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Dynamic behavior of a deepwater hard suspension riser under emergency evacuation conditions

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A R T I C L E I N F O

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A B S T R A C T

A model is developed to investigate the dynamic behavior of a deepwater drilling platform riser system under emergency evacuation conditions. In the model, the riser in the ocean environment is modeled as a beam with coupled transverse and axial motions, and its upper and lower ends are respectively connected to the platform and to the lower marine riser package with hard joints. The fluid forces and the added mass and drag forces are modeled using a semi-empirical Morison equation, so the equations of the model are nonlinear, coupled, and multibody. The model is discretized in a finite element approach and solved using Newmark's method. Its validity is verified using ANSYS. Using the model, the influences of platform motion, riser suspension length, ocean load, and platform evacuation speed on the dynamic behavior of the riser are determined, and the results can provide theoretical support for the design and practical operation of hard suspension pipe strings.

1. Introduction

In offshore oil development, it is very important to have an appropriate and rapid evacuation strategy to avoid damage in the event of a typhoon. In order to reduce the operation risks and the recovery time, the riser usually disconnects from the wellhead and suspends from the drilling platform to be evacuated, as shown in Fig. 1. In the disconnected condition, the lower end of riser can be regarded as a free boundary. For the rigid suspension mode shown in Fig. 2, the expansion joins of the riser are folded, with the riser suspending from the diverter shell, the tensioner no longer bears the weight of the riser, therefore, the rotation constraints of the pipe and the platform must be considered. In emergency evacuation operations with the rigid suspension mode, the top of the riser system is rigidly connected with the drilling platform or drilling ship trough a tensioner or a universal joint. Thus, the motion of the drilling platform is transmitted directly to the riser system and thereby produces vibrations. In extreme sea conditions, these vibrations may cause the riser system to collide with the moon pool or to shear off as a result of loss of strength or buckling failure. In addition, since the Lower Marine Risers Package (LMRP) is connected to lower bottom of the suspension system, in emergency condition, the maximum dynamic top tension of the riser system is likely to exceed the design limit load of the lifting device, leading to the falling accident of the riser system. Therefore, the operation of the rigid suspension riser must comply with the basic design criteria, such as those presented in Table 1.

Early conventional riser designs were usually based on static analyses. However, with offshore operations taking place in ever-increasing water depths and with the consequent increase in riser length, the influence of dynamic factors on the riser has become more and more obvious (Wang, 2014). The long and thin pipe strings are more prone to suffer from serious dynamic response problems under the action of waves and currents (Qi, 2015).

Previous experimental and theoretical investigations (Chang et al., 2009; Zhou and Liu, 2016; Liu et al., 2013; Mao et al., 2016a, 2016b; Gong et al., 2014; Gong and Xu, 2016) have shown that the dynamic response of the riser is affected by a number of factors, including the top tension, the mud density in the pipe, the top and bottom rotational stiffnesses, the offset of the drilling ship, the presence of auxiliary pipelines, and waves and current flows, among many others. A few studies (Morooka et al., 2006; Abdel Raheem, 2016; Chatjigeorgiou and Mavrakos, 2010; Elsayed et al., 2016; Wang et al., 2014; Reyes et al., 2016) on the dynamics behavior of slender ocean pipes have been reported. The nonlinear dynamic modeling method presented in these studies provided a meaningful reference for the evacuation dynamic analysis of deep water risers. In spite of these, the study on the hanging evacuation dynamic behavior of the ocean riser is still very limited.

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Nomenclature

E	is Young's modulus
A_0	is the cross-sectional area
I_0	is the area moment of inertia of the cross-section around the neutral axis
ρ	is the material density
C_A	is the added mass coefficient
C'_D	is the drag coefficient for an oscillating cylinder in still water
ρ_f	is the density of the surrounding fluid
A_f	is the cross-section of the displaced volume
V_O	is the volume of the deformed riser
M_{LMRP}	is the mass of Lower Marine Risers Package
ω	Is the angular frequency of the system
$u_{\text{boat}}(t)$	is the heave displacement of the drilling platform

Sparks et al. (1982) investigated the longitudinal resonant behavior of deepwater risers under disconnection condition. A study by Brekke et al. (2004) found that heaving motion of the drilling platform will cause damage to the riser system induced by dynamic compression and excessive stress at the top, and eventually increase the risk of collision between the riser system and the fairing or moon pool.

Steddum (2003) analyzed the axial and lateral dynamic responses of a riser with additional mass and axial damping, and proposed an improved design for connection and suspension components of the riser system. An experimental study and a numerical simulation of a three-dimensional suspension riser model were carried out by Itoh et al. (2006). Ambrose et al (2001) examined the stress and load performances of soft and hard suspension riser systems under different environmental conditions and found that, compared with the soft suspension mode, a riser system with hard suspension is more sensitive to sea conditions and to the dry–wet weight ratio.

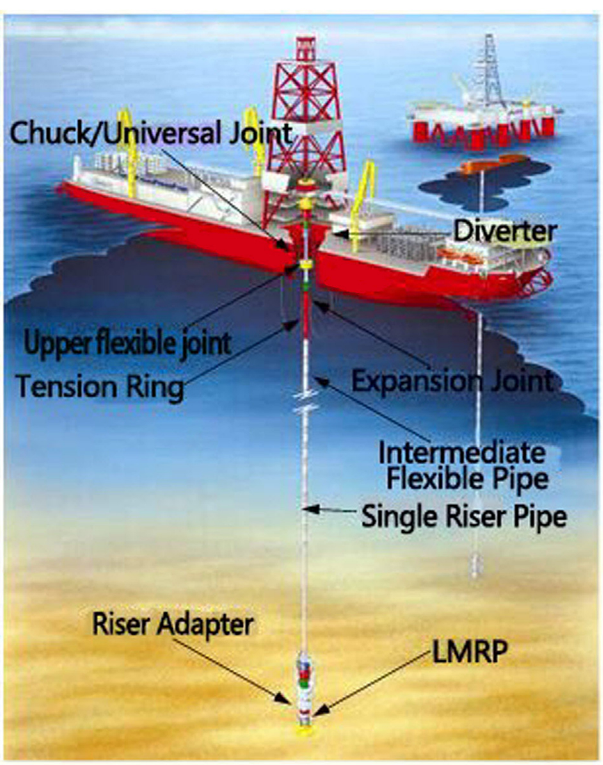

Fig. 1. Rigid suspended riser system for deepwater drilling.

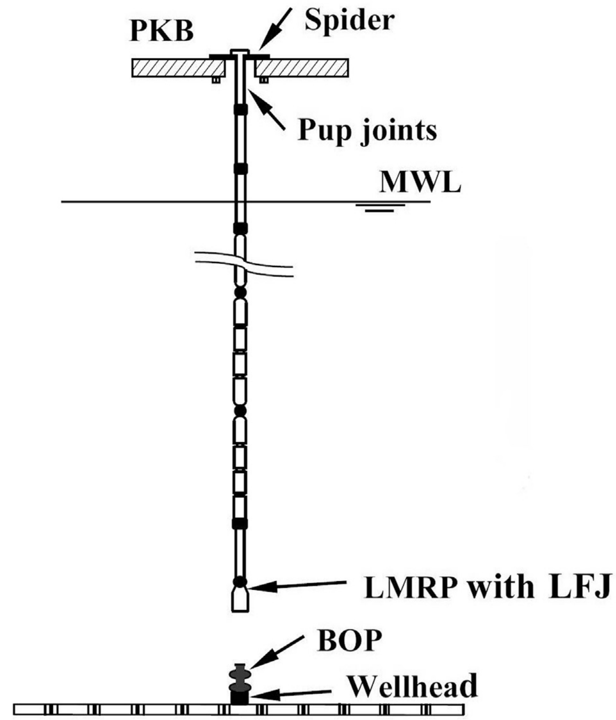

Fig. 2. Mechanical model of a rigidly suspended riser under emergency evacuation conditions. PKB, packer; MWL, mean water level; LMRP, lower marine riser package; LFJ, lower flex joint; BOP, blowout preventer.

The longitudinal vibrational response of a rigid suspension riser was analyzed by Zhang and Gao (2010). They found that the natural frequency and dynamic load of the riser changed with its weight. To suppress the generation of resonances between the riser and ocean waves, it is necessary to reduce the dynamic load. Dai and Gao (2009) carried out a finite element analysis of a rigid suspension riser system and calculated the strength of the system under three different current conditions. Also using a finite element method, Wu et al (2014) investigated the dynamic behavior of a rigid suspension riser system under evacuation conditions, taking account of the effects of platform motion, waves, and currents. None of the above studies considered coupling between the longitudinal and transverse vibrations of the riser. A flexible segment model and a rigid finite element method were respectively proposed by Xu and Wang (2012) and Adamiec-Wójcik et al. (2015) to analyze the dynamic behavior of risers. Coupled longitudinal and lateral vibrations of a simply supported beam were analyzed by Xing and Liang (2015) and Hu and Yang (2010), and coupled longitudinal and lateral vibrations of the tension leg of an offshore platform by Han and Benaroya (2000). Their results show that the effects of coupling become more obvious with increasing slenderness ratio (the ratio of the length to the cross-sectional radius).

Compared with a general beam or a tension leg, a hard suspension pipe string has a greater slenderness ratio, and its load environment is also more complex. Therefore, the purpose of this paper is to establish a coupled dynamic model of a hard suspension riser. On this basis, the

Table 1
Design criteria of hard suspension drilling riser (Qi, 2015).

Item	Limit value
Maximum allowable stress MPa	370
Maximum allowable tension MN	8.898
Minimum allowable tension MN	0.445
Angular displacement of top/^{o}	6
Rotation angle of lower flexible joint/^{o}	9
The inner diameter of the outer casing of the diverter m	1.524
Dimensions of the moon pool m × m	39 × 7.6