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RESEARCH PAPER

Drift-off warning limits for deepwater drilling platform/riser coupling system

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Abstract: The drift-off dynamic model of deepwater drilling platform and riser coupling system was established. An analysis method on drift-off warning limits of deepwater drilling platform and riser coupling system was proposed, and a deepwater drilling platform/riser system was taken for case study. The analysis model of deepwater riser, wellhead and conductor coupling system and the drift-off dynamic model of platform were established respectively. The drift-off dynamic solver of deepwater platform was developed. The coupling dynamic characteristics and coupling effect of the deepwater drilling platform and riser system were analyzed in combination with example, and the analysis method for drift-off warning limits was described. The results show that: the riser load acting on platform plays a driving role in the platform drift-off in the initial drift-off stage, and begins to inhibit the platform drift-off gradually as the drift-off displacement increases; During the platform drift-off, the transient response speed of upper riser parameters is high, while the transient response of lower riser parameters presents an obvious hysteresis effect; As the current speed increases or water depth decreases, the drift-off warning limits of deepwater drilling platform/riser coupling system decrease and the deepwater drilling riser should be disconnected earlier.

Key words: deepwater drilling; drilling platform; riser; drift-off dynamic model; drift-off warning limits

Introduction

Mooring and dynamic positioning (DP) system are often used to keep deepwater floating platform in position. DP system is widely employed in deepwater and ultra-deepwater drilling platform due to its convenient positioning and good mobility. In the normal drilling process, the deepwater drilling platform is kept near the subsea wellhead in the horizontal direction under the action of DP system to maintain the structural integrity of riser system and ensure the success of deepwater drilling. However, DP system may fail, and then platform will drift off from the subsea wellhead under the influence of marine environment loads; in the process, the platform would pull the top of riser away from the subsea wellhead during, so the lower marine riser package (LMRP) needs to be disconnected timely before the drift-off displacement is too large, to avoid serious accidents, such as riser broken, subsea wellhead damage, BOP damage and even well blowout[1–4]. Therefore, it is very important to establish drift-off warning limits for deepwater drilling platform/riser coupling system.

Dynamic analysis of deepwater drilling platform/riser coupling system is the basis of the calculation of drift-off warning limits. The dynamic characteristics of deepwater drilling riser system have been widely studied, but in these studies, the platform was taken as static or dynamic top boundary of drilling riser, and the coupling effect between riser and platform was not considered[5–7]. Besides, the connected envelope, hang-off window and installation window of deepwater drilling riser system have been established while the drift-off warning limits of riser system have not been established specific to platform/riser coupling system[8–10]. Based on the previous study, the drift-off dynamic model of deepwater drilling platform/riser coupling system is established in this paper. An analysis method on drift-off warning limits of deepwater drilling platform/riser coupling system is proposed. The dynamic characteristics of platform/riser system and the coupling law between deepwater platform and riser are studied. And the drift-off warning limits for deepwater drilling platform/riser coupling system are determined.

1. Drift-off dynamic model of deepwater drilling platform/riser coupling system

Fig. 1 shows the deepwater drilling platform/riser coupling

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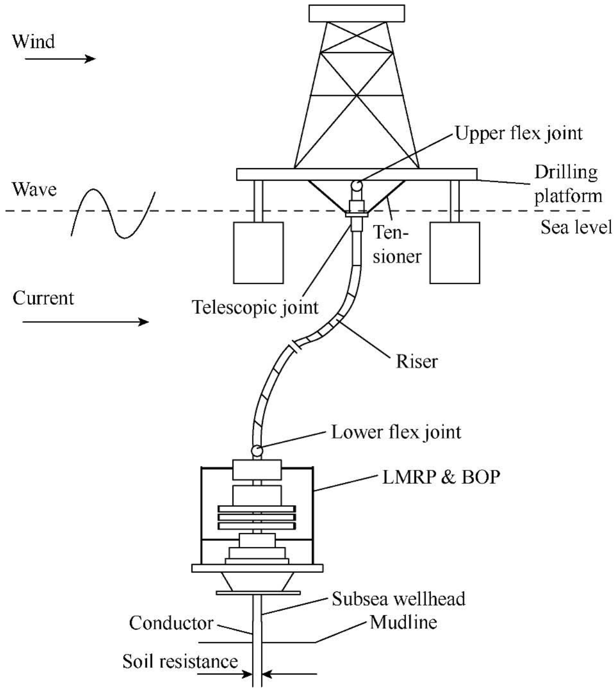

Fig. 1. Deepwater drilling platform/riser coupling system.

system during deepwater drilling. The top end of riser is hanged on drilling platform via tensioner and upper flex joint (UFJ), and the bottom end of riser is connected to blowout preventer (BOP), subsea wellhead and conductor via LMRP. The deepwater drilling platform, tensioner, riser, LMRP, BOP, wellhead and conductor form a complete deepwater drilling system[11]. During the normal drilling operation, the deepwater platform suffers ocean environment loads such as wind, wave and current, while riser system suffers wave, current loads and soil resistance. Besides, the deepwater platform and riser also interact on each other. For example, the deepwater platform drifts off under the influence of loads of wind, wave and current when the DP system fails. The platform will pull the top of riser system away from subsea wellhead in the horizontal direction during the drift-off, and the dynamic characteristics of deepwater drilling riser system will change. In return, the riser system will produce a driving force or restoring force to change the drift-off motion of the platform. Thus, the load of deepwater platform/riser system is complex, the dynamic analysis model for the drift-off of deepwater platform and riser should be established respectively to analyze the coupling mechanics of the platform/riser system iteratively.

1.1. Dynamic analysis model of deepwater drilling riser system

As shown in Fig. 1, the deepwater drilling riser/wellhead/conductor system is under the combined loads of wave, current and soil resistance. The dynamic analysis differential equation of the system is given as[12–13]:

$$F(z,t)=\frac{\partial^2}{\partial z^2}\left[E\,I_{\mathrm{r}}(z)\frac{\partial^2 x}{\partial z^2}\right]-\frac{\partial}{\partial z}\left[T_{\mathrm{r}}(z)\frac{\partial x}{\partial z}\right]+M_{\mathrm{r}}(z)\frac{\partial^2 x}{\partial t^2} \tag{1}$$

The marine environment load per unit length on the riser above the mudline is written as:

$$F_{\mathrm{sea}}(z,t)=\frac{\pi}{4}\rho C_{\mathrm{M}}D_{\mathrm{h}}^2\dot{u}_{\mathrm{w}}-\frac{\pi}{4}\rho\left(C_{\mathrm{M}}-1\right)D_{\mathrm{h}}^2\ddot{x}+\frac{1}{2}\rho D_{\mathrm{h}}C_{\mathrm{D}}\left(u_{\mathrm{w}}+u_{\mathrm{c}}-\dot{x}\right)\left|u_{\mathrm{w}}+u_{\mathrm{c}}-\dot{x}\right| \tag{2}$$

The soil resistance force per unit length on the conductor under the mudline is expressed as[14]:

$$F_{\mathrm{soil}}(z,x)=p(z,x)D_{\mathrm{c}}(z) \tag{3}$$

Besides, the top of riser is under the influence of platform drift-off, and the specific drift-off motion can be calculated based on the drift-off dynamic model of deepwater platform.

1.2. Drift-off dynamic model of deepwater drilling platform

The drift-off analysis model of platform has close relationship with its local coordinates and motion state. The global reference frame and body-fixed reference frame are established respectively in order to describe the motion state of platform accurately, as shown in Fig. 2. XOY is the global reference frame, and $X_{\mathrm{b}}O_{\mathrm{b}}Y_{\mathrm{b}}$ is the body-fixed reference frame. The angle between the global and body-fixed reference frames is denoted by ψ. The relationship between the global reference frame and body-fixed reference frame is given by:

$$\dot{\boldsymbol{\eta}}=\boldsymbol{R}(\psi)\boldsymbol{v}=\begin{bmatrix}\cos\psi & -\sin\psi & 0\\ \sin\psi & \cos\psi & 0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}u\\ v\\ r\end{bmatrix} \tag{4}$$

where $\boldsymbol{\eta}=\begin{bmatrix}y_1 & y_2 & \psi\end{bmatrix}^{\mathrm{T}}$

The deepwater drilling platform vibrates in six degrees of freedom but does not drift off under the first order wave force. The deepwater platform drifts off in surge, sway and yaw under the loads of wind, current and second order wave force. The nonlinear body-fixed equation of drift-off motion is written as[15–16]:

$$\boldsymbol{M}\dot{\boldsymbol{v}}+\boldsymbol{C}_{\mathrm{RB}}\boldsymbol{v}=\boldsymbol{\tau}_{\mathrm{curr}}+\boldsymbol{\tau}_{\mathrm{wind}}+\boldsymbol{\tau}_{\mathrm{wave}}+\boldsymbol{\tau}_{\mathrm{thruster}}+\boldsymbol{\tau}_{\mathrm{riser}} \tag{5}$$

The mass matrix of platform in equation (5), including its own mass and added mass due to its motion, is defined as:

$$\boldsymbol{M}=\begin{bmatrix}m+X_u & 0 & 0\\ 0 & m+Y_v & Y_r\\ 0 & N_v & I_z+N_r\end{bmatrix} \tag{6}$$

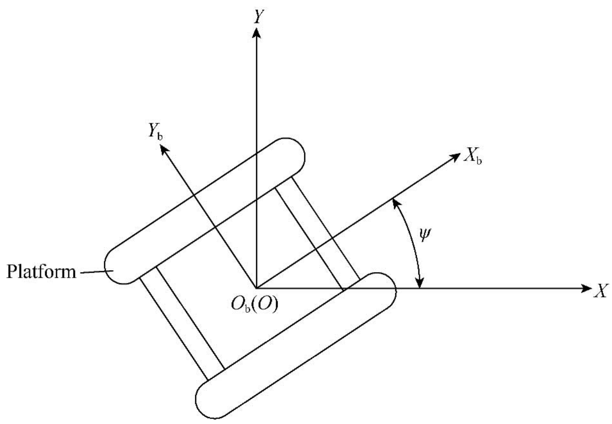

Fig. 2. Global and body-fixed reference frames.