An Overview of Design, Analysis, Construction and Installation of Offshore Petroleum Platforms Suitable for Cyprus Oil/Gas Fields

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Abstract
Offshore structures are used worldwide for a variety of functions and in a variety of water depths, and environments. Since right selection of equipment, types of platforms and method of drilling and also right planning, design, fabrication, transportation, installation and commissioning of petroleum platforms, considering the water depth and environment conditions are very important, this paper will present a general overview of these aspects. This paper reviews the fundamentals behind all types of offshore structures (fixed or floating) and, in the case of fixed platforms, will cover applications of these principles. The overall objective is to provide a general understanding of different stages of design, construction, loadout, transportation and installation of offshore platforms. Finally, for different sea-water depths, in which the Cyprus platforms are intended to be installed, suitable kinds of offshore platforms are proposed.

Keywords: *Rigs, Platforms, Offshore, Structure, Planning, EPC Constract,*

Introduction
Offshore platforms have many uses including oil exploration and production, navigation, ship loading and unloading, and to support bridges and causeways. Offshore oil production is one of the most visible of these applications and represents a significant challenge to the design engineer. These offshore structures must function safely for design lifetimes of twenty-five years or more and are subject to very harsh marine environments. Some important design considerations are peak loads created by hurricane wind and waves, fatigue loads generated by waves over the platform lifetime and the motion of the platform. The platforms are sometimes subjected to strong currents which create loads on the mooring system and can induce vortex shedding.

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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. The offshore oil and gas platforms are generally made of various grades of steel, from mild steel to high-strength steel, although some of the older structures were made of reinforced concrete.

Within the category of steel platforms, there are various types of structures, depending on their use and primarily on the water depth in which they will work.

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

Offshore oil rig and platform types

Different types of offshore oil rigs and platforms are used depending on the offshore oil/gas field water-depth and situation.

Rigs are used for the drilling of the wells and platforms are installed in the field for extracting oil/gas operation. Main types of rigs and platforms are briefly explained as follows: Drilling for natural oil/gas offshore, in some instances hundreds of miles away from the nearest landmass, poses a number of different challenges from drilling onshore. With drilling at sea, the sea floor can sometimes be thousands of feet below sea level. Therefore, while with onshore drilling the ground provides a platform from which to drill, at sea an artificial drilling platform must be constructed.

Moveable offshore drilling platforms/rigs

There are two types of offshore drilling rings/platforms. The first type is moveable offshore drilling rigs that can be moved from one place to another and the second type is the fixed rigs/platforms.

Drilling barges

Drilling barges are used mostly for inland, shallow water drilling. This typically takes place in lakes, swamps, rivers, and canals. Drilling barges are large, floating platforms, which must be towed by tugboat from location to location. Suitable for still, shallow waters, drilling barges are not able to withstand the water movement experienced in large open water situations.

Jackup platforms/rigs

Jackup rigs are similar to drilling barges, with one difference. Once a jackup rig 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 barge. However, jackup rigs are suitable only for shallower waters, as extending these legs down too deeply would be impractical. This rig type can only operate to 500 feet in the depth of water. These rigs are typically safer to operate than drilling barges, as their working platform is elevated above the water level.

Submersible platforms/rigs

Submersible rigs, also suitable for shallow water, are like jackup rigs in that they come in contact with the ocean or lake floor. These rigs consist of platforms with two hulls positioned on top of one another. The upper hull contains the living quarters for the crew, as well as the actual drilling platform. The lower hull works much like the outer hull in a submarine – when the platform is being moved from one place to another, the lower hull is filled with air – making the entire rig buoyant. When the rig is positioned over the drill site, the air is let out of the lower hull, and the rig submerges to the sea or lake floor. This type of rig has the advantage of mobility in the water; however, once again its use is limited to shallow water areas.

Semi-submersible platforms/rigs

This is an offshore oil rig that has a floating drill unit that includes columns and pontoons that, if flooded with water, will cause the pontoons to submerge to a depth that is predetermined. Semi-submersible rigs are the most common type of offshore drilling rigs, combining the advantages of submersible rigs with the ability to drill in deep water. Semi-submersible rigs work on the same principle as submersible rigs; through the 'inflating' and 'deflating' of its lower hull. The rig is partially submerged, but still floats above the drill site. When drilling, the lower hull, filled with water, provides stability to the rig. Semi-submersible rigs are generally held in place by huge anchors, each weighing upwards of ten tons. These anchors, combined with the submerged portion of the rig, ensure that the platform is stable and safe enough to be used in turbulent offshore waters.

Semi-submersible rigs can also be kept in place by the use of dynamic positioning.

Semis-ubmersible rigs can be used to drill in much deeper water than the rigs mentioned above. Now with a leap in technology, depths of up to 6,000 feet (1,800 m) can be achieved safely and easily. This type of rig platform will drill a hole in the seabed and can be quickly moved to new locations.

Drillships

Drillships are exactly as they sound: ships designed to carry out drilling operations. These boats are specially designed to carry drilling platforms out to deep-sea locations. A typical drillship will have, in addition to all of the equipment normally found on a large ocean ship, a drilling platform and derrick located on the middle of its deck. In addition, drillships contain a hole called a “moonpool”, extending right through the ship down through the hull, which allows for the drill string to extend through the boat, down into the water. This offshore oil rig can drill in very deep waters.

Drillships use 'dynamic positioning' systems. Drillships are equipped with electric motors on the underside of the ships hull, capable of propelling the ship in any direction. These motors are integrated into the ships computer system, which uses satellite positioning technology, in conjunction with sensors located on the drilling template, to ensure that the ship is directly above the drill site at all times.

Fixed platforms

In certain instances, in shallow water, it is possible to physically attach a platform to the sea floor. This is what is shown above as a fixed platform rig. The 'legs' are constructed of concrete or steel, extending down from the platform, and fixed to the seafloor with piles. With some concrete structures, the weight of the legs and seafloor platform is so great, that they do not have to be physically attached to the seafloor, but instead simply rest on their own mass. There are many possible designs for these fixed, permanent platforms. The main advantages of these types of platforms are their stability; as they are attached to the sea floor, there is limited exposure to movement due to wind and water forces. However, these platforms cannot be used in extremely deep water; it simply is not economical to build legs that long.

Different types of fixed offshore platforms are shown in Figure 1.

Template (jacket) platforms

This type of fixed platform is the one usually installed in the Persian Gulf, the Gulf of Mexico, Nigeria, and California shorelines and is made of steel (Sadeghi 1989, 2001). Template platforms mainly consist of jacket, decks and piles.

All of the petroleum platforms installed in the Persian Gulf are of the Template (Jacket) type. At the present time about 145 template platforms belonging to Iran and about 130 template platforms belonging to Arabian countries are installed in the Persian Gulf. Figure 2 shows one template platform.

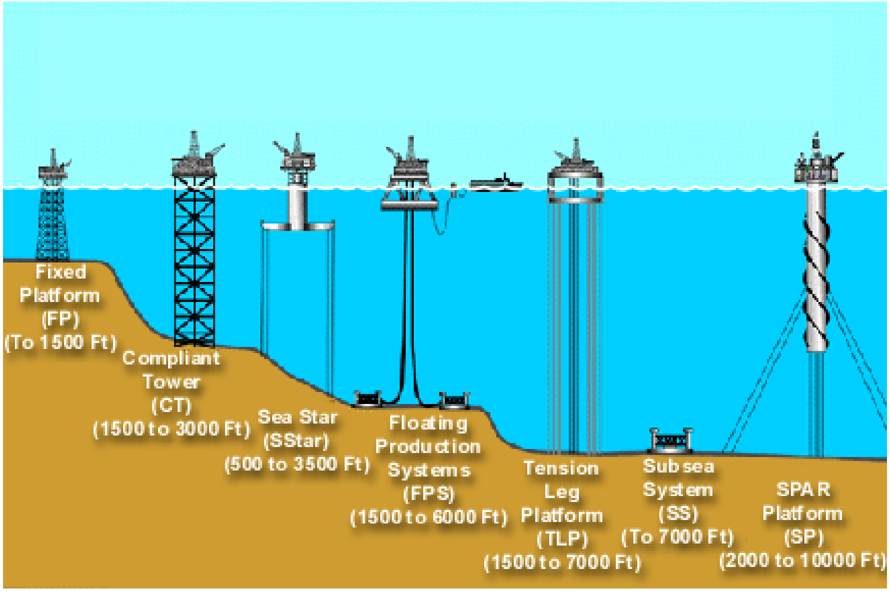

Figure 1. Different types of offshore fixed platforms

Figure 2. Offshore Template Platform

Compliant Towers (Tower platforms)

Compliant towers are much like fixed platforms. They consist of a narrow tower, attached to a foundation on the seafloor and extending up to the platform. This tower is flexible, as opposed to the relatively rigid legs of a fixed platform. This flexibility allows it to operate in much deeper water, as it can 'absorb' much of the pressure exerted on it by the wind and sea. Despite its flexibility, the compliant tower system is strong enough to withstand hurricane conditions.

Seastar platforms

Seastar platforms are like miniature tension leg platforms. The platform consists of a floating rig, much like the semi-submersible type discussed above. A lower hull is filled with water when drilling, which increases the stability of the platform against wind and water movement. In addition to this semi-submersible rig, however, Seastar platforms also incorporate the tension leg system employed in larger platforms. Tension legs are long, hollow tendons that extend from the seafloor to the floating platform. These legs are kept under constant tension, and do not allow for any up or down movement of the platform. However, their flexibility does allow for side-to-side motion, which allows the platform to withstand the force of the ocean and wind, without breaking the legs off. Seastar platforms are typically used for smaller deep-water reservoirs, when it is not economical to build a larger platform. They can operate in water depths of up to 3,500 feet.

Floating production systems

Floating production systems are essentially semi-submersible drilling rigs, as discussed above, except that they contain petroleum production equipment, as well as drilling equipment. Ships can also be used as floating production systems. The platforms can be kept in place through large, heavy anchors, or through the dynamic positioning system used by drillships. With a floating production system, once the drilling has been completed, the wellhead is actually attached to the seafloor, instead of up on the platform.

The extracted petroleum is transported via risers from this wellhead to the production facilities on the semi-submersible platform. These production systems can operate in water depths of up to 6,000 feet.

Tension leg platforms

Tension leg platforms are larger versions of the Seastar platform. The long, flexible legs are attached to the seafloor, and run up to the platform itself. As with the Seastar platform, these legs allow for significant side to side movement (up to 20 feet), with little vertical movement. Tension leg platforms can operate as deep as 7,000 feet.

Subsea system

Subsea production systems are wells located on the sea floor, as opposed to at the surface. As in a floating production system, the petroleum is extracted at the seafloor, and then can be 'tied-back' to an already existing production platform. The well can be drilled by a moveable rig, and instead of building a production platform for that well, the extracted oil and natural gas can be transported by a riser or even undersea pipeline to a nearby production platform. This allows one strategically placed production platform to service many wells over a reasonably large area. Subsea systems are typically in use at depths of 7,000 feet or more, and do not have the ability to drill, only to extract and transport.

Spar Platforms

Spar platforms are among the largest offshore platforms in use. These huge platforms consist of a large cylinder supporting a typical fixed rig platform. The cylinder however does not extend all the way to the seafloor, but instead is tethered to the bottom by a series of cables and lines. The large cylinder serves to stabilize the platform in the water, and allows for movement to absorb the force of potential hurricanes. The first Spar platform in the Gulf of Mexico was installed in September of 1996. It's cylinder measured 770 feet long, and was 70 feet in diameter, and the platform operated in 1,930 feet of water depth.

Summary of Offshore Construction Project stages

Similar to the other fields of activities, the offshore platform construction services can be provided on a turn-key basis, i.e. covering investment feasibility studies, basic and detailed design, procurement, installation of steel structures and equipment, and commissioning. All or any of the above listed work stages can be performed under the supervision of an independent certifying authority followed by the issue of a certificate of class.

Basically an offshore platform construction project includes the following phases:

- Investment feasibility studies
- Construction site survey including diving inspections of installation locations
- Conceptual, basic and detailed design
- Platform element strength calculations
- Design approval by the regulating authorities
- Procurement
- Fabrication of steel structures
- Preparation of platform elements transportation and offshore installation procedures

- Loadout, transportation and installation operations
- Commissioning

Usually, fabrication of steel structures for such facilities as offshore platforms is carried out at locations significantly remote from the installation site. Transportation of such large-sized elements is a complicated operation requiring a special design, with structural strength calculations for the transportation conditions.

Since offshore construction operations require prompt response and coordination of design, engineering, material/equipment supply and steel structure fabrication activities, some of them are often performed simultaneously due to the tight scheduling requirements.

Design of offshore fixed platforms

The most commonly used offshore platforms in the Gulf of Mexico, Nigeria, California shorelines and the Persian Gulf are template type platforms made of steel, and used for oil/gas exploration and production (Sadeghi 1989, 2001).

The design and analyses of these offshore structures must be made in accordance with recommendations published by the American Petroleum Institute (API).

The design and analysis of offshore platforms must be done taking into consideration many factors, including the following important parameters:

- Environmental (initial transportation, and in-place 100-year storm conditions)
- Soil characteristics
- Code requirements (e.g. American Institute of Steel Construction “AISC” codes)
- Intensity level of consequences of failure

The entire design, installation, and operation must be approved by the client.

Different analyses needed for template platforms

Different main analyses required for design of a template (jacket) type platform are as follows (Sadeghi 2001):

- In-place analysis
- Earthquake analysis
- Fatigue analysis

- Impact analysis
- Temporary analysis
- Loadout analysis
- Transportation analysis
- Appurtenances analysis
- Lift/Launch analysis
- Upending analysis
- Uprighting analysis
- Unpiled stability analysis
- Pile and conductor pipe drivability analysis
- Cathodic protection analysis
- Transportation analysis
- Installation analysis.

Environmental parameters

The design and analysis of fixed offshore platforms may be conducted in accordance with the API's "Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms – Working Stress Design (API-RP-2A-WSD)". The latest revision of API-RP-2A-WSD is the 21st edition dated December 2000. The API specifies minimum design criteria for a 100-year design storm. Helicopter landing pads/decks on offshore platforms must conform to API RP-2L (latest edition being the 4th edition, dated May 1996)

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 of up to 4 m in shallow waters. The wave heights up to 12.2 meters and wind velocities up to 130 km/hr for the Persian Gulf, coupled with tides up to 3 m are considered in design of platforms (Sadeghi 2001).

The design wave height in the Southern Caspian Sea is about 19 m for a return period of 100 years, and for the North Sea is over 32 m depending on the location.

The API RP-2A also specifies that the lowest deck must maintain a minimum of 1.5 m air gap between the bottom of the deck beams and the wave crest during the maximum expected level of water considering the combination of wave height and tides.

The platform should resist the loads generated by the environmental conditions and loadout, transportation and installation loads plus other loads generated by onboard equipment.

Geotechnical data

Another essential part of the design of offshore structures is the soil investigation. The soil investigation is vital to the design of offshore structures, because it is the soil that ultimately resists the enormous forces and movements present in the piling, at the bottom of the ocean, created by the presence of the platform in the storm conditions.

The under seabed soil normally can be clay, sand, silt, or a mixture of these. Each project must acquire 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. This type of report is developed by doing soil borings at the desired location, and then performing in-situ and laboratory tests in order to develop data usable to the platform design engineer.

The soil report should 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. It should also show shear resistance values and pile tip end bearing values. Pile axial capacity values are normally called “T-Z” values, shear values are called “P-Y” values, and end bearing values are called “Q-Z” values (Sadeghi 2001, American Petroleum Institute [API] 1996).

These values, once provided to the engineer by the geotechnical engineers, will be input into the structural analysis model (normally in StruCad, FASTRUDL or SACS software), and will determine minimum pile penetrations and size, considering a factor of safety of 1.5. For operating loads, the FS must be 2.0 for piles. The unity check ratios must not exceed 1.0, in the piles or anywhere else in the platform (API 1996).

Pile penetrations will vary depending on platform size and loads, and soil characteristics, but normally range from about 30 meters to about 100 meters.

For heavy platforms in the Persian Gulf, pile diameter is about 2 m and pile penetration is about 70 m under the seabed.

The soil characteristics are also used for a pile drivability analysis. Sandy soils are very desirable for axial end bearing, but can be detrimental to pile driving when encountered near the surface. Clay soils are easier to drive piles through but do not provide good support for end bearing, although they provide good resistance to laterally loaded piles.

Software used in the platforms design

To perform a structural analysis of platforms, the following software may be used (Sadeghi 2001):

- SACS, FASTRUDL, MARCS, OSCAR, StruCAD or SESAM for structural analysis.
- Maxsurf, Hydromax, Seamoor for hydrodynamics calculations.
- GRLWEAP, PDA, CAPWAP for pile analyses.

Structural analysis

To perform a structural analysis of a platform, a structural model of the structure is developed normally using one of the following common software packages developed for the offshore engineering: SACS, FASTRUDL, MARCS, SESEM, OSCAR or StruCAD (Sadeghi 2001).

A model of the structure should include all principal members of the structure, appurtenances and major equipment.

A typical offshore structure supported by piles normally has a deck structure containing a Main Deck, a Cellar Deck, Sub-Cellar Deck and a Helideck. The deck structure is supported by deck legs connected to the top of the piles. The piles extend from above the Mean Low Water through the mudline and into the soil. Underwater, the piles are contained inside the legs of a “jacket” structure which serves as bracing for the piles against lateral loads. The jacket may also serve as a template for the initial driving of the through leg piles (The piles may be driven through the inside of the legs of the jacket structure). In the case of using skirt piles the piles may be driven from outside of the legs of the jacket structure. The structural model file consists of:

- The type of analysis, the mudline elevation and water depth.
- Member sizes
- Joints definition.
- Soil data (i.e. mudmat bearing capacity, pile groups, T-Z, P-Y, Q-Z curve points).
- Plate groups.
- Joint coordinates.
- Marine growth input.
- Inertia and mass coefficients (C_D and C_M) input.
- Distributed load surface areas.
- Wind areas.
- Anode weights and locations

- Appurtenances weights and locations
- Conductors and piles weight and location
- Grouting weight and locations
- Load cases include dead, live and environmental loading, crane loads, etc.

Any analysis of offshore platforms must also include the equipment weights and a maximum deck live loading (distributed area loading), dead loads in addition to the environmental loads mentioned above, and wind loads. Underwater, the analysis must also include marine growth as a natural means of enlargement of underwater projected areas subject to wave and current forces.

The structural analysis will be a static linear analysis of the structure above the mudline combined with a static non-linear analysis of the soil with the piles.

Additionally, checks will be made for all tubular joint connections to analyze the strength of tubular joints against punching. The punching shear analysis is colloquially referred to as “joint can analysis”. The Unity Checks must not exceed 1.0.

All structural members will be chosen based on the results of the computer-aided in-place and the other above-mentioned analyses. The offshore platform designs normally use pipe or wide flange beams for all primary structural members.

Concurrently with the structural analysis the design team will start the development of construction drawings, which will incorporate all the dimensions and sizes optimized by the analyses and will also add construction details for the field erection, transportation, and installation of the structure.

The platforms must be capable of withstanding the most severe design loads and also of surviving a design lifetime of fatigue loading. The fatigue analysis is developed with input from a wave scatter diagram and from the natural dynamic response of the platform, and the stiffness of the pile caps at the mudline by applying Palmgeren-Miner formula (Sadeghi 2001). A detailed fatigue analysis should be performed to assess cumulative fatigue damage. The analysis required is a “spectral fatigue analysis” or simplified fatigue analysis according to API.

API allows a simplified fatigue analysis if the platform (API 1996):

- Is in less than 122 m (400 ft) water depth.
- Is constructed of ductile steel.
- Has redundant framing.
- Has natural periods less than 3 seconds.

Client permits and approval process

All offshore platform designs (whether structural or facilities) must be approved by the Client. The analysis results must demonstrate that the platforms have been designed using standard accepted methods and that the structures will be able to perform adequately in accordance within the design parameters as prescribed by the API RP-2A and the American Institute of Steel Construction (AISC) codes or other codes.

The permit application package must contain an analysis summary (and explanation of the modifications, if applicable) and show the maximum foundation design loads, and unity checks. It must have attached copies of the soil report, and the certified structural construction drawings. The drawings and analyses and the complete package must be signed by the Consultant Lead Engineer, and the Project Manager and be submitted to the Client.

Fabrication (Construction)

The API RP-2A lists 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 American Society for Testing and Materials (ASTM) grade A36 (yield strength, 250 MPa) (AISC). For higher strength applications, the pipe must conform to API 5L, grade X52.

All materials, welds and welders should be tested carefully. For cutting, fitting, welding and assembling, shop drawings are necessary. A suitable fabrication yard on shorelines should be selected. This fabrication yard must be well equipped and be large enough for fabrication and loadout of platforms.

Loadout and transportation

The offshore structures are generally built onshore in "fabrication yards" for cost savings and to facilitate construction. Upon completion, these structures have to be loaded out and be transported offshore to the final assembly site, on board a vessel. Therefore an offshore design and analysis of a structure must include a loadout and transportation analysis as well.

All stages of the loadout of the structure should be considered and the stresses checked. Before transportation of the platform, a seafastening 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, the engineer must have an environmental report showing the worst seastate conditions during that time of the year throughout the course of the intended route. 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 (Sadeghi 2001).

Installation

All the structural sections of an offshore platform must also be designed to withstand the lifting/launching, upending, uprighting and other installation stresses.

The jackets must be designed to be self-supporting during the pile driving and installation period. Mudmats are used at the bottom horizontal brace level which will be transferred to the temporary loads to the seabed surface and soil before completion of the pile driving operation. The mudmats are made of stiffened steel plates and are generally located adjacent to the jacket leg connections for obvious structural reasons.

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 (in this regard setup and self weight penetration of pile should be taken into account). The other sections (add-ons) must be field welded to the first section 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 trimmed at the design “top of pile” elevation. Te jacket will then be welded to the piles about 1.0 meters or less below the top of the piles around scheme plate.

Examples of the dimensions, weights and costs of some platforms

Based on the experiences of the author from different projects in which the author was involved as Project Manager, Project Engineering Manager and Project Engineer, the following values are presented:

a) – For template platforms installed in the Persian Gulf:

Max. Water depth: 72 m (Max. water depth in Persian Gulf is about 120 m). Weight: between 500 tonnes and 10,000 tonnes (3,000 tonnes for jacket and piles plus 7,000 tonnes for a production platform)

Price: up to 80,000,000 USD/platform

Price for a gas offshore complex: 400,000,000 USD (for 4 platforms and pipeline to shore)

Detail design contract price: 3% to 5% of total price

Procurement portion price: about 55% of total price

b) – For semi-submersible platforms installed in the Caspian Sea:

Max. Water depth: 1,000 m (Max. water depth in Southern Caspian Sea 1027 m and Max. water depth in Northern Caspian Sea about 150 m) (Kosarev & Yablonskaya 1884, KEPCO Engineering Department 2001, Sadeghi 2004).

Weight: about 30,000 tonnes

Price: about 350,000,000 USD for platform plus 60,000,000 USD for 3 tugboats

Conclusion

Each platform/rig type is chosen mainly due to water depth considerations, and due to the deck equipment necessary to perform its service. The jackup platforms may be used in relatively shallow water depths up to 150 m (about 500 feet). The fixed template (jacket) platforms vary in size and height, and can be used in water depths up to about 300 meters, although most commonly in water depths less than 150 meters.

The semi-submersible platforms/rigs are used in water depths up to 1800 meters (about 6,000 feet). The Tension Leg Platforms are used in water depths greater than 300 meters.

The SPAR platforms are used in very deep water exploration.Since the selection of drilling rig and petroleum platform type depend on the seawater depth in which the oil/gas fields are situated, the following solutions are provided for the Cyprus oil/gas fields considering the environment conditions and sea water depths:

a) For water depths up to 150 m, tender rig or Jack-up rig for drilling and template (Jacket) for oil/gas extraction.
b) For water depths between 150 m and 300m, semi-submersible rig for drilling and template (jacket) platform for oil/gas extraction.
c) For water depths between 300 m and 400m, semi-submersible rig for drilling and guyed-tower platforms for oil/gas extraction.
d) For water depths between 400 m and 1800m, semi-submersible rig for drilling and Tension leg platform or semi-submersible platform for oil/gas extraction.
e) For water depths more than 1800 m, drillship rig for drilling and tension leg, subsea system or spar platforms for oil/gas extraction.

Considering the importance of fabrication and installation time factor, more expensive rigs/platforms and procedures may also be studied.

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