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Mast damping properties - cross-wind response

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1. Introduction

Over the past decade there have been several instances of the failure of lightweight masts due to excessive response to wind action. The response in each case has been driven by vortex excitation and mostly at quite low wind speeds is the first mode. The number of these masts, particularly on buildings, has increased with the demand for telecommunications. As a consequence of this it has became necessary to be able to predict whether a given mast design will exhibit excessive response to vortex excitation and if so to design a damper which will contain the response to acceptable levels.

The pioneering work of Scruton in the 1950's established some criteria in relation to a mass-damping parameter which has been defined in two ways, the Scruton number $S_C = \frac{2m\delta}{\rho d^2}$ and a parameter popularised by Vickery in relation to chimneys, $K_S = \frac{m\zeta}{\rho d^2}$

giving $S_C = 4\Pi K_S$

where m is mass per unit length
ρ is fluid density
d is cross-wind width
δ is logarithmic decrement of damping
ζ is fraction of critical damping.

For circular cantilevered cylinders in low turbulence Scruton's early measurements suggested that if the mass-damping parameter $K_S > 1.5$ there was little likelihood of critical cross-wind response. Vickery for chimneys in turbulent super-critical Reynolds number flows has suggested $K_S > 2$ is satisfactory and ESDU suggests that $K_S > 2.5$ is satisfactory. However it is known from work by Cheung that in a certain Reynolds number range, 3×10^5 to about 2×10^6 the effects of surface roughness and turbulence intensity can change the cross-wind excitation significantly and Melbourne has shown that longitudinal strakes can also have a similar effect. For masts with some of these characteristics it is suggested that $K_s > 4$ is necessary to avoid critical cross-wind response. Carrying this through to rectangular sections there are situations where critical response can occur even for values around $K_s > 10$.

This paper will discuss some recent studies into these effects and outline parameter effects and the need for further studies to facilitate the prediction of critical cross-wind response of masts and structure members.

2. Structural Damping

Direct measurements of cantilever mast and structure member damping have given values of the critical damping ratio of between 0.001 and 0.005. Almost inevitably where this has occurred, or is anticipated, it has been necessary to incorporate additional damping into the system to satisfy the mass-damping criteria. To contain cross-wind oscillations (essentially in a plane cross-wind) the hanging chain impact damper provides an inexpensive and simple means of providing the additional damping. It is noted that such dampers do not work if the motion is more circular as centrifugal force will hold the chain to one side.

3. Some Tests Results

The full programme of tests proposed will take several years. Some ad-hoc studies have been carried out in recent years and more recently some preliminary sub-critical Reynolds number studies on a cantilevered smooth circular cylinder have been conducted. It is proposed here to give examples for a cantilevered circular cylinder. These two examples will illustrate just how much more susceptible sharp edged structures are to critical resonant response to vortex excitation relative to that of a smooth circular cylinder at sub-critical Reynold numbers, even with significant turbulence.

The test cylinder was a 50mm diameter aluminium tube with a 2mm wall thickness. A 1.85m length of this tube was cantilevered from a concrete block just below the floor of the wind tunnel working section and was fitted with strain gauges calibrated to measure base overturning moment in the cross-wind and along-wind directions. Grid turbulence was generated upstream to give a turbulence intensity of 12% at the test position. The damping of the model was varied by using a hanging chain damper in the top of the tube.

In Figure 1 the results of the measurements are presented in the form of cross-wind base overturning moment standard deviation coefficient, $C_{\sigma M}$, versus Reduced Velocity, V_r, for various values of the mass-damping parameter, K_s, where

$$C_{\sigma M} = \frac{\sigma_M}{1/2\rho\overline{V}^2 dh^2}, \qquad V_r = \frac{\overline{V}}{n_1 d}, \qquad K_s = \frac{m\delta}{\rho d^2}$$

where σ_M is standard deviation base overturning moment
ρ is air density
$\overline{V}$ is mean wind speed
d is cylinder diameter
h is cylinder height
n_1 is the first mode frequency
m is mass per unit length
ξ s fraction of critical damping ratio.

From Figure 1 it can be seen that even for $K_s = 1.8$ and turbulence intensity 12% the first mode response at the critical Reduced velocity of 5.5 is quite significant, and could even be considered excessive for some design considerations. However it is of more interest to note the response at the second mode critical Reduced Velocity of 32. Although the value of $C_{\sigma M}$ is 0.4 compared with 3.6 for the first mode, the velocity is six times higher and hence (because of the velocity squared effect) the resultant second mode response is four times the first mode response in magnitude.

The addition of two vertical strakes makes two major changes. Firstly the critical first mode Reduced Velocity shifts to 7.6, because the vortex sheddy frequency characteristic is quite different from that of the circular cylinder (and for a square section this would to go to 10), and secondly the magnitude of the response coefficient has nearly doubled due to the introduction of the longitudinal sharp edges. The combined effect of adding the strakes, for the same value of $K_s = 1.8$, is to increase the magnitude of the first mode critical response by a factor of three. To contain the critical first mode response with the strakes it can be seen that a mass-damping parameter value of at least five would be required, and even this might be considered marginal in some cases to meet fatigue requirements.

References

Scruton, C. And Walshe, D.E.J. (1957). A means of avoiding wind excited oscillations of structures of circular or near circular cross-section. Nat. Phys. Lab. Report/Aero/335.

Scruton, C. (1963). On the wind-excited oscillations of stacks, towers and masts. Proc. 1st Conf. Wind Effects of Buildings and Structures, NPL Teddington UK, HMSO, pp. 798-936.

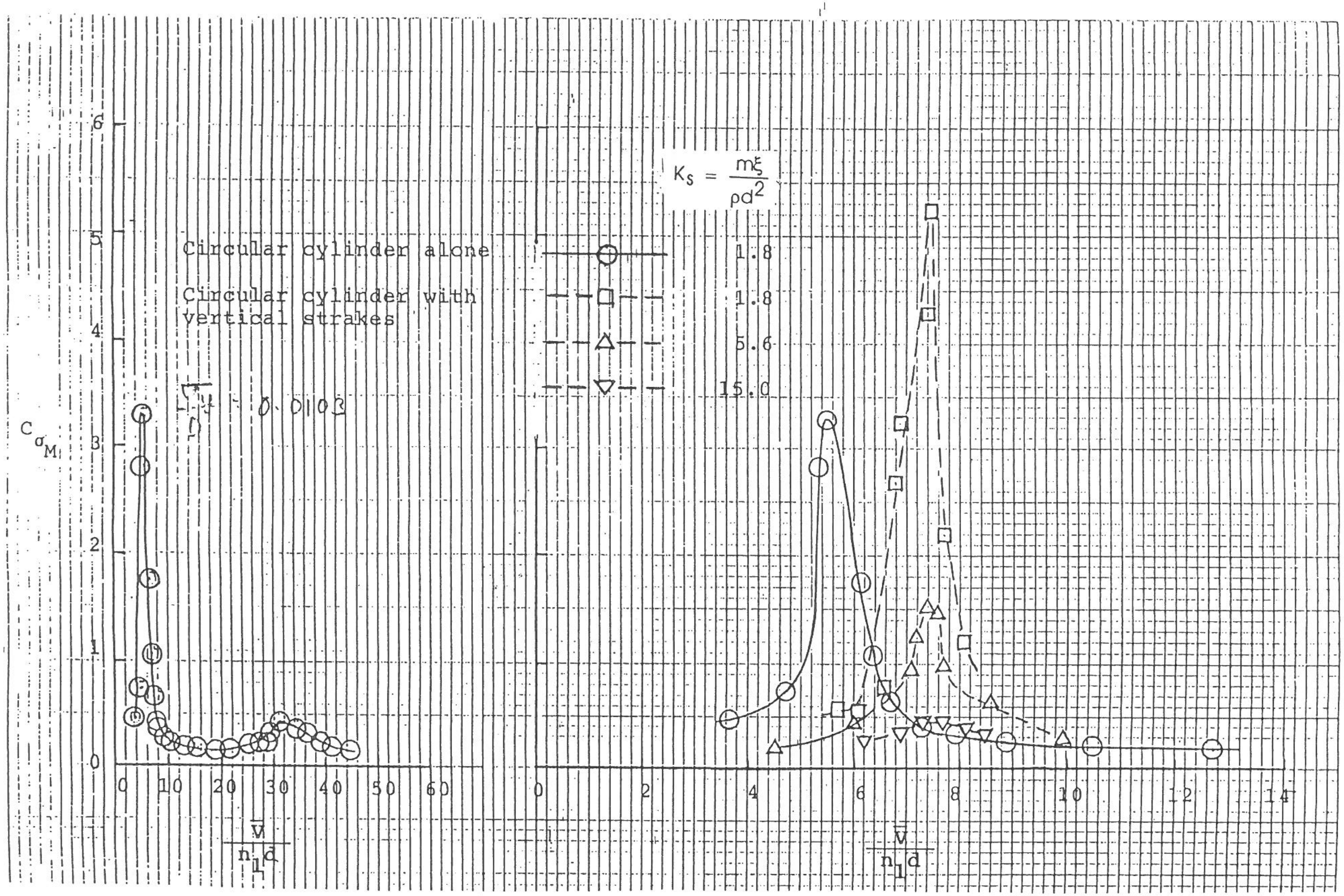

FIG. 1 Standard deviation base bending moment coefficient as a function of Reduced Velocity for a cantilevered circular cylinder with and without two vertical strakes across wind, cylinder height/diameter = 37, strake height/diameter = 0.22, turbulence intensity = 12%.