The analysis on coupling vibration of drill string and marine riser in deep-water drilling

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ABSTRACT
During drilling in the deep water, the system including marine riser and drill string over the wellhead exits strong dynamic response because of the motion of platform. The contact-collision problem between the drill string and marine riser under platform swaying is a highly non-linear dynamics problem, drill string and marine riser contact-collision position along the axis of marine riser is randomly distributed, and that there exits friction. In this paper, by using the method of finite element, the model of dynamical behavior of the system is set up, the state of contact between marine riser and drill string shows randomness. The rule of free lateral coupling vibration of drill string and marine riser has been obtained; the result shows the situation of random contact between drill string and marine rising. By case analysis the result shows that the platform swaying has great effect to the system of marine riser and drill string.

Keywords: drill string; marine riser; coupling vibration; deep-water drilling

1. INTRODUCTION

Deep-water drilling is one of the advanced drilling technologies at present. With the world's decreasing for oil and gas reserves and demand increases, undersea oil and gas exploration has been developed to deep water and ultra deep-water gradually. The bad oceanic environment brings very big difficulty on drilling engineering. As the oil and gas development moving into deeper water, drilling and completing behaviors have been signification effected by severe weather [1]. With the increase of water depth, the forces of riser system are more severe and complicated, and higher strength and stability are requested. Sometimes drilling platform was forced to interrupt drilling work because riser system can not bear huge external forces [2]. Deep-water drilling technology problems have increasingly attracted people's attention, related technical problems in deep-water drilling also become a focus of the study, coupling vibration of drill string and marine riser in deep-water drilling is one of important problems. At present, for riser system research, only marine riser, in general the influence of drilling string is ignored. This paper analyzed the coupling effect of drilling string and marine riser, established the mechanics model, the static and dynamics rules were obtained. Result of calculation is more truthfulness.

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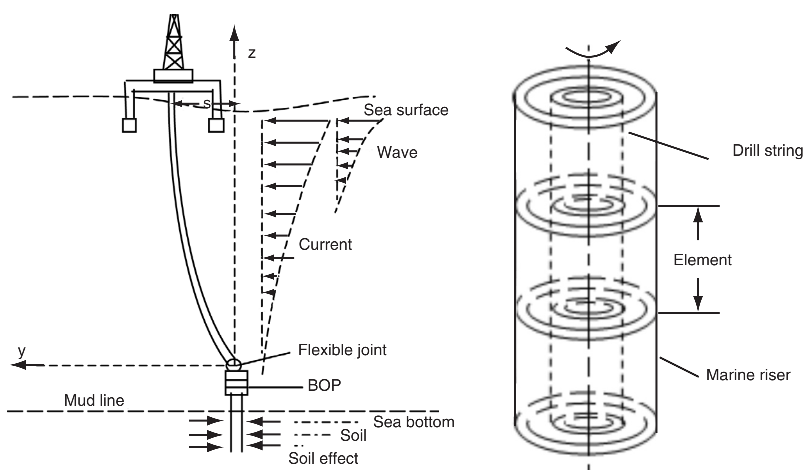
2. COUPLING MECHANICAL MODEL

As the contact position of marine riser and drill string is unknown in the contact-collision problem, there exits a sudden touch or a sudden non-contact, this will cause the system to sudden changes in stiffness. In addition contact problem often involves solving friction response, convergence of results is difficult. The results of analysis and calculation for contact problem by using finite element can be a good fit with the actual project situation.

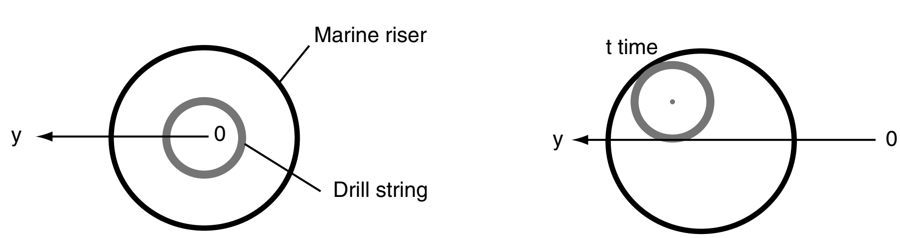
In order to achieve the coupling problems of the rotary drill string and marine riser under platform drift case, the coupling mechanical model of drill string and marine riser between drilling platform and wellhead is established, platform drifting is S (as Fig. 1). Suppose marine riser and the drill string are elastic beam which have same cross-section. Boundary condition: the upper boundary condition is that the string is connected with the drilling platform, and drifts with the platform drifting; the lower boundary condition is that marine riser fixed at the wellhead (flexible joint) where the drill string is not fixed [3, 4].

When the slender drill string is rotating, if its horizontal deformation is less than ring space gap, it doesn't contact with the riser. Otherwise the drill string will contact the marine riser and will impact each other, then contact stress and friction com into being, as shown (a) and (b) (Fig. 2).



(a) Drill string and marine riser under platform swing (b) Undeformed drill string and marine riser

Figure 1 The coupling model of marine riser and drill string.



(a) Non-Contact drill string and marine riser (b) Contact drill string and marine riser

Figure 2 The state of contact between drill string and marine riser.

3. MECHANICAL EQUATION

For the system including marine riser and drill string, the finite element dynamic equation is established correspondingly in the overall coordinate system:

$$[M_g]\left\{\ddot{\delta}_g\right\}+[K_g]\left\{\delta_g\right\}=\left\{F_g\right\}+\left\{R_g\right\} \tag{1}$$

$$[M_z]\left\{\ddot{\delta}_z\right\}+[K_z]\left\{\delta_z\right\}=\left\{F_z\right\}+\left\{R_z\right\} \tag{2}$$

Where: $[M_g]$, $[M_z]$, $[K_g]$, $[K_z]$, $\left\{\ddot{\delta}_g\right\}$, $\left\{\ddot{\delta}_z\right\}$, $\left\{F_g\right\}$, $\left\{F_z\right\}$, $\left\{R_g\right\}$, $\left\{R_z\right\}$ are mass matrix of marine riser and drill string, stiffness matrix, acceleration of the node array, external force vector of the node, and contact force vector of unknown contact points [5, 6].

Combining the finite element dynamic equation of marine riser and drill string, yield:

$$\begin{bmatrix} M_g & 0 \\ 0 & M_z \end{bmatrix}\begin{Bmatrix}\left\{\ddot{\delta}_g\right\}\\ \left\{\ddot{\delta}_z\right\}\end{Bmatrix}+\begin{bmatrix} K_g & 0 \\ 0 & K_z \end{bmatrix}\begin{Bmatrix}\left\{\delta_g\right\}\\ \left\{\delta_z\right\}\end{Bmatrix}=\begin{Bmatrix}\left\{F_g\right\}\\ \left\{F_z\right\}\end{Bmatrix}+\begin{Bmatrix}\left\{R_g\right\}\\ \left\{R_z\right\}\end{Bmatrix} \tag{3}$$

Abbreviated as

$$[M]\left\{\ddot{\delta}\right\}+[K]\left\{\delta\right\}=\left\{F\right\}+\left\{R\right\} \tag{4}$$

Eqn (4) is dynamic coupling equation of slender marine riser and drill string.

4. DISPLACEMENT OF NODES

For the contact conditions of the marine riser and the drill string can be described as follows: The first analysis of a pair of node A, B, after loaded its position change is A', B', before loaded the space vector between A and B is $\vec{\delta}_0$, after loaded the space vector is $\vec{\delta}'$, the displacement of two nodes are $\vec{u}_A$ and $\vec{u}_B$, as can be seen from Figure 3.

$$\vec{\delta}_0+\vec{u}_B=\vec{\delta}'+\vec{u}_A \tag{5}$$

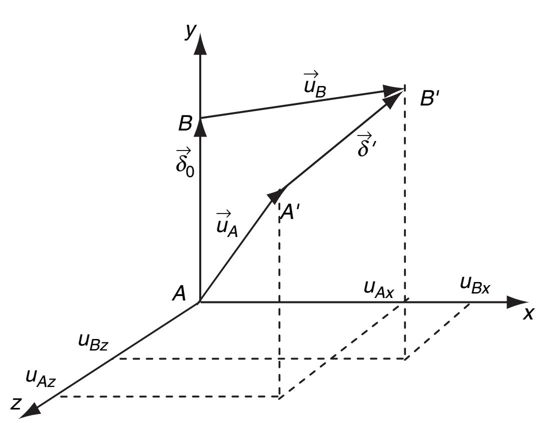


Figure 3 Displacement of node in coordinate system.

Its component type is

$$\begin{cases} \delta'_x = u_{Bx} - u_{Ax} \\ \delta'_y = u_{By} - u_{Ay} + \delta_0 \\ \delta'_z = u_{Bz} - u_{Az} \end{cases} \tag{6}$$

5. INTERACTION FORCE

As the friction between marine riser and drill string is mainly static friction, consider only the maximum static friction of the surface. When there exits contact with the trend of relative sliding between the node *A* and *B*, the interaction force between them as follows:

$$\begin{cases} R_{Ax} = -R_{Bx} \\ R_{Ay} = -R_{By} \\ R_{Az} = -R_{Bz} \\ \sqrt{R_{Bx}^2 + R_{Bz}^2} = \mu R_{By} \end{cases} \tag{7}$$

Where: μ is friction coefficient, R_{Ax}, R_{Ay}, R_{Az}, R_{Bx}, R_{By} and R_{By} are elastic contact force component between node *A* and *B* in the coordinate system.

The relative sliding direction of nodes on the contact surface is arbitrary, the angle between relative sliding trends and *x* axis is α (Fig. 4). Projection of maximum static friction in the two coordinate axis is

$$R_{Bx} = \mu R_{By} \cos\alpha \ \text{sign}(\delta'_x) \tag{8}$$

$$R_{Bz} = \mu R_{By} \sin\alpha \ \text{sign}(\delta'_z) \tag{9}$$

The angle α is determined by the relative displacement between the nodes

$$\alpha = \arctan\left(\frac{u_{Bz} - u_{Az}}{u_{Bx} - u_{Ax}}\right) \tag{10}$$

Here, $\text{sign}(\delta'_x)$ and $\text{sign}(\delta'_z)$ are sign function.

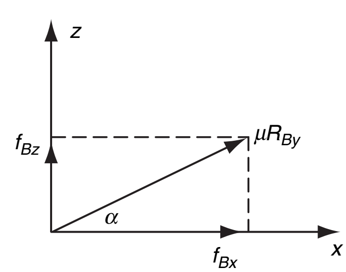


Figure 4 Friction and its component.

6. CONTACT CONDITION

Summing up the above analysis, the conditions and status of the contact forces between marine riser and drill string can be obtained [7, 8].

Non-contact

$$\delta'_y > 0 \tag{11}$$

$$\begin{cases} R_{Ax} = R_{Bx} = 0 \\ R_{Ay} = R_{By} = 0 \\ R_{Az} = R_{Bz} = 0 \end{cases} \tag{12}$$

Contact with no friction

$$\begin{cases} u_{Bx} = u_{Ax} \\ u_{By} = u_{Ay} - \delta_0 \\ u_{Bz} = u_{Az} \end{cases} \quad \begin{cases} R_{Bx} = -R_{Ax} \\ R_{By} = -R_{Ay} \\ R_{Bz} = -R_{Az} \end{cases} \tag{13}$$

Contact with friction

$$\begin{cases} u_{Bx} = u_{Ax} \\ u_{By} = u_{Ay} - \delta_0 \\ u_{Bz} = u_{Az} \end{cases}, \quad \begin{cases} R_{Bx} = -R_{Ax} \\ R_{By} = -R_{Ay} \\ R_{Bz} = -R_{Az} \end{cases} \text{ and } \begin{cases} R_{Bx} = \mu R_{By} \cos\alpha \,\mathrm{sign}(\delta'_x) \\ R_{Bz} = \mu R_{By} \cos\alpha \,\mathrm{sign}(\delta'_z) \end{cases} \tag{14}$$

7. EXAMPLE CALCULATION

Mechanical problem about marine riser and drill string under platform drifting includes: the free lateral vibration when the platform static drift or no static drift; dynamic response analysis of marine riser and drill string.

First, select the following data, water depth 500 m, the platform drift is water depth 3%, drill string material properties: steel grade S-135, elastic modulus 2.06×10^{11}Pa, Poisson's ratio 0.3, geometry size of drill string and marine riser can be shown (Table 1).

7.1. THE RESULT OF LATERAL VIBRATION

The natural lateral coupling vibration frequency of marine riser and drill string system can be obtained under drilling platform drifting 15 m or no-drifting (Fig. 5).

Table 1 Date of drill string and marine riser.

Drill string		Marine riser	
OD/m	0.127	OD/m	0.533
ID/m	0.108	ID/m	0.508
Sectional area /m^2	0.0035	thickness /m	0.0125
Moment of inertia /m^4	1.11×10^{-5}	sectional area /m^2	0.0204
Joint OD /m	0.168	moment of inertia /m^4	6.92×10^{-4}

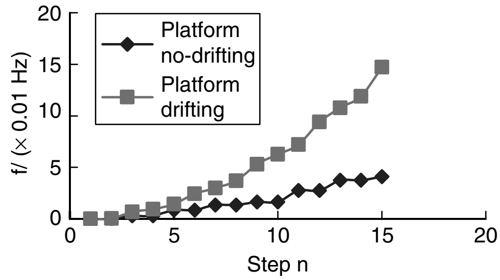


Figure 5 Frequency of lateral coupling vibration of system.

As can be seen: In deep-water conditions, the lateral coupling frequency of system including marine riser and drill string is very low, lower than the water waves frequency. Moreover, as the platform drifting, the lateral coupling frequency of system will higher than the drilling platform no-drifting, platform drifting makes the system of drill string and marine riser more sensitive to the wave [9, 10].

7.2. THE EFFECT OF PLATFORM MOTION TO MARINE RISER

Movement of platform has strong impact to the system of drill string and marine riser, when the platform swaying at 0.5 s period, the system's dynamic behavior of marine riser and drill string at t = 1.2 s is described. The horizontal displacement of system of marine riser and drill string is shown (Fig. 6), multi-point contact situation occurs. Pressure situation of drill string and marine riser at t = 1.2 s and 3.9 s under bending state is shown (Fig. 7), pressure distribution is random, and multi-contact. The most stressful position has a distance of about 80 m at the bottom of the marine riser; the position of marine riser is easily failure. The state of force at this point performs approximate characteristics of periodic, maximum contact force increases with vibration of the drilling platform, the result shows that the dynamic behavior of the drilling platform has great effect to the system of marine riser and the drill string.

As in the analysis process, the marine riser and the drill string are very long, and there are many contact point, in the process of calculation time spent is very large, and run slowly.

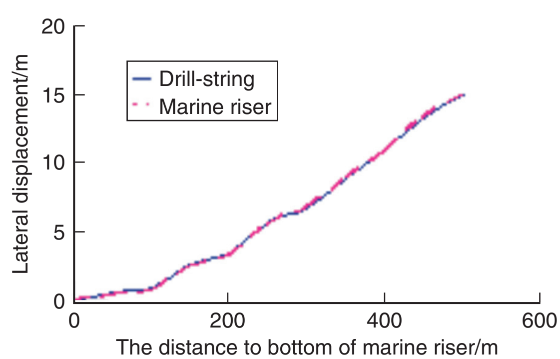


Figure 6 Lateral displacement of marine riser and drill string.

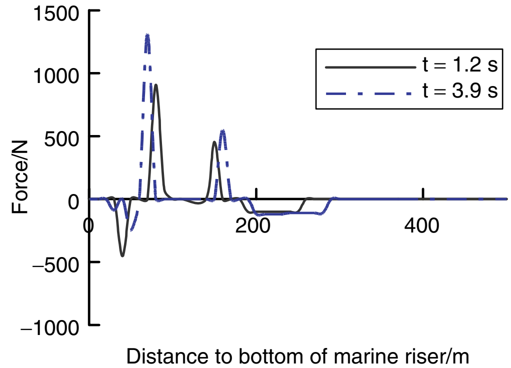


Figure 7 Pressure between contact node.

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