MECHANICAL ANALYSIS OF DEEPWATER DRILLING RISER UNDER DIFFERENT OPERATING MODES

by

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This article uses the deepwater drilling riser equipped on a specific ocean drilling vessel as an example to establish a dynamic analysis model of the riser, and analyzes the lateral deformation characteristics of the riser under different working conditions and examines the impact of various factors on the lateral displacement of the riser. Research shows that under normal connection modes, maximum deformation occurs at the upper-middle section of the riser. Under suspended evacuation modes, the lateral deformation of the riser exhibits a trend of initially increasing and then decreasing. Ocean current velocity is one of the primary influencing factors on the lateral vibration characteristics of the riser.

Key words*: deepwater drilling riser, different operating modes, hard hang off, soft hang off*

Introduction

Domestic and international scholars have conducted extensive theoretical and applied research on the stress issues of deepwater drilling risers. Albino *et al.* [1], established a finite element model to predict the response of the riser by considering environmental and operational conditions. Wang *et al.* [2], established a model to analyze the lateral dynamic characteristics of riser installation process, considering the influence of drifting motion of the top floating platform. Song *et al.* [3], utilized the finite difference method to establish a mechanical model for the towing process of the riser.

This article takes the drilling riser configured on a certain ocean drilling vessel as the research target. It establishes a dynamic analysis model of the deepwater drilling riser under normal connection and suspended evacuation operating modes, and discusses the lateral deformation characteristics of the deepwater drilling riser under different modes, along with the effects of various factors on the lateral displacement of the riser.

Mechanical model

The deepwater drilling riser can be categorized into two operating conditions: normal connection and evacuation modes. Based on different top connection methods, it can further be classified into hard hang off mode and soft hang off mode, as shown in fig. 1. The governing equation can be expressed as [4, 5]:

$$EI\frac{\partial^4 y(x,t)}{\partial x^4} - T(x)\frac{\partial^2 y(x,t)}{\partial x^2} + m\frac{\partial^2 y(x,t)}{\partial t^2} = F(x,t) \tag{1}$$

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where E is the modulus of elasticity of the riser, I – the polar moment of inertia of the riser, $T(x)$ – the distribution of axial force of the deepwater drilling riser along the water depth, m – the mass of a unit length of deepwater drilling riser in seawater, and $F(x, t)$ – the lateral loads (marine environmental loads) acting on the deepwater drilling riser.

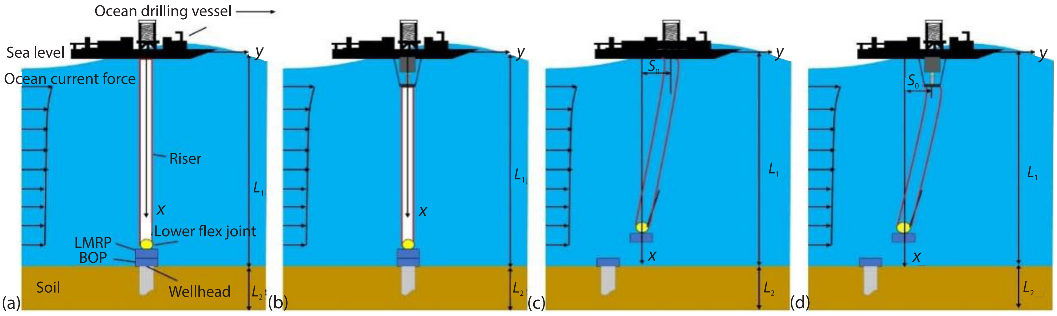

Figure 1. Operation of deepwater drilling riser under different operating modes; (a) hard hang off connection, (b) soft hang off coonnection, (c) hard hang off evacuation, and (d) soft hang off evacuation

The axial tension of the deepwater drilling riser varies under different modes. In normal connected mode, the axial tension primarily originates from the self-weight of the riser and the tension at the top, and can be expressed:

$$T(x) = T_{\text{top}} - \int_0^x mg\,\mathrm{d}z \tag{2}$$

where T_{top} is the top axial tension.

In the scenario of a suspended evacuation, the axial tension of the riser includes the gravity of the bottom LMRP and its own weight. It can be expressed:

$$T(x) = \int_x^L mg\,\mathrm{d}x + m_{\text{LMRP}}\,g \tag{3}$$

where L is the length of the riser and m_{LMEP} – the mass of LMRP.

The lateral load on the riser mainly consists of the combined forces of wave and current acting on a unit length of the deepwater drilling riser, which can be represented by the Morison equation [6]:

$$F(x,t) = \frac{1}{2} C_D \rho_{\text{w}} D \left(v_w + v_c\right)\left|v_w + v_c\right| + \frac{\pi D^2}{4} C_M \rho_{\text{w}} \frac{\mathrm{d}v_w}{\mathrm{d}t} \tag{4}$$

where C_D is the drag coefficient, C_M – the inertial mass coefficient, ρ_{w} – the sea water density, D – the outer diameter of the deepwater drilling riser, v_w – the wave horizontal velocity, v_c – the ocean current velocity, and $\mathrm{d}v_w/\mathrm{d}t$ – the horizontal acceleration of wave particles.

Boundary conditions

In the soft hang off mode connection, flexible joints are used to connect the top of the riser pipe to the platform and the bottom to the BOP, with rotational stiffnesses of K_u and K_d, respectively, and the bottom is treated as a fixed end. Therefore, the boundary conditions for the riser pipe under this operating mode can be expressed:

$$\begin{gathered} y(0,t)=S(t),\ EI\left.\frac{\partial^2 y}{\partial x^2}\right|_{x=0}=EI\frac{\partial^2 y(0,t)}{\partial x^2}=K_u\frac{\partial y(0,t)}{\partial x}=0 \\ y(L,t)=0,\ EI\left.\frac{\partial^2 y}{\partial x^2}\right|_{x=L}=EI\frac{\partial^2 y(L,t)}{\partial x^2}=K_d\frac{\partial y(L,t)}{\partial x}=0 \end{gathered} \tag{5}$$

In the hard hang off mode, a rigid connection is used between the top of the riser and the platform, while the bottom is connected in the same manner as in the soft hang off mode. Therefore, the boundary conditions for the riser under this operating mode can be expressed:

$$\begin{gathered} y(0,t)=S(t),\ \frac{\partial y(0,t)}{\partial x}=0 \\ y(L,t)=0,\ EI\left.\frac{\partial^2 y}{\partial x^2}\right|_{x=L}=EI\frac{\partial^2 y(L,t)}{\partial x^2}=K_d\frac{\partial y(L,t)}{\partial x}=0 \end{gathered} \tag{6}$$

During suspended evacuation operating modes, the top connection of the riser remains the same as in normal operating conditions, while the bottom is completely free. Therefore, the boundary conditions for suspended evacuation operating modes in both the soft hang off and hard hang off modes can be expressed:

$$\begin{gathered} y(0,t)=S(t),\ EI\left.\frac{\partial^2 y}{\partial x^2}\right|_{x=0}=EI\frac{\partial^2 y(0,t)}{\partial x^2}=K_u\frac{\partial y(0,t)}{\partial x}=0 \\ y(L,0)=0,\ EI\frac{\partial^2 y(L,t)}{\partial x^2}=K_d\frac{\partial y(L,t)}{\partial x}=0 \end{gathered} \tag{7}$$

$$\begin{gathered} y(0,t)=S(t),\ \frac{\partial y(0,t)}{\partial x}=0 \\ y(L,0)=0,\ EI\frac{\partial^2 y(L,t)}{\partial x^2}=0 \end{gathered} \tag{8}$$

Case study and parameter sensitivity analysis

Case study

Taking a water depth of 2500 m as an example. The main parameters for the example are shown in tab. 1, and the configuration of the riser system is shown in tab. 2.

Table 1. The main parameters for the example

Parameter	Value	Unit	Parameter	Value	Unit
External diameter of riser	0.5334	[m]	Wave period	8	[s]
Wall thickness of riser	0.0191	[m]	surface current velocity	1.09	$[\text{ms}^{-1}]$
Steel density	7850	$[\text{kgm}^{-3}]$	Water depth	2500	[m]
Drilling fluid density	1140	$[\text{kgm}^{-3}]$	modulus of elasticity	210	[GPa]
Seawater density	1025	$[\text{kgm}^{-3}]$	Rotation stiffness of upper flex joint	8800	$[\text{Nm}^{-1}]$
LMRP	152	[tonne]	Rotation stiffness of lower flex joint	127400	$[\text{Nm}^{-1}]$
BOP	192	[tonne]	CD	1.2	–
Foam density	33	[pcf]	Cm	2	–
Wave height	6	[m]			

Table 2. The configuration of the deepwater drilling riser system

Joint name	No. of joints	Joint length [m]	Base elevation from mudline [m]
Diverter	1	5.5	2514.6
Upper flex joint	1	0.3	2514.3
Telescopic joint	1	28	2487.8
40ft pup joint	1	12.2	2475.6
15 ft pup joint	1	4.6	2471.0
10 ft pup joint	1	3.0	2468.0
2000 ft buoyancy joint	8	182.9	2285.1
Fill-up valve joint	1	6.1	2279.0
2000 ft buoyancy joint	16	365.8	1913.1
4000 ft buoyancy joint	27	617.2	1296.1
6000 ft buoyancy joint	27	617.2	678.8
8000 ft buoyancy joint	20	457.2	221.6
Slick joint	9	205.7	15.9
Lower flex joint	1	0.3	15.6
LMRP	1	6.1	9.5
BOP	1	6.3	3.0

Under normal connection mode, the deepwater drilling riserexperiences lateral displacement due to the combined action of lateral wave-current forces and axial tension. Their lateral displacements are illustrated in fig. 2. As indicated in fig. 2, the maximum displacement of the riser pipe under hard hang off mode occurs at a distance of 1074 m from the sea surface, with a maximum displacement of 26.96 m, while under soft hang off mode, the maximum displacement occurs at a distance of 1006 m from the sea surface, with a maximum displacement of 19.21 m. The maximum deformations of the riser occur near the upper-middle section, and the riser exhibits greater deformation under the hard hang off mode.

Under the evacuation condition of the riser, the displacement of the deepwater drilling riser is shown in fig. 3. As indicated in fig. 3, the deformation of the riser exhibits a trend of increasing initially and then decreasing. The maximum displacement occurs at around 1800 m. Due to differences in connection methods at the top of the riser, the riser under the soft hang off mode experiences greater lateral displacement.

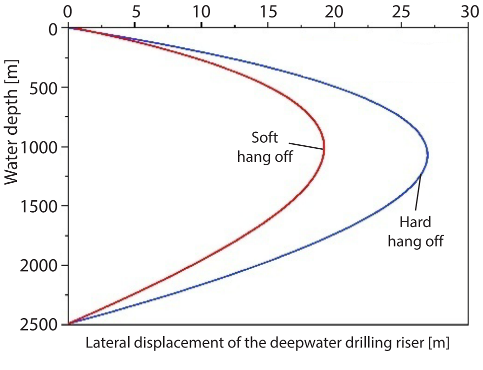

Figure 2. The lateral displacement of the riser underthenormal connection mode

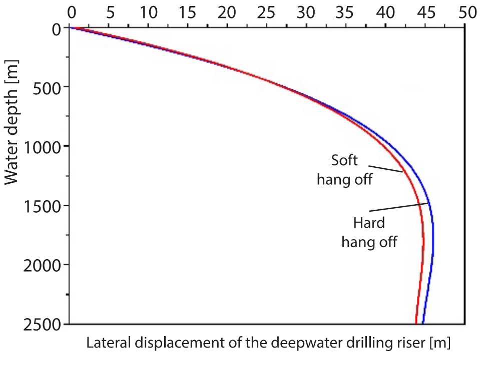

Figure 3. The lateral displacement of the riser under the evacuation mode

Parameter sensitivity analysis

The lateral displacement of the riser under hard hang off mode and soft hang off mode is shown in fig. 4 for wave heights of 5 m, 8 m, 13 m, and 18 m.

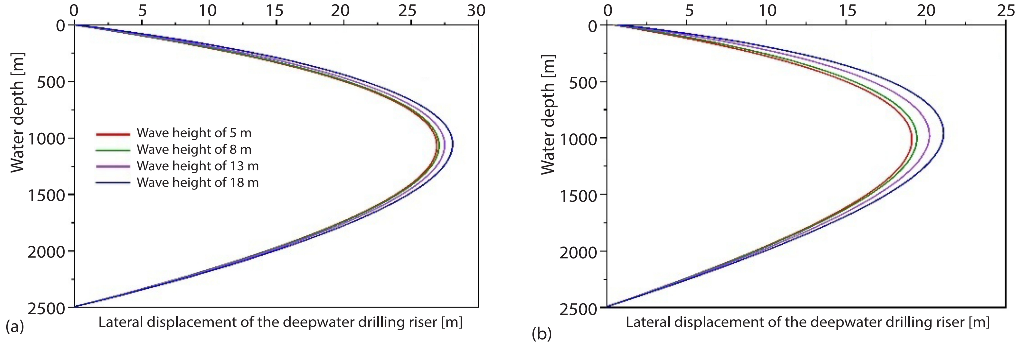

Figure 4. The influence of wave height on the lateral displacement of the riser; (a) hard hang off and (b) soft hang off

The lateral displacement of the riser under hard hang off mode and soft hang off mode is depicted in fig. 5 for wave periods of 8 seconds, 13 seconds, 18 seconds, and 23 seconds.

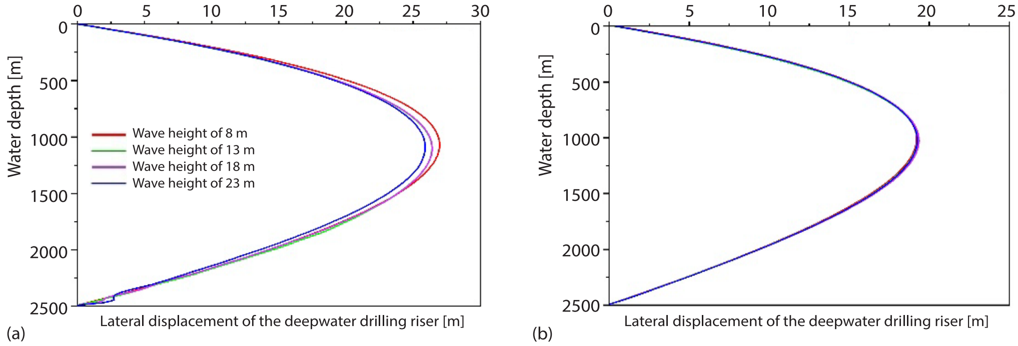

Figure 5. The influence of wave period on the lateral displacement of the riser; (a) hard hang off (b) soft hang off

The lateral displacement of the riser under hard hang off mode and soft hang off mode is illustrated in fig. 6 for surface current velocities of 1 m/s, 1.5 m/s, 2 m/s, and 2.5 m/s.

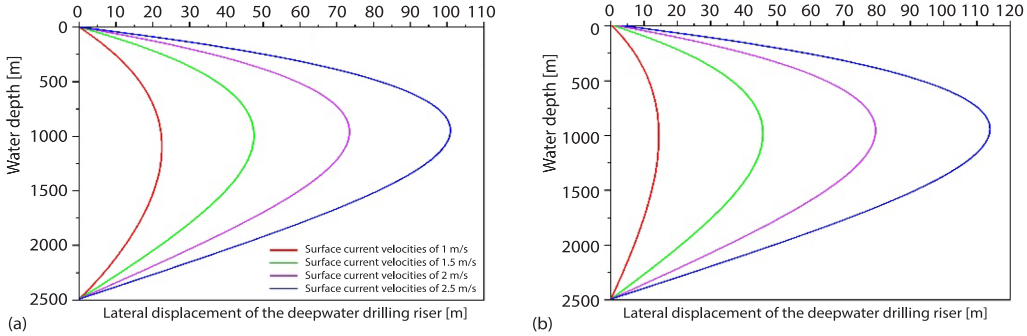

Figure 6. The influence of surface current velocity on the lateral displacement of the riser; (a) hard hang off and (b) soft hang off

From figs. 4-6, it is evident that wave height and wave period are minor influencing factors on the lateral vibration characteristics of the riser, while surface current velocity is one of the primary influencing factors. Under the hard hang off mode, as the surface current velocity increases from 1-2.5 m/s, the maximum lateral vibration displacement of the riser increases from 22.51-100.89 m. Under the soft hang off mode, the maximum lateral vibration displacement of the riser increases from 14.45-113.92 m.

Conclusion

Under normal connection conditions, the maximum deformation occurs near the upper-middle section of the riser pipe, with the riser under hard hang off mode exhibiting a greater degree of lateral deformation. Under evacuation conditions, the deformation of the deepwater drilling riser shows a trend of initially increasing and then decreasing. At the top of the riser pipe, there is a significant displacement near the top under the soft hang off mode. Therefore, when using soft hang off, it is important to be mindful of the potential for component damage due to the large displacements at the top end. Surface current velocity is one of the primary influencing factors on the lateral vibration characteristics of the riser. Therefore, particular attention should be paid to changes in surface current velocity during operations.

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