

## **ANALYSIS OF OFFSHORE JACKET PLATFORM**

**Harish N<sup>1</sup>, Sukomal Mandal<sup>2</sup>, Shanthala B<sup>3</sup>, Subba Rao<sup>4</sup>**

**1- PG student, 2- Dy Director, NIO, Goa, 3 – Research scholar, 4- Professor**

**National Institute of Technology Karnataka Surathkal-575025**

**Email: harish.nitk@rediffmail.com**

### **ABSTRACT**

The estimation of response parameters plays an important role in the design of offshore structure. The periodic inspection and monitoring of offshore platforms for certification needs the study of the responses of structures owing to wave and wind forces. The complex dynamic behavior of the platform to the environmental loads makes it difficult to calculate exactly the dynamic responses. The present need of the industry is to have a time saving and accurate calculation methods, which can be in good agreement with the actual response parameters.

Pierson-Moskowitz (P-M) spectrum is used for the calculating wave height and wave period for different wind speed. For a wind speed of 41.67 m/s, a significant wave height 14.86 m and wave period 21.66 sec is considered for the present investigation. The responses of the structure to the varying wave and wind forces at different water depth are analyzed using well defined dynamic analysis method. The industry standard StruCAD software package developed specially for offshore structural analysis is used to obtain platform displacement response under varying external loadings. In the present analysis, dynamic behavior of the structure and deflection of the platform is studied for individual and combined wind and wave forces.

### **INTRODUCTION**

Offshore oil reserves are explored and exploited using offshore structures. Hence the main driving force behind this technology of installation of offshore platform has come from oil industry and need for exploration of the extensive hydrocarbons reserve existing in the offshore regions. Its use is however not limited solely to the industry, but an important application exists for military and navigational purpose also. The total number of offshore platform in various bays, gulf and oceans of the world is increasing year by year, most of which are of fixed type.

There are more than 9000 offshore oil and gas installations around the world, these offshore installations are used for drilling, preparing water or gas for injection into the reservoir for processing oil and gas, cleaning the produced water for disposal into the sea and accommodating the staff. Recently, many researchers have worked on the control of large civil structures [Abdel-Rohman, 1996; Leipholz and Abdel-Rohman, 1986; Terro et al, 1999; Yamamoto et al, 1991; Gobrnick and Legge, 1996; Kawano, 1993]. This is the case because these structures are dynamically vulnerable to seismic excitations and excessive random shocks. In the case of offshore structures exposed to wave forces, several researchers have developed and implemented passive and/or active control systems to ensure the safety of the structures.

Modern offshore platforms have evolved into flexible constructions with water depths exceeding 300 m (1000 feet) and sophisticated superstructures [Abdel-Rohman, 1996]. Self-excited nonlinear hydrodynamic forces are induced due to the flexibility of such structures, and their large deformations cause a highly nonlinear response [Chakrabati, 1987]. Possible solutions to ensure safety include increasing the stiffness of

the structure [Rajagopalan, 1993], thus moving the natural frequencies away from resonance. This is usually performed by increasing the cross-sectional area of individual elements and/or adding bracing members to the structure. However, the huge costs inflicted by the latter passive approach render active control methods a more attractive alternative [Leipholz and Abdel-Rohman, 1986].

Chakrabati (2005) describes a historical development of offshore structures, some studies on loads, responses and design of fixed offshore platforms.

The wave force on slender tubular member is described as the summation of orbital velocity- dependent drag force and orbital acceleration-dependent inertial force. Though this methodology, originally proposed for a vertical circular cylinder resting on the sea bed and piercing the sea surface by Morison *et al.* (1950), is widely used for the calculation of wave forces on tubular members, uncertainty still prevails in assigning the values for the hydrodynamic coefficients of drag,  $C_D$ , and inertia  $C_M$ .

The present paper deals with the dynamic behavior of the jacket platform and analysis the deflection characteristics of the structure.

## LOADS ON THE STRUCTURE

For the present analysis loads considered are

- a) Dead and Live load
- b) Wind force
- c) Wave force

### Dead and live load

Dead loads include all fixed items in the platform deck, jacket, flare and bridge structures. Live loads are defined as movable loads and will be temporary in nature. Total load considered for the analysis is 20,000 tonnes.

### Wind force

American Petroleum Institute (API RP 2A) recommends the following formula to calculate wind force on offshore structures,

$$F = 0.5 \rho C_s A U^2 \quad (1)$$

Where,

F = Wind force in KN,

U = sustained wind velocity in m/Sec

$C_s$  = Shape coefficient,

A = Projected area of object,  $m^2$

For the present analysis wind force considered is 41.67 m/Sec.

### Calculation of wave height and wave period

The first systematic and reliable way of establishing an ocean wave spectrum is carried out by Pierson and Moskowitz [Pierson and Moskowitz 1964] and is widely accepted for the waves of fully developed sea. The Pierson-Moskowitz spectrum is defined as:

$$S(\omega) = \left( \frac{A}{\omega^5} \right) * e^{\left( \frac{-B}{\omega^4} \right)} \quad (2)$$

Where,  $A = 0.0082g^2$ ,  $B = 0.74 \left( \frac{g}{u} \right)^4$ ,  $\omega = 2\pi f$

$u$  = wind speed in m/s,  $g$  = gravitational acceleration in  $m/s^2$ ,  $f$  = frequency in Hz

The statistical parameters were evaluated using the spectral moments as follows:

$$\text{Significant wave height } H_s = 4 \sqrt{m_0}$$

$$\text{Zero crossing wave period, } T_z = \sqrt{\frac{m_0}{m_2}}$$

Where,  $m_n = \int_0^\infty f^n S(f) df$

From P-M spectrum for a wind speed of 41.67 m/sec the estimated significant wave height, 14.86 m and wave period, 21.66 sec are considered for the analysis.

### Wave force

The determination of the forces exerted by waves on structure is very complex task. Waves can be represented analytically using different theories. There are three basic forms of waves: (1) sinusoidal waves, (2) cnoidal waves, (3) solitary waves. To calculate wave forces, one must first select a proper wave theory to compute the water particle velocities and acceleration. Generally sinusoidal wave theory is suitable for deep water waves. In the present study simple sinusoidal wave theory (Airy wave theory) is used. The ratio of horizontal dimension (D) to wave length (L) is smaller than 0.05 hence we can calculate the wave load using Morrison's Formula.

Wave load per unit length is

$$F = 0.5 \rho C_D D |u| u + \rho C_M \frac{\pi D^2}{4} \frac{du}{dt} \quad (3)$$

Where,

$C_M$  and  $C_D$  are the hydrodynamic inertia and drag coefficients,

$\rho$  = Water density,  $D$  = Pile diameter,  $u$  = Water velocity

$\frac{du}{dt}$  = water acceleration

The expression for the horizontal components of the velocity and acceleration of water are:

$$u = \frac{\pi H}{T} \frac{\cosh k(Z+d)}{\sinh kd} \cos(kx - \sigma t) \quad (4)$$

$$\frac{du}{dt} = -2 \frac{\pi^2}{T^2} H \frac{\cosh k(Z+d)}{\sinh kd} \sin(kx - \sigma t) \quad (5)$$

Where,  $x=0$ ;  $\sigma t = \theta$

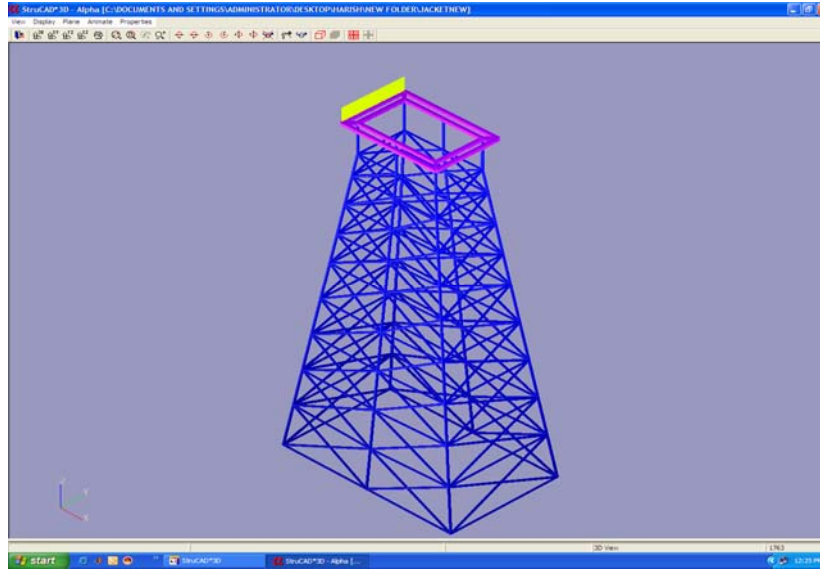
$d$  = depth of water;  $H$  = wave height;  $T$  = wave period;

$Z$  = distance of particle from free surface.

### STRUCTURAL MODEL

In the present study a fixed platform made up of steel structure is used for analysis. Total height of the structure is 220 m. Bottom dimension is 110 m X 70 m and at 200 m height dimension is 50 m X 30 m. At the top of the deck the dimension is 60 m X 40 m. All vertical legs are 1.5 m in diameter and the wall thickness is 0.2 m. The diagonal bracings are 1.25 m diameter and the wall thickness is 0.15 m and horizontal

bracings are 1.1m diameter and 0.05 m wall thickness. The computer 3D model of the structure is shown in Fig 1. As per requirement of inputs to StruCAD, the structural members and nodes are defined. A total of 74 nodes and 248 structural members are considered for the proposed Jacket structure.



**Fig.1. Computer 3-D Model of the Jacket Structure**

### Dynamic response analysis using StruCAD

The basic dynamic equation for forced vibration is given by

$$m\ddot{x} + c\dot{x} + kx = F(t) \quad (6)$$

Where,

m is the mass matrix (lumped or consistent),

c is a viscous damping matrix (which is normally selected to approximate energy dissipation in the real structure),

k is the stiffness matrix for the system of structural elements,

$x$ ,  $\dot{x}$  and  $\ddot{x}$  are the absolute node displacements, velocities and accelerations, respectively.

F(t) is external loading.

In Strucad, the structure is subjected to a single repeatable wave and steady state response is calculated using Fourier series. The basic assumption behind this approach is that the same repeatable wave is stained long enough to establish a steady state response. The theoretical approach is as follows: (StruCAD\*3D, Zentech Inc. Huston)

A full cycle of wave is applied to the structure. The hydrodynamic forces are calculated using Morison's equation, and saved for each time step and each member. This distributed member forces are then calculated to equivalent joints loads using static equilibrium.

For each wave time step, the joint load vector created above is multiplied by the mode shape deflections to calculate the generalized forces for each mode.

Working with a mode at a time, and considering the fact that the generalized forces calculated for different time steps represent a periodic function, a Fourier transformation can be applied to generate a series of sinusoidal forcing functions with

different frequencies and amplitude, which would represent the same periodic function if they are superimposed at any time during the wave period.

Considering the fact that each structural mode represents a single degree of freedom system with appropriate stiffness, mass, and damping properties, the static state response of each mode due to any of the sinusoidal Fourier components can be easily calculated. The total response of each can be obtained by linear superposition of response due to each Fourier component.

The response calculated above for each individual mode can be linearly summed to derive the overall response of the structure.

After completion of the process, the StruCAD\*3D program will report the time history of the mud line forces and the moment for both modal static and the modal dynamic cases. The comparison between the results of these two reports can be used to estimate the dynamic amplification.

## **RESULT AND DISCUSSION**

The dynamic analysis of the Jacket platform is carried out for 200 m water depth with different loading conditions. The physical description of the selected jacket offshore platform is shown in Fig 1. The deck weight is assumed to be 20,000 tonnes and is equally distributed on the top of the deck.

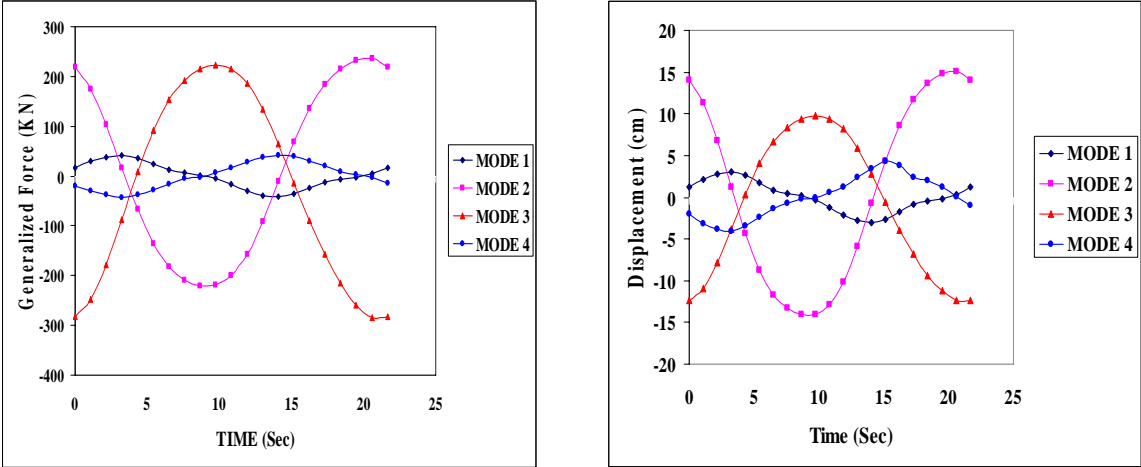
In this study dynamic behavior of the platform and deflection of jacket platform at water level are considered. To start from the scratch, tower at water depth of 200 m is analyzed for individual load cases. The deck displacements to the individual load cases and combined load cases are studied.

### **Wave Response Analysis of the Structure**

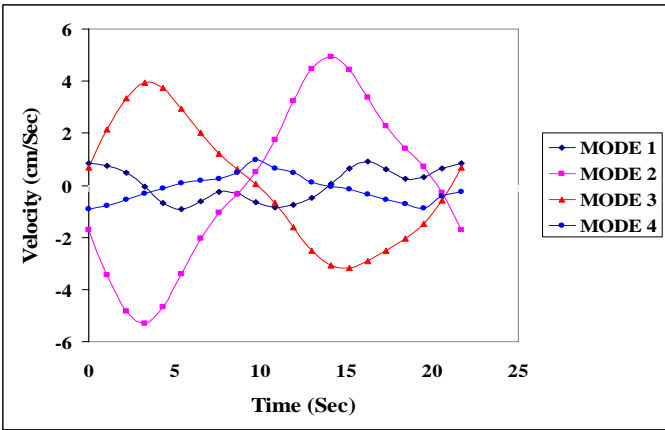
The dynamic analysis of Jacket platform is carried out for the wave and wind forces derived from P-M spectrum. To illustrate the dynamic behavior of the structure a particular wave response analysis result is described below.

Structure at 200 m water depth is subjected to a wave height 14.86 m with wave period of 21.66 Sec. To illustrate the dynamic response of the platform to wave loading, the time history plots of the generalized forces and generalized displacements for the first four modes are given in Fig.2. The first and the fourth mode and the second and third modes are found to be similar magnitude but in opposite direction. From Fig 2 we observe that the maximum force of 236.08 kN and maximum displacement of 15.14 cm has occurred in mode shape number 2 at time 20.577 sec. Also from Fig 2 we notice that the structure exhibits the sinusoidal behavior. The time histories of the generalized velocity are shown in Fig 3. For Mode-II case, time history of estimated generalized force, velocity and displacement are shown in Fig-4. It is observed that the generalized forces and generalized displacements have similar variation.

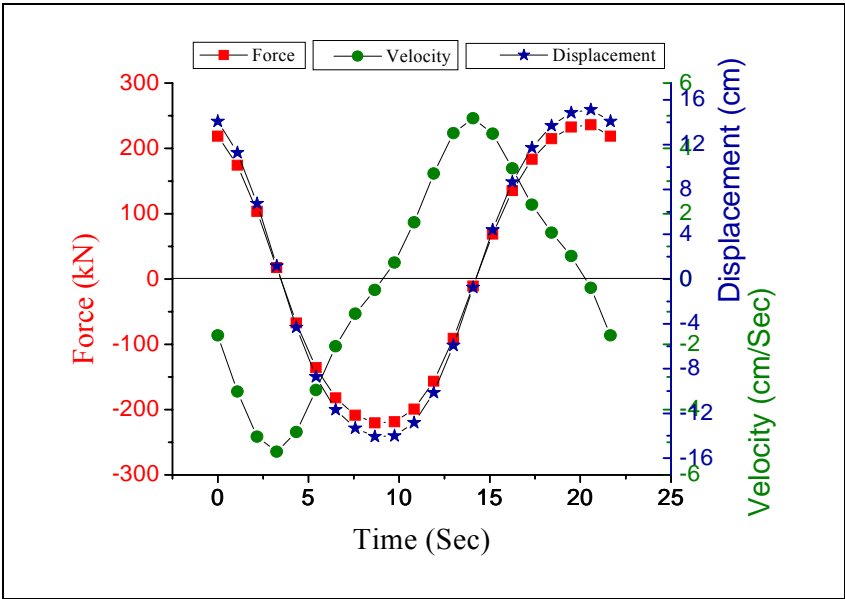
The above results of the dynamic analysis are carried out in order to understand the response nature of platform to the wave forces.



**Fig.2. Time History of Generalized Force and Generalized Displacement at Different Mode**



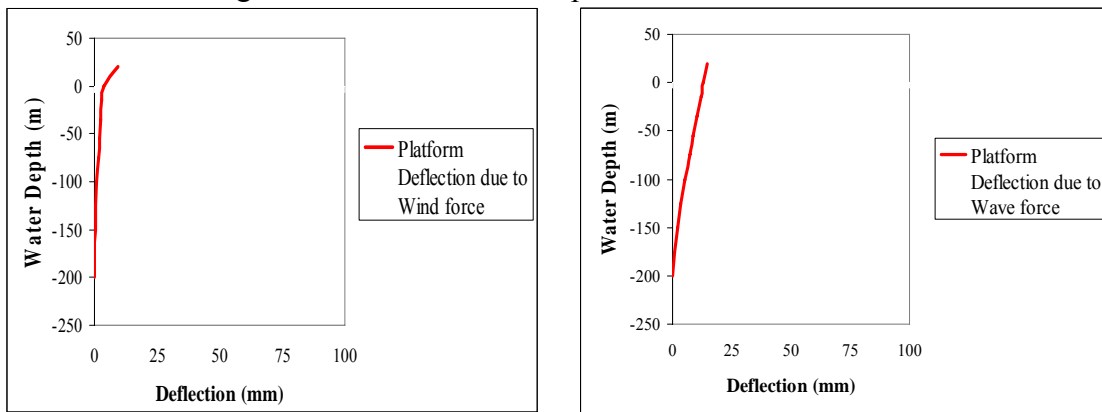
**Fig.3 .Time History of Generalized Velocity**



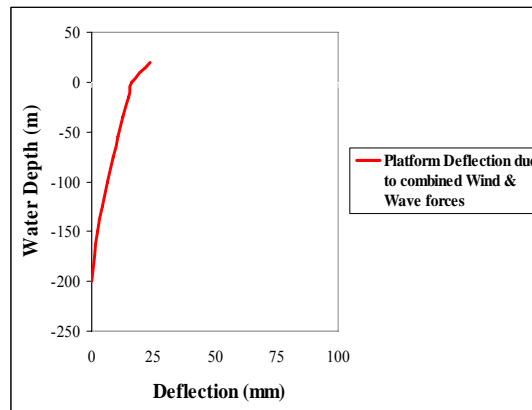
**Fig.4. Time history of generalized force, velocity and displacement**

### Displacement of the Structure

Even though time series deflection of the platform were estimated using StruCAD, only maximum deflection to each wave and wind forces are extracted. The StruCAD analysis was conducted for a 200 m water depth to get wave response parameter for the maximum wind and wave forces that are taken from the P-M spectrum. The deflection responses to the wind and wave force are shown in Fig 5. It should be noted that the response considered are deflection in global Y-direction. The estimated deflection due to combined wind and wave forces are shown in Fig 6. As mentioned earlier deflection response in the global Y-direction extracted from the analysis result. From Figs. 5 and 6 we observe that the platform deflections are proportional to the wind and wave loadings. The maximum platform deflection is 2.39cm at the top side of the deck for a wave height of 14.86 m and wind speed of 41.67 m/Sec.



**Fig.5. Jacket Platform deflection for individual Wind & Wave Forces**



**Fig. 6. Jacket Platform deflection for combined Wind and Wave Force**

### CONCLUSIONS

In the present analysis, deflection of the platform is studied for individual and combined wind and wave forces. It is done for the maximum wind and wave forces only on the positive Y direction. It is noted that the maximum deflection is 2.39 cm due to combined wind and wave forces. Dynamic analysis of the structure is studied to know the dynamic behavior of the structure. From the dynamic analysis we noted that the maximum displacement occurred in mode shape number 2.

## REFERENCES

1. Abdel-Rohman, M., 'Structural control of a steel jacket platform', *Structural and Engineering Mechanics* 4(2), 1996, 125–138.
2. Chakrabarti, S K., *Hydrodynamics of Offshore Structures*, Springer, Berlin, 1987.
3. Chakrabarti, S K., *Handbook of Offshore Engineering*, Elsevier, Oxford, UK, 2005.
4. Gobrick, R. and Legge, N., 'Hibernia: The next generation of offshore platform control systems', *IEEE Industry Applications Magazine* 2(3), 1996, 6–14.
5. Kawano, K., 'Active control effects on dynamic response of offshore structure', in *Proceedings of 3rd ISOPE*, Singapore, 1993, pp. 498–504.
6. Leipholz, H. H. and Abdel-Rohman, M., *Control of Structures*, Martinus Nijhoff Publishers, Dordrecht, The Netherlands, 1986.
7. Morrison, J.R., O'Brien, M.P, Johnson, J.W., Schaaf, S.A. The Force Exerted by Surface Waves on Piles. *Petroleum Transaction*. Vol. (189), 1950, 149-157.
8. Pierson, W.J, and Moskowitz, L. A proposed spectrum forms for fully developed wind sea based on the similarity theory of S.A Kitaigorodskii, *journal of geophysical research*, 1964, 69, 5181-5190
9. Rajagopalan, K., 'Reliability of offshore jackets using point estimation', in *Proceedings of the 3rd ISOPE*, Singapore, 1993, pp. 606–612.
10. Terro, M. J., Mahmoud, M. S., and Abdel-Rohman, M., 'Multi-loop feedback control of offshore steel jacket platforms', *Computers & Structures* 70, 1999, 185–202.
11. Yamamoto, I., Terada, Y., and Yokokura, K., 'An application of a position keeping control system to floating offshore platform', in *Proceedings of the International Conference on Industrial Electronics, Control and Instrumentation, IECON'91*, Kobe, Japan, 1991, pp. 1867–1872.
12. StruCAD\*3D, Zentech Inc. Huston, USA