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New Method in Suppressing Vortex-Induced Vibration of Marine Riser

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Abstract. Marine risers are key apparatus in connecting the subsea wells to the oil production platform. When the ocean current flow past a riser, the vortex shedding behind riser may induce vibration. If the frequency of vortex shedding is approaching or equal to the natural frequency of riser, the resonance will be generated. Such phenomenon leads to the potential fatigue damage of riser. Therefore, the safety and assurance of marine risers are widely arousing the interest of offshore engineering. In present paper, previous apparatus or methods in suppressing vortex-induced vibration (VIV) of risers used in marine engineering are firstly analyzed, and correspondingly the conditions in design of VIV suppressors are proposed. Based on the Bernoulli equation, the disturbance in flow around a bluff body and the relationship of vortex shedding in span-wise direction, a new method of VIV suppression is proposed. The numerical results have shown that the vibration of risers could be reduced by such disturbance.

Introduction

Risers are key apparatus in connecting the submarine wells to the oil platform in marine engineering. When the ocean flow comes across the risers, the fluctuating fluid forces will be generated and act on such structure due to the vortex alternately shedding. Correspondingly, the vibration is appeared, called vortex-induced vibration (VIV). Especially, as the frequency of vortex shedding is approaching or equal to the natural frequency of structure, the vibrating amplitude will be obviously amplified, as well as the fluid forces. Such phenomenon leads to the potential fatigue damage of structure, even the oil drilling activity and production. Therefore, the safety and assurance of marine risers are widely arousing the interest of marine engineers [1-3].

In a recent half century, many devices and methods in suppressing VIV were proposed by researchers through experiments and applications. More details about the features and applications for those suppressors could be referenced in Hafen, et al. [4], Sarpkaya & Isaacson [5], Zdravkovich [6], Kumar, et al. [7], Wu and Sun. [8] and Lin [9]. However, there are still some disadvantages for previously applied devices. For example, the streamline fairing [10] with very good aerodynamic performance results into the reduction of lift and drag. Howbeit, the variation of flow direction would weaken those effects, or the rotatable instruments would introduce new dynamical instability of whole structure. In present paper, the main purpose is to investigate a new device in suppressing VIV from the point of actual application in marine engineering.

Conditions in design of VIV suppression of marine risers

Through the analysis of physical mechanics of VIV suppression in previous typical devices, some conditions in design and engineering's application of suppressors should be proposed as follows,

(1) Sensitivity of flow direction: independent of variation of flow direction for complex incoming flow , including wave, ocean flow and inner wave;
(2) Mechanism of VIV suppression: based on the first limitation, the mechanism of VIV suppression should be realized through the disturbances on the flow around the body and along the span-wise direction;

(3) Practical engineering: simple design, low cost, easy manufacture, installation and repair, especially avoiding to modify the original riser;
(4) Effect of VIV suppression: realizing the reduction of vertical oscillating amplitude, even to the suppression of vortex shedding;
(5) Effect of marine environment: reducing such effect on the VIV suppressor as low as possible, such as the attachment of marine organism on the device.

Theory of VIV suppression

Based on the Bernoulli equation and disturbances on the flow around the body and span-wise correlation. Through analyzing the previous researches about the VIV suppressors and experiments, a kind of passive control method is adopted.

Generally, the fluid forces acted on the structure are typically expressed as follows,

$$C_{\Phi}(C_D, C_L, C_A) = 2\int_{\Gamma}[-pn + \frac{1}{\text{Re}}(\nabla u + \nabla u^T)n]ds \tag{1}$$

where C_D, C_L and C_A are coefficients of drag, lift and axial forces, Γ is the structural boundary, p is the pressure, $\boldsymbol{n}$ is the normal direction along the structural boundary, Re is the Reynolds number, $\boldsymbol{u}$ is the velocity vector, T is the matrix transpose, s is the integration area.

In the above equation (1), the first item on the right-hand side is the component of pressure difference, and the second item is the viscous component due to the fluid viscosity and corresponding shear stress. Practically in marine engineering, the Reynolds number is commonly high enough. Therefore, the viscous component is relatively secondary. The way in weakening the fluid force is focused on the reduction of component of pressure difference.

On the other hand, from the point of energy variation, the Bernoulli equation with the assumption of idea fluid is written as

$$\frac{U^2}{2} + gz + \frac{p}{\rho_f} = C(\psi) \tag{2}$$

where U is the incoming velocity, g is the acceleration of gravity, z is the height position, ρ_f is the fluid density, C is the constant along the same streamline ψ.

The first item on the left-hand side of equation (2) is the kinetic energy, the second the potential energy, and the third the pressure energy. If variation of the potential energy could be neglected by the introduction of disturbances, the pressure energy would be reduced when the local kinetic energy is increased. Accordingly, the proposed method is to find a disturbance to enhance the fluid kinetic energy around the body and realize the reduction of pressure energy near, and then reduce values of pressure on body surfaces based on the theory of boundary layer with the approximation of the first order. The final goal is to reduce the fluctuating lift force and then the oscillating amplitude of structure.

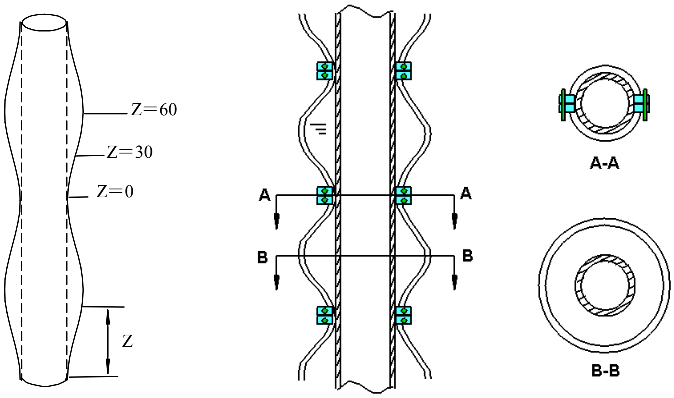
New device of VIV suppression

From above conditions in design of marine risers, a new kind of device of VIV suppression is proposed, typically such as the harmonic shroud as shown in Figure 1. The physical mechanism of such disturbance is listed as follows,

(1) From the point of vortex dynamics, the introduction of geometric disturbance along the span leads to the generation of additional vorticity on cylinder surfaces, such as stream-wise and vertical components of vorticity, rather than the only span-wise vorticity generated. Those additional vorticity with the specific distributions plays an important role in disturbing the flow around the body, vortex shedding and span-wise correlation;

(2) To avoid the effect of the attack angle due to the variation of flow direction on the suppressor, the cross-section should be circle. That is, the original disturbance in the stream-wise and span-wise plane would be transferred into the radial span-wise plane, which results into the diameter of structure varied along the span, and furthermore the vortex shedding.

Hence, there are a lot of geometric disturbances belonging to such kind, such as the spherical, ellipsoidal and conical disturbances. They have similar mechanism of disturbances on flow. However, there are a lot of works that should be carried out by numerical simulations and experiments to investigate the effects of disturbance parameters on VIV.



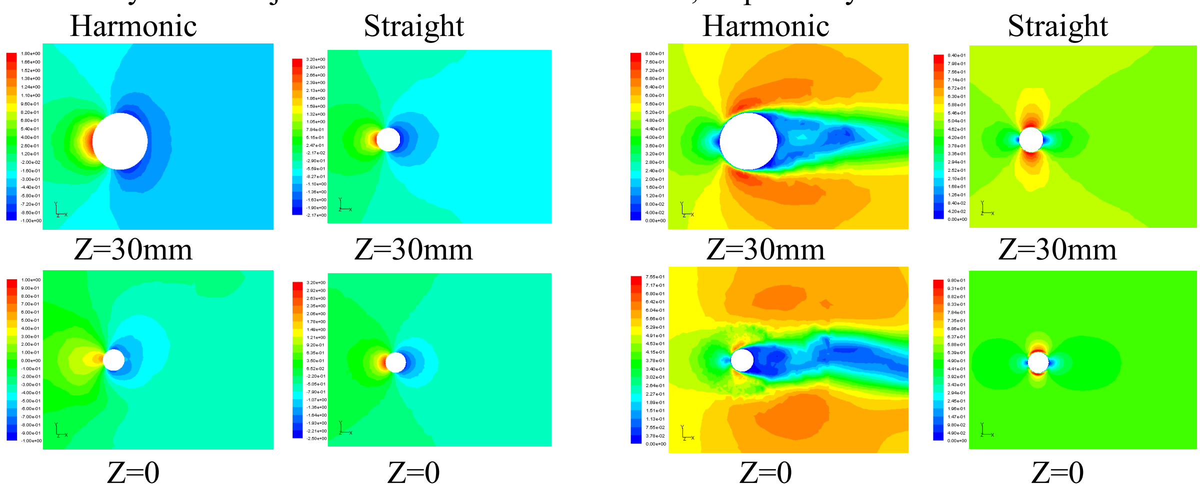
(a) (b) (c)

Fig. 1 The harmonic shroud as a new kind of VIV suppressor.

Initial simulations of harmonic disturbance

The flow around the structure with the harmonic disturbance is numerically simulated. The diameter of straight cylinder is 10 millimeter, and the non-dimensional wavelength of disturbance is 6, the wavy steepness, the ratio of the wave height to the wavelength, is 0.1.

As shown in Figure 2, the contours of the pressure coefficient and stream-wise component of velocity near the cylinder are presented at two span-wise positions, z = 0 and z=3, where the diameters of disturbed cylinder are just the minimum and maximum, respectively.



(a) The contours of the pressure coefficient.

(b) The contours of the stream-wise velocity.

Fig. 2 The contours of the pressure coefficient and velocity for the harmonic and straight cylinders at different span-wise positions at the incoming velocity of 0.5 m/s.

In Table 1, the base pressure coefficients for the harmonic cylinder are obviously greater than those for the straight cylinder. The values of pressure coefficients are reduced, indicating the physical mechanism of such disturbance effectively.

In Figure 2, by comparing the contours of pressure coefficients and stream-wise velocity, the region of wake for the harmonic cylinder is obviously greater than that for the straight cylinder, indicating that the vortex-formation length would be increased and correspondingly the base pressure coefficient increased. Moreover, the increasing vortex-formation length is helpful in weakening the vortex shedding and lift. Therefore, it shows the potential ability in suppressing VIV.

Table 1 The base pressure coefficients for the harmonic and straight cylinders at different span-wise positions at different incoming velocity.

Z(mm)	$Re=10^4$(U=0.5m/s)		$Re=2\times10^4$(U=1m/s)	
	Straight	Harmonic	Straight	Harmonic
0	-2.5	-0.6	-2.4	-1.75
15	-2.17	-0.5	-1.6	-1.34
30	-2.17	-0.6	-2.6	-1.6

Summary

(1) A new kind of method in VIV suppression used in marine risers is proposed based on the Bernoulli equation and disturbances on flow around the body and span-wise correlation.
(2) From the numerical simulations, such disturbance is effective in reducing the lift force and suppressing vortex shedding, even the structural oscillating amplitude.
(3) Such device has many advantages in design and manufacture, compared to the strake and streamline fairing. It is a potential application in marine engineering in future.

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