The SCR Wave-Rigid Body Rotation Model Maximum Amplitude Analysis Influenced by Z Direction Motion Based on Cable3D

Bo Zhu1,*, Weiping Huang1, Xinglong Yao1 and Juan Liu2
1Shandong Key Laboratory of Ocean Engineering, Ocean University of China, Qingdao 266071, China
2Institute of Civil Engineering, Agriculture University of Qingdao, Qingdao 266009, China
*beiji_dongjie@qq.com

Abstract. Rigid body rotation(RBR) of steel catenary riser(SCR) is a problem which cannot be ignored in the calculation of transverse flow displacement and other velocity and acceleration. For the chapter, on basis of the RBR, wave force model, the large-deflection slender beam model(LDSB) and the suspension point’s z direction motion, the influence of RBR on the transverse direction displacement of the SCR is explored. The results of analysis indicate that the structure is large affected by the wave and cross flow motion relative to RBR. With water depth augment, the maximum amplitude reduces from 10th to 200th. The displacement of RBR on the structure increases with the increase of vector S, and decreases with the diminution of vector S. At 140 nodes, the effect is greatest. There exists phase difference between rigid body oscillation and linear motion superposition the wave load, In working conditions 2 and 3, it is more significant. And the amplitude increased, offset or even decreased.

1. Introduction

The steel catenary riser is an important equipment for offshore production. Min Lou et.al [1] studied vibration suppression of risers. The marine risers with fairings through LES was researched by Jingyu Qu et.al [2]. Min Lou[3] make a study of VIV suppression of parallel risers. The steep S of flexible riser with influence of top angle, volume and mid water arch on the configurations was put forward by Dapeng Zhang et.al [4]. Jieying Sun[5] researched the risers and mooring system for S-spar consideration of heave damping plates. The lazy-wave unbonded flexible riser for layers’s fatigue analysis was introduced by Tunan Fu et.al [6]. Zhiwen Wu et.al researched dynamic analysis riser under waves and vortex[7-8]. Vamshikrishna Domala and Raji Sharma [9] researched vortex-induced vibration response of riser.

In the actual platform-riser-mooring system, riser is connected with the platform through the flexible joint, and the platform-mooring system movement has an effect on the riser’s response. Based on Cable3d-SCR model, the z-directional linear harmonic motion is added to the SCR model to study the influence of Z movement to the structure. By placing the rigid body swing as a load term superimposed on the structure equation, the comparison is made to the response of SCR between the oscillation of the rigid body and no the oscillation.
2. SCR LDSB and RBR Model

2.1 Calculation Vibration Theory[7][10]

The load gravity, hydrodynamic load, hydro static load, inertial and drag force and so on will be expressed in load $q$ of SCR.

$$\mathbf{M}\ddot{\mathbf{r}} + \mathbf{B}\dot{\mathbf{r}}^{(4)} - (\lambda \mathbf{r}')' = q$$  \hspace{1cm} (1)

$\mathbf{M}$ the quality matrix for SCR; $\mathbf{B}$ stiffness matrix for SCR; $\lambda$ Lagrangian for SCR. $q$ -the uniform force for SCR.

2.2 SCR Rigid Rotation System Model.

Under the action of wave, current and so on, there is a rotation taking the OB as the axis of rotation. As shown in figure 1. $S$ is the rotation radius.

Table 1 shows the linear parameters of conditions.

The response value of 10, 80, 140 and 200 are 2.53031m, 0.93382m, 0.55306m and 0.38387m. After superimposed RBR, maximum amplitude of 10-200 are 2.52998m, 0.92835m, 0.54688m, 0.38299m. The response increase of the node 10-200 are -0.01%, -0.59%, -1.12% and -0.23%. It shows with the increase of the node, structure transverse response decrease gradually. After the superposition of RBR, the structural response is weakening.

As shown in figure 2-figure 5 the response of each node of the structure decreases with the top movement amplitude reduce or the increase of the motion frequency as shown in table 2.

3. The SCR response of z linear harmonic motion.

The response of the SCR model in z direction is the main content of this paper. In this paper, the response of the Cable-SCR model is used to calculate the displacement. On the basis of applying wave load, the z direction motion, rigid body swing are superimposed on the SCR. Table 1 shows the linear parameters of conditions.

The response value of 10, 80, 140 and 200 are 2.53031m, 0.93382m, 0.55306 m and 0.38387m. After superimposed RBR, maximum amplitude of 10-200 are 2.52998m, 0.92835m, 0.54688m, 0.38299m. The response increase of the node 10-200 are -0.01%, -0.59%, -1.12% and -0.23%. It shows with the increase of the node, structure transverse response decrease gradually. After the superposition of RBR, the structural response is weakening.

As shown in figure 2-figure 5 the response of each node of the structure decreases with the top movement amplitude reduce or the increase of the motion frequency as shown in table 2.
Table 1. The Top Load Response Parameters for Conditions [10]

| Number | A (m) | T (s) | f (Hz) | \( \omega \) (Hz) |
|--------|-------|-------|--------|-----------------|
| Con.1  | 3.0   | 10.80 | 0.093  | 0.581           |
| Con.2  | 2.0   | 9.90  | 0.101  | 0.634           |
| Con.3  | 1.0   | 9.00  | 0.111  | 0.698           |

Table 2. The Maximum Amplitude

| Number | Location | No RBR(m) | With RBR(m) | \( \eta \) (%) |
|--------|----------|-----------|-------------|---------------|
| Con.1  | 10th     | 2.53031   | 2.52998     | -0.01%        |
| Con.1  | 80th     | 0.93382   | 0.92835     | -0.59%        |
| Con.1  | 140th    | 0.55306   | 0.54688     | -1.12%        |
| Con.1  | 200th    | 0.38387   | 0.38299     | -0.23%        |
| Con.2  | 10th     | 1.76981   | 1.76936     | -0.03%        |
| Con.2  | 80th     | 0.74533   | 0.74471     | -0.08%        |
| Con.2  | 140th    | 0.45808   | 0.46017     | 0.46%         |
| Con.2  | 200th    | 0.28692   | 0.28663     | -0.10%        |
| Con.3  | 10th     | 0.96836   | 0.96843     | 0.01%         |
| Con.3  | 80th     | 0.51933   | 0.52159     | 0.44%         |
| Con.3  | 140th    | 0.3507    | 0.35698     | 1.79%         |
| Con.3  | 200th    | 0.24682   | 0.24670     | -0.05%        |

Figure 2. The amplitude of 10th varies with conditions.

Figure 3. The amplitude of 80th varies with the conditions.
3.1 Deep water linear Wave and SCR Interaction Model \cite{7}

If the floating platform or SCR moves with \( \dot{x} \) and \( \ddot{x} \), relative Morison motion formula:

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

\( A \) -the projection areas, \( \rho \) - the sea water density, \( V_0 \) -the drainage volume, \( C_m \) - the additional mass coefficient, \( C_M \) -the mass coefficient, \( C_D \) -the drag force coefficient.

4. Conclusion

The RBR of SCR is an important problem for cross-flow response relative to VIV. In this article, the maximum amplitude for the Cable-SCR model used to calculate is studied, as formula 1- formula 3. By placing the RBR model and wave model as a load term superimposed on the SCR equation, the maximum amplitude of the RBR is in comparison with the response of SCR no the oscillation, as figure 2- figure 5 and figure 6- figure 9. It shows with the node number increases, structural cross-flow
response decrease gradually from 10th to 200th, as table 2. After the superposition of RBR, the increased structural maximum amplitude is weakening. And the change is the alike between maximum amplitude and the rotation radius vector S, From 10th to 140th, it gradually increased and then decreased to 200th.

The superposition or offset is on behalf of phase difference between the waves, the linear motion and rigid body rotation, as table 2.

Acknowledgments
Thanks to professor Zhang Jun from Texas A&M University and thanks for the support of the national natural science foundation of China (51239008). Thank you for all your help.

References
[1] Min Lou, Yan Zhu. Experimental Study on Vortex-induced Vibration Suppression of Tandem risers with Three-control-rods [J]. Ship & Ocean Engineering, 2018, 47(01): 124-128.
[2] Jingyu Qu, Jing Yang, Xiaofeng Sun, Junbo Qu. CFD Simulation Study on Hydrodynamics Impact of Marine Risers with Fairings [J]. Ship Engineering, 2018, 40(01): 17-20+112.
[3] Min Lou, Canxi Mei, Wenyi Dong. Experimental Study on Vortex Induced Vibration Suppression Device of Risers in Parallel Arrangement [J]. Ship & Ocean Engineering, 2018, 40 (01): 21-26+105.
[4] Dapeng Zhang, Yong Bai, Wangqi Zhao, Keqiang Zhu. Steep Configuration and Parameters Sensitivity Analysis of Deepwater Flexible Riser[J]. Low Temperature Architecture Technology, 2018, 40(01): 106-113.
[5] Jieying Sun, Shuhua Zhang, Hui Chen, Lei Feng. On Number of Heave Damping Plates of S-spar Platform and Coupling Analysis of risers and Mooring System [J]. Ship & Ocean Engineering, 2018, 47(01): 89-93.
[6] Tunan Fu, Weiping Huang, Shugang Cao, Shuang Chang. Fatigue Analysis on the Lazy-Wave Flexible Riser in Catenary Anchor Leg Mooring System [J]. Naval Architecture and Ocean Engineering, 2018, 34(01): 49-55+58.
[7] Juan Liu. 2013 Study of Out-of-Plane Motion of SCRs with Rigid Swing[D]. Qingdao: China Ocean University.
[8] Zhiwen Wu, Canrong Xie, Guoxiong Mei, Hongyuan Dong. Dynamic analysis of parametrically excited marine riser under simultaneous stochastic waves and vortex [J]. Advances in Structural Engineering, 2018, 1-16
[9] Vamshikrishna Domala, Raji Sharma. An experimental study on vortex-induced vibration response of marine riser with and without semi-submersible [J]. Proceedings of the Institution of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment, 2018, 232(2): 176-198.
[10] Xing-long Yao. 2018 On the Dynamic response and Fatigue of Steel Catenary Riser with Rigid Swinging [D]. Qingdao: China Ocean University