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VIV AND CONTROL IN SUBMERGED FLOATING TUNNEL'S CABLES

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Abstract. *The vortex-induced vibration (VIV) of cables in Submerged Floating Tunnel (SFT) will occur when the current pass by cables in a certain flow rate. The VIV will exacerbate the fatigue failure of the cables and reduce the life and safe of SFT. In this paper, the effect of control vibration methods of cables with fairing and control rods were analyzed by using numerical method considering fluid-structure interaction. Influence of different inclination angles and flow directions on the vortex-induced vibration of cables with suppression designs is explored on the basis of investigation for marine risers. The results showed that the two proposed methods for vortex-induced vibration in cables of SFT both have good suppression effects along the flow direction and suppression designs with fairing was superior to suppression designs with three control rods. The suppression effect of control rods was significantly improved when the cables are inclined. The analysis also demonstrates that the control rods may partly increase the VIV of cables in SFT when the flow direction changes and lead failure of suppress the vortex-induced vibration of cables. The fairing in suppression vibration designs of SFT has better adaptability than control rods for a variety of environments.*

1 INTRODUCTION

The cables are important components of SFT structure, by which the tubes are connected to seabed foundation, and can steadily maintain the tubes suspended to a certain depth in water, as shown in Figure 1. Meanwhile, the cables also can limit the vertical and horizontal displacement of tubes [1]. Seawater is moving at any time by many factors. When the seawater flows through the cables, vortex shedding will occur in the rear region of cables and periodical force will act on the cables. It may lead to vortex-induced vibration (VIV) of cables [2-4]. The cables' natural frequency is generally lower, close to the frequency of vortex shedding. It will easy to produce self-locking phenomenon (Lock-in), which will cause substantial vibration and exacerbate fatigue and failure of cables [5]. Thus, the study of vortex-induced vibration suppression method has important theoretical and practical significance

Currently, a lot of researches have been done only for cables vortex-induced vibration [6-7]. However, the study for vortex induced vibration suppression of SFT is almost blank. Fortunately, in the marine engineering, there have been many suppression methods for the marine riser vortex induced vibration, which may be used to control the vortex-induced vibration in cables of SFT. The main suppression methods include: (a)Weaken the impact of vortex-induced vibration by adjusting dynamic characteristics of structures; (b) Control or change the formation and development of the vortex shedding to reduce the vortex-induced force. In this paper, the method that changes the shape of cylinder section or adds the subsidiary spoiler device to suppress the vortex-induced vibration of cables was presented. Wang investigated the suppression effect of fairing and other two self-designed vibration suppression measures by experiment [5]. Song further proposed the method which suppresses vortex-induced vibration for the marine riser by using three control rods based on the design of one control rod, and found the effect was wonderful [8].

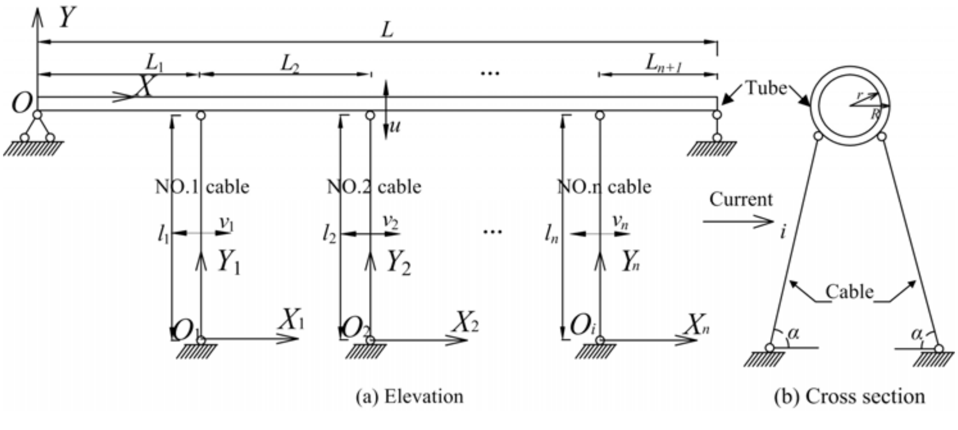


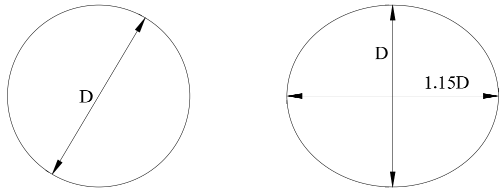
Figure 1: The submerged floating tunnel and computing sketch

Most of marine risers are mounted vertically. However, a lot of cables for SFT are designed to incline besides vertical cables. So, it is questioned whether the methods of fairing or control rods for marine risers can be directly or not used on the SFT. In this paper, the effect of controlling the vortex-induced vibration in cables of SFT with the help of fairing or control rods is analyzed by separate coupling numerical method (SCNM). Some measures and suggestions are presented.

2 SUPPRESSION DESIGNS

For the typical STF shown in Fig. 1, the designed cables can be approximated as a cylinder which hinge on seabed foundations and tubes. The parameters of cables are as follows: length L=100m, diameter D=0.3 m, elastic modulus $E=1.95\times10^{11}Pa$, density ρ=7800kg/m^3, cable stress $\sigma=0.4f_{\mathrm{pk}}$, f_{pk} is the standard value of strand tensile strength, f_{pk}=1860Mpa. The seawater around cables is assumed as ideal fluid, and the flow is considered as uniform flow. The parameters of seawater are as follows: density ρ_{w}=1000kg/m^3, velocity v=2.15m/s.

The suppression designs (fairing and three control rods) are used on vertical cables(α=90°) and inclined cables(α=60°) of SFT. The horizontal projection of cables without any suppression designs is shown in Figure 2, the horizontal projection of cables with fairing is shown in Figure 3, the horizontal projection of cables with three control rods is shown in Figure 4.



(a) (b)

Figure 2: Cables without any suppression designs(a: vertical; b: incline 60°)

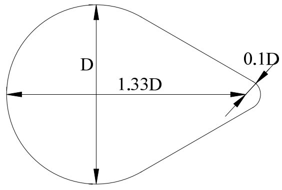
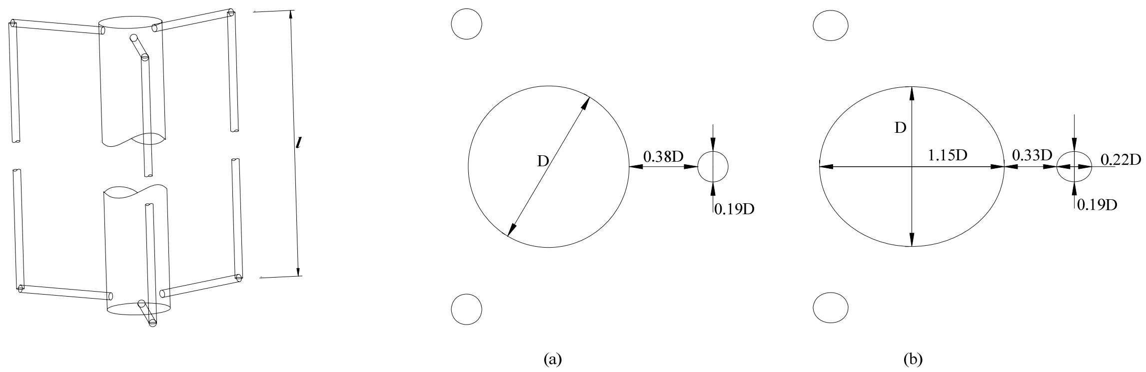


Figure 3: Cables with fairing (vertical and incline 60°)



(a) (b)

Figure 4: Cables with three control rods (a: vertical; b: incline 60°)

3 NUMERICAL SIMULATION METHOD

At present, the fluid-structure interaction (FSI) problem can not be solved in a unified equation system due to the limited technical conditions. In this case, an approximate method-separate coupling numerical method (SCNM) is widely used in fluid-structure analysis. The SCNM calculation process is as follows:

(a) At time *t*, the flow field around cables is simulated by CFD to solve hydrodynamic loads on cables which will be passed to the structural calculation software immediately;

(b) Then, the displacements of cables are obtained by structural calculation software under the corresponding action of load, which will be returned to CFD software to update the flow field grid;

(c) At time $t+\Delta t$, step (a) is repeated. Flow chart is shown in Figure 5. Here, the CFD software is Fluent, the structural calculation software may be ABAQUS, ANSYS or self-programmed software and the third-party software used to exchange data is MpCCI etc.

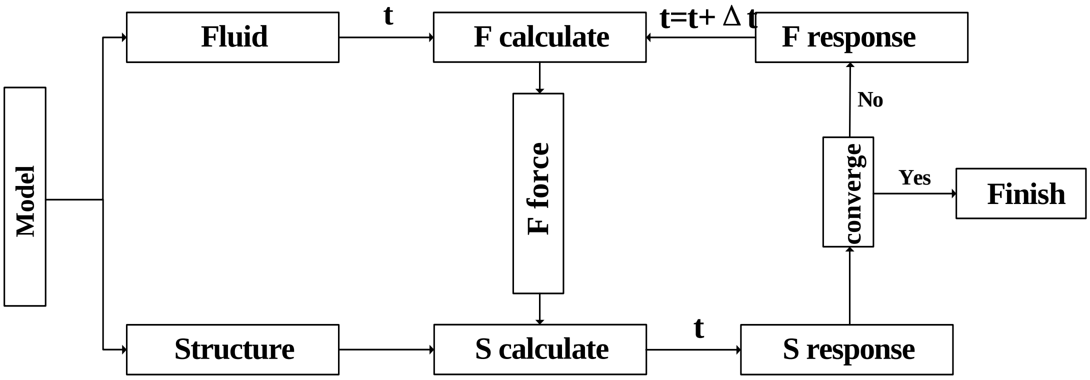


Figure 5: Flow chart of SCNM calculation

4 MATHEMATICAL MODEL

Taking the above discussed parameters of designed cables as an example, calculation models of flow field and cable are shown in Figure 6, and the analysis is carried out on the two-dimensional scale.

4.1 Flow field

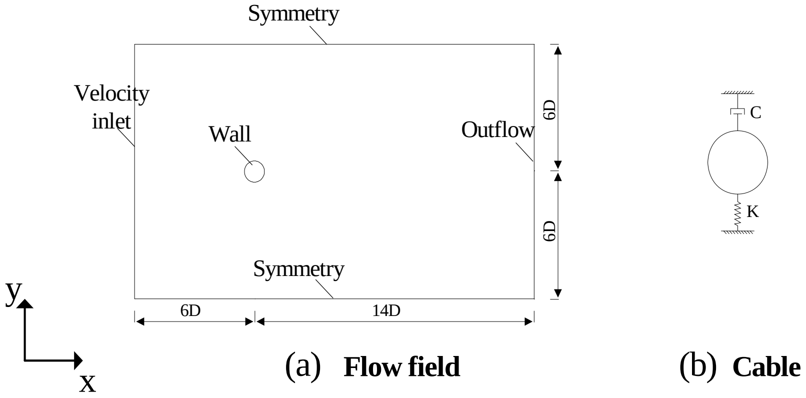
Calculation method: Detached Eddy Simulation (DES).

Boundary conditions: Velocity inlet, u=2.15 *m/s*, direction-left to right. Outflow, pressure is zero. Wall, non-slip boundary; symmetry, normal flow rate is zero.

4.2 Cable

Calculation method: Finite Element Method (FEM).

Boundary conditions: Displacement in x-direction is constrained, u_x=0. Cable is elastically constrained in the y-direction, K= 25311 *kN/m*.



(a) **Flow field** (b) **Cable**

Figure 6: Calculation models of flow field and cable

5 ANALYSIS CASES

In order to investigate the effect of different suppression vibration designs, the 9 cases have been selected and listed in Table 1.

Case	Suppression	Incline angle α (degree)	Flow angle θ (degree)	Case	Suppression	Incline angle α (degree)	Flow angle θ (degree)
1	None	90	0	6	fairing	60	0
2	Adding control rods	90	0	7	none	60	45
3	Fairing	90	0	8	control rods	60	45
4	None	60	0	9	fairing	60	45
5	Adding control rods	60	0				

Table 1: Calculation cases

6 RESULTS AND ANALYSIS

The displacement curves of cables for case 2 and 3(α =90, θ =0) with two suppression vibration designs are shown in Figure 7. No suppression vibration in case 1 is also drawn in Figure 7. It is found that the maximum amplitude of cables with suppression vibration designs were both generally less than that of cables without any suppression designs. It meant that the effect of the two suppression designs could suppress the vortex-induced vibration. Specially, suppression design with fairing was superior to suppression designs with three control rods when the flow direction was constant. The fairing could almost completely suppress the occurrence of vortex-induced vibration of cables.

In practice, most of cables must be installed with a certain inclination angle, in order to resist the horizontal force due to flow seawater acted on the tube. So, it is necessary to research that whether the suppression designs could be applied to the inclination cable. As shown in Figure 8, when α was changed from 90 degree to 60 degree, for case 4 and 6, the maximum amplitude of cables with none increased slightly (from 0.204 *m* to 0.217 *m*). Surprisingly, the suppression effect of control rods was significantly improved. The maximum amplitude decreased from 0.136m to 0.089 *m*. Meanwhile, fairing could still suppress the occurrence of vortex-induced vibration perfectly. Therefore, it was found that inclination of cables would not lead to the failure of suppression designs with fairing and control rods. Conversely, it would enhance the effect of suppression.

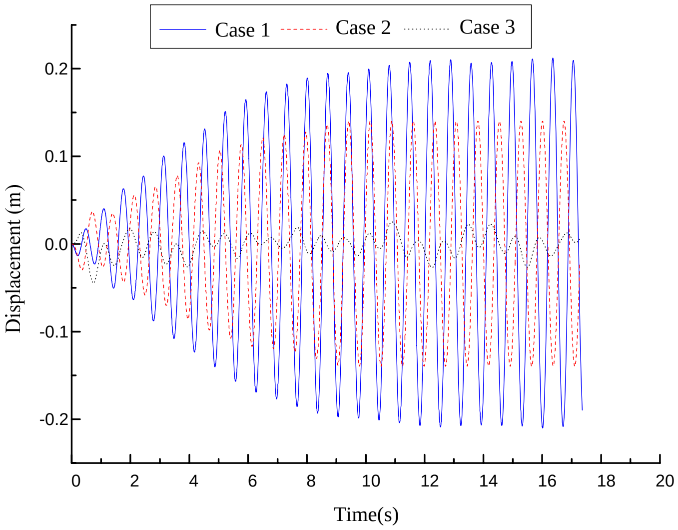


Figure 7: Displacement curves of cables(α =90 degree, θ =0).

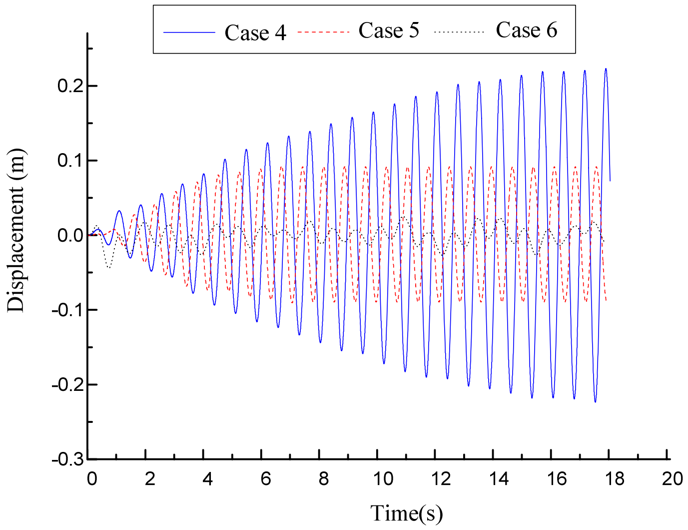


Figure 8: Displacement curves of cables(α =60 degree, θ =0).

In the ocean, it is generally difficult to predict the direction of seawater flow, or the flow direction may change over time. So, it is meaningful to analyze the impact of flow direction changing to 45 degree. Figure 9 gave the comparison of displacement curves of cables for case 4 and 6. It showed that the maximum amplitude of cables with none increased slightly from 0.217m to 0.244 m. But it is worth noting that the maximum amplitude of cables with control rods increased substantially, from 0.136 m(α =90 degree, θ =0) or 0.089 m (α =90 degree, θ =0) to 0.240 m, increased by 76%% and 170% respectively. The value was close to the maximum displacement value of cables with none. It meant the suppression designs had failed. In addition, the maximum amplitude of cables with fairing also significantly increased to 0.114 m. However, the value was still smaller than cables with none. The results showed that fairing had better adaptability than control rods on the change of the flow direction.

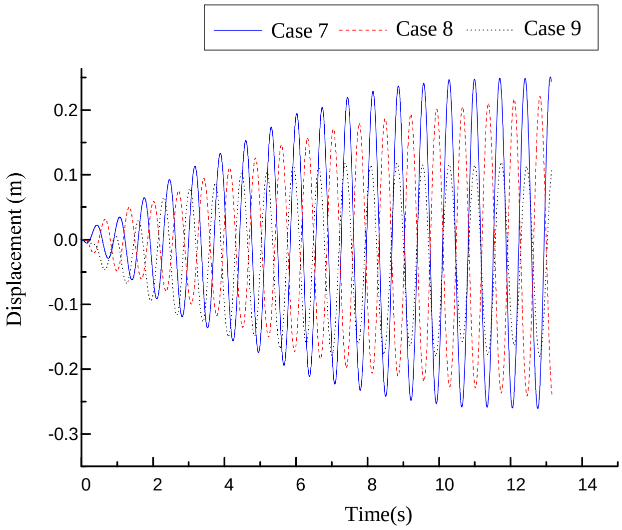


Figure 9: Displacement curves of cables(α =60 degree, θ =45 degree).

7 CONCLUSIONS

The suppression vibration effect of fairing and control rods for cables of SFT were analyzed by using separate coupling numerical method (Fluent + MpCCI + ABAQUS) based on the researches of vortex-induced vibration suppression designs for marine risers. The effect of inclination angle and flow direction has been discussed. The following conclusions can be drawn from these analyses:

(1) The effect of fairing and control rods for cables of SFT are good when the flow direction is constant and cables are vertical. Compared of the two suppression vibration designs, fairing are significantly better which can almost completely suppress the vortex-induced vibration of cables.

(2)The inclination of cables will not lead to the failure of suppression vibration designs with fairing and control rods. Conversely, it would enhance the effect of suppression.

(3)The control rods will fail to suppress the vortex-induced vibration of cables when flow direction changing, but the fairing can still play better. In general, the fairing in suppression vibration designs of SFT has better adaptability than control rods for a variety of environments.

ACKNOWLEDGEMENT

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