NUMERICAL SIMULATION OF VORTEX-INDUCED VIBRATION FOR A REAL SIZE DRILLING RISER SYSTEM WITH AUXILIARY LINES

TENGTENG KONG[1, 2], WENBO WU[1, 2, 3], JIASONG WANG [1, 2*]
[1]*Department of Engineering Mechanics, School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, 200240, China*
[*]*jswang@sjtu.edu.cn*
[2]*Key Laboratory of Hydrodynamics（Ministry of Education）, Shanghai Jiao Tong University*
[3]*School of civil engineering, Guangzhou University, 510006, China*

Keywords: *riser system；auxiliary line；vortex-induced vibration；vortex shedding；numerical simulation*

In our recent study on the flow control modeling for a drilling riser system with auxiliary lines, it was shown that the auxiliary lines can suppress the vortex shedding on the main riser at all incidence angles [1]. This finding is of significance to the real engineering of drilling operation. Here we further simulate the vortex-induced vibration (VIV) response for this real-size drilling riser system in service in the South China Sea by the secondary development of OpenFOAM platform. By simulating the VIV of the riser system at various angles of attack under typical reduced velocity, the influence of the flow direction on the vortex shedding and response process of the riser system was analyzed. The obtained results indicate that the auxiliary lines can effectively suppress the vortex shedding on the main cylinder and reduce the amplitude due to the clamping of the downstream auxiliary lines, but the effect is greatly related to the angle of attack. The VIV of a real-size drilling riser system does not show an upper branch and the amplitude is much smaller than the amplitude of a single cylinder.

1. Introduction

The vortex-induced vibration of a circular cylinder has encountered in a lot of practical engineering fields, especially in the offshore engineering. As a consequence of significant interactions of vortex shedding and structural dynamics, VIV will cause fatigue damage and thus seriously affect the engineering operations and may even bring environmental accidents. In last several decades, the mechanism of VIV has been studied in detail, both experimentally and numerically. Zhao et al. [2,3] studied the vibration response of two cylinders at low Reynolds numbers for tandem and parallel rigid connections. Rahmanian et al. [4] studied the VIV characteristics of staggered rigidly mounted cylinders and found that there may be multiple locking zones in the vibration of the cylinder. Zhao & Yan [5] studied the characteristics of VIV when two cylinders with different diameters were staggered, and discussed the effects of gap and incoming angle of attack on the locking zone. The coupled motion of multiple cylinders (triple cylinders and above) is rarely seen in literature. This article starts from the actual engineering background and simulates the vortex-induced vibration response of a real-size drilling riser system.

2. Problem description

Fig.1 is the sketch of the cross section of a real drilling riser system with auxiliary lines. In the riser system, the auxiliary lines had different diameters and distributed asymmetrically around the main line. The complicated flow was investigated based on the different incidence angles. In Fig.1, α represents the incidence angle of the flow, θ is the circumferential angle of the main line, U is the free stream velocity of the flow. The diameter of the main line is represented as D, the diameters of the auxiliary lines in the riser system and the geometrical parameters are shown in Fig.1. All the cylinders in the riser system were rigidly connected, i.e. the risers moved synchronously at any time.

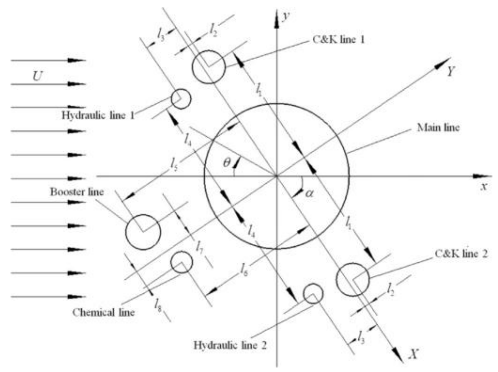


Fig.1 Sketch of the model for a real drilling riser system

Fig.2 shows that the risers can move in the in-line and cross flow directions simultaneously, and the stiffness coefficient and the damping coefficient are the same in both directions. The vortex-induced vibration of the drilling riser system at different angles of attack can be obtained by changing the angle of attack at the incoming flow.

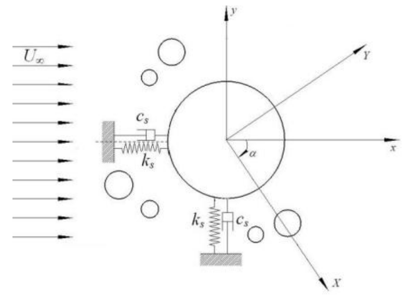


Fig.2 Sketch of the model for VIV of a real drilling riser system

3. Governing equations and computational model

In this paper, the secondary developed OpenFOAM was used to compute the VIV of the riser system by the finite volume method, and all cylinders moved synchronously and were modeled using a single spring oscillator model. The analytical form of the governing equations of unsteady flow of viscous incompressible fluid in Cartesian coordinates can be expressed as follows:

$$\frac{\partial U_i}{\partial x_i} = 0 \tag{1}$$

$$\rho\frac{\partial U_i}{\partial t} + \rho\frac{\partial}{\partial x_i}\left(U_j U_i\right) = \mu\frac{\partial^2 U_i}{\partial x_j \partial x_j} - \frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} \tag{2}$$

where μ is the molecular dynamic viscosity, U is the time-average velocity vector of the fluid, τ is the Reynolds stress tensor, p is the pressure, ρ is the density of the fluid. K-ω model was used here, and the Reynolds stresses were computed in two-equation models with the Boussinesq expression.

4. Validation of tandem cylinders

In order to validate the computational method in this paper, the results of VIV of single circular cylinder and tandem cylinders computed with OpenFOAM were compared with the results of other researchers. The non-dimensional transverse displacement (A^*_y) and non-dimensional transverse frequency (f^*_y) were defined as:

$$A^*_y = \frac{A_y}{D}, \quad f^*_y = \frac{f_y}{f_n} \tag{3}$$

where A_y is the displacement in the cross-flow direction, D is the diameter of the cylinder, f_n is the natural frequency of the riser system, f_y is the frequency of the transverse vibration of the cylinder, which the value is equal to the vortex shedding frequency and calculated by the FFT of the lift coefficient.

Assi et al. [6] studied the wake-induced vibration(WIV) in a tandem arranged system. Two cylinders were placed in series, and the distance between the centers of the cylinders was P. The upstream cylinder was stationary, and the downstream cylinder could only vibrate in the cross-flow direction. Both cylinders had a diameter of D and a uniform flow velocity of U. It can be seen from Fig.3 that the RMS amplitude of the downstream cylinder agrees well with the results of Assi et al. [6] , and the numerical difference is not obvious; the variation trend of the amplitude with reduced velocity is the same as that of Assi et al. [6], which can reflect the WIV amplitude of the downstream cylinder continues to increase as the reduced velocity increases. Therefore, it can be considered that the error between the results of this paper and the results of Assi et al. [6] is within the experimentally acceptable error.

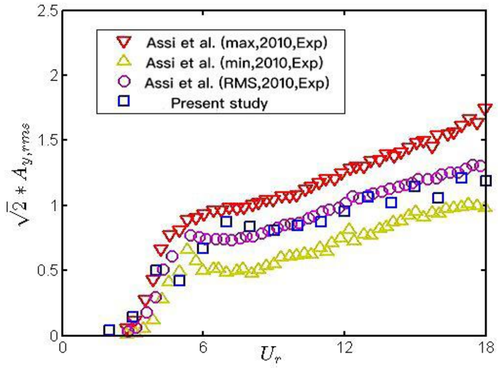
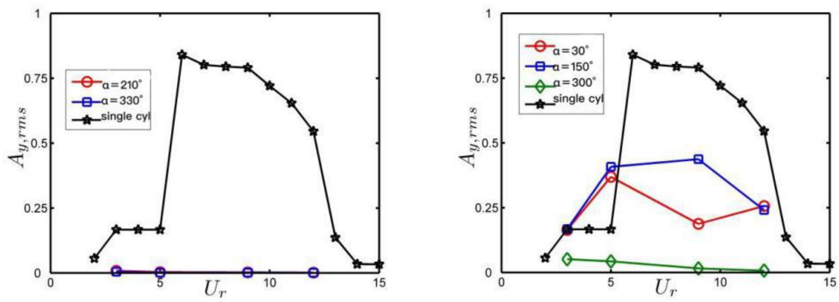


Fig.3 The vortex-induced vibration amplitude of the downstream cylinder

5. Results and discussions

In this section, the results and discussions about this simulation were given from the vibration amplitudes to flow fields. Fig.4 shows the amplitudes of VIV at various incoming angles of attack for a real-size drilling riser system. In order to more clearly show the variation at different angles, the amplitudes are shown in the different diagrams according to the flow patterns described in Wenbo Wu et al. [1]. CVP there represents the clamped vortices pair mode, and SVF is the single vortex forming mode.

As can be seen from Fig.4, the upper branch of the riser system does not appear at any angle of attack, and its amplitude is much smaller than that of a single cylinder, especially at 210°, 300° and 330°, the amplitudes are almost close to zero.

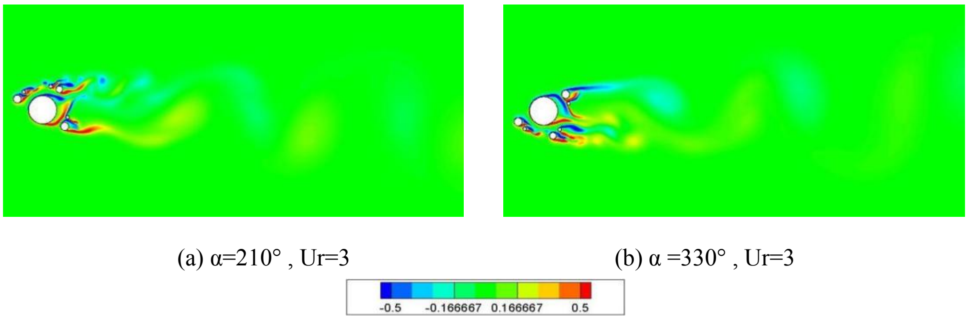


(a) CVP (b) SVF

Fig.4 The vortex-induced vibration amplitude of the riser system at different incidence angles

From the analysis in the previous section, it can be known that the VIV of the drilling riser system is very weak at some angles of attack and can be considered as a static cylinder system. In practical conditions, the stability of the riser has a significant impact on the ease of drilling operations and the risk factor. Therefore, the flow field near the cylinder system during the vortex-induced vibration of the riser is further analyzed and studied.

Fig.5 shows the vorticity contour at the reduced velocity corresponding to the maximum amplitude of the cylinder system under different angles of attack. Each diagram corresponds to the time when the riser system is located at the valley value. It can be seen from Fig.5 that the vortices near the riser system are affected by multiple auxiliary lines and the vortices are irregularly distributed. As can be seen from Fig.4(a), almost no vortex-induced vibration occurs in the riser system at 210° and 330°. According to the vorticity contour, at 210° and 330°, the shear layer on the main line is confined to a very small area by the downstream auxiliary lines, and disappears quickly due to the interaction, so obvious discrete vortices in the riser system wake cannot be observed.



(a) α=210° , Ur=3 (b) α =330° , Ur=3

Fig.5 The vorticity contour near the riser system

6. Conclusions

In this paper, the vortex-induced vibration of a real-size drilling riser system under various attack angles was numerically simulated by the second developed OpenFOAM platform. The obtained results indicated that the auxiliary lines can effectively suppress the vortex shedding on the main cylinder and reduce the amplitude, but the effect is greatly related to the angle of attack. When auxiliary lines were located downstream of the main line, the VIV was so weak because the main line cannot shed vortex due to the clamping of the downstream auxiliary lines, especially at 210°, 300° and 330°, the amplitudes were almost close to zero. However, due to the characteristics of multi-cylinder, multi-size, irregular arrangement, etc., this article cannot analyze the role of each sub-cylinder in the riser system, nor can it discuss the effect of auxiliary lines in the joint action of the riser system to the main line. Therefore, it is necessary to simplify the model and conduct more in-depth research.

Acknowledgments

The authors are grateful to the support from the National Natural Science Foundation of China (Grant nos. 11372188), the National Basic Research Program of China (973 Program) (Grant no. 2015CB251203) and Innovative Special Project of Numerical Tank of Ministry of Industry and Information Technology of China (2016-23/09).

References

[1] Wenbo Wu, Jiasong Wang, Shiquan Jiang,et al. Flow and flow control modeling for a drilling riser system with auxiliary lines. Ocean Engineering, 2016, 123: 204-222.

[2] Zhao, M. Flow induced oscillation of two rigidly coupled circular cylinders intandem and side-by-side arrangements at a low Reynolds number of 150 [J]. Physics of Fluids, 2013, 25: 123601.

[3] Zhao, M., Murphy, J.M. and Kwok, K. Numerical simulation of vortex induced vibration of two rigidly connected cylinders in side-by-side and tandem arrangements using RANS model [J]. Journal of Fluids Engineering, 2016, 138: 021102.

[4] Rahmanian, M., Zhao, M. and Cheng, L. et al. Two degree of freedom vortex induced vibration of two mechanically coupled cylinders of different diameters in steady current [J]. Journal of Fluids and Structures, 2012, 35: 133-159.

[5] Zhao, M. and Yan, G. Numerical simulation of vortex induced vibration of two circular cylinders of different diameters at low Reynolds number [J]. Physics of Fluids, 2013, 25: 083601.

[6] Assi, G.R.S., Bearman, P.W. and Meneghini, J.R. On the wake-induced vibration of tandem circular cylinders: the vortex interaction excitation mechanism [J]. Journal of Fluid Mechanics, 2010, 661: 365-401.