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Influence of Geometric Parameters on Fatigue Life of Two-Planar Tubular DKT Joints Based on Fracture Mechanics Under a Combination Loading

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ABSTRACT
According to SKK Migas, Indonesia has operated 613 units of offshore platforms which is 54.65% of the platforms are more than 20 years old, and 24.63% are between 16-20 years old. With the extension of its operation time, the structural integrity of the old platform will decrease. One of the potential consequences is structural failure due to cyclical loading caused cracks. This research aims to determine the influence of geometric parameters beta (β), gamma (γ) and tau (τ) in DKT twoplanar tubular joints on fatigue life based on fracture mechanics. By varying geometric parameters, we can see the influence of geometric parameters on fatigue life under combined loads of axial, in-plane bending, and out-of-plane bending moments. The tubular joints are modeled locally and analyzed using Finite Element Analysis (FEA), and the crack is modeled as a semi-elliptical form. Fatigue life analysis is performed by varying geometric parameters under the combined loads. After carrying out a sensitivity analysis on all geometric parameters, it was concluded that the gamma parameter (γ) had the most influence on the combined load with a sensitivity of 89%..

Keywords: *Fatigue Life, Fracture Mechanics, Tubular Joint.*

1. INTRODUCTION
Based on the information presented in the SKK Migas presentation at the 3rd Indo Decomm in Oil and Gas Conference, Indonesia has operating 613 fixed offshore platform units since production the first commercial in offshore areas. Of the total platforms, as much as 54.65% were more than 20 years old, while 24.63% were aged between 16-20 year. With extended operational time, the platform will certainly experience a decrease in performance due to problems with its structure. Structural strength evaluation generally considers fatigue life analysis, especially at tubular joints, both in the chord and brace sections that are connected through welding technology [1]. Cyclic loads on tubular joints in welded parts can give rise to initial cracks which are an indication of potential fracture mechanics failure [2]. These cracks can propagate and cause structural failure [3]. On offshore platforms that have been in operation for more than 20 years and have crack records in their inspection data, fracture mechanics methods are generally used to approach fatigue life. A significant factor in the fracture mechanics method is the variable that describes the stress intensity in the crack [4].

Prediction of crack growth in determining fatigue life is generally based on the Paris Law theory, which is expressed through an exponential relationship between the Stress Intensity Factor (SIF) and the crack growth rate. The Paris theory was developed by considering the influence of the stress ratio R and crack strength KC on the crack growth rate. The Stress Intensity Factor Range (ΔK) can be used to overcome the problem of non-linearity in crack growth rates [5].

The load on the tubular joint will result in stress around the intersection between the chord and brace. The stress distribution in tubular joints is very complicated to detect, so this area deserves attention. At points along the weld area between the chord and brace, stress is higher than other areas [6]. The locations or points where the greatest stress occurs are called hot spots, and the stress that occurs is called hot spot stress [7]. Hot spot stress in tubular joints affects the accuracy of fatigue life calculations in tubular joints [8]. The maximum stress that occurs in multi-planar joints can be greater than in uniplanar joints. So, the estimation of stress concentration factors for multiplanar joints is more complex [9].

2. METHODOLOGY
2.1 Modelling
In this research, the tubular joints to be analyzed are focused on two-planar DKT tubular joints. The selection of these joints is based on the highest unity check (UC) values from previous analysis, specifically the global analysis. The global analysis results revealed that the DKT joint is the most critical two-planar joint based on the obtained unity check (UC) results of the global simulation. DKT joint modeling is based on the actual geometry and dimensions, which consist of a chord and 6 braces, each with their respective sizes. The length of the chord and brace in the local model is minimum 6 x Outside Diameter (OD) [10].

Table 1. The dimension of DKT joint model

Item	OD (mm)	WT (mm)	L (m)
Chord 1	1676	24.1	10
Joint can	1714	38.1	2
Chord 2	1676	24.1	10
Brace 1	508	10	5
Brace 2	609	10	5.3
Brace 3	609	8	7.8
Brace 4	508	10	5
Brace 5	609	10	8
Brace 6	609	8	7.5

Table 1 presents the outside diameter, the section length, and wall thickness of the DKT joint. Figure 1 presents the comprehensive local representation of the DKT joint. Modeling of welds in tubular joints greatly influences the calculation of stress that occurs. Modeling the weld as a solid element provides more significant results compared to ignoring the weld profile [11]. The calculation of weld dimensions is referenced from [12]. The height and length of the weld are determined by performing weld modeling between the brace and chord in the DKT joint, which has been geometrically represented

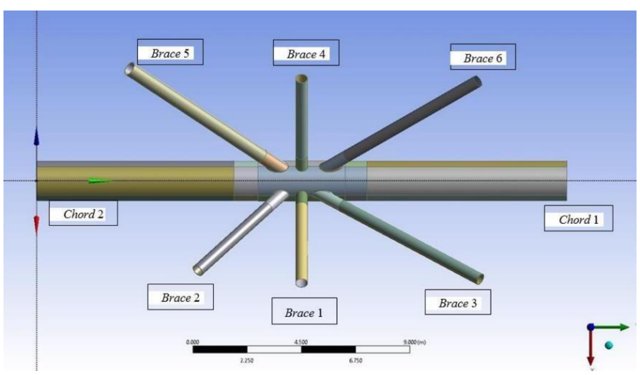

Figure 1. Local model of the DKT joint

2.2 Boundary Conditions

The two-planar tubular DKT joint model is built with boundary conditions that aim to accurately describe the actual structural conditions. Fixed supports are applied at both ends of the chord to resist rotational and translational movements. In the context of finite element structural analysis, a "fixed support" signifies the complete restriction of all degrees of freedom, preventing any movement of the model elements [13]. The load acting on the brace is applied to the end surface of the brace. The magnitude of the combined loading (axial, in-plane bending, and out-of-plane bending) on the brace members is illustrated in Table 2. The boundary condition on DKT joint model shown in Figure 2.

Table 2. Loading on each brace of the model

Brace	Fx (N)	Fy (N)	Fz (N)	My (N-mm)	Mz (N-mm)
Brace 1	135000	-1304	351	1850000	1850000
Brace 2	1250000	-5767	-4327	-3160000	6790000
Brace 3	769000	-36	-632	-1740000	-4570000
Brace 4	156360	-931	246	2790000	-2840000
Brace 5	-2958070	6165	-8641	-10240000	-9830000
Brace 6	1120380	-5715	8765	-1680000	-2210000

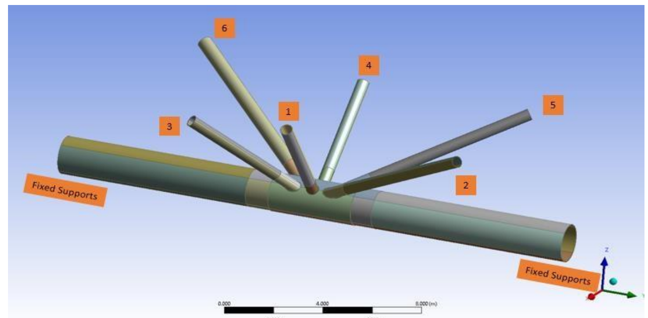

Figure 2. Boundary condition of DKT joints

2.3 Mesh Generation

For better mesh quality, mesh generation is adjusted to parts that are considered critical. The entire structure is divided into several parts according to needs and capabilities. To produce better stress in the welded joint, the mesh size is adjusted in the welded part. The part around the weld is smaller than other areas. This method increases the precision of the output by solving it using the model into finer subdivisions [14].

The resulting mesh for a two-planar tubular DKT joint is shown in Figure 3. Purpose of meshing sensitivity analysis is to validate the model and the number of elements has converged so that it can be used for further analysis [15]. Meshing sensitivity analysis was carried out by increasing the number of elements and analyzing the probe stress at the joint due to combined loading (axial, in-plane bending, and out-of-plane bending). The stress probe used is at the critical point of the joint, which is the weld area and will not change during the increase in the number of mesh elements and the analysis shown in Figure 4. A stress probe is considered valid when it has reached a constant with a maximum error of 2% and the mesh can be used. So, with the 10th mesh variation with the number of elements 241449 with a probe stress of 258.1 MPa is considered valid and can be used for further analysis.

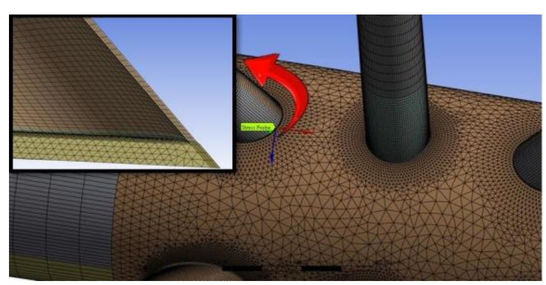
Figure 3. Mesh Generation for DKT Joints

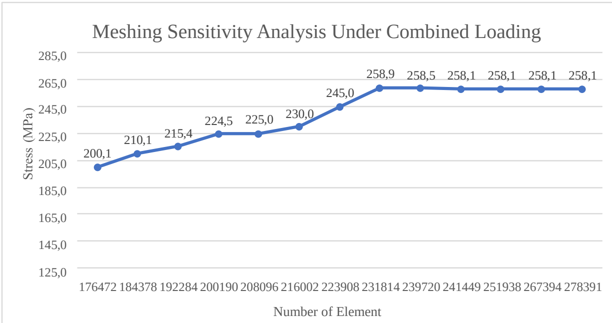

Figure 4. Meshing Sensitivity Under Combined Loading

2.4 Variation of Geometric parameters

The objective of this research is to determine the effect of geometric parameters beta (β), gamma (γ), and tau (τ) on the fatigue life of two-planar tubular DKT joints due to combined loads (axial, in-plane bending, and out-of-plane bending). The beta (β) parameter represents the outside diameter ratio between chord and brace, gamma (γ) represents the ratio between outside diameter and wall thickness of chord, and tau (τ) represents the wall thickness ratio between chord and brace. The geometric parameters are used by the engineer to carry out the initial design of the jacket platform. Variations of geometric parameter values are shown in Table 3.

Table 2. Variations of geometric parameters of the tubular DKT joints

Parameter	Variation	OD Chord (mm)	WT Chord (mm)	OD Brace (mm)	WT Brace (mm)	Value
β	A B	2064	38	609	8	0.2
	C	1714	38	609	8	0.3
		1614	38	609	8	0.4
	D	1314	38	609	8	0.5
	E	1064	38	609	8	0.6
γ	F	914	38	609	8	12
	G	1314	38	609	8	17
	H	1714	38	609	8	22
	I	2064	38	609	8	27
	J	1714	27	609	8	32
τ	K	1714	43	609	7	0.16
	L	1714	38	609	8	0.21
	M	1714	38	609	10	0.26
	N	1714	38	609	12	0.31
	O	1714	35	609	12.5	0.36

2.5 Hot Spot Stress Calculation and Crack Modeling

Hot-spot stresses on the outer surface of the chord are required to determine the crack point to be modeled. Calculation of hot-spot stress on this research refers to the book IIW-XV-E [16]. The method used is a linear extrapolation method with 2 points extrapolation reference, namely at points 0.4t and 1.4t where "t" is the chord thickness. These two points start from the weld toe where the highest stress occurs. Figure 5 shows an illustration of hot spot stress extrapolation points. Hot spot stress is defined as the maximum principal stress. This matter because the hot spot stress is the largest extrapolation of the distribution the maximum principal stress is just outside the region influenced by the geometry welding [17].

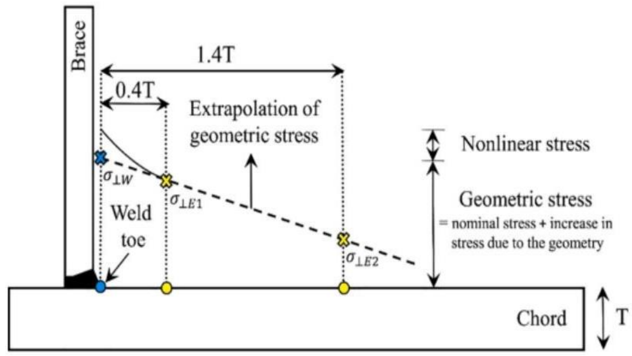

Figure 5. Extrapolation Method to Determine the Hot Spot Stress

The crack modeled uses a semi-elliptical crack type because this type is often used in several previous studies for modeling fatigue life based on fracture mechanics. The crack modeled using the assumption of an initial crack depth of 0.5 mm and a ratio of crack length 0.15 [18]. The scheme of the crack can be seen in Figure 6, "t" is the thickness of the chord, "a" is the depth crack and "2c" is the crack length. Cracks are modeled in areas hot spot stress. This is because hot spot stress areas are areas which has the maximum stress before cracking occurs. The modeled crack has an orientation crack that are parallel to the longitudinal direction of the tubular due to the more dominant axial load. Crack modeling is modeled at points stress hot spots as in Figure 7.

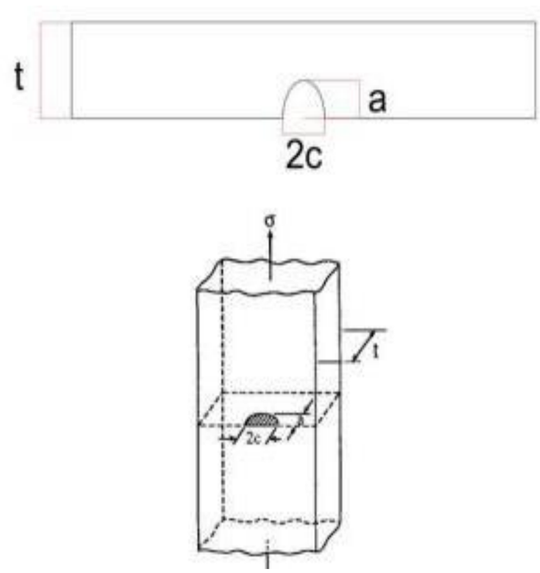

Figure 6. Crack Making Scheme

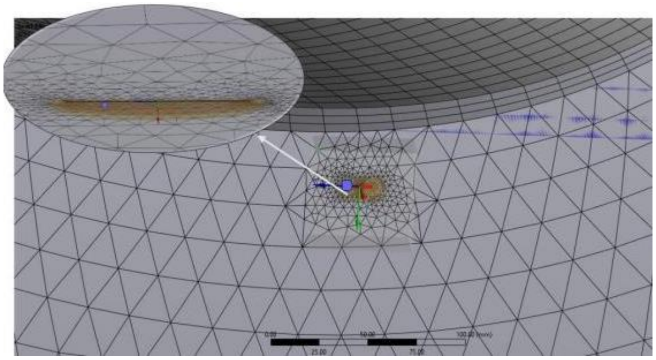

Figure 7. Crack Modeling in DKT Tubular Joints

Crack meshing sensitivity analysis was carried out by comparing crack front divisions to stress intensity factors (KI) [19]. Based on Figure 8, the KI value is stable at 327.18 MPa.mm0.5 when the crack front divisions value is 30 to 37. The crack model valid and can be used for further analysis.

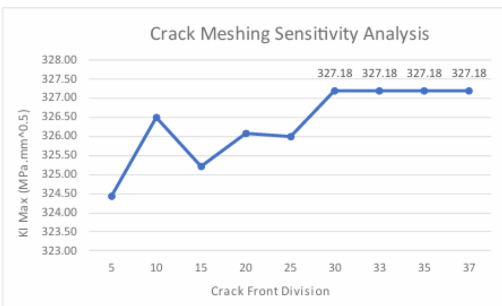

Figure 8. Crack Meshing Sensitivity Analysis

2.6 Fatigue Life Calculation Using Fracture Mechanics

In fatigue life prediction analysis, an intensity factor output is required stress from analysis on the finite element method of cracks in tubular joint DKT. The stress intensity factor describes the situation stress at the crack tip, related to the crack growth rate, and used to establish failure criteria due to fracture. Analyzed K in this study is K mode I (KI) cracking which is related to normal separation of the crack surface under the action of stress, which is so far most encountered in practice.

Based on the Paris-Erdogan law Range Stress Intensity Factor (ΔK) obtained from the difference between K at maximum load and K at load minimum. Analysis of crack propagation speed (da/dN) requires crack parameters (C and m) based on the type of material. The C and m values for each material were obtained empirically using data obtained from fatigue tests. The type of material used in this research is ferrite-pearlite steel which has C and m of 3.6 x 10-10 and 3.0 [20]. Analysis of crack propagation rate using Equation 1.

$$\frac{da}{dN} = 3.6 \times 10^{-10}\ (\Delta ki)^{3.0} \qquad (1)$$

The material used in this research is ASTM A572 with a yield stress of 355 MPa. This material has a fracture toughness (KIC) of 97 MPa.mm$^{1/2}$ [21]. The maximum crack depth in ASTM A572 steel can be calculated using Equation 2. Calculation of remaining fatigue life using Equation 3.

$$acr = \left(\frac{KIC}{\sigma max\sqrt{\pi}}\right)^2 \qquad (2)$$

$$N = \int_{a0}^{af} \frac{da}{C(\Delta k)^m} \qquad (3)$$

3. RESULT AND DISCUSSION

3.1 Stress on the Model

Von Mises stress is a scalar quantity that includes normal stress and tangential stress on the three main axes. It is used to assess a material's resistance to plastic deformation. Von Mises stress will be used as the basis for calculating stress distribution. Based on Figure 9, the Maximum Von Mises Stress that occurs is 258 MPa and is still below the yield stress for ASTM A572 material of 355 MPa.

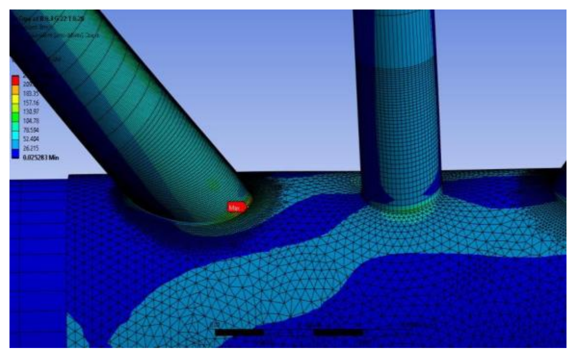

Figure 9. Maximum von mises stress on DKT joints

3.2 Hot Spot Stress Result

The reference point is determined by extrapolating from the location of the highest stress within the brace. The maximum stress for the combined loading occurs at the weld to along brace 5. Therefore, this location serves as a starting point for extrapolating the hot spot stress. Hot spot stress sampling is taken every 45 degrees along the weld toe as in Figure 10, the result shown in Table 4. Based on Figure 11, the K and N variations have the highest hot spot stress of 274.29 MPa from weld toe point 270°.

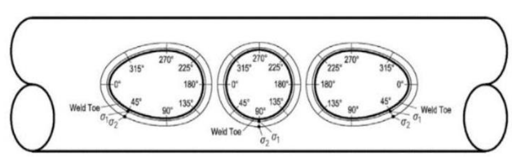

Figure 10. Location determination of hot spot stress at the weld toe

Table 4. Hot Spot Stress at Any Point on the Weld Toe

Angle (degree)	Hot Spot Stress (MPa)
0	37.52
45	80.95
90	79.77
180	7.92
225	179.42
270	274.29
315	150.81

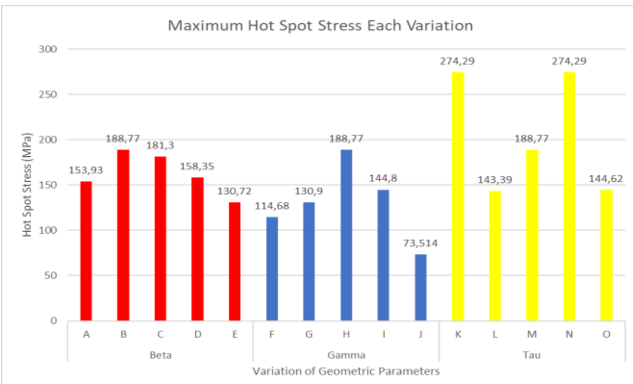

Figure 11. Maximum Hot Spot Stress Each Variation

3.3 Fatigue Result

The parameter beta (β) represents the ratio outside diameter between chord and brace. This section provides the findings of the study on the impact of beta (β) on the fatigue life tubular joints DKT. From the fatigue life result in Figure 12, value of parameter beta (β) gives the fatigue life raise up significantly and have max value on variation E (beta value 0,6) which has the highest value of parameter beta with fatigue life 61 years.

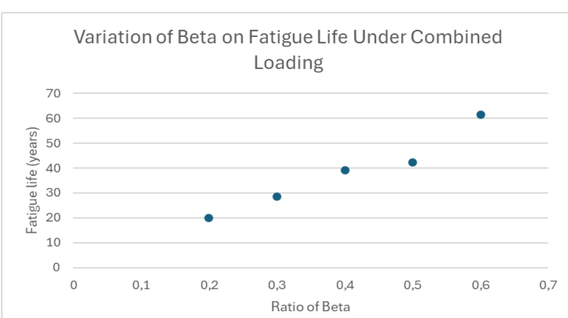

Figure 12. Variation of Beta on Fatigue Life Under Combined Load

The parameter gamma (γ) represents the ratio between outside diameter and wall thickness of chord. This section provides the findings of the study on the impact of gamma (γ) on the fatigue life tubular joints DKT. From the fatigue life result in Figure 13, value of parameter gamma (γ) gives the fatigue life fluctuated value. The gamma (γ) parameter has the highest fatigue life of 72 years in variation F (gamma value 12) and has the lowest fatigue life 29 years in gamma variation H (gamma value 22).

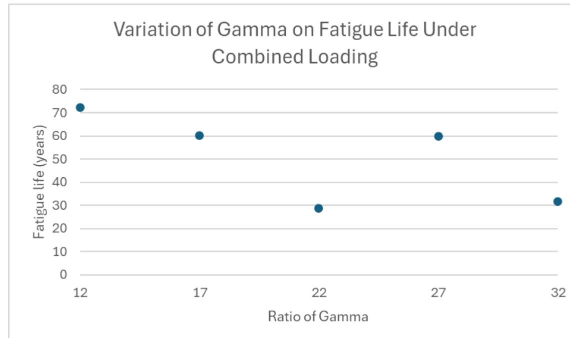

Figure 13. Variation of Gamma on Fatigue Life Under Combined Load

The parameter tau (τ) represents the ratio wall thickness between chord and brace. This section provides the findings of the study on the impact of tau (τ) on the fatigue life tubular joints DKT. From the fatigue life result in Figure 14, value of parameter tau (τ) gives the fatigue life fluctuated value. The tau (τ) parameter has the highest fatigue life of 95 years in variation K (tau value 0.16) and has the lowest fatigue life of 29 years in gamma variation M (tau value 0.26).

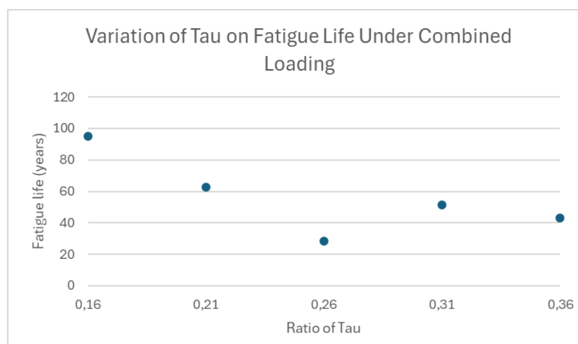

Figure 14. Variation of Tau on Fatigue Life Under Combined Load

Sensitivity analysis is a technique used to understand how variations in the input parameters of a model affect the output or performance of the model. By carrying out sensitivity analysis, adjustments can be made to critical parameters so that the desired results can be achieved with higher efficiency. In this study, the sensitivity of each geometric parameter to the combined load on the DKT tubular connection was analyzed. After carrying out sensitivity analysis on all parameters, it was found that the gamma parameter had the greatest sensitivity compared to other parameters. The sensitivity of the gamma (γ) parameter to the fatigue life of DKT tubular joints is 89%. Result of sensitivity analysis shown in Table 5.

Table 5. Sensitivity Analysis Each Parameter

Geometric Parameter	Sensitivity (%)
Beta	3%
Gamma	89%
Tau	62%

CONCLUSIONS

Based on the analysis conducted, the following conclusions were obtained from this Study.

1. The maximum von mises stress that occurs in the two-planar DKT joint under combined loads is 258 MPa, located at the weld toe of brace 5.
2. The maximum hot spot stress of all parameter variations is 274.29 MPa in the K and N variations.
3. These three parameters give varied effect to the fatigue life in the DKT tubular joint. The parameters gamma (γ) and tau (τ) give fatigue life fluctuations with sensitivity of 89% and 62%. The beta (β) parameter generally increases fatigue life.

REFERENCES

1. Ahmadi H and Zavvar E 2020 Degree of bending (DoB) in offshore tubular KT-joints under the axial, in-plane bending (IPB), and out-of-plane bending (OPB) loads Applied Ocean Research 95 102015
2. Prastianto R W, Hadiwidodo Y S, Widhestomo S W and Yazhahir R 2018 Stress Distribution along the Weld Toes of Tubular KT and KDT Joints under Balance Axial Loads and In-Plane-Bending Moments Science and Technology Publications 2018 170-175
3. Ahmadi H and Nejad A Z 2017 Local joint flexibility of two-planar tubular DK-joints in OWTs subjected to axial loading: Parametric study of geometrical effects and design formulation Ocean Engineering 136 1–10
4. Fageehi Y A 2022 Prediction of Fatigue Crack Growth Rate and Stress Intensity Factors Using the Finite Element Method Advances in Materials Science and Engineering 2020 2705240
5. Hertzberg R W, Vinci RP and Hertzberg J L 2020 Deformation and fracture mechanics of engineering materials (US: John Wiley & Sons)
6. Prastianto R W, Syahroni N, Syalsabila F and Rozi M F 2024 Bending load effects on stress concentration factor distribution of multi-planar DTKY tubular joints E3S Web of Conferences 483 03018
7. Hidayat U 2016 Studi Parametrik pada Multiplanar Tubular Joint Double K Terhadap Nilai SCF Undergraduate Thesis Institut Teknologi Sepuluh Nopember, Surabaya
8. Prastianto R W, Adha I A, Hadiwidodo Y S, Rosyid D M and Mulyadi Y 2023 Hot Spot Stress Analysis of a Two-
9. Planar DTY Tubular Joint Subjected to Axial Loading IOP Conf. Series: Earth and Environmental Science 1166 012036
10. Prastianto R W, Hadiwidodo Y S, Fuadi I F, Naibaho M B Y P and Rahardianto P N 2018 Stress concentration factor distribution of inclined brace in multiplanar offshore tubular double kt joints IOP Conf. Series: Earth and Environmental Science 162 012049
11. Efthymiou M 1988 Development of SCF formulae and generalized influence functions for use in fatigue analysis Proceedings of the Offshore Tubular Joints Conference (OTJ'88)
12. Zavvar E, Hectors K and Waele W D 2021 Stress concentration factors of multi-planar tubular KT-joints subjected to in-plane bending moments Marine Structure 78 103000
13. AWS 2020 Structural Welding Code-Steel (USA: American Welding Society)
14. Hardian M A, Prastianto R W, Rosyid D M, Mulyadi Y and Syalsabila F 2024 The Effects of Degree of Bending
15. (DoB) in Multi-planar DTKY Tubular Joint on the Stress Concentration and Intensity Factors for Fatigue Assessment of Offshore Structures Lecture Notes in Civil Engineering 466 593-607
16. Prastianto R W, Syahroni N, Syalsabila F and Rizkhita A R 2024 The geometrical parameters effect on the degree of bending of multiplanar DTKY tubular joint for offshore platforms E3S Web of Conferences 483 03017
17. Noviyanti I, Prastianto R W and Murdjito 2021 Stress Distribution Analysis of DKDT Tubular Joint in a Minimum Offshore Structure Rekayasa 14 191-199
18. Hobbacher A 2008 Recommendations for fatigue design of welded joints and components (Paris: International Institute of Welding)
19. DNVGL-ST-N001 2020 Marine Operations and Marine Warranty (Norway: Det Norske Veritas)
20. ABS 2022 Fracture Analysis for Marine and Offshore Structures (New York: American Bureau of Shipping)
21. Fageehi Y A 2022 Prediction of Fatigue Crack Growth Rate and Stress Intensity Factors Using the Finite Element Method Advances in Materials Science and Engineering 2022 2705240
22. Barsom J M and Rolfe S T 1999 Fracture and fatigue control in structures: applications of fracture mechanics (Pennsylvania: ASTM)
23. Barbosa V S and Ruggieri C 2018 Fracture toughness testing using non-standard bend specimens – Part II: Experiments and evaluation of T0 reference temperature for a low alloy structural steel Engineering Fracture Mechanics 195 297–312.