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Aspects on offshore drilling process in deep and very deep waters

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Abstract: Offshore is a broad concept and therefore in this article offshore refers to drilling wells of oil and gas in the hydrocarbons deposits located deep from the seabed. Oil and gas is drilled wells with help of different offshore structures, for example rigs and vessels. Offshore drilling is a complex process where a borehole is drilled through the seabed. Of course, offshore refers to energy activity located at a distance from the shore. Oil and natural gas is located below the bedrock, which makes it difficult to extract them. A limited amount of inland oil has driven oil industry to the seas to find more oil deposits. There are high financial markets in the offshore industry and that is why much money is being invested in new offshore structures all around the world. Offshore structures are constructed for many different purposes worldwide. The structures are expensive to construct but there is an opportunity to have significant financial profit.

Keywords: deep and very deep water, oil, gas, drilling platform, marine currents, offshore.

1. Introduction

Offshore structures are constructed for many different purposes worldwide. The structures are expensive to construct but there is an opportunity to have significant financial profit. The construction process demands a lot of expertise from the designers because the offshore regulations set high standards for the building process. Working with oil and gas is always dangerous and the risks are higher than in normal marine structures such as ships. Different offshore structures are designed for various water depths.
Classification of water depths:

- < 50 meters – Very shallow water;
- < 500 meters – Shallow water;

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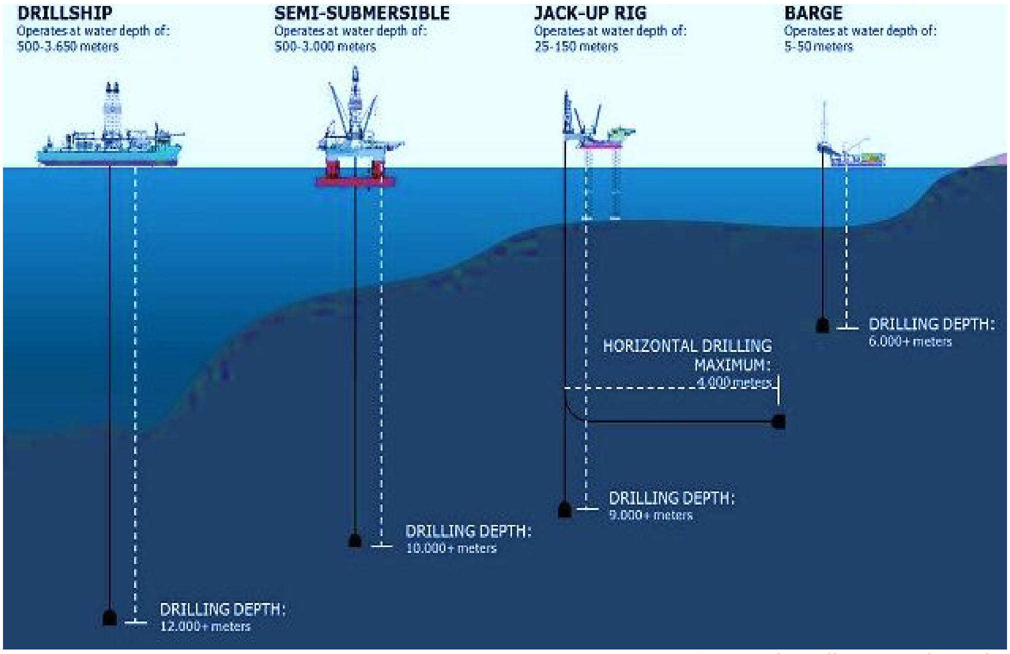
- < 1500 meters – Deep water;
- > 1500 meters – Very deep water.

Offshore structures are classified to rigs and vessels. Offshore oil rigs (also known as platforms) must service safely for over 25 years. Difficult sea conditions with salt water set challenges to the rigs and it is crucial to consider the circumstances as peak loads created by storm winds and waves. The structures are made of various grades of steel and the platforms are the tallest structures on the earth. Their massive weight demands special transportation methods on the sea.

Offshore rigs, also known as platforms are massive structures which are built for oil and gas drilling out of the seabed. Platforms are equipped with storages where the oil can be reserved before it is transported to refineries. Several people are working on the rigs and usually there are accommodation areas for them. Depending on the requirement, rigs can be fixed to the seabed or can be floating with anchors and wires, from example in Fig. 1 - Types of drilling rigs and structures [1].



Sources: https://www.google.com/

Fig. 1. Types of drilling rigs and structures [1].

Drilling barge (Fig. 2)

These drilling barge it's specific equipped for drilling operations in smooth seas, - they are designed to work in shallow water (less than 50 meters deep) -, or mostly used for shallow drilling in non-ocean waters. Evident, these platform's exactly what it sounds like: a floating barge with drilling equipment. Normally it's not equipped with its own propulsion machinery. Maxim drilling depth is approximately 50 meters = 165 ft. Tugboats tow the platform out to the site, where anchors hold it in place. However, given that drilling barges basically just float on the surface, they're only suitable for calm waters and very shallow water.

Sources: https://www.google.com/

Fig. 2. Drilling barge rig.

Jack-up rig (Fig. 3)

The jack-up rig is an oil rig that it is suitable for drilling in water depths up to 150 meters = 492 ft
(~ 500 ft). Jack-ups are categorized to two main types; the independent-leg type with normally three legs with a lattice construction, and the mat type where the legs are attached to a very large mat that rests on the seabed. Both types have a hull. They are floating in their location, lowering their legs to the seabed, and jacking the hull out of the water to the required elevation. The advantage of the jack-up design is that it offers a steady and relatively movement-free platform in the drilling position and starts operation quickly and easily.

Semi-Submersible Platform (Fig. 4)

Semi-Submersible platforms are floating structures that include pontoons and columns. They are the most popular drilling platforms, because they can be moved from one place to another. The large anchors or the dynamic positioning system hold the positioning of the rig. These types of platforms can be used in water depths up to 3000 meters = 9,842 ft (~ 10,000 ft).

Sources: https://www.google.com/

Fig. 3. Jack-up rig

Sources: https://www.google.com/

Fig. 4. Semi-Submersible Platform

Drillship (Fig. 5)

These vessels have a ship-shaped design and they are fitted with drilling equipment. The dynamic positioning system keeps them stable at the sea and drillships can change the drilling site quickly. Because of this mobility, drillships are more expensive to construct than semi-submersibles. In the fore of the ship there is an accommodation area for the crew. Drillships can be operated in water depth up to 3650 meters = 11,975 ft (~ 12,000 ft).

Sources: https://www.google.com/

Fig. 5. Drillship *(from Ocean Rig).*

2. The Offshore Drilling Process

The offshore drilling industry requires complex machinery and hundreds of people. At every stage, there are things that can go wrong, so extra care needs to be taken at every stage.

First, a large diameter hollow tube called a conductor is embedded in the seafloor along with a jet drill. When the conductor penetrates about 250 feet beneath the seabed, the jet drill is removed and a different drill bit is introduced. This drill bit is connected to a drill pipe and has special teeth that crush or break the rocks in the seafloor, making a deeper hole. Once the desired depth is reached, the drill bit and drill pipe are brought back to the surface.

Once the drill bit is brought back to the surface cement is pumped down the drill pipe and through a nozzle pushed out on the sides. The cement goes between the pipe and the conductor. After a few hours, the cement hardens. Once the cement is set, drilling continues with a smaller diameter drill bit. Drilling goes deep down into fresh rocks [2].

An offshore drilling process is illustrated in the Figure 6.

Most of deep and very deep water wells are drilled vertically. For economic reasons, the exploitation is expected to be achieved through directional or horizontal drilling or by means of multilateral wells. The water depth represents the most important factor that is taken into account when wells are designed.

So, designing drilling in deep and very deep water regions cannot be considereda routine procedure. Many companies consider that drilling in deep and very deep waters is more complicated when associated to pressures at high temperatures, as wel as when drilling in equilibrium is required. Another important element for designing wells in deep and very deep waters is represented by the environment factors, to refer the: action of winds, waves and marine currents; bottom conditions; ecosystem.

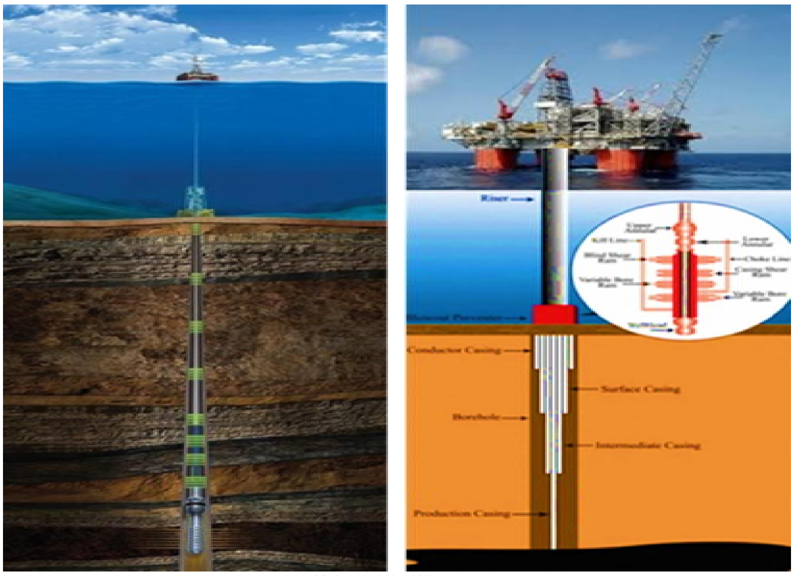


Fig. 6. Offshore drilling process [2].

2.1. Drilling from floating offshore rigs

The techniques for drilling offshore wells from floating rigs are basically the same as those used for onshore wells.

In general, the factors involved in drilling wells from floating rigs are due to the following:

- The wellhead is located on the seabed;
- The submarine BOPs are located on the subsea wellhead and are controlled hydraulically or electrically from the surface;
- The BOPs are connected to the rig by means of a marine riser (enabling the drilling fluid to circulate upwards);
- The marine riser, connected at the top of the BOP stack, has a ball joint on its base and a slip joint above sea level to offset the horizontal and vertical movements of the rig;
- The lines for preventing blowouts (kill lines and choke lines) run from the surface manifold on the rig to the subsea wellhead, as independent lines fixed to the outside of the marine riser. [3]

2.2. The Blow-Out Preventer (BOP) and marine riser

In offshore drilling BOPs have the same function as those used in onshore wells, but are connected in a single complex (the BOP stack) before being mounted on the wellhead, so as to reduce assembly times at the sea bottom. The BOP stack is lowered and fastened to the wellhead by means of a hydraulically controlled connection, ensuring hydraulic sealing (see Fig. 7).

After a suitable depth has been drilled, the drill bit is removed and replaced with a steel tube called the casing. The casing is fitted at the wellhead with what’s referred to as a BOP (blow-out preventer) placed on top of the wellhead.

The main function of the BOP is to prevent the uncontrolled flow of liquid and gases during the drilling process.

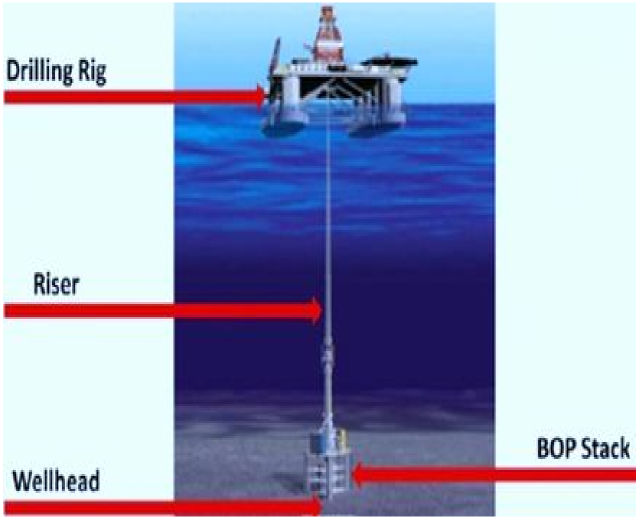


Fig. 7. Offshore drilling process

The BOP is fitted with a riser that allows the drilled fluids to return to the surface, connecting the new oil well to the rig itself. A drill pipe is lowered down from the riser, through the BOP and into the wellhead, extending down into the well itself. Drill fluid or mud is pumped back through the pipe. The mud eventually circulates around up through the marine riser and back to the surface of the oil rig.

In the event of temporarily abandoning the well because of adverse weather and sea conditions, it is possible to suspend the pipes on the shaped rams of the lower BOP, to unscrew the pipes and to close the well with the upper blind rams – at this point it is possible to disconnect also the marine riser and possibly to abandon the site.

The marine riser can be reconnected when the sea and weather conditions improve.

The hydraulic lines controlling the various functions of the BOP stack converge in a connector block, to which is connected the bundle of flexible pipes for their control from the surface.

As drilling continues, sets of different diameters of casing are used to penetrate into the rock. Each run of casing is cemented to provide integrity. High-tech measurement devices are sent down the hole to detect features of the rock. Using a combination of sound wave tools, electrical tools, and radiation measurements, instrument readings are taken from inside the well to determine the presence of oil.

The drilling riser system interfaces with the wellbore system, which includes: the surface casing and the soils in which the surface casing is set.

The drilling riser system interfaces with the rig system, which includes: the riser tensioning system; the rig itself, including rig performance in various marine and ocean environment conditions.

With this information, it is decided whether the well should be completed for production.

3. Forces Acting On a Drilling Riser System

The forces acting on a drilling riser system are: pressure, currents, wind and waves.

3.1. Pressure

The pressure of water increases greatly at depth. Subsea equipment must be designed to operate in these high-pressure environments. Equipment in service on the sea floor, such as marine risers and BOPs, will see much more external pressure than equipment higher up, such as drilling riser connections (for example, at 3,000 m = 9,840 ft. the water pressure is 4,400 psig = 30.3 MPa). Any connections made up at the surface will likely have sea water intrusion into any tiny crevices, unless the material is hydrophobic.

The pressure differential affects the loads on the bolts of the flanged connections of the subsea equipment. For example an internal burst pressure can add to the tensile force on a connector in the following two different two ways:

- Piston effect due to pressure acting on an end cap;
- Pipe shortening due to ballooning of the pipe.

The pressure differential loads must be included incorporated in determining the bolt pre-load (among other load sources). In deep and very deep water operations, the sea-water pressure can approach 5,000 psi = 34.5 MPa. The pressure and temperature of the seawater at great depth should be considered when considering corrosion mitigation strategies for flanges and bolts, such as cathodic protection and protective coatings. [3]

3.2. Currents

Surface and subsea currents can be significant. One of the most significant impacts on deep water drilling and production riser design is that strong currents may occur at any time, from any direction in deep and very deep waters, it from the loop current, warm core eddy currents, or cold core eddy currents. The loading these currents place on riser and BOP connectors is mainly riser displacement at depths where currents are sufficiently fast. The lateral displacement of the rig and riser caused by both waves and current will place a lateral load on the top of the BOP resulting is some seemingly minor displacement of the top of the BOP. This load will transfer as a bending moment to the wellhead connector and the wellbore casing through bottom BOP flange. This bending moment can be significant, and place tensile forces on bolts that are over and above the bolt preload. [3]

The measurements of the marine currents are necessary in more drilling operations in deep and very deep water regions. Before starting drilling, currents at different levels are analyzed in order to choose the equipment well. Monitoring the currents will continue during drilling in order to make the optimum decisions during drilling operations. So, at the same time a complete profile of the currents must be projected in order to anticipate the stress on the riser casing and the surface joint casing.

3.3. Wind and Waves

Sea or Ocean surface wind and waves impact deep and very deep waters drilling operations in several ways:

a) Wind speed and direction impact the amount and direction of lateral movement of the drilling rig, and resultant forces on the riser, the BOPs, and the wellhead connector. For drill ships, lateral movement can be somewhat mitigated by facing the ship into the wind.

b) Wind speed and direction also affects the sea state. A constantly high wind coming from a consistent direction for an extended area can cause relatively high seas.

c) Wave height impacts the heave (vertical movement) of the drilling rig. Unless extreme, any forces on the drill rig are mitigated by the riser slip joint at the top of the riser.

d) Wave height, direction, and wave period impact the amount and direction of lateral movement of the drilling rig, and resultant forces on the riser, the BOPs, and the wellhead connector. For drill ships, lateral movement can be somewhat mitigated by facing the ship into the seas.

e) Wave period may impact fatigue life of drilling riser/BOP components, but only if the forces on the riser-BOP-wellhead are significant.

The analysis of the impact of wind and waves on riser/BOP loading need to take all these factors into consideration as they all occur simultaneously. [3]

The three pieces of equipment that manage riser tension during rig operations in response to movement induced by wind and waves are

1) The rig tensioner system attached to the riser tensioner ring;
2) The riser slip joint;
3) The riser flex joint (or ball joint).

The new technologies allow the exploitation of oil and gas in regions which are situated far away from the shore, sometimes over 200 marine miles, approximate 370.6 km.

In the deep and very deep water region, the drilling activity can be deployed only by the help of dynamically positioned marine semisubmersible rigs, and by the help of the drilling ships.

Figure 8 represent effect the wind, waves and currents can displace the rig and the riser.

Also the need to take into account the fact that the upper and lower parts of the riser casing present a potential risk of instability due to the dynamic effect during fast disconnecting.

When offset is zero, then the length of the riser is the water depth (at mean sea level) minus the height of the BOP above the sea floor. We also, the scheme in Fig. 8 presents the component assembly of a riser stack and the stress regime from the riser casing, the:

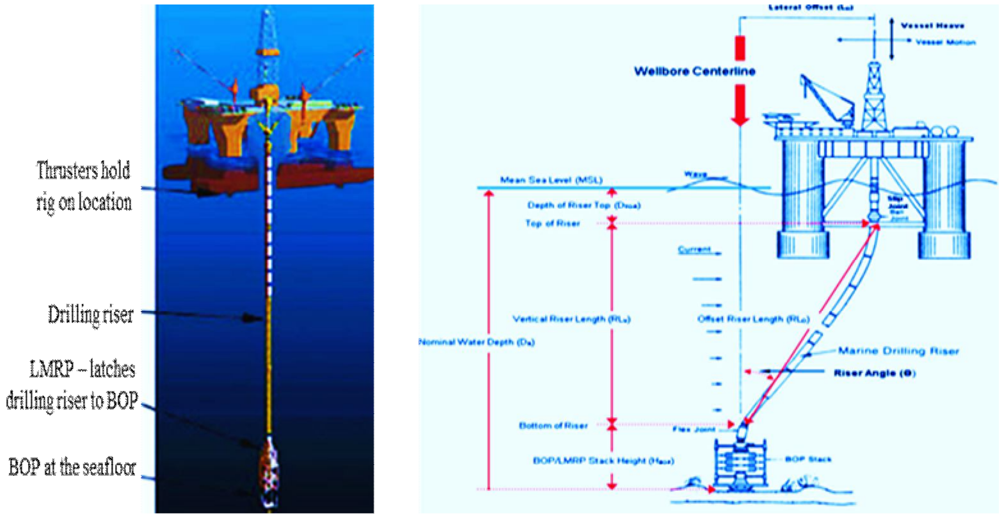


Fig. 8. Effect of the wind, waves and currents causing lateral offset of rig. [3], [7]
(*from phase dynamically positioned a the platform marine*).

- Wave action;
- Linear weight of risers;
- Differential pressure due to the difference of specific weight mud - sea water;
- Resistance at the action the marine currents and the relative movement of the platform, and,
- Efforts from the upper part and lower part of the riser casing.

When wind, waves and current drive the rig off centerline the distance between the rig and the top of the BOP stack is increased slightly. This extra riser length is accommodated for by expansion of the slip joint's. Of course, the riser casing is represented by a pillar connected to spherical articulations in the lower part, – lower flexible riser mounted above the BOP/LMRP stack -, and in the upper part – upper flexible riser mounted immediately under the diverter.

The flexible risers, by construction, have different angles 10° for the lower flexible riser coupling and 15° for the upper flexible riser coupling.

Taking this example a bit further, if the slip joint bottoms-out a lateral force will be placed on the BOP. This will be in addition to the tensile load placed on the riser system.

The calculus of the riser casing has at its basis the recommendations of the standard API RP 16Q and imposes the testing of the riser tack established for the three operational.

4. Drilling Riser System Design Process

The purpose of a riser system design effort is to ensure that a drilling riser system can be successfully constructed, deployed, and operated to enable safe drilling of a well. Although this section deals with design techniques for a complete riser system, the design and construction of components must have been performed prudently so they will perform as required by the riser system.

API RP 16Q states, "The marine drilling riser is best viewed as a system. It is necessary that designers, contractors, and operators realize that the individual components are recommended and selected in a manner suited to the overall performance of that system". It is for just this reason that this appendix will discuss overall riser system analysis processed before delving deeper into the design processes for flanges and flange bolts.

Because of the complexity of the design and operation of a drilling riser system, API RP 16Q presents several types of design methodologies that can be used at the discretion of the lease operator, the drilling contractor, a drill rig shipyard, or the OEM.[4]

The most common are:

- Operability analysis;
- Failure analysis;
- Fatigue analysis.

Additionally API RP 16Q describes methodologies for:

- Recoil analysis;
- Disconnected riser analysis.

The first three design methodologies will be highlighted below.

4.1. Operability Analysis;

Operability analysis is performed that a riser of a specific design can be safely deployed and operated on a specific rig, in a specific location, during a set of anticipated drilling/wellbore conditions, and under a set of assumed environmental conditions.

This analysis is done to ensure the following:

- Riser can be safely run and retrieved;
- Riser can stay connected to allow safe drilling;
- Riser can be connected, disconnected, and re-connected;
- Riser can be safely "hung off" the tensioner system after LMRP disconnection—until the riser can be pulled or re-connected;
- Rig is suitable for the riser (rig tensioning system capability, moonpool configuration, DP capability). [5]

There are a series of weight and size analysis that are done regarding deploying a specific riser system. However the main thrust of the operability analysis is to communicate to the drilling contractor conditions under which the LMRP must be disconnected from the lower BOP stack to protect the structural integrity of both the riser system and the well. This is called the "drive-off/drift-off analysis." [4]

The analysis is made using a certain set of assumptions. These assumptions include marine and ocean conditions and weight of the mud in the drilling riser.

Riser system parameters evaluated include the following:

- Flex/ball joint angles;
- Tensioner stoke;
- Telescopic joint stroke;

- Riser stresses;
- Wellhead and casing loads.

4.2. Failure analysis

Failure analysis or *weak point* has only one purpose: to evaluate all components of a drilling riser system as designed, manufactured, deployed, and operated and to ensure that if a failure occurs it will occur ABOVE the BOP. In other words, weak points in the riser system are calculated and the likely first component to fail is identified. A weak point failure below the BOP would disable the ability to control the well and a blowout would likely occur. This would require a re-design of the riser system. If the ability to disconnect (as assured by the watch circles) is the first line of defense, failure analysis is the second (and final) line of defense.

4.3. Fatigue analysis

It is interesting that fatigue analysis has been the least-accepted design effort by industry. Perhaps this is because there was a perception that the higher frequency load cycles due to rig heave resulted in relatively low stress levels. These higher frequency, lower-load conditions were

- Wave motion and lateral rig movement;
- Tension load cycles due to rig heave, which may occur if the riser tensioning system is not operating properly;
- Vortex-Induced-Vibration (VIV) caused by surface currents that was thought be a near surface phenomenon that could be mitigated by increasing riser tension at the surface or by placing fairings on the shallow portion of the riser.

In the past, the high-load events that drove fatigue were considered to be the routine bi-weekly pressure testing of BOPs. Recent developments have indicated that riser system and component fatigue life can be finite in the dynamic ocean environment. Fatigue is most likely driven by ocean currents. [6]

It is now known that there is the potential for significant currents to exist at all depths in a deepwater location. Eddy currents exist from the surface down to depths of 1,000 m = 3,280.83 ft (~ 3,300 ft.).

4.4. The watch circle concept

Maximum rig lateral offset that can be tolerated without causing mechanical failure of the riser or any of its components by excessive tension or bending moment is usually documented by a "watch circle".

The watch circle concept imposes an important safety operational limit. In practice, three watch circles are established as depicted in Figure 9. [4], [5], [6]

So, in Fig. 9, three mobile offshore drilling unit watch circles are established:

1) The point of disconnect (POD) circle is the *first black watch circle* to be calculated. This is the maximum lateral offset that can be tolerated by the riser system and its components without a mechanical failure at some point in the riser system.

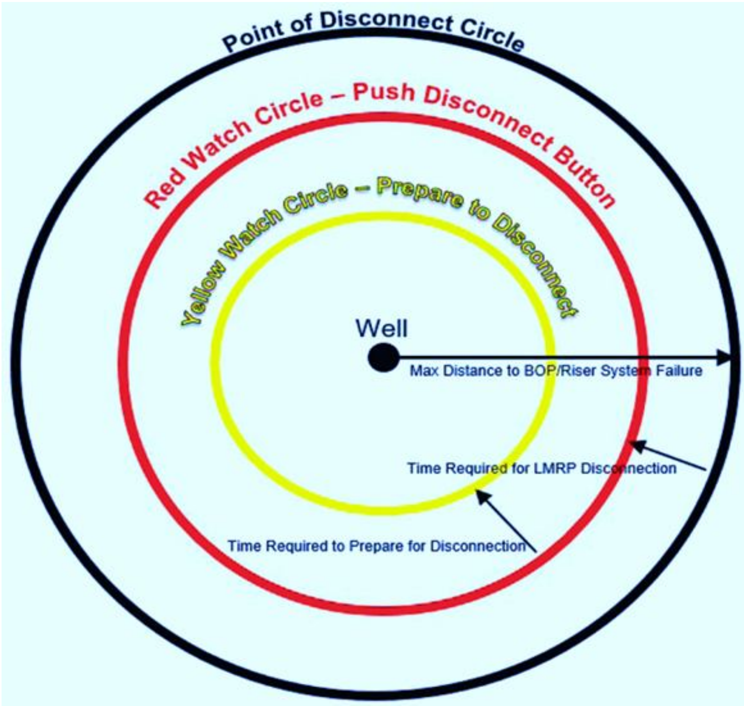


Fig. 9. Mobile Offshore Drilling Unit watch circle.

As a rig moves towards the POD limit:

- Ball joint is maxed out;
- Tension increases due to riser length at angle;
- The riser slip joint strokes out;
- The riser tensioning system reaches its lower limit;
- Tension is added to riser top;
- Bending moment on wellhead and BOP results;
- Current could add or subtract a small amount.

2) The *red watch circle* is calculated from the POD Circle. It represents the largest lateral offset at which the disconnect sequence should begin (so, the "red button" is pushed). This disconnect sequence includes operations such as closing BOP rams. The sequence may take 1 to 3 minutes, depending on the BOP.

3) The *yellow watch circle* is calculated from the red watch circle. It represents the largest lateral offset at which preparations for a disconnect should begin. These preparations may include things like pulling the drill bit off bottom to prevent it from being stuck by falling cuttings, or spacing out the drill pipe to ensure no tool joints are across the BOP shear ram. Spacing out in deep water takes some time. There are critical human factors considerations here in determining the time for individual drilling crews to make these preparations.

Observations about the watch circle:

1) The POD circle is calculated on a set of assumptions (for example: actual wind, waves, surface currents and actual underwater currents, actual loads or positions of riser components etc.).
2) The condition that results in the most conservative calculation of the POD circle is the condition where the riser telescopic joint strokes out and outer barrel/tension ring is at its lowest elevation in the moonpool.

5. Conclusions

Offshore drilling is a complex process where a borehole is drilled through the seabed. Oil and gas is drilled wells with help of different offshore structures; offshore structures classified in marine platforms and vessels. Offshore oil rigs must service safely for over 25 years. Difficult sea conditions with salt water set challenges to the rigs and it is crucial to consider the circumstances as peak loads created by storm winds and waves.

The design of subsea equipment must also consider the effect of differential pressure. The difference between the internal pressure and the external pressure is referred to as the "differential pressure". During deep water drilling, the mud density can be 2157 kg/m^3 or larger, while the sea-water density remains the same for 1031 kg/m^3.

In normal operations there is no significant compression loads on the riser system. Flange ring gaskets will experience normal compression loads due to flange bolt pre-loading. Unless flange bolts are pre-loaded to highly, ring gasket compression should be within design limits.

In the event of temporarily abandoning the well because of adverse weather and sea conditions, it is possible to suspend the pipes on the shaped rams of the lower BOP, to unscrew the pipes and to close the well with the upper blind rams – at this point it is possible to disconnect also the marine riser and possibly to abandon the site. The marine riser can be reconnected when the sea and weather conditions improve. The techniques for drilling offshore wells from floating rigs are basically the same as those used for onshore wells.

Regarding *Operability Analysis*, this establishes operational limits for the riser to be deployed. The primary operational limits are as follows: maximum tension setting; minimum top tension; maximum lateral offset.

Regarding *Fatigue Analysis*, this looks primarily at the conductor pipe, the wellhead and wellhead connector, and the riser string. Because it is so stout, fatigue analysis is not performed on the BOP or its components. The effects of fatigue are cumulative. The fatigue life of these permanent components must be managed expeditiously. These components are situated below the BOP during well construction and below the subsea tree during production. Failure would likely result in a catastrophic well control event.

Regarding the *red and yellow watch circles*, API RP 16Q states: "Both determinations rely on many assumptions about the platforms or vessel's trajectory (change in offset and heading versus time) as well as the time required to recognize and respond to the drive-off or drift-off, prepare for emergency disconnect, for the emergency disconnect to complete, and for the Lower Marine Riser Package (LMRP) to separate from the lower stack prior to reaching a maximum allowable point of disconnect (POD)".

Regarding, evaluating the reservoirs placed at the level of deep and very deep water regions, thisis one represents the main objective for the exploration and appraisal wells.

The operation limits in emergency situations will not be, of course, surpassed, as long as the safety limits are reached. If the drilling rig reaches a certain distance from the well center, - from example: a declivity of 5° in relation to the vertical -, then the risers are de-connected from the well. Consequently, it's recommended that, the operation limits of the bottom equipment are generally determined by the depth of the water and the marine currents.

An important aspect is represented by the determination of the optimum weight of the riser casing in water. Finally, the elements of the riser casing must resist to some unwanted events such as losing the dynamic position or an emergency disconnecting. Anyway, it is very difficult to establish an optimum configuration in the absence of a rich experience of operating in very deep waters.

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Finally, the elements of the riser casing must resist to some unwanted events such as losing the dynamic position or an emergency disconnecting. Anyway, it is very difficult to establish an optimum configuration in the absence of a rich experience of operating in very deep waters. This is probably the reason why the API standard is still only a recommendation and specification.

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