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STRESS UTILISATION OF JACKET STRUCTURE UNDER ENVIRONMENTAL LOADING

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ABSTRACT

The level of stress utilisation within structural elements due to external and transferred loads between structural members may be estimated. This may routinely be performed at early design stages where all loading parameters and assumptions are predicted to act on the structure that results the response under normal operating condition. The paper addresses loading parameters, discuss analysis steps that have been applied to the structure and illustrate subsequent results of the stress utilisation within the structure due to the response to external and transferred load acting on the structure. Particular application includes the studies on typical shallows or medium water depth jacket structures under normal and extreme loading conditions.

1.0 INTRODUCTION

All structures that are designed have a certain level of strength usage during operation. The remaining (reserve) strength within the structure indicates the level of safety inherits by that structure. It is important to structural engineer to know this reserve strength level so that one can estimate necessary allowances includes at design stages to fit the specific purpose of the structure.

In this paper, strength usage is presented as a stress utilisation within the structure as referred to API codes. The analysis procedure carried is discussed and results of structural response are presented as base shear and overturning moment for whole structure and stress utlisation for selected elements. The study focused on two main loading cases, i.e., base case and extreme loading conditions.

2.0 STRUCTURAL MODEL

Typical four legged jacket structure (refer Fig. 1) installed in medium water depth was used in this study. It measures 17.3 m x 17.3 m at the base and 9.4 m x 9.4 m at elevation (+)5.65 m extended up to elevation (+)15.8 m. Jacket legs are battered to provide larger base for the structure at the mudline and thus assist in resisting higher environmentally induced overturning moments. The structure is supported by a single pile at each leg and propped a single conductor pipe having diameter of 0.76 m. The deck fixed on top of this framed tubular having a size of 10 m x 10 m with a total weight of 500 tonnes. Finite element program was employed to model this structure and perform associated analyses.

Tubular members that formed the structure are made of a uniaxial element with tension compression, torsion and bending capabilities. Structural members are capable to be used in simulating ocean waves and current forces as well as load vectors of hydrostatic effects. The element has six degrees of freedom at each node; x, y and z directions and rotations about the nodal x, y and z axes as shown in Fig. 2.

3.0 LOADING MODEL

Throughout its service life one offshore structure will experience several modes of loading. These loads may be classified as the following, namely; dead load, imposed loads, hydrostatic loads, environmental loads, deformation loads and accidental

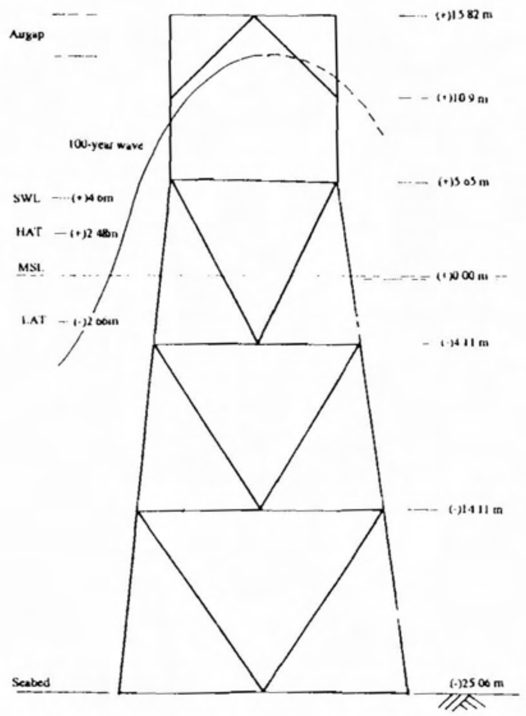


Fig. 1 Jacket Structure.

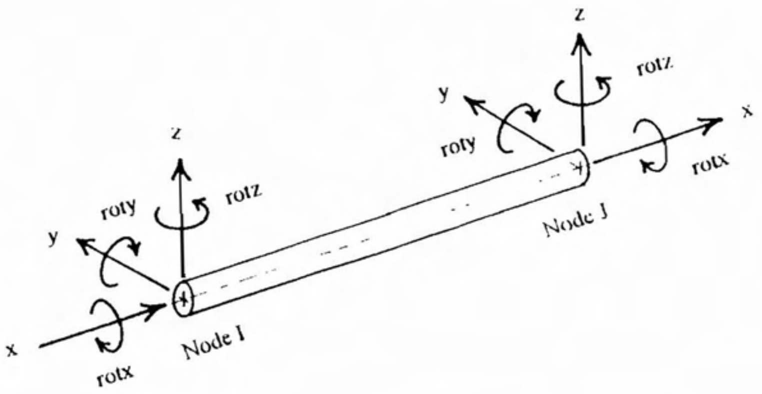


Fig. 2 General Model Of Structural Element

loads. Among the above groups of loading, environmental loads known to contribute the biggest percentage of the total load on any offshore structure. Environmental loads may be contributed by one or a combination of the following elements namely; wind, wave and current as well as snow and ice. Figure 3 graphically shows combination of the above mentioned environmental loading model acting on a structure.

3.1 Wind Loading

Winds exert predominantly steady forces on the exposed parts of offshore structures although there are significant gust components that induce high unsteady local forces on structural components. Wind forces are modelled from the following relationship [1];

$$F_W = \frac{1}{2} \rho C_S A_W V^2 \tag{1}$$

where: ρ is the wind density, C_S is the shape coefficient, A_W is effective are subjected to wind load and V is wind speed.

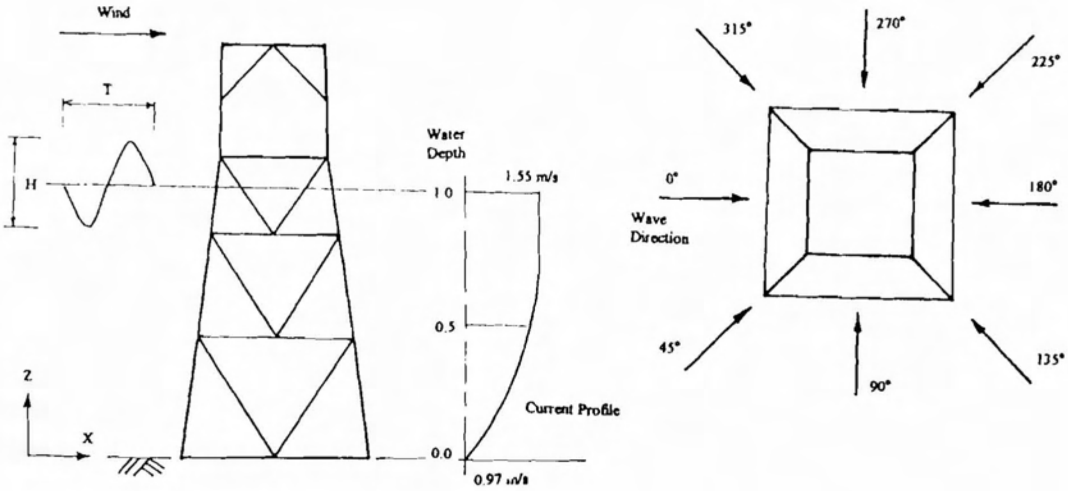


Fig. 3 Wave, Wind and Current Loading On The Structure

Average wind speeds for 50-year return period at 10 m above still water level (SWL) were used for base case loading condition. Wind speed for return periods other than 50-year may be estimated from the following relationship [1];

$$V_N = 0.71\ (1+0.106 \ln N)\ V_{50} \qquad [2]$$

where N is return period.

3.2 Current Loading

Ocean currents also exert largely steady forces on submerged structures although the localised effects of vortex shedding induced unsteady force components on structural members. Simplified vertical profiles of storm surge current may be obtained using the following relationships [1];

$$u_{s(z)} = \bar{u}_s + \left(\frac{z - h'}{10} \right) \qquad for \quad h' \le z \le h \qquad [3]$$

$$u_{s(z)} = \bar{u}_s \qquad for \quad 0 \le z \le h' \qquad [4]$$

where; $u_{s(z)}$ is speed of storm surge current plus wind drift at height z above the sea bed, $\bar{u}_{s(z)}$ is depth-average storm surge current, z is height above sea bed, h is total height between sea bed and SWL and h' is height above the sea bed at which current profile changes slope.

3.3 Wave Loading

The largest force experienced by most offshore structures are contributed by the gravity waves [2]. Detail formulation on wave loading models may be found elsewhere [3]. Wave account for most of structural loading and its type depends on the size (usually diameter) of the structural component as compare with the wave length. In the case of tubular members usually found in jacket structures that are much smaller diameter than the length of the wave which produce significant loading, the pattern is significantly unaffected by the structure present, i.e., the incident flow is virtually uniform in the vicinity of the structure. Generally, wave loads on fixed lattice type offshore structures are estimated based on Morison's equation [4], that combining inertia and drag components of forces, given the total force on the cylindrical member as;

$$F = F_{drag} + F_{inertia}$$

$$F = \frac{1}{2} \rho C_D D u|u| + \rho \frac{\pi}{4} D^2 C_M \dot{u} \qquad [5]$$

where C_D and C_M are drag and inertia coefficient respectively, ρ is density of water, u and u are velocity and acceleration of water particles respectively and D is diameter of structural members.

Relationships of horizontal and vertical water particle velocities (u and v), as well as horizontal and vertical water particle accelerations (u *and* v), are given by [5];

$$u = \frac{\pi H}{T} \frac{\cosh k(y + d)}{\sinh kd} \cos (kx - \omega t) \qquad [6]$$

$$v = \frac{\pi H}{T} \frac{\sinh k(y + d)}{\sinh kd} \sin (kx - \omega t) \qquad [7]$$

$$\dot{u} = \frac{2\pi^2 H}{T^2} \frac{\cosh k(y + d)}{\sinh kd} \sin (kx - \omega t) \qquad [8]$$

$$\dot{v} = - \frac{2\pi^2 H}{T^2} \frac{\sinh k(y + d)}{\sinh kd} \cos (kx - \omega t) \qquad [9]$$

where H is wave height, T is wave period, k is wave number, y is distance from SWL, d is water depth, and ω is wave frequency.

The above equations are representing linear wave or Airy wave theory. In practice, guide in selecting wave theory may be referred to its validity according to local environmental parameters, i.e., wave height, wave period as well as water depth [8, 9].

3.4 Effects of Marine Growth

Another source that influenced the magnitude of loading on structures is marine growth that attached to immersed structural members. It can significantly affect the performance of offshore structures. For example a 50-mm thickness of marine growth can increase the overall loading by 5.64 percent [6]. They comprise of large variety of organisms contributed to the fouling of the structure. They range from microscopic slimes to very large flapping weeds and also include a variety of animal species and can generally be grouped into soft and hard fouling [7]. Significant fouling may be expected at any site within two years of installation and some cleaning usually required after about four years.

4.0 RESPONSE ANALYSIS

Studies of structural responses to environmental loading are performed with two distinct cases namely; (1) base case and (2) extreme loading case. In base case analysis, the environmental parameters are referred to magnitude of 50-year return period while the extreme case refers to environmental parameters having 100-year return period. External loading onto the structure will results in the response of the structure that could be expressed in the form of stress utilisation.

Stress utilisation within the structure under combination of axial tension and compression as well as axial tension and bending are estimated using the following relationship [10];

$$\frac{f_a}{0.6F_y} + \frac{f_b}{F_b} \leq 1.0 \qquad [10]$$

where f_a is allowable stress (tension or compression), f_b is bending stress, F_y is yield stress and F_b allowable bending stress.

The degree of structural response to the action of environmental loading parameters is represented by the level of stress utilised within its structural members.

This is a ratio of the loading induced stress to the maximum permissible stress within the structure.

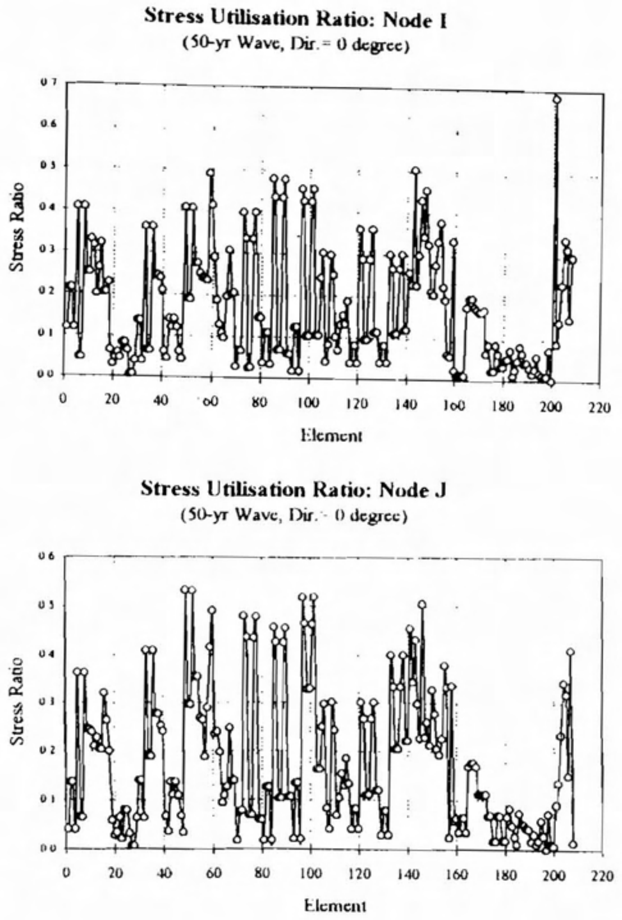
This is the basis to the selection of critical element within the structure that may require further analysis or redesign. Selected critical elements also representing location and orientation of members within the structure.

5.0 RESULTS AND DISCUSSION

Generally there are two types of loads acting on any element and joint within the structure. They are direct external load and transferred (indirect) load from other elements. In this study, responses in term of stress utilisation within the structure due to environmental loading parameters are examined.

Directionally, offshore structure encountered different magnitude of environmental parameters that passed through it. For example, there are variations in wave height, wave period, wave length, wind speed, current velocities as referred to each incident angle examined. It was found that for the particular location in this study, the maximum magnitude of environmental loading will come from northern direction, i.e., $\phi = 0$ degree as given in Fig. 3.

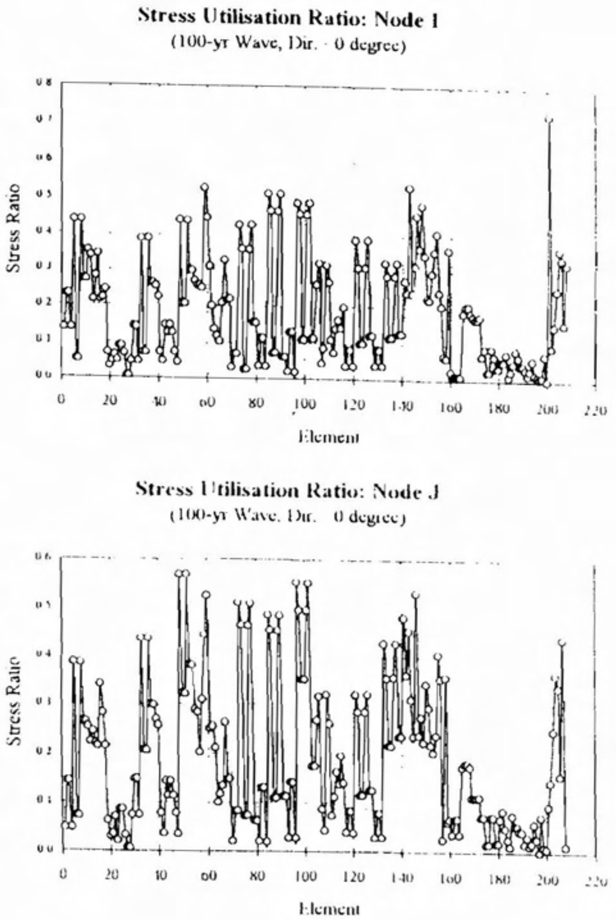
Figures 4 and 5 shows overall stress utilisation of the structure for base case and extreme case respectively due to loading from direction of $\phi = 0$ degree. From this information, elements within the structure having high values of stress utilisation representing location, orientations were selected. These elements presented in Table 1.



Stress Utilisation Ratio: Node I
(50-yr Wave, Dir. = 0 degree)

Stress Utilisation Ratio: Node J
(50-yr Wave, Dir. = 0 degree)

Fig. 4 Stress Utilisation Ratio For Nodes I & J
(Base Case Condition, 50-yr Return Period, $\phi = 0^{o}$)


Stress Utilisation Ratio: Node I
(100-yr Wave, Dir. 0 degree)

Stress Utilisation Ratio: Node J
(100-yr Wave, Dir. 0 degree)

Fig. 5 Stress Utilisation Ratio For Nodes I & J

(Extreme Condition, 100-yr Return Period, $\phi = 0^{o}$)

Table 1 Selected Structural Elements For Detail Analysis

Element Orientation	Element No.	Nodes	Length (m)
Horizontal	60	24, 25	7.30
	109	35, 36	6.15
Inclined	49	122, 21	1.1554
	102	89, 37	5.8097
Vertical	4	7, 150	7.1025
	95	87, 35	5.0002

Figure 6 shows the magnitude of base shear and overturning moment experienced by the structure under extreme design conditions for all incident angles. Maximum base shear and overturning moment are 3.9 MN and 73 MNm respectively. These values actually indicate an increase of 7.3 percent in base shear and 7.4 percent in overturning moment of the structure as compared to values obtained when the structure under environmental loading having 50-year return period.

Stress utilisation experienced by each selected element are presented in Figure 7 under similar loading condition. Generally the increments in stress utilisation ratio are between 5 to 10 percent of the base case ratio. Further analysis on these elements may be performed to determine their reliability (hence the safety factor) with respect to various loading cases. It was understood that if the structure would fail, the most likely elements might experience that are from the one listed in Table 1.

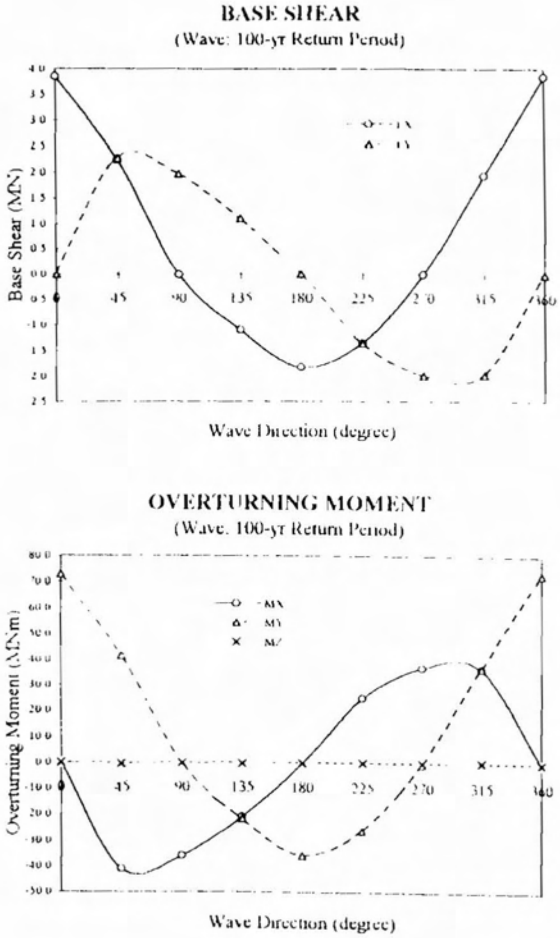


Fig. 6 Base Shear And Overturning Moment For Extreme Design Case

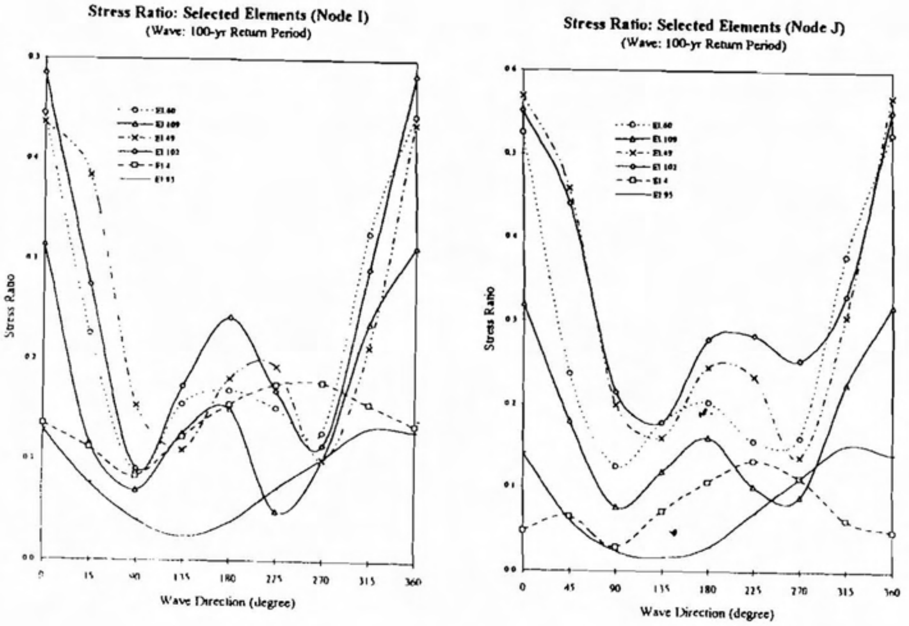


Fig. 7 Stress Utilisation Ratio For Selected Elements Under Extreme Loading Conditions

6.0 CONCLUDING REMARKS

Two distinct loading models were employed namely; base case loading conditions (based on 50-year return period) and extreme case loading conditions (based on 100-year return period).

Selection of elements to represent the structure in the study is made based on their stress utilisation ratio as well as their locations and orientations. Maximum magnitudes of base shear and overturning moment experienced by the structure are found to be 3.9MN and 73 MNm respectively.

The level of safety in all structural element is high as shown by relatively low stress utilisation ratio in all structural elements for all wave incident directions. In other word the reserved strength within the structure is still high. The maximum values of structural response are due to wave, current and wind coming from the North (i.e., $\phi = 0^{o}$).

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