] predicted of hot spot stress distribution for tubular K-joint under basic loadings.

Research on the distribution of SCF on multiplanar tubular joints was done by Chiew et al [9], for the multiplanar tubular XX-joints. Karamos et al [10] derived the SCF formula and investigated stress distribution along intersection line on the multiplanar DT-joint due to the bending load. Research was also undertaken by Wingerde et al [11] formulating the SCF formula for uniplanar tubular joints K and multiplanar KK. Woghiren and Brennan [12] developed a set of parametric formulae to predict the values of SCF in multi-planar rack-stiffened tubular KK-joints. Bonar Naibaho [13] presented about SCF parametric study of multiplanar tubular KDT-joint. Arvina Puspaningtyas [14] researched about stress intensity factor parametric study of multiplanar tubular joint with fracture mechanics. Ibnu Fasyin Fuadi [15] derived the SCF formula for multiplanar tubular DKT-joint.

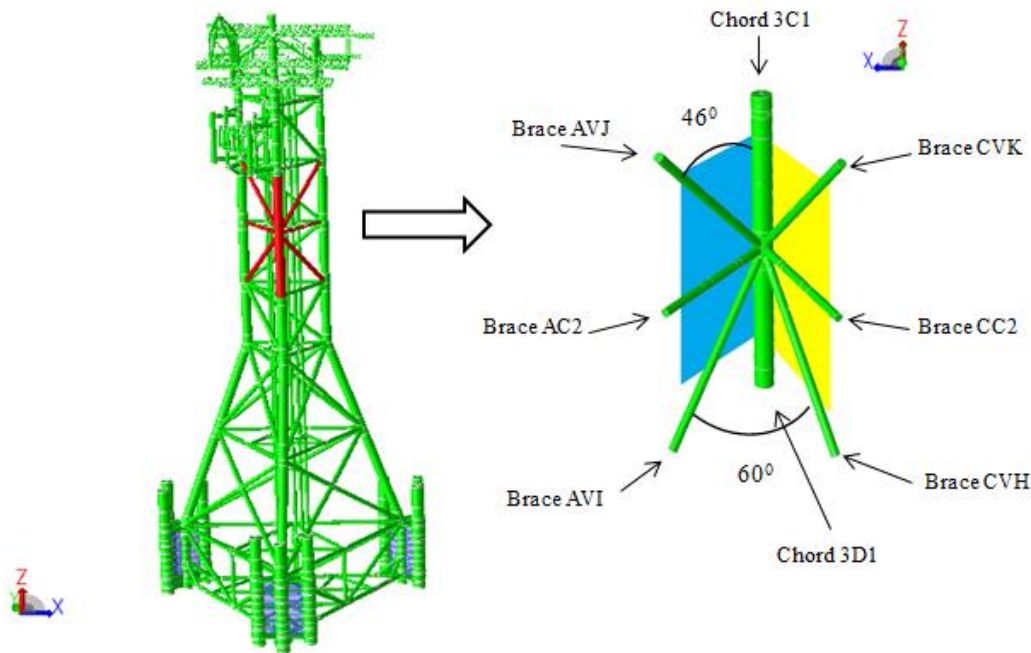
## 3. Parametric numerical study of weld toe geometric stress distribution on the outer brace

### 3.1. Finite element modelling, analysis, and validation

The structure to be analyzed in this case is a Multi-Planar Double KT tubular joint on the bracing of jacket platform structure (see Figure 1). Data used in this local analysis are structural geometry data, material properties and loading of the global analysis of structure jacket platform. The loading data is obtained from the global modeling of the structure (see Table 1 and Table 2).

The chord and brace have the same material properties. The steel density is 563,5 lb / ft<sup>3</sup>. Yield strength and Poisson's ratio are 50 ksi and 0.3, respectively, and with Young modulus of 30,000 ksi.

In this multiplanar double KT tubular joint will be varied with several parameters, namely the parameters of beta ( $\beta$ ), tau ( $\tau$ ), gamma ( $\gamma$ ), and the angle between chord and brace ( $\theta$ ). The definition of each the tubular joint geometric parameters are:  $\beta$  ( $= d/D$ ) is ratio between diameter of brace and chord;  $\tau$  ( $= t/T$ ) is ratio between wall thickness of brace and chord;  $\gamma$  ( $= D/2T$ ) ratio between diameter and wall thickness of chord; and  $\theta$  stands for angle between chord and brace.



**Figure 1.** Multiplanar double KT tubular joints taken from global analysis

**Table 1.** Geometry of multi-planar double KT tubular joint

| Joint Member | Thickness (in) | Outside Diameter (in) | Inside Diameter (in) | Length (in) |
|--------------|----------------|-----------------------|----------------------|-------------|
| Chord 3C1    | 2              | 54                    | 50                   | 312         |
| Chord 3D1    | 2              | 54                    | 50                   | 312         |
| Brace CVK    | 1              | 24                    | 22                   | 540         |
| Brace AVJ    | 1              | 24                    | 22                   | 540         |
| Brace CC2    | 1              | 24                    | 22                   | 384         |
| Brace AC2    | 1              | 24                    | 22                   | 384         |
| Brace CVH    | 1              | 24                    | 22                   | 540         |
| Brace AVI    | 1              | 24                    | 22                   | 540         |

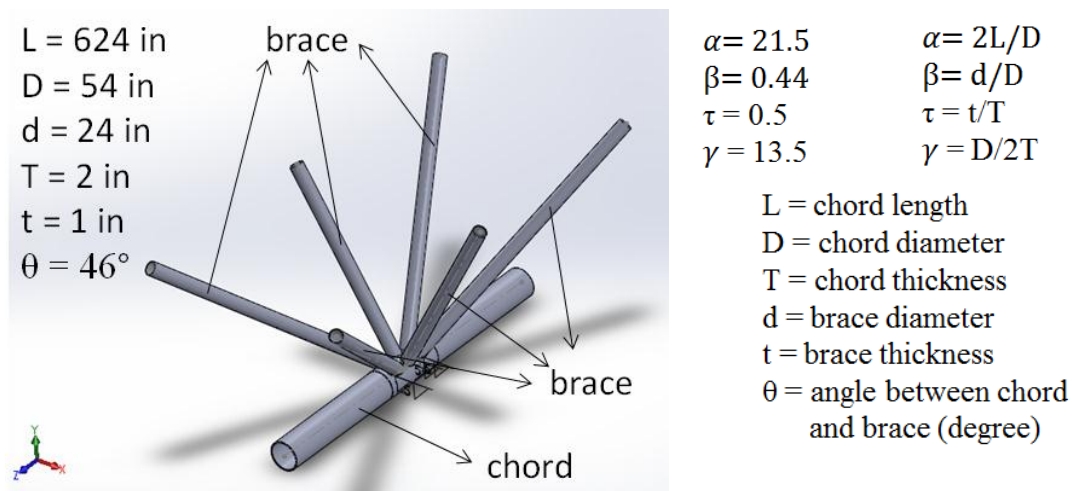
As mentioned earlier, the aim of the present research is to study the effect of dimensionless geometrical parameters on the SCF distribution along the weld toe (on the chord side) of the main (inclined) brace. Different values assigned to each non-dimensional parameter are as follows:  $\beta = 0.35, 0.4, \text{ and } 0.45$ ;  $\gamma = 10, 12, \text{ and } 15$ ;  $\tau = 0.35, 0.45, \text{ and } 0.55$ ;  $\theta = 36^\circ, 46^\circ, \text{ and } 56^\circ$ . These values are selected to cover the practical range of the normalized parameters typically found in multi-planar tubular joints of offshore structures, namely:  $0.3 \leq \beta \leq 0.5$ ;  $0.3 \leq \tau \leq 0.6$ ;  $10 \leq \gamma \leq 14$ ; and  $30^\circ \leq \theta \leq 60^\circ$ .

**Table 2.** Moment and forces on multi-planar double KT tubular joint

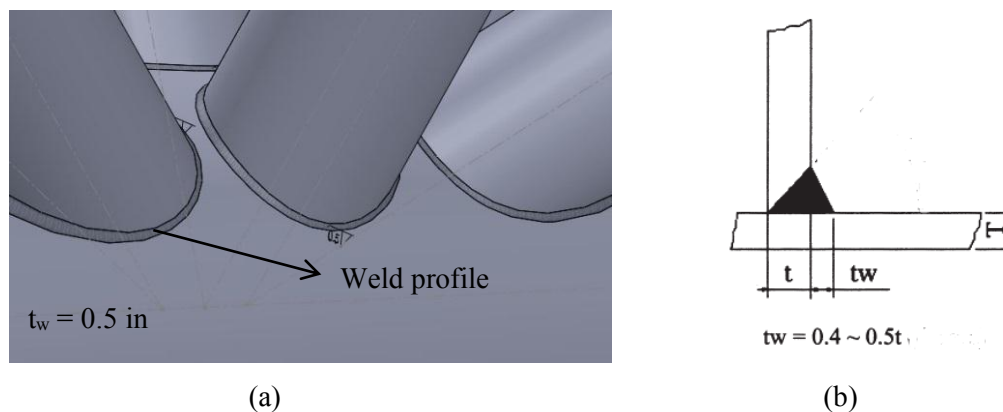
| Joint Member | Moment (kips-in) |        |      | Force (kips) |       |      |
|--------------|------------------|--------|------|--------------|-------|------|
|              | Mx               | My     | Mz   | Fx           | Fy    | Fz   |
| Brace CVK    | -0.5             | -32.9  | -10  | -48.6        | -0.01 | -0.1 |
| Brace AVJ    | 2.3              | -116.6 | 12.7 | -13.5        | -0.05 | 1.4  |
| Brace CC2    | 213.4            | -675.8 | -5.4 | 9.9          | 0.01  | 9.8  |

|           |       |        |      |       |       |      |
|-----------|-------|--------|------|-------|-------|------|
| Brace AC2 | -94.6 | -384.8 | 3.7  | 10.1  | -0.01 | 5.6  |
| Brace CVH | 1.2   | -42.9  | 20.5 | 49.7  | 0.04  | -0.1 |
| Brace AVI | -0.68 | -186.3 | 31.4 | -13.8 | -0.11 | 1.6  |

Multi-planar double KT tubular joint to be analyzed is modeled using preprocessor software of Solid Work software for its geometry (see Figure 2) based on data in Table 1. Then the geometry is exported into finite element method-based software where in the material properties and loading data are inputted according to Table 2. Weld modeling is necessary because the intersection between the two tubular (brace and chord) will form intersection line, where the stress concentration occurs in the area along the intersection line. The welding size along the brace-chord intersection satisfies the AWS specifications [16].

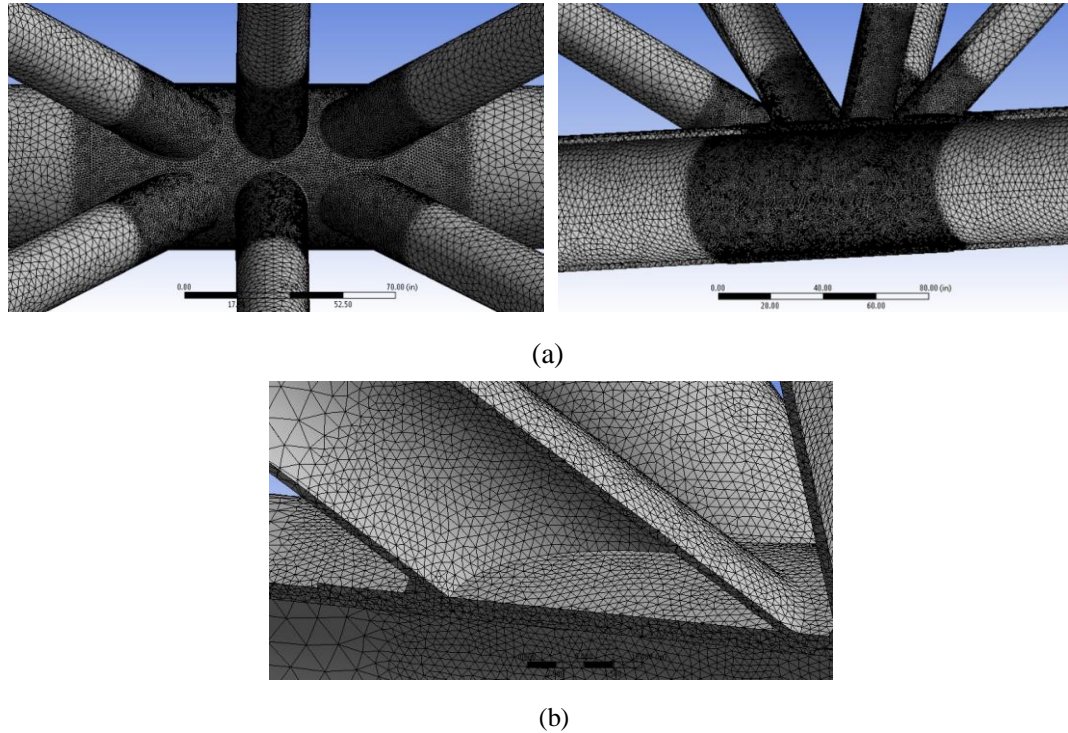


**Figure 2.** Multiplanar double KT tubular joints for local analysis



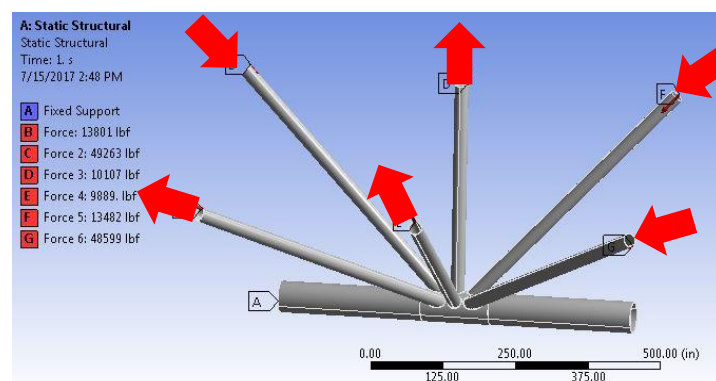
**Figure 3.** Weld size along the brace-chord intersection satisfies the AWS specifications (a) Weld profile on the model (b) AWS D 1.1. Specifications for the weld

After modeling the multiplanar DKT tubular joint, then meshing is done. Meshing strategy for the model is performed with meshing size is made smaller (smooth) on regions around the connection between the brace and chord. While in regions far from the connection area as observation areas, meshing size is made larger (coarser). The element used for the model is a solid three-dimensional element with a linear element type of tetrahedron (see Figure 4).



**Figure 4.** Meshing on multiplanar double KT tubular joints (a) Global view of the generated mesh (b) Local view of the generated mesh

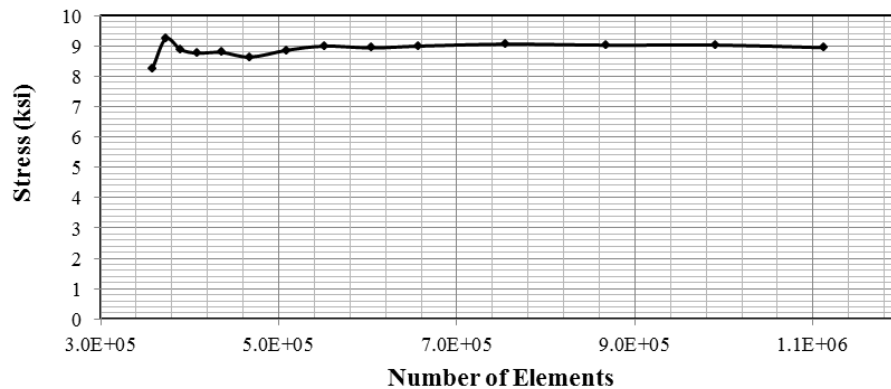
The chord end fixity conditions of tubular joints in offshore structures may range from “almost fixed” to “almost pinned” with generally being closer to “almost fixed”. For analysis in this study, it is assumed that all of the constraints are fixed on both ends of the chord. The tubular joint model with the parameter  $\alpha > 12$ , the magnitude of the stress at the joint area is not affected by the boundary conditions on the chord. In this study the value of parameter  $\alpha = 21.5$  was assigned for all the models. The loading applied to the model are axial forces that the values are obtained from the results of the global modeling as presented in Table 2. Loading directions and boundary condition of the models can be seen at Figure 5.



**Figure 5.** Loading and boundary condition of the model



The meshing sensitivity analysis is performed to ensure the consistency and accuracy of the analysis output from the finite element model as a function of the number of elements used. Size of meshing is iteratively changed, until the stress generated at a particular location becomes constant. From the results of meshing sensitivity test (see Figure 6), it is found that the number of meshing elements whose stress output is near constant at a particular point is meshing with the number of elements as many as 1,000,000 elements.



**Figure 6.** Graph of meshing sensitivity analysis

**Table 3.** Result of meshing sensitivity test

| No | Number of elements | CPU time (minute) | Disk Storage (bytes) | Stress (ksi) | Change (%) |
|----|--------------------|-------------------|----------------------|--------------|------------|
| 1  | 358,179            | 10                | 1,168,567,338        | 8,261        |            |
| 2  | 373,059            | 10.2              | 1,179,997,513        | 9,235        | 10,547     |
| 3  | 390,022            | 10.3              | 1,195,417,876        | 8,877        | 4,037      |
| 4  | 408,545            | 10.5              | 1,205,657,858        | 8,763        | 1,301      |
| 5  | 435,671            | 10.8              | 1,217,451,712        | 8,788        | 0,284      |
| 6  | 467,794            | 11.3              | 1,220,329,118        | 8,633        | 1,795      |
| 7  | 509,145            | 11.7              | 1,239,971,901        | 8,859        | 2,551      |
| 8  | 551,325            | 12.1              | 1,245,735,142        | 8,992        | 1,479      |
| 9  | 603,822            | 12.6              | 1,250,661,018        | 8,933        | 0,660      |
| 10 | 656,583            | 13                | 1,260,421,134        | 8,991        | 0,645      |
| 11 | 754,722            | 13.6              | 1,277,445,914        | 9,058        | 0,740      |
| 12 | 867,228            | 14.1              | 1,282,657,781        | 9,025        | 0,366      |
| 13 | 990,615            | 14.7              | 1,295,957,708        | 9,029        | 0,044      |
| 14 | 1,111,926          | 15.5              | 1,311,581,327        | 8,942        | 0,973      |

Other step to validate the results of the local analysis is to compare it with the global model in term of the nominal stress in the brace using Von Mises stress, as presented at Table 4.

**Table 4.** Nominal stress validation

| $\sigma_N$ Von Mises (ksi) |                   | Error (%) |
|----------------------------|-------------------|-----------|
| FEA (Global model)         | FEA (Local model) |           |
| 9,0297                     | 9,0298            | 0,000916  |

From Table 4 it is shown that the percentage error is 0.000916% which is below 1%, indicating that the local analysis is close to the global analysis both in terms of structural modeling, loading, and

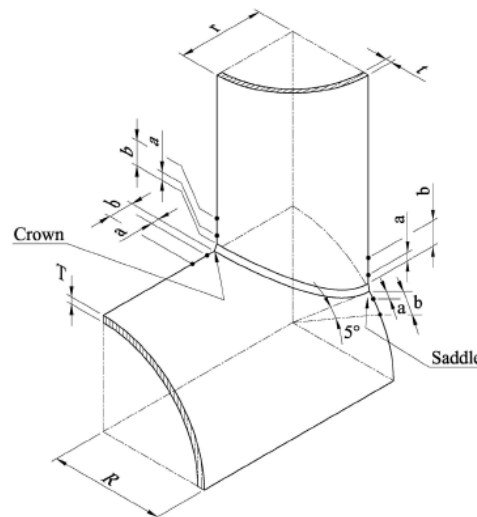
boundary conditions and also the results of the analysis. So that the local analysis is well validated by the global analysis results.

### 3.2. Hot-spot stress and SCF calculation

The widely accepted conventional approach for fatigue strength assessment of tubular joints is to use the geometric stresses at the weld toe. According to DNVGL-RP-C203 [17] hot-spot stress determined using linear extrapolation. The linear extrapolation method is done by making two points forming an area which will be extrapolated in linear stress. In this study, to determine the distance of two linear extrapolation points used refers to DNVGL-RP-C203 (see Figure 7). The maximum principal stress is used as linear extrapolation to determine the hot-spot stress [18].

After the known nominal stress and hot-spot stress, the formula stress concentration factor is:

$$SCF = \frac{\sigma_{maks}}{\sigma_n} \quad (1)$$

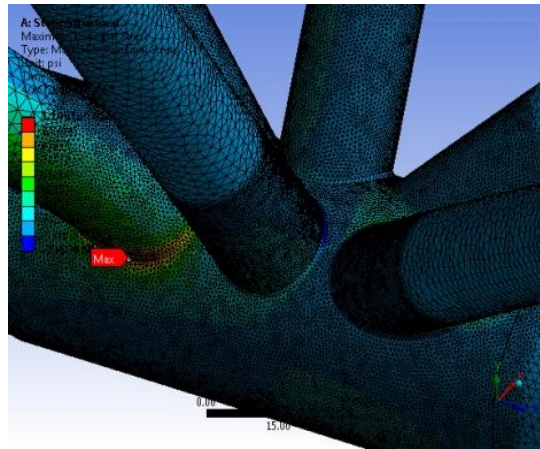


**Figure 7.** Extrapolation procedure recommended by DNVGL-RP-C203

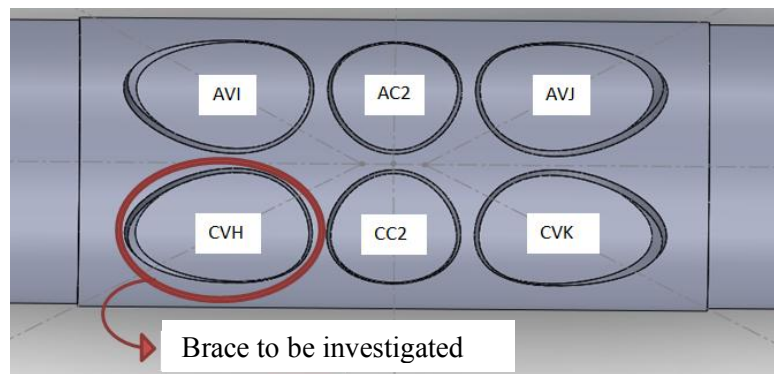
## 4. Results and analysis

The result of the parametric study with finite element approach is performed to determine the effect of the non-dimensional parameter variation on the stress distribution along the intersection line between the brace and the chord, which in study is done along the weld toe on the chord side. Stress distribution along the weld toe on the chord side to be investigated only on the joint between the brace with the chord that experienced the greatest stress.

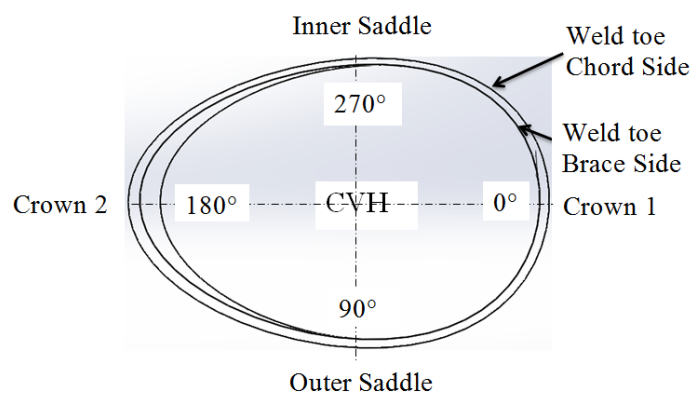
In this study, the joint between the brace and the chord that experienced the greatest stress due to the axial force is in the CVH brace (inclined brace) as can be seen at Figures 8 and 9. The intersection line with oval-shaped approached using angle in degree (see Figure 10). The crown point 1 is assumed to be the angle  $0^\circ$  and the  $360^\circ$  angle indicating that the point of crown 1 is the starting point of the investigation and the end point of the investigation. The saddle outer point is assumed to be an angle of  $90^\circ$ , the crown 2 points assumed to be angle of  $180^\circ$  and the inner saddle is assumed to be angle  $270^\circ$ . Different values assigned to each non-dimensional parameter are as follows:  $\beta = 0.35, \beta = 0.4, \beta = 0.45$ ;  $\gamma = 10, \gamma = 12, \gamma = 15$ ;  $\tau = 0.35, \tau = 0.45, \tau = 0.55$ ;  $\theta = 36^\circ, \theta = 46^\circ, \theta = 56^\circ$ .



**Figure 8.** Maximum stress occurs at the inclined brace-CVH



**Figure 9.** Location of inclined brace to be investigated



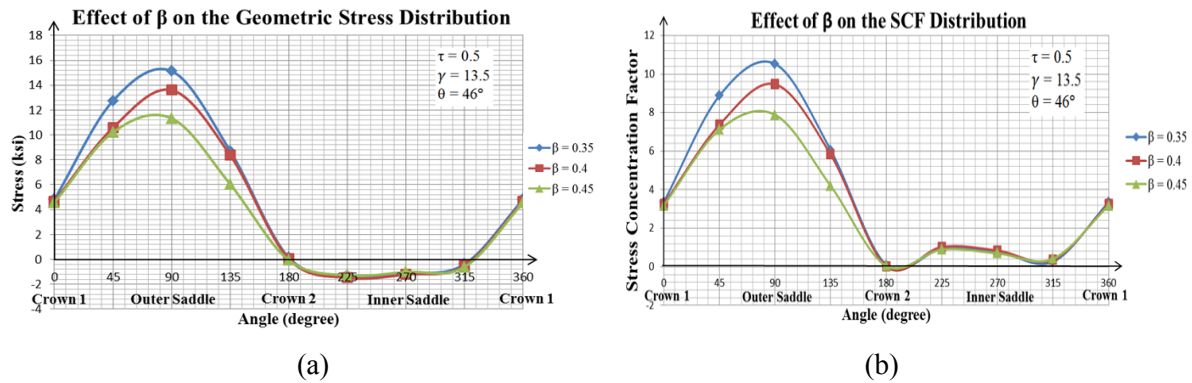
**Figure 10.** Intersection line of inclined brace to be investigated with angle approach

#### 4.1. Effect of $\beta$ on the geometric stress and SCF distribution

The parameter  $\beta$  is the ratio of brace diameter to chord diameter. In this study, variation of the  $\beta$  is  $\beta = 0.35$ ,  $\beta = 0.4$  and  $\beta = 0.45$ . Increasing the  $\beta$  in the models having constant value of chord diameter leads to increase of brace diameter. All parameters except the  $\beta$  parameter, i.e., the parameters  $\tau$ ,  $\gamma$  and  $\theta$  are made equal to the three models ( $\tau = 0.5$ ;  $\gamma = 13.5$ ;  $\theta = 46^\circ$ ).



Results of investigation that can be seen in Figure 11 indicate that increase of the  $\beta$  leads to decrease both geometric stress and SCF distribution along the weld toe (on the chord side). According to the three models, the maximum geometric stress and maximum SCF occurs at the same point, i.e. at the outer saddle point (angle  $90^\circ$ ).

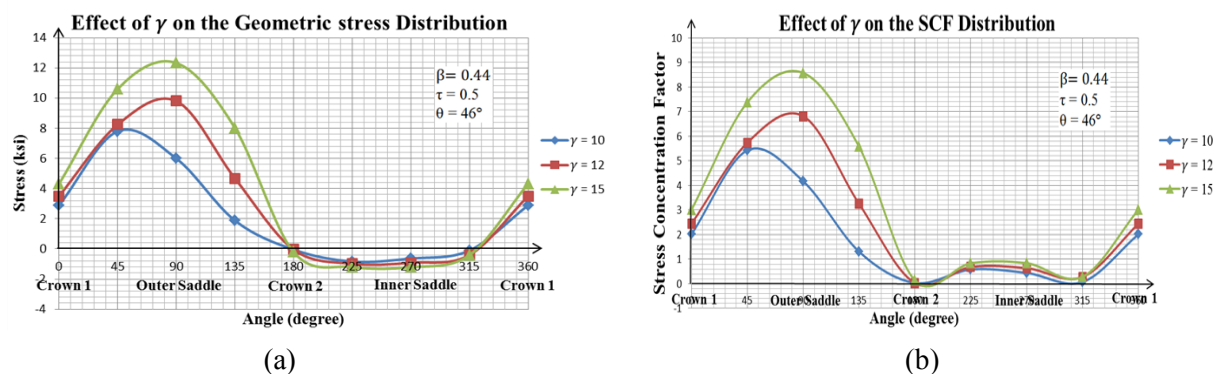


**Figure 11.** Effect of  $\beta$  on the (a) geometric stress distribution, (b) SCF distribution

#### 4.2. Effect of $\gamma$ on the geometric stress and SCF distribution

The parameter  $\gamma$  is the ratio of diameter or radius to thickness of chord. In this study, the  $\gamma$  is varied in three models with different size of parameter  $\gamma$  made for these models, i.e.  $\gamma = 10$ ,  $\gamma = 12$  and  $\gamma = 15$ . Increase of  $\gamma$  in the models having constant value of chord diameter leads to decrease of chord thickness. All parameters except the  $\gamma$  parameter, i.e., the parameters  $\beta$ ,  $\tau$  and  $\theta$  are made equal to the three models ( $\beta = 0.44$ ;  $\tau = 0.5$ ;  $\theta = 46^\circ$ ).

Results of investigation (can be seen in Figure 12) indicate that increase of the  $\gamma$  leads to increase geometric stress and SCF distribution along the weld toe (on the chord side). In the  $\gamma = 12$  and  $\gamma = 15$  models, the maximum geometric stress and SCF occurs at the saddle outer point (angle  $90^\circ$ ) while for the model  $\gamma = 10$ , the maximum geometric stress and peak SCF occurs at a point with an angle of  $45^\circ$ .

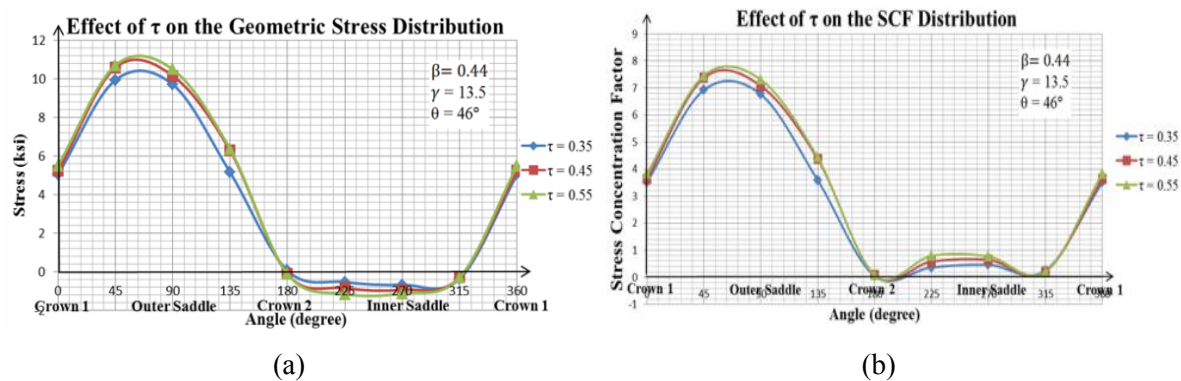


**Figure 12.** Effect of  $\gamma$  on the (a) geometric stress distribution (b) SCF distribution

#### 4.3. Effect of $\tau$ on the geometric stress and SCF distribution

The parameter  $\tau$  is the ratio of brace thickness to chord thickness. In this study, the  $\tau$  is varied in three models with different size of parameter  $\tau$  made for these models, i.e.  $\tau = 0.35$ ,  $\tau = 0.45$  and  $\tau = 0.55$ . Increase of  $\tau$  in the models having constant value of  $\gamma$  leads to increase of brace thickness. All parameters except the  $\tau$  parameter, i.e., the parameters  $\beta$ ,  $\gamma$  and  $\theta$  are made equal to the three models ( $\beta = 0.44$ ;  $\gamma = 13.5$ ;  $\theta = 46^\circ$ ).

Opposite to the effects of the two previous parameters,  $\beta$  and  $\gamma$ , results of investigation (as presented at Figure 13) indicate that increase of the  $\tau$  leads to also increase geometric stress and SCF distribution along the weld toe (on the chord side). According to the three models, the maximum geometric stress and peak SCF occurs at the same point which is at an angle of  $45^\circ$ .

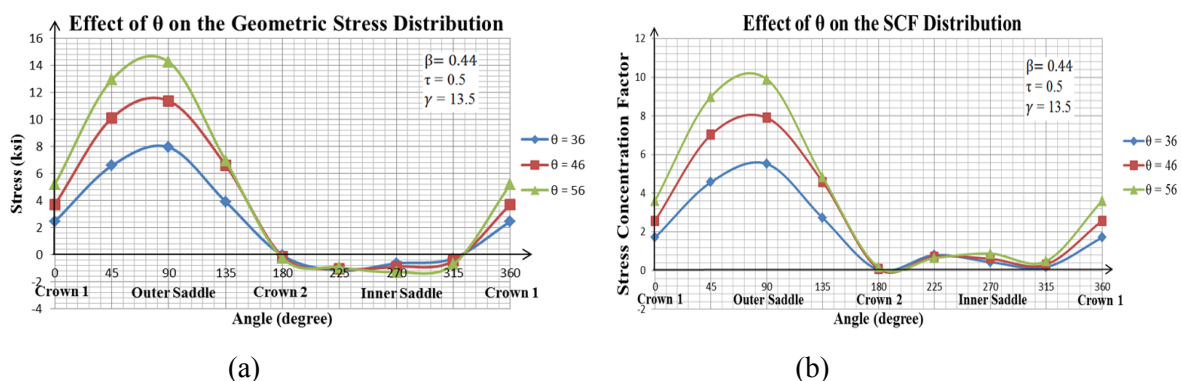


**Figure 13.** Effect of  $\tau$  on the (a) geometric stress distribution, and (b) SCF distribution

#### 4.4. Effect of $\theta$ on the geometric stress and SCF distribution

The parameter  $\theta$  is angle between brace to chord. In this study, the  $\theta$  is varied in three models with different size of parameter  $\theta$  made for these models, i.e.  $\theta = 36$ ,  $\theta = 46$  and  $\theta = 56$ . All parameters except the  $\theta$  parameter, i.e., the parameters  $\tau$ ,  $\gamma$  and  $\tau$  are made equal to the three models ( $\beta = 0.44$ ;  $\tau = 0.5$ ;  $\gamma = 13.5$ ). In principle it is free to select values of these  $\beta$ ,  $\tau$ , and  $\gamma$  as long as in the common range as already mentioned previously. For this analysis, the chosen values is in order to enrich data for this research.

Results of investigation (can be seen in Figure 14) indicate that increasing the  $\theta$  leads to decrease geometric stress and SCF distribution along the weld toe (on the chord side). According to the three models, the maximum geometric stress and peak SCF occurs at the same point, i.e. at the outer saddle point (angle  $90^\circ$ ).



**Figure 14.** Effect of  $\theta$  on the (a) geometric stress distribution (b) SCF distribution

## 5. Conclusions

The results of parametric studies show that the increase of the  $\beta$  leads to decrease of SCF and geometric stress. While the increase of the  $\tau$ ,  $\gamma$  and  $\theta$  leads to increase of SCF and geometric stress. The maximum geometric stress and peak SCF occurs at the same point caused by variation of  $\beta$ , i.e. at the outer saddle point (angle  $90^\circ$ ). For variation of  $\gamma$ , in the  $\gamma = 12$  and  $\gamma = 15$  models, the maximum geometric stress and SCF occurs at the saddle outer point (angle  $90^\circ$ ) while for the model  $\gamma = 10$ , the maximum geometric stress and peak SCF occurs at a point with an angle of  $45^\circ$ . The maximum geometric stress and peak SCF occurs at the same point by variation of  $\tau$ , with an angle of  $45^\circ$ . For variation of  $\theta$ , the maximum

geometric stress and peak SCF occurs at the same point, i.e. at the outer saddle point (angle  $90^\circ$ ). The effect of parameters  $\beta$ ,  $\gamma$  and  $\theta$  on the SCF are greater than the effect of parameters  $\tau$ .

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