

Review Article

OFFSHORE ENGINEERING: AN OVERVIEW OF TYPES AND LOADINGS ON STRUCTURES

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Since the 1970s a need for deep water structure that would exploit energy resources such as oil and natural gas has arisen. Depending upon the depth of the sea water and as per the requirement, various types of platforms are designed. When deep water combines with hostile weather condition, necessary conventional fixed offshore structures require excessive physical dimensions to obtain the stiffness and strength. The study considers some important forces such as wind, ocean wave's buoyant forces, current loading and marine growth. Accurate prediction of the wave loadings on the structures is extremely important for design purpose for that software's are introduced. Software analysis of the structure in every possible manner gives a desirable result which helps in designing the structure. Each part of the structure is simulated by considering actual and environmental loads on it. This paper highlights the engineering behind offshore structures through types and different loading conditions.

Keywords: Offshore, Wave loading, Wind loading, Forces, Oil and gas, Load simulation

INTRODUCTION

Offshore 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. However, most of the offshore structures however have been built to support the

activities of petroleum industries. Exploratory drilling is done from mobile platforms or carefully positioned ships. Production and storage operation involves more permanent structures. Offshore platforms have many uses including oil exploration and production, navigation, ship loading and unloading, and to support bridges and cause ways.

These offshore structures must function safely for design lifetimes of 25 years or more and are subject to very harsh marine

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environments. Some important design considerations are peak loads created by hurricane wind and waves. The platforms are sometimes subjected to strong currents which create loads on the mooring system and can induce vortex shedding. Offshore platforms are huge steel or concrete structures used for the exploration and extraction of oil and gas from the earth's crust. Offshore structures are designed for installation in the open sea, lakes, gulfs, etc., many kilometers from shorelines. These structures may be made of steel, reinforced concrete or a combination of both.

Offshore platforms are very heavy and are among the tallest man-made structures on the earth. The oil and gas are separated at the platform and transported through pipelines or by tankers to shore.

The design of marine structures compatible with the extreme offshore environmental condition is most challenging and creative task for the ocean engineers. The marine engineer's goal is to conceive and design a lasting structure that can withstand the adverse conditions of high winds and waves, earthquakes, tsunami and ice effect. These structures are analyzed in all possible manners to avoid the loss of property and life of workers as they are situated long away from shore line and constructed at a depth more than 200 m.

HISTORICAL PERSPECTIVE

The earliest offshore structure for oil drilling was built around 1887 off the coast of southern California near Santa Barbara. This was simply a wooden wharf outfitted with a ring for drilling vertical wells into the sea floor. More elaborate platforms supported by timber piers were then built for oil drilling, including

installation for the mile deep well in Caddo lake, Louisiana (1911) and the platform in lake Maracaibo, Venezuela (1927). Soon after these early pier systems were built, it became apparent that the lifetime of timber structures erected in lakes or oceans is severely limited, because of attacks by marine organisms. For this reason reinforced concrete replaced timber as the supporting structure for many offshore platforms up to the late 1940s. Over the next 50 years about 12,000 platform structures were built offshore, usually of steel but more recently precast concrete was used.

Offshore mooring system has a variety of configurations. All have anchors or groups of pipelines in the seabed with flexible lines, leading to buoys, ship or platform structures. The function of mooring system is to keep the buoy, ship or platform structure at a relatively fixed location during engineering operations. When the pipeline were first laid offshore, no extraordinary analyses or deployment techniques were needed, since they were in shallow water and were of small diameter. As the platforms were built in deeper or deeper water with multiple well slots, large diameter pipelines of higher strength were required. During the 1960s, engineers met this challenge with new design and with refined methods of analysis and deployment. Throughout the world there are at present about 90,000 km of marine pipelines. Since 1986 the rate of building new marine pipelines has been about 1,000 km per year. Pipeline varies from 1 km to 100 km in length and 7 cm to 152 cm in diameter. The pipelines of smaller diameter are used to transport oil and gas from wellhead, and those of large diameter are used to load and unload oil from tankers moored at

offshore terminals. At present a Norwegian project has a 1,000 km line extending from the Troll field to Belgium completed in the year 1992, Kuwait has the loading line of largest diameter 152 cm.

PURPOSE

Today, the worldwide requirement of oil is increasing rapidly and for that more offshore structure are needed. This paper gives an overview knowledge of offshore engineering such as various types of structures, loadings on structure and its simulations.

TYPES OF OFFSHORE STRUCTURE

Depending on the water depth and environmental conditions, the structural arrangement and need for new ideas is required. Based on the geometry and behavior, the offshore structures for oil and gas development have been divided into the following categories:

1. Fixed Platforms
 - A) Steel template structures
 - B) Concrete gravity structures
2. Compliant Structures
 - A) Compliant tower
 - B) Guyed tower
 - C) Articulated tower
 - D) Tension leg platform
3. Floating structures
 - A) Floating production system

Fixed Platform

Steel Template Structures

The steel template type structure consists of a tall vertical section made of tubular steel members supported by piles driven into the sea bed with a deck placed on top, providing space for crew quarters, a drilling rig, and production facilities. The fixed platform is economically feasible for installation in water depths up to 500 m. These template type structures are fixed to seabed by means of tubular piles either driven through legs of the jacket (main piles) or through skirt sleeves attached to the bottom of the jacket. The principle behind the fixed platform design is to minimize the natural period of the structure below 4 seconds to avoid resonant behavior with the waves (period in the order of 4 to 25 seconds).

Jack up Ring

Jack up rings are similar to drilling barges, with one difference. Once jack up ring is towed to the drilling site, three or four 'legs' are lowered until they rest on the sea bottom. This allows the working platform to rest above the surface of the water, as opposed to a floating barrage. However, jack up rings are suitable only for shallow waters, as extending these legs down too deeply would be impractical. This ring type of ring can only operate at a water depth of 500 feet.

Concrete Gravity Platforms

Concrete gravity platforms are mostly used in the areas where feasibility of pile installation is remote. These platforms are common in areas with strong seabed geological conditions either with rock outcrop or sandy formation. These kinds of platforms are located in some parts of North Sea oil fields and the Australian coast. The concrete gravity

platform by its name derives its horizontal stability against environmental forces by means of its weight. These structures are basically concrete shells assembled in circular array with stem columns projecting above water to support the deck and facilities. The main advantage of these types of platforms is their stability, as they are attached to sea floor and hence there is limited movement due to wind and water forces. Concrete gravity platforms have been constructed in water depths as much as 350 m.

COMPLIANT STRUCTURES

In addition to the developing technologies for exploration and production of oil and natural gas, new concepts in deepwater systems and facilities have emerged to make ultra-deepwater projects a reality. With wells being drilled in water depths of 3000 m, the traditional fixed offshore platform is being replaced by state-of-the-art deepwater production facilities, which are now being used in water depths exceeding 500 m. All of these systems are proven technology, and in use in offshore production worldwide.

Compliant Tower

Compliant Tower (CT) is much like fixed platforms. It consists of a narrow, flexible tower and a piled foundation that can support a conventional deck for drilling and production operations. The flexibility of compliant towers withstands large lateral forces by sustaining significant lateral deflections, and is usually used in water depths between 300 m and 600 m.

Guyed Tower

Guyed tower is an extension of compliant tower with guy wires tied to the seabed by

means of anchors or piles. The guy ropes minimize the lateral displacement of the platform topsides. This further changes the dynamic characteristics of the system.

Tension-Leg Platforms

A tension-leg platform is a vertically moored floating structure normally used for offshore production of oil or gas, and is particularly suited for water depths around 1,000 m to 1,200 m (about 4,000 ft). The platform is permanently moored by means of tethers or tendons grouped at each of the structure's corners. A group of tethers is called a tension leg. A feature of the design of the tethers is that they have relatively high axial stiffness (low elasticity), such that virtually all vertical motion of the platform is eliminated. This allows the platform to have the production wellheads on deck (connected directly to the subsea wells by rigid risers), instead of on the seafloor. This makes for a cheaper well completion and gives better control over the production from the oil or gas reservoir. Tension Leg Platform (TLP) consists of a floating structure held in place by vertical, tensioned tendons connected to the sea floor by pile-secured templates. The larger TLPs have been successfully deployed in water depths approaching 1,250 m. Mini-Tension Leg Platform (Mini-TLP) is a floating mini-tension leg platform of relatively low cost developed for production of smaller deepwater reserves which would be uneconomic to produce using more conventional deepwater production systems. The world's first Mini-TLP was installed in the Gulf of Mexico in 1998.

Articulated Tower

Articulated tower is an extension of tension leg platform. The tension cables are replaced by

one single buoyant shell with sufficient buoyancy and required restoring moment against lateral loads. The main part of the configuration is the universal joint which connects the shell with the foundation system. The foundation system usually consists of gravity based concrete block or sometimes with driven piles. The articulated tower concept is well suited for intermediate water depths ranging from 150 m to 500 m.

FLOATING STRUCTURES

Floating Production System

Floating Production System (FPS) consists of a semi-submersible unit which is equipped with drilling and production equipment. It is the most common type of offshore drilling rings, combining the advantages of submersible rings with ability to drill in deep water. The ring is partially submerged, but still floats above the drill site. When drilling, the lower hull, filled with water, provides stability to the ring. Semi-submersible rings are generally held in place by huge anchors with wire rope and chain, or can be dynamically positioned using rotating thrusters. Production from subsea wells is transported to the surface deck through production risers designed to accommodate platform motion. The FPS can be used in a range of water depths from 300 m to 1,500 m.

Floating Production, Storage and Offloading System

Floating Production, Storage and Offloading System (FPSO) consists of a large tanker type vessel moored to the seafloor. An FPSO is designed to process and stow production from nearby subsea wells and to periodically off-load the stored oil to a smaller shuttle tanker. The shuttle tanker then transports the oil to an

onshore facility for further processing. An FPSO may be suited for marginally economic fields located in remote deepwater areas where a pipeline infrastructure does not exist. Currently, there are no FPSOs approved for use in the Gulf of Mexico. However, there are over 70 of these systems being used elsewhere in the world.

TYPES OF LOADS

Loads on offshore structures are gravity loads and environmental loads. Gravity loads arise from dead weight of structure and facilities either permanent or temporary. Seismic loads arise from gravity loads and are a derived type. Environmental loads play a major role in governing the design of offshore structures. Before starting the design of any structure, accurate prediction of environmental loads is important. Various environmental loads acting on the offshore platform is listed below.

1) Gravity Loads

- A) Structural Dead Loads
- B) Facility Dead Loads
- C) Fluid Loads
- D) Live Loads
- E) Drilling Loads

2) Environmental Loads

- A) Wind Loads
- B) Wave Loads
- C) Current Loads
- D) Buoyancy Loads
- E) Ice Loads
- F) Mud Loads

3) Seismic Loads

GRAVITY LOADS

Structural Dead Loads

Dead loads include all fixed items in the platform deck, jacket, bridge and flare structures. It includes all primary steel structural members, secondary structural items such as boat landing, pad eyes, stiffeners, handrails, deck plating, and small access platforms. The primary structural steel members are calculated based on the structural information in the model automatically when a computer program is used to analyze the structure. But the weight of the secondary structural steel items shall be calculated applied to the structural model at appropriate locations.

Facility Dead Loads

The structure built either for drilling or wellhead type platform or for process type platform supports various equipment and facilities. These are fixed type items and not structural components. They do not have any stiffness to offer in the global integrity of the structure and shall not be modelled. The weight of such items shall be calculated and applied at the appropriate locations according to the plan of the structure. These items include

- a) Mechanical equipment
- b) Electrical equipment
- c) Piping connecting each equipment
- d) Electrical Cable trays
- e) Instrumentation items

Fluid Loads

The fluid loads are weight of fluid on the platform during operation. This may include all the fluid in the equipment and piping. The weight of these items shall be calculated accurately and applied to the correct locations.

Live Loads

Live loads are defined as movable loads and are temporary in nature. Live loads will only be applied on areas designated for the purpose of storage either temporary or long term. Further, the areas designed for lay down during boat transfer of materials from boat shall also be considered as live loads. Other live loads include open areas such as walkways, access platforms, and galley areas in the living quarters, helicopter loads in the helipad, etc. These loads shall be applied in accordance with the requirement from the operator of the platform.

Drilling Loads

Drilling loads are due to drill rigs placed on the top of the platform for drilling purposes. Normally, drilling rigs are as heavy as 500 tons to 1000 tons. These will deliver reaction forces on the deck and the stiffness of the drilling rigs is not considered in the structural analysis. Hence the weight of the structure shall be applied as load on the structure. Further, during drilling, additional loads are developed due to drill string and pulling operations. These loads are also considered in the analysis.

ENVIRONMENTAL LOADS

Wind Loads

The wind speed at 10 m above Lowest Astronomical Tide (LAT) is normally provided (V_0). This wind speed shall be extrapolated to the height above for the calculation of wind speed. The extrapolation shall be calculated as follows:

$$V = V_0 \frac{y^{1/8}}{10}$$

where, Y is the elevation of point in consideration in 'm' above LAT and V is the velocity at that point. Wind loads shall be calculated as per *API RP2A* guidelines. Sustained wind speeds (10 min mean) shall be used to compute global platform wind loads and gusty wind (seconds) shall be used to compute the wind loads to design individual members.

The wind pressure can be calculated as,

$$F_w = \frac{\rho g}{1} V^2$$

where F is the wind pressure per unit area, ρ (0.01255 KN/m³) is the density of air, g is the gravitational acceleration (9.81 m/s²) and V is the wind speed in m/s. The above equation can be simplified by substituting the values and can be expressed as

$$F_w = 0.6V^2 \text{ kN} / \text{m}^2$$

The total wind load on the platform can be calculated using the wind blockage area and the pressure calculated as above. The shape coefficient (C_s) shall be selected as per *API RP2A* guidelines. But for the calculation of global wind load (for jacket and deck global analysis) shape coefficient can be 1.0.

The total force on the platform can be calculated as,

$$f_x = F_w A_x C_s \quad f_y = F_w A_y C_s$$

Wave and Current Loads Methodology

In applying design waves load onto the offshore structures, there are two ways of applying it.

- Design wave method
- Spectral Method

In design wave method, a discrete set of

design waves (maximum) and associated periods are selected to generate loads on the structure. These loads are used to compute the response of the structure. In the spectral method, an energy spectrum of the sea-state for the location are taken and a transfer function for the response will be generated. These transfer function are used to compute the stress in the structural members.

Design Wave Method

The wave loads exerted on the jacket is applied laterally on all members and it generates overturning moment on the structure. Period of wind generated waves in the open sea can be in the order of 2 to 20 s. These waves are called gravity waves and contain most of the wave energy. Maximum wave shall be used for the design of offshore structures. The relationship between the significant wave height (H_s) and the maximum wave height (H_{max}) is

$$H_{max} = 1.86H_s$$

The above equation corresponds to a computation based on 1,000 waves in a record. The design wave height (in Meters) for various regions is tabulated below.

API RP2A requires that both 1 year and 100 year recurrence wave is used for the design of jacket and piles. Appropriate combination of loads with these waves shall be used in the design.

Spectral Method

Instead of simulating the design wave environment by discrete maximum wave, a design sea-state described by energy spectrum for the given site is used in the load simulation.

Table 1: Maximum Design Waves in Various Regions

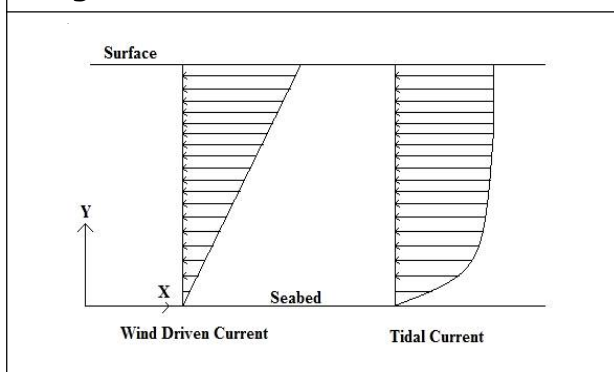
Region	1 year	100 year
Bay of Bengal	8	18
Gulf of Mexico	12	24
South China Sea	11	24
Arabian Sea	8	18
Gulf of Thailand	6	12
Persian Gulf	5	12
North Sea	14	22

Current Profile

Ocean currents induce drag loading on offshore structures. These currents together with the action of waves generate dynamic loads. Ocean currents are classified into tidal current and wind driven current. Wind driven currents are small in nature and they vary linearly with depth whereas tidal currents vary nonlinearly with depth.

The current variation with depth is shown in Figures and can be expressed as below:

$$V_T = V_{ot} \frac{y^{1/7}}{h}$$

Figure 1: Current Profile on Structure

where V_T is the tidal current at any height from sea bed, V_{ot} is the tidal current at the surface, y is the distance measure in 'm' from seabed and h is the water depth.

$$V_w = V_{ow} \frac{y}{h}$$

where V_w is the wind driven current at any height from sea bed, V_{ow} is the wind driven current at the surface, y is the distance measure in 'm' from seabed and h is the water depth.

Application of wave load on structure is shown in Figure 2.

Marine Growth

Marine growth is an important part in increasing the loads on offshore structures. The growth of marine algae increases the diameter and roughness of members which in turn cause the wave or current loading to increase. The thickness of marine growth generally decreases with depth from the mean sea level and it is maximum in the splash zone. The thickness of marine growth in the splash zone can be as much as 20 cm and will reduce below to 5 cm. In deeper zones, the thickness may be negligible. Splash zone is a region where the water levels fluctuate between low to high. In general, the splash zone varies between -3 m and +5. In structural analysis, the increased diameter of the member ($D = d + tm$) shall be included so that the wave and current loads can be calculated correctly. D and d are the diameter of increased member and original member respectively and tm is the thickness of the marine growth. The roughness of the marine growth is an important parameter in determining the drag and inertia

coefficients. The made relevant *API RP2A* clauses may be referred for more details.

Morison Equation

Wave and current loading can be calculated by Morison equation.

$$F_T = C_D \rho_w D V |V| + \frac{\pi D^2}{4} C_m \rho_w a$$

where F_T is the total force, ρ_w is the density of water, C_D and C_m are the drag and inertia coefficients respectively, D is the diameter of the member including marine growth, V is the velocity and a is the acceleration.

The first term in the equation is drag component (FD) and the second term is the inertia component (FI). This can be expressed as

$$F_T = F_D + F_I$$

Most of the time, current exists in the same direction of the wave propagation and hence the current shall be taken into consideration in the load calculation. However, algebraic sum of wave and current loads is different from calculation of load by adding the horizontal water particle velocity with the current velocity and computing the loads. Current velocity shall be added using vector with the water particle velocity before computation of drag force, i.e. $V = V_w + V_c$ where V is the total velocity, V_w is the velocity due to waves and V_c is the velocity of current.

BUOYANCY LOAD

The offshore structural members are mostly made buoyant by air tight sealing of the welds to avoid water entry. This is purposely planned, so that the overall structure has adequate

buoyancy during installation. Typical example is the jacket structure. This kind of structure requires at least a reserve buoyancy of 10% to 15%. The reserve buoyancy is defined as buoyancy in excess of its weight. To obtain this buoyancy, structural tubular members are carefully selected such that their buoyancy / weight ratio is greater than 1.0. This means that the member will float on water. On other hand, if the member is part of a structure supported at its two ends and forced to be submerged by weight of other members, this member will experience an upward force equal to the displaced volume of water. This is called buoyancy force. The buoyancy force can be calculated by two methods as shown in Figure 3.

- Marine Method
- Rational Method

Marine Method

The marine method assumes that the member considered having rigid body motion. This means that the weight of the member is calculated using submerged density of steel and applied to the member vertically down as a uniformly distributed load.

Rational Method

The rational method takes in to account the pressure distribution on the structure; results in a system of loads consisting of distributed loads along the members and concentrated loads at the joints. The loads on the members are perpendicular to the member axis and in the vertical plane containing the member.

Ice Loads

For structures located in Polar regions and cold countries, ice loading shall be considered in the design. In these regions, the ice sheets of

varying thickness can move from one location to other due to tide and under water current. These ice sheets when come closer and hit the offshore structures, a large impact force is experienced by the structure.

This kind of force cannot be calculated by means of analytical tools; an empirical equation is available and can be used to estimate the force (F_{ice})

$$F_{ice} = C f A$$

where,

f_{ice} = Crushing strength of ice vary between 1.5 MPa and 3.5 MPa

C_{ice} = Ice force coefficient varies between 0.3 to 0.7

A = Area struck by ice (Diameter of member x ice sheet thickness)

Mud Loads

Platforms located in the vicinity of the river mouth (shallow water platforms) may experience the mud flow loads. The river flow

Figure 2: Wave Loading on Jacket Structure

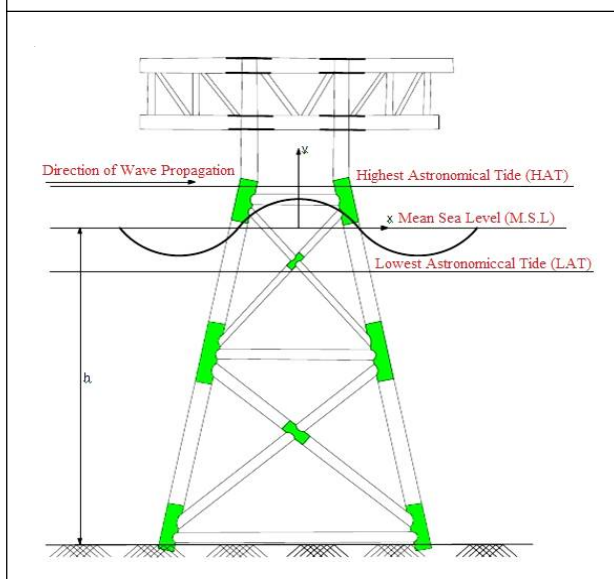
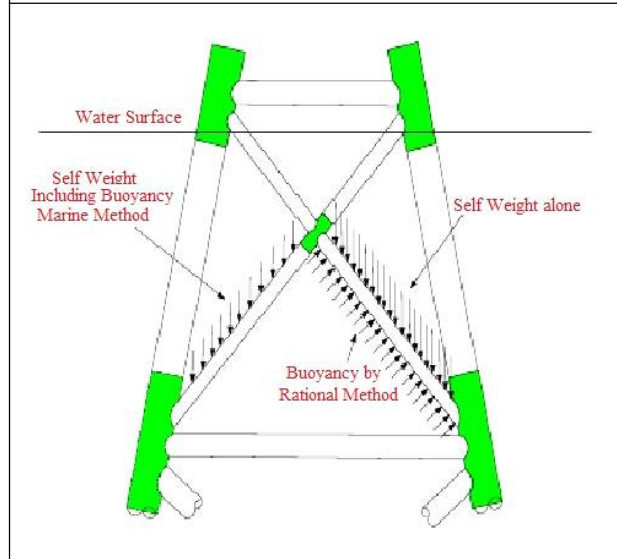


Figure 3: Buoyancy Calculation Methods



brings sediment transport and nearby mud towards the platform and may slide through the location. Sometimes over a long period of time sediment settlement at the location of the platform may have sloping surface and mud slides can also generate mud loads.

These loads can be calculated using

$$F_{mud} = C_{mud} \tau D$$

where,

C_{mud} = Force Coefficient that varies between 7 and 9

τ = Shear strength of soil 5 kpa to 10 kpa

D = Diameter of pile or member

LOAD SIMULATION

Dead Loads

The dead loads of primary structural members such as deck beams, braces, jacket legs and braces, piles etc shall be calculated by the program automatically based on their dimensions and unit weight of the material supplied.

Equipment Loads

Generally, the equipment weight is manually entered based on VENDOR supplied information. The weight of the equipment shall be distributed to the deck beams or plating depending on the load transfer method adopted for the design of the equipment skid.

Fluid Loads

The fluid loads are based on equipment operating weight. This can also be obtained from the equipment manufacturer. The contents of the equipment can be calculated as below:

$$W_{fluid} = W_{Oper} - W_{dry}$$

where,

W_{oper} and W_{dry} are the weight of equipment in operating and dry conditions, respectively.

Drilling Loads

Drilling equipment include rig, drill strings, mud tanks, etc. These equipments are also similar to the other equipment described above except that the drilling rig is not fixed equipment. Normally, these shall be applied as point loads on the skid beams. There may be several load cases to cover all the well positions.

Live Loads

The live loads shall be applied on open areas not occupied by equipment or facilities. This can be applied as member loads.

Wind, Wave and Current

Wind

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.

Wave and Current

The wave and current shall be simulated using software contained modules. Manual calculation and application of these loads will lead to large errors and approximations since the number of members are very high.

CONCLUSION

1. Each platform/ ring type is chosen mainly due to water depth considerably and due to the deck equipment necessary to perform its service.
2. Selection of offshore structures based on water depths
 - A) The jack up ring - 90 m to 150 m
 - B) The fixed platforms - up to about 600 m
 - C) Semi-submersible platforms - up to 1000 m
 - D) The tension leg platforms - greater than 300 m to 1200 m.
 - E) The spar platform - more than 1800 m.
3. Forces on these structures due to the ocean and atmosphere include ocean waves and currents, wind, buoyancy and friction at the base.
4. Various loading parameters are described here, which are key factors that must consider in the analysis and design of offshore structures.
5. The present of marine growth, has significant effects on the hydrodynamic loading of offshore structures and should be taken into consideration in the design and analysis of structures.

6. Compliant structures have found primary offshore application in the oil industry.
7. Whole structural platform is analyzed by various ways such as dynamic analysis, impact analysis, seismic analysis, fatigue analysis and push over analysis.
8. Corrosion in offshore structure is the main influencing factor in reducing the strength of the structure; this can be treated properly for good stability.
9. New software developed for analysis of offshore structure predicts structural behavior in all possible manners and it reduces human stress.

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