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Fatigue Life and Crack Initiation of K and N Type Jacket Structure Using 3D Fatigue FE Analysis

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Abstract

Jacket structures are widely used as foundation structures for offshore wind energy. The jacket structure as a truss shape structure is not deformed easily and has the advantage of keeping the structure stable under wind load. The offshore jacket structures are subjected to unstable repetitive loads such as wind, and wave loads in the deep sea. These harsh environments lead to the deterioration of material performance and fatigue failure with cracks in the structure. It is crucial to locate fatigue cracks since they might compromise a structure's overall stability.

In this study, fatigue life and crack initiation for different braced jacket structures were investigated. First, 3D non-steady heat conduction analysis and thermal elastic-plastic analysis were performed to reproduce the initial state of the weld joint in the jacket structure. The heat history obtained from the 3D non-steady heat conduction analysis was enforced as an input in thermal elastic-plastic analysis to calculate welding deformation and residual stress. Next, the fatigue FE analysis of the jacket welding structure was carried out using the residual stress and welding deformation as initial values along with the external cyclic loadings. The 3D fatigue FE analysis employed cyclic hysteresis constitutive equations and fatigue damage theory to calculate the fatigue life and crack initiation. The 3D fatigue FE results were compared with the S-N curve by European code 3 and the hot spot stress (HSS) method. The results show that the 3D fatigue FE method effectively calculates the fatigue life and finds crack initiation.

Keywords

jacket structure, truss structure, residual stress, fatigue life, fatigue crack initiation, 3D fatigue FE analysis

1 Introduction

The oceans are rich in renewable energy sources, and many marine structures have been built to exploit these sources. A jacket structure is a kind of support structure widely used in offshore installations such as oil, gas, and wind power generation. The jacket substructure is a type of truss structure, that is very simple and easy to design and manufacture, it is not easily deformed, and keeps the structure stable. The disadvantages of the truss structure are buckling and fatigue problems. Most of the safety studies on the structure before construction have considered the buckling problem. Meanwhile, the jacket structure needs to work for decades in the ocean, so the truss structure is subjected to repeated loadings for decades in the ocean and has fatigue problems, so the fatigue study is essential. There are various types of trusses in the substructure of the jacket structure, and the truss structure is connected by welding, so the residual stress and welding deformation after welding are inevitably generated.

A lot of researchers have studied the fatigue life of jacket structures but still, there is a scarcity of research which affect is more dominant on the fatigue life leading to the crack initiation and finally fatigue rupture. Lee et al. [1] used the Allowable Stress Design (ASD) method to optimize the design and reliability analysis of jacket structures in a load-limited environment. Sun et al. [2] conducted a safety study and reliability analysis of the substructure after optimal design using the ANSYS software in the ocean-limiting environment. Tian et al. [3] optimized the conduit frame structure by changing the jacket structural layout and evaluated the optimized structure in the ultimate limit state. The results proved that the optimized conduit frame structure can effectively reduce

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the weight and stress concentration. Motlagh et al. [4] used a genetic algorithm to optimize the jacket offshore platform structure and used two optimization schemes, CF and WCF-Optimization, to reduce the weight of the jacket offshore platform structure. Failla et al. [5], carried out two uncoupled analyses for wind and wave loads and seismic loads for conduit jacket and tripod structures in offshore wind power generation, respectively. Sandhya et al. [6] used SACS (Structural Analysis Computer System) software for the design and analysis of offshore jacket structures and were able to calculate the static load and buckling characteristics of the structures better. They demonstrated that the method can be used for linear performance studies of offshore jacket structures. Kim et al. [7] analyzed the jacket-type fixed offshore wind turbine using FAST (Fatigue, Aerodynamics, Structures, and Turbulence) software. Cao et al. [8] used ANSYS software to obtain the residual stresses from the welding simulation of K-joint structures. The loads were applied to two different K-joint models with and without weld residual stresses. The stress concentration factors of these two models were calculated and the residual stresses were evaluated to affect the stress concentration factor (SCF). Lee [9] determine the degree of damage to the jacket support structure using the neural network method. Min et al. [10] estimated the size and location of damage to the jacket structure by cosine similarity and magnitude index. Also, they verified using ABAQUS software. Dong et al. [11] used hot spot stresses to analyze four different tubular joints. The characteristic of fatigue damage in the selected joints was predicted and compared under different models. Kyung et al. [12–14] investigated the fatigue life and cracks obtained in truss joint structures using large fatigue test specimens. Their results were compared with the S–N curves of the Japan Steel Construction Council (JSSC). Also, they analyzed the stress concentration coefficients of the truss K-joint structure under different conditions by the finite element method. Wang et al. [15] conducted experiments using a 1:8 proportion jacketed structure and demonstrated the validity of the Morison equation. Similarly, Ji et al. [16] fabricated a proportion jacket structure and verified the experimental results by using the nonlinear finite element method. The analysis considered the effects of corrosion and crack damage on the structure. Zheng et al. [17] finite element model of the k-joints was developed using ABAQUS and validated using experimental data. Ju [18] and Ju et al. [19] used IEC-61400-3 Standard loading for fatigue analysis of jacket support structures. They evaluated the torsion generated by the paddle above as the main cause of fatigue damage, so reducing the caused torsion can improve the fatigue life of the joint. Also, the fatigue damage of the structure was calculated using Miner's criterion under the wave load. Ivanhoe et al. [20] and Shittu et al. [21] used a parametric FEA model to simulate the OWT jacket support structure considering buckling, deflection, and fatigue. The reliability of the structure was evaluated using FORM (first-order reliability method). Also, random parametric 3D finite element analyses were performed using ANSYS software, and the reliability of the structure was calculated by applying FORM, and the analysis results showed that the fracture is highly sensitive to the initial crack size. Larsen et al. [22, 23] studied the hot spot stresses in the k-node jacket structure and learned that there is a large uncertainty in the hot spot stresses.

Uncertainty in hot spot stress leads to uncertainty in fatigue life. It is recommended that uncertainty be considered when calculating the fatigue life of welded pipe joints in offshore structures.

In this study, the fatigue analysis of two different types of truss structures was carried out according to the fatigue FE analysis method. During the fatigue finite element analysis, the welded structure is first simulated. Thermal histories are obtained to calculate the magnitude of residual stresses and weld distortion. In fatigue analysis, fatigue damage simulation of the structure under repeated loading considering residual stress and welding deformation was carried out. Finally, based on fatigue FE analysis results, the fatigue life and initial crack location of two different types of structures were compared.

2 FE welding analysis procedure

The jacket structure is mostly used to develop marine energy. The shapes of the jacket substructure are made of steel tubes connected by welding. The fatigue analysis of welding and non-welding structures shows that the residual stresses and welding deformation after welding significantly affect the structure's fatigue life in Do et al.'s [24] study. Therefore, the fatigue analysis of different substructures was carried out by first performing a welding analysis to obtain the residual stress and welding deformation. First, we used 3D non-steady heat conduction FE analysis for the welding simulation of the welding process in the structure. The temperature history of the welding was obtained. In the 3D thermal elastoplastic FE analysis, the temperature-dependent mechanical material properties and thermal load are used as input for getting the residual stresses, and weld deformation. The residual stresses and weld deformations were applied to fatigue analysis to obtain the fatigue life and crack initiation [25–27].

2.1 K and N Type model of Jacket substructure

In offshore wind power structures, a lot of jacket structures were used to utilize wind resources. In Fig. 1 (a) and (b), different truss shapes are applied to the substructure of the jacket structure, for example, K and N-type. In Fig. 1 (c) and (d) the structure is symmetrical. In the K and N-type tubular joints, the chord and brace tubes are of the same size but with different angles. The size of the chord and brace tubes can be found in Fig. 1 (c) and (d), where the diameter of the chord steel tube is 1200mm and the thickness is 35 mm. The diameter of the brace steel tube is 800 mm and the thickness is 20 mm. The weld size of the K-type tubular joint is depicted in Fig. 1 (c). The angle is the same so the weld size at positions (1 and 4) and (2 and 3) are the same. In N-Type tubular joint welding size is shown in Fig. 1 (d). The angle is the same as the K-type tubular joint so the welding size at positions (3 and 4) are the same. In the N-type tubular joint one brace is welded to the chord vertically, so the weld sizes at positions (1 and 2) are the same. In finite element analysis, eight-node iso-parametric solid elements were used. and the mesh sizes of the K and N-Types can be seen in Fig. 2. In the weld section, very fine mesh was used.

2.2 3D non-steady heat conduction FE analysis

Firstly, welding simulations were performed using 3D non-steady heat conduction FE analysis in K and N-type tubular joints. The thermo-physical constants were considered when performing the welding simulation. From Fig. 3, temperature-dependent thermo-physical constants (density, heat conductivity, and specific heat) vary with temperature [28, 29]. Fig. 4 (a), (b) shows the heat source distribution and temperature history of K and N-type tubular joints after welding. It can be seen in the Fig. 4 that the heat source mainly affects the parts near welding.

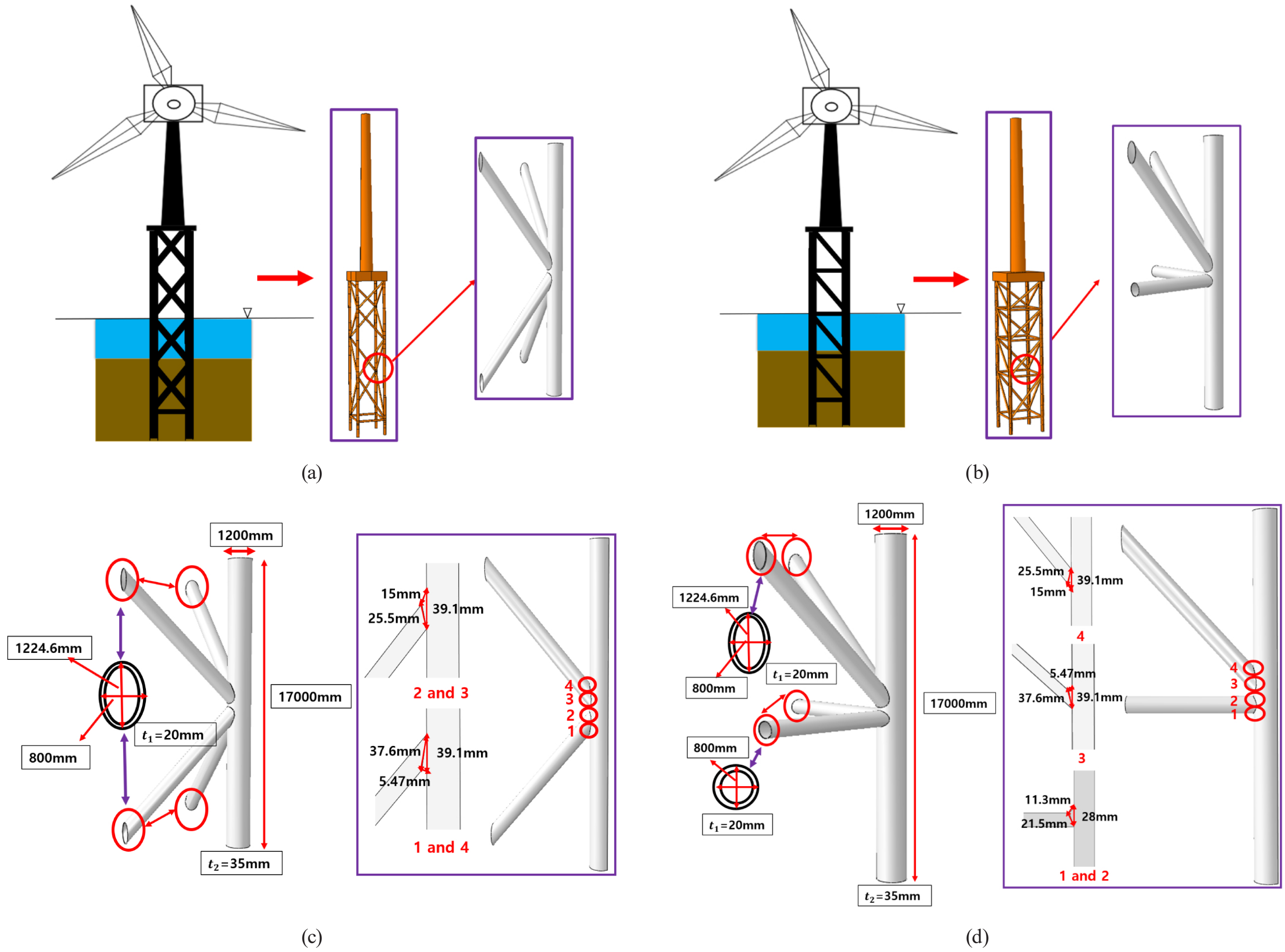


Fig. 1 Model geometry and welding size; (a) Jacket structure with K-Type shape, (b) Jacket structure with N-Type shape, (c) K-Type model size and welding joint size, (d) N-Type model size and welding joint size.

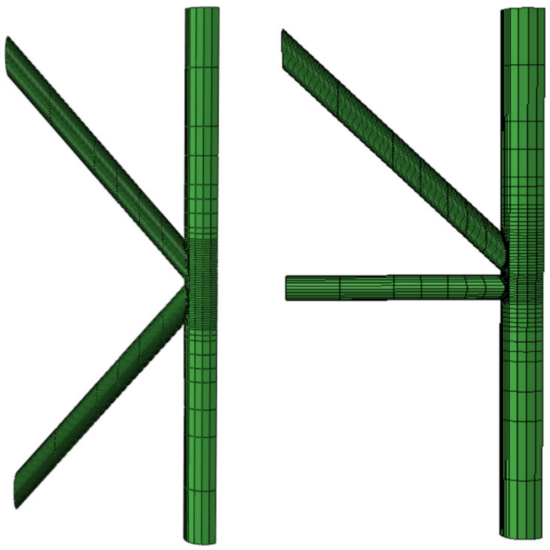


Fig. 2 K and N-Types Model Mesh size

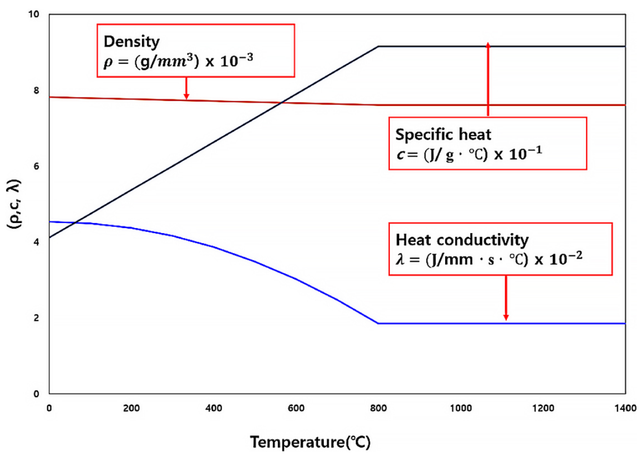


Fig. 3 Temperature-dependent physical constants and material properties

2.3 3D thermal elastoplastic FEM analysis

From Fig. 5, the mechanical material properties (Young's modulus, Poisson's ratio, coefficient of thermal expansion, yield stress, ultimate stress) change with temperature, and the temperature-dependent mechanical properties were obtained by carrying out high-temperature tensile tests. In the 3D thermal elastoplastic FE method, the welding temperature history and the temperature-dependent mechanical properties were used as input for the calculation of residual stresses and weld deformation of the tubular joints [27–29]. Geometric nonlinear theory and material nonlinear theory are applied in the 3D thermal elastoplastic FEM.

The tubular joints connected by welding, the heat source of welding will generate residual stress and welding deformation [30, 31]. Fig. 6 (a) and (b) show the welding residual stress distribution in both K and N-type tubular joints. The residual stress and welding deformation after welding mainly affects the welding part and HAZ area, so the residual stress near the welding part in Fig. 6 (a) and (b) was considered.

The XYZ direction of the structure can be seen in Fig. 6 (a) and (b), and the residual stress in the X direction is highest, with a magnitude of 500 MPa in both K and N-type tubular joints.

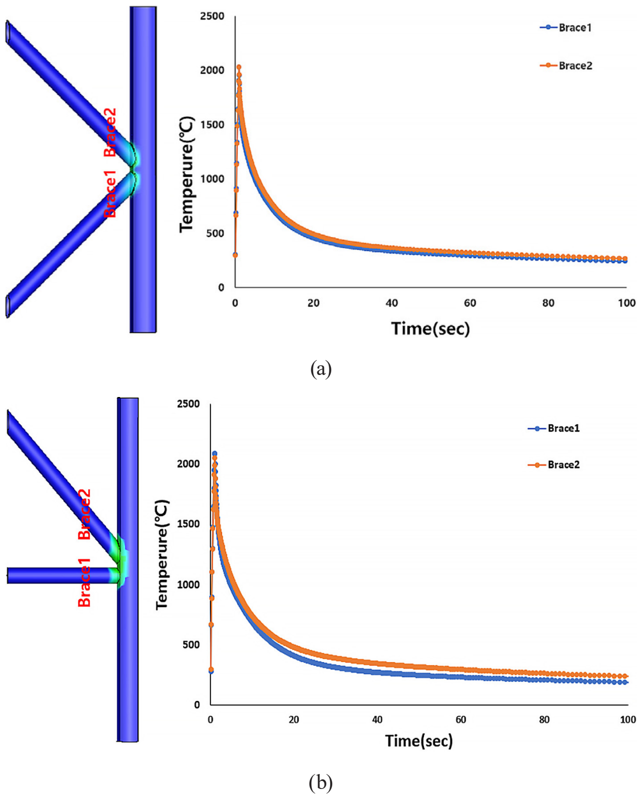


Fig. 4 Welding position and temperature; (a) K-Type Welding position and history, (b) N-Type Welding position and history

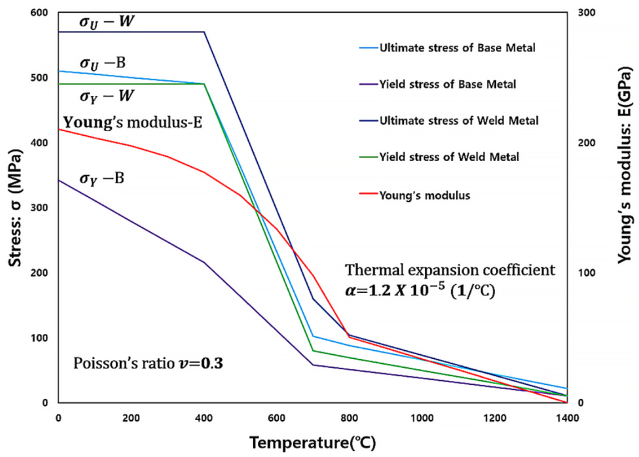


Fig. 5 Temperature-dependent mechanical material properties

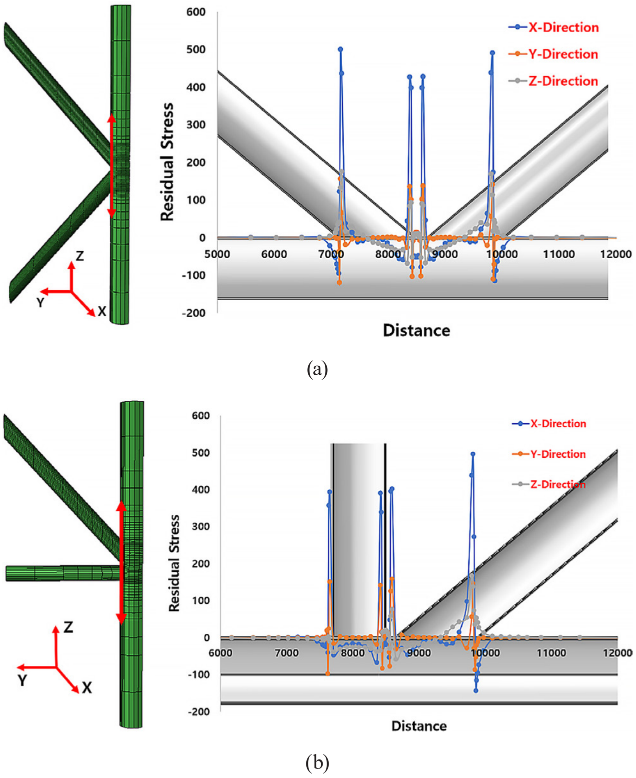


Fig. 6 Residual stress distribution; (a) K-Type residual stress, (b) N-Type residual stress

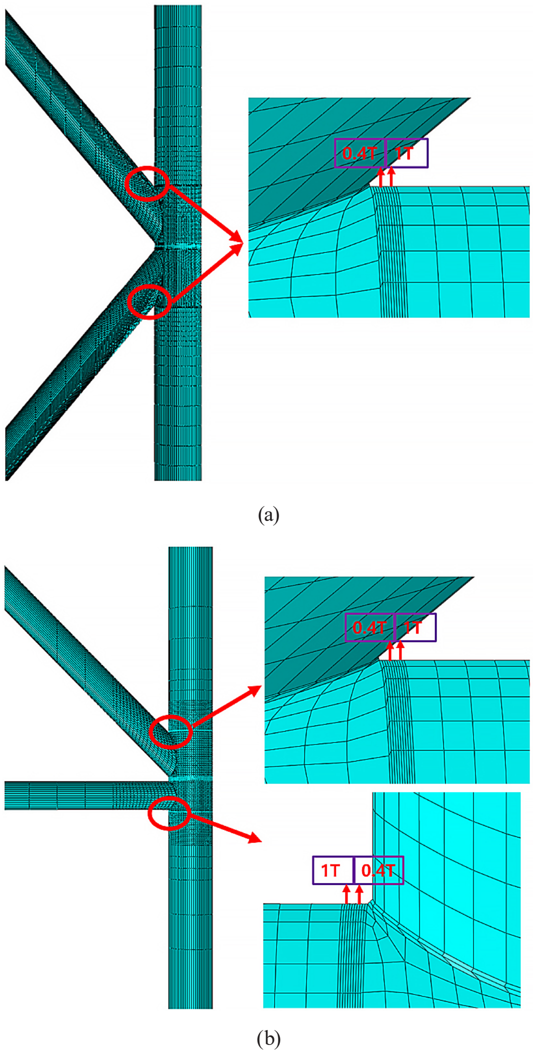


Fig. 7 Hot Spot Stress locations of K-Type and N-Type; (a) Hot spot stress of K-Type, (b) Hot spot stress of N-Type

3 Fatigue life calculation by HSS method

The diversity and complexity of welded structures make it costly and time-intensive to perform fatigue tests on them. Therefore, recently most of the researchers have used the hot spot stress method to analyze the fatigue life of the structure. In the IIW design recommendation [32, 33], the mesh size is classified as fine mesh and coarse mesh, and according to the mesh classification, we can obtain the hot spot stress by Eq. (1) and fatigue life by Eq. (2). In Fig. 7 (a) and (b), the locations of hot spot stresses for K-type and N-type are shown. The use of fine mesh can be used to obtain more accurate stresses in the 3D FE analysis. In this case, we also can use the hot spot stress method to analyze the fatigue life of the structure.

$$\sigma_{h_s} = 1.67\sigma_{0.4t} - 0.67\sigma_{1.0t} \tag{1}$$

$$\log\left(N_f\right) = \frac{12.476 - 3\times\log\left(\sigma_{hs}\right)}{1-0.18\log\left(\dfrac{16}{t}\right)} \tag{2}$$

4 Fatigue life calculation by 3D fatigue FE analysis method

The theory of continuous damage mechanics is used in the 3D fatigue analysis to incorporate the effect of crack initiation and calculate the fatigue life. The full coupling analysis method is used in the analysis for calculating the damage variable variations during the analysis [24–28]. According to the magnitude of the damage variable, we can obtain whether the structure is ruptured or not, the damage variable formula is $D = 1 - \dfrac{A_D}{A_T}$, and the concept of effective stress is introduced in the variation of damage variable, $\bar{\sigma}_{ij}^{D} = \dfrac{\sigma}{1-D}$. When $D = 0$, no damage occurs to the structure. When $0 < D < 1$, the structure is partially damaged. When $D = 1$, cracking occurs [28]. The variation of damage variables is considered in elastic and plastic strain rates.

The elastic strain rates equation is:

$$\varepsilon_{ij}^{e} = \frac{1+\nu}{E}\frac{\dot{\sigma}_{ij}}{1-D} - \frac{\nu}{E}\frac{\dot{\sigma}_{kk}}{1-D}\delta_{ij}. \tag{3}$$

Here Von Mises stress equation is:

$$\sigma_{eq} = \left(\bar{\sigma}_{ij}^{D} - X_{ij}^{D}\right)_{eq} = \left[\frac{3}{2}\left(\frac{\sigma_{ij}^{D}}{1-D} - X_{ij}^{D}\right)\left(\frac{\sigma_{ij}^{D}}{1-D} - X_{ij}^{D}\right)\right]^{1/2}. \tag{4}$$

The plastic strain rates equation is:

$$\varepsilon_{ij}^{p} = \dot{\lambda}\frac{\partial F_P}{\partial \sigma_{ij}} = \frac{3}{2}\frac{\dot{\lambda}}{1-D}\frac{\frac{\sigma_{ij}^{D}}{1-D} - X_{ij}^{D}}{\sigma_{eq}}, \tag{5}$$

$\bar{\sigma}_{ij}^{D}$: deviatoric part of effective stress tensor, X_{ij}^{D} : deviatoric part of the back stress tensor, X_{ij}^{D} : deviatoric part of the back stress tensor, σ_{ij}^{D} : deviatoric part of stress tensor, $\dot{\lambda}$: plastic multiplier, v: Poison's ratio

In high-cycle fatigue, fatigue is generally loaded at room temperature using stress less than the yield stress. In uniaxial loading, we can obtain the cyclic damage variation and the number of cycles after failure based on the cyclic loading. The calculation formula is as follows:

$$N_f = \begin{cases} \dfrac{q\left(1/2(1-R)\right)^{2q}}{C\left(1+R^{2q}\right)}\dfrac{1}{(2q+1)(1-\alpha)}\sigma_{af}^{-2q}, & R<0 \\ \dfrac{q\left(1/2(1-R)\right)^{2q}}{C\left(1-R^{2q}\right)}\dfrac{1}{(2q+1)(1-\alpha)}\sigma_{af}^{-2q}, & 0 \le R < 1, \end{cases} \tag{6}$$

where $R = \sigma_{\min}/\sigma_{\max}$ and $\sigma_{af} = (1-R)\sigma_{\max}/2$, α is loading function. Applying the uniaxial fatigue damage theory to three dimensions, the following equation is obtained. Here $2q$ is replaced by β.

$$\delta D = \left[1-(1-D)^{\beta+1}\right]^{\alpha}\left[\frac{A_{II}}{M(\sigma_m)(1-D)}\right]^{\beta}\delta N \tag{7}$$

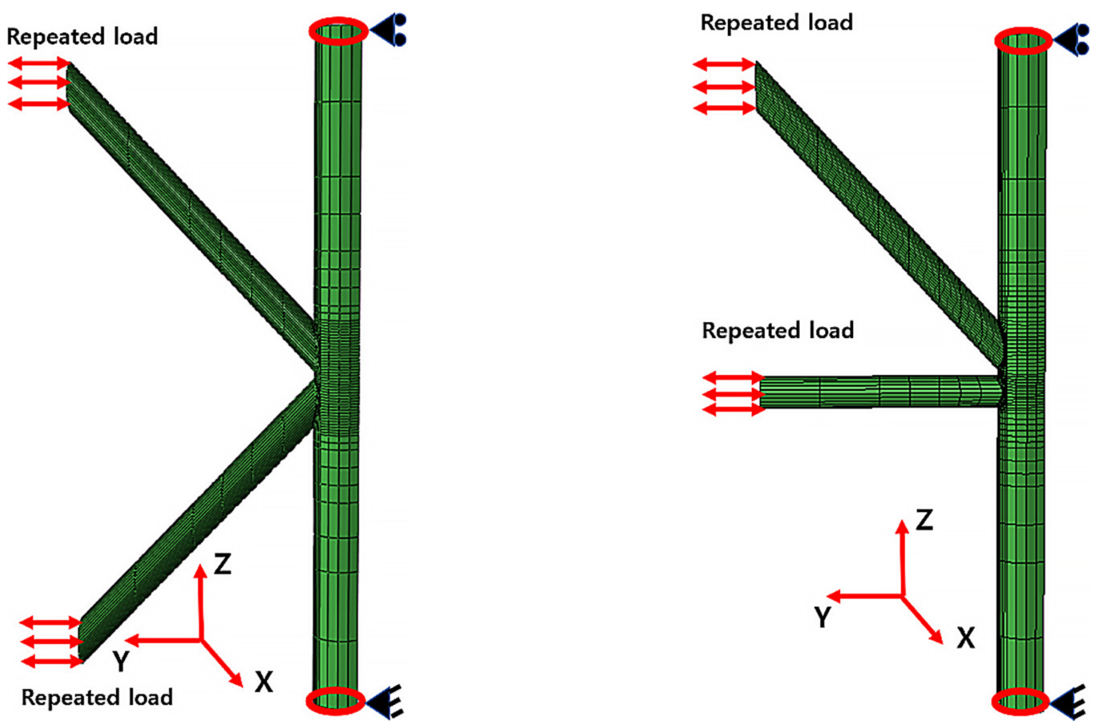
The number of cycles to failure is

$$N_f = \frac{1}{(1+\beta)(1-\alpha)}\left(\frac{A_{II}}{M(\sigma_m)}\right)^{-\beta}, \tag{8}$$

here $M(\sigma_m) = M_0\left(1-3b\overline{\sigma_H}\right)$, M_0, β, b are material coefficients. A_{II}: amplitude of octahedral shear stress N: number of cycles. By using the above equations, we calculate the fatigue life and crack initiation under constant load depending on the different structures.

4.1 Boundary condition of truss structure

The same boundary conditions were applied to K and N-type tubular joints as shown in Fig. 8 (a) and (b). In both K and N-type tubular joints, the constant amplitude cyclic loading was applied on the top of both braces in the Y direction. For boundary conditions, one end of the chord member was completely fixed in the XYZ direction, and the other end of the chord member was fixed only in the XY direction in both tubular joints.

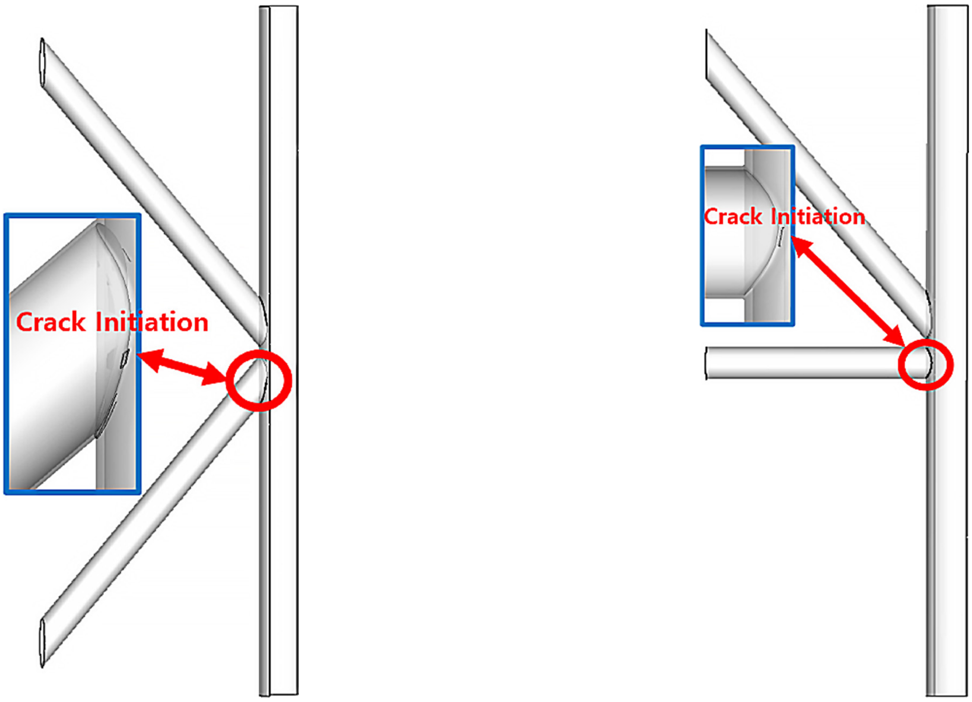


(a) (b)

Fig. 8 Load and boundary condition; (a) K-Type boundary condition, (b) N-Type boundary condition

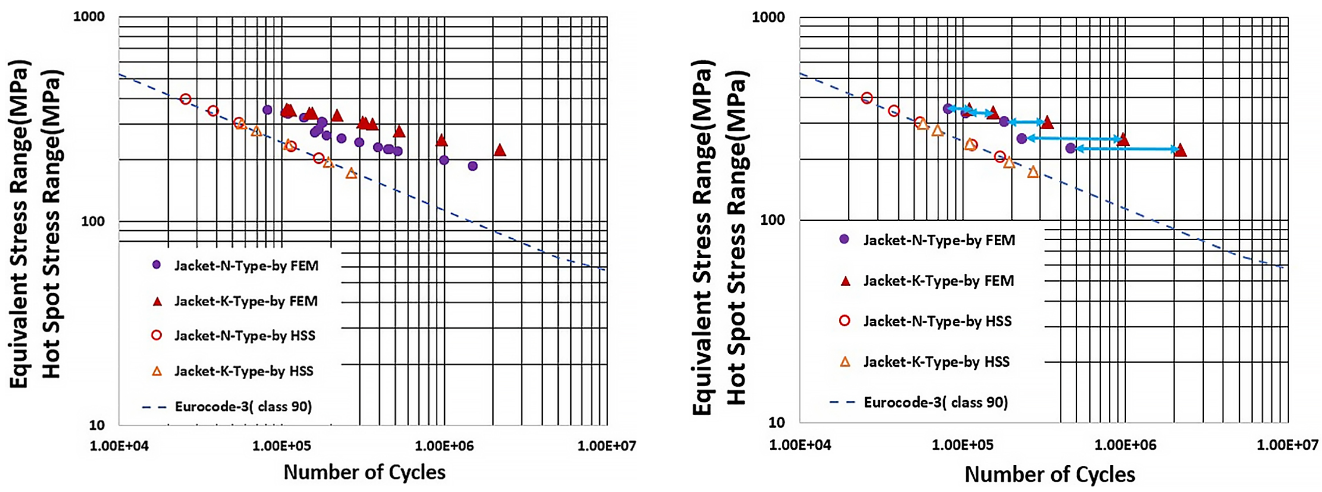
4.2 The crack initiation and fatigue life of the K and N types of truss structures

The fatigue analysis of the structure was performed using the 3D fatigue FE analysis method. From Fig. 9 (a) and (b), we can see that the crack initiation of the K and N Types of truss structures occurs at different places. Fig. 10 (a), shows the fatigue life of K and N Type tubular joints obtained under different constant loads. Fig. 10 (b) shows the S–N curve for K-type and N-type structures. The number of cycles in the same stress range is shown in Table 1 to indicate specific fatigue life. It was confirmed that the higher the number of cycles, the longer the fatigue life becomes. The S–N results were reliable when compared with the IIW recommendation and Eurocode-3 Standard for FE fatigue results [34]. Fig. 10 (b), depicts the comparison of the different fatigue lives obtained for the same stress range. The results concluded that the fatigue life of the K-type tubular joint is longer than that of N-type tubular joint under the same stress range.



(a) (b)

Fig. 9 Crack initiation; (a) K -Type crack initiation, (b) N-Type crack initiation



(a) (b)

Fig. 10 Comparison of the fatigue life of FEM with HSS of IIW recommendation and S-N curve of Eurocode-3 standard; (a) Fatigue life of K and N-Type (b) Fatigue life comparison same stress range for K and N-Type

Table 1 Number of cycles in the same stress range

Stress range (MPa)	Number of cycles of K-Type Jacket	Number of cycles of N-Type Jacket
350	109,514	81,877
337	154,067	105,189
303	329,964	179,977
252	976,773	233,608
223	2,180,733	456,782

5 Conclusions

Fatigue crack location and fatigue life were analyzed for K-Type and N-Type welded structures using the fatigue FEM in this study. The fatigue FE method was performed by introducing the cyclic hysteresis constitutive model and continuum damage mechanics theory. To reproduce the welding imperfection of the welding part, 3D non-steady heat conduction analysis, and thermal elastic-plastic analysis were performed, the results of which are as follows:

1. The welded joints of the substructure were reproduced by getting the residual stress and weld deformation of the welded part.
2. The fatigue life of K-Type and N-Type structures was compared with the S–N curve of Eurocode design standards and IIW recommendation.
3. It was confirmed that the fatigue life of the weld joint of the K-type structure was longer than that of the N-type structure.
4. The fatigue FE method was verified as a useful method for finding the fatigue life and crack location.

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References

[1] Lee, J. H., Kim, S. Y., Kim, M. H, Shin, S. C., Lee, Y. S. "Design optimization and reliability analysis of jacket support structure for 5-MW offshore wind turbine", Journal of Ocean Engineering and Technology, 28(3), pp. 218–226, 2014. (in Korean) https://doi.org/10.5574/KSOE.2014.28.3.218

[2] Sun, M. Y., Lee, S. B., Lee, K. Y., Moon, B. Y. "The study on substructure design and analysis for 5MW offshore wind turbine", Journal of the Korean Society of Marine Engineering, 38(9), pp. 1075–1080, 2014. (in Korean) https://doi.org/10.5916/jkosme.2014.38.9.1075

[3] Tian, X. J., Sun, X. Y., Liu, G. J., Deng, W., Wang, H. H., Li, Z. X., Li, D. X. "Optimization design of the jacket support structure for offshore wind turbine using topology optimization method", Ocean Engineering, 243, 110084, 2022. https://doi.org/10.1016/j.oceaneng.2021.110084

[4] Motlagh, A. A., Shabakhty, N., Kaveh, A. "Design optimization of jacket offshore platform considering fatigue damage using Genetic Algorithm", Ocean Engineering, 227, 108869, 2021. https://doi.org/10.1016/j.oceaneng.2021.108869

[5] Failla, G., Santangelo, F., Foti, G., Scali, F., Arena, F. "Response-spectrum uncoupled analyses for seismic assessment of offshore wind turbines", Journal of Marine Science and Engineering, 6(3), 85, 2018. https://doi.org/10.3390/jmse6030085

[6] Sandhya, G. "Analysis of offshore jacket structure", International Research Journal of Engineering and Technology, 5(1), pp. 722–729, 2018.

[7] Kim, J. W., Heo, S. H., Koo, W. C. "Analysis of dynamic response characteristics for 5 MW Jacket-type fixed offshore wind turbine", Journal of Ocean Engineering and Technology, 35(5), pp. 347–359, 2021. (in Korean) https://doi.org/10.26748/KSOE.2021.058

[8] Cao, Y. G., Meng, Z. B., Zhang, S. H., Tian, H. Q. "FEM study on the stress concentration factors of K-joints with welding residual stress", Applied Ocean Research, 43, pp. 195–205, 2013. https://doi.org/10.1016/j.apor.2013.09.006

[9] Lee, J. W. "Damage estimation method for jacket-type support structure of offshore wind turbine", Journal of the Korea Academia-Industrial Cooperation Society, 18(8), pp. 64–71, 2017. (in Korean) https://doi.org/10.5762/KAIS.2017.18.8.64

[10] Min, C. H., Kim, H. W., Park, S. H., Oh, J. W., Nam, B. W. "Similarity-based damage detection in offshore jacket structures", Journal of Ocean Engineering and Technology, 30(4), pp. 287–293, 2016. (in Korean) https://doi.org/10.5574/KSOE.2016.30.4.287

[11] Dong, W. B., Moan, T., Gao, Z. "Long-term fatigue analysis of multi-planar tubular joints for jacket-type offshore wind turbine in time domain", Engineering Structures, 33(6), pp. 2002–2014, 2011. https://doi.org/10.1016/j.engstruct.2011.02.037

[12] Kyung, K. S., Gil, H. B., Shin, B. C. "Static and fatigue characteristics of truss panel point", Journal of Korean Society of Civil Engeneers, 21(1–A), pp. 73–82, 2001. (in Korean)

[13] Kyung, K. S., Lee, J. H., Park, J. E., Lee, S. J., Kong, B. S. "Evaluation of stress concentration factors of jacket truss structure according to geometric shape", Journal of Korean Society of Steel Construction, 32(1), pp. 55–65, 2020. (in Korean) http://doi.org/10.7781/kjoss.2020.32.1.055

[14] Kyung, K. S., Lee, J. H., Park, J. E., Lee, S. J. "Structural behavior characteristics of jacket structure according to geometrical condition", Journal of Korean Society of Steel Construction, 30(3), pp. 163–173, 2018. (in Korean) http://doi.org/10.7781/kjoss.2018.30.3.163

[15] Wang, S. F., Larsen, T. J., Bredmose, H. "Experimental and numerical investigation of a jacket structure subject to steep and breaking regular waves", Marine Structures, 72, 102744, 2020.
https://doi.org/10.1016/j.marstruc.2020.102744

[16] Ji, C. Y., Xue, H. Z., Shi, X. H., Gaidai, O. "Experimental and numerical study on collapse of aged jacket platforms caused by corrosion or fatigue cracking", Engineering Structures, 112, pp. 14–22, 2016.
https://doi.org/10.1016/j.engstruct.2016.01.001

[17] Zheng, B. F., Zhang, K., Wang, J. C., Shu, G. P., Jiang, Q. L. "Test and design of stainless-steel K-joints in cold-formed circular hollow sections", Journal of Constructional Steel Research, 177, pp. 106–447, 2021.
https://doi.org/10.1016/j.jcsr.2020.106447

[18] Ju, S. H. "Increasing the fatigue life of offshore wind turbine jacket structures using yaw stiffness and damping", Renewable and Sustainable Energy Reviews, 162, 112458, 2022.
https://doi.org/10.1016/j.rser.2022.112458

[19] Ju, S. H., Su, F. C., Ke, Y. P., Xie, M. H. "Fatigue design of offshore wind turbine jacket-type structures using a parallel scheme", Renewable Energy, 136, pp. 69–78, 2019.
https://doi.org/10.1016/j.renene.2018.12.071

[20] Ivanhoe, R. O., Wang, L., Kolios, A. "Generic framework for reliability assessment of offshore wind turbine jacket support structures under stochastic and time dependent variables", Ocean Engineering, 216, 107691, 2020
https://doi.org/10.1016/j.oceaneng.2020.107691

[21] Shittu, A. A., Mehmanparast, A., Hart, P., Kolios, A. "Comparative study between S-N and fracture mechanics approach on reliability assessment of offshore wind turbine jacket foundations", Reliability Engineering and System Safety, 215, 107838, 2021.
https://doi.org/10.1016/j.ress.2021.107838

[22] Larsen, M. L., Arora, V., Adhikari, S., Clausen, H. B. "Optimization of welded K-node in offshore jacket structure including the stochastic size effect", Marine Structures, 82, 103128, 2022.
https://doi.org/10.1016/j.marstruc.2021.103128

[23] Larsen, M. L., Arora, V., Lützen, M., Pedersen, R. R., Putnam, E. "Fatigue life estimation of the weld joint in K-node of the offshore jacket structure using stochastic finite element analysis", Marine Structures, 78, 103020, 2021.
https://doi.org/10.1016/j.marstruc.2021.103020

[24] Do, V. N. V., Lee, C.-H., Chang, K.-H. "High cycle fatigue analysis in presence of residual stresses by using a continuum damage mechanics model", International Journal of Fatigue, 70, pp. 51–62, 2015.
https://doi.org/10.1016/j.ijfatigue.2014.08.013

[25] Wang, Z. M., Chang, K. H., Muzaffer, S. "Fatigue analysis of the effects of incomplete penetration defects on fatigue crack initiation points in butt-welded members", Journal of Welding and Joining, 38(6), pp. 543–550, 2020.
http://doi.org/10.5781/JWJ.2020.38.6.4

[26] Chang, K. H., Kang, S. U., Wang, Z. M., Muzaffer, S., Hirohata, M. "Fatigue finite element analysis on the effect of welding joint type on fatigue life and crack location of a tubular member", Archive of Applied Mechanics, 89, pp. 927–937, 2019.
https://doi.org/10.1007/s00419-019-01513-4

[27] Muzaffer, S., Chang, K. H., Wang, Z. M., Kang, S. U. "Comparison of stiffener effect on fatigue crack in KT-type pipe joint by FEA", Welding in the World, 66, pp. 783–797, 2022.
http://doi.org/10.1007/s40194-022-01254-z

[28] Nguyen Van Do, V., Lee, C.-H., Chang, K.-H. "A nonlinear CDM model for ductile failure analysis of steel bridge columns under cyclic loading", Computational Mechanics, 53, pp. 1209–1222, 2014.
https://doi.org/10.1007/s00466-013-0964-2

[29] Chang, K. H., Lee, C. H. "Characteristics of high temperature tensile properties and residual stresses in weldments of high strength steels", Material Transactions, 47(2), pp. 348–354. 2006.
http://doi.org/10.2320/matertrans.47.348

[30] Yi, M. S., Seo, J. K. "Residual stress study of high manganese steel riser pipe manufactured by longitudinal butt welding (1): residual stress measurement and FE analysis", Journal of Welding and Joining, 39(2), pp. 135–143. 2021.
http://doi.org/10.5781/JWJ.2021.39.2.1

[31] Wu, C. B., Wang, C., Kim, J. W. "Welding distortion prediction for multi-seam welded pipe structures using equivalent thermal strain method", Journal of Welding and Joining, 39(4), pp. 435–444. 2021.
http://doi.org/10.5781/JWJ.2021.39.4.12

[32] Zhao, X.-L., Packer, J. A. "Fatigue design procedure for welded hollow section joints: IIW Document XIII-1804-99 and IIW Document XV-1035-99 Recommendations of IIW Subcommision XV-E", Abington Publishing, 2000. ISBN 978-1-85573-522-4

[33] Hobbacher, A. "Recommendations for fatigue design of welded joints and components", International Institute of Welding (IIW), Paris, France, IIW Document IIW-1823-07 ex XIII-2151r4-07/XV-1254r4-07, 2008.

[34] European Comission "EN 1993-1-1:2005 Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings", Final Draft, European Comission, Ispra, Italy, 2005.