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Experimental Study on Aerodynamic Countermeasure for Galloping Vibration of Stay Cables Attached with Lamps: Perforated Shrouds

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SUMMARY:
The perforated shroud is proposed to solve the cable galloping caused by the installation of rectangular lamps. Wind tunnel force tests are performed to verify the effectiveness of the perforated shroud based on the quasi-steady assumption. The effects of vertical and inclined cables, uniform flow and turbulence, different porosities, different holes, and different shroud diameters are all considered in the force measurement wind tunnel test. According to the test results, both the shroud with circular holes of 19.6% porosity and the shroud with rectangular holes of 36.0% porosity have galloping coefficients greater than 0 for the vertical model. A galloping coefficient greater than 0 is found in the shroud with circular holes of 19.6% and 34.9%porosity, and the shroud with rectangular holes of 36.0% porosity for the inclined model. They are suggested for use in engineering applications. A turbulence of 9% increases the critical wind velocity slightly. The addition of the perforated shroud does not necessarily result in a greater force coefficient, but it does result in a greater wind load on the cables due to the increased diameter.

Keywords: Cable galloping, Perforated shroud, Lamps

1. GENERAL INSTRUCTIONS

In recent years, lamps installed on stay cables have caused large vibrations (An et al., 2021; Deng et al., 2021). After decades of research and practice, winding helix lines on cable surfaces and installing a damper at the end are the most effective measures to restrain cable vibration, including the most challenging rain-wind-induced vibration (RWIV) and vortex-induced vibration (VIV). However, a study (An et al., 2022) shows that helical lines have little advantage for galloping caused by lamps. The damping ratio (or *S*c) required to suppress the galloping is greater than the previous damping ratio (or *S*c) required to suppress the RWIV and VIV. For super-long cables, it is very difficult to achieve high mechanical damping due to the limitation of the damper installation position. Therefore, it is necessary to develop effective aerodynamic control. Although there are some studies on the aerodynamic and vibration characteristics of cable with rectangular lamps (An et al.,2021;2022; Deng et al.,2021), no studies on related aerodynamic control have been reported.

The perforated shroud was initially proposed by Price (1956). In the next two decades, many scholars (Walshe and Wootton, 1970) found that it can effectively suppress the vortex-induced vibration of chimneys and the tower. In recent years, many studies (Sun et al. 2021) have explained the mechanism that perforated shroud can effectively suppress vortex-induced vibration. Kleissl and Georgakis (2011) first studied the aerodynamic forces of the combination of cable and perforated shroud. It was found that aerodynamic forces have a very low dependency on the Reynolds number. There was no dry galloping, according to the quasi-steady assumption.

In general, the vortex-induced vibration of the cylinder can be effectively suppressed by adding a perforated shroud outside the cylinder. At the same time, holes on a perforated shroud can prevent the formation of a rivulet. Therefore, rain-wind-induced vibration can be effectively prevented. The idea of using a perforated shroud to suppress the galloping of cables with lamps is proposed. The aerodynamic coefficients are obtained by force test in a wind tunnel. Based on the quasi-steady assumption, the effectiveness of the perforated shroud on cable galloping is verified.

2. FORCE MEASUREMENT WIND TUNNEL TESTS

2.1 Test Model

There are 7 types of test models in total, which are named Models 0, 1, 2, 3, 3a, 3b, and 4, as shown in Fig.1(a)~(g). The outer shrouds are made by 3D printing. The holes on the perforated shrouds are characterized by three parameters, including the porosity factor β, the hole size D_h and the hole spacing S. The porosity factor β refers to the ratio of the area of the hole in the perforated shroud to the total area of the perforated shroud. β can be changed by adjusting the hole size D_h and the hole spacing S, as shown in Fig.1.

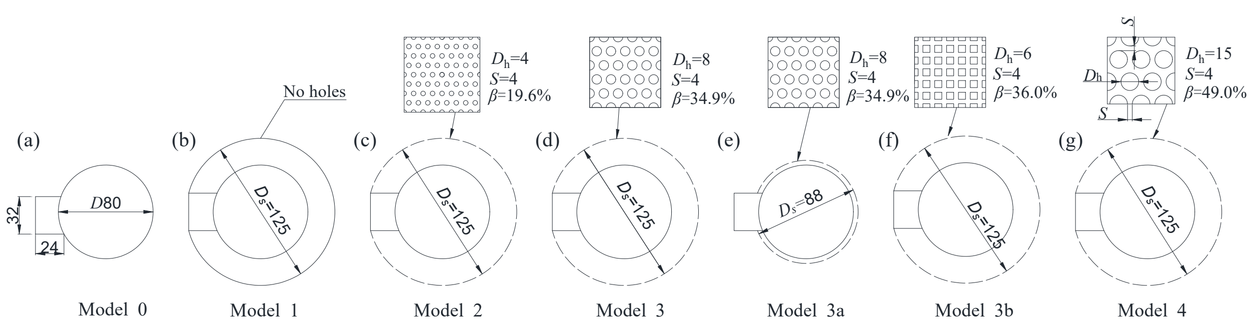

Figure 1. Sketch map of the test models (unit: mm)

2.2 Wind tunnel tests on vertical and inclined test models

High-frequency force balance (HFFB) was adopted to measure the aerodynamic forces of the test models. The HFFB was fixed at the center of the turntable and the test model was vertically and inclined installed at the top of the HFFB. To eliminate the boundary layer effect near the floor of the test section, a compensation model was installed at the bottom of the model. The cross-section of the compensation model is the same as the test model. Vertical model tests and inclined model tests are carried out in uniform flow and turbulent flow. The wind velocity of uniform flow is 8.58m/s. The wind velocity of turbulent flow is 7.86 m/s and the I_{uu} is 9%.

Figure 2. Photo of the vertical test Model 3a installed in the test section

Figure 3. Photo of the inclined Model 0 installed in the test section

3. EFFECT OF DIFFERENT POROSITY

Fig.4 shows the effect of different porosity on the aerodynamic coefficients of the vertical model. When the porosity is 19.6%, the galloping force coefficient is greater than 0 at different wind attack angles. This indicates that Model 2 will not occur galloping, and the porosity of 19.6% is effective in suppressing galloping. Its application in engineering is recommended. In general, opening holes in the shroud can increase the critical galloping wind velocity.

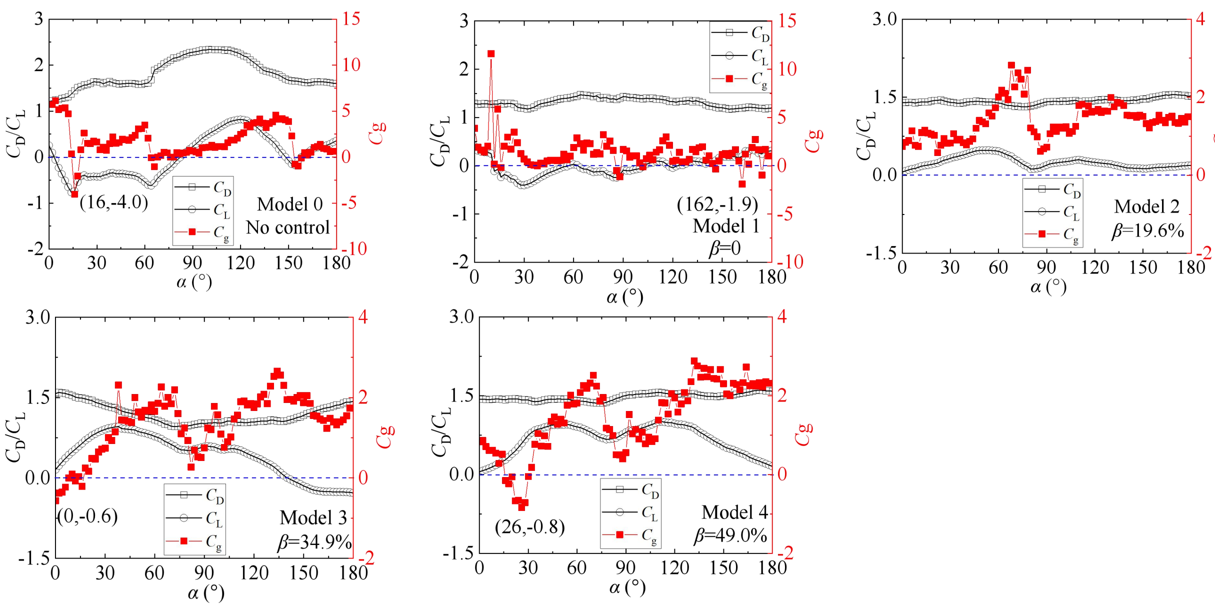

Figure 4. The effect of different porosity on the aerodynamic coefficients of the vertical model

4. EFFECTS OF TURBULENCE

Fig.5 compares the aerodynamic coefficients of inclined Model 0 and Model 3 under uniform and turbulent flow. In turbulent flows, the minimum C_g can be increased by 78.6%, indicating that the galloping critical wind velocity can be increased by a factor of 4.7.

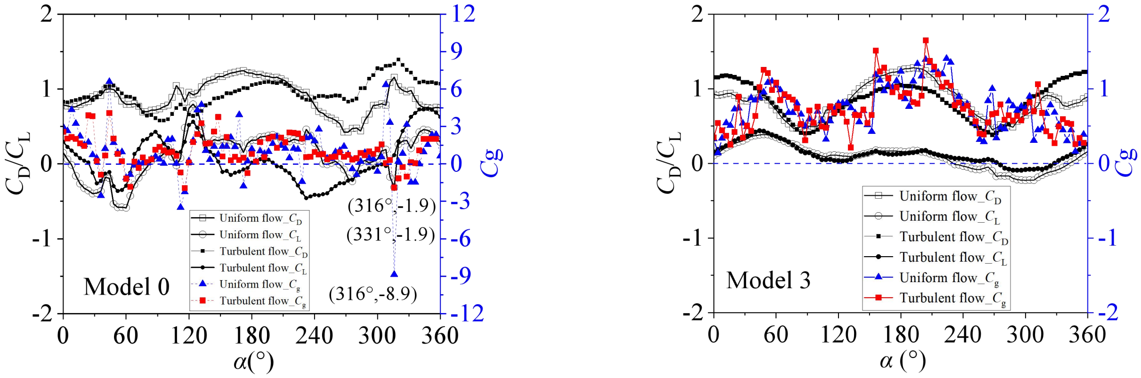

Figure 5. Effect of the turbulence on the inclined Model 0 and Model 3

5. CONCLUSIONS

The paper aims to investigate the effectiveness of perforated shrouds on the suppression of galloping of cables with lamps. In both the vertical and inclined models, the perforated shrouds significantly mitigate galloping and increase the critical wind velocity of galloping. The porosity of the shroud plays an important role in the effectiveness of vibration suppression. For the vertical model, both the shroud with circular holes of 19.6% porosity and the shroud with rectangular holes of 36.0% porosity has a galloping coefficient greater than 0, which can effectively avoid galloping. They are recommended for engineering applications. For both vertical and inclined models, the turbulence of 9% slightly increases the critical wind velocity but does not fundamentally change the galloping characteristics.

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