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Methods of Reliability Analysis for Cracks in Offshore Tubular Jacket Structures

Akobo Iboroma Z.S.[1], Nitonye Samson.[2], Agbor Yihiedin S.[3]
[1]Department of Civil Engineering, Rivers State University, Port Harcourt, Nigeria.
[2]Department of Marine Engineering, Rivers State University, Port Harcourt, Nigeria
[3]Centre of Excellence in Marine and Offshore Engineering, Rivers State University, Port Harcourt, Nigeria.

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ABSTRACT: The Reliability of a Jacket tubular joint is not only dependent on the values of the Hot Spot Stress, but also significantly influenced by the crack size in the jacket tubular. The determination of Reliability of the Jacket tubular is very important for improving the fatigue life of the structure and ensure safety of life and property on the offshore platform. In this research a stress number of cycle (S-N) method was used to carry out stress calculations and fatigue sensitive points on the KT- tubular joint. The Fracture Mechanics FM method was used for fatigue crack growth modelling. The probability of failure and Reliability of the Jacket tubular were estimated using the First Order Reliability Method (FORM) based on two case scenarios where crack size and Hot spot stresses were varied. It was seen that variation of crack size and Hot spot stress had an adverse effect on the reliability and probability of failure of the jacket tubular. The results of the Reliability in the two case scenarios were moderate. The analysis was carried out with MATLAB 2019 computer programming software. The fatigue analysis of the tubular jacket KT-joint using the S-N method was calibrated with the Fracture Mechanics (FM) method using FORM to estimate the probability of failure and reliability of the tubular jacket KT-joint. This shows that the reliability index decreased with increase in the probability of failure for the two cases and the probability of failure increased with increase in crack size for case 1 and increase in Hot spot stress for case 2.

Key Words: Reliability, Jacket tubular joint, Hot Spot Stress, crack size, Probability, failure rate, FORM

I. INTRODUCTION

Reliability Analysis of marine structures is a very important design consideration both for ship structures, fixed and floating offshore platforms for oil and gas exploration and exploitation. Reliability analysis deals with the prediction of fatigue life of a structure, that is, how long the structure can last in a given environment, its failure modes and how it can withstand forces such as wave loads, slamming loads, corrosion, leaks, current, ice, etc. that are exerted on it. In order to assess the reliability and durability of an existing structure, the statistical distribution of each of the significant influencing factors such as service loading, structural performance parameters of the material as well as of the fabricated structure, environmental conditions, inspection and repair procedures must be adequately characterized Paliou et al (1987). A small fatigue failure of a structure can lead to the complete failure of the structure, which will eventually lead to the destruction of life, properties and financial loss. Reliability analysis helps in the decision making on the necessity of repairs and/or replacement of the damaged structure (structural element) that is planning of inspection and maintenance activities.

The tubulars are very important components of the jacket structures which make up the frame work of the jacket structures and as such their failure can lead to the total collapse of both the jacket structure and the offshore structure. As such reliability analysis is important to be carried out to predict the fatigue life and the damage done to the structures. In this research, the reliability analysis based on the stress analysis for cracks was conducted on hollow tubular joints that are subjected to wave loads in order to predict their probability of failure and reliability over time.

Hence the research carried out reliability analysis based on stress analysis for cracks in an offshore Jacket tubular subjected to wave loads, it reviews of existing reliability methods, adopted a suitable method to carry out the reliability analysis for fatigue life and crack propagation in the KT-tubular joint and also estimated the Reliability of the offshore tubular jacket KT-joints.

II. REVIEW OF SOME LITERATURE

Reliability analysis of tubular jackets for cracks based on structural analysis is a very important aspect to consider during analysis of offshore structures because crack initiation in the tubular jacket can cause the complete failure of the jacket structure and the offshore platform. A Jacket structure is a welded tubular space frame consisting of vertical or battered legs supported by a lateral bracing system Chen et al (2016). Shittu et al (2020) presented the state-of-the-art methods used for Structural Reliability Analysis (SRA) of marine structures. The study focused on the reliability methods and their variations aiming at qualifying their advantages and limitations with applicability to design metal offshore jacket structures Shittu et al (2020). The different methods that were utilized are: First Order Reliability Method (FORM) Second Order Reliability Method (SORM), Importance Sampling method (IS), Response Surface Method (RSM) and Monticello Simulation (MCS). The Limit State Function (LSF) for implicit and explicit estimation was done by the Finite Element Analysis (FEA). The study focused specifically on the probabilistic fatigue and fracture mechanics approaches.

Chandran (2016) carried out a structural reliability analysis of tubular K-joints on a Circular Hollow Section (CHS) of an offshore jacket structure using ANSYS computer software and concluded that in the four cases of loading, the stress was maximum at some point of the joint parallel to chord length. The tubular K-joint was more effective in carrying the load with increase in chord thickness. For the out-plane bending force condition, the joint started to yield at a load of 4KN, so more consideration was to be given for this condition. The yielding point for Tensile loading was same as that of compressive loading Chandran (2015). Several studies have shown different ways of reliability analysis of jacket tubulars for cracks based on structural analysis which have been very efficient over the years. In recent years many researchers Cossa et al (2011), Ebid (2015), Zhang et al (2020) and Nitonye (2020) have recently concentrated on reliability analysis of jacket tubulars and their foundations subjected to different load conditions and cracks using different reliability methods. Little or no study has been carried out to analyze the effect of variation of crack size and hot spot stress parameters on the probability of failure and reliability of the tubular Jacket structure.In, this work, the reliability analysis of an offshore jacket tubular joint was carried out to determine the probability of failure and reliability of the tubular joints by varying the crack sizes and Hot spot stresses in the joints using the First Order Reliability Method.

III. MATERIALS AND METHODS

The materials considered in this research is the steel offshore jacket tubular joint, the environment is sea water and the software used in this analysis is MATLAB R2019a Model. The Stress Number of Cycles (S-N)method was used to determine the fatigue damage through stress analysis on one Brace of a hollow tubular KT-joint of an offshore jacket structure using the DNV-GL RP C-203 rules. The Fracture Mechanics (FM) method was used to determine crack propagation in the KT-joint.

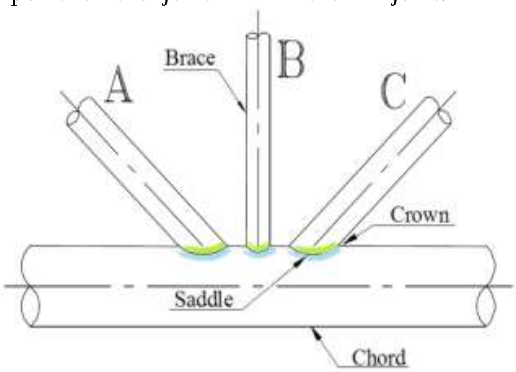

Figure 1: Schematic representation of a KT-joint Ahmad et al (2019)

A KT- tubular joint has three braces. It is a composite joint, which can be identified as a combination of two simple joint forms, in this case the K and T joints. The load pattern for this joint is more complex. Ideally axial forces should be balanced within the braces, that is the net force into chord member is low. Fig 1 show a schematic representation of a KT-Joint.

3.1 Stress Number of Cycles (S-N) Method
Table 1 is the table for the given brace and chord parameters used for the stress analysis of the tubular jacket KT-joint

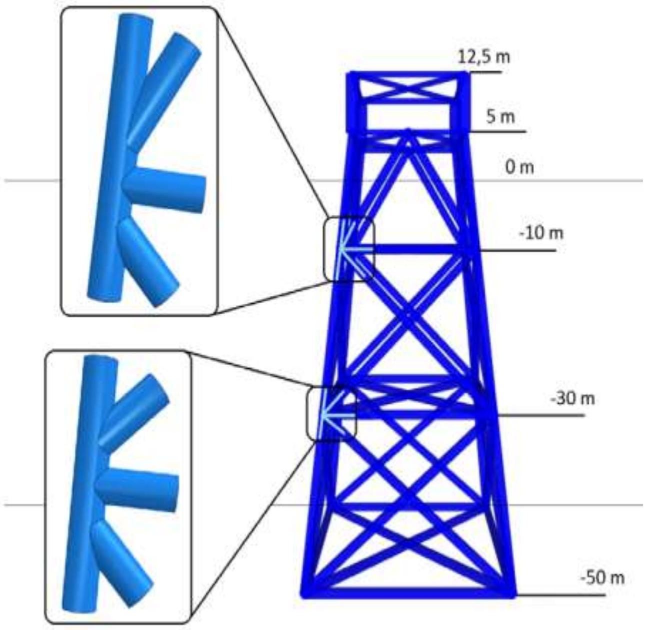

Figure 2: Jacket Structure showing the tubular joint (KT) Ahmad et al (2019)

Table 1 Dimensions of the KT-Joint Asgarian et al (2018)

Brace	Outer Diameter (mm)	Thickness (mm)	Angle in deg.(θ)	Gap between braces(mm)	Chord Length (mm)
A	1200	16	28	g_{AB} = 400	
B	1200	14	89		
C	1200	16	46	g_{BC} =400	
Chord	1248	40			9000

Table 2 Validity range for Parametric equations Asgarian et al (2018)

Geometric ratios	Parametric equations: Kuang		Wordsworth		Efthymiou	Lloyd's Register	
	Lower	Upper	Lower	Upper	Lower	Lower	Upper
α	6.66	40	8	40	4	4	NA
β	0.3	0.8	0.13	1	0.2	0.13	35
ϒ	8.33	33.3	12	32	8	10	32
τ	0.2	0.8	0.25	1	0.2	0.25	1
θ	0	90	30	90	20	30	90
ζ	0.01	1	NA	NA	-0.6β/sinθ	0	1

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Step 1: Calculation of geometrical ratios of the joint
Geometrical ratios
These ratios are critical parameters in the determination of stress concentration factors using established parametric equations
Can slenderness ratio $\alpha = 2L/D$, (1)
Brace to chord diameter ratio (≤ 1) $\beta = d/D$, (2)
Chord slenderness ratio $\Upsilon = D/2T$, (3)
Brace to chord thickness ratio $\tau = t/T$, (4)
Relative gap $\zeta = g/D$, (5)

Step 2: Conduction of a validity test to confirm if the ratios and the angles are within the limits prescribed for the valid use of the parametric equations with the following parameter in the Table 2.

Step 3: Calculation of the SCF for all the members at the critical points for all three modes of loading: (Axial, in-plane bending (IPB) and out of plane bending (OPB).

calculation of the SCF for all the members at the critical points for all three modes of loading: (Axial, in-plane bending (IPB) and out of plane bending (OPB).
The stress concentration factor SCF is calculated for each brace and chord. It is defined as the ratio of the highest stress in the connection (or hotspot stress f_{HS}) to the nominal brace stress f_{NOM},
$SCF = f_{HS}/f_{NOM}$ (6)
Equations according to DNV-RP-C203contained in the appendix for Efthymiou and Durkin for calculation of stress concentration factor SCF in both chord and brace for KT- joints are given below:

FOR CHORDS:
Chord A
Chord:

$$SCF_{CA} = \tau_A^{\ 0.9}\gamma^{0.5}(0.67 - \beta_A^{\ 2} + 1.16\beta_A)\sin(\theta_A.deg)\left[\frac{\sin(\theta_{max}.deg)}{\sin(\theta_{min}.deg)}\right]^{0.3} \quad (7)$$

$$SCF_{chord\ A} = SCF_{CA}\left[\frac{\beta_{max}}{\beta_{min}}\right]^{0.3}\ [1.64 + 0.29\beta_A^{\ -0.38}atan(8.\zeta_{AB})] \quad (8)$$

Chord B

$$SCF_{cB} = \tau_B^{\ 0.9}\gamma^{0.5}(0.67 - \beta_B^{\ 2} + 1.16\beta_B)\sin(\theta_B.deg)\left[\frac{\sin(\theta_{max}.deg)}{\sin(\theta_{min}.deg)}\right]^{0.3} \quad (9)$$

$$SCF_{chord\ B} = SCF_{cB}\left[\frac{\beta_{max}}{\beta_{min}}\right]^{0.3}\ [1.64 + 0.29\beta_B^{\ -0.38}atan(8.\zeta_{BC})] \quad (10)$$

Chord C

$$SCF_{cC} = \tau_C^{\ 0.9}\gamma^{0.5}(0.67 - \beta_C^{\ 2} + 1.16\beta_C)\sin(\theta_C.deg)\left[\frac{\sin(\theta_{max}.deg)}{\sin(\theta_{min}.deg)}\right]^{0.3} \quad (11)$$

$$SCF_{chord\ C} = SCF_{cC}\left[\frac{\beta_{max}}{\beta_{min}}\right]^{0.3}\ [1.64 + 0.29\beta_C^{\ -0.38}atan(8.\zeta_{AB})] \quad (12)$$

FOR BRACE:
For the diagonal braces A and C:
$\zeta = \zeta_{AB} + \zeta_{BC} + \beta_B$ (13)
For the central brace B:
$\zeta_B = \max(\zeta_{AB}.\zeta_{BC})$ (14)
For gap joints:
C = 0

$$A = \sin(\theta_{max} - \theta_{min})^{1.8}[0.131 - 0.084\,.atan[(14\zeta) + (4.2.\beta_A)]]\ C\beta_A^{\ 1.5}\gamma^{0.5}.\tau_A^{-1.22} \quad (15)$$

$$SCF_{braceA} = 1 + (1.97 - 1.57.\beta_A^{\ 0.25}).\tau_A^{-0.14}\ (\sin(\theta_A.deg))^{0.7}\ .SCF_{chordA} + A \quad (16)$$

$$B = \sin(\theta_{max} - \theta_{min})^{1.8}[0.131 - 0.084\,.atan[(14\zeta_B) + (4.2.\beta_A)]]\ C\beta_B^{\ 1.5}\gamma^{0.5}.\tau_B^{-1.22} \quad (17)$$

$$SCF_{braceB} = 1 + (1.97 - 1.57.\beta_B{}^{0.25}).\tau_B{}^{-0.14}\ (sin(\theta_B.deg))^{0.7}\ .SCF_{chordB}\ +\ B \quad (18)$$

$$C = sin(\theta_{max}\ -\ \theta_{min}\ )^{1.8}[0.131 - 0.084\ .atan[(14\zeta) +\ (4.2.\beta_C)]]\ C\beta_C\ \ {}^{1.5}\gamma^{0.5}.\tau_C^{-1.22} \quad (19)$$

$$SCF_{braceC} = 1 + (1.97 - 1.57.\beta_C{}^{0.25}).\tau_C{}^{-0.14}\ (sin(\theta_C.deg))^{0.7}\ .SCF_{chordC}\ +\ C \quad (20)$$

Stress Range (HSSR) are computed thus from equations below using the already calculated SCFs

$$\Delta\sigma_1 = SCF_{AC} * \Delta\sigma_x\ +\ SCF_{MIP} * \Delta\sigma_{my} \quad (21)$$

$$\Delta\sigma_2 = \frac{1}{2}(SCF_{AC} + SCF_{AS}) * \ \Delta\sigma_x + \frac{1}{2}\sqrt{2}SCF_{MIP} * \Delta\sigma_{my} - \frac{1}{2}\sqrt{2}SCF_{MOP} * \Delta\sigma_{mz} \quad (22)$$

$$\Delta\sigma_3 = SCF_{AC} * \Delta\sigma_x\ +\ SCF_{MOP} * \Delta\sigma_{mz} \quad (23)$$

$$\Delta\sigma_4 = \frac{1}{2}(SCF_{AC} + SCF_{AS}) * \ \Delta\sigma_x - \frac{1}{2}\sqrt{2}SCF_{MIP} * \Delta\sigma_{my} - \frac{1}{2}\sqrt{2}SCF_{MOP} * \Delta\sigma_{mz} \quad (24)$$

$$\Delta\sigma_5 = SCF_{AC} * \Delta\sigma_x\ +\ SCF_{MIP} * \Delta\sigma_{my} \quad (25)$$

$$\Delta\sigma_6 = \frac{1}{2}(SCF_{AC} + SCF_{AS}) * \ \Delta\sigma_x - \frac{1}{2}\sqrt{2}SCF_{MIP} * \Delta\sigma_{my} - \frac{1}{2}\sqrt{2}SCF_{MOP} * \Delta\sigma_{mz} \quad (26)$$

$$\Delta\sigma_7 = SCF_{AC} * \Delta\sigma_x\ +\ SCF_{MOP} * \Delta\sigma_{mz} \quad (27)$$

$$\Delta\sigma_8 = \frac{1}{2}(SCF_{AC} + SCF_{AS}) * \ \Delta\sigma_x - \frac{1}{2}\sqrt{2}SCF_{MIP} * \Delta\sigma_{my} - \frac{1}{2}\sqrt{2}SCF_{MOP} * \Delta\sigma_{mz} \quad (28)$$

3.2 Fracture Mechanics Method (FM) Method

The Paris- Erdogan equation for determination of crack propagation is given as:

$$\frac{da}{dN} = C.(\Delta K)^m \quad (29)$$

Where a = crack length, N is number of cycles, ΔK is Stress Intensity Factor SIF range, C and m are the material constants

The Stress Intensity Factor (SIF) is given as:

$$K = Y.\sigma\sqrt{\pi.a} \quad (30)$$

Where σ is the applied uniform tensile stress acting on the specimen in the direction perpendicular to the crack plane, Y is a dimensionless parameter that depends on the geometry of the specimen.

$$Where\ a_o = 0.11mm\ \ m = 1.16;\ \ Y = 1;$$

$$C = 1.8287\ x\ \frac{10^{-13}mm}{(Mpa\sqrt{mm})^m}$$

$$N = 4.38\ x\ 10^{11}\ cycles \quad (31)$$

Where a_o is the initial crack size, a_c is the critical crack size, Std. dev Δa is the standard deviation of the crack extension and Std. dev $\Delta\sigma$ is the standard deviation of the hot spot stress range.

calculation of the reliability index, probability of failure and Reliability using the First Order Reliability Method (FORM) when the parameters of the Resistance are varied:

Using the First Order Reliability Method (FORM) from equation (32)

The safety margin is given as;

$$M = \frac{2}{(2-m)Y^m(\sqrt{\pi a})^m[\Delta a^{\frac{2-m}{m}}]} - C(\Delta\sigma)^m N \quad (32)$$

The mean of the Resistance μ_R is given as;

$$\mu_R = \frac{2}{(2-m)Y^m\ (\sqrt{\pi.a})^m\left[\Delta a^{\frac{2-m}{2}}\right]} \quad (33)$$

and the mean of the Load of given as;

$$\mu_s = C(\Delta\sigma)^m\ N \quad (34)$$

The standard deviation for the resistance part is given as:

$$\sigma_R = [std\ dev\ \Delta a.(\mu_R)^2]^{\frac{1}{2}} \quad (35)$$

and the standard deviation for the load part is given as:

$$\sigma_S = [std\ dev\ \Delta\sigma.(\mu_S)^2]^{\frac{1}{2}} \quad (36)$$

The Reliability index of the tubulars is calculated using:

$$\beta = \frac{(\mu_R - \mu_S)}{\sqrt{\sigma_R{}^2 - \sigma_S{}^2)}} \quad (37)$$

The Cumulative distribution function Φ is gotten from the cumulative distribution table

The probability of failure of the structure is calculated using:

$$P_F = 1 - \Phi\beta \quad (38)$$

And Reliability of the structure calculated using:

$$Reliability = 1 - P_F \quad (39)$$

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Table 3 Fracture Mechanics Model Parameters, Units and Values

Parameter	Unit	Values					
a_c	mm	16	20	25	30	35	40
a	mm	15.89	19.89	24.89	29.89	34.89	39.89
HSSR	Mpa	1.69	2.694	3.318	6.889	7.112	10.414
Std dev Δσ	Mpa	0.894	0.921	1.263	1.926	2.256	2.50
Std dev Δa	mm	0.45	0.47	0.52	0.59	0.69	0.72

IV. RESULTS AND DISCUSSION

Results for Fatigue and Stress Analysis Using The S-N Curve Method

The results for the fatigue and Stress Analysis for the braces and chord are presented as Table 4 and 5

Table 5 shows the values for the SCFs as computed and solved by the MATLAB software for the chord and the braces (A, B and C) for conditions of in plane, out of plane and relationship of location of the braces one to another.

In Table 6, the Hot Spot Stress Ranges were calculated in 3 brace and chord locations for 3 sea states of wave height (Hs) 1.5m, 2.0m and 2.5m respectively and at 8 hot spot locations.

The Hot Spot Stress Ranges were calculated for all the three sea stateswith wave heights (Hs) of 1.5m, 2.0m and 2.5m. The hot spot stress ranges for both chord and brace locations (A,B and C) is highest at the 7^{th} hot spot location and it is called the Maximum hot spot stress range (Max HSSR). The Max HSSR is used to perform the analysis to get the fatigue life of the KT joint and also the crack analysis using the fracture mechanics method.

From the results in Table 7, it is shown that the fatigue life in years based on a given design fatigue factor (DFF) value for both brace and chord locations (A, B and C) is very large which indicates that the reliability of the KT tubular joints is ok and will not fail.

From Table8 and 9, The Fracture Mechanics (FM) Method was used to analyze the crack propagation in the KT-joints by adopting the Paris Erdogan equation for crack growth or propagation. The First Order Reliability Method FORM was then used to estimate the reliability index, probability of failure and the Reliability of the KT-joints, considering two case scenarios. In case 1, the difference in crack size or crack extension was varied and in case 2, the Stress Range was varied using the Maximum Hot Spot Stress Ranges from sea state 3 of wave height (Hs) 1.5m, 2.0m and 2.5m respectively

Table 4 Results for Estimated Geometric Ratios of the KT- Joints

Ratio	Chord	Brace A	Brace B	Brace C
A	14.42307692			
B		0.961538462	0.9615385	0.96153846
ϒ	15.6			
τ		0.4	0.35	0.4
ζ		0.320512821	0.3205128	
θ		28	89	46

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Table 5 Results for SCF Calculations

Chord calculation		
SCF CA	0.878	
SCF AC chord A		1.750
SCF CB	1.658	
SCF chord B	3.304	
SCF CC	1.345	
SCFchord C	2.681	

	maximum value of SCFs		
Summary	**SCF AC/AS**	**SCF MIP**	**SCF MOP**
Chord location			
A	1.750	0.976	3.189
B	3.304	1.478	4.508
C	2.681	1.315	2.874
Brace Location			
A	1.487	2.341	2.765
B	2.589	2.073	4.201
C	2.005	2.341	2.492

Table 6 Results for Calculation Of Hot Spot Stress Range For Different Sea States For Global Analysis On Joints

Calculation of HSSR for Hs=1.5m according to SCF in DNV-RP-C203

HSSR (Mpa)	□ □ □	□ □ □	□ □ □	□□ □	□ □ □	□ □ □	□ □ □	□ □ □	**MAX. HSSR**
Brace Location									
A	1.543	1.310	1.370	1.294	1.520	1.522	1.693	1.539	1.693
B	0.099	-0.646	-1.013	-0.786	-0.099	0.646	1.013	0.786	1.013
C	1.820	1.528	1.729	1.522	1.810	1.644	1.901	1.651	1.901
Chord Location									
A	0.547	-2.305	-3.441	-2.331	0.510	0.225	4.498	0.225	4.498
B	1.026	-3.557	-4.613	-3.097	0.970	0.391	6.609	0.391	6.609
C	0.835	-2.209	-2.768	-1.840	0.785	0.303	4.387	0.303	4.387

Calculation of HSSR for Hs=2.0m according to SCF in DNV-RP-C203

HSSR (Mpa)	□ □ □	□ □ □	□ □ □	□ □ □	□ □ □	□ □ □	□ □ □	□ □ □	**MAX. HSSR**
Brace Location									
A	2.0793	1.783	1.873	1.766	2.054	2.040	2.261	2.058	2.261
B	0.1277	-0.919	-1.427	-1.099	-0.128	0.919	1.427	1.099	1.427

C	2.5231	2.120	2.400	2.115	2.515	2.283	2.638	2.289	2.638
Chord Location									
A	0.6162	-3.222	-4.764	-3.257	0.566	4.315	5.946	0.251	5.946
B	1.1542	-4.330	-6.453	-4.384	1.078	6.321	8.685	0.437	8.685
C	0.9395	-2.597	-3.920	-2.645	0.872	4.180	5.731	0.339	5.731

Calculation of HSSR for Hs=2.5m according to SCF in DNV-RP-C203

HSSR (Mpa)	□□□	□□□	□□□	□□□	□□□	□□□	□□□	□□□	**MAX. HSSR**
Brace Location									
A	2.5462	2.160	2.202	2.021	2.350	2.369	2.694	2.507	2.694
B	0.1562	-1.084	-1.690	-1.305	-0.156	1.084	1.690	1.305	1.690
C	3.178	2.674	3.028	2.667	3.168	2.872	3.318	2.879	3.318
Chord Location									
A	0.7914	-3.766	-5.591	-3.810	0.729	5.172	7.112	0.323	7.112
B	1.4828	-5.035	-7.542	-5.101	1.389	7.596	10.414	0.563	10.414
C	1.2068	-3.000	-4.559	-3.059	1.123	5.036	6.889	0.436	6.889

Table 7 Results for Estimation Of Fatigue Life And Cumulative Damage In Chord And Brace Members Of The KT- Joint

Calculation of fatigue life in brace members

BRACE	FATIGUE LIFE (Years)		
Location	Cumulative damage	Fatigue life, (DFF=1)	Fatigue life, (DFF=3)
A	2E-08	40435054.48	13478351.49
B	2E-09	511451895.6	170483965.2
C	4E-08	23487349.41	7829116.468

Calculation of fatigue life in Chord members

CHORD	**FATIGUE LIFE (Years)**		
Location	**Cumulative damage**	**Fatigue life, (DFF=1)**	**Fatigue life, (DFF=3)**
A	1E-05	80043.30121	26681.1004
B	8E-05	11913.61998	3971.206659

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C	7E-06	141353.8734	47117.95781

From the result in Table 5, for the SCF for axial loading for chord location, it is seen that the SCF has the highest value at chord location B which is 3.304, to show that stress is more concentrated on the chord B location of the joint. For SCF for moment in plane bending (MIP), the stress concentration factor SCF has the highest value at chord location B of value 1.478 and the same case with SCF for moment out of plane with value of 4.508. All of this points to the fact that chord location B of the joint should be monitored more because it is prone to failure with time. Also for brace locations, SCF for axial loading is highest at chord location B with value 2.589, SCF for MIP is highest at both brace location A and C, SCF for MOP is highest at chord location B with value 4.201 showing that all the locations of the braces in the joints are likely prone to failure.

From the result in Table 6, The Hot Spot Stress Ranges were calculated for all the three sea states with wave heights (Hs) of 1.5m, 2.0m and 2.5m. The hot spot stress ranges for both chord and brace locations (A,B and C) is highest at the 7^{th} hot spot location and it is called the Maximum hot spot stress range (Max HSSR). The Max HSSR is used to perform the analysis to get the fatigue life of the KT joint and also the crack analysis using the fracture mechanics method. From the results for the hot spot stress ranges, it is seen that the HSS is maximum at the seventh Hot spot location for both chord and brace locations for all the three sea states. The hot spot stress area is where fatigue crack is expected to occur and that is the seventh location for the KT-joint. From the results in Table 7, it is shown that the fatigue life in years based on a given design fatigue factor (DFF) value for both brace and chord locations (A, B and C) is very large which indicates that the reliability of the KT tubular joints is ok and will not fail.

In Table 9 The Fracture Mechanics (FM) Method was used to analyze the crack propagation in the KT-joints by adopting the Paris Erdogan equation for crack growth or propagation. The First Order Reliability Method FORM was then used to estimate the reliability index, probability of failure and the Reliability of the KT-joints, considering two case scenarios. In case 1, the difference in crack size or crack extension was varied and in case 2, the Stress Range was varied using the Maximum Hot Spot Stress Ranges from sea state 3 of wave height (Hs) 1.5m, 2.0m and 2.5m respectively.

The values of the Tables are used to plots the graphs in figures 1-7. Detailed discussion were made after each graph.

Results for Crack Propagation Analysis Using the Fracture Mechanics Method (FM)

Table 8 Results for Reliability Index, Probability of failure And Reliability When Crack Size or Depth Is Varied Which Is Case 1

Crack Extensions\ Δa		Reliability Index β	Cumulative Distribution Function φ	Probability of Failure P_F	Reliability R
Δa_1	15.89	1.474	0.492	0.3673	0.6327
Δa_2	19.89	1.4072	0.4207	0.4079	0.5921
Δa_3	24.89	1.34235	0.4099	0.4497	0.5503
Δa_4	29.89	1.2635	0.3962	0.4994	0.5006
Δa_5	34.89	1.1709	0.3790	0.5562	0.4438
Δa_6	39.89	1.147	0.3729	0.5722	0.4278

Table 9: Results for Reliability Index, Probability Of Failure And Reliability when Hot Spot Stress Range (HSSR) Is Varied Using The Hot Spot Stress Variation In Sea State 3 which Is Case 2

HSSR Δσ		Reliability Index β	Cumulative Distribution Function Φ	Probability of Failure P_F	Reliability R
$\Delta\sigma_1$	1.69	1.474	0.4292	0.3673	0.6327
$\Delta\sigma_2$	2.694	1.4285	0.4207	0.399	0.601
$\Delta\sigma_3$	3.318	1.3939	0.4177	0.4177	0.5823
$\Delta\sigma_4$	6.889	1.1478	0.3729	0.5719	0.4281
$\Delta\sigma_5$	7.112	1.1169	0.3665	0.5906	0.4094

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$\Delta\sigma_6$	10.414	0.8619	0.2995	0.7464	0.2536

GRAPHS FOR CASE 1

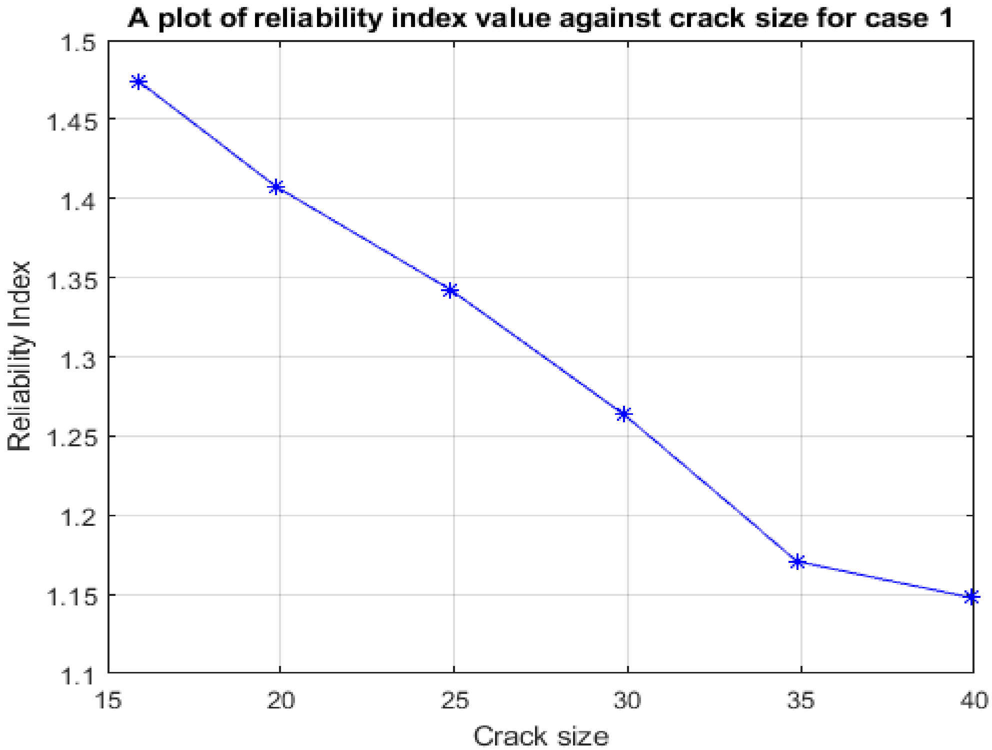

Figure 1: Reliability index against Crack size for case 1

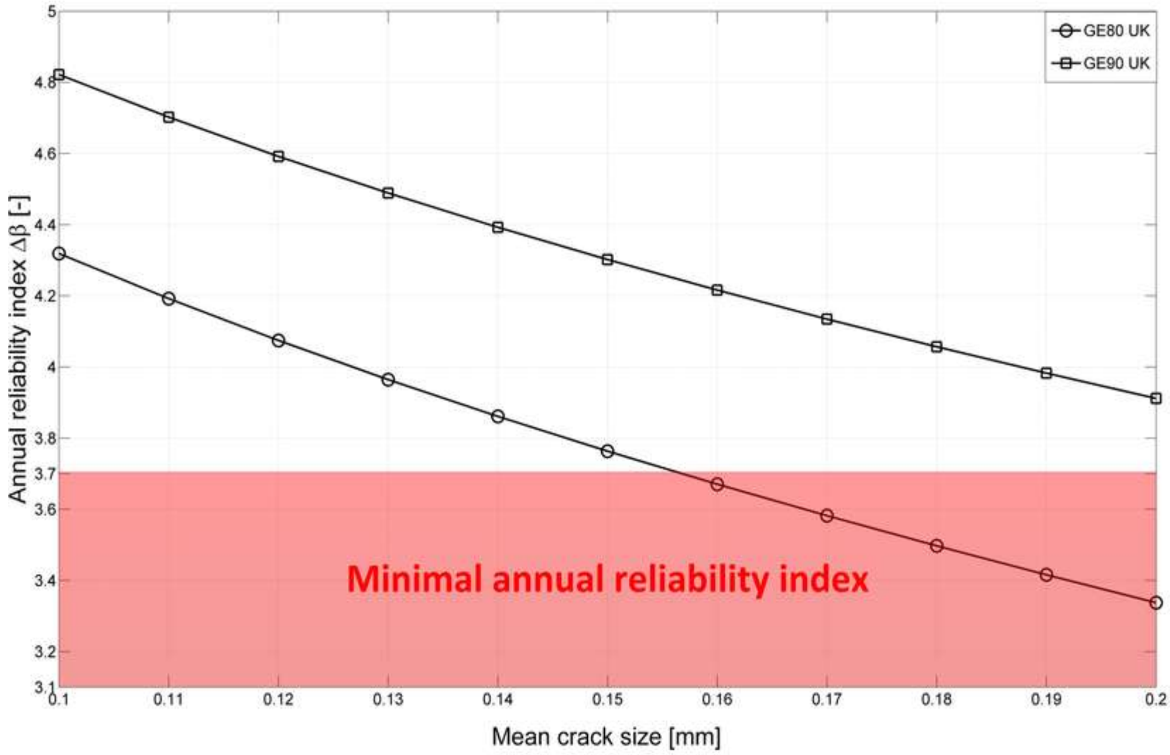

Figure 2: Annual Reliability index against Mean Crack size, Bathurst et al.(2008)

From the graph in Figure 1for case 1, the reliability index decreases with increase in crack size. A high value of reliability index implies that the probability of failure of the structure will be very low and as such the reliability of the structure will be high, but if the reliability index has a very low value or decreases, it implies that the probability of failure of the structure will be very high which will eventually lead to the failure of the structure. From Figure 1 it can be seen that crack size affects the reliability of the structure adversely. If the crack size keeps increasing the reliability of the structure will be low leading to failure of the structure. Figure 2 is a validation graph which shows that reliability index decreases with increase in crack size and is similar to Figure 1. Figure 3 shows that the probability of failure of the structure increases with increase in crack size. Figure 4 shows that probability of failure increases with decrease in the reliability index and Figure 5 validates the result of Figure 4. From the graph in Figure 6 for case 2, it can be seen that the probability of failure of the structure increases with increase in Hot Spot Stress Range. This shows the adverse effect that stress has on the structure. If the structure is subjected to environmental loads and stress that it cannot withstand, it will eventually fail.Figure 7 shows that the reliability index decreases with increase in the probability of failure. From the reliability resultsfor the two cases, the reliability of the structure is seen to be moderate.

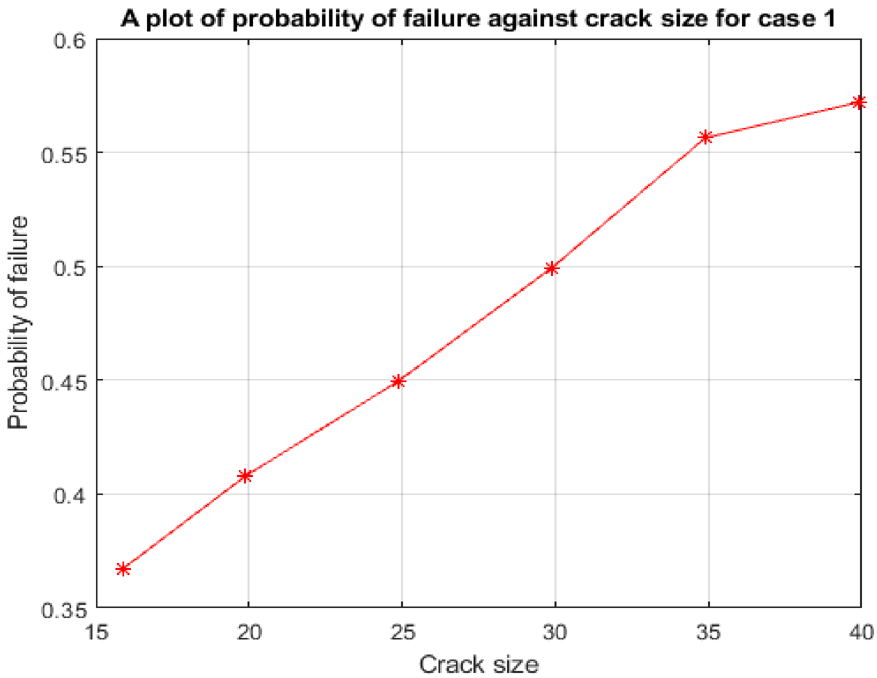

Figure 3:Probability of failure against crack size for case 1

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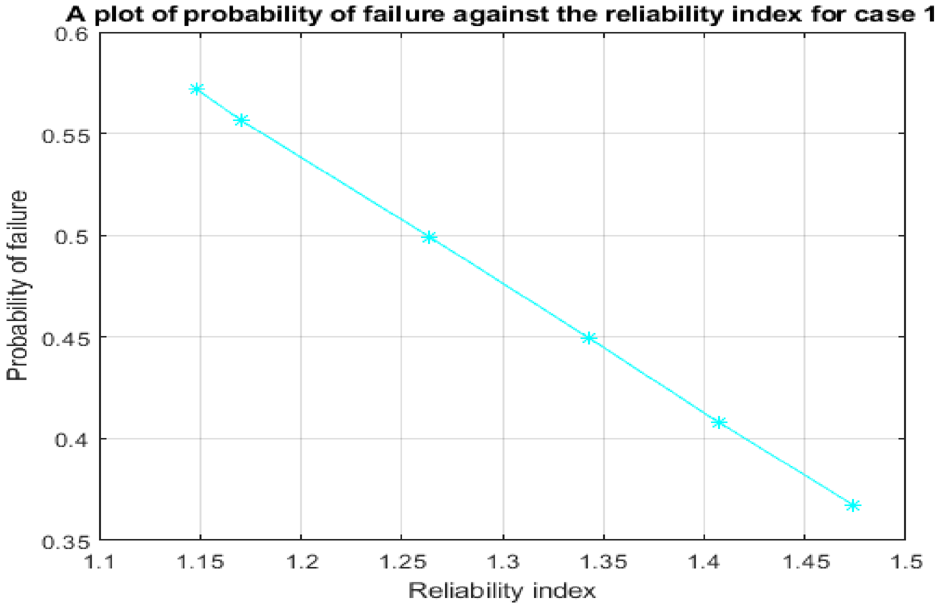

Figure 4: Probability of Failure against reliability index

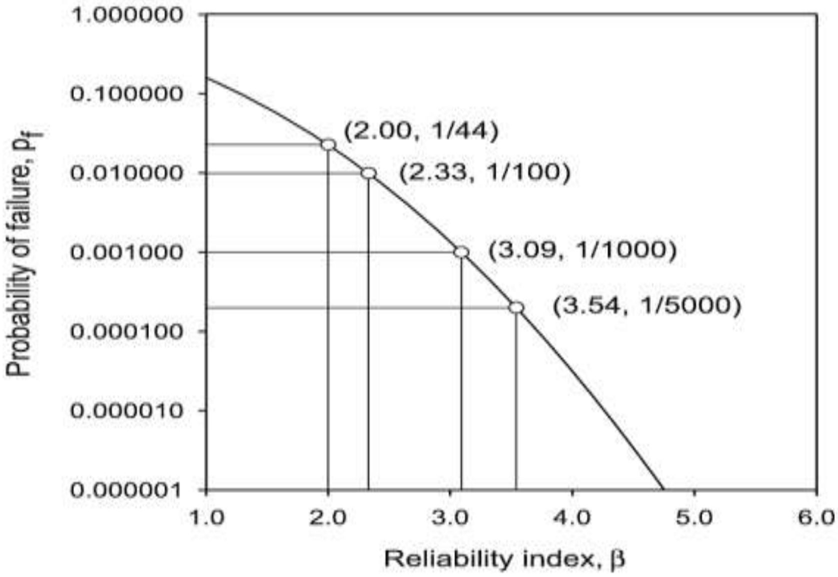

Figure 5:Probability of failure against reliability index, Bathurst et al. (2008)

GRAPHS FOR CASE 2

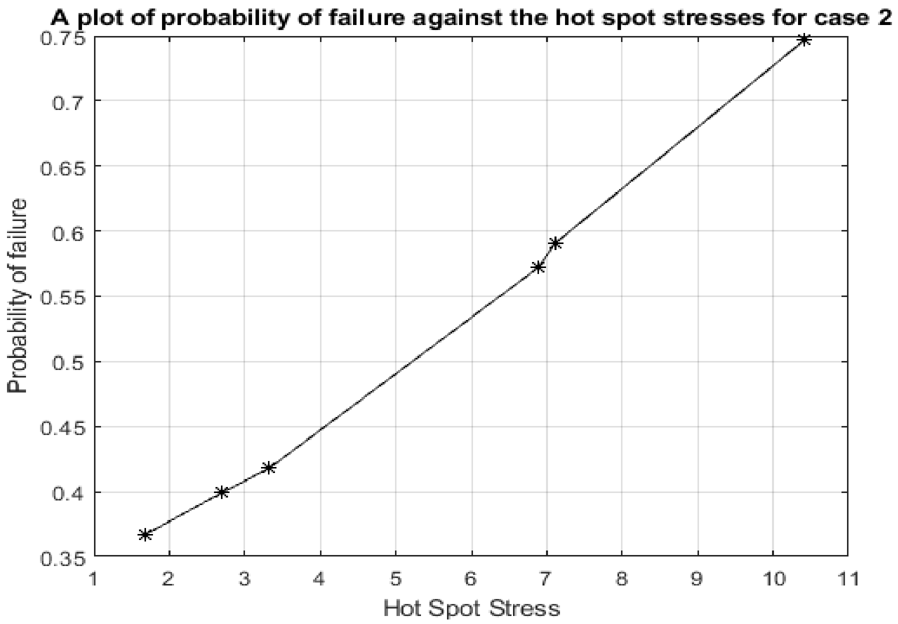

Figure 6:Probability of failure against Hot spot stress for case2

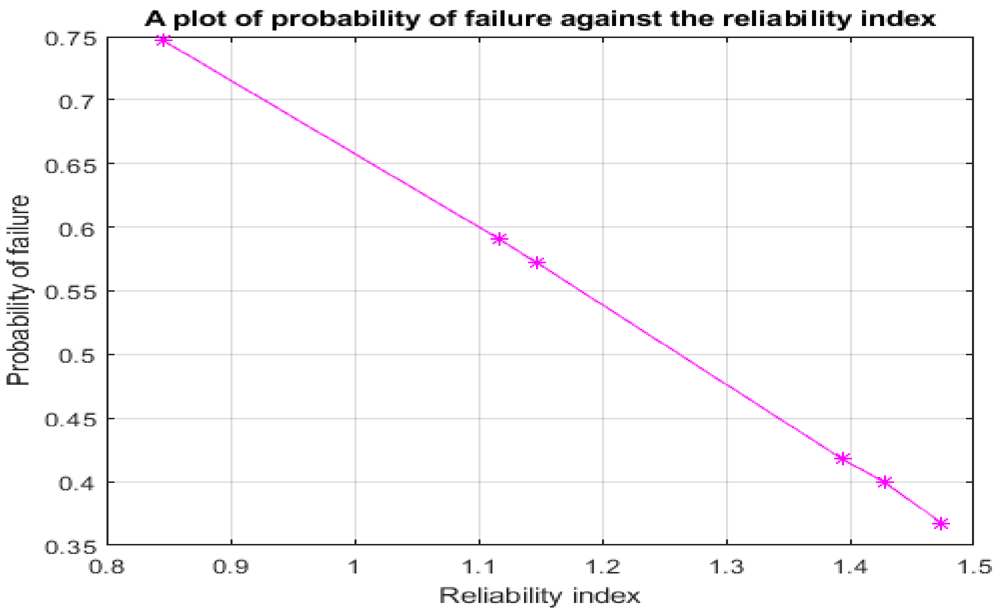

Figure 7: Probability of failure against Reliability Index for case 2

V. CONCLUSION

From the Data input, analytical and software analysis, results obtained from there and discussions of the results, the following conclusions can be made.In this study, the fatigue analysis of a KT-joint using the S-N method is calibrated with a stochastic model for fatigue crack growth which accounts for uncertainties in loading, critical crack size, material parameters. The probabilistic Fracture Mechanics Analysis model is combined with results from inspection and the First Order Reliability Method (FORM) is used to estimate the probability of failure and Reliability of the KT- joint. The reliability index decreases with increase in the probability of failure for the two cases. Also, the probability of failure for case 1 increases with increase in crack size and the probability of failure for case 2 increases with increase in Hot Spot Stress.

In this study, the reliability analysis of an offshore tubular jacket KT-joint was carried out using the First Order reliability method (FORM) in two case scenarios by varying the crack size in the first case and varying the Hot spot stress in the second case in order to check the effects of the variation of those parameters on the probability of failure and reliability of the tubular jacket KT-joint.

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