Fatigue Analysis of Fixed Jacket Platform using FEM

Tahseen A. Abd Alhusein, Jaffar A. Kadim

Abstract—This research deals with subject of fatigue analysis for steel jacket platform due to the effect of waves loads using power spectra statistical analysis. Two dimensions analysis was carried with the base of structure represented as ficed and elastic support in which finite element method FEM was used via SAP2000 V20 software to estimate the joint stresses. The fatigue age of the joint was found by S-N curves and fracture mechanism. For loading enticipated, 15 sea state was taken during one year using modified Pierson-Moskowitz equation and Airy theory applied to find the velocities, and acceleration offf waters particles which need in Morison's equation as applied load one they members off structure for which Morison's equation consist of drag force and inertia force. Also, transform function was employed in junction with Morison's equation to carried out power spectra density and the calculated stresses converted to concentration stresses by using stress concentration factor obtaining from three methods such as Visser, Kuang et. al. , and Kellog. Finally, the fatigue analysis was achieved for four joints which chosen from the structure, two near still water level and two near mudline (seabed) to be able of analysis of the structure sufficiently and the assessment of the structure for fatigue and calculate age of the joint depended on two methods during this study (S-N curves such as AWS-X modified curve, BS-F curve, and DNV curve) and (fracture mechanics approach). The results showed that the stresses were more for elastic base leading to decreasing of the structure life where increasing of the stress cause failure of joint to be greater but with defferent ratios which given as 14% when used AWS-X modified curve, 13.8% for BS-F curve, 13.84% for DNV curve, and 16% for fracture mechanics approach. In S-N curve method BS-F curve is the critical case in fatigue assessment, BS-F is 2.93 times of AWS-X modified and 5.35 times of DNV curve. Also, we noticed the difference between this study and a proposed structure the difference is 10.7% when used S-N curve method and 8.42% when used fracture mechanics approach.

Index Terms— Fatigue; Power Spectra; SAP2000 V20 Program; S-N Curve; Fracture Mecanism.

◆

1 INTRODUCTION

The Jackets structures are type of steel offshore structures that are build with way form shoreline and are called as (jackets), and this name originates from the start days of the offshore industry when atrussed structures [1]. The jacket platform consist of tubular members interconnected to make a three-dimensional structure, and components are fabricated and assembled at onshore after that transport to an offshore locate and installed. Usualy, offshore requires to design complex, and complicated process. Design for offshore structures must be safety against extreme hostile environment that can be predicated only with a great deal of uncertainty, they are rest on a soil whose properties and behavior vary randomly and are known only to approximate degree of accuracy [2,3].

In 2018 Imanol Martinez Perez et. al. [11] reportrd a fatigue analysis study of mooring chains under Tension Loading using a multiaxial fatigue criterion for two different mean loads. The paper present an example of the implementation of the Dang Van fatigue criterion for studying the fatigue behavior of mooring chains under tension. It quantified the effect of the mean load on the fatigue lifetime and the failure location. Furthermore, it also proposed a simplified approach to reduce the complexity and the computational time of the fatigue analysis using Dang Van fatigue criterion as follows: in the first part an example of the fatigue assessment was reported. Two different loading conditions with the same load amplitude but different mean loads were studied. The assessment method was based on two steps: a mechanical analysis and a fatigue analysis. In the second part, a simplified fatigue assessment method was proposed in which a ratio between the fatigue lifetimes of two loading conditions have the same load amplitude but different mean load, is formulated. This ratio has been obtained analytically using the geometric representation of the Dang Van fatigue Criterion. Finally, the paper ends with a discussion, based on recent works, regarding the formulation of the locus of the Dang Van criterion and the fatigue properties used for the calibration of this criterion.

In 2019 Romali Biswal et. al. [12] performed a study to aimed a realistic fatigue life estimation of the monopile structure using operational service loads recorded by online monitoring systems. Fatigue damage analysis has been conducted at the circumferential weld joints using finite element (FE) method by considering geometrical and material property discontinuities. Global-local modelling of the OWT was performed in as-welded condition to capture the local stress range at the weld toe, which acts as the critical site where cracks are most likely to initiate and propagate. The S-N fatigue design approach and maximum stress range at the weld toe have been used to determine the fatigue crack initiation life in monopiles. The results from the proposed approach show that a realistic life assessment can be made on monopile structures by accounting for the geometrical effects at the circumferential welds.

Finally in 2019 Moises Jimenez-Martinez [13] reviewed a statistical analysis of statistical fatigue damage assessment for stochastic loadings which used to reduce loads with low damage contribution, while the uncertainties from external sources. The process required a generatation of a spectrum to perform the accelerated tests. Subsequently, the spectrum can be extrapolated, which increases the damage and reduces the testing time. In his work, a review of the main types of offshore structures is presented, including a description of the

- *Tahseen A. Abd Alhusein Assistant Research, College of Engineering, University of Basrah, Basrah – Iraq,*
  E-mail: Tahseenabd85@yahoo.com
- *Jaffar A. Kadim, Lecture in Civil Department College of Engineering, University of Basrah, Basra, Iraq. Ph.D. Civil Engineering.*
  E-mail: jafaarahmed@yahoo.com

main statistical signal process analysis. In addition, a review of the damage model used in offshore analysis was presented. The process could modelled as a Gaussian or narrow-band process, depending on the variable amplitude loading which generates a random process due to waves.

2 THE STUDY IMPORTANCE

This study deals with the evalution of lifetime fatique of offshore structure beginning from the sea state repsentation as random processes passing to many various teqniques and reaching to applied the S-N and fracture mechanics approaches. Unfortunly, this subject involves many parts in which each part required different mathd in formulation its function such as sea state representation, load estimation, problem analys, stress determination, tand fatique assessment. These different aspect are not given explain in most refrences dealing with this subject, therefore this paper aims to describe and the illustration the most important issuses related to fatique estimation.

3. RESEARCH METHODOLOGY

For fatique assessment, the probabilistic method was depended on frequency to describe waves as random process in which the load consedered as power spectral density (PSD) to evaluate wave forces on steel jacket platform as recommended in many refrences to get on force on structure followed by the calculating stresses. In the firest, the problem starts as presentation sea state using pierson-Moskwitz spectrum [14] which described by two parameters (significant wave height and zero up crossing period). Second, the wave theory adopted here to estimate the water particle velocity and acceleration was Airy wave theory, and these are inputted into Morison's equation to estimate the structure member forces. Third step is the evalution the internal force on structure (finding normial stresses in tubular members and in the considered joints) by using finite element methods (FEM) via SAP2000 V.19 program. The stresses were calculated for 15 sea state. Analysis of steel jacket platform was investicated for two cases, in the first case for fixed support (neglecting soil effect) while the second for case for pile-elastic support (soil effect was considered). After found stresses , the stress concentration factor (SCF) was multiplied to the nominal stresses to convert it to hot spot stress at joints, then finally goes to method of fatigue assessment by two approaches for which the first is is S-N curve (based on Palmgren-Miner rule) and the second is the fracture mechanics approach (FM).

3.1 Sea State Formulation

Figure 1 shows the irregular waves which depended on experimental measures of surface wave heights are analysed in a statistical sense to obtaining (wave spectra) and other statistical parameters in since the seas environments essentially are random processes and depends on physical parameters (water depth ,wind speed, wave height, wave period, mudline characteristics, and other factors). During a stochastic analysis of offshore structure the random (irregular) sea surface elevation can be approximated by a statistical model.So, the energy related the sea surface elevation is represented by a power spectral density function (also called as sea spectral) [4].There are two special forms of a general stochastic process (random), which are the stationary, and ergodic processes, are frequently assumed in probabilistic analysis of offshore structure.

If the probability distribution is independent on time, a process is called stationary. This implying that the statistics of a stationary process is not mannered by a shift in the time origin. This implying that the mean, mean square, variance, and standard deviation of the process do not depend on time. The ergodic properties of the process is one important concept in the stochastic (random) analysis in which the stationary process is called ergodic, if the time average of a stationary process is equal to the ensemble average [15,16].

The sea state has been observed to be stationary in statistical sense for a short period of time where in the short term descriped as the time history of sea surface elevation over a period of few hours (three to six hours) that represent to Gaussian distribution. Wave forecasting techniques allow us to determine the sea states that will occur during the life of the structure, and in particular the worst case, usually the sea state corresponding to a storm with a return period of 100 years. A simplified description of the sea states from very small to extreme wave is presented in 15 sea state. In thiswork the seastate is description using the modified Pierson-Moskowitz spectrum specified in terms of the significant wave height (H_s) and the zero up-crossing period (T_z) used in this present study which is given by the expression [16]:

$$\int_{\eta}(\omega) = \frac{H_s^2 T_z}{8\pi^2}\left(\frac{T_z\omega}{2\pi}\right)^{-5} \exp\left(-\frac{1}{\pi}\left(\frac{T_z\omega}{2\pi}\right)^{-4}\right) \tag{1}$$

Where $\int_{\eta}(\omega)$ is the spectral density of the sea surface elevation $\eta(t)$, ω is the frequency in rad/sec.

3.2 Wave Load Calculations

In this study to calculating the waves loads on a jacket platform joints a four different subjectsare combined together in which the first one is the sea state modeling while the seond is related to the velocity and acceleration componetes estimation of wave theory that formulated by Airy theory[4]. Since any fluid as, water, air, etc... effects through a structure the particles of fluid is remote from original paths because structure is existed so the disturbing motion of these particles is basically depended on the characteristics of the fluid and the structure leading to the effect of the structure on wave movement is basically neglected when the ratio between diameter of the srtucture over water wave length is less than (0.2), and for this case the structure is typified as permeable structure (most offshore structures are cosidered as permeable structures) [18].

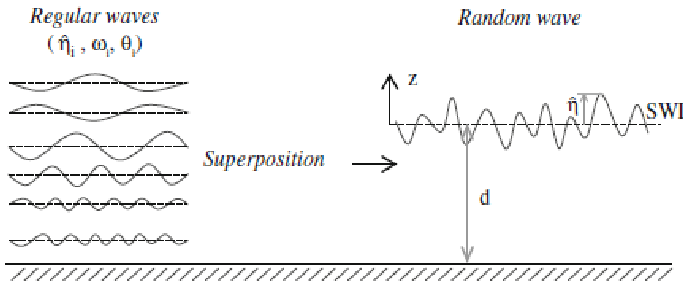

Figure 1 A number of regular wave profiles and representation of a random wave pattern [12].

Considering (H) is the wave height, (T) is the wave period, w is the circular frequency of the wave $(\omega = 2\pi / T)$, and $K(T = 2\pi / L)$ is the wave number obtained from the dispersion relation. The fluid particle velocities and accelerelerations are then given by Airy theory as:

$$\mathbf{W^2 = gK\tanh(kd)} \tag{2}$$

$$\mathbf{V_x = \frac{\pi H}{T}\frac{\cosh(kz)}{\sinh(kd)}\cos(kx-\omega t)} \tag{3}$$

$$\mathbf{V_z = \frac{\pi H}{T}\frac{\sinh(kz)}{\sinh(kd)}\sin(kx-\omega t)} \tag{4}$$

$$\mathbf{a_x = \frac{2\pi^2 H}{T^2}\frac{\cosh(Kz)}{\sinh(kd)}\sin(kx-\omega t)} \tag{5}$$

$$\mathbf{a_z = \frac{2\pi^2 H}{T^2}\frac{\sinh(kz)}{\sinh(kd)}\cos(kx-\omega t)} \tag{6}$$

The force exerted on fixed vertical cylindrical pile and inclined pile by surface waves was first considered by Morison et al (1950) therefore the third step is applicable Morison equation to estimate the hydrodynamic force on a normal orientation of offshore member which consists of two parts-the drag force, and the inertia force [15-18].
Morison's equation = Drag force + Inertia force
The power spectral density function for this force is given as;

$$\int_{FF}(\omega) = \left[\frac{(C_M+C_A)^2}{\sinh^2 kd}\omega^4\left\{\int_0^d \cosh kzg(\bar{z})dz\right\}^2 + C_D\frac{8\omega^2}{\pi\sin^2 kd}\left\{\int_0^d \cosh kz\sigma_{vx}g(\bar{z})dz\right\}^2\right]\int_\eta \tag{7}$$

The parameter (C_D) is equal to(c_d ρD/2, in kg/m²), and (C_M) is equal to (cmρA, in kg/m). Th,e coefficients (drag coefficient, c_d) and (inertia coefficient, c_m) are calculated from laboratory experiments indicate a general range of 0.6 to 1.2 for (c_d), and 1.2 to 2 for (c_m) depending up on flow conditions and surface roughness [17].

One needs first to compute the variance of the water particle velocity, σ_{vx} which is a function of the velocity spectrum using the coefficient in Morison's formula was written as:

$$\boldsymbol{\sigma_{v_x}^2 = \int_0^\infty \int_{v_x v_x}(\omega)d\omega = \int_0^\infty \omega^2\frac{\cosh^2_{kz}}{\sinh^2_{kd}}\int_\eta(\omega)d\omega} \tag{8}$$

$$\boldsymbol{\vec{C}_D = C_D\sqrt{(8/\pi)\sigma_{v_x}}} \tag{9}$$

σ_{vx}: represents the standard deviation (m² /s).

The final step is transform the member forces to joint forces using equivalent virtual work principle.

3.3 Formulation of the Structure

The offshore structure is modeled via a finite element formulation and then analyzed by using SAP2000 V20 . The used element is BEAM element and it is modeled as a straight line which is connected by two points at the ends. The mass of any element is assumed to be focused on point masses at each of its nodes, and distribution for element mass to these nodes is separated equally [19] and added massis assigned to each element lying below still water depth. The viscous damping is taken equals to 0.05 for all modes considering by the problem and the stiffness matrix iscalculted in similar manner asdefined by the program. For soil-structure (pile foundation) interaction , in this study the foundation is assumed to be rigid and the springs which representing the soil perform as uncoupled elements. This method is satisfactory and is the more popular approach used in modelling soil structure interaction. Based on this approach, formulae have been derived using elastic theory;

$$\mathbf{k = \frac{E_s}{(1-\mu^2)D}} \tag{10}$$

$$\mathbf{K_H = \frac{E_s}{(1-\mu^2)}L = \frac{500C_u}{(1-\mu^2)}L} \tag{11}$$

$$K_V = \frac{K_H}{8} = \frac{E_s}{8(1-\mu^2)}L = \frac{500C_u}{8(1-\mu^2)}L \tag{12}$$

Where; K_H, and K_V are the horizontal, and vertical stiffnesses respectively. E_s is the modulus of elastisity of soils, C_u is undrain cohesion μ is poisson's ratio, and D is outer diameter the radius of circular base.

3.4 Dynamic Analysis

The dynamic analysis are concerned on two parts, the first deal with free vibration using eign value and eign vector analysis while the second part deals with forced vibration using power spectra density (PSD) in which the wave forces are formulated as power force density function in order to understand the dynamic behavior and response of offshore structural system. Since offshore structures are made from welded tubular joints of varying complexity with respect to size, shape, and load carrying capacity. These joints can be loaded in any combination of three modes. These include axial loading, out-of-plane (OPB), and inplane (IPB) bending, illustrated in Figure 2 [16]. Due to the complexity of joint geometry and shell behaviour of welded tubular joints that govern local stresses are non-uniformly distributed.

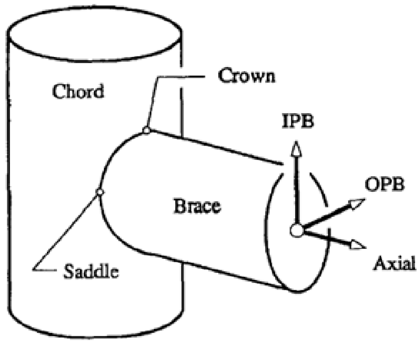

Figure 2 Illustration of IPB, OPB, and axial loading.

3.5 Definition of Hot Spot Stress

The hot spot stress is considered to control the complete fatigue life of a tubular welded joint. It is the stress at the weld toe calculated by manner of a linear extrapolation to the weld toe of the geometric stress. The definition is illustrated in Figure 2. The hot spot stress excludes the contribution to the stress concentration caused by the notch effect of the weld geometry. This definition is not stated very clearly in many design codes [16] and, depending on the code used, can result in misinterpretation of this important parameter, Hot spot stress= Nominal stress×Stress Concentration Factor, where nominal stress is obtained from SAP2000 rogram and a number of semi-empirical relations based on dimension and geometry of a joint are available in the literature to estimate the stress concentration factors. The relationship for K joint as given be Visser (1974), Kuang et al (1975) and Kellog (1976) are represented below; Visser formula for K joint for both chord and brace, Kuang et al formulae for K joint, and Kellog formulae for K joint.

3.6 Fatigue Life Estimation

The prediction of fatigue damage in offshore steel structures is associated with a range of amplitudes and frequencies of environmental loadings, the complexity of stress distribution and the presence of flaws and cracks caused by different manufacturing and installation processes. The fatigue-damage process in welded structures consists mostly of crack propagation. The inherent imperfections in the metal may significantly decrease the fatigue life of a structure as the fatigue cracks can grow readily from such inadvertently introduced cracks [16].

3.6.1 S-N curve approach

The S-N curves which serve as a measure of the fatigue resistance of the metal to applied load reversals, relates the applied stress range to the number of cycles to fracture of the metal. There are many S-N curves in existence based on experimental data for example: British Welding Institute (BS-F) curve, American Welding Society (AWS-X) curve, the modified AWS-X curve, and DNV curve. These curves are shown in Figure 3. It may be noted that the BS-F curve exists only for the range of 10^5 to 2×10^6 cycles. Its application to high cycle fatigue damage is, therefore, based on extrapolation and may not be desirable. AWS-X modified curve is formed by the extension of the AWS-X curve's same slope for cycles greater than 2×10^6.

The basic design S-N curve is given by the following equation:

$$\log N = \log a_d - m\log\left(\Delta\sigma\left(\frac{T}{t_{ref}}\right)^k\right) \qquad (13)$$

Where; m = negative inverse slope of the S-N curve (m_1 and m_2 are used to describe the slopes of the left and right parts of two-sloped S-N curves. The S-N curve is used in the Palmgren-Miner rule to calculate the fatigue damage of a joint. The Palmgren- Miner's rule is stated in the words of Miner, "The number of cycles applied at a given stress level is proportional to the life expended. When the total damage by this concept reaches 100 percent, the fatigue specimen should fail". Miner's rule is based on linear accumulation of damage and is expressed as:

$$DR = \sum_{i=1}^{s} \frac{n_i}{N_i} \qquad (14)$$

Where DR is the damage ratio, s is the number of stress blocks considered, n_i is the number of stress cycles for stress range block i and Ni is the allowable number of stress cycles of stress range as given by S-N curve. The fatigue damage given by Eq.(14) is for a particular sea state. The total fatigue damage is taken as the summation over all the sea states of the damage caused by each sea state weighted by its probability of occurance.

$$TD = \sum p_j DR_j \qquad (15)$$

Where, TD is the total damage and P_i is the probability of occurrence of a sea state J. Failure of the joint occurs when the total damage sums upto unity. The inverse of the total damage provides the predicted fatigue life of a welded joint [16.17].

3.6.2 Fracture mechanics approach

Fatigue life of a welded joint is defined by the time-span needed in the growth of crack from the initial crack size a_i (original imperfections) to the final crack size af (unstable length). The fatigue growth rate is believed to be a material property and is strongly dependent on the stress intensity factor k. The parameter k is directly related to the applied stress, the crack length and the geometry of the joint and weld metal. Figure 2 for fatigue crack growth rate is integrated to obtain the total number of cycles to failure Ń as:

$$\tilde{\mathbf{N}} = \frac{2}{(\mathbf{m}-2)\mathbf{c}(1.1\sigma_{\mathbf{h}})^{\mathbf{m}}\pi^{\mathbf{m}/2}}[(\mathbf{a_i})^{(2-\mathbf{m})} - (\mathbf{a_f})^{(2-\mathbf{m})/2}] \tag{16}$$

$$\sigma_h = (\bar{h}_\sigma^m)^{1/m} \tag{17}$$

Where; a_i is initial crack size, a_f is final crack size,and $C=4.5\times10^{-12}$, $m=3.3$ are constant parameters which are experimentally evaluated, and σ_h weighted average stress range and the ratio of $\acute{N}/\sum n_i$ gives the fatigue life of the welded joint in years.

3.7 Description of Offshore Structure

The example for steel jacket platform analysed is a doubly symmetric as shown in Figure 3. This structure consist of many of tubular members. This steel jacket platform analysed is a doubly symmetric as shown in Figure 4. This structure consist of many of tubular members which basically call chord and brace. These members are as vertical members, horizontal members, and inclined members. The main reason of taken and selected this structure is related to the previous study of fatigue life estimation using frequency domain [16]. The details of a steel jacket platform are gven as: Height of structure = 50 m, Width of short side of frame = 15 m, Length of long side of frame = 30 m, Depth of water = 35 m, Weight of the deck =12500 tons, Drag coefficient (c_D) = 1.4, Inertia coefficient (c_m) = 2, Damping ratio = 0.05, Diameter of column = 1 m, Wall thickness of column =0.04 m, Diameter of short horizontal = 0.5 m, Wall thickness of short horizontal = 0.025 m, Diameter of short diagonal = 0.3 m, Wall thickness of short diagonal = 0.01 m, Diameter of long horizontal = 0.5 m, Wall thickness of long horizontal = 0.025 m, Diameter of long diagonal = 0.5 m, Wall thickness of long diagonal = 0.025 m, Length of pile foundation inside soil = 40 m, Diameter of pile foundation inside soil = 1 m, Wall thickness of pile foundation inside soil = 0.04 m.

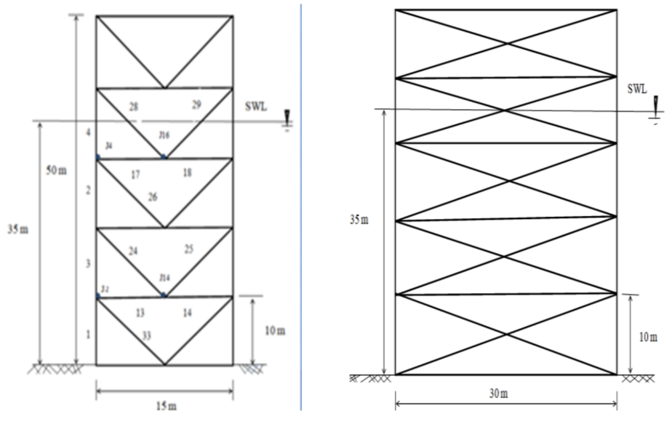

Figure 3 Short- and long side of the structure

3.8 Sea state Estimation

The first step is to estimation of sea state during one year period, herein 15 seastate were taken and used as given by [16]. To applied P-M equation, there are variable calls wave number, and denoted by (k) which is given by expression:

$$k = \frac{\omega^2}{g}\tanh(kd) \tag{18}$$

From above expression it notice that wave number is vary with frequency change. Also, the peak frequency (ω_m) of the wave is evaluating for each state of sea state [15]. The peak frequency depended on many variables as wind speed and fetch length as shown in Table 1. Therefore, Pierson-Moskowitz valued are estimated for 15 seastates by equation 1 and their values for sea state 13,14, and 15 are estimated for specified sea state 12 to 15 as shown figure 4.

Table 1 Shows values of peak frequency (ω_m) for 15 sea state

Sea state	zero up-crossing period, Tz (s)	Peak frequency,ω_m (rad/s)	Sea state	zero up-crossing period, Tz (s)	Peak frequency, ω_m (rad/s)
1	1.49	0.237	9	7.84	1.248
2	2.54	0.404	10	8.40	1.337
3	3.33	0.530	11	8.94	1.423
4	4.24	0.675	12	9.46	1.505
5	5.12	0.815	13	9.95	1.583
6	5.89	0.937	14	10.89	1.733
7	6.59	1.049	15	12.38	1.970
8	7.23	1.151	-	-	-

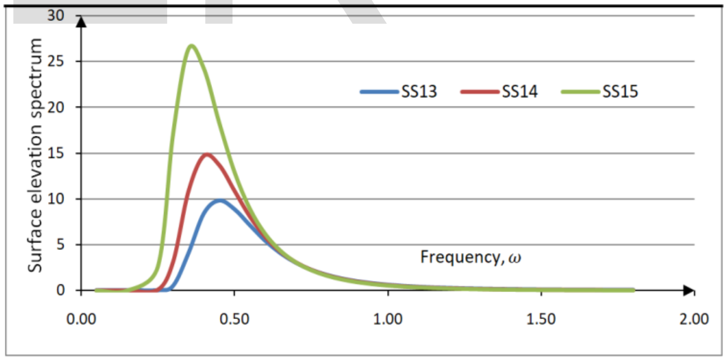

Figure 4 Shows sea surface elevation spectrum for sea state 13,14, and 15.

3.9 Determine of Morison's Equation

The method of load estimation in this study depended on Morison's equation in which in this equation the hydrodynamic forces are divided in two terms (drag and inertia force) so that Morison's Equation are employed here to find the hydrodynamic forces for 15 sea states noting that its application is not in time domain but in frequency domain as power spectra density force which estimation by equation 7. The load which is estimated from Morison's equation based on statistic approach, and take 15 sea state when used Morison's equation, where transform function is applied in terms of Morison's equation (drag and inertia) to get on statistical solution. Figure 5 shows shape of load applied on individual structure member for som sea states.

From Figure 5, it is so clearly that the loads of waves on the members of a steel jacket platform has significant variation according to the specific sea state but the peck load frequency is so closer for various sea state. Also, it notice that load shape is function of frequencies (curve form) between load square and frequencies (power spectral density), where the load gradually starts in increasing until reaches to maximum value after that gradually decreases to very small value. These curves are obtained from Morison's equation and consist of two terms (drag and inertia). Notice that load depends on sea state, where increases with increment in significant wave height, therefore for sea state No.15 the load more than sea state No.14 etc...

Since the meber forces depending on many factors as illustrating in equation 7 which leads to the resulting loads very from member to other. After member force estimation, these loads are transformed to the joints of jacket structures. Each joint take load which contributing from connected members that depending on the joint location, member orientation and geometry in the structure, therefore it is required a factor for each joint gets on load based on effect of above notes. Joints which are near the seabed (mudline) will take less load because intensity of waves reduce when remote from sea surface and near to seabed. Table 2 shows the variation of wave load with water depth as mentioned by the horizontal force factor (F_h) and vertical force factor Factor (F_v)

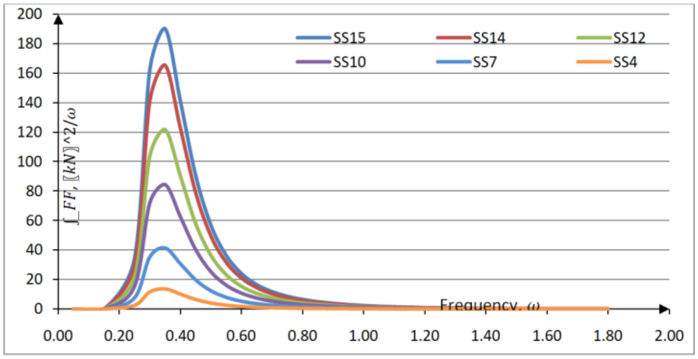

Figure 5 Shows shape of load applied on for sea state (SS) 4,7,10,12,14, and 15.

Table 2 Values of factors which represent vary load of waves with water depth.

Joint	Factor (F_h)	Factor (F_v)
4,10	1	0.3
3,9	0.45	0.13
2,8	0.11	0.003
1,7	0	0

4. APPLICATION

4.1 Effect of Consideration Base of the Structure as Elastic Foundation

At case the base of structure was elastic, the jacket platform is weakened under the loads effect. For representation this effecting we consider following two cases, . The first one is taken as the legs of the jacket platform are inside the soil and there are impedance developed from the soil in which the length of piles inside the soil are 40 m while the second case is a fixed base foundation.

There are many various parameters are effected on the pile head impedance [4,16] which are based on soil properties such as unit weight, dynamic shear modulus, material damping, and Poisson's ratio. There are three types of soil [21], 1-Stiff, 2-Medium, and 3-Soft. The other properties for soil are same in each of three cases with respect to shear modulus. Clay soil is considered in this study and values of unit weight and other parameters are given below [19].

Unit weight of soil (kN/m^2)=20, Material damping=0.03 for steel in air,0.05 for steel in water,0.15 for soil, Poisson's ratio=0.4, Modulus of elastisity of clay soil (Mpa)=24, and Undrain cohesion,(kN/m^2)=48.Equations of elastic foundation are given in chapter three. Length of pile inside soil is (40 m) and divided into (20) element each one is (2 m) length and values k_k and k_v for each element are ewstimated according equations 1 and 12 respectively.

4.2 Model Analysis

This work is carried out by analysis a steel jacket platform on two stages; 1- First case, by considering the base of structure as fixed base 2-Second case, by considering the base of structure as elastic foundation. In each case of representation of the foundation, the structure is analysed. The analysis consist of using one to six modes of the structure. The time periods, and frequencies are obtained. The Figures 6 and 7 show the first three deformed mode shapes. The natural frequencies and periods of modes are obtained from this analysis for two cases of restraining condition of base of the structure. Table 3 shows values of natural frequencies and periods. From table which deals with analysis of six modes for structure and found natural frequencies and periods where compared with proposed structure [4]. The differences were not exceed 30%, where difference was 29.429% for frequencies and 23.333% for periods (between analysis structure during this study and proposed structure [16]). The difference was 23.21% for frequencies and 21.052% for periods (between two cases of representation of structure base, first by cosideration the base was fixed,while second case considered elastic foundation).

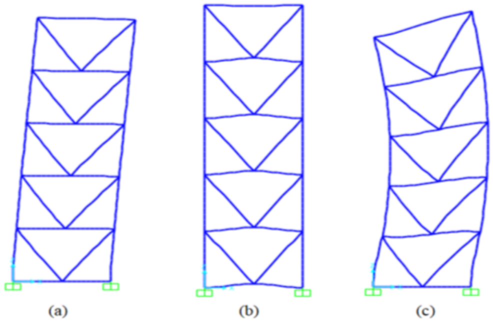

Figure 6 Mode shapes for steel jacket platform (fixed base).

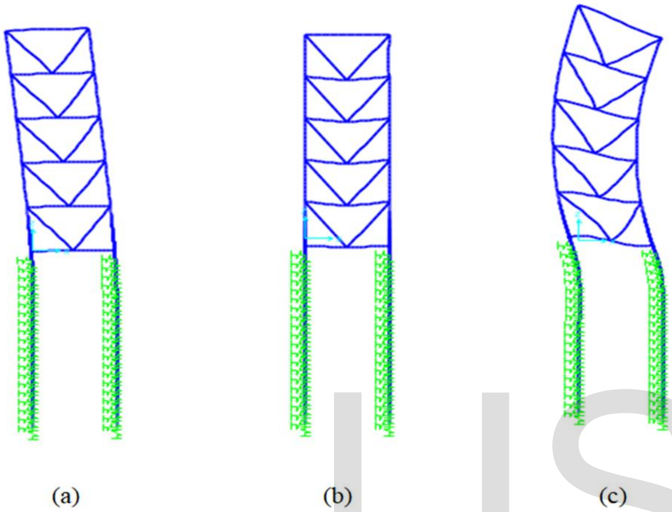

Figure 7 Mode shapes for steel jacket platform (e lasticbase).

Table 5 Values of natural frequencies (ω) and periods (T).

Mode	Fixed base		Elastic base		Elastic base [4]		Ratio	
	ω	T	ω	T	ω	T	ω	T
1	0.24	4.10	0.21	4.71	0.24	4.10	1.147	0.872
2	1.97	0.51	1.72	0.58	1.96	0.51	1.145	0.873
3	2.25	0.44	2.07	0.48	2.22	0.45	1.084	0.922
4	2.84	0.35	2.84	0.35	2.86	0.35	1.000	1.000
5	5.20	0.19	4.31	0.23	3.33	0.30	1.205	0.830
6	10.51	0.10	8.07	0.12	6.67	0.15	1.303	0.768

4.3 Stress Concentration Factors

As a repercussion of structural representation, the fatigue analysis of a steel jacket platform is limited to the damage evaluation of the structural joint for the plane frame which is considered in this study. During present study we will deals with four joints (J16, J4, J14, and J2) as shown in Figure 4. Two joints (J16 and J4) are situated near the still water level (SWL), and other (J14 and J2) are situated near the mudline. The hot spot stresses are assumed at location of intersection each chord with brace. Commonly, the hot spot stress between the diagonal and horizontal member is forecasted to ridden maximum damage, therefore fatigue life is goveron in this location. The stress concentration factors are explained by Visser, Kuang et. al. , and Kellog as mentioned used to show the effect of the different in SCF on the fatigue failure which event in the welded joints. There are factors effect on values of SCF as diameter of member, thickness of member, angle between the members, etc.. . Table 4 below gives values of SCF depended on Visser, Kuang et. al. , and Kellog.

Table 4 Shows values of stress concentration factor (SCF).

Method	Force Type	J16	J4	J14	J2
Visser	SCFaxial	4.256	2.64	4.256	2.64
	SCFbending	4.256	2.64	4.256	2.64
Kuang et. al.	SCFaxial	3.17	3.55	3.17	3.55
	SCFbending	1.99	1.867	1.99	1.867
Kellog	SCFaxial	1.835	1.517	1.835	1.517
	SCFbending	1.835	1.517	1.835	1.517

4.4 Dynamic Response of the Structure

There is response between the structure and external loads (waves loads), and this response cause to incidence internal forces as axial force, shear, and bending moment, also the deformations and displacements are obtained. These are given by determined it from SAP2000 V20 program which is used in this work.

4.5 The Structure response

The axial force is developed due to applied loads on the structure. It's generated in members of structure which are called chord and brace member. The bending moment is generated and also it's developed due to loads effect on the structure. The displacements are obtained during this analysis for a steel jacket platform. Two cases of determination the response of the structure, first case is a fixed base of the structure, while second case is an elastic base of the .

The obtaining on the stresses are important process during this study. SAP2000 V20 is used in this research. Determination of the stresses for each state of sea states are required to assess life of the joints. Figures 8 and 9 show values of the stresses for 15 sea states. Displacements and rotation are zero at the base of structure for case the base assumed fixed foundation where fixed prevents the transition and rotation, while the displacements and rotation were obtaining when considered the base assumed elastic foundation, but less than displacements at tip point of the structure because tip point is more effecting when waves loads are applied and also tip point was free. The stresses were obtaining for two cases, first case the base assumed fixed foundation and second case assumed elastic foundation. From two cases we noticed differences between values of the stresses where the stresses for elastic foundation are more and cause when we considered the base was elastic foundation, at this case the structure was weaker, therefore the fatigue damage will be more. Significant wave height is effecting on the value of stress where with increasing in significant wave height noticed that the stresses increase, therefore the stresses in sea state No.15 more than sea state No.14 etc...

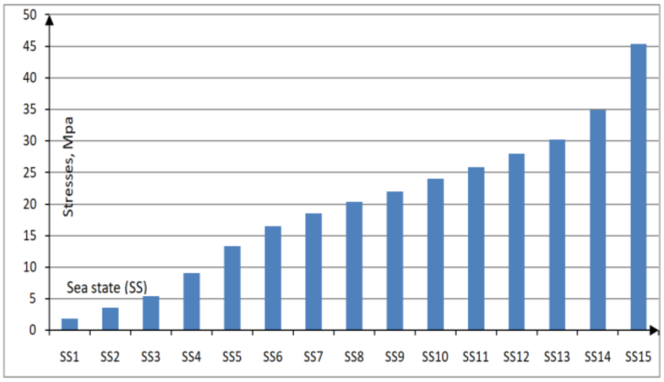

Figure 7 Shows values of the stresses in Mpa for 15 sea state (the base of structure was fixed).

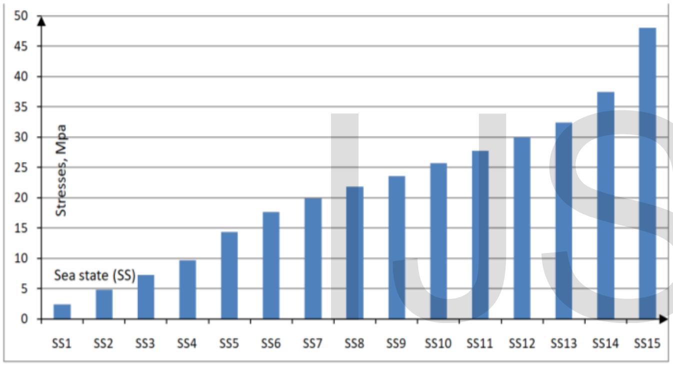

Figure 8 Shows values of the stresses in Mpa for 15 sea state (the base of structure was elastic).

4.6 Computation of Fatigue Life

Fatigue life (life of joint) is obtained based on knowledge or assess of fatigue damage at the joints (four joints, two near SWL and two near mudline). Two methods are used in this study to evaluate fatigue damage 1- S-N curve approach which is consisted of AWS-X modified, BS-F, and DNV as explained in refrence [20], 2- Fracture mechanics approach.

4.6.1 S-N curve approach

The fatigue damage for one year at the four joints mentioned above and caused by each sea state is determined and for brifly only joint J16 is given in Table 6 and joint J2 in table 7 for case fixed base of the structure. The results in general that the fatigue damage will be increasing with the increment in significant wave height, but number of cycles also effect on results of fatigue damage. Also, figure 9 and 10 display fatigue damage for J14 (the base of structure was fixed) and fatigue damage for J4 (The base of structure was elastic) repectively.After obtaining on fatigue damage of 15 sea state for four joints now can to find the critical case (cumulative damage) of fatigue damage or life of structure by consideration effecting of sea states together as explain in Table 8 and 9.

Table 6 Fatigue damage for joint J16 associatted to two support conditions

Sea state (SS)	The base was fixed			The base was elastic		
	AWS-X modified	BS-F	DNV	AWS-X modified	BS-F	DNV
1	0.00000554	0.00073741	0.00025218	0.000000000027	0.000000076616	0.000000026200
2	0.00005297	0.00356972	0.00122075	0.00063427	0.02297841	0.00785800
3	0.00034696	0.01552594	0.00530945	0.00413615	0.09960779	0.03406318
4	0.00269502	0.07247425	0.02478424	0.01332066	0.24024632	0.08215777
5	0.00897485	0.16299032	0.05573830	0.04433004	0.54002649	0.18467451
6	0.01349701	0.19919750	0.06812018	0.06676958	0.66075371	0.22595997
7	0.01330152	0.17506438	0.05986730	0.06574807	0.58034209	0.19846136
8	0.01157142	0.13859749	0.04739661	0.05735327	0.46039846	0.15744387
9	0.00910474	0.10064740	0.03441870	0.04469783	0.33194540	0.11351638
10	0.00708590	0.07180280	0.02455462	0.03501467	0.23797572	0.08138128
11	0.00505840	0.04755342	0.01626199	0.02488231	0.15706874	0.05371328
12	0.00355097	0.03089029	0.01056365	0.00539879	0.04229448	0.01446357
13	0.00241730	0.01945502	0.00665309	0.00366108	0.02656075	0.00908306
14	0.00346114	0.02407957	0.00823456	0.00526746	0.03299399	0.01128306
15	0.00093096	0.00498310	0.00170409	0.00134180	0.00655492	0.00224161

Table 7 Fatigue damage for joint J2 associatted to two support conditions

Sea state (SS)	The base was fixed			The base was elastic		
	AWS-X modified	BS-F	DNV	AWS-X modified	BS-F	DNV
1	0.00000791	0.00096344	0.00032947	0.000000000005	0.000000021273	0.000000007275
2	0.00008331	0.00008331	0.00008331	0.00000090	0.00016824	0.00005754
3	0.00052845	0.02128630	0.00727934	0.00078360	0.02860325	0.00978154
4	0.00415782	0.10032566	0.03430867	0.00249546	0.06841101	0.02339472
5	0.01375265	0.22448185	0.07676674	0.00842187	0.15539886	0.05314222
6	0.02078369	0.27535792	0.09416499	0.01267569	0.19003530	0.06498695
7	0.02052974	0.24241494	0.08289938	0.01255441	0.16763664	0.05732721
8	0.01788988	0.19216348	0.06571473	0.01094456	0.13292727	0.04545755
9	0.01398344	0.13885523	0.04748475	0.00854376	0.09595963	0.03281561
10	0.01090447	0.09920840	0.03392660	0.00667529	0.06865904	0.02347954
11	0.00779666	0.06578142	0.02249547	0.00474182	0.04530340	0.01549254
12	0.00548151	0.04277955	0.01462946	0.01095768	0.07192010	0.02459474
13	0.00371518	0.02685460	0.00918355	0.00743970	0.04520641	0.01545937
14	0.00533619	0.03331638	0.01139330	0.01065598	0.05596665	0.01913909
15	0.00145305	0.00695843	0.00237960	0.00271117	0.01110886	0.00379893

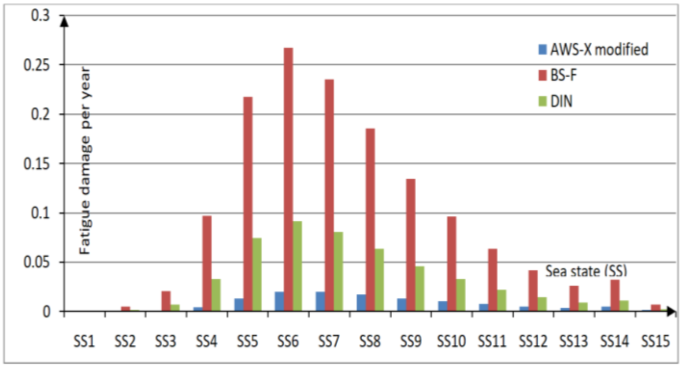

Figure 9 Fatigue damage for J14 (The base of structure was fixed)

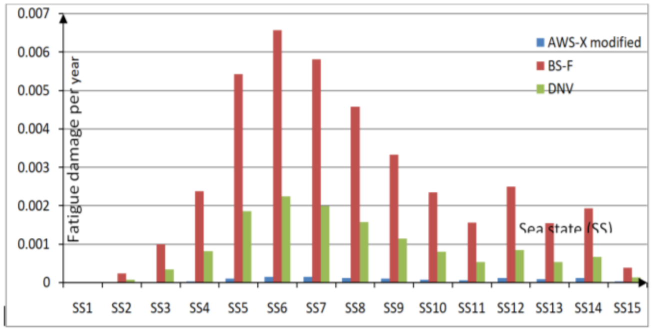

Figure 10 Fatigue damage for J4 (The base of structure was elastic).

Table 8 Shows value of fatigue damage.

Location	Fatigue damage Method					
	Fixed base			Elastic base		
	AWS-X modified	BS-F	DNV	AWS-X modified	BS-F	DNV
J16	0.0046339	0.0281770	0.0069641	0.0053787	0.0327054	0.0080833
J4	0.0209600	0.0663130	0.0314998	0.0243285	0.0769704	0.0365623
J14	0.0582751	0.1148106	0.0875790	0.0676407	0.1332623	0.1016542
J2	0.0574053	0.1053741	0.0862718	0.0666311	0.1223092	0.1001370

Table 9 Shows value of joint life in year

Location	Life of joint					
	Fixed base			Elastic base		
	AWS-X modified	BS-F	DNV	AWS-X modified	BS-F	DNV
J16	215.80	35.49	143.59	185.92	30.58	123.71
J4	47.71	15.08	31.75	41.10	12.99	27.35
J14	17.16	8.71	11.42	14.78	7.50	9.84
J2	17.42	9.49	11.59	15.01	8.18	9.99

4.6.2 Fracture mechanics approach

Fracture mechanics (FM) is another method to evaluate the fatigue damage of joints. Basically, it's depended on principle of developed crack during life of the structure and growth of crack size from initial (a_i) to final (a_f). Values of initial and final crack size are taken as (0.25, 0.50, 1.00) for intial and (5.0, 7.5, 10.0) for final crack width respectively. The values of the constants (c, m) which are experimantally obtained as mentioned before in which the values of these constant parameters are represent properties of the material. The number of cycles generated due to ranges of stresses for each state of sea states are calculated from equations as mentioned in section 3.6.2.

Herein, the fracture mechanics approach is used for two cases, 1- First case, by considering the base of structure treated as fixed, and 2- Second case, by considering the base of structure treated as elastic foundation. Effect of two cases on fatigue analysis is discoursed in next sections. Values of the weighted average stress range as shown in Table 10 which calculated and for two cases of the base of structure. The (σ_h) is calculated depended on SCF from Kuang et. al. (1975). After that, we can to find the total number of cycles to failure as shown inTable 11 and finally it can to evaluate the age of joint (life of the welded joints in years) as given in Table 12.

Table 10 Gives values of the weighted average stress range (MPa)

Joint	Fixed base	Elastic Base
J16	34.69792884	39.19890347
J4	38.82375246	15.23769178
J14	25.85386641	34.47110147
J2	28.9561954	46.73931072

Table 11 Values of (Ń) based on different values of (a_i and a_f) and for two cases for representation of base of the structure

Location	Fixed base	Elastic Base
J16	108447090.3	91095555.88
J4	20200928.59	16968780.02
J14	11695274.45	9824030.536
J2	5316033.84	4465468.426

Table 12 Values of age of joint in years for two cases of the base of structure

Location	Fixed base	Elastic Base
J16	13.26	11.1384
J4	2.47	2.0748
J14	1.43	1.2012
J2	0.65	0.546

From previous result, the assessment of fatigue damage (joint damage) or life of joint depended on range of stresses and number of cycles. When values of stresses increase the fatigue damage increases or in other word decreasing in the life of joint, but for number of cycles large effecting where sometimes we notice failure of joint with sea state less stress from other sea states, this because number of cycles are more. Four joints were chosen in fatigue analysis, two near still water level (SWL) and two near mudline to give accepted analysis for fatigue. Life of J16 was more than J4 and both J16 and J4 were more than J14 and J2 while J2 was more than J14 and these differences because location of these joints according to effecting waves loads and the stresses which generate in these joints. There are differences between the methods which used for determine life of joints (S-N curves and fracture mechanics approach) also, there are differences between two cases from foundation representation where difference about (14%) for AWS-X modified curve, (13.8%) for BS-F curve, (13.84%) for DNV curve, and (16%) for fracture mechanics approach.

5. CONCOLUSIONS

1- Using of Power Spectral Density (PSD) method in this work when evaluating the loads and analysis in the SAP2000 V20 program to assess the life of structure as a result of fatigue.

2 - Identify to the many of methods to find the age of the joint (life of structure) such as S-N curves, and fracture mechanics approach, where S-N curve consist of AW-X modified, BF-S , and DNV curves.

3. Note the difference in results where there is a difference between S-N curves, and fracture mechanics method as well as a difference between the types of S-N curves.

4 - Obtaining the natural frequencies and periods of the structure from the model analysis and comparison with the model from a previous study [4] where the difference was 29.429% for frequencies and 23.333% for periods (between the analysis during this study and proposed structure [4]), while the difference was 23.21% for frequencies and 21.052% for periods (between two cases of representation of the structure base, fixed and elastic base).

5 - Note of the effecting of soil on the analysis of fatigue where noted that the impact of fatigue was more when the effect of soil was considered to the base of structure.

6 - Discuss the difference of results S-N curves and fracture mechanics approach for two cases of the foundation, first by the representation of the base of structure as a fixed base, and second by the representation of the base of structure as an elastic base where there was a difference in the results between the two cases,where the difference was 14% when we used AWS-X modified curve, 13.8% for BS-F curve, 13.84% for DNV curve, and 16% for fracture mechanics approach.

REFERENCES

[1] Robert T. Hudspeth Waves and Waves Forces on Coastal and Ocean Structures, Singapore: World Scientific Publishing, 2006.

[2] Etube L. S. Fatigue and Fracture Mechanics of Offshore Structures, 1st Ed., UK: St. Edmunds bury Press Limited, 2001

[3]- Bea R. G., Pawsey S. F., and Litton R. W. "Measured and Predict Wave Forces on Offshore Platforms", Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 117, No. 5, September/October 1991, pp. 511-532.

[4] Fatigue in Offshore Structure A Steels, Proceedings of a Conference organized by the Institution of Civil Engineers, held in London on 24-25 February 1981THOMAS TELFORD LTD, LONDON, 1981.

[5] A. Almar-Naess 1985FATIGUE HANDBOOK Offshore Steel Structures, TAPIR, Norway.

[6] Vugts J. H., and Hayes D. J. 1979Dynamic analysis of fixed offshore structures: A review of some basic aspects of the problem, Engineering Structures Volume 1, Issue 3, April 1979, Pages 114-120, https://doi.org/10.1016/0141-0296(79)90020-8.

[7] Enrique J. Laya, Jerome J. Connor, and Sunder S. Shyam "Hydrodynamic Forces on Flexible Offshore Structures", Journal of Engineering Mechanics, Vol. 110, No. 3, March 1984, pp. 433-448.

[8] Jiang Qian, andXiu-xi Wang 1992 Three-dimensional stochastic response of offshore towers to random sea waves, Computers & Structures Volume 43, Issue 2, 17 April 1992, Pages 385-390, https://doi.org/10.1016/0045-7949(92)90156-T.

[9] Sajed Nemati Havigh, Mehdi Behdarvandi Askar 2017 The Process of Fatigue Analysis on Fixed Metal Offshore Platforms Marine Science 2017, 7(1): 10-16

[10] Jing Xu, Dongshi Wang, Hui Huang, Menglan Duan, Jijun Gu & Chen An 2017 A vortex-induced vibration model for the fatigue analysis of a marine drilling riser, Journal SHIPS AND OFFSHORE STRUCTURES, Vol. 12 Supp1 No. S1-S280-S287, https://doi.org/10.1080/17445302.2016.1271557

.

[11] Imanol Martinez Perez, Philippe Bastid, Andrei Constantinescu, and Vengatesan Venugopal 2018 MULTIAXIAL FATIGUE ANALYSIS OF MOORING CHAIN LINKS UNDER TENSION LOADING: INFLUENCE OF MEAN LOAD AND SIMPLIFIED ASSESSMENT , OMAE2018-77552: Proceedings of the ASME 2018 37th International Conference on Ocean, Offshore and Arctic Engineering OMAE2018 June 17-22, 2018, Madrid, Spain.

[12] Romali Biswal, and Ali Mehmanparast 2019 Fatigue damage analysis of offshore wind turbine monopile weldments, ICSI 2019 The 3rd International Conference on Structural Integrity rocedia Structural Integrity 17 (2019) 643–650.

[13] Moises Jimenez-Martinez 2019 Fatigue of offshore structures: A review of statistical fatigue damage assessment for stochastic loadings, International Journal of Fatigue Volume 132, March 2020, 105327,.

[14] Cassidy M. J. Non-Linear Analysis of Jack-Up Structures Subjected to Random Waves, Ph. D., thesis, University of Oxford, 1999.

[15] Sarpkaya T. and Isaacson M. Mechanics of Wave Forces on Offshore Structures, 1st Ed. New York: Van Nostrand Reinhold Company, 1981.

[16] Brebbi A C. A., and Walker S., 1979 Dynamic Analysis of Offshore Structures, Billing & Sons Ltd.,, London.

[17] Ashok Gupta, and Ramesh Prasad Singh 1986 Ramesh Prasad inghFatigue Behaviour of Offshore Structures, Springer-Verlag Berlin, Heidelberg, 001: 10.1007/978-3-642-82899-7.

[18] Robert M. Sorensen Basic Coastal Engineering, 3rd Ed., USA: Springer Science+ Business Media, 2006.

[19] Indrajit Chowdhury and Shambhu P. Dasgupta Dynamics of Structure and Foundation–A Unified Approach 1. Fundamentals, UK: CRC Press/Balkema, 2009.

[20] Halil Karadeniz 2013 Stochastic Analysis of Offshore Steel Structures An Analytical Appraisal, Springer-Verlag London, DOI 10.1007/978-1-84996-190-5.