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Influence Of Soil-Structure Interaction On Fatigue Life Of Offshore Structures

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Abstract:

Offshore jacket structures are extensively used for exploration and exploitation of offshore hydrocarbons since seventies. These bottom fixed lattice structures are subjected to wave loading throughout its lifetime. Tubular joints are prone to high stress level and their fatigue life is decided by this. Offshore structural design codes such as API, DNV etc., have given the procedure for the fatigue life estimation based on the stress level predicted at local level. This procedure has been adopted to predict influence of soil structure interaction on fatigue life of jackets and the results are reported. The scope of numerical investigations extends to the influence of depth of fixity as well.

1.Introduction

A structure located in ocean and has no fixed access to main land is categorised as an offshore structure and it is designed to stay in position in all weather conditions. Offshore structures may be fixed to the seabed or may be floating and support the exploration and production of hydrocarbons. The structural design of the offshore structure is distinct based on the type of structure, rather than its function.

Bottom supported structures such as jacket structures are typically constructed from welded steel tubular members. These members act as a truss supporting the weight of the processing equipment, and the environmental forces from waves, wind and current. Fixed platform jackets need to have adequate buoyancy to stay afloat during installation. Jacket structures are the most common offshore structures used for drilling and production.

Fatigue is an important failure mode of offshore jacket structures since these are subjected to dynamic variable amplitude loading throughout their lifetime. The welded tubular joints of these structures are susceptible to fatigue damage due to high SCF along the tubular intersections. Cracks normally occur at the weld toe at hot spot regions either on the chord or the branch members. The number of stress cycles that may be endured by a joint depends upon the loading mode the magnitude of the nominal stress ranges, the global joint configuration and the weld quality.

1.1.Loads Acting On Offshore Structure

Loads acting on an offshore structure are both static and dynamic type. The static loads on the structure come from gravity loads, deck loads, hydrostatic loads and current loads. The dynamic loads originate from the wind and waves.Forces due to waves hit on an offshore structure can be computed from the wave parameter, structural dimensions and configuration.

1.2.Fatigue Design And Analysis

In the design of tubular connections, due consideration should be given to fatigue. Fatigue design criteria in current codes [API 2007] are based on component failure modes and commonly a linear global model of the structure is considered to determine the load effects in the components.

In the deterministic method, structural responses and hot spot stresses are generated for each of the discrete waves. The summation of fatigue damages due to these discrete wave load cases are then summed up to obtain the total damage during the life of the structure.

In the spectral method the sea state energy spectra are employed used to generate the transfer function for the structural response and this function is used to estimate the hot spot stresses in the joints.

1.3.Fatigue Life Estimation Procedure For Offshore Structure

The sequence for fatigue analysis has been available elsewhere [Chakrabarti, 2005]and steps are given below:

- Long-term wave climate is the starting point fatigue analysis. This is the aggregate of all sea states occurring yearly.
- Global scale space frame or coarse finite element models based on shell elements is performed to obtain structural response in terms of nominal cyclic stresses in the structure at large for each sea state of interest.
- Geometric stress concentrations at all potential hot spot locations within the relevant connections must be considered, since fatigue failure initiates as a local phenomenon.
- Accumulated stress cycles are then counted, and applied against suitable fatigue criteria to complete the analysis of fatigue damage.

Present study involves the fatigue life prediction of offshore jacket structures using finite element analysis. It has been envisaged to carry the global analysis of the structure and to find out the critical joint bending moment. Local analysis of the joint has been proposed to find out hot spot stress and subsequently the fatigue life. Soil structure interaction effects at various fixity levels are also investigated.

2. Literature Review

Experimental Investigations on offshore tubular structure have been reported in the literature. Major outcome of such investigation pertain to hotspot stress[Wordsworth 1981], critical joints [Booth 1981], constant amplitude wave loading [Booth and Holmes 1981]. Analytical investigations are mainly based on the finite element analysis. Such investigations reflect the influence of welding induced residual stress at the joint [Sarkaniet al 2000]. Fatigue life prediction based on spectral analysis has been reported by Moazenet al [2002].

3.Global Analysis Of Jacket Structure

3.1.Modelling

Preliminary dimension of a jacket structure for water depth 80m and significant wave height 30m have been arrived at based on API code provision and shown in Fig 1. Wave loads in the structure have been carried out using a MATLAB code developed for this purpose which is available elsewhere [Prashob, 2012]. Airy's first order theory has been used for this structural analysis and has been performed using ANSYS. The tubulars are modelled using BEAM188 and the soil by Combin14 element. A typical finite element modelhas been shown in Fig 2. Static and modal analysis has been carried out.

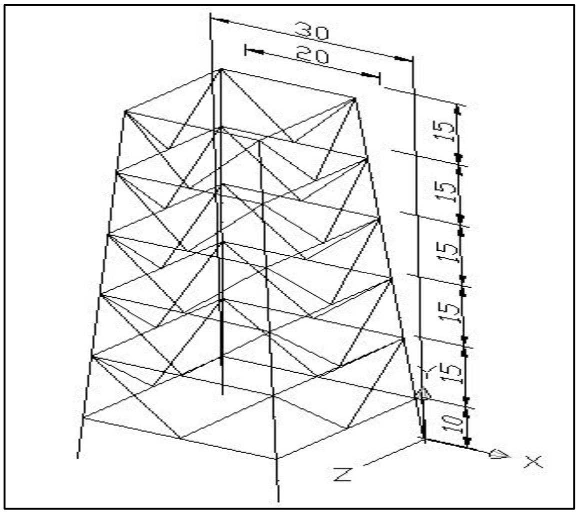

Figure 1: Dimension of Jacket Structure

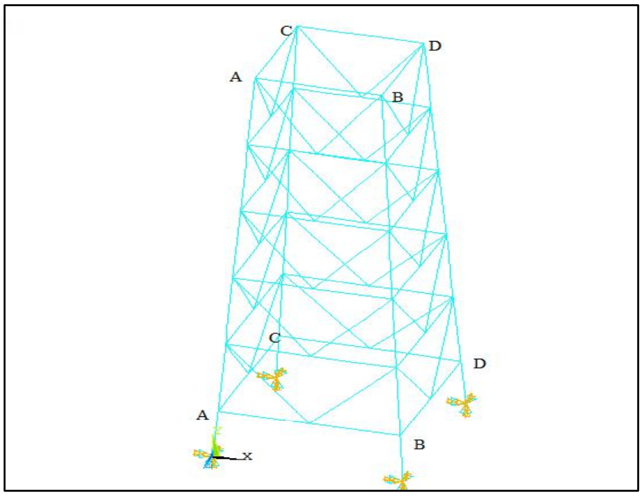

Figure 2: Finite element model of Jacket structure

3.2 .Soil-Structure Interaction

Soil structure interaction analysis incorporates the load deflectionbehaviour of surrounding foundation soil on the structural deflections and stresses. It is necessary to develop soil-pile interface elements and springs to model soil behaviour. It has been generally recognized that the interaction between soil and the structure can indeed affect the response of structures, especially for those structures founded on relatively flexible soil. Therefore, the inclusion of the soil-structure interaction (SSI) effects is particularly important for the offshore jacket structures founded in soft clays. The horizontal stiffness of the soil is calculated as

$$K_h = \frac{8ER}{2-\upsilon}$$

Where, E is the Young's modulus, υ the Poisson's ratio and R the radius of pile

3.3. Analysis Of Jacket Structure

Linear elastic analysis is carried out for the following boundary conditions.

- Fixed at the seabed where all nodes are free except at the attachment of structure at soil.
- Fixed at characteristic depth (CD) where the influence of characteristic depth of the structure is considered by extending the foundation to depth six times the diameter of piles.
- Fixed at foundation depth (FD) where Pile length is taken as 30 m.

- Fixed at characteristic depth with SSI where the springs are attached at a gap of 1m *i.e.* one end of the spring is attached to the characteristic length and the other end is constrained.
- Fixed at foundation depth with SSI where the spring element is attached along the foundation depth of the structure.

The relevant bending moment evaluated from the global analysis necessary for the local analysis for the above mentioned boundary conditions are shown in Table 1 and the corresponding deflections is shown in Table 2.

End condition	**Maximum bending moment**	
	Without SSI	**With SSI**
Fixed at seabed	317110N-m	NA
Fixed at characteristic depth	616810 N-m	343980N-m
Fixed at foundation depth	1294100N-m	332300N-m

Table 1: Maximum bending moment in the jacket structure

End condition	**Maximum deflection**	
	Without SSI	**With SSI**
Fixed at seabed	0.1818 m	NA
Fixed at characteristic depth	0.4460 m	0.2421 m
Fixed at foundation depth	2.5097 m	0.2952 m

Table 2: Maximum deflection in the jacket structure

End condition	Maximum stresses	
	Without SSI	With SSI
Fixed at seabed	1.0500×10^8 N/m^2	NA
Fixed at characteristic depth	1.1116×10^8 N/m^2	1.0517×10^8 N/m^2
Fixed at foundation depth	1.3229×10^8 N/m^2	1.0493×10^8 N/m^2

Table 3: Maximum stresses in the jacket structure

4. Local Analysis Of Tubular Joint

The calculated maximum bending moments occurring at the nodes in particular joints of the jacket due to wave is taken for local analysis. Local analysis is done to generate the maximum stress in the joints. K-joint from the jacket structure fixed at different end conditions is analysed by applying the corresponding bending moments from the global analysis and equally distributed among the nodes at the brace ends and the degrees of freedom at the chord ends is fixed. The K-joint is modelled using Shell93 elements. Finite element mesh of the K-Joint is shown in Fig 3.

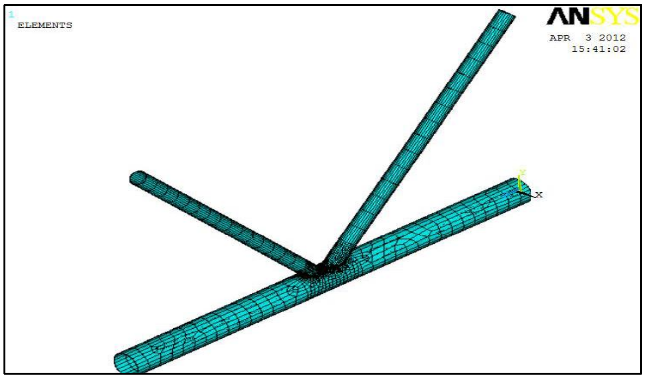

Figure 3: Fine mesh at intersection of K-joint

End condition	**Maximum stress N/m^2**	**Minimum stress N/m^2**	**Stress range MPa**	**von-Mises stress N/m^2**
Fixed at seabed	1.98×10^7	-1.13×10^5	19.71	2.66×10^7
Fixed at characteristic depth	3.86×10^7	-2.19×10^5	38.33	5.17×10^7
Fixed at foundation depth	8.09×10^7	-4.59×10^5	80.43	10.90×10^7
Fixed at characteristic depth with SSI	2.15×10^7	-1.22×10^5	21.37	2.88×10^7
Fixed at foundation depth with SSI	2.08×10^7	-1.18×10^5	20.65	2.79×10^7

Table 4: Stresses in the K-joint

4.1.Fatigue Life Estimation

The fatigue life assessment of a tubular joint is performed on a hot spot stress basis, using S-N curves. The procedure given in charts [ABS 2010] has been followed.

The ABS S-N Curves for tubular intersection joints are denoted as follows

- ABS - T(A) for the “In-Air” condition
- ABS - T(CP) for the “Cathodic Protection” condition
- ABS - T(FC) for the “Free Corrosion” condition

Here the S-N curve for the tubular joints in seawater with cathodic protection is taken and shown in fig.

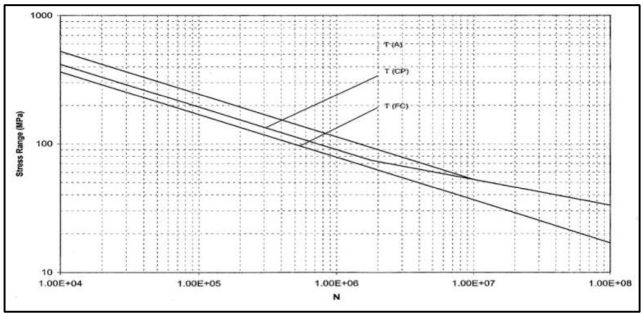

Figure 4: ABS Offshore S-N Curves for Tubular Joints[ABS guide for the fatigue assessment of offshore structures November 2010]

4.1.Fatigue Life Calculation

The number of cycles for fatigue is calculated using the above S-N Curve and the following equation.

$N=A\times S^{-m}$

No of expected cycles per day has been calculated = 8.64×10^{3}. Fatigue life of the structure is calculated and shown in table 5.

End condition	Stress range MPa	No of cycles the structure withstands	No of days the structure withstands	Fatigue life in years
Fixed at seabed	19.71	95.33×10^{6}	11033	30
Fixed at characteristic depth	38.33	50×10^{6}	5787	15
Fixed at foundation depth	80.43	1.5×10^{6}	173	6 months
Fixed at characteristic depth with SSI	21.37	74.8×10^{6}	8657	23
Fixed at foundation depth with SSI	20.65	82.9×10^{6}	9594	26

Table 5: Number of cycles for fatigue for the structure

End condition	**No of days the structure withstands**	**Fatigue life in years**
Fixed at seabed	11033	30
Fixed at characteristic depth	5787	15
Fixed at foundation depth	173	6 months
Fixed at characteristic depth with SSI	8657	23
Fixed at foundation depth with SSI	9594	26

Table 6: Fatigue life for the structure

4.3.Results And Discussion

Fatigue life of the structure has been reduced by 50% and 98% when the depth of fixity is considered at characteristic depth and foundation depth respectively. When soil-structure interaction effects are considered fatigue life has been increased by 35% and 98% for fixity at characteristic depth and foundation depth respectively.

5.Conclusion

The effect of fixity and soil structure interaction in fatigue life has been brought out. The necessity to evaluate the fatigue life in association with the design check based on allowable stress and soil structure interaction effects has been identified.

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