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Study on lateral vibration analysis of marine riser in installation-via variational approach

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ABSTRACT

In this paper, a dynamic analysis model has been established to analyze lateral vibration of marine riser in installation. The governing differential equation has been deduced by variation method. The general formula of riser lateral dynamical response has also been obtained through analyzing the analysis model and the boundary conditions. In this model, the riser is regarded as a beam suspended in the floating drilling platform (ship) and subjected to the axial force and the lateral forces changes with time and water depth (WD). Finally, the expression of the lateral vibration has been obtained and the maximum lateral vibration displacement variations with WD, riser size, weight of Blow out preventers and Lower Marine Risers Package (BOPS/LMRP), wave height and wave period have also been discussed.

1. Introduction

Marine riser connecting the subsea wellhead and floating drilling platform (ship) is the key equipment in deep-water drilling and exploration. The correct design and installation will directly relate to the success of deep-water drilling operation and the economic efficiency of the whole project. Because of the complexity of the marine environment, many factors can affect the riser dynamical characteristics. With the increase of WD, the riser length and the influence of sea current and wave on riser increase which result to the riser stress state more severe and complex. The dynamic response of marine riser becomes the hot and difficult research of deep-water drilling.

Scholars have done quite a number of researches on riser mechanical behavior. For static analysis, Burke B G (1974) has deduced the riser mechanical deformation control differential equation with elastic mechanics method. V. J. Modi et al. (1994) have derived an equation of motion for a marine riser undergoing large deflections and rotations. Chainarong Athisakul et al. (2002) have presented a variational approach for two-dimensional large strain static analysis of marine risers. Shi et al. (2004) have studied the riser strength with 3-D finite element model established with considering the characteristics of big deformation and small strain under combination action of lateral and axial force using nonlinear theory. 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. (2014) have established a static analysis model and control equation to give static analysis on mechanical behavior of riser in installation and have done sensitively analysis on several operation and environment factors. Because of importance of the riser dynamic problem, many scholars have given analysis on riser dynamical response. Robert M. Sexton and L. K. Agbezuge (1976) have developed a computer model to make a dynamic analysis of the riser by calculating the riser stress, deflections and lower ball joint angle. Egeland et al. (1982) have presented some common research methods for riser dynamic analysis. Bruce E. Bennett and Michael F. Metcalf (1977) have made some nonlinear dynamic analysis of coupled axial and lateral motions of marine riser and the analysis method allows engineers to investigate riser pipe bucking stability. Simmonds D.G (1980) has established a nonlinear equation to analyze riser dynamical response and the equation has been solved by finite difference method. W. R. Azpiazu and V.N.Nguyen (1984) have analyzed the vertical dynamics of marine riser to determine the amplitude of dynamic forces and displacement caused by heave action. A. D. Trim (1991) has derived an equation of axial motion of a tensioned marine riser and a number of practical problems including the dynamic response following an emergency disconnection have been considered. Geir Moe and Bjern Larsen

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(1997) have developed a differential equation describing the motions of marine riser with asymptotic solution. A. Ertas (2006) has proposed the riser dynamic differential equation solved by the finite difference method. Khan R. A. (2006) has made some dynamic analysis of risers 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 L et al. (2005) has addressed the votex-induced vibrations with a wake oscillator mode and a theoretical analysis has been carried out to predict the wave-packets amplitude and distribution. Chang (2008), Sun et al. (2009), Ju et al. (2011) have did some research on riser random nonlinear dynamic response, axial suspension dynamic analysis and long-term fatigue of wave-induced analysis with theoretical and numerical simulation method.

The above mentioned research focus on the riser deformation, strength and fatigue damage problems after subsea wellhead and BOPS/LMRP have been connected. Few literatures discuss the analysis of mechanical behavior including static and dynamic of riser during installation. No matter how remarkable the drilling platform dynamic positioning capability is, there is still a distance between BOPS/LMRP and subsea wellhead when the BOPS/LMRP is lowed to the mud line. Under this circumstance, the floating drilling vessel needs to be moved to realize the connection of BOPS/LMRP and the subsea wellhead. So, the distance must be figured out before deep-water drilling operation. In this paper, the riser lateral vibration characteristics during installation has been analyzed via variational approach with actual current and wave parameters. The analysis model and control equation have been established. Finally, the distance is figured out which has a guidance significant to the actual drilling operation. Moreover, analysis results allow engineers to grasp the riser actual state during its installation and to improve the riser mechanical state by changing some operation parameters.

The main structure of paper contains four parts: first, the analysis model and lateral vibration control equation of riser in installation have been established, and a solution method is followed to present the method of solving the control equation, then an example calculation and sensitivity analysis is given, and some conclusions have been drawn at last.

2. Analysis model

In order for convenient calculation and formula derivation, the following assumptions are used to stipulate the present formulation:

- The material of the marine riser is linearly elastic.
- The riser top is connected with the drilling vessel and be regarded as a fixed end without displacement.
- The riser end is a free end connected with BOP/LMRP which is regarded as a mass block.
- Riser out diameter remains unchanged and the whole riser is regarded as a beam with constant cross-section.
- The whole length of riser is subjected to lateral force generated by sea wave and current.

After the conductor is installed, BOPS/LMRP is lowered together with the riser into the sea water to connect the subsea wellhead. During this process, the riser is subjected to both axial tension force generated by top tensioner, self-weight and BOPS/LMRP weight and lateral force generated by sea current and wave. Due to the sea current and wave changes with time and water deep, the riser will generate lateral vibration during installation, as shown in Fig. 1. According to the assumptions presented above, the analysis model can be regarded as a beam located in the vertical plane and subjected to both non-uniform tension force and lateral force. The top of the beam is fixed and the end of the beam is a free end. Take the connection point of drilling ship and riser top as the origin of the coordinate, and the positive direction of x axis is vertical to the bottom of the sea and the positive direction of y axis is the same as that of the lateral force.

In order to obtain the riser differential equation during installation, a micro body with length dx is cut off at the water depth x from the sea surface, and the force analysis of the micro body is shown in Fig. 2. Based on the principle of work-energy, the differential equation is deduced as follows:

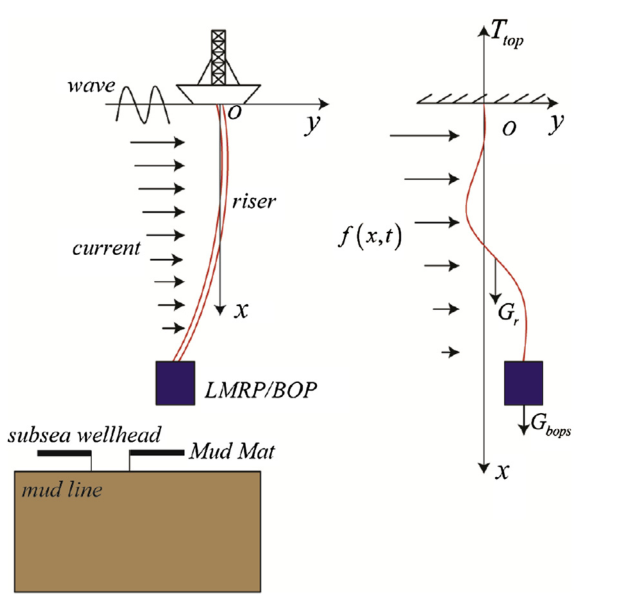

Fig. 1. Riser installation process schematic diagram and lateral vibration analysis model.

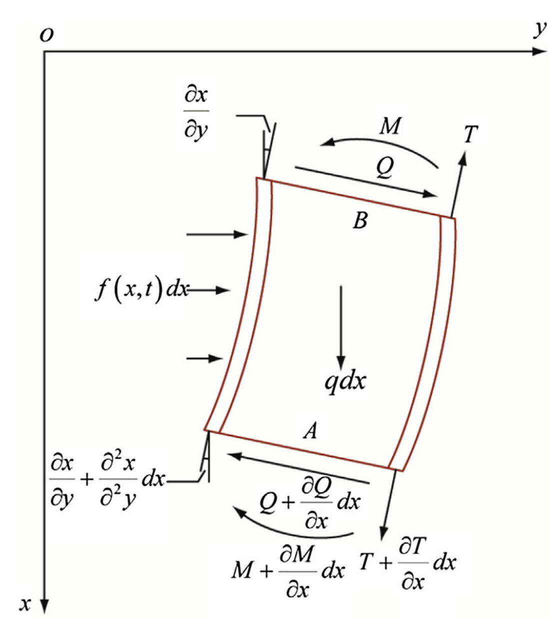

Fig. 2. Riser micro body analysis model.