INTERFERENCE TORSIONAL EXCITATION OF TALL BUILDINGS

by

W.J.Zhang[1], K.C.S.Kwok[2] and Y.L.Xu[3]

1,2 Postgraduate Scholar and Associate Professor respectively, School of Civil & Mining Engineering, University of Sydney
3 Research Fellow, Cyclone Testing Station, James Cook University

1. INTRODUCTION

Modern tall buildings which have innovative structural systems and complex exterior geometry tend to be more sensitive to wind-induced torsional excitation. When two or more such tall buildings are in close proximity, interference effects from neighbouring buildings may cause a much more complex flow field around the principal building and lead to enhanced dynamic torques and motions on the principal building.

The aerodynamic interference of tall buildings on overall alongwind or crosswind excitations has received extensive attention. Torsional interference, however, has received relatively less attention. Reinhold et al (1977) and Blessmann et al (1985) used direct pressure measurement techniques to explore torsional interference between two prisms in both smooth and turbulent flows while Thorddsen et al (1985) used a force balance technique to investigate the same problem. Their research shows that interference effects of neighbouring buildings on the torsional response of principal building are significant. Both pressure measurement and force balance techniques disregard aeroelastic effects.

In this paper, a tall square building model was tested in wind tunnel by using an aeroelastic test rig designed for pure torsional vibration. Four types of interfering models were used to provide interference. Critical locations of different interfering models were identified and the extent of interference was estimated in terms of buffeting factor contours. The explanation of the torsional excitation and interference mechanism was pursued.

2. EXPERIMENTAL ARRANGEMENTS

Wind tunnel tests were conducted in the No.2 Boundary Layer Wind Tunnel at the School of Civil and Mining Engineering, the University of Sydney. A 1:400 scale wind model of natural wind flow over open country terrain was developed over the fetch of the working section. A basic 0.1 x 0.1 x 0.5 m (b x b x h) tall square prism model was the subject of extensive wind tunnel tests. This model was of a rigid wooden construction and fixed on an aeroelastic test rig designed for pure torsion. The building prototype was assumed to have a structural damping of 1% of critical damping and a fundamental frequency of 0.4 Hz. All measurements were taken on this building, to be referred to as the "principal" building. There were four types of interfering models each of which had the same height as the principal model: a square model of 0.1 m breadth; a circular model of 0.1 m diameter; a smaller square model of 0.06 m breadth; and a smaller circular model of 0.06 m diameter. The elastically supported principal model and the rigid interfering models were set up on a coordinate grid with the longitudinal axis of X extending from 10b upstream to -4b downstream and the lateral axis of Y extending from 0b to 6b, as shown in Fig.1. Both building models were orientated with one face normal to the wind.

The mean and standard deviation twisting angle responses of the principal building model with and without interfering models were measured at several reduced wind velocities U_r. The torsional response signals were processed in real-time and the data were transferred and analysed further to obtain torsional buffeting factor contours, torsional excitation spectra, aerodynamic damping and probability distributions of the responses.

3. TORSIONAL BUFFETING FACTOR CONTOURS

The torsional buffeting factor is defined as the ratio of torsional response with interfering building present to the corresponding value for the isolated building. The torsional buffeting factor contour is a two-dimensional plan which reflects the variation of the buffeting factor with the position of the interfering building. The critical location for interfering building and the extent of the interference effect can be easily found using these contours.

For a square interfering building model with the same size as the principal model and at a reduced velocity of 6, the critical location for the interfering building was found to be upstream at (X,Y) ≈ (5.5b, 2.5b), which produced a torsional buffeting factor of 1.43. When the reduced velocity was increased to 10, the maximum interference region which was orientated diagonally upstream covered an area from X = 5b-9b and Y = 0b-2b, peaking with a buffeting factor of 2.23.

For a circular interfering building model of 0.1 m diameter and identical height to the principal building, a reduced velocity of 7 was chosen for detail investigation. The tested reduced velocity was based on the principal building. At this velocity, the Strouhal Number of the circular building (S ≈ 0.14) ensured that the frequency of the vortices shed from the circular building coincided with the natural frequency of the principal building, producing "resonant buffeting". As expected, comparatively larger buffeting factors were found in the region around (X,Y) = (4b, 1.5b) with a peak value of 2.16. A much smaller reduced velocity of 4.2 was used for the circular interfering building model of 0.06m diameter. At this reduced velocity, the vortex shedding frequency of the smaller circular interfering model also coincided with the natural frequency of the principal building model submerged in the wake. The maximum buffeting factor value was 1.92, which occurred at around (X,Y) = (3.5b, 1.2b).

Another smaller square interfering model of 0.06m width was also used to provide interference effects. At a reduced velocity of 6, the Strouhal Number of the square building (S ≈ 0.1) ensured that the resonance buffeting happened again. As a result, a resonance buffeting factor of 1.98 was found at (X,Y) = (3.5b, 1.5b). It should be noted that this velocity corresponded to a lower and more frequent wind velocity in practice.

4.TORSIONAL EXCITATION SPECTRA WITH INTERFERENCE

The interference mechanism of torsional excitation is studied by examination of the changes in the torsional excitation spectra of the principal building, which identify the frequency composition of the torsional excitation.

Indeed, due to the resonant buffeting the torsional excitation spectra were substantially changed by the introduction of the interfering buildings. The dominant frequencies in the approach flow caused by vortex shedding from the upstream building were registered on the torsional excitation spectra in the form of peaks. Fig.2 (a) shows the generalised torsional excitation spectrum of the isolated building with wind incidence normal to the model face at the reduced velocity of 6. There was no obvious vortex shedding component. The dominant mechanism seems to be incident turbulence because the broad peak in longitudinal wind turbulence spectrum coincided with the broad peak of the torsional excitation spectrum in Fig.2 (a). However, a smaller square interfering building at the reduced velocity of 6 and the critical location (X,Y) = (3.5b, 1.5b) induced a new peak in the torsional excitation spectrum, as shown in Fig.2 (b). The new peak was located at a reduced frequency of 0.16, which indicates the Strouhal Number of the smaller square building is 0.096. The corresponding buffeting factor was 1.98. Compared with the corresponding isolated building case, incidence turbulence flow, which was a dominant mechanism for the isolated building, was accompanied by the vortex shedding. As for the same size square interfering building at the critical location (X,Y) = (8.5b, 0.5b) and at the reduced velocity of 10, there was also a new peak in the torsional excitation spectrum. The peak was centred at the reduced frequency of 0.09, which indicated the Strouhal Number of the upstream interfering building was modified from a normal value of 0.10 to 0.09 by the presence of the downstream principal building. The combined input of the vortex shedding energy plus incidence turbulence energy caused a significant resonant type response in the principal building and resulted in a buffeting factor of 2.23.

Similarly, a resonant peak appeared in the torsional excitation spectrum of the principal model with the circular interfering building model of 0.1m diameter at the critical location (X,Y) = (4b, 1.5b). The peak was centred at a reduced frequency of 0.14, which corresponded closely to the Strouhal Number of the circular building. Consequently, a reduced velocity of 7 was the critical resonant buffeting velocity at which a buffeting factor of 2.16 was recorded. In similar fashion a smaller circular interfering building of 0.06m diameter induced a resonant peak too in the torsional excitation spectrum at the lower reduced velocity of 4.2.

Further analysis showed that the critical locations due to resonant buffeting interference mechanism depend on both the scale and propagation route of the vortices shed. The critical locations were usually located where the edge of the wake just impacts the half face of the principal building.

5. RESPONSE PROBABILITY AND DAMPING RATIO ANALYSES

Probability analysis of torsional response peaks of the isolated building showed that, within the studied reduced velocity range, the torsional response was essentially normally distributed (Zhang, Kwok and Xu, 1992). With interference effects, the torsional response was still essentially normally distributed, despite significant resonance due to vortex shedding from the upstream buildings. In some cases, e.g., circular interfering buildings, there were only a small departure from the normally distributed process and a slight reduction in the peak factor.

Damping ratio analysis of the isolated building by means of envelopes of auto-correlation functions suggested that torsional aerodynamic damping ratio was small (about 0.0% - 0.2%) in the reduced velocity range studied. The effect of the interfering buildings on the total or aerodynamic damping of the principal building was also found to be small.

6. CONCLUSIONS

The presence of an upstream interfering building can substantially enhance the dynamic torsional response of the principal building when the vortex shedding from the interfering building is in resonance with the natural frequency of the principal building submerged in the wake. The maximum increase in dynamic responses due to this resonant buffeting was by a factor 2 or more. Of particular concern is the observation that the resonant buffeting will occur at lower reduced velocities if the circular or square interfering buildings are smaller than the principal building. When resonant buffeting occurred, an obvious peak can be found in the measured torsional excitation spectra. The peak was centred at the Strouhal Number of the interfering building and hence the natural frequency of the principal building. However, the excitation energy associated with incident turbulence and distributed at the lower frequency range was not obviously affected. Even with the interference effects, the torsional response of the principal building was still essentially normally distributed and the aerodynamic damping ratio was also small.

7. ACKNOWLEDGEMENTS

This research project was supported by a Wind Engineering Scholarship from the University of Sydney for the first author. The authors acknowledge the assistance of Mr. David Cockram and Mr. M. Maclean in making the testing rig and models, and Mr. G. Reardon, the technical director of the Cyclone Testing Station, in providing the equipment for authors to complete this paper.

8. REFERENCES

Blessmann, J. and Riera, J.D. (1985). Wind excitation of neighbouring tall buildings, J. of Wind Eng. Ind. Aerodyn., Vol.18, pp.91-103.

Reinhold, T.A., Tieleman H.W. and Maher, F.J. (1977). Interaction of square prisms in two flow fields, J. of Wind Eng. Ind. Aerodyn., Vol.2, pp. 223-241.

Thoroddsen, S.T., Cermak, J.E. and Peterka, J.A. (1985). Mean and dynamic wind loading caused by an upwind structure, Proc. of the Fifth U.S. Nat. Conf. on Wind Eng., Texas Tech. Univ., Nov. 6-8, 4A, 73-80.

Zhang, W.J., Kwok, K.C.S. and Xu, Y.L. (1992). Torsional response and interference effect of wind-excited tall buildings, to appear as Research Report, School of Civil and Mining Eng., Univ. of Sydney, Australia.

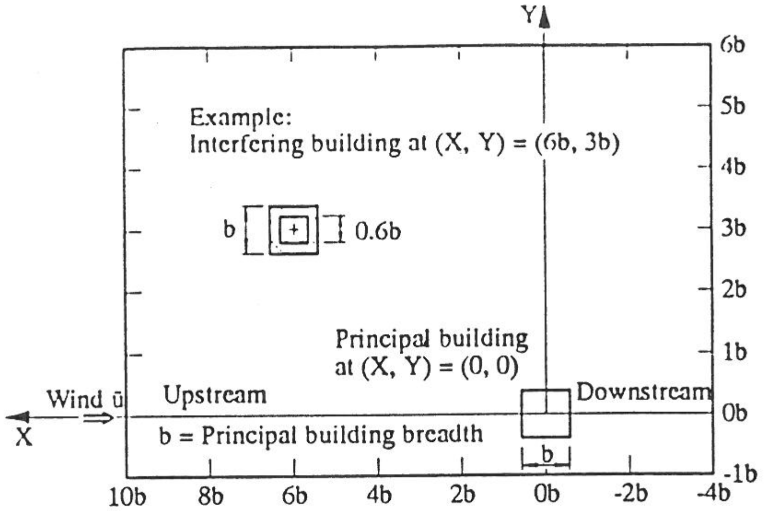

FIG. 1 X-Y CO-ORDINATE GRID FOR LOCATING THE INTERFERING BUILDING

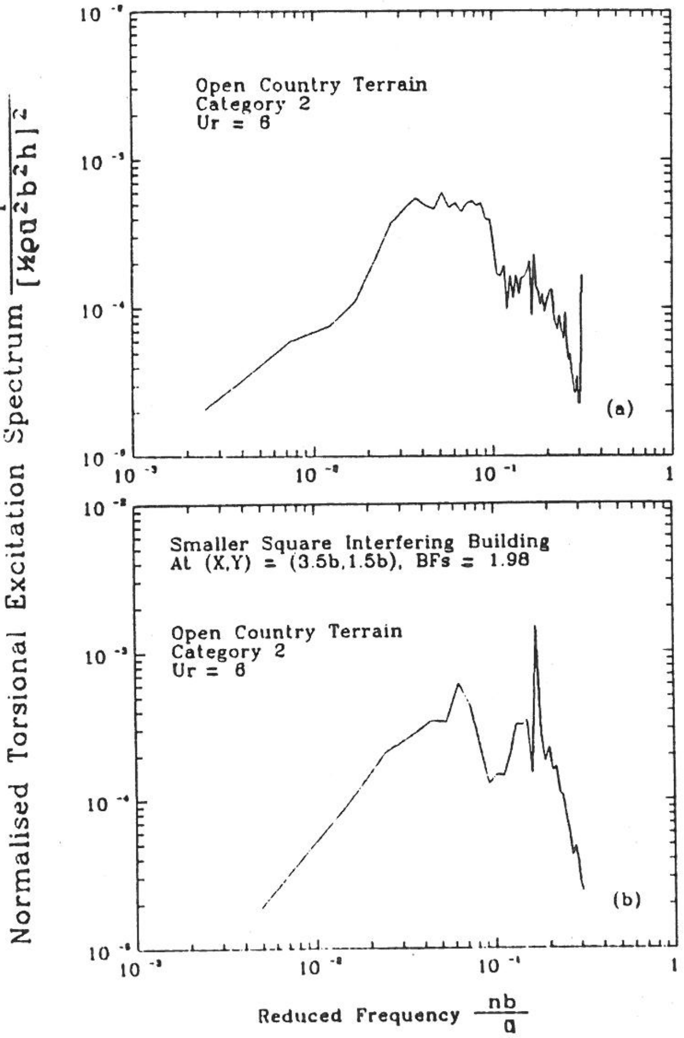

FIG. 2 TORSIONAL EXCITATION SPECTRA