RETRACTED ARTICLE: Dynamic boundary of floating platform and its influence on the deepwater testing tube

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ABSTRACT
The motion of the floating platform is one of the important factors influencing the safety of testing string. The allowable motion limits of various floating drilling platforms are discussed and their calculation formulas are presented, based on which the nonlinear dynamic response characteristics of the testing tube are investigated through ABAQUS software. Results show that an excessive offset of floating platform will cause many problems to testing tube, such as operation difficulty in rising and landing pipe string, disconnection difficulty of testing tree in case of emergency. Under heave motion and slow drift motion condition, the maximum Mises stress appears in the part closed to the upper end. The heave and horizontal motions of the platform have a superposition influence on the axial force of the pipe. So, a more precise dynamic theoretical model should be developed to study the longitudinal-transverse coupled vibration of testing string in the future.

Introduction
Besides the wind, wave and ocean current, the test string system also has to bear the influence of the motions of floating platform, such as the drift, swing and heave of the drilling boat or platform. So, it is of great practical significance to find out the influence of platform motion on the dynamic behavior of the test tube.

The static behavior analysis of highly deformed risers were carried out successively by Chucheepsakul and Monprapussorn (2000), Karunakaran et al. (1999) and Santillan and Virgin (2011). The vortex-induced vibration responses of marine risers were investigated by Xue et al. (2015) and Gao and Low (2016) through numerically simulating and theoretical analysis. Ge et al. (2019) presented a method for the fatigue analysis of marine risers. Guo et al. (2001), Meng and Guo (2012), Zhang et al. (2015) and Pa’idoussis et al. (2007) discussed the coupled effects of internal and external flow on the dynamic behavior of testing tube by establishing dynamic models. The focus in the above studies was put on the lateral vibration of the riser under the internal and external flow excitation. The influence of platform motion on the lower pipe string kept unclear.

A matrix iteration method based on two dimensional pipe-beam was used by Zhu (1988) to solve the large deflection of marine risers and to investigate the effects of top tension, transverse drift of drilling boat and wave load on the pipe string. They found that the classical solution based on small displacement hypothesis will cause great deviation for the dynamic analysis of the riser of deep-water floating production system. Finite element method was used by Xie et al. (2011) to investigate the dynamic behavior and the variation of stress with time at different position. In their computational model, the heave motion load which is compensated by the compensation system of the hook and the horizontal displacement of the drilling vessel were used respectively as the force boundary condition and displacement boundary condition of the top of the test tube. A nonlinear finite element analysis model of deep-water testing tube system was established by Liu et al. (2014) to determine the offset warning limits of the deep-water operation platform, the test work window and the safe operation boundary of the pipe disconnection. Based on the conceptual design of FDPSO-TLD, the dynamic model of the TLD (tension deck) system is established by Lei et al. (2015) to investigate the axial dynamic response of the riser caused by ship heave. Zhang and Li (2015) studied the influence of the phugoid motion of the floating ship on the axial tension. OrcaFlex software was used by Gong et al. (2014) to study the dynamic superposition effect, including surface wave, ocean current, pipeline transport ship motion, and the collision between the pipeline and the pipe support roller. Wang et al. (2015) proposed a dynamic analysis method of marine riser under the coupling action of forced excitation and parametric excitation which are respectively induced by transverse wave and the rise-fall motion of floating boat.

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A new method to meet the requirements of riser stability and bottom tension allowance was developed by Yang et al. (2015) to investigate the influence of real axial force and effective axial force on the lifting mechanical properties. Liu et al. (2016) and Dai et al. (2014) proposed a drift dynamics model for the deep-water drilling platform and the riser system and studied the coupling dynamics characteristics of the deep-water drilling platform and riser system.

The comprehensive analysis of the motion of the platform and its influence on the mechanical behavior of testing tube is still lacking. Therefore, the purpose of this paper is to analyze the various possible motions of the platform and their mathematical description, based on which the influences of platform motion on the dynamic behavior of the testing tube are investigated.

Dynamic boundary analysis of floating platform

Under the action of ocean environment loads (wind, wave and current), the floating platform mainly produces six kinds of motion responses, such as surging, swaying, heave, pitch, rolling and flat rolling, among them, the effect of flat rolling on the floating platform is the smallest and can be ignored. Pitching and rolling are related to the swing characteristics of the floating platform. Surging and swaying belong to the motion in horizontal direction, which directly affects the positioning of the floating platform. In general, the assumption that the wind, wave and ocean currents act in the same plane is made to analyze the limiting conditions of the pipe structure. In the analysis of the influence of the platform motion on the testing string, the main consideration is the pitching and heaving motion of floating platform.

Motion limit of floating platform

The allowable motion limit, which is related to the motion compensation device and the operator's proficiency, is the basic requirement for the platform designer and is also the basis for the evaluation of the platform motion performance. In fact, motion limit is not only related to the seabed condition, but also to the water depth and the motion period. The deeper the water, the smaller is the allowable range of motion. The smaller the period, the smaller is the allowable range of motion. The allowable motion limits of semi-submersible platform and drilling ship of a well in Liwan in South China Sea are listed in Table 1.

| Movement mode               | Large semi-submersible drilling platform and drilling vessel | Medium semi-submersible drilling platform and drilling vessel | Small drilling vessel |
|-----------------------------|-------------------------------------------------------------|-------------------------------------------------------------|-----------------------|
| Drilling and reaming        | 4.88 14 5                                                   | 3.66 11 5                                                   | 2.13 6 5              |
| From the drill              | 5.49 12 7                                                  | 4.27 9 7                                                   | 2.44 5 7              |
| Salvage, logging, cementing | 3.35 14 3                                                  | 2.74 11 3                                                  | 1.52 9 3              |
| Lifting and landing BOP group and riser | 1.98 2.2 1                        | 1.52 2.2 1                                                  | 0.82 2.2 1            |
| Riser is disconnected       | 21.3 18 10                                                 | 13.7 14 10                                                 | 10.7 12 10            |

* Double (m), ** double (°), *** from the wellhead vertical line, the depth of water%.
where $k$ is added mass coefficient depending on the shape of the lower part of platform, for circular section $k = 1$, for rectangular section $K$ is selected in Table 2.

The amplitude of heave motion of floating platform under wave force can be determined according to the method proposed in the literature (Guo et al., 2001)

$$ u_p = \sqrt{\frac{(\rho_s g)^2 + (u_w \omega)^2}{(\rho_s g + m \omega^2)^2 + (u_w \omega)^2}} u_w $$

Where $u_w$ is the amplitude of wave motion (m).

**Nonlinear dynamic response of testing tube under platform motion**

**Establishment of finite element model**

The 4½-inch Q-125 test tube of a well in Liwan in South China Sea is taken as the studied object. In actual operation, as the wellhead on the mud line is fixed by a hanger shown in Figure 2, it can be seen as a fixed constraint. So the dynamic response of test tube in deep-water is mainly affected by the marine environment and platform motion and its numerical model is established in this section.

1. Basic parameters of 4½-inch Q-125 test tube
   - Yield strength $\sigma_s = 861.3$ MPa;
   - Elastic modulus $E = 210$ GPa;
   - Density, 7850 kg/m$^3$;
   - Poisson ratio, $\mu = 0.3$;
   - Seawater depth, 1450 m;
   - Tube length of in seawater section, 1480 m.

2. Displacement and load boundary conditions
   - Pipe element is used to discretize the testing tube shown in Figure 3, the static liquid column pressure in the annulus between the test tube and riser, and the gas pressure inside the test tube being taken into account. According to the actual condition, the wellhead on the mud line is simplified to a fixed constraint and the platform motion is taken as the dynamic boundary of the upper end of testing tube. The wave period of deep water is taken as 9 s and the amplitude of platform heave motion is assumed to be 1 m after the heave displacement is compensated by a compensation system. For the horizontal motion of the platform, 2% of the water depth is used to represent the average offset.

According to these analysis, the dynamic boundary of the floating platform and load are shown in Table 3.

**Effect of average offset of floating platform**

The floating platform has an average deviation under the ocean environment load, which is mainly due to the effect of the steady current load and is the main part of the horizontal motion of the platform. To investigate the influence of the average deviation of the platform on the testing tube, the offset value is taken as 1%~6% of water depth.

Figure 4 shows that the stress in the testing tube varies linearly with water depth, except for the sudden change on the tube section closed to mud well head. With the platform offset increasing, the stress level in test tube overall increase. This phenomenon is similar to the influence of the top tension on the strength of the riser. The reason for this is that when the offset is...
increased, the test string is stretched, and the hook load will be increased accordingly, resulting in increased stress in the test tube. The effect of average offset on the transverse displacement of test tube is shown in Figure 5, which indicates the linear relation between the displacement and water depth.

In fact, excessive offset will have a greater effect on the deep-water test operation. For instance, for a excessive deflection angle of the tube section near mud line, it is difficult to rise and land the test string and to disconnect the underwater test tree in emergency condition. In severe cases, the test tree may be stuck and unable to escape. So, in general, the deflection angle of the deep-water test string should not exceed 2 degrees. Because of the relatively small size of the drill string, its maximum deflection angle can reach about 9 degrees.

**Combined effects of heave motion and mean offset**

The dynamic behavior of the testing tube under the combined influence of mean offset and platform heave motion with 9 s cycle is investigated. Dynamic boundary of the platform and load parameters are shown in Table 4. The time-history responses of the stress, displacement, velocity and acceleration of the top, middle position and the position of mud line are shown in Figures 6–13. As can be seen from the figures, the stress and displacement amplitudes of the deep-water test tube decrease gradually from top to bottom. Whereas the alternating amplitudes of the upper and lower ends are larger than that of the middle point. This is related to the top boundary of the test tube, the constraint of the mud line and the distribution of the damping. The velocity and acceleration decrease gradually from the top to the bottom evidently because of the damping effect. The dynamic response of the test string is random under the condition of platform heave and mean deviation. Moreover, wave motion, as well as the response of platform is stochastic. So, the response of the testing tube under the condition of heave motion and average deviation is also a stationary stochastic process.
As the floating platform heaves to the longitudinal limit positions $y = \pm 1$ m and offsets to the horizontal limit position $x = \pm 40.5151$ m (mean deviation plus slow drift amplitude, namely $2\% \times$ water depth $+0.3024\sqrt{1450}$), the Mises stress in testing tube is shown in Figure 14. It can be found in the figure that as the floating platform sinks to the limit position, the maximum stresses (131.754 MPa and 176.565 MPa) of the test tube appears at the bottom end connected to the hanger. Whereas, with the floating platform rising to the limit position, the maximum stresses (228.616 MPa and 263.194 MPa) appears at the top which is the position of the hook on the platform deck. The main reason for this phenomenon is that the falling motion counteract the axial force produced by the offset of the platform, and the axial tension load of the testing tube increases due to the superposition of rising motion and the offset of the platform.

**Conclusion**

The dynamic boundary of floating platform has been analyzed and the its influence on the dynamic response of deep-water testing tube has been investigated. The following conclusions are drawn from the results obtained:
Figure 4. Effect of platform offset on the stress of test tube.

Figure 5. Effect of platform offset on the displacement of test tube.

Table 4. Dynamic boundary of the platform and load parameters.

| Dynamic boundary | Heave movement | $\sin \frac{2\pi}{9} t$ | Horizontal movement | $T = 9$ |
|------------------|---------------|-------------------------|---------------------|--------|
| Load             | Annular fluid pressure | 16.970 MPa | 29 m | 2% Water depth |
|                  | Pressure in testing tube | From mudline head to the platform Wellhead 28.63 ~ 25.11 MPa | Density of pipe 7850 kg/m$^3$ |
| Gravity          | Gravity       | Density mud 1170 kg/m$^3$ | Measured |
Larger offset of platform cause greater hook load and Mises stress in testing tube. Moreover, an excessive offset, resulting in deflection angle of the lower end of the test tube, will lead to operation difficulty of rising and landing testing tube. The average offset value should not exceed 6% of the water depth.

It has been displayed in the coupling analysis of heave motion and mean shift that the response of

**Figure 6.** Longitudinal displacement time-history response of upper node.

**Figure 7.** Longitudinal Mises stress time-history response of upper node.

**Figure 8.** Longitudinal acceleration time-history response of upper node.
the test tube under the coupling condition of heave motion and average deviation is also a stationary stochastic process. The stochastic theory is needed to analyze the safety of the testing tube.

It is shown in the stress analysis of the test tube under the limit displacements of platform. As the floating platform sinks to the limit position, the maximum stresses of the test tube appears at the bottom.
Figure 12. Longitudinal acceleration time-history response of middle node.

Figure 13. Longitudinal Mises stress time-history response of middle node.

Figure 14. Mises stress distribution of test tube as floating platform is in limit position.
end connected to the hanger with value 131.754 MPa and 176.565 MPa. Whereas, with the floating platform rising to the limit position, the maximum stresses (228.616 MPa and 263.194 MPa) appears at the upper top. The main reason for this phenomenon is that heave motion and horizontal motion of the platform will have superposition influence on the axial force of the pipe.

**Disclosure statement**

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**References**

Chucheepsakul, S., & Monprapussorn, T. (2000). Divergence instability of variable -arc-length elastica pipes transporting fluid. *Journal of Fluids and Structures*, 14(6), 895–916. https://doi.org/10.1006/jfls.2000.0301

Dai, H. L., Abdelkefi, A., & Wang, L. (2014). Modeling and nonlinear dynamics of fluid-conveying risers under hybrid excitations. *International Journal of Engineering Science*, 81:1-14. https://doi.org/10.1016/j.ijengsci.2013.03.009

Gao, Y. D., & Low, Y. M. (2016). An efficient importance sampling method for long-term fatigue assessment of deepwater risers with time domain analysis. *Probabilistic Engineering Mechanics*, 45, 102–114. https://doi.org/10.1016/j.probengmech.2016.04.003

Ge, X. B., Li, Y. P., Shi, X. L., Chen, X., Ma, H., Yang, C., Shu, C., Liu, Y. (2019). Experimental device for the study of liquid-solid coupled flutter instability of salt cavern leaching tubing. *Journal of Natural Gas Science and Engineering*, 66, 168–179. https://doi.org/10.1016/j.jngse.2019.03.026

Gong, S. F., Xu, P., Bao, S., Zhong, W., He, N., Yan, H. (2014). Numerical modelling on dynamic behaviour of deepwater S-lay pipeline. *Ocean Engineering*, 88(2014), 393–408. https://doi.org/10.1016/j.oceaneng.2014.07.016

Guo, H. Y., Wang, S. Q., & Liu, D. F. (2001). Study on static and dynamical analysis of a marine riser conveying flowing fluid subjected to environmental loads. *Journal of Ocean University of Qingdao*, 31(4), 605–611. https://doi.org/10.3969/j.issn.1672-5174.2001.04.018

Karunakaran, D., Lund, K. M., & Nordive, N. T. (1999). Steel catenary riser configurations for North Sea field developments. *OTC10979*, 331–338. https://doi.org/10.4043/10979-MS

Lei, S., Zhang, W. S., et al. (2015). H∞ control for axial dynamic response of marine risers. *Chinese Journal of Computational Mechanics*, 32(5), 644–649. https://doi.org/10.7511/jdxl201505011

Liu, K., Chen, G. M., Chang, Y. J., Liu, X. Q., Meng, X. Y. (2014). Warning control boundary of platform offset in deepwater test string. *Acta Petrolei Sinica*, 35(6), 1204–2010.

Liu, X. Q., Chen, G. M., Chang, Y. J., Ji, J., Fu, J., Song, Q. (2016). Drift-off warning limits for deepwater drilling platform/riser coupling system. *Petroleum Exploration and Development*, 43(4), 701–707. https://doi.org/10.1016/S1876-3804(16)30082-9

Meng, D., & Guo, H. Y. (2012). Nonlinear dynamic analysis of deepwater steel catenary riser in-line vibration. *Journal of Ship Mechanics*, 16(1–2), 127–135. https://doi.org/10.1016/j.jsm.2012.01.015

Pai doussis, M. P., Luu, T. P., & Prabhakar, S. (2007). Dynamics of a long tubular cantilever conveying fluid downwards, which then flows upwards around the cantilever as a confined annular flow. *Journal of Fluids and Structures*, 24(1): 111-128. https://doi.org/10.1016/j.jfluidstructs.2007.07.004

Santillan, S. T., & Virgin, L. N. (2011). Numerical and experimental analysis of the static behavior of highly deformed risers. *Ocean Engineering*, 38(13), 1397–1402. https://doi.org/10.1016/j.oceaneng.2011.06.009

Wang, Y. B., Gao, D. L., & Fang, J. (2015). Coupled dynamic analysis of deepwater drilling riser under combined forcing and parametric excitation. *Journal of Natural Gas Science and Engineering*, 27(2015), 1739–1747. https://doi.org/10.1016/j.jngse.2015.10.038

Xie, X., Fu, J. H., Zhang, Z., He, Y. F. (2011). Mechanical analysis of deep water well testing strings. *Natural Gas Industry*, 31(1), 77–79. https://doi.org/10.3787/j.issn.1000-0976.2011.01.017

Xue, H. X., Wang, K. P., & Tang, W. Y. (2015). A practical approach to predicting cross-flow and in-line VIV response for deepwater risers. *Applied Ocean Research*, 52, 92–101. https://doi.org/10.1016/j.apor.2015.05.005

Yang, J., Meng, W., Yao, M. B., Gao, D., Zhou, B., Xu, Y. (2015). Calculation method of riser top tension in deep water drilling. *Petroleum Exploration and Development*, 42(1), 119–122. https://doi.org/10.1016/S1876-3804(15)60014-3

Zhang, L., Wu, H., Yu, Y., Zeng, X., Zhou, J., Xie, B., Shi, M., Huang, S. (2015). Axial and transverse coupled vibration characteristics of deep-water riser with internal flow. *Procedia Engineering*, 126, 260–264. https://doi.org/10.1016/j.proeng.2015.11.238

Zhang, W. S., & Li, D. D. (2015). Active control of axial dynamic response of deepwater risers with Linear Quadratic Gaussian controllers. *Ocean Engineering*, 109 (2015), 320–329. https://doi.org/10.1016/j.oceaneng.2015.09.018

Zhu, F. G. (1988). Large-deflection analysis of marine risers. *The Ocean Engineering*, 6(3), 27–33. https://doi.org/10.16483/j.issn.1005-9865.1988.03.005