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Dynamic response of a tower with a triangular planform.

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Abstract

The dynamic response of a tower with a triangular planform has been studied using a linear mode aeroelastic model. Response measurements were taken for ranges of angles of wind incidence and reduced velocities. It has been shown that the dynamic response of a triangular tower is dependent on its cross-sectional dimensions.

Introduction

There is extensive literature into the wind-induced response of towers of rectangular and square planforms. However, there is limited knowledge about the wind-induced response of towers of triangular planforms. This paper will present a wind tunnel study for a tower of triangular planform and aims to expand the knowledge of the wind induced dynamic response.

Experimental Setup

A 1:400 scale model was tested in Terrain Category 3 flow conditions as defined in AS/NZS1170:2.2011. The model was based on a full scale equivalent tower of a height of 250m, a building density of approximately 360 kg/m^3, and a linear mode shape. The cross-sectional dimensions and axis system of the model, and angles of wind incidence, are defined in Figure 1.
The moment data have been non-dimensionalised into coefficient form by using *a* and as expressed in Equation 1. Reduced velocity, V_r, has also been expressed in terms of *a* (Equation 2).

$$C_{M_{gg}} = \frac{M_{gg}}{\frac{1}{2}\rho V_h^2 a h^2} \tag{1}$$

$$V_r = \frac{\overline{V}_h}{n_{gg} a} \tag{2}$$

where
C_M = moment coefficient
M_{gg} = moment about designated axis
gg = axis of interest, either X-X, Y-Y or Z-Z
ρ = density of air
$\overline{V}_h$ = velocity at the height of the model
h = height of the model
a = nominated width of the model
n_{gg} = model frequency of designated axis

Results

Graphs of normalised standard deviation response for critical damping $\zeta = 0.01$ are presented in Figure 2.

Dynamic Response about the X-X axis

It has been shown in Figure 2(a) that for wind incident angles between 90 to 140° the response of the model increases compared to wind angles outside this range. This response was shown to generally increase with increasing V_r.

The mechanism driving this increase in dynamic response is believed to be wake excitation separating off the leading corners of the model.
It is also noted that the peak response for V_r = 11.0 ad V_r = 12.1 are similar in magnitude but occur at different wind directions, β = 100° for V_r = 11.0 and β = 110° for V_r = 12.1.

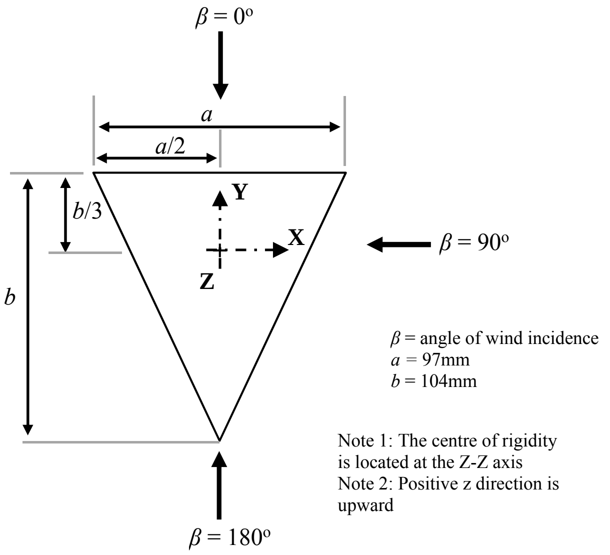
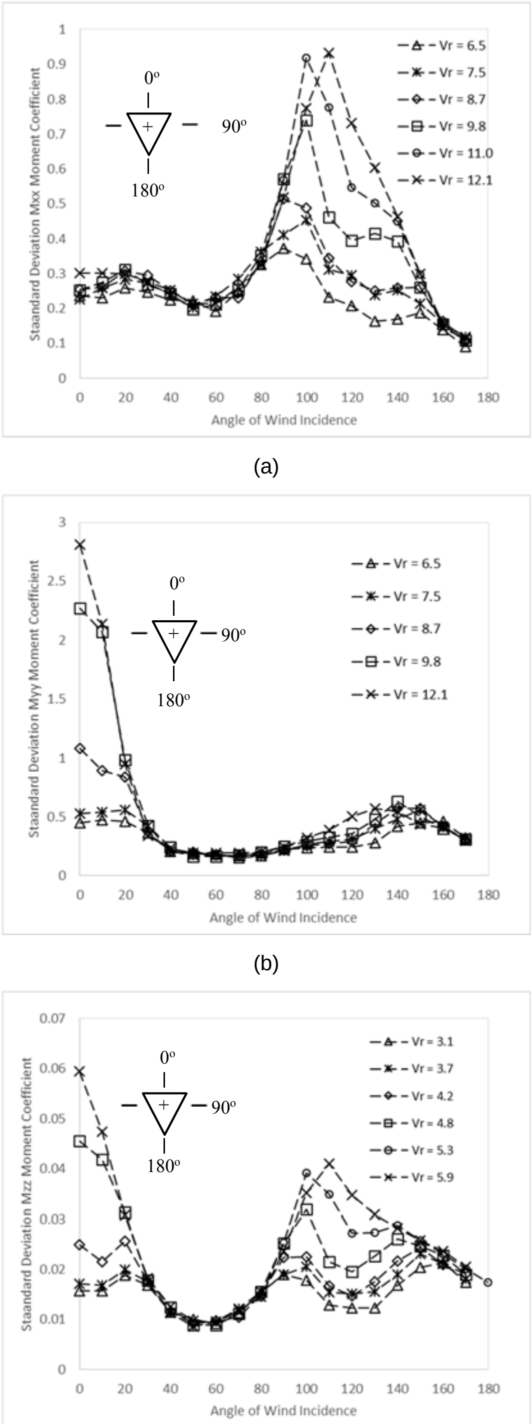


Figure 1. Cross-sectional dimensions and axis system of model and definition of the angles of wind incidence.

Dynamic Response about the Y-Y axis

The dynamic response about the Y-Y axis as a function of angle of wind incidence for different V_r is presented in Figure 2(b). For an angle of wind incidence around 0° there was a small increase in the dynamic response about the Y-Y axis (i.e. a crosswind response) for V_r = 6.5 and 7.5 indicating that the wake excitation forces separating off the leading edges of the model were present. As V_r increases above 8.7 there is an significant increase in the dynamic response about the Y-Y axis. Figure 3 shows the moment spectra about the Y-Y axis for 0° for V_r = 6.5, 7.5, 8.7, 9.8 and 12.1. Observation of the spectra showed the presence of a narrow banded peak, centred at the model frequency about the Y-Y axis, which increased with increasing V_r. This indicated that the dynamic response was being driven by wake excitation acting onto the other faces of the model. The significant increase in dynamic response suggests that the model was approaching "lock-in", similar to that reported by Kwok and Melbourne [1] for cross-wind dependent lock-in excitation of tall structures.
For the angles of incidence between 100-160°, there is an increase in the dynamic response about the Y-Y axis with the peak between 130-140°. This peak response about the Y-Y axis was considerably lower compared to the response for β = 0°.



(c)

Figure 2 - Normalised standard deviation response about a) the X-X axis, b) the Y-Y axis and c) the Z-Z axis.

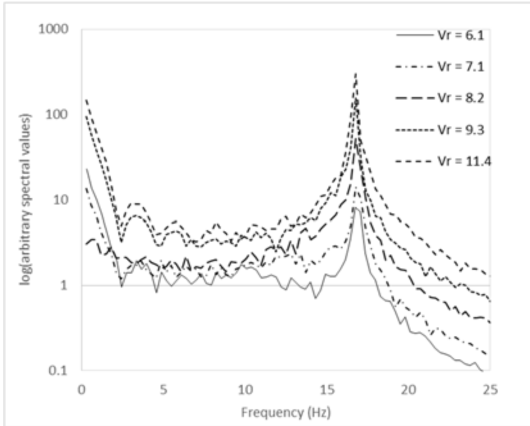


Figure 3 – Moment Spectra of response about the Y-Y axis at 0º angle of wind incidence for V_r = 6.5, 7.5, 8.7, 9.8 and 12.1.

Dynamic Response about the Z-Z axis

Figure 2(c) presents the dynamic response about the Z-Z axis and it has shown that the response is significantly influenced by the responses in the X-X and Y-Y axes, or more specifically the mechanisms driving the dynamic responses of these other axes. For example, the distinct peak at 0º angle of wind incidence of dynamic response about the Z-Z axis corresponds to the peak dynamic response about the Y-Y axis. The wake excitation that drives the dynamic response about the Y-Y axis would be also driving the dynamic response about the Z-Z axis. The magnitude of the Z-Z response would be expected to be influenced by the relative positions of the resultant force vector and the location of the Z-Z axis. It should be noted that the high dynamic response about the Z-Z axis for $\beta = 0º$ was not present in the study by Beneke and Kwok [2] for a tower with a different triangular planform (with the ratio of equivalent cross-sectional dimensions *a* to *b* of 2 compared to 0.93 for this study). This suggests that the dynamic response about the Z-Z axis, and probably the X-X and Y-Y axes also, are dependent on the cross-sectional dimensions of the triangular tower.

Conclusions

Wind tunnel model measurements were conducted on a 1/400 scale model of a building with a triangular planform. The tests showed that flow onto the face of the triangle produced a high dynamic crosswind response and dynamic response about the Z-Z axis. The tests demonstrated that the dynamic responses about the Z-Z axis are greatly influenced by the dynamic responses of the X-X and Y-Y axes and are driven by the same excitation mechanisms. This study, when compared with other studies on towers with a triangular planform, also indicated that the dynamic response about the Z-Z axis, and potentially about all three axes, is dependent on the cross-sectional dimensions of the triangular tower.

References

Kwok, K. C. S. and Melbourne, W. H. (1981) Wind induced lock-in excitation of tall structures, J Struct Div, ASCE, Vol 107, No ST1, Jan, pp 57-72

Beneke, D. L., and Kwok, K. C. S. (1993) Aerodynamic Effect of Wind Induced Torsion on Tall Buildings, Journal of Wind Engineering and industrial Aerodynamics, 50: pp 271-280