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Analysis of Nonlinear Hydrodynamic Loads Acting on an Offshore Structure

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A B S T R A C T

Oil exploration started as early as the 19th century and the oil exploration initially was concentrated on land. As the need for oil expands at an explosive rate, need for and new discoveries are eminent. During the middle of the 20th century, oil discovery started in the near shore and medium range of water depth. The offshore construction is the installation of structure and facilities in marine environments, usually for the production and transmission of electricity, oil, gas and other resources. Offshore oil and gas production is more challenging than land-based installations due to the remote and harsher environment. There are two main categories of offshore structures, fixed and floating. The Jacket Structure comes under fixed type offshore structure. Jacket type structures are appropriate for relatively shallow water depth up to 500m. This structure is capable of accounting for static load and buckling behaviour of tubular struts. These structures will be fixed to seabed by means of tubular piles either driven through legs of jacket or through skirt sleeves attached to the bottom. 95% of offshore platforms around the world are jacket supported. Since Jacket structures are very expensive and weight optimization, the focus of this project is to study and analyse the offshore jacket structure. This study is to be done by using STAAD Pro software for the analysis of the offshore jacket structure.

Keywords: ***Current load, fixed offshore structure, Jacket Structure, STAAD Pro software, Wind load, Wave load.***

1. Introduction

Oil exploration started as early as the 19th century and it initially was concentrated on land. As the need for oil expands at an explosive rate, the need for new discoveries is eminent. During the middle of the 20th century, oil discovery started in the near shore and medium range of water depth. Therefore, the structure which is constructed for this purpose is called Offshore Structure. The offshore construction is the installation of structure and facilities in marine environments, usually for the production and transmission of electricity, oil, gas and other resources. These structures are constructed on or above the continental shelves and on the adjacent continental slopes take many forms and serve multiple purposes such as towers for microwave transmission, installations for power generation, portable pipeline systems for mining the ocean floor and a few platforms and floating islands that serve as resort hotels. Most of the offshore structures however have been built to support the activities of petroleum industries.

1.1 Types of offshore structure –

Based on the geometry and behavior, the offshore structure has been divided into following categories:

1.1.1 Fixed Platforms

- Steel Template Structure: The steel template type structure consists of a tall vertical section made of tubular steel members supported by piles driven into the sea bed. The fixed platform is economically feasible for installation in water depths up to 500 m.
- Concrete Gravity Platform: Concrete gravity platforms are mostly used in the areas where feasibility of pile installation is remote. Concrete gravity platforms have been constructed in water depths as much as 350 m.

1.1.2 Compliant Structure

- Compliant Tower (CT): CT consists of a narrow, flexible tower and piled foundation that can support a conventional deck for drilling and production operation.
- Guyed Tower: This tower is an extension of a compliant tower with guy wires tied to the seabed by means of anchors or piles.
- Tension Leg Platform: It is a vertically moored floating structure. This platform is permanently moored by means of tendons grouped at each of the structure corners.

- Articulated Tower: This tower is a linear structure flexibly connected to the sea bed through a joint and held vertically by buoyancy force acting on it.

1.1.3 Floating Structure

- Floating Production System (FPS): FPS consists of a semi-submersible limit which is equipped with drilling and production equipment. It can be used in a range of water depths from 600 m to 2500m.
- Floating Production, Storage Offloading System (FPSO): FPSO is a large tanker type vessel moored to the seafloor. FPSOs are the most prominent floating platforms for production. This floating production system is a floating production storage and offloading system (FPSO) with production and processing equipment, water (gas) equipment, public facilities, and living facilities mounted on a ship with storage and an offloading vessel.
- Semi-submersible Platform: The semi-submersible platform is a versatile underwater vessel used in offshore operations, including offshore drilling rigs, safety vessels, oil production platforms and heavy lift cranes. They've got decent ship stability and seakeeping, better than drill ships. Semi-submersibles are multi-legged floating structures with large decks.
- Spar Platform: A spar is a type of floating oil platform broadly used in very deep waters and is named for logs used as buoys in shipping that are vertically moored. Spar production platforms have been installed as an alternative to conventional platforms. The deep draft design of the spars makes them less affected by wind, waves and tides and facilitates both dry-tree and subsea production.

1.2. Types of Loads acting on an offshore structure:

1.2.1 Gravity Loads

- 1.2.1.1 Structural Dead Load
- 1.2.1.2 Facility Dead Load
- 1.2.1.3 Fluid Load
- 1.2.1.4 Live Load
- Drilling Load

1.2.2 Environmental Load

- Wind Load
- Wave Load
- Current Load
- Bouyancy Load
- Ice Load
- Mud Load
- Wave Slamming
- Wave Slapping

1.2.3 Seismic load

2. Literature Review

2.1 Wind load

The wind force exerted on the structure at elevation Z, can be calculated as :

$$fwind(z) = \frac{\rho}{2} \times u^2 \times Cs \times A \times \rho$$

where,

f_{wind} : wind force at elevation, Z in [N] ρ : mass density of air at ambient temperature and pressure is 1.226 kg/m3

u : wind speed at elevation Z in [m/s]

Cs : shape coefficient associated with the geometry/shape

A : area of object in [m^2] (Nikolov, n.d.)

2.2 Wave and current load

The wave and current force imposed on offshore jacket structures is calculated based on Morison's equation developed in 1950. The Morison's equation consists of two components, namely, the inertia and drag components mathematically expressed as:

$$f_{wave}(z,t) = 0.5 \times \rho \times C_d \times A \times u(z,t) \times |u(z,t)| + (\frac{\pi}{4}) \times \rho \times C_m \times D^2 \times u(z,t)$$

where,

ρ : mass density of seawater in [kg/m3]

A : projected area normal to the cylinder axis per unit length (diameter of cylinder) in [m 2]

C_D : drag coefficient

u (z, t) : water particle velocity acting normal to the axis of the member, in [m/s]

D : diameter of circular cylinder unit length (including marine growth) in [m]

C_m : inertia coefficient

u̇ (z, t) : water particle acceleration acting normal to the axis of the member, in [m/s2]

For typical fixed offshore platform design and reassessment, the global wave forces are calculated based on the American Petroleum Institute recommended values of C_D and C_m are as follows:

For a smooth surface: $C_D = 0.65$, $C_m = 1.6$

2.3 Morison's Equation

Morison equation, a semiempirical formula based on flow theory, has been widely used in the calculation of wave loads of small-scale marine structure whose ratio of radius and length is less than 0.2. The theory assumes that the small-scale marine structure has no significant effect on the wave motion, and that the effects of waves on the structure is mainly composed of viscous effect and the added mass effect.

$$f_h = C_d \times \rho \times D \times U_x|U_x| + C_m \times . \rho \times \frac{\pi D^2}{4} \times \frac{\delta_{ux}}{\delta_t}$$

2.4 Wave slam and slap force

The water particle kinematics gets vigorously modified as the wave crest hits the structure. Hence, a method based on drag equation with a modified coefficient (CP) is useful and is shown in Equation 2. The force is termed as 'slap force'

$$F_p = \frac{1}{2} \times C_p \times \rho \times D_h \times u_h \times |u_h|$$

The vertical forces developed on the horizontal members and decks of the structures are generally termed as wave 'slam force', $F_s = \frac{1}{2} \times C_s \times \rho \times D_v \times u_v \times |u_v|$.

3. Methodology

3.1 Design wind speed (Vz) = Vb × k1 × k2 × k3

Where,

Vb = Basic wind speed

k1= Risk coefficient

k2 = Terrain factor

k3 = Topography factor

3.2 Basic wind Pressure (Pz) = 0.60 x Vz^2

Wave & Current load: Wave loading is a random process. There are tidal, circulation and storm generated currents. Wave and Current Load is calculated using Shore Protection Manual Volume 76. Formula for calculating it is given below,

3.2.1 Relative wave length,

$lo = \frac{gT^2}{2\pi} = \frac{9.81\times(8.51)^2}{2\pi} = 113.$

Where,

g = acceleration due to gravity

T = Mean time period = 8.51 sec

3.2.2 Velocity calculation for Morison's equation,

$(u) = \frac{H}{2} \times (\frac{\frac{g}{T}}{lo}) \times \frac{cosh(\frac{2\pi(z+D)}{lo})}{cosh(\frac{2\pi d}{lo})} \times cos(\frac{2\pi t}{T})$

Where,

H = significant wave height = 3.648 m

lo = wavelength

t = Propagation of wave

d = water depth

z = defined height

D = diameter of circular cylinder

3.3 Acceleration calculation for Morison's equation,

$$u' = \frac{H}{2} \times \frac{g}{lo} \times \frac{cosh(\frac{2\pi(z+D)}{lo})}{cosh(\frac{2\pi d}{lo})} \times T \times sin(\frac{2\pi t}{T})(\frac{-2\pi t}{T^2}) + cos(\frac{2\pi t}{T}) \times 1$$

3.4 Morison's equation,

$$(Fr) = \frac{1}{2} \times Cd \times \rho \times D \times u \times |u'| \times dz + \pi D^2$$

Where,

Cd = Drag coefficient (0.65)

Cm= inertia coefficient (1.6)

ρ = mass density of saline water

dz =1 (area of small element)

u = velocity

u'= acceleration

4. Result and Discussion

4.1 WIND LOAD

Design wind speed (Vz) = Vb × k1 × k2 × k3

Where,

Vb = Basic wind speed

k1= Risk coefficient

k2 = Terrain factor

k3 = Topography factor

Basic wind Pressure (Pz) = 0.60 x Vz^2

4.2 WAVE LOAD

1) Relative wave length,

$$lo = \frac{gT^2}{2\pi} = \frac{9.81\times(8.51)^2}{2\pi} = 113.07m$$

Where,

g = acceleration due to gravity

T = Mean time period = 8.51 sec

2) Velocity calculation for Morison's equation,

$$(u) = \frac{H}{2}\times(\frac{\frac{g}{T}}{lo})\times\frac{cosh(\frac{2\pi(z+D)}{lo})}{cosh(\frac{2\pi d}{lo})}\times cos(\frac{2\pi t}{T})$$

where

z = specified depth(m)	v = velocity (m/s)	z = specified depth(m)	v = velocity (m/s)
0	0.49164	-16	0.67132
-1	0.49088	-17	0.6978
-2	0.49164	-18	0.72644
-3	0.49391	-19	0.75732
-4	0.49771	-20	0.79053
-5	0.50305	-21	0.75732
-6	0.50993	-22	0.79053
-7	0.51839	-23	0.82619
-8	0.52845	-24	0.86439
-9	0.54014	-25	0.90526
-10	0.5535	-26	0.94892
-11	0.56856	-27	0.99551
-12	0.58538	-28	1.04518
-13	0.60401	-29	1.09806
-14	0.62449	-30	1.15434
-15	0.64691		

Where,

H = significant wave height = 3.648 m

lo = wavelength

t = Propagation of wave

h = water depth

3) Acceleration calculation for Morison's equation,

$$u' = \frac{H}{2} \times \frac{g}{lo} \times \frac{cosh(\frac{2\pi(z+D)}{lo})}{cosh(\frac{2\pi d}{lo})} \times T \times sin(\frac{2\pi t}{T})(\frac{-2\pi t}{T^2}) + cos(\frac{2\pi t}{T}) \times 1$$

z= specified depth	u'= acceleration	z= specified depth	u'= acceleration
0	0.05778	-16	0.0789
-1	0.0577	-17	0.08202
-2	0.5778	-18	0.08538
-3	0.05805	-19	0.08901
-4	0.0585	-20	0.09291
-5	0.05912	-21	0.0971
-6	0.05993	-22	0.10159
-7	0.06093	-23	0.1064
-8	0.06211	-24	0.11153
-9	0.06348	-25	0.11701
-10	0.06505	-26	0.12284
-11	0.06683	-27	0.12906
-12	0.0688	-28	0.13567
-13	0.0799	-29	0.14271
-14	0.0734	-30	0.15018
-15	0.07603		

4) Morison's equation,

$$(Fr) = \frac{1}{2} \times Cd \times \rho \times D \times u \times |u| \times dz + \pi D^2$$

Where,

Cd = Drag coefficient (0.65)

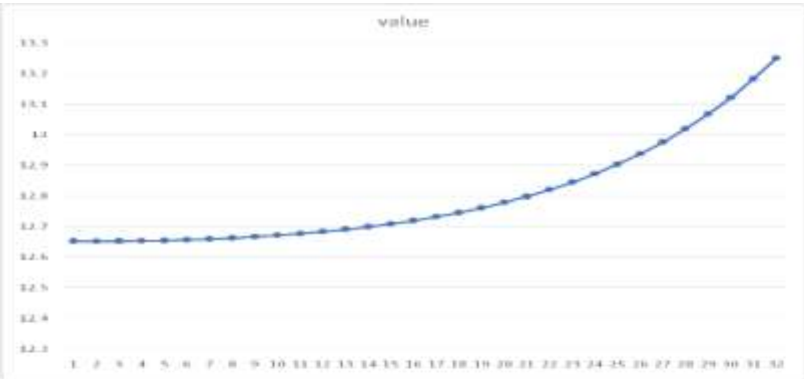
Cm= inertia coefficient (1.6)

dz =1 (area of small element)

u = velocity

z = specified depth(m)	Fr = Total force	z = specified depth(m)	Fr = Total force
0	12.6523	-16	12.7321
-1	12.6521	-17	12.746
-2	12.6523	-18	12.7617
-3	12.6532	-19	12.7791
-4	12.6546	-20	12.7987

-5	12.6567	-21	12.8207
-6	12.6593	-22	12.8451
-7	12.6627	-23	12.873
-8	12.6667	-24	12.904
-9	12.6714	-25	12.9386
-10	12.677	-26	12.9773
-11	12.6835	-27	13.0206
-12	12.6909	-28	13.069
-13	12.6994	-29	13.1231
-14	12.709	-30	13.1837
-15	12.7198		



5.Conclusion

The hydrodynamic analysis was completed using Morrison's Equation aiming the maximum optimization of structure. According to SPM-Vol.76 1984, wave and current forces can be collectively calculated if precise wavelength is known. The collective consideration of wave and current loads resulted in optimization in analysis of structure and thus would also result in optimization during design of structure.

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