

Fatigue Analysis of Offshore Structures in Indian Western Offshore

Nitin Nehra, Praveen Bhat and N. Panneerselvam

Abstract Oil and Natural Gas Corporation (ONGC), the national oil company of India, operates more than 270 steel tubular welded offshore structures which are piled to ocean bottom. All these structures have been designed to meet the strength and fatigue limit state requirements as per API RP 2A WSD. These offshore structures are subjected to continuous cyclic wave loads and hence fatigue susceptibility needs to be explored. In this paper, stochastic fatigue assessments of an existing offshore platform for life extension purpose have been discussed. The fatigue lives have been estimated as per parametric equations suggested by Efthymiou. A fatigue factor of safety value of 2.0 has been considered in this study, and $S-N$ curves provided in API are used for cumulative damage (Palmgren Miner's Rule) assessment. All the joints which are found to have lower fatigue lives than design life have been included for type III inspection (as per API RP 2A-WSD) using state-of-the-art NDE techniques (NDT). These studies employed for drawing up the joint inspection campaigns.

Keywords Welded tubular joints · $S-N$ curves · NDT · Inspection campaign API RP2A · Stochastic fatigue

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1 Introduction

Jacket-type fixed offshore platforms are the most commonly used fixed offshore structures installed in the western offshore of India, and these structures predominantly have two substructures one is jacket which is from bottom of the sea to few meters above the mean sea level and another one is deck which is placed on the jacket. The design life of these structures is 25 years, and many platforms have outlived their design lives but are still needed for 15–20 years. These offshore platforms are, in general, large and complex, three-dimensional framed structural systems, usually fabricated using steel tubular members interconnected through welded joints. These structures are predominantly subjected to oscillatory/cyclic environmental loads and due to this oscillating nature of load; fatigue characterizes a primary mode of failure of their components. Hence, fatigue life estimation is an integral part of design philosophy of offshore structures and to generate the inspection plans during the service life. The fatigue damage at any point in the structure depends on the complete stress history during the structures service life [1]. The calculation of this stress history and its effects on the material is a complex task. The irregular nature of the sea, size of structure, evaluation of stress concentration factors in welded joints and possible dynamic effects, etc., contribute to the complexity of the fatigue life assessment [1]. Fatigue in offshore structure is a typical high cycle fatigue phenomenon. Most damages are caused by the occurrence of many cycles of small stress ranges. The occurrence of few severe storms with return period more than one year is unimportant for fatigue damage consideration. The response of the structure in sea states of relatively low wave height and short mean wave period is of prime concern.

These offshore structures are designed as per established recommended practice/codes, e.g., NORSOK-N006/API RP2A WSD.

This paper presents the spectral fatigue analysis using SACS software for life estimation of existing jacket type of offshore structures based on $S-N$ curve approach using Efthymiou's parametric equations for SCF and Palmgren Miner's Rule. This unmanned jacket platform is secured to seabed with four main piles and two skirt piles and installed in year 1976 in western Indian offshore. It has completed its design life and needs to check fit-for-purpose.

2 Fatigue in Offshore Tubular Structures

2.1 Fatigue Assessment

Fatigue Damage Total no of stress cycles required to failure is called fatigue damage and represented as follows:

$$\text{Fatigue Damage} = \frac{\text{No. of Stress cycles applied}}{\text{No. of Stress cycles resisted}} \tag{1}$$

Stress fluctuations normally occur predominantly as result of wave loads. These wave induced stresses are of variable magnitude and occur in random order [2]. The true time history of the local stresses is almost invariably simplified in that it is assumed to be adequately described in statistical terms by a reasonable number of stress blocks [2]. Each stress blocks consists of a number of cycles of constant stress range. Thus, the sequence of variation in the true stress history is lost. The cumulative effects of all stress blocks representing the stress history is estimated by Miner’s rule of liner accumulation of damage.

$$\text{Total Fatigue Damage} = \sum_{i=1}^s \frac{n_i}{N_i} \tag{2}$$

- s* Number of stress blocks considered
- n_i* Actual number of stress cycles for stress block of range *i*
- N_i* Number of stress cycles resisted of stress range *i*

Fatigue failure is to occur when the total fatigue damage reaches unity. In a fatigue analysis, this criteria can be considered as the definition of local fatigue failure. This does not necessarily imply a failure in reality, let alone a partial or complete collapse of the structure. Hence, fatigue life is defined as follows:

$$\text{Fatigue Life} = \frac{\text{Total Fatigue Damage}}{\text{Design Life}} \tag{3}$$

Before carrying out a cumulative damage calculation for any potential location at a tubular joint, it is necessary to determine the stress response over the range of sea conditions that structure can expect to experience during its life. Random sea conditions are usually described in the short term, i.e., over a period of a few hours, by one of the many directional wave spectrum formulae. These give the component of wave at each frequency and direction in terms of parameters such as significant wave height; mean zero crossing period and mean wave direction. The proportion of time for which each sea-state persist (over a period) (i-e probability) completes the description of sea.

Stress Concentration Factor (SCF) In offshore tubular joints, the welds are the most sensitive part due to the high local stress concentrations. Fatigue lives at these locations should be estimated by evaluating the hot spot stress range (HSSR) and using it as input into the appropriate *S-N* curve [3]. Thus, the SCF for a particular load type and at a particular location along the intersection of weld may be defined as:

$$SCF = \frac{\text{HSSR at the location}}{\text{Range of the nominal brace stress}} \quad (4)$$

The SCF should include all stress raising effects associated with the joint geometry and type of loading, except the local (microscopic) weld notch effect, which is included in the $S-N$ curve [3]. Minimum eight locations (four on chord and four on brace) on welded joint section required to cover all relevant hot spot stress area. SCF approach is widely used for estimation of fatigue of tubular joints. Efthymiou SCF equations are considered to offer the best option for all joint types and load types (Figs. 1 and 2).

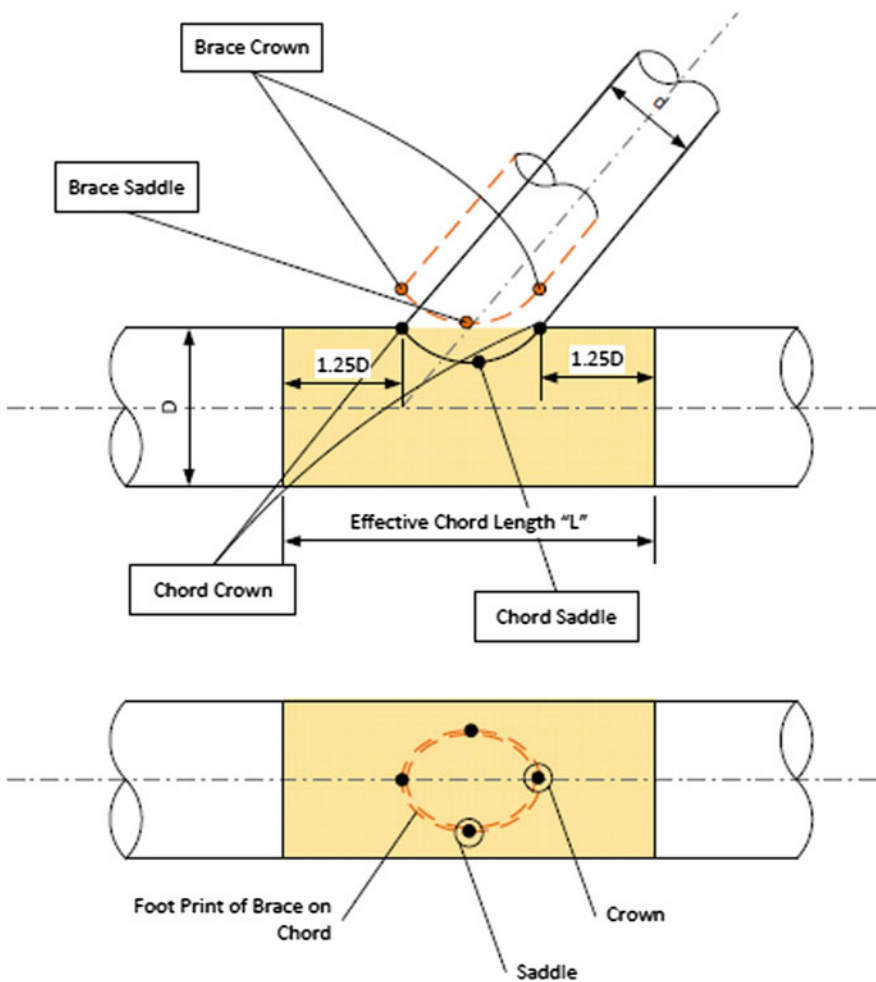


Fig. 1 Hot spot locations. Source <http://nptel.ac.in>

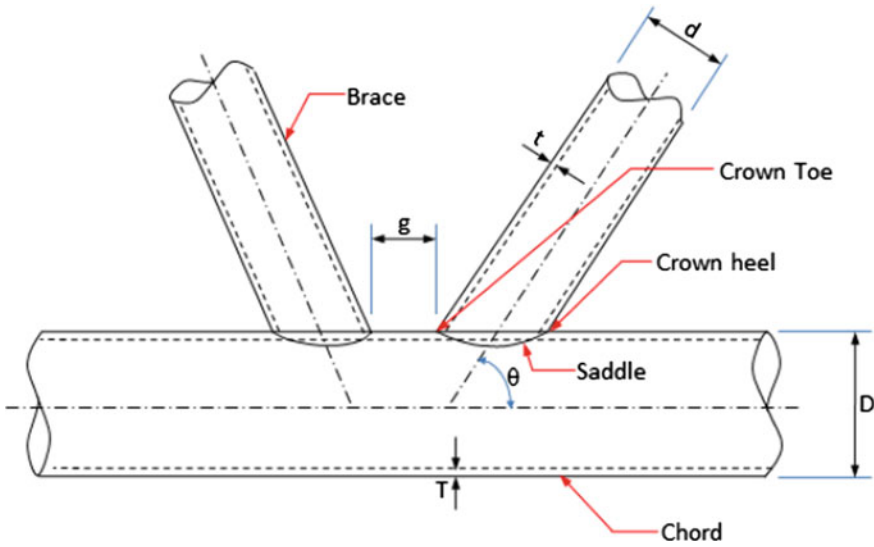


Fig. 2 Typical offshore tubular connection. Source API RP2A WSD 2007, p. 52

S-N Curve. Relation between stress (S) and no of stress cycles (N) and can be plotted on a logarithmic scale as a straight line and is referred as $S-N$ curve. A typical $S-N$ curve is given below for a welded tubular joint.

$$\text{Log}_{10}(N) = \text{Log}_{10}(K) - m \text{Log}_{10}(S) \tag{5}$$

where m is a slope of the curve and K is the geometric constant (Fig. 3)

Sea State. Oceanic sea state can be represented with energy spectrums. A spectrum is the relation between spectral density (S) and wave frequency (ω). The different sea states are shown in Fig. 4.

In the current study, sea is considered fully developed and the Pierson-Moskowitz (P-M) spectrum described by Eq. (5) has been used.

$$S_{\eta}(\omega) = \frac{\alpha g^2}{(\omega)^5} e^{\left\{-\beta \left[\frac{\omega_0}{\omega}\right]^4\right\}} \tag{6}$$

where,

α Philip constant = 0.0081

β 0.74

ω_0 Frequency corresponding to the peak value of the energy spectrum

The sea state is represented by selecting a sufficient number of frequencies for considering the jacket response transfer functions. The range of time periods selected varies between 1 and 15 s. 2% structural damping has been considered in the analysis (Fig. 5).

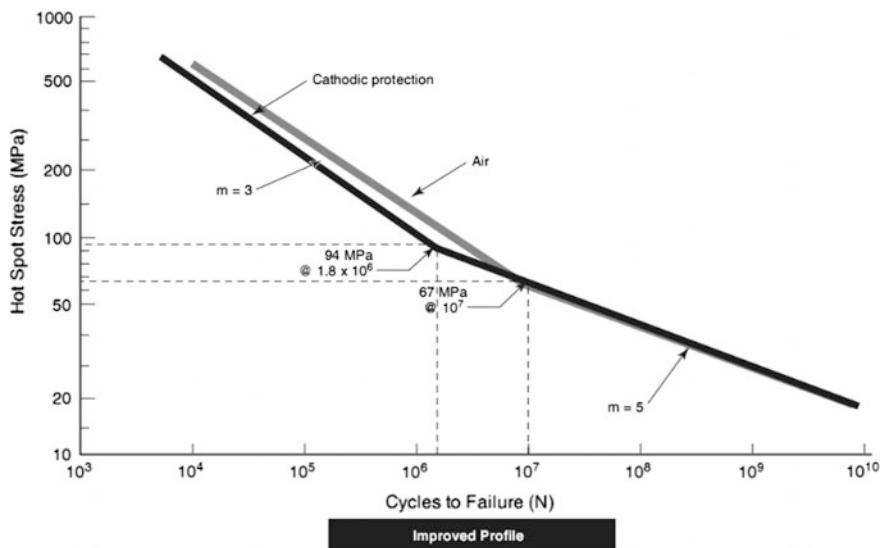


Fig. 3 S-N curve for offshore welded structures. Source API RP2A WSD 2007, p. 59

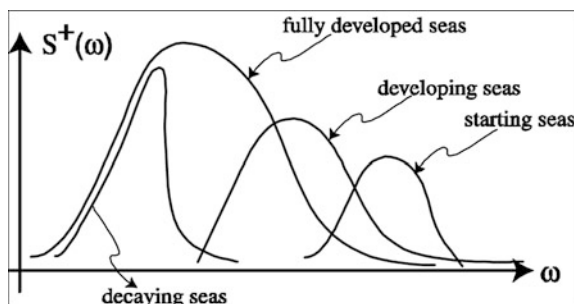


Fig. 4 Sea states. Source web.mit.edu/13.42/www/handouts/reading-wavespectra.pdf, p. 3

2.2 Analysis Methodology

Fatigue analysis involves using wave response to generate a transfer function for each wave direction which relates global load to excitation frequency, specifying a wave spectrum to which the structure will be subjected.

Calculate Centre of Damage Wave Height For fatigue analysis of offshore structure, a super element is created for soil properties due to the nonlinear behavior of soil. This super element is created for the center of damage (COD) wave that represents the spectrum of fatigue waves. This COD wave height (H_{cs}) and time period (T_{cz}) are calculated as follows:

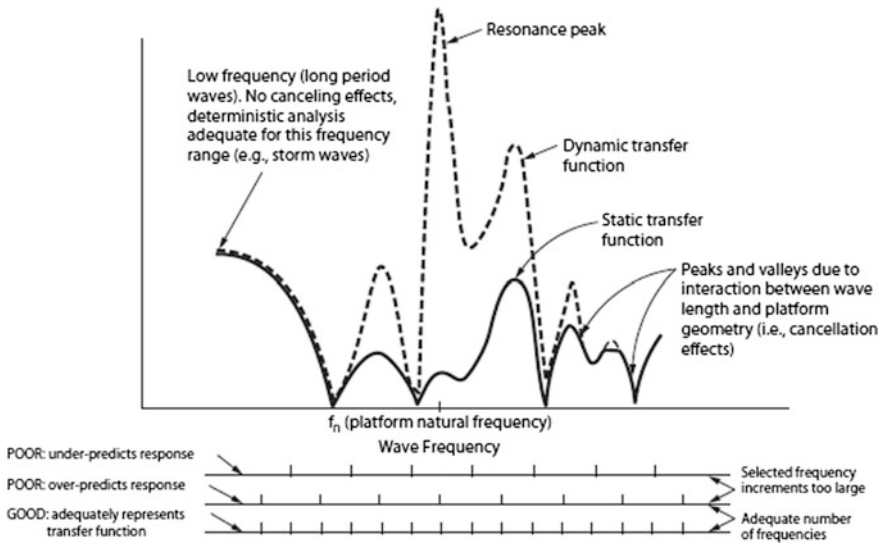


Fig. 5 Selection of frequencies for detailed analyses. Source API RP2A WSD 2007, p. 201

$$H_{cz} = \frac{\sum D_i H_{si}}{\sum D_i} \tag{7}$$

$$T_{cz} = \frac{\sum D_i T_{zi}}{\sum D_i} \tag{8}$$

where

- D_i estimate damage of sea state $i = (P_i H_{si}^m / T_{zi})$
- P_i probability of occurrence of sea state i
- H_{si} significant wave height of sea state i
- T_{zi} zero crossing period of sea state i
- A 1.8
- m inverse slope of $S-N$ curve

The fatigue analysis is represented in the following flow chart (Fig. 6).

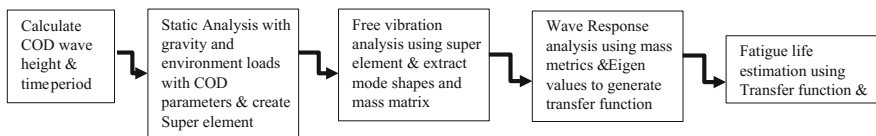


Fig. 6 Flow chart for spectral fatigue analysis

Joint	Joint type	Fatigue damage	Service life (years)	Joint	Joint type	Fatigue damage	Service life (years)
1006	K	28.41381	3.167474	401L	TK	2.722906	33.05292
4007	T	19.67677	4.573921	302L	TK	2.192823	41.04298
4015	K	1.858529	48.42539	1005	T	2.086545	43.1335
4015	K	15.07281	5.971017	404L	TK	1.708574	52.6755
206L	T	5.722737	15.72674	4006	T	1.885135	47.74194
2011	T	4.728998	19.03152	1001	T	1.341135	67.10734
304L	TK	4.339304	20.74065	4008	T	1.309376	68.73502
RA9	K	3.644766	24.69294	1003	K	1.292088	69.6547
4001	TK	2.964391	30.36037	3007	K	1.09974	81.83755
403L	TK	2.683205	33.54198	1011	T	1.066322	84.40226
1007	T	1.032743	87.14655	RB9	K	1.048158	85.86492

These joints have been included for the type III inspection to be done during the scheduled underwater inspection for detection of damages, if any.

4 Conclusion

Offshore steel jacket structures are vulnerable to damage due to fatigue action of waves, and hence require to be adequately assessed from fatigue strength point of view. A stochastic analysis provides an efficient and reliable method for carrying out fatigue assessment of offshore structures as it simulates the prevalent distribution of wave energy over the entire frequency range and incorporates the representative structural dynamics in the analysis.

Acknowledgements We acknowledge the support and resources provided by ONGC required for carrying out this study. The study has been immensely beneficial in understanding the pertinent issues relevant to the structural behavior of jacket structures and is of vital importance in purview of ONGC’s operational requirements to carry out life extension studies of existing platforms. We extend our sincere thanks to Shri C. Tandi, ED-HoI, IEOT-ONGC for his generous support and encouragement. We are also immensely grateful for the continuous motivation received from Shri Dinesh Kumar, GGM–Head of Structures Section, IEOT-ONGC.

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