Journal of Natural Gas Science and Engineering 19 (2014) 84–90

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Static analysis of deep-water marine riser subjected to both axial and lateral forces in its installation

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ARTICLE INFO

Article history:
Received 25 March 2014
Received in revised form
25 April 2014
Accepted 28 April 2014
Available online 20 May 2014

Keywords:
Marine riser
Mechanical behavior
Static analysis
Installation window

ABSTRACT

In order to analyze riser stress and deformation in its installation, a static analysis model and equation have been established and the equation is solved by the finite difference method. In this model, the riser is regarded as a beam suspended in the floating drilling platform (ship) and subjected to both axial and lateral forces. In order to connect the Blowout Preventer Stack (BOPS) and the subsea wellhead, the floating drilling platform (ship) needs to move to drag the riser and BOPS. However, during the movement of floating drilling platform (ship), the riser stress distribution will change. The total stress variation with the movement speed of floating drilling platform (ship) has been figured out. Because riser deformation could be affected by several operational factors and environmental factors, the deformation variation with water depth, riser size, BOPS weight, sea surface wind velocity, sea surface tide velocity, wave height and wave period are discussed. Results show that there is a maximum movement speed of floating drilling platform (ship). If the actual speed is greater than the maximum value, the riser material will be in danger of damage. The riser deformation will increase as water depth, sea surface wind velocity and sea tide velocity increase and will decrease as riser size and BOPS weight increase. However, wave height and wave period almost have no impact on riser deformation. Since the analysis model established is a static one, the dynamic problem is not discussed in this paper.

1. Introduction

Marine riser is the key equipment connecting subsea wellhead and floating drilling platform (ship) in deep-water drilling and exploration. Riser installation is an extremely important process in deep-water drilling, which directly relates to the success of deep-water drilling operation and the economic efficiency of the whole project. An accurate grasp of riser deformation and stress distribution has a positive effect on the installation process.

Scholars have done quite a number of researches on riser mechanical behavior. Gosse and Barksdale (1969) developed a mathematical model to analyze the marine riser behavior, and the nonlinear differential equation describing the static mechanics was solved by using the finite-difference approximation. Burke (1973) deduced the riser mechanical deformation control differential equation with elastic mechanics method. Sexton and Agbezuge (1976) developed a computer model making a dynamic analysis of the riser by calculating the riser stress, deflections and lower ball joint angle. Bennett and Metcalf (1977) made some nonlinear dynamic analysis of coupled axial and lateral motions of marine riser, and the analysis method allowed engineers to investigate riser pipe bucking stability. Azpiazu and Nguyen (1984) analyzed the vertical dynamics of marine riser to determine the amplitude of dynamic forces and displacement caused by heave action. Trim (1991) derived an equation of axial motion of a tensioned marine riser and a number of partical problems were considered, including the dynamic response following an emergency disconnection. Modi et al. (1994) derived an equation of motion for a marine riser undergoing large deflections and rotations. Moe and Larsen (1997) developed a differential equation describing the motions of marine riser with asymptotic solution. Athisakul et al. (2002) presented a variational approach to two-dimensional large strain static analysis of marine risers. Ertas (2006) proposed the riser dynamic differential equation, which was solved by the finite difference method. Khan (2006) 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 were also analyzed. Yuanjiang (2008), Sun and Chen (2009), Shaodong et al. (2011) did some research on riser stochastic nonlinear dynamic

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http://dx.doi.org/10.1016/j.jngse.2014.04.019
1875-5100/

response, hanging axial dynamic analysis and wave-induced long-term fatigue analysis with theoretical and numerical simulation method. Shouwei et al. (2013) 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.

The above mentioned researches are about riser mechanical behavior after subsea wellhead and floating drilling platform (ship) have been connected. However, the research of riser mechanical behavior during installation is insufficient. Few literature have discussed the riser mechanical characteristics during its installation. The importance of riser installation to deep-water drilling has been discussed above. So, the purpose of this paper is to analyze riser mechanical behavior to obtain riser stress and deformation distribution during its installation operation and to provide some guidance on actual installation operation. The best installation window has also been analyzed in this paper.

Although the analysis model established in this paper is a static one, the riser lateral bending deformation calculated is the maximum value. That is to say, the analysis model focuses on the most dangerous working conditions during riser installation process. For this problem, the differential equation of dynamic analysis and the static analysis are similar, as mentioned in many literature. If we ignore the vortex-induced vibration and the fatigue problems, the main difference between dynamics and statics for this problem is that the dynamics can calculate the variation of riser bending deformation with time. However, the bending deformation calculated by the dynamic model is always less than or equal to those calculated by the static model. What's more, the vibration period of riser is far less than the riser installation operation time. Therefore, the riser bending deformation always exhibits the maximum value during its installation process. So, the results calculated by the static model in this paper can be regarded as a guidance on operation.

2. Analysis model

After the conductor is installed, Lower Marine Risers Package (LMRP) and BOPS are lowered, together with the risers, 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 weight and lateral force generated by sea current and wave, as shown in Fig. 1.

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. The riser differential control equation (de Souza et al., 1997) can be represented as:

$$\frac{d^2}{dx^2}\left[EI(x)\frac{d^2y}{dx^2}\right] - T(x)\frac{d^2y}{dx^2} - w\frac{dy}{dx} = F_l(x) \quad (1)$$

Where, $EI(x)$is the riser flexural rigidity along the x axis, $N\cdot m^2$; $T(x)$ is the riser tension force distribution along the x axis, N; w is the per unit length weight of riser in sea water, N/m; $F_l(x)$ is the total lateral force distribution along the x axis, N.

If the variation of riser flexural rigidity along the x axis is ignored, Eq. (1) can be written as:

$$EI\frac{d^4y}{dx^4} - T(x)\frac{d^2y}{dx^2} - w\frac{dy}{dx} = F_l(x) \quad (2)$$

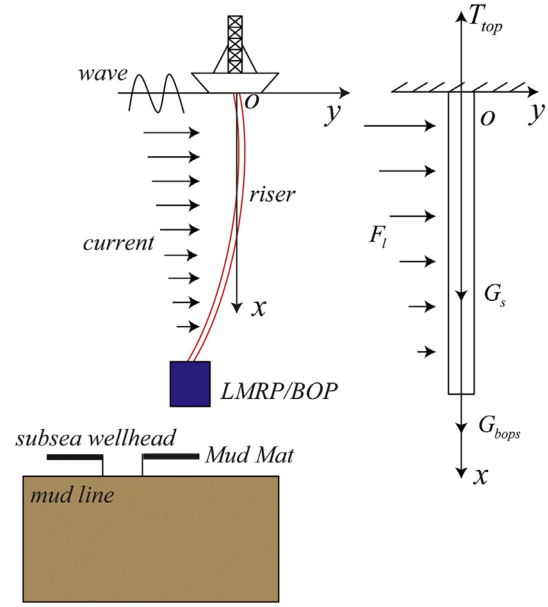

Fig. 1. Riser installation process schematic diagram and mechanical analysis model.

As shown in Fig. 1, the analysis model of the marine riser is a beam with lateral loads in a vertical plane. The top end of the riser is fixed and the bottom end of the riser is connected with the LMRP/BOPS. However, the axial size of LMRP/BOPS is far less than that of

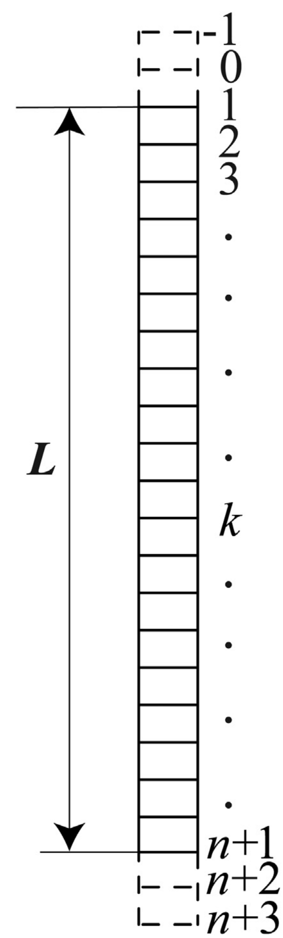

Fig. 2. Riser discretization schematic diagram.