CROSS-WIND RESPONSE OF A SLENDER SQUARE PRISM

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1. Introduction

This paper presents the results of a wind tunnel study undertaken at the CLP Power Wind/Wave Tunnel Facility (WWTF) into the cross-wind response of an isolated slender square prism with sharp corners and an aspect ratio of 44:1. As for other slender structures, the combined effects of mass, stiffness, damping and aerodynamic shape will govern its wake-excited response, and the variation of these fundamental parameters is investigated here.

Of particular interest in this study is the effectiveness of various types of aerodynamic treatment in reducing or eliminating lock-in excitation. Their successful application to structures, such as the helical strakes used by Scruton and Walshe (1957) for lightly damped chimney stacks, and diversity of form and function, indicated by Zdravkovich's (1981) review, make for both interesting and effective solutions.

2. The Basic Configuration

Two separate aeroelastic models were used in this study, one made of timber and the other of aluminium, in order to investigate the effects of varying mass. Both aeroelastic models were capable of two-degrees-of-freedom, rigid body rotation about their point of zero deflection, and were suitably restrained by the stiffness of the aluminium bars on which they were mounted.

The aspect ratio of each square prism was 44:1, with side length of 35 mm and height of 1540 mm. The timber model in its bare configuration is shown in Figure 1. Where required, damping was provided via a fluid bath located underneath the wind tunnel.

The high-speed test section of the CLP Power Wind/Wave Tunnel Facility was calibrated so that the mean wind speed varied by less than 10% over the upper 5/6 of the models. The turbulence intensity varied between 6% (at two-thirds height) and 8% over the upper 5/6 of the prisms.

Wind tunnel tests were conducted at reduced velocities (RV) within the range of 3.5 to 25 for each configuration, which correspond to Reynolds numbers (Re) in the range of around 3.5×10^3 to 2×10^4. All wind tunnel tests were undertaken with the incident wind normal to one face of the mast, as this was expected to cause the largest cross-wind response for the bare mast configuration. The mast's response at each reduced velocity was determined as the average of five individual measurements of 60 seconds duration each.

3. Effects of Aerodynamic Treatment

As well as the bare configuration, three aerodynamic treatments were tested in the wind tunnel. These were chosen specifically to address the flow separation occurring at the leading edges of the prism, and included:

- a four-start cylindrical strake over the full height of the prism using 2.7 mm OD PVC tubing and inclined at 45°, as shown in Figure 2;
- four 45° porous screens, with a width of 10 mm, attached over the full height of the prism, as shown in Figure 3;

- four corner vanes, each with a gap between the vane and the corner of the prism of approximately 5 mm, radius of curvature of 6 mm, and arc length of approximately 17 mm, as shown in Figure 4.

Cross-wind standard deviation tip deflections, normalised with respect to the side length of the prism, are presented in Figure 5 for each of the aerodynamic treatments investigated. As might be expected, the largest dynamic response was measured for the bare configuration, which is no doubt due to its clearly defined separation mechanism. For reduced velocities of the order of 10, the four-start cylindrical strake decreased the dynamic response by approximately 10% and the porous screens reduced the response by approximately 30%. In comparison, the addition of four corner vanes to the prism apparently eliminated lock-in phenomena, reducing the cross-wind dynamic response by almost two orders of magnitude.

Measurements of the wake spectra for the bare configuration indicated a Strouhal number (St) of approximately 0.14, which suggested that resonant response would occur at a reduced velocity just in excess of 7. Monitoring of time histories during testing confirmed this to some extent, as do the slight bumps which appear on the graphs for the bare configuration and also with strake attached in Figure 5. For the corner vane configuration, St was estimated from wake spectra to have increased to approximately 0.19, highlighting the influence of the curved corners.

An additional interesting result was the effect of the various treatments on the mean along-wind moment. Relative to the bare configuration at a reduced velocity of 10, the helical strakes provided a 10% reduction in mean drag, the porous screens a 10% increase, while the corner vanes decreased the along-wind moment by 50%.

4. Effects of Damping

The effects of damping on the cross-wind standard deviation tip deflections of the bare configuration are presented in Figure 6. For the purposes of comparison, the results obtained from the corner vane configuration are also included. Up to reduced velocities of around 13, the corner vane configuration provides even greater response reductions than for a damping of 5% of critical. The prism's response as a function of damping is presented in Figure 7 for a reduced velocity of 9.

5. Effects of Mass

In general, increasing the Scruton number (Sc), as defined in Equation (1), has the effect of reducing the effects of vortex shedding.

$$\mathrm{Sc} = \frac{m\xi}{\rho D^2} \qquad (1)$$

where:

m = mass per unit length (kg/m);
ξ =damping ratio;
ρ = density of air (1.2 kg/m^3);
D = outside diameter or dimension of mast (m).

Aeroelastic tests were undertaken with a damping ratio approximately 0.35% of critical along the cross-wind axis to investigate the effects of a fivefold increase in Sc by increasing prism mass, results of which are presented in Figure 8. The effectiveness of increasing mass (which reduced the dynamic response by a factor of five) can be assessed alongside the effectiveness of using corner vanes, which essentially eliminated lock-in response and reduced galloping response by a factor of three.

6. Conclusions

Aeroelastic tests were undertaken to determine the effectiveness of various aerodynamic treatments in reducing the dynamic response of a slender square prism. The main findings of this study were:

- corner vanes are potentially a more effective aerodynamic treatment than either a cylindrical strake or porous screens for a sharp-edged square prism;
- corner vanes reduced prism response to approximately the same level as that corresponding to a damping of 5% of critical;
- improvements gained by increasing the mass to increase Scruton number for a square prism are not as significant as those obtained using corner vanes;
- the installation of corner vanes has the effect of increasing the Strouhal number and decreasing the along-wind (drag) response.

7. References

[1] Scruton, C. and Walshe, D.E.J., (1957), A means for avoiding wind-excited oscillations of structures with circular or nearly circular cross-section, Natl. Phys. Lab. (U.K.), Aero Rep. 335.

[2] Zdravokovich, M.M., (1981), Review and classification of various aerodynamic and hydrodynamic means for suppressing vortex shedding, Journal of Wind Engineering and Industrial Aerodynamics, Vol. 7, pp 145 - 189.

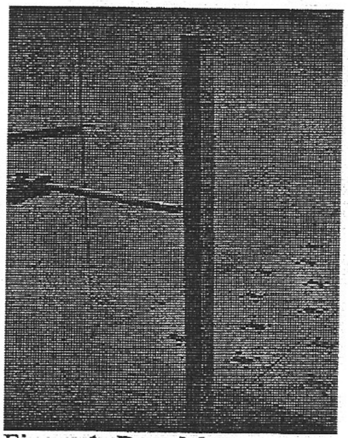

Figure 1: Bare Mast

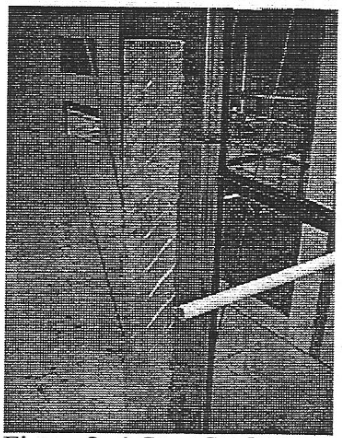

Figure 2: 4-Start Strake

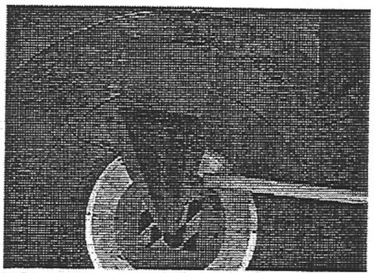

Figure 3: 45° Porous Screens

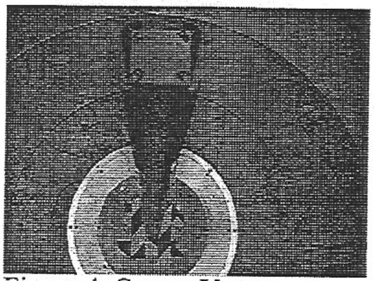

Figure 4: Corner Vanes

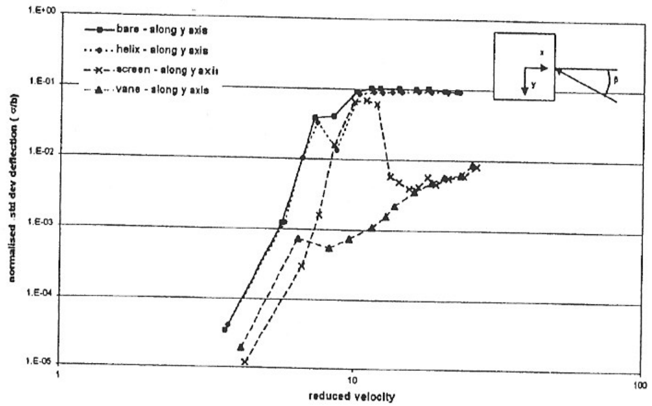

Figure 5: Effects of aerodynamic treatment

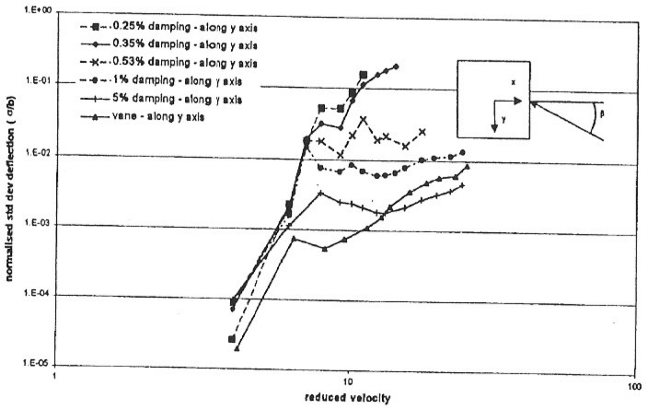

Figure 6: Effects of damping

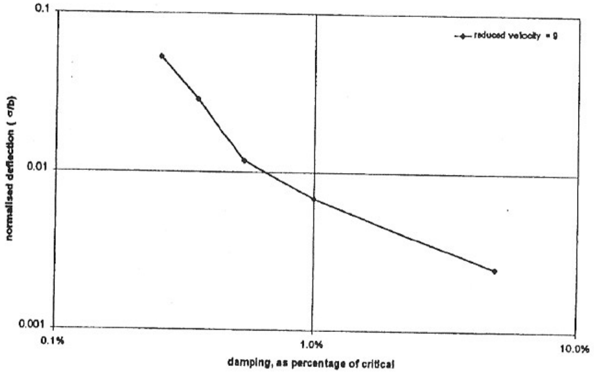

Figure 7: Response vs damping

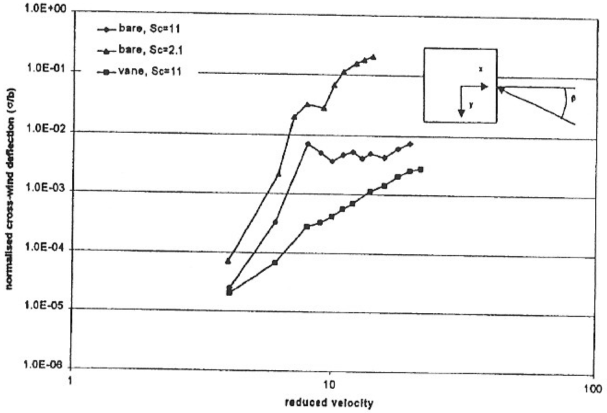

Figure 8: Effects of mass