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Mechanical behavior analysis for the determination of riser installation window in offshore drilling

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A R T I C L E I N F O

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A B S T R A C T

The purpose of this paper is to figure out the safety operation window of riser in installation through taking three kinds of mechanical behavior. In this paper, the sea surface current velocity, surface wind velocity, wave height and wave period are taken as the evaluation factors of marine environment. The fleet angle at riser top section, the Mises equivalent stress on riser critical section, the axial dynamic load on riser bottom section and the riser transverse resonance are considered as the limiting factors which restrains the further complicacy of marine environment. Results show that the wave height and wave period mainly affect the lateral vibration frequency and the dynamic load. The sea surface wind velocity and sea surface current velocity determines the fleet angle and the Mises equivalent stress. However, compared with the fleet angle, the maximum equivalent stress is the main influence factor which limits the installation operation window. In general, under the circumstance of avoiding transverse resonance, smaller wave height and longer wave period are good for marine riser installation. The research has some reference value for safe and effective installation of marine riser.

1. Introduction

Marine riser is the key equipment connecting the subsea wellhead and floating drilling platform (ship) in offshore drilling and exploration. Whether to explore or develop the offshore oil and natural gas resources, drilling operation is needed and essential and riser installation is the first job to be done in the conventional way of offshore drilling at present. The installation operation is a basic and extremely important process which directly determines the success and economic of the whole project. The first question which must be answered by engineers is that, for a given marine environment, whether the riser can be installed or not and how difficult the installation is. In order for answering this question accurately, the safety operation window of riser in installation must be figured out.

The mechanical analysis of riser has been studied for a long time, and papers, analysis and computer programs are numerous on this subject. Gosse and Barksdale, 1969 have developed a mathematical model to analyze the marine riser behavior and the nonlinear differential equation describing the static mechanics have been solved by finite difference approximation. Burke (1974) has deduced the riser mechanical deformation control differential equation with elastic mechanics method. Sexton and Agbezuge, 1976 have developed a computer model taking a dynamic analysis of the riser to calculate the riser stress, deflections and lower ball joint angle. Egeland et al. (1982) have presented some most common methods for riser dynamical analysis. Bennett and Metcalf, 1977 have made some nonlinear dynamic analysis of coupled axial and lateral motions of marine riser, and the analysis method allowed engineers to investigate riser pipe buckling stability. Simmonds (1980) has established a non-linear equation to analyze riser dynamical response and the equation have been solved by finite difference method. Azpiazu and Nguyen, 1984 has analyzed the vertical dynamics of marine riser to determine the amplitude of dynamic forces and displacement caused by heave action. Trim (1991) has derived an equation of axial motion of a tensioned marine riser and a number of practical problems have been considered. Modi et al. (1994) have derived an equation of motion for a marine riser undergoing large deflections and fleets. Moe and Larsen, 1997 have developed a differential equation describing the motions of marine riser with asymptotic solution. Chainarong et al. (2002) have presented a variational approach for two-dimensional large strain static analysis of marine risers. Ertas (2006) has proposed the riser dynamic differential equation and

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solved by the finite difference method. Khan (2006) has made some dynamic analysis of risers which are subjected to regular or irregular wave with ABAQUS software and the variation of riser bending stress with low frequency drilling ship movement and wave motion and current velocity have also been analyzed. Mathelin and de Langre, 2005 have addressed the vortex-induced vibrations with a wake oscillator mode and a theoretical analysis has been carried out to predict the wave-packets amplitude and distribution. Shi and Chen (2004) have studied the riser strength with 3-D finite element model. Chang (2008), Sun and Chen (2009) and Ju et al. (2011, 2012) have done some research on riser stochastic nonlinear dynamic response, hanging axial dynamic analysis and wave-induced fatigue analysis with theoretical and numerical simulation method. Zhou et al. (2013) have studied the mechanical properties of riser subjected to shear flow with experimental method and found the riser "one third effect" which can be explained through an analysis of the mechanical model and material mechanics theory. Wang et al. (2014a, b, 2015) have taken both static and dynamic analysis on riser mechanical behavior in installation and corresponding discussions and conclusions have been presented. The literature mentioned above mainly focus on mechanical behavior of riser after the installation completes and fewer references cover the installation window of riser in installation. For a given marine environment, whether the riser can be installed or not and how big the risk is if the installation is carried out. To answer this question accurately, riser mechanical behavior including lateral static analysis, lateral dynamic analysis and axial dynamic analysis in installation must be analyzed. What's more, corresponding operation specifications and guidelines are lack of and the installation operation is guided by experience at present. So, the purpose of this paper is to figure out the safety installation window through considering all of the above three kinds of mechanical behavior of riser in installation.

The remainder of the paper is organized as follows. The mechanical model of riser in installation is presented in Section 2 and the determination method of installation window is given in Section 3. Then, three kinds mechanical analysis (corresponding control equations and boundary conditions) of riser in installation is shown in Section 4. After that, the installation window is figured out through a case study in Section 5. The related conclusions are drawn in Section 6.

2. Mechanical model

Fig. 1 is the schematic diagram of riser installation operation. As shown in Fig. 1, the whole system includes floating drilling platform (ship), upper flex/ball joint, tensioner line, tensioner ring, telescopic joint, marine riser, lower flex/ball joint, Lower Marine Riser Package (LMRP) and Blowout Preventers (BOPs). After the conductor is jetted completely, the LMRP/BOPs is lowered together with the riser into the sea water to connect the subsea wellhead. During this process, the loads on riser include gravity, top tension force produced by tensioner line, bottom tension force due to the gravity of LMRP/BOPs, lateral force which changes with time and water depth and results from the combination action of sea wave and sea current.

The analysis model of riser in installation can be regarded as a beam located in the vertical plane and subjected to both non-uniform axial and lateral forces. Due to the action of sea wave and current, the floating drilling vessel presents both lateral and longitudinal vibration. The riser top is connected with the floating drilling vessel by top tension system. So, the upper boundary condition of riser is the same with the response of floating vessel to wave and current. The axial loads include self-weight, tension force both on riser top and bottom section. Because the axial size of LMRP/BOPs is far less than the riser itself, it can be simplified as a lumped mass block and its effect is to provide a constant tension on riser bottom section of. So, the relationship between axial force and water depth is linear (Wang et al., 2014a, b).

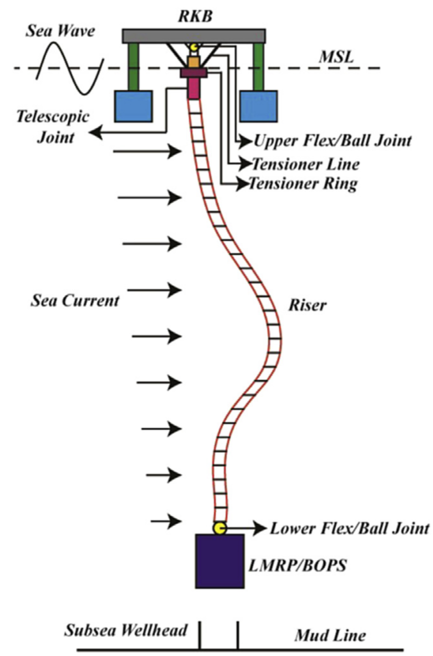

Fig. 1. System of marine riser installation operation.

3. Determination method of installation window

The main purpose of this paper is to figure out the installation window and answer whether the installation operation can be carried out and how difficult the operation activity is for a given marine environment and riser mechanical properties. For a given deep offshore drilling, the first consideration is the choice of the drilling platform (ship). The max water depth in operation, motion performance, the ability to resist the wind and sea waves, the ability of dynamic positioning are the main factors which determine the capacity of the drilling vessel. The main content of the paper is to analyze the influence of the riser installation with the riser mechanical characteristics when the capacity of drilling vessel is kept as a constant.

From the perspective of riser mechanical properties, the installation operation window is defined as a specific environment parameter (in the case of other factors are kept as constant): if beyond this value the strength of riser would not satisfy the operation requirement. The following three kinds of mechanical behaviors analysis are carried out to check the service status of riser (Riser top fleet angle, Mises equivalent stress at critical point and dynamic load at riser bottom section) as the limiting factor in installation:

- Lateral static analysis: Although the spread direction of wave and current is different in most of the time, there is always a moment that the spread direction of them coincides during riser installation. Under this circumstance, riser stress state is the most serious. So, this part of the analysis is to figure out the lateral mechanical behavior of riser and to obtain the riser deflection and stress distribution. The most concerned parameters of this analysis are the maximum Mises equivalent stress