GENERAL GUIDANCE FOR PLANNING, DESIGN AND CONSTRUCTION OF OFFSHORE PLATFORMS

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ABSTRACT

Offshore platforms are among the most significant and the tallest structures in the world which must operate reliably in a wide range of very challenging environments and have a large impact on the economy and industrial advancement of countries. It is very important to plan, design, construct and install such offshore structures correctly. The penalties for not doing so can be enormous in both environmental and economic terms. A general guide for offshore structures engineering is presented in this paper. Its purpose is to offer a universal vision template for the different phases of planning, design, construction, load-out, transportation and installation of these offshore structures. The paper covers mainly offshore template (jacket) platforms.

Keywords: Planning, Design, Construction, Jacket, Offshore Platform

INTRODUCTION

Offshore structures must function safely for their total design lifetimes. This presents a serious challenge as they are among the largest structures constructed and must endure some of the severest environmental extremes experienced by any man made structure.

This paper covers mainly the design and construction of fixed offshore platforms. *These types of structure are mainly used in the Gulf of Mexico, North Sea, Alaska,* Persian Gulf and Caspian Sea. For additional information on the environmental data for the Persian Gulf, Caspian Sea and Mediterranean Sea, different types of offshore structures, together with necessary formulas and the data needed for design and analysis of such structures, the instructions, data and recommendations given by API (2010), Sadeghi (1989, 2001, 2007a, 2007b, 2008, 2013), US Army Coastal Engineering Research Center (1980), Sadeghi and Nouban (2013), US Army Corps of Engineers (2002) and Nouban (2015) can be used.

DIFFERENT TYPES OF OFFSHORE PLATFORMS

Depending upon the water depth, environmental, geotechnical and operational conditions, different types of offshore petroleum platforms such as template, tower, guyed tower, gravity, tension leg, jack up, semi-submersible and ship type platforms are used. There are two main groups of offshore platforms/rigs; the first group includes moveable offshore drilling rigs that can be moved from one place to another and the second group are the fixed platforms. The main types of offshore platforms are briefly explained below.

Moveable Offshore Platforms

Jack-up platforms

Jack-up platforms are suitable for shallower waters and can be moved from one place to another.

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Submersible platforms

Submersible platforms/rigs are also suitable for shallow waters. Like jack-up platforms they are in contact with the seabed.

Semi-submersible platform

Semi-submersible platforms/rigs have floating drill units that include columns and pontoons. They are the most common type of offshore drilling rig and are generally held in place by huge anchors, each weighing more than ten tons. They can also be kept in place by the use of dynamic positioning systems. Such rigs typically drill in deep waters of up to 1,800 meters. These platforms drill holes in the seabed and have the advantage that they can be relatively quickly moved between locations.

Fixed Platforms

There are many possible designs of fixed platforms. The main advantage of these types of platforms is their stability. As they are attached to the sea floor, there is limited movement due to the effects of wind, current and wave forces. However, these platforms cannot be used in extremely deep water. The main types of fixed platforms are briefly explained below.

Template (jacket) platforms

Template platforms, also called jacket platforms, are commonly employed in the Persian Gulf, Gulf of Mexico, Nigeria, California shorelines and are made of steel. Template platforms, comprise basically of a jacket, decks and piles.

Tower platforms

Tower platforms are narrow towers, attached to a foundation on the seabed. This type of tower is flexible.

Tension Leg Platforms

Tension Leg Platforms (TPLs) are used in deep waters. The long, flexible tension legs (cables) are attached to the seabed. TPLs can operate in waters as deep as 2,100 meters.

Gravity Platforms

Gravity platforms, also called ConDeep platforms, are fixed platforms which are made of concrete. This type of platform is mainly used in the North Sea and in Brazilian waters.

WAVE MECHANISM AND WAVE THEORIES

Wave mechanics and wave theories, including wave classifications governing equations of wave theories, different wave theories such as Airy, Stockes (second and fifth orders), Stream Function, Cnoidal, Solitary and Trochoidal waves, and the related equations are presented by Sadeghi (1989 and 2001), Sarpkaya and Isacicson (1981), US Army Corps of Engineers (2011) and, Nouban and Sadeghi (2014) which provide further information.

Information on wave characteristics prediction methods, based on the equations of Stevenson, S.M.B. (Sverdrup-Munk-Bretschneider), Bretschneider, Pierson-Moskowitz, JONSWAP (Joint North Sea Wave Project), can be found in literature such as those presented by Sadeghi (2001) and US Army Coastal Engineering Research Center (1980).

Pierson-Moskowitz in 1964 presented three equations for a wave Spectrum. Further equations were submitted by Moskowitz in the same year. Hasselmann in 1973and 1976 proposed the equations of JONSWAP.

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The Morison formula is typically used to calculate the hydrodynamic forces applied to jacket structural members.

TEMPLATE PLATFORM DESIGN BASES

The principals for the design and analysis of fixed template platforms, along with recommendations for design, analysis, construction, load-out, transportation and installation of platforms, are provided in some references such as API code (2010) and the book written by Sadeghi (2001) and are presented briefly below.

Construction Stages

Offshore platform construction typically includes the following phases:

I. Design
II. Procurement
III. Construction
IV. Load-out
V. Transportation
VI. Installation
VII. Commissioning
VIII. Operation

The fabrication of the steel structures of offshore platforms is usually performed in construction yards located a significant distance from the installation site. The Load-out, transportation and installation of jackets require special designs and structural strength calculations. A detailed work breakdown structure (WBS) is required for the phases of planning, design and construction of such structures. For more information, refer to Muyiwa and Sadeghi (2007), Sadeghi and Babolian (2016), Nouban (2016), and Sadeghi and Nouban (2016).

Different Analyses Needed

The main analyses required for the design of a template platform are as follows:

i. In- place analysis
ii. Earthquake analysis
iii. Fatigue analysis
iv. Impact analysis
v. Temporary analysis
vi. Load-out analysis
vii. Transportation analysis
viii. Appurtenances analysis
ix. Lift or Launch analysis
x. Upending analysis
xi. Up-righting analysis
xii. Un-piled stability analysis
xiii. Pile and conductor pipe drivability analysis
xiv. Cathodic protection analysis
xv. Transportation analysis

xvi. Installation analysis.

Environmental Parameters

The design and analysis of template platforms can be conducted in accordance with the API-RP-2A-WSD. The API specifies minimum design criteria for a 100-year design storm.

Normally, for the analysis of offshore platforms, the environmental parameters include wave heights of as much as 21 meters (depending on the water depth) and wind velocities of 170 km/hr for Gulf of Mexico, coupled with tides up to 4 m. The wave heights up to 12.2 meters and wind velocities up to 130 km/hr for Persian Gulf, coupled with tides up to 3 m are considered in design of platforms. The design wave height of the Southern Caspian Sea is about 20 m for a return period of 100 years, and for North Sea it is over 32 m depending on the location. The platform must be designed to resist the loads imposed by the environmental conditions, construction, load-out, transportation and installation plus other loads created by onboard equipment. The environmental protection regulations (Nouban and Sadeghi, 2013) also need to be fulfilled.

Loading

Forces applied to the platforms, including ship impact; dead and live loads; current, wind, earthquake forces; fatigue, load combinations are considered in the design phase. For further information, refer to Sadeghi (1989, 2001).

Design and Analysis of Mudmats and Piles

Essential parts of the design of offshore structures are soil investigation and pile design. Each project acquires a site-specific soil report showing the soil stratification and its characteristics for load bearing in tension and compression, shear resistance, and load-deflection characteristics of axially and laterally loaded piles. The soil report needs to show the calculated minimum axial capacities for piles of the same diameter as the platform design piles, SRD curves, different types of mudmat bearing capacity, pile group action curves, shear resistance values, pile tip end bearing values and lateral pile axial capacity values.

Sadeghi (1989, 2001) has provided different methods used for design of piles.

The ultimate capacity of piles under lateral loading, in cases of long/flexible and short/rigid piles based on the equations of Brooms, Brinch Hansen, Davisson, Robinson, Rise and Matlock for different types of soils (cohesive and non-cohesive soils) and also different conditions of API code, related computer software, soil-structure interaction and useful recommendations are given by Tamlinson (1987), API (2010) and Sadeghi (1989, 2001).

These values may be input into the structural analysis computer model to determine the minimum pile penetrations and sizes.

Pile penetration will vary depending on platform size, loads, and soil characteristics, but normally ranges from about 30 to 100 meters. For heavy platforms in the Persian Gulf, pile diameter is about 2 m and pile penetration is about 70 m below the seabed.

The soil characteristics are also used for a pile drivability analysis.

Software

The following software can be used for the structural analysis of platforms:

i. For structural analysis: SACS, FASTRUDL, MARCS, OSCAR, StruCad or SESAM,

ii. For the hydrodynamic calculations of barges: Maxsurf, Hydromax, Seamoor,

iii. For pile analyses: GRLWEAP, PDA, CAPWAP.

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Structural Analysis

To perform structural analysis, structural model is normally developed using one of the software packages mentioned in Section 4.6. A model of the structure should include all principal members of the structure, appurtenances and major equipment.

A typical template platform normally has a topside containing a Main Deck, a Cellar Deck, Sub-Cellar Deck and a Helideck. The topside is connected to the top of the piles. The piles extend from the top level of jacket through the mudline and into the soil. The jacket may serve as a template for the driving of the through-leg piles (The piles are driven through the inside of the legs of the jacket). The piles may be driven from outside the legs of the jacket in the case of using skirt piles and using an underwater hammer.

The structural model file consists of:

a. The mudline elevation and water depth,
b. Member sizes,
c. Joints definition,
d. Soil data including; mudmat bearing capacity, pile groups, T-Z, P-Y, Q-Z curve data,
e. Joint coordinates,
f. Marine growth input,
g. Inertia and mass coefficients,
h. Distributed load surface areas,
i. Wind areas, [25]
j. Anode weights and locations,
k. Appurtenances weights and locations,
l. Conductor pile and pile weights and their locations,
m. Grouting weight and locations,
n. Load cases include dead, live, environmental and crane loads, etc.

The structural analysis is a static linear analysis of the structure above the mudline combined with a static nonlinear analysis of the soil with the piles.

Checks are made for all tubular joint connections to analyze the strength of tubular joints against punching. The punching shear analysis is referred to as “joint can analysis”.

The platforms must be capable to withstand the most severe design loads and also surviving a design lifetime of fatigue loading.

A detailed fatigue analysis is required to assess cumulative fatigue damage. The analysis required is a “spectral fatigue analysis” or simplified fatigue analysis according to API. The fatigue analysis is performed with input from a wave scatter diagram and from the natural dynamic response of the platform by applying the Palmgren-Miner formula.

The Palmgren-Miner formula (1924, 1945) does not reflect the temporal sequence of loading cycles and is based only on the number of cycles. Dissipated energy-based fatigue formulas (not only based on cycle numbers) such as Sadeghi’s fatigue formula gives more accurate results (Sadeghi 1998, Sadeghi et al. 1993a and 1993b Sadeghi and Nouban 2016).

Construction

The API RP-2A code, or similar codes list the recommended material properties for structural steel plates, steel shapes and structural steel pipes. As a minimum, steel plates and structural shapes must conform to the ASTM grade A36 or equivalent.

All materials, welds and welders should be tested carefully. For cutting, fitting, welding and assembling, shop drawings are necessary.

Load-out and Transportation

The jackets are generally built onshore in "construction yards" for cost savings and to facilitate construction. Upon completion, they have to be loaded out and to be transported to offshore assembly site. The design and analysis of a jacket include load-out and transportation calculation as well. All stages of the load-out should be considered and the stresses should be checked. Before transportation, sea-fastening analysis is performed and the platform parts (jacket, decks, and appurtenances) are fastened to the barge. In the transportation analysis, the motions of roll, pitch, heave and yaw should be considered.

To perform a transportation analysis, an environmental report showing the worst sea-state conditions during that time of the year throughout the course of the intended route need to be available for design. Generally, based on Noble Denton criteria for transportation, it may assume a 20-degree angle of roll with a 10 second roll period, and a 12.5-degree angle of pitch with a 10 second period, plus a heave acceleration of 0.2 g.

Installation

All the structural sections must also be designed to withstand the lifting/launching, upending, up-righting, and other installation stresses.

The jackets must be designed to be self-supporting during pile driving and installation period. Mudmats are used in the bottom horizontal brace level, which transfer the temporary loads to the seabed surface and soil before completion of pile driving operation. The mudmats are made of stiffened steel plates and are generally located adjacent to the jacket leg connections near the mudline level.

The piles must be designed to withstand the stresses during pile driving operation. The piles are installed in sections. The first section must be long enough to go from a few meters above the top of the jacket leg to the mudline. The other sections (add-ons) must be welded to the first section (main piece) and the following add-ons at an elevation slightly higher than the top of the jacket legs.

When all the piles have been driven to the required design target penetrations, they will be cut at the design "top of pile" elevation. The jacket will then be welded to the piles about 1.0 meters or less below the top of the piles around scheme plate.

CONCLUSION

This paper gives general guidance for the essential steps required in the planning, design and construction of offshore structures. The selected reference books and the other related codes, together with the software recommended in this paper can be considered as reliable guides.

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