Evaluation of Extreme Conditions for Transportation of Offshore Drilling Equipment Using Riser Column

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Abstract. Considering the increase in offshore production activities taking place in deep water depths, the operations related to well drilling and oil production are becoming more complex and expensive and demands detailed analysis to assess the safety of the procedures. An example is the transportation of equipment with large dimensions such as the Blow-Out Preventer (BOP) and Lower Marine Riser Package (LMRP) pack, which is a procedure that needs attention since it is costly and demands a lot of time due to deep water depths at which this equipment is being installed. In addition, the pack can reach resonance zones during the installation procedure, increasing the relevance of dynamic analyses. In this context, the objective of this paper is to study the feasibility of transporting the BOP/LMRP without the need to withdraw the equipment to the drilling rig, which, in some cases, should considerably reduce the time and cost of the operation. In addition, the work addresses the main forces acting on the drilling riser during this procedure and the need to perform specific analyses. Typical equipment will be studied at three different depths considering different navigation speeds and wave heights. Criteria such as maximum stress and limit angle of the lower flexjoint are evaluated. Although the wave and Vortex Induced Vibration (VIV) fatigue phenomena have not been studied, the main goal is to assess whether extreme efforts are points of attention in transport operations with the BOP/LMRP set suspended.

Keywords: offshore, drilling system, BOP stack, equipment transportation.

1 Introduction

1.1 Context and Motivation

Due to the high consumption of petroleum products, it is becoming increasingly necessary to perform exploitation activities through wells that are deeper and more difficult to access. With the increase in depth, there is a critical factor related to the time required for the installation of equipment used in the well's drilling and oil production. In the case of the BOP/LMRP this factor becomes even more significant, since the installation is executed using the riser column that in the future will perform well drilling. It is a rigid vertical riser formed by joints connected to the rig deck, one by one, until the set of equipment reaches the surface casing on the seabed. Despite being associated with a high lead time, this is a well-controlled and considered safe procedure for equipment installation. After the completion of a well drilling procedure, the BOP/LMRP is removed and can be transported to a nearby oil well where it will operate in another drilling process. The time required for this transportation should be optimized to avoid the renting cost a mobile offshore drilling unit (MODU) and to speed up the drilling process, which requires the development of research in this area to obtain a solution for these cases.

1.2 Objective

Based on these considerations, this article presents a numerical study of the transportation procedure of a BOP/LMRP. The study considers simulations of the transportation process by the suspended method and compares the extreme efforts acting on the riser with the normative criteria specified by the API 16Q standard [1], verifying the feasibility of the process and the necessary requirements for MODU navigations in ultra-deep water depths considering speeds greater than the limits imposed by the standard. The present study will be limited to obtaining the extreme efforts, not considering fatigue efforts that arise in the drilling riser due to the dynamic movement of the MODU and due to vortex-induced vibrations (VIV) of its slender structure. Some papers present studies on the BOP/LMRP transport, such as Sognesand [22], Sevillano [3] and Hull [4], but it is still a subject little addressed, which requires attention and study for the prevention of accidents during its execution.

2 BOP Transportation

As explained in Thomas [5], after the completion of the drilling procedure, the BOP is removed, and an abandonment cap is installed on the top of the high-pressure liner to protect the sealing areas from falling materials and environmental actions during the abandonment period of the well. After that, the BOP can be immediately installed on another wellhead or it can be collected and stored for future operations. If there is another wellhead available for BOP installation, the traditional procedure is composed by: the total retrieval of the equipment, up to the rig; the BOP/LMRP transportation through the drilling rig to the point where the new wellhead is located; the installation procedure using the drilling riser. The BOP installation and retrieval procedures are carried out slowly, since both are performed using the drilling riser, which is composed of rigid sections and must be assembled as the equipment is moved.

Figure 1 presents a graph with the results obtained by a study made by Holland [6], which calculates the time required to perform the procedures of recovery and subsequent installation of the BOP, through the traditional method, in depths ranging from 200 to 7000 feet. It can be noted that for a 6800 feet (2072 meters) water depth the estimated duration for these operations is close to 100 hours (between 4 and 5 days). It should also be considered that this estimate does not include the necessary time for the MODU to move between both wells. In addition, oil wells are currently located in deeper water depths, reaching up to 3000 meters, what demands even more operational time.

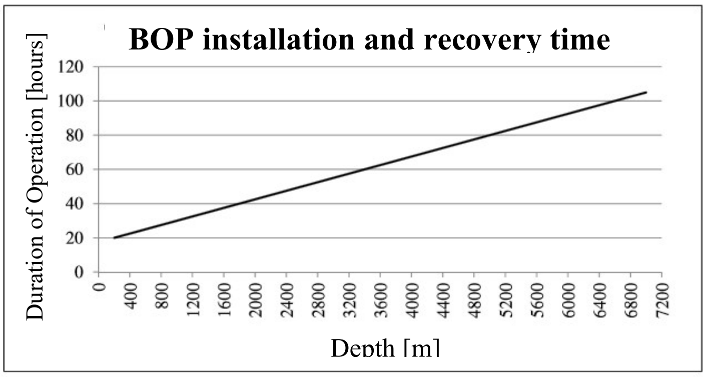

Figure 1. BOP installation and collection time for each depth using the traditional installation method [6].

Usually, companies need to rent MODUs to perform procedures related to well drilling, therefore the speed of these operations is directly related to costs and the reduction of operating time represents a significant saving for the company. Considering that, an alternative to speed up the transportation of the BOP is to have the equipment submerged close to the seabed, suspended by the drilling riser,, , eliminating the need for retrieval and subsequent lowering of the BOP. Figure 2 illustrates the process of transporting a BOP suspended by the riser. In this method the BOP is lifted by the riser until it reaches a certain depth, then the MODU moves towards the new wellhead, keeping the riser and equipment suspended – at this point the BOP is transported like a pendulum. Upon reaching the installation point, the equipment descends until it is installed in the wellhead. During the process, both the BOP and the riser column are influenced by environmental loads. Wave action on the vessel causes dynamic displacements in the system, while the current profile can generate undesirable stresses and VIV on the riser column, as well as increasing the navigation speed of the system.

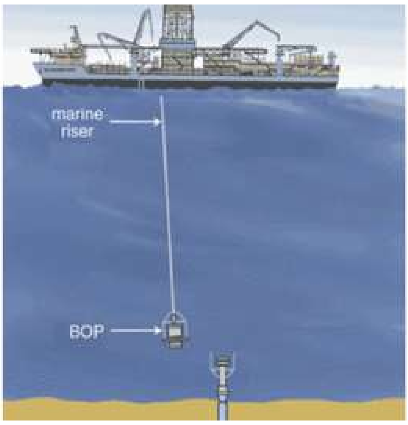

Figure 2. Representation of the transportation process of a submerged BOP [7].

2.1 Recommendations and Protocols for the Transportation of BOP/LMRP Using Riser Column

To verify the feasibility and necessity of the transportation of the BOP/LMRP by the suspended method, the work of Sognesand [2] points out some factors related to the conditions of the route that must be checked. During the transportation of the BOP/LMRP by the suspended method, an operation failure may occur resulting in the equipment falling to the seabed. Such an incident would be disastrous, and the existence of structures installed on the seabed could make it even more critical.

Therefore, when defining the route, the crossing of the BOP with other structures should be avoided. If this is not possible, Transocean's practical recommendation [8] determines that the production of the equipment installed on the seabed should be interrupted during the execution of the crossing. It is also necessary to check the bathymetry of the existing seabed to ensure that the suspended equipment will not collide with ground elevations. The transportation of the suspended BOP requires that some standards and protocols must be followed, these protocols can be defined by local authorities or by the transportation companies.

According to Transocean's practical recommendation [8], a move-specific plan must be prepared before the transportation operation, the plan should include the following elements: distance of installation move; amount of riser proposed to be suspended in order to maintain sufficient clearance with the seabed during the entire course of the move; operating procedures; transit conditions including maximum environmental conditions and current profile; definition of the riser and equipment's data; bathymetry along the proposed transit route; use of ROV to monitor BOP clearance to seabed obstructions (when the clearance is less than 500 feet); risk assessment report (WRA).

2.2 Verification Criteria

The API 16Q standard [1] defines criteria to be checked to ensure that BOP installation and transportation procedures are performed without operational risks. The criteria define a limit for the stresses acting on the riser column and for the vertical displacements of the equipment, which occur due to the influence of environmental loads. Because the riser column is rigid, to verify the stresses along its length, it is necessary to consider the real tension and the bending moment response. The real tension is obtained through the eq. (1).

$$T_r = T_{ef} - p_e A_e + p_i A_i. \tag{1}$$

where T_r is the real tension, T_{ef} is the effective tension, p_e is the external pressure, p_i is the internal pressure, A_e is the external area and A_i is the internal area of the riser. Therefore, the value of the maximum stress in the riser section can be obtained from eq. (2).

$$\sigma_{max} = \frac{T_r}{A} + \frac{M}{I}\frac{D_e}{2}. \quad (2)$$

where σ_{max} is the maximum stress, M is the bending moment, A is the cross-sectional area, I is the moment of inertia and D_e is the outer diameter.

To obtain the maximum stress value, Equation (2) was applied at all time intervals of the dynamic analysis, making it possible to obtain the most unfavorable ratio of tension and moment acting concomitantly along the entire riser. According to the API 16Q standard [1], the maximum stress allowed during any type of operation with a drilling riser is equivalent to 67% of the yield stress of the material, therefore the stress limit in the riser column must respect eq. (3).

$$\sigma_{max} \leq 0.67\sigma_y. \quad (3)$$

Another criterion that should be checked is the occurrence of compressive stresses along the line during the installation procedure, which may occur due to excessive displacement of equipment in resonance zones. For this purpose, the minimum forces acting in the lower part of the line must be obtained, more specifically in the connection of the riser with the LMRP. According to the API 16Q standard [1] the maximum angle of the Lower Flex Joint must also be verified during the installation procedure, limited to the value of 3.6 degrees in situations where the riser is connected to the LMRP. This same criterion will be used in the case studies of this paper.

According to the Transocean practical recommendation [8] the observed top riser angle must be limited to 2.5 degrees so as to avoid contact with the hull, moonpool, or diverter housing, or prevent exceedance of the angle limits of the flexjoint or gimbal, whichever is less and, during the move, the speed of the riser must be kept less than 0.3 kts (0.154m/s) relative to the majority of the current profile.

2.3 System Resonance Phenomena

Figure 3 shows a graph containing, on the right in purple, the natural period of the installation system for a range of riser lengths from 0 to 4000 meters; in blue, the vertical motion RAO of the drilling rig responsible for installing the equipment. On the left, the graph shows the Jonswap wave spectra for peak periods from 4 to 14 seconds. It should be noted that it is more possible for safety criteria to be exceeded in the resonance zones, regions where waves loading on the vessel, may present a significant period near to the natural period of the installation system, which may cause an amplification of the vertical movements of the hanging equipment set.

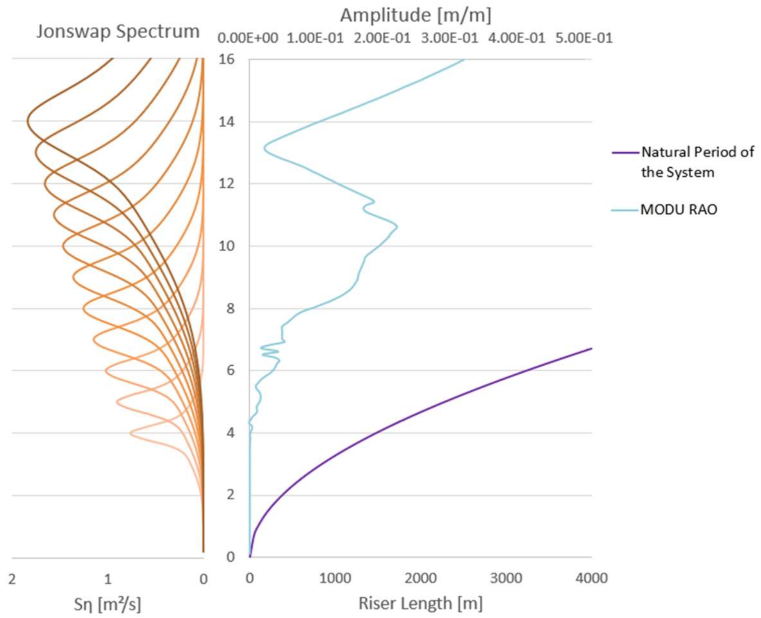

Figure 3. Graph containing, on the right, natural period for a BOP installation system and drilling rig RAO; on the left, Jonswap spectra for various periods (Tp).

Another situation that can present critical results occurs when the wave significant period is near to the natural periods of the one or more degrees of freedom of the MODU. In this case, the amplification of the MODU movements may result in the occurrence of high displacements in the equipment connected to the riser column, which may result in high stress amplitudes.

3 Description of the Case Studies

3.1 Drilling System Components Data

The main components of the drilling system modeled are: the MODU (drill ship), the drilling riser joints, the lower flexjoint and the equipment to be transported (BOP and LMRP). During the BOP installation and transportation operations the drilling riser is supported by the rotary table, located on the derrick of the vessel, at 37m height from the drillship keel. The heave motion RAOs of the MODU, relative to the equivalent point on the rotary table, for waves with 0° incidence, are presented in Fig. by the side of the image of the model studied in the software Situa-PROSIM.

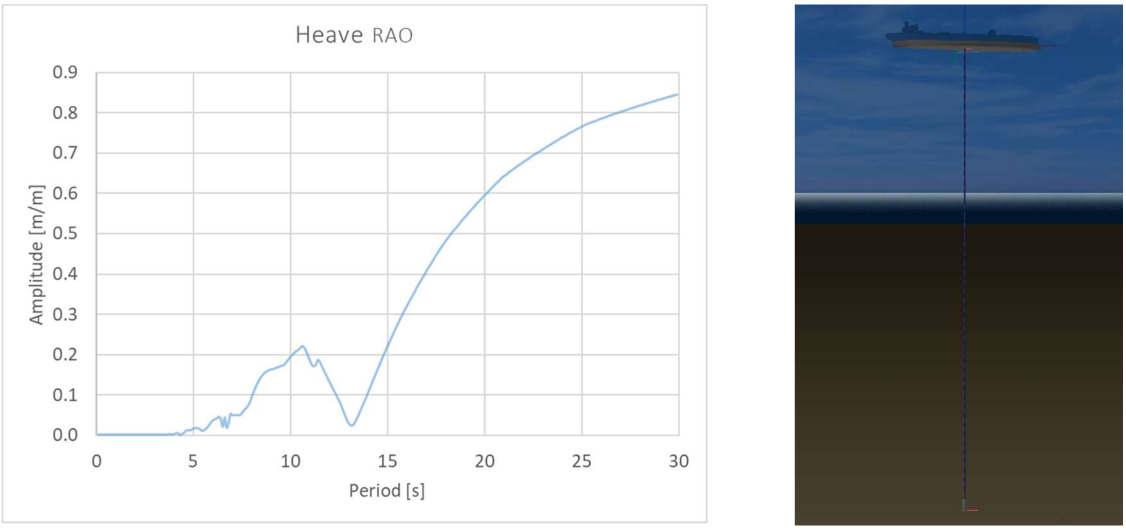

Figure 4. RAO Graphic at the Rotary Table and image of the model studied in Situa-PROSIM.

The riser column was modeled with two sections, based on real models found in the literature. The lower section has a length of 425 meters and does not make use of riser buoyancy, while the upper section has a specific length in each case studied to reach the required transport depth and was modeled with the use of riser buoyancy. During the procedures that will be studied, the drilling riser must be filled with seawater, so they were modeled with internal fluid with a specific weight of 10,025 kN/m³. The riser used in the model has an external diameter of 0.533 meters and an internal diameter of 0.492 meters along its entire length, the yield strength of the steel used is 448,000 kN/m² and its Young's modulus is 210 GPa.

The modeling also includes a section equivalent to the lower flex joint. In the model the device will be represented by a line segment inserted between the drilling riser and LMRP equipment. Its length is 2.061 meters.

In this work a set of equipment with dimensions and mass equivalent to equipment usually used in current projects for drilling wells in Brazil, which have 6-drawer BOP and can be used in the drilling of the pre-salt layer. The BOP/LMRP was modeled as a single body with a weight in air of 4025 kN, weight in water of 3493 kN, length and width of 5.9 meters and height of 15.32 meters.

For the case study, three depths were used for the equipment: 1000 meters, 1500 meters and 3000 meters, which are equivalent to the riser lengths of: 1023m,1525m and 3023m.

3.2 Environmental Loads

In this work the uncoupled models are used where wave loads is applied on the vessel, represented by RAO, and on the riser, while the hydrodynamic drag forces is applied on the riser and BOP/LMRP. the riser fatigue damage caused by the MODU dynamic movement and by Vortex Induced Vibration (VIV) are not studied here; the objective is limited to present the extreme structural response during the transportation of suspended equipment. Although the ISO 13624-2 standard [9] mentions that the dynamically positioned drillship can operate within 30° of a head sea in a severe storm, the wave incidences were studied at 0 degrees to the bow with irregular seas with heights (Hs) of 2 and 3 meters and Tp of 7s, 9s and 11s. A triangular current profile is used in the studies where the surface water velocity is 0.9 m/s and the velocity at the position of the equipment is 0.1 m/s.

3.3 Drilling Rig Speed

The speed of the navigation during the BOP/LMRP transportation process is directly related to the stresses that will arise along the riser during the operation. Therefore, several studies can be done in order to relate navigation speed with these efforts, allowing to obtain a scenario with the best cost-benefit for this process. Herethe the BOP/LMRP transportation considers two speeds of navigation: 1.0m/s and 1.5 m/s. The objective is to verify by structural analysis if it is possible to perform the procedure under these conditions, in addition to providing a comparison of the results in the two scenarios.

The transportation movement of the MODU was represented in the model by inserting a rectangular current profile along the entire riser with a constant speed equivalent but opposite to the value of the vessel speed. This velocity profile is vectorially added to the current velocity profile. This approximation was possible since the navigation speed is low and does not affect the MODU RAOs.

4 Results

The results obtained for maximum stress in the riser are compared with the safety criterion provided by the API 16Q standard [1]. The graph in Fig 5 presents the results for cases with transport speed of 1.0 m/s and 1.5 m/s. In this context, the maximum allowable stress was not met.

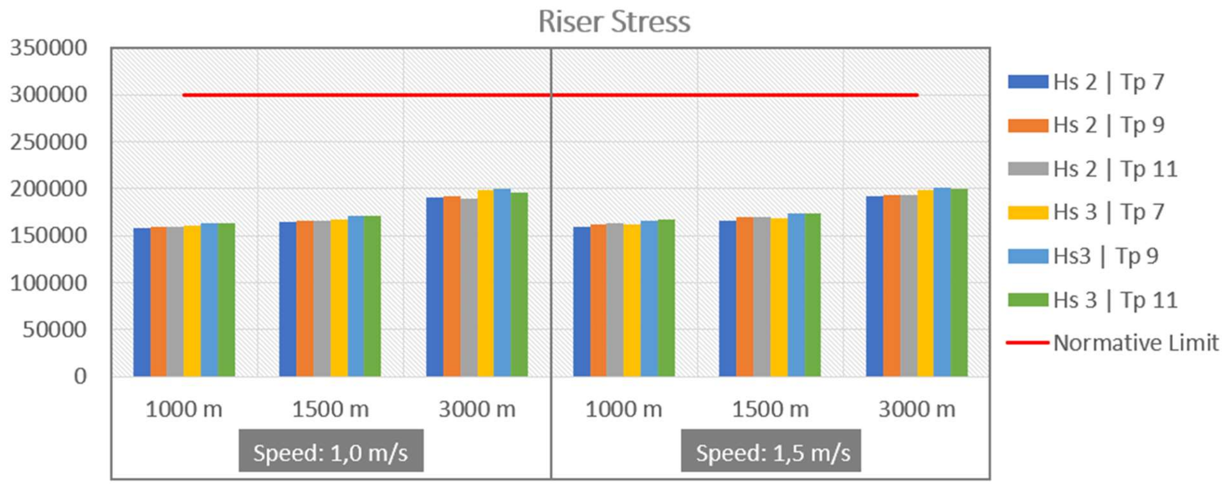

Figure 5. Result graphic showing the riser stress at each study case.

Regarding the maximum angle criterion of the lower flex joint, the values obtained in the simulations varied between 0.046 and 0.103 degrees. As already mentioned, the normative limit by API 16Q [1] is 3.6 degrees, which indicates that, according to studies carried out, there is a large safety margin with respect to this criterion.

5 Conclusions

This article addresses the verification of safety criteria defined by standard to ensure that the operation of transporting equipment suspended by the riser column is performed without risk of accident. The main criteria verified are related to extreme stresses present in the drilling riser model due to the wave dynamic motions of the MODU and also due to navigation velocity and the environmental loading along the riser, besides the verification of the maximum angle of the lower flex joint during the simulations.

The study was carried out considering two transportation speeds: 1.0 m/s and 1.5 m/s. The results obtained for stress in the riser during operation were below the limit of 67% of the yield strength of steel in all cases studied, these considering transport depth of 1000, 2000 and 3000 meters, Hs of 2 and 3 meters and Tp of 7, 9 and 11 seconds. In the verification of the angle of the lower flex joint, the maximum values obtained were much smaller than the limit of 3.6 degrees imposed by the standard, which reaffirms that, relating to extreme structural analysis, the cases studied show no violation of this two criteria studied here .

It is important to emphasize that this work did not consider the fatigue damage on the riser during the transportation process, either due to the MODU dynamic motions or due to the VIV of the riser column. Complementary studies in future works should be elaborated considering these effects.

Acknowledgements. This work was partially supported by the Brazilian funding agencies CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico, grant number 312249/2021-7), and CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), finance code 001.

Authorship statement. The authors state that there is no potential financial or non-financial competing interest.

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