IOP Conf. Series: Materials Science and Engineering **392** (2018) 032039 doi:10.1088/1757-899X/392/3/032039

Response analysis with cable3D of the SCR rigid rotation model under the wave action and y direction motion in the oil production and transportation

Bo Zhu[1], WeiPing Huang[1], XingLong Yao [1], Juan Liu[2]

[1] Shandong Key Laboratory of Ocean Engineering,Ocean University of China Qingdao 266071,China

[2] Institute of Civil Engineering, Agriculture University of Qingdao,Qingdao 266009,China

E-mail: beiji_dongjie@qq.com

Abstract. The steel catenary riser(SCR) is an important equipment for offshore oil production. Its research is very important for the safety of oil exploitation. The SCR has a rigid rotation axis from the hanging point to the touch down point(TDP). The influence of rigid body rotation on the response of the cross flow is not negligible.This paper considers the bending vibration model, the rigid body model, and the wave forces mode. The effects of rigid body rotation on the structure acted on wave action and y direction motion is studied.The calculation shows that the response of the structure is the largest in the top area and the structure response value no longer changed greatly after a certain depth.The higher the amplitude in the top region, the faster the response goes down.After coupling top y-direction motion, the phenomenon of decreasing with response of water depth is still present, and the effect of rigid body swing on the structure is not more than that of the wave load. It is expected that the above research can be helpful for the design of steel suspension chain riser.

1. Introduction

In recent years, the development and exploitation of energy resources have gradually expanded from traditional fossil and water energy sources to cleaner energy sources, such as solar energy, wind energy and tidal energy.In terms of the deep water oil and energy resources that I am personally engaged in research, the development of its deep water oil and gas field has developed from the main shallow water depth of 500 meters to a deeper water depth of 100-1500m, or even more than 3000m.In the main production equipment of deep-water oil and gas field, besides the floating platform on the top, the development of deep-water riser and umbilical cable is also very important. Its research is very important for the safety of oil exploitation.

In recent years, researches on risers include viv, interaction with platform and mooring system and fatigue calculation and risk assessment. Chunning Ji et al.[1] use Cg LES_IBM in-house code to analyze the viv of a flexible riser subjected to an inclined flow.Yuchao Yuan et al.[2] propose a new domain viv prediction method considering the added mass coefficient.Zhen Liu er al[3] consider the influence of internal flow on natural frequencies and mode shapes of SCR.Tiebing Shan et al.[4] consider the effect of multi-riser system for platform and mooring systems design.Shuai Hao et al.[5] put forward a new method not based on engineering accident statistics to investigate failure risk.

This paper concern for steel catenary risers is mainly focused on rigid body oscillation.The rigid body rotation of steel catenary riser is due to the effect of wave, current and so on, which causes the whole structure to swing or rotate. Juan Liu [6] first put forward the rigid rotation model coupled with riser's bending vibration model.The calculation shows that the wave load affect tens of metres under the sea, and the vibration impact on the upper of riser is bigger. By contrast, the riser rigid body swing has less impact on the upper of riser, and obvious effects on the bottom of riser. Juan Liu, Weiping Huang [7][8] calculated the vibration coupling of rigid body rotation and vortex-induced vibration, and believed that the rigid body vibration's displacement was the same as that of the riser's vortex-induced vibration. The influence could not be ignored.Xinglong Yao [9][10][15] proved steel catenary riser exist rigid body modal .

Dynamic response of the SCR rigid body rotation model system has an axis from the suspension point to the TDP. The changes of the suspension point and the TDP will render the SCR model change, and also change the radius of the motion, in reverse, influencing the response of SCR rigid body rotation model. In this article, the influence of rigid body rotation on the riser is researched by the top y linear motion and wave action.

2. SCR Large Deformation Slender Beam Model

2.1. SCR Rigid Rotation Model[6][7].

Cable3D was used to calculate the model. According to the momentum conservation theorem, momentum theorem, and Bernoulli-Euler theory, the vibration control equation of the riser can be obtained[11][12].

$$M\ddot{r} + \left(Br''\right)'' - (\lambda r')' = q \tag{1}$$

M quality matrix of the beam; B stiffness matrix of the beam; λ the Lagrangian of the beam, q the beam distribution force;

According to the momentum moment theory, the riser's rotation equation is:

$$(m + m_a)s^2\ddot{a}_r + c_a s^2\dot{a}_r + mgc_1 sa_r = q_z\sqrt{s_1^2 + s_2^2} + q_x c_2 s_3 \tag{2}$$

m m_a - the riser's quality and added mass, s- the vector diameter of the rotation axis, α_r $\dot{\alpha}_r$ $\ddot{\alpha}_r$ -the riser's angular displacement, angular velocity and angle acceleration. c_a -the additional damping coefficient, q_x q_z -environmental load, c_1, c_2 -the projection of ω in x and y direction, s_1, s_2, s_3 -the projection of s in x , y and z direction.

After adding equation (2) as the coupling part to equation (1) , the following equation can be obtained:

$$M\ddot{r} + \left(Br''\right)'' - (\lambda r')' = q + mg - (m + m_a)\ddot{r}_r - c_a\dot{r}_r \tag{3}$$

As shown in figure 1,there is a rotation around the OB axis. B-the touch down point, O-the hanging point.

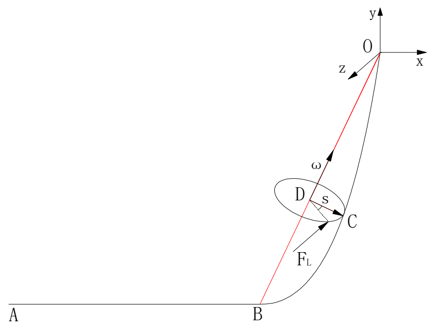

Fig.1 Rigid rotation system of SCR[9]

2.2. Wave Force Model.[8]
If the cylinder moves in waves with an acceleration $\ddot{x}$ and a velocity $\dot{x}$, the morison equation is:

$$f_H = \frac{1}{2} C_D \rho A(u_x - \dot{x})|u_x - \dot{x}| + C_M \rho \frac{\pi D^2}{4} \frac{\partial u_X}{\partial t} - C_m \rho \frac{\pi D^2}{4} \ddot{x} \quad (4)$$

A -the projection areas ρ - the sea water density; $\overline{V}_0$ -the drainage volume; C_m - the additional mass coefficient; C_M -the mass coefficient; C_D -the drag force coefficient;

Adding equation (4) to equation (3), the equation can be obtained:

$$M\ddot{r} + (Br'')'' - (\lambda r')' = q + mg - (m + m_a)\ddot{r}_r - c_a \dot{r}_{rL} + f_H \quad (5)$$

2.3. SCR motion boundary conditions[13][14].
Fixed constraint are adopted at the bottom of SCR;when calculating the analysis, the y direction is added to the calculation document.The equation (5) is added to the rigid body swing as a load term.

3. The rigid body rotation response of the SCR under the wave action and y linear motion.
This section only takes wave action into account, not thinking about the effect of sea current.The wave incidence direction is Y direction.Table 1 displays parameters of the top linear motion in each working conditions.

Table 1 The y linear motion parameters of the top suspension point[15]

Condition	Amplitude(m)	Cycle(s)	Frequency(Hz)	Angular Frequency(Hz)
1	3	10.80	0.09	0.58148
2	2	9.90	0.10	0.63434
3	1	9.00	0.11	0.69778

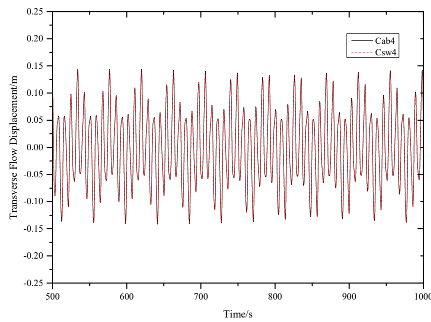

Figure 2. The 10th node displacement of the riser in working condition 1

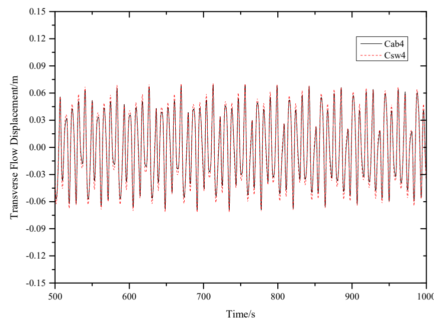

Figure 3. The 80th node displacement of the riser in working condition 1

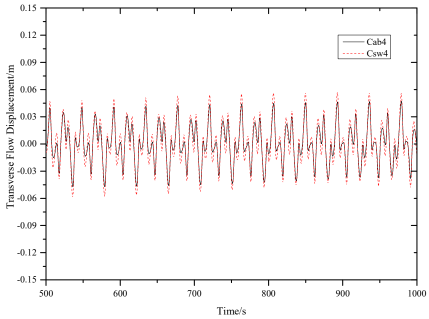

Figure 4. The 140th node displacement of the riser in working condition 1

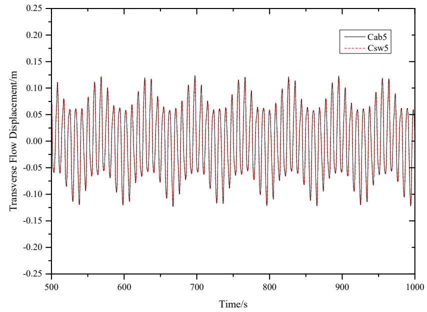

Figure 5. The 10th node displacement of the riser in working condition 2

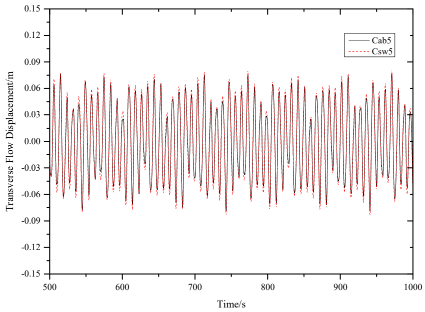

Figure 6. The 80th node displacement of the riser in working condition 2

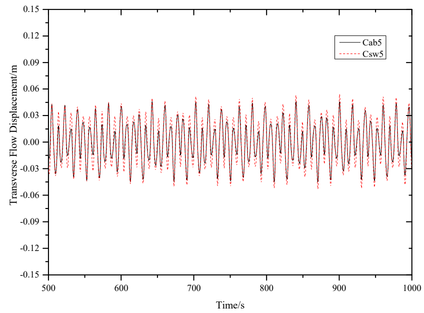

Figure 7. The 140th node displacement of the riser in working condition 2

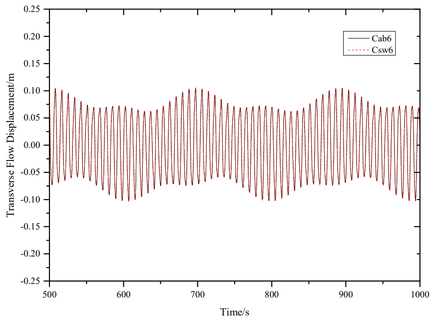

Figure 8. The 10th node displacement of the riser in working condition 3

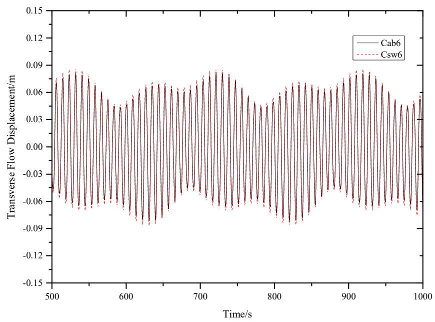

Figure 9. The 80th node displacement of the riser in working condition 3

IOP Conf. Series: Materials Science and Engineering **392** (2018) 032039 doi:10.1088/1757-899X/392/3/032039

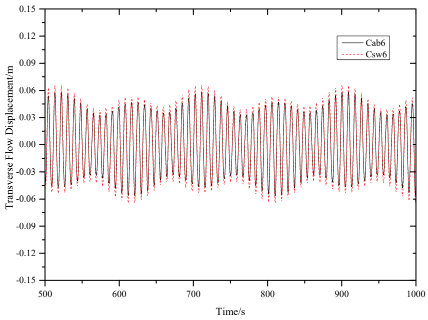

Figure 10. The 140th node displacement of the riser in working condition 3

Table2 Node Relative reduction Response of the Riser

Condition	Node	Cab(m)	Relative reduction	Csw(m)	Relative reduction
1	10th	0.14425	51.99%	0.14350	50.68%
1	80th	0.06925	32.01%	0.07077	19.64%
1	140th	0.04708		0.05687	
2	10th	0.12319	38.14%	0.12307	34.33%
2	80th	0.07621	39.97%	0.08082	33.14%
2	140th	0.04575		0.05404	
3	10th	0.10465	22.72%	0.10595	18.84%
3	80th	0.08087	28.30%	0.08599	23.26%
3	140th	0.05798		0.06599	

[a] Cab- the response of wave and top y direction motion.
[b] Csw- the motion of the wave action, the top y direction motion and rigid rotation.
[c] The relative reduction -(the last node's amplitude - the next node's amplitude)/ the last node's amplitude *100%.

Table3 Node Response of the Riser

Condition	Node	Cab(m)	Csw(m)	Growth Rate(%)
1	10^{th}	0.14425	0.14350	-0.52%
1	80^{th}	0.06925	0.07077	2.19%
1	140^{th}	0.04708	0.05687	20.79%
2	10^{th}	0.12319	0.12307	-0.10%
2	80^{th}	0.07621	0.08082	6.05%
2	140^{th}	0.04575	0.05404	18.12%
3	10^{th}	0.10465	0.10595	1.24%
3	80^{th}	0.08087	0.08599	6.33%
3	140^{th}	0.05798	0.06599	13.82%

Figure 2-4, figure 5-7 and 8-10 were working condition of conditions 1-3 results, without considering current. No matter whether the superposition of rigid body rotation, with the increase of water depth, structure by wave load and top sports are reduced, and also response value reduced. The greater amplitude, the greater the structure displacement attenuation. In figure 2-4 of condition 1 ,no rigid body rotation is taken for an example. The node calculation results of 10th, 80th, 140th are 0.1425m, 0.06925 m, and 0.04708 m. It showed with the increase of the water depth, the riser's transverse displacement under wave action and y direction linear motion reduced. Response value at the top of riser is the largest structure response value, after the 80th in the vicinity of 0.05 m.For the node 10^{th} in condition 1-3, the structure response calculated value 0.14425m, 0.12319m and 0.10465m was attenuated with the amplitude decreasing 3m, 2m and 1m for condition 1-3. And the maximum value is in the working condition 1, and the minimum was condition 3. Similarly, the relative reduction amplitude decreased 51.99%, 38.14% and 22.72% is positively correlated with the amplitude decreasing 3m, 2m, and 1m for conditions 1-3. The larger the amplitude is , the greater the attenuation is .

Under waves, the top y direction motion and the rigid body rotation, the calculated results of node 10th, 80th, 140th are 0.14350m, 0.07077m and 0.05687m.It showed with the increase of water depth, cross flow response of the structure is in abate on the top wave action ,y direction movement superimposed of rigid body rotation. After the superposition of rigid body swing, relative less of transverse displacement are 50.38%, 19.64%.

As a linear superposition between rigid body effect and the waves action, the top effect in both the structural response and relative amplitude, the rigid body swing makes structure at the top near the hanging point response amplitude growth weakly, and away from the top area gradually increase 0.52%, 0.52% and 20.79%. As the amplitude decreasing 3m, 2m and 1m for condition 1-3, the amplitude of rigid body oscillation decreased 20.79%, 18.12% and 13.82%.But in terms of numerical value, it was near 0.05m. It is significant to pay attention to that structural displacement trend under the superposition of rigid body swing and only under the action of waves and the top y direction motion are similar. The structure displacement affected by rigid body rotation does not exceed the waves and the top load effects.

4. Conclusion

Deep water oil and gas are important to energy supplement, while in deep water oil and gas development, rigid body oscillation of steel catenary pipeline is the focus topic.

The cross flow calculation of steel catenary riser under wave action , y direction motion ,and linear movement ,around the top of the suspension point and touch down point for the rigid body rotation, cannot be ignored. Combined with Cable3d's large deflection flexible rod theory and rigid body oscillation model, it is a good method to solve this kind of complex response. Adopts fixed constraint at the bottom of the SCR, adding the top y direction motion to calculate and superposition of rigid body swing effect,the characteristics of cross flow amplitude are studied.

Under wave load action, the displacement of the riser decreases gradually with the water depth, and the response value is the largest in the top region.And the structure's response is no longer changed greatly after a certain depth.It is noteworthy that the relative amplitude of the decrease is related to the water depth, which is positively correlated with the load. And the higher the top area is ,the larger the amplitude is and the faster the attenuation is.After coupling the top y direction linear motion, the phenomenon the displacement decreases with the increase of the depth persists, and the impact of top y direction linear motion is not more than the influence of wave load effects on structures.

Acknowledgments

It is my honor to be supported by the National Natural Science funds of China(51239008). I am very grateful to professor Professor Jun Zhang, Texas A&M University for providing me with the right to use the software to do some work.Thanks to all the help from god ,everyone and everything. I wish you all the best.

IOP Conf. Series: Materials Science and Engineering **392** (2018) 032039 doi:10.1088/1757-899X/392/3/032039

References

[1] Chunning Ji Guoyuan Xing Li Zhang Dong Xu 2018 Numerical simulations of vortex-induced vibration of flexible riser subjected to inclined flow *Journal of Harbin Engineering University* **39(2)** pp324-331.
[2] Yuchao Yuan Hongxiang Xue Wenyong Tang 2018 Time domain vortex-induced vibration responses of a riser in consideration of the variation effect of added mass coefficient *Journal of Vibration and Shock* **37**(1) pp53-59.
[3] Zhen Liu Yongbo Zhang Jianjie Niu Haiyan Guo 2018 Dynamic Characteristics Analysis of Steel Catenary Riser with Internal Flow *Periodical of ocean university of China* **48**(7) pp130-135.
[4] Tiebing Shan Fanghao Pan Haoran Wang 2018 Study on effect of riser system on positioning perfornance at deepwater semi-submersible production platform *The Ocean Engineering* **36**(2) pp 9-18.
[5] Shuai Hao Yang Yu Lei Wu Jianxing Yu Ning Zhang 2018 Risk Analysis on Buckling Failure of Deepwater TTRs Under Complex Loads *Journal of Tianjin University(Science and Technology)* **51**(6) pp555-565.
[6] Juan Liu. Study of Out-of-Plane Motion of SCRs with Rigid Swing[D].Qingdao:China Ocean University,2013
[7] Juan Liu and Wei-ping Huang 2014 Fluid-structure interaction analysis for VIV of steel catenary risers *Journal of Vibration and Shock* **33**(3) pp41-45.
[8] Juan Liu and Wei-ping Huang 2014 Analysis of OUT-OF-PLANE Motion of SCRS with Rigid Rotation *Engineering Mechanics* **31**(2) pp53-57.
[9] Xinglong Yao Weiping Huang Shuang Chang Juan Liu and Xue-peng Fu 2017 Modal analysis and experimental verification of out-of-plane vortex induced vibration of SCR *Journal of Vibration and Shock* .
[10] Xinglong Yao Weiping Huang Juan Liu and Kunhong Luo 2017 Study on the Coupling of Rigid swing and vortex-induced vibration of steel catenary risers *Ship & Ocean Engineering* **46** pp191-197.
[11] Xing-lan BAI Study on Method for Nonlinear Analysis of Deepwater SCR Based on Inertial Coupling [D]. Qingdao : China Ocean University, 2009
[12] Xiao-hong Chen Studies on dynamic interaction between deep – water floating structures and their mooring tendon systems . Texas A&M university,2002 32-36
[13] Ning Liang Weiping Huang and Chao-fan Yang 2016 Study on method of interaction between steel catenary riser and nonlinear seabed *The Ocean Engineering* **34**(1) pp40-49.
[14] Shuang Chang Wei-ping Huang and Chaofan Yang 2017 The influence of nonlinear seabed on the dynamic response and fatigue damage of SCR at TDZ *The Ocean Engineering* **35(2)** pp67-82.
[15] Xinglong Yao.On the Dynamic Response and Fatigue of Steel Catenary Riser with Rigid Swinging[D].Qingdao:China Ocean University,2018