Dynamic Response of Offshore Structures – An Overview

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Abstract- **Offshore Construction is the installation of the structures and facilities on a marine environment, usually for the production and transmission of electricity, oil, gas and other resources. Offshore structures are being challenged to counteract the depletion of oil resources with the new set of discoveries. By 2010, the increase in drilling platforms induced the demand for offshore structures in deep sea. Hence, the quest on the research and development of the deep-water structures has resulted in the recent advancement and thrust in this area. In the design of buildings onshore, it is influenced mainly by the permanent and operating loads, whereas the design of offshore structures is dominated by environmental loads, especially waves and winds, and the loads arising in the various stages of construction and installation. In this paper, the focus is on wind load, introduction to wind load, its effect on offshore structures, analysis procedure and the design considerations of wind load for offshore structures. A case study of Hurricane Andrew has also been studied.**

Keywords **– Codal provisions, Dynamic effects, Hurricanes, Wind action, Wind Speed**

I. INTRODUCTION

One of the greatest discoveries of 20th century was oil and it has so many applications that it cannot be separated from mankind. The oil exploration has started as early as 1900 and the oil exploration initially was concentrated on land. As the need for oil expands in an explosive rate, need for and new discoveries was eminent. During the middle of 20th century, oil discovery started in near shore and medium range of water depth. The need for qualified offshore structural personnel are rapidly increasing as the oil industry moves into deeper water in the search for additional supplies of oil and gas, new technology is emerging at a rapid peace for the development of new concepts for offshore platforms. Various environmental loads act on offshore structures like wind, wave, current, tides, snow, ice, earthquake etc. The environmental loads affect the safety of the structure and hence, there is a requirement of analysis and consideration in design. The effects of wind loads, the analysis of offshore structures for wind loads and the design considerations have been given [8].

A. Load Considerations

The following loads and any dynamic effects resulting from them should be considered in the development of the design loading conditions:

i. Dead Loads
ii. Live Loads
iii. Environmental Loads
iv. Construction Loads
v. Removal and Reinstallation Loads
vi. Dynamic Loads

B. Design Methods

Design of offshore structures includes three methods namely:

i. Working Stress Design Method (WSD)
ii. Limit State Method or Load and Resistance Factor Design (LRFD)
iii. Plastic Design Method

II. METHODOLOGY

A. Wind- Introduction

With the increase in demand for oil and gas, a large number of offshore structures have been constructed through out the world. Offshore structures are designed for random wind and wave loads. At the global level the lateral wind load in the design of fixed offshore structures is of the order 10% of the total lateral loads and 25% in the case of compliant and floating platforms. Practical estimation of design dynamic wind loads for complex shaped deck structures is an involved exercise. However, the effects of extreme wind load, which constitutes one of the primary loads on local components such as flare-outs, silos, cranes, helipad structures, ladders etc. are significantly more than that of normal wind [2].

B. Characteristics

1) Wind Spectrum: The wind effect on an offshore structure becomes important when the superstructure (portion above the MWL) is significant. The wind generally has two effects - one from the mean speed and the other from the fluctuation about this mean value. The mean speed is generally treated as a steady load on the offshore structure. For a fixed structure, it is only the mean speed that is taken into account. In case of floating structures, the dynamic wind effect may be significant and may not be ignored.

2) Wind Speed: The accepted steady wind speeds in a design of an offshore structure are generally taken as the average speed occurring for a period of 1-h duration.

3) Sustained Wind Speed: The greatest one (1) minute mean wind speed, expected to occur over a return period of 100 years and related to a reference level of 10 m above sea level, is generally referred to as the sustained wind speed, u_S. This sustained wind speed is to be used for the determination of global loads.

4) Gust Wind Speed: The greatest three (3) second mean wind speed, expected to occur over a return period of 100 years, is referred to as the gust wind speed, U_G. This gust wind speed is to be used for the determination of local loads [8].

C. Effect of Wind Action

Dynamic wind effects during cyclones/ hurricanes:

i. Wind load contribution is 10% of total lateral loads in jackets and about 25% in compliant structures during normal winds, and these loads tend to increase to 20% and 40-50%, respectively, in jackets and in compliant structures, in the event of cyclonic winds.
ii. The dynamic pressure due to wind [0.5 ρ_a V(t)*V(t)] becomes higher in cyclones, as the density of air is higher due to excessive moisture content and presence of micro molecules of water particles, in addition to the prevailing higher wind velocities than in normal conditions.
iii. Similar to topographic effects of hillocks and valleys on onshore structures, a high wave can cause temporal speed up of wind on offshore structures.
iv. Turbulent wind-induced loads dominate deck structural loading and design.
v. Increased dynamic forces on deck.
vi. Increased uplift forces on helideck or similar lifting surfaces on the deck.
vii. Turbulent wind on lattice structures (the complexities of the loading during cyclonic winds are yet not known fully even from full-scale measurements on onshore structures) and on cylindrical flare-outs and storage tanks.
viii. Down burst loads on deck structures.
ix. Wind flow trained by wave crest and trough under the platform causing reversal of forces of uplift and drag.
x. Turbulent wakes of one structure over the other on the deck, as well as one platform over the other.
xi. Unsteady turbulent wind over crane booms and cantilever girders causing torsional dynamic loads.
xii. Impact of debris of cladding, berthed ships and boats on the platform structures [2].

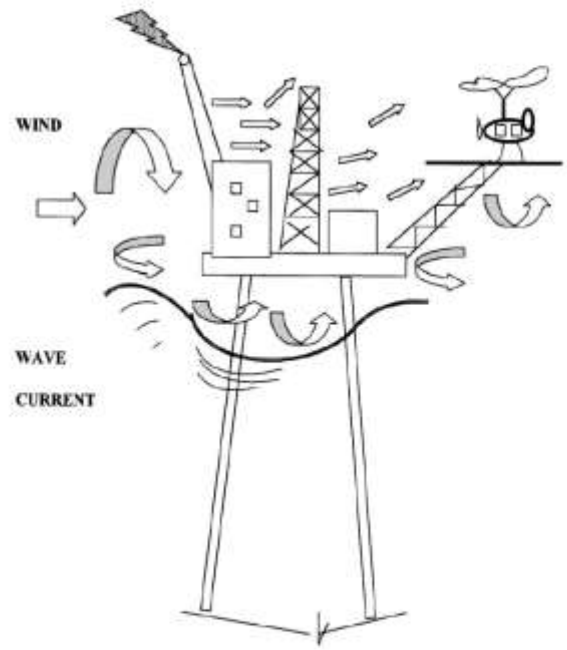

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Fig. 1 Action of Wind On Offshore Structure

D. Analysis

Wind loads are normally calculated manually and applied to deck edge usually on nodes at the periphery. Diagonal or non-orthogonal wind load cases can be generated from loads from orthogonal cases. For example, the loads in +X, +Y, -X and -Y will be applied manually. The load case for 45 degree can be generated suitably using loads in +X and +Y.

1) Formulation: The wind speed at 10m above LAT (Lowest Astronomical Tide) is normally provided (Vo). This wind speed shall be extrapolated to the height above for the calculation of wind speed.

The extrapolation shall be calculated as below:

$$V = V_0 \left(\frac{y}{10}\right)^{\frac{1}{8}}$$

Where, y is the elevation of point in consideration in m above LAT and V is the velocity at that point.

The wind pressure can be calculated as,

$$f_w = \frac{\rho g}{2} V^2$$

Where, f_w is the wind pressure per unit area, ρ (0.01255 kN/m^3) is the density of air, g is the gravitational acceleration (9.81 m/sec^2), and V is the wind speed in m/sec.

The total force on the platform can be calculated as,

$$F_x = f_w A_x C_s$$

$$F_y = f_w A_y C_s$$

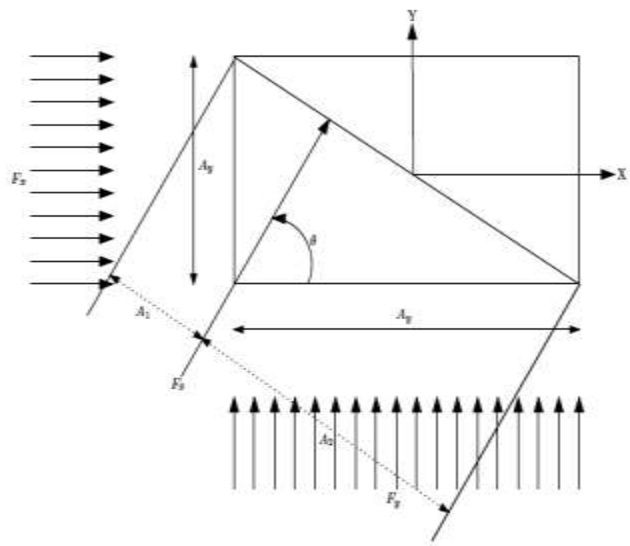

Fig. 2 FBD of Deck For Analysis Of Forces

The exposed areas (Ax and Ay) shall be calculated as length x height or width x height depending on the axis system followed.

Wind load on oblique directions can be calculated using following relationship.

$$F_\theta = F_x \cos(\theta) + F_y \sin(\theta)$$

In practical design, it is often only Fx and Fy will be calculated and applied in the structural analysis as basic loads and the wind load erect due to non-orthogonal directions are simulated using factors in terms of Fx and Fy in the load combinations.

The projected areas can be calculated as

$$A_1 = A_x \cos(\theta) \text{ And } A_2 = A_y \sin(\theta)$$

$$\text{Also, } F_\theta = f_w(A_1 + A_2)$$

$$F_\theta = f_w(A_x \cos(\theta) + A_y \sin(\theta))$$

$$F_{\theta x} = f_w(A_x \cos(\theta) + A_y \sin(\theta)) \cos(\theta)$$

$$F_{\theta y} = f_w(A_x \cos(\theta) + A_y \sin(\theta)) \sin(\theta)$$

Where, $F_{\theta x}$ and $F_{\theta y}$ are the components of F_θ in x and y directions respectively.

Ratio between $F_{\theta x}$ and F_x can be expressed as

$$\frac{F_{\theta x}}{F_x} = \frac{f_w(A_x \cos(\theta) + A_y \sin(\theta)) \cos(\theta)}{f_w A_x}$$

$$\frac{F_{\theta x}}{F_x} = \cos(\theta)^2 + (A_y/A_x) \sin(\theta) \cos(\theta)$$

Similarly, ratio between $F_{\theta y}$ and F_y can be expressed as

$$\frac{F_{\theta y}}{F_y} = \frac{f_w(A_x \cos(\theta) + A_y \sin(\theta)) \sin(\theta)}{f_w A_y}$$

$$\frac{F_{\theta y}}{F_y} = \sin(\theta)^2 + (A_x/A_y) \sin(\theta) \cos(\theta) \text{ [8]}$$

E. Design Consideration from NORSOK Standard N-003 and API Standard RP-2A Provisions

For a short-term condition, the wind may be described by means of an average wind velocity and a superimposed fluctuating wind gust with a mean value equal to zero, as well as a mean direction.

The characteristic wind velocity u (z, t) (m/s) at a height z (m) above sea level and corresponding averaging time period t less than or equal to t_0 = 3600 s may be calculated as:

$$u(z,t) = U(z)(1 - 0.41 I_u(z) \ln(t/t_0))$$

(Eqn. 6, Cl. 6.3.2, pg. 23, NORSOK Std. N-003e2; Eqn. 2.3.2-1, Cl. 2.3.2b, pg. 19, API Standard RP-2A)

Where,
The 1 h mean wind speed U(z)(m/s) is given by

$$U(z) = U_0\left[1 + C \ln\frac{z}{10}\right]$$

(Eqn. 7, Cl. 6.3.2, pg. 23, NORSOK Std. N-003e2)

$$U(z) = U_0\left[1 + C \ln\frac{z}{32.8}\right]$$

(Eqn. 2.3.2-2, Cl. 2.3.2b, pg. 19, API Standard RP-2A)

$$C = 5.73 \times 10^{-2} \times (1 + 0.0457 \times$$

(Eqn. 2.3.2-2, Cl. 2.3.2b, pg. 19, API Standard RP-2A)

Where, the turbulence intensity factor I_u (z) is given by,

$$I_u(z) = 0.06[1 + 0.043U_0]\frac{z}{10}^{-0.22}$$

(Eqn. 8, Cl. 6.3.2, pg. 23, NORSOK Std. N-003e2)

$$I_u(z) = 0.06[1 + 0.131U_0]\frac{z}{32.8}^{-0.22}$$

(Eqn. 2.3.2-3, Cl. 2.3.2b, pg. 19, API Standard RP-2A)

Where, U_0 (m/s) is the 1 h mean wind speed at 10 m

For situations where the low-frequency excitation is of importance, the following one-sided energy density spectrum of the longitudinal velocity fluctuations at a particular point in space is recommended, see Andersen and Lovseth (1992):

$$S(f) = \frac{320(\frac{U_0}{10})^2(\frac{z}{10})^{0.45}}{(1 + \tilde{f}^n)^{\frac{5}{3n}}}$$

(Eqn. 9, Cl. 6.3.2, pg. 24, NORSOK Std. N 003e2)

$$S(f) = \frac{320(\frac{U_0}{32.8})^2(\frac{z}{32.8})^{0.45}}{(1+\tilde{f}^n)^{\frac{5}{3n}}}$$ (Eqn. 2.3.2-4, Cl. 2.3.2b, pg. 19, API Standard RP-2A)

Where, n=0.468

$$\tilde{f} = 172f\left(\frac{z}{10}\right)^{\frac{2}{3}}\left(\frac{U_0}{10}\right)^{-0.75}$$ (Eqn. 10, Cl. 6.3.2, pg. 24, NORSOK Std. N 003e2)

$$\tilde{f} = 172f\left(\frac{z}{32.8}\right)^{\frac{2}{3}}\left(\frac{U_0}{32.8}\right)^{-0.75}$$ (Eqn. 2.3.2-5, Cl. 2.3.2b, pg. 19, API Standard RP-2A)

Where, S (f) (m/s/Hz) is the spectral density at frequency f (Hz), z (m) is the height above sea level, U_0 (m/s) is the 1 h mean wind speed at 10 m above sea level.

The Harris wind spectrum may be considered when action effects in structures such as flare towers, which are sensitive to the high frequency excitation are to be calculated.

1) Mean wind actions: Structures or structural components that are not sensitive to wind gusts may be calculated by considering the wind action as static. The mean wind action (F) on a structural member or surface, acting normal to the member axes or surface, should be calculated by:

$$F = \frac{1}{2}\rho C_s A U_m^{\ 2}\sin\alpha$$ (Eqn. 11, Cl. 6.3.2, pg. 24, NORSOK Std. N- 003e2)

Where, ρ is the mass density of air, C_s is the shape coefficient, A is the area of the member or surface area normal to the direction of the force, U_m is the wind speed, α is the angle between the direction of the wind and the axis of the exposed member or surface. For information about shape coefficients, CS may be found in ENV 1991-2-4 and DNV Classification Note 30.

2) Fluctuating wind actions: Structures that are sensitive to wind gusts shall be calculated by considering the wind action as a dynamic action.

The mean wind velocity is based on a 1 h period. The total wind speed is the sum of a mean velocity and a fluctuating component u (t). The wind force on a structure with a velocity, which is negligible, compared to the wind velocity, can be calculated by:

$$F = \frac{1}{2}C_s A[U_m + u(t))]^2 \approx \frac{1}{2}\rho C_s A\left[U_m^{\ 2} + 2U_m u(t)\right]$$ (Eqn. 12, Cl. 6.3.2, pg. 25, NORSOK Std. N- 003e2)

This means that the fluctuating wind force is linear in the fluctuating velocity [6].

III. CASE STUDY- HURRICANE ANDREW

A. Introduction

Hurricane Andrew was a Category 5 Atlantic hurricane that struck South Florida in August 1992, and was the most destructive hurricane in Florida's history. The storm was also ranked as the costliest hurricane in United States history until being surpassed by Katrina in 2005. Andrew caused major damage in the Bahamas and Louisiana as well, but the greatest impact was in South Florida, where it produced devastating winds with speeds as high as 165 mph. When Hurricane Andrew whipped up the water surrounding hundreds of offshore rigs, modern drilling-platform architecture was heavily damaged.

1) Damage effects of Hurricane Andrew on Offshore Structures: By the Government's count, Hurricane Andrew damaged 249 out of 3,800 offshore platforms in Federal gulf waters, but spilled oil amounted to less than 500 barrels. Recovery crews skimmed nearly half of that, up, and no slicks were found along the shoreline.

A Texaco platform apparently caused the worst environmental damage after Hurricane Andrew ripped a rig called the Treasure 75 from its moorings. The wind and waves sent the platform sailing more than four and a half miles before one of its 30,000-pound anchors tore through a concrete-sheathed oil pipeline, spilling 300 barrels. The platform then ran aground in 35 feet of water.

Hurricane Andrew washed away three platforms belonging to the gulf's biggest oil-and-gas producer, the Chevron Corporation.

Of the estimated 3850 offshore structures throughout the Gulf of Mexico's outer continental shelf, about 2000 were exposed to Andrew's hurricane winds. Of those exposed, only 243 sustained while 112 suffered structural damage. Many of the structures damaged were older structures almost as old as 16 years.

Hurricane Andrew was not a very strong hurricane as it moved to the Gulf of Mexico, but the damage inflicted by wind was significant. This suggests that either the platforms that experienced damage were not adequately designed for wind, or over the years of operation, fatigue and other causes of degradation had reduced their resistance to loads [1].

Following is the major damage witnessed during Andrew Hurricane:

Table I
Major Damage Witnessed During Hurricane Andrew

Damage Scenario	Number of Occurrences
Platforms toppled	45
Platforms bent over	89
Platforms that suffered irreparable structural	43

damage	
Platforms that suffered significant but repairable damage	100
Mobile drilling units set adrift	5

IV. DISCUSSION & CONCLUSION

- The dynamic loads viz. Wind, Wave, Current, and Earthquake forces have a major impact on offshore structures. Hence their determination is of the utmost importance.
- This paper focused on the procedure of analysis and design considerations for determination of wind force acting on offshore structures.
- It is observed that during gusty winds, to avoid skidding of base of derrick on offshore platforms, interference and base flexibility can reduce the severity of extreme wind load effects. Hence, for times like extreme wind conditions, the design for deck components requires caution.

V. RECOMMENDATIONS:

From the review of journal articles [1-2], future scope for investigations include the following:

- Improved quantification of wind field characteristics
- Mapping of wind condition round the deck for human safety and operational considerations
- Improved gust loading factors for offshore applications
- For the design of components on the deck, the dynamic effects must be understood by conducting more elaborate full-scale measurements, by instrumenting existing platforms and analyzing both the load and response data.

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