TENSION LEG PLATFORMS: AN OVERVIEW OF PLANNING, DESIGN, CONSTRUCTION AND INSTALLATION

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ABSTRACT

A Tension Leg Platform, which is called TLP, in short, is a type of fixed platforms that is anchored to the seafloor. The Deck platform and the hull of LTP's are connected to the foundations at the seafloor using tensioned tendon legs. Foundations of LTB's are anchored to the seabed using concrete piles. In this paper planning, design and construction of tension leg platforms are described.

Keywords: Offshore Structures, Planning, Design, construction, Oil and Gas, TLP, Tension Leg Platforms.

INTRODUCTION

A tension leg platform (TLP) is a vertically connected unsinkable compliant structural system that buoyancy of the platform creates tension in the anchoring system. The TLP generally designed to serve a number of functional roles together with offshore oil and gas usage. It is mostly used for deep-water applications. The TLP system consists of many sub-systems, each of which has a precedent in the offshore or marine industry. The value of the TLP is in the systematic effect of one component on another. The design is a highly interactive process, which should be considered for functional requirements, size of the parts and proportion, equipment layout and space allocation, hydrodynamic reaction, structural details, weight and centers of gravity, etc. All disciplines involved in the design process should be considered several iterations to obtain a proper balance of the design factors. (DNV-OS-C105, 2008) This paper summarizes available information and guidance for the design, fabrication, and installation of the TLP system. The terminology used in the design of the LTPs are shown in following figure.

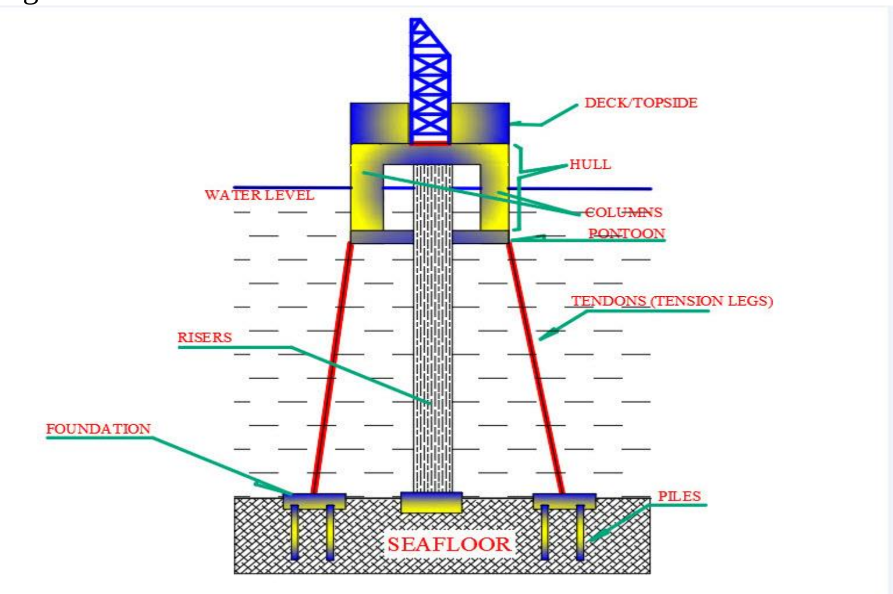

Figure .1 Terminology used in design calculations of the TLP.

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PLANNING CONSIDERATIONS

The TLP structures have many operational advantages of the fixed platform while reducing the cost of production in water depths up to about 1500 m. Its production and maintenance operations are same as fixed platforms. TLPs are weight sensitive but have limitations in accommodating heavy payloads. The TLP is produced and transported to the offshore site where the tendons are already installed on foundations, which are produced earlier at the seabed. Then, the TLPs from its four edges connected to the tendons (AISC, 2005).

Advantages of the TLPs are as follows:

(i) They are Mobile and can be used later again,
(ii) Since the platform has minimal vertical motion they are stable,
(iii) Water depth does not affect the cost of the TLP as the depth increase like other methods,
(iv) The TLPs can be constructed easily in deep waters,
(v) Cost of the maintenance is relatively low when compared with other methods.

Disadvantages of the TLPs are:

(i) The amount of the initial budget is high,
(ii) Cost of subsea are high,
(iii) Fatigue problem,
(iv) Maintenance of subsea systems are difficult and storage capacity is comparably low.

THE DESIGN PROCESS

An understanding of the entire design order and its relationship to external constraints such as financial, scheduling, equipment, and manpower requirements is required.

In planning the design process, it is important to realize the operator's contracting strategy for engineering, fabrication, and installation. Depending on how the contracting is structured between, the various parties involved. The design process should include plans and schedules for possible model testing of the platform.

The following are some of the key factors that need to be considered when developing plans for the TLP.

i. Drilling, production, quarters,
ii. Environmental, seafloor, and regulatory conditions, Capital and operating costs, risk,
iii. Service life,
iv. Contracting strategy,
v. Construction Materials, methods, assembly, and installation.

Conceptual Design

Conceptual design translates the functional requirements into the offshore design of architectural and engineering characteristics during the initial design calculations. It embodies technical feasibility studies to determine such fundamental elements as length, width, depth, draft, hull shape, anchoring system, and well and riser systems to satisfy the environmental criteria, functional requirements, and installation feasibility. The conceptual design includes initial lightship weight estimates and anchoring pretension.

The vertical stiffness of the tendon system is generally selected such that the heave, roll, and pitch periods of the TLP have low natural periods relative to the dominant periods of the wave energy, to minimize wave amplification (Wilson et al., 2003).

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Preliminary design later refines the parameters affecting cost and performance. Certain controlling factors such as platform geometry, number, and type of wells, anchoring pretension and payload should not change significantly after completion of this phase. Additionally, an associated base-case installation plan for the selected configuration is developed at this stage. Completion of preliminary design provides a precise definition that will furnish the basis for the development of project plans and specifications.

The final design stage delineates precisely features such as hull shape, dynamic response, structural details, use of different types of steel, spacing and type of frames and stringers. Paramount among the final design features are weight and center-of-gravity determination. The final general arrangement is also developed during this stage. This fixes the overall volumes and areas for consumables, machinery, living and utility spaces, and handling equipment. Depending on how the project contracting is structured, the installation-engineering input may become significant at this stage (Sankarbabu et al., 2007).

The last stage of design is the development of detailed fabrication drawings and construction specifications. These are the installation and construction instructions to yard tradesmen and are subject to the approval of the designer. Platform operation and inspection plans are also developed at this project stage.

Materials used in the design

Selection of the strength and quality levels for steel, cement grout, concrete, and other materials for the platform, foundation, and other components will generally follow the criteria commonly used for offshore structures. This paper shows steel as the primary structural material but specifically does not preclude the consideration of other materials (Kirk, 1982).

Critical locations in the platform may require specification of steel with enhanced properties consistent with predicted loadings. Strength, toughness, and fatigue resistance of the specified platform materials shall be consistent with expected fabrication practices and the inspectability of each critical location during service. Steel for the tendons may be higher strength structural steel and will affect the method of tendon fabrication and inspection as well as tendon type and service. The tendons operate under high cycle fatigue stresses superimposed on the mean stress tensile load in a seawater environment. The material should have acceptable properties in the final condition to meet the requirements of strength, toughness, and resistance to corrosion and corrosion fatigue. The material should possess adequate fracture toughness to withstand the largest non-reject able weld flaw allowed by the tendon fabrication specification at design maximum loads and minimum exposure temperatures. Resistance to stress corrosion cracking under operating conditions is critical since detection of such cracks is difficult during service. In-service inspection requirements, intervals, and methods of determining allowable defect size should be considered (Sadeghi, 2001).

Loads used for the design of the TLP's

Dead loads are non-variable static weight loads of the LTPs. These parts of the platform structure and any permanent equipment does not change during the life of the structure.

Live loads are variable static loads that can be changed, moved or removed during the life of the structure. Maximum and minimum payloads should be considered (Bentley.com, 2018).

Wind Forces

The wind conditions used in a design should be determined with appropriate means from wind data collected in accordance with Section 5 and should be consistent, in terms of joint probabilities of occurrence, with other environmental parameters assumed to occur

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simultaneously. A TLP has long natural periods in the surge, sway, and yaw, which may be excited by energy in the wind spectrum. The effects of the complete wind spectrum, including sustained and fluctuating winds, should be considered in determining the wind-induced platform loads and responses. These analyses require knowledge of the wind turbulence intensity, spectra, and spatial coherence. Wind speed and direction change in space and time. On length scales typical of even large offshore structures, statistical wind properties were taken over durations of the order of an hour change with elevation. Within long durations, there will be shorter durations with higher average speeds. Therefore, a wind speed value is only feasible if qualified by its elevation and duration. A reference value is the one-hour mean speed at the reference elevation of 10 m (DNV GL, 2018).

Ice Loads

Superstructure icing can affect tendon tension and increase local wind loads due to the increased frontal area. Wave-induced motions of floating ice can impose local impact forces, which should be considered in the design of the structure.

Wave Impact Forces

Wave slap and wave slamming forces should be evaluated for local effect on structural or flotation members and, if warranted, be included in the overall solution of the equation of motion. Wave slap forces on the columns are a potential source of tendon "ringing" responses and should be evaluated for the design of column structure. For hull external appurtenance design, wave-slamming forces due to wave-particle velocities and wave run-up jets should be considered for locations subject to free surface encounter (possibly including top of the column).

Earthquakes

For TLP sites where earthquakes are a concern, appropriate ground acceleration time histories should be obtained. For TLP tendon tension responses, the vertical ground motion is much more critical than horizontal ground motion. For foundations, both vertical and horizontal motion may be important. Additional guidelines for earthquake ground motion are referred to in API 2A-WSD (Chandrasekaran, 2018).

Accidental Loads

The potential for accidental loads arising from various kinds of the collision, dropped or swung objects, or other events should be considered in the design of the structure. Consideration should be given to employing active and passive measures in the design to resist or absorb such loads. These measures could include, but not be limited to, thickening deck plate in areas where material handling is performed, shielding risers in the wave zone, or determining the energy absorption capacity of the structure and/or anchoring system. For the latter consideration, such absorption capacity should be consistent with the size and actual speed of vessels working close to the platform.

Fire and Blast Loading

Unexpected fires or explosions may cause real problems for the offshore structures which deal with hydrocarbons. Explosions can cause an overpressure that causes to destroy the offshore structures. Fires also cause a thermal loading on close structural members that causes both deformations and unexpected stresses. Therefore, the design of an offshore structure should include a detailed treatment of potentially adverse loadings.

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SITE CONSIDERATIONS

Environmental conditions depend on geographic place, the geographic area, the foundation conditions, currents, tides, and wind speeds.

Accurate data on water depth and tidal variations are needed to fabricate tendon components so that the TLP operates at its design draft. Estimates of reservoir compaction and seafloor subsidence over the life of an oil field's depletion are also needed for the same reasons, as well as for setting deck elevation above still water (Principia-group.com, 2018).

The orientation of the LTP will be controlled by the directions of prevailing and extreme design waves, winds, and currents and by operational requirements. Platform orientation also needs to be considered within the context of the full-field architecture and may involve other issues such as referenced to true north, subsea tie-ins, onsite floating storage and/or production units, tanker offloading facilities, and marine traffic routes.

ENVIRONMENTAL DATA

Selection of the environmental data required is the responsibility of the operator. The dynamic nature of the TLP requires that the platform designer work closely with a meteorological-oceanographic specialist to develop data and interpretations in the form needed for the particular design/analysis methods to be used (Csiamerica.com, 2018).

Recognized statistical methods and models should be applied in the assessment of extreme and normal environmental conditions. The estimated reliability and used data should carefully documented and recorded. The methods used in developing available data into models should be described in detail.

The seafloor characteristics are obtained using seafloor site surveys. Seafloor site survey used to obtain data for a geologic assessment of foundation soils and the surrounding areas. It is also used to identify seafloor irregularities that could be operational hazards such as pockmarks, shallow gas, near-surface faults, debris flows, diapirism, and hard grounds.

Site Investigation

Site-specific geotechnical searches should be performed to find out the various soil types and their physical and engineering specifications for design. The foundation which pile supported structures should yield at least the soil test data necessary to find out the axial capacity of piles in tension and compression, axial and lateral pile load-deflection characteristics and mud mat penetration vs resistance.

A large movement of the seafloor may be caused by waves, earthquakes and soil loads. Such soil movements can impose significant lateral and vertical forces against foundations. Therefore, the aim of geotechnical site investigations in areas of seafloor instability should be sufficient to get design criteria for the effects of these movements (Software, 2018).

Design approaches to the main parts of the Tension Leg Platforms

A tension leg platform (TLP) is a vertically connected platform with tensioned anchoring lines vertically anchored to the floating platform, with its excess buoyancy; they are called tendons or tethers. The LTPs are vertically restrained, while it is compliant in the horizontal direction to let surge, sway, and yaw movements. The structural action resulted in low vertical force in rough seas, columns and pontoons in TLP are constructed with tubular members according to the buoyancy force exceeds the LTPs platform weight. The excess buoyancy created is balanced by the pretension in the stretched anchoring. Substantial pretension is required to prevent the tendons from falling slack even in the deepest trough, which is achieved by increasing the free-floating draft. As the requirement of pretension is

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too high, pretension cannot be imposed in tethers by any mechanical means. During commissioning, void chambers (columns and pontoon members) are filled with ballast water to increase the weight; this slackens the tendons. After tendons are securely fastened to the foundation in the seabed, de-ballasting is carried out to impose necessary pretension in the tendons (Tekla, 2018).

Under static equation of equilibrium,

(Weight of the platform) + (Initial pre-tension in tethers) = (buoyancy force) (1)

The pinned connection is provided between the deck and the anchoring lines to hold-down the platform in the desired position. Due to lateral forces, the platform moves along the wave direction. Horizontal movement is called offset. Due to horizontal movement, the platform also has the tendency to have increased immerse volume of members. Thus, the platform will undergo set-down effect. The lateral movement increases the tension in the tethers. The horizontal component of tensile force counteracts the wave action and the vertical component increases the weight, which will balance the additional weight imposed by set-down. TLP is a hybrid structure with two groups of natural periods.

Typical natural periods of the TLPs are designed far from the range of wave excitation periods and typically for TLP resonance periods of 132 s (surge/sway) and 92 s as well as 3.1 s and 3.5 s, that are obtained with proper design. The TLP design engineers have to keep the natural periods in heave and pitch below the range of important wave energy, which is obtained from the detailed structural form. The failure may either occur due to tether pullout or fatigue effect on the tethers.

Many functional requirements of a platform require special attention during the planning stages of design. In all cases, personnel and material requirements should be considered in relation to the safety and efficiency of the platform. Drilling facilities, production facilities, production risers, well systems, hull compartmentation, air gap, installation procedures.

Tendon Systems

The tendon system consists of the tendons, and ancillary components needed for operation, including load measurement systems and inspection or monitoring apparatus. The tendon system restrains motion of the platform in response to wind, waves, current, and tide to within specified limits. The tendons connect points on the platform to corresponding points on a seafloor foundation. By restraining, the platform at a draft deeper than that required displacing its weight; the tendons are ideally under a continuous tensile load that provides a horizontal restoring force when the platform is displaced laterally from its still water position. Generally very stiff in the axial direction, the tendon system limits heave, pitch, and roll response of the platform to small amplitudes while its softer transverse compliance restrains surge, sway, and yaw response to within operationally acceptable limits.

Foundations

The foundation system of the LTPs refers to the foundations used to connect the tendon legs to the seafloor. Parts of the foundation structures are leg templates and well templates or both on a single piece of the foundation that are anchored using piles, suction anchors, gravity, mud mats, or combinations. The design of the foundation structure should ensure that permissible limits of stress, displacement, and fatigue are not exceeded during and after installation.

Types of foundations for the TLP:

i. Foundation consisting of individual piles, to which individual tendons are directly

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connected,

ii. Foundation consisting of a foundation template anchored to the ocean floor by piles (driven or suction), which carry both lateral and tensile loads from multiple tendons connected to the template,

iii. Shallow foundations such as non-piled gravity foundations to which the tendons are directly attached,

iv. Combination of items i.) and ii.) with a template for each leg or one template common to all legs,

v. Auxiliary foundations consisting of anchor piles, deadweight clumps, drag anchors, or other types of anchors to which a catenary anchoring system is attached for use during installation or operation.

Site Selection and Preparation

The proper selection and preparation of the fabrication site are instrumental to the successful construction. Important considerations are as follows:

i. Coastal site:

The fabrication yard should have a deepwater dry dock or means for transferring the hull into the water. It may be skidded onto a submersible barge or launched directly into the water. If the dry dock does not have sufficient depth, the use of auxiliary buoyancy and/or stability modules to support the hull during construction may be acceptable,

ii. Sheltered offshore construction area:

Deepwater construction facilities may be located offshore, away from the fabrication yard, and insufficiently deep and sheltered waters to allow convenient access for either float over deck mating or integral deck construction,

iii. Deepwater channel:

For wet tow, a deep-water channel should be available to permit towing the completed structure to sea. The minimum channel depth should be sufficient to allow the platform to be towed at a draft commensurate with specified stability criteria. Alternatively, for a dry tow, a site, which allows placement of the structure on a dry tow transport vessel, is required.

FABRICATION AND INSTALLATION

The method of platform fabrication should be considered as part of the preliminary design since the method selected will significantly affect not only structural design but also the feasibility of fabrication at a chosen site (El-Reedy, 2017).

There are four basic methods of platform fabrication as follows:

i. Deck float over:
With this method, the deck is constructed in one piece separately from the hull, floated over the hull, lowered, and mated to it using controlled ballast and jacking procedures. Outfitting of the deck is usually completed prior to deck mating,

ii. Modules:

With this method, the deck facilities are installed in the form of stacked modules on top of the hull. This is generally done at a final outfitting facility prior to final tow to the installation site. Modules may be designed to carry global loading between columns or to "float" on sliding supports. In the latter case, a structural frame connecting the columns should carry the global loading between columns,

iii. Integral deck and hull:

With this method, the deck is constructed integrally with the hull. A sufficiently deep dry dock or a convenient, sheltered deep-water site is a prerequisite for this type of construction. Outfitting of the deck may be completed together with the construction of the deck subassemblies or may take place subsequent to deck and hull construction,

iv. Deck lifting:

The deck is constructed in one piece and is lifted and integrated offshore.

TRANSPORTATION

Transportation of the LTPs should be planned considering structural design in order that loadings during loadout, tow, and launch are clearly defined. Applicable regulations and/or codes such as those of the United States Coast Guard and the International Maritime Organization should be considered. Model testing may be used to confirm analysis results. The methods used should be based on well-proven principles, techniques, systems and equipment. Qualified experienced personnel should be used for these operations.

Precautions should be taken during transportation to sea to avoid damage to the structure. Transportation can be either by towing or by carriage on a mobile heavy-lift vessel. Escort tugboats to provide protection against damage should be considered. Stability criteria for transportation should be selected as appropriate for the time, duration, and location of the route as well as for the degree of damage protection and control afforded. The ability either to outrun or to seek a safe harbor during a storm will have a significant effect on the motion requirements for the transportation. Specific transportation requirements will depend on whether or not the vessel is operated (Gerwick, 2007).

CORROSION PROTECTION

Steel materials should be protected from the effects that convert a refined metal to a more chemically stable form, such as its oxide, hydroxide, or sulfide. By the use of a corrosion protection system that is described in with DNV-RP-B401, or NACE SP0176. The corrosion protection systems include coatings, cathodic protection, corrosion allowance, and corrosion monitoring. Overprotection may cause hydrogen embrittlement and needed to prevent damage to the coating layers (Singh, 2017).

WAVE ANALYSIS AND FURTHER INFORMATION

For extra technical specification and data on the ecological information together with equations and the information required for outline and examination of such structures as well as the damage evaluation, the guidelines, information and suggestions given by (API, 2010), (Sadeghi, 1989, 1998a, 1998b, 2004, 2007a, 2007b, 2008, 2011, 2013 and 2017), (US Army Coastal Engineering Research Center, 1980), (US Army Corps of Engineers, 2002), Muyiwa and Sadeghi, 2007), (Sadeghi and Nouban, 2010, 2011, 2016, 2017), (Sadeghi and Aleali, 2008) (Nouban and Sadeghi, 2013 and 2014), (US Army Corps of Engineers, 2011), (Nouban, 2016), (Nouban et al., 2016, 2017) may be utilized.

CONCLUSION

All designed LTB structures should have the ability to resist all types of loads effecting on them. These phases should also consider temporary loads and conditions as well. Separately, production, transportation, lifting, towing and installation arrangements must be well-planned. Construction materials and the complexity of joints should be selected according to the importance of the structure. Monitoring principles also must be set to control and maintain the LTB structure.

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