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DEVELOPMENT OF AN ENLARGED WORKING SECTION FOR BOUNDARY LAYER WIND TUNNEL TESTS WITH REDUCED BLOCKAGE EFFECTS

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ABSTRACT

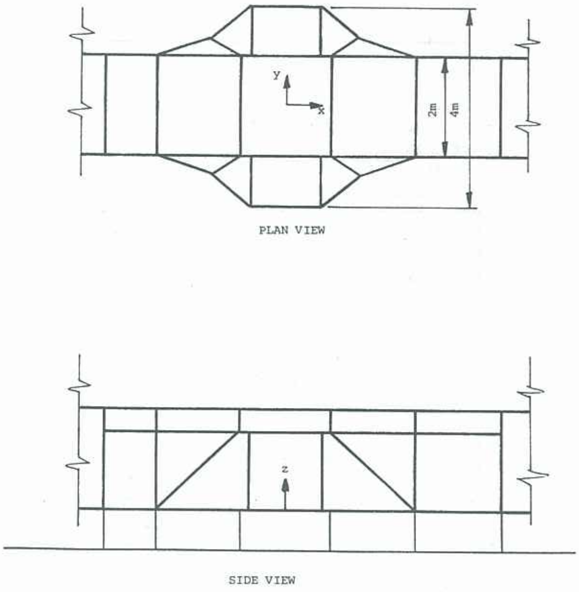
A 2 m by 2 m working section of the existing 450 kW wind tunnel at Monash University has been enlarged to accommodate a 4 m diameter turn-table. Using triangular and rectangular vorticity generators augmented with floor roughness elements, natural wind boundary layer models have been developed for wind engineering model studies, particularly on tall buildings. Experimental data have shown that good reproduction of the required full scale wind speed and turbulence intensity profiles can be obtained and the effects of blockage on the wind tunnel measurements have been reduced with the enlarged conical test working section.

INTRODUCTION

The study of wind effects on buildings and structures in wind tunnels has been widely adopted in the past two decades. Many wind tunnels have been developed around the world to model natural wind boundary layers for wind engineering research and consultancy. Wind tunnel tests for buildings before construction have become mandatory in many countries to ensure a satisfactory wind environment and to provide experimental data for optimal design of the structure and cladding. As time has progressed, the scope of these studies has increased and new problems have emerged. The increase in demand for the use of wind tunnels has stimulated the need for improved wind tunnel features to cope with the blockage effect of city models, different operational functions, and to minimize the tunnel running and model setting up time. Working section modifications on the 450 kW Boundary Layer Wind Tunnel at Monash University have been explored with a view to overcoming these problems and will be discussed in this paper.

WIND TUNNEL EXTENSION

To increase the efficiency and versatility of the 450 kW Boundary Layer Wind Tunnel at Monash University, developed by Melbourne (1977), the centre working section (2 x 2 x 15 m) has been partly enlarged to accommodate a 4 m diameter turntable; this results in its diameter being twice the basic section width, with a conical or pyramidal section being interposed in the lower part of the working section, as shown in Figure 1. This widening of the wind tunnel floor at the working section has two prominent effects. Firstly, it provides a large enough turn-table in most cases for models of all relevant upstream buildings to be present for all wind directions and thus enabling efficient computer controlled operation of the motorized turn-table. Secondly, it provides a bigger working section area where the building models are located, thus reducing the wind tunnel blockage effects.



PLAN VIEW

SIDE VIEW

Figure 1 Extension of the 2 m x 2 m working section of the 450 kW Boundary Layer Wind Tunnel at Monash University.

VELOCITY PROFILES

While the turn-table has increased twofold in diameter, the tunnel cross-section area has increased by less than one third. Techniques have been developed to generate the boundary layer models of the natural wind by flow over a triangular vorticity generator and a relatively short fetch of roughness elements augmented by a trip board installed in the upstream low-speed working section. The mean velocity and longitudinal turbulence intensity horizontal profiles across the working section for a 1/400 scale model are shown in Figures 2 and 3. Cross-plots to give vertical profiles at various distances from the centre have shown that a range of mean wind speed and turbulence intensity profiles to meet the various terrain category requirements of the Australian Standards

Association, Wind Loading Code AS1170, can be satisfactorily obtained over a distance of ±200 mm from the centre of the working section.

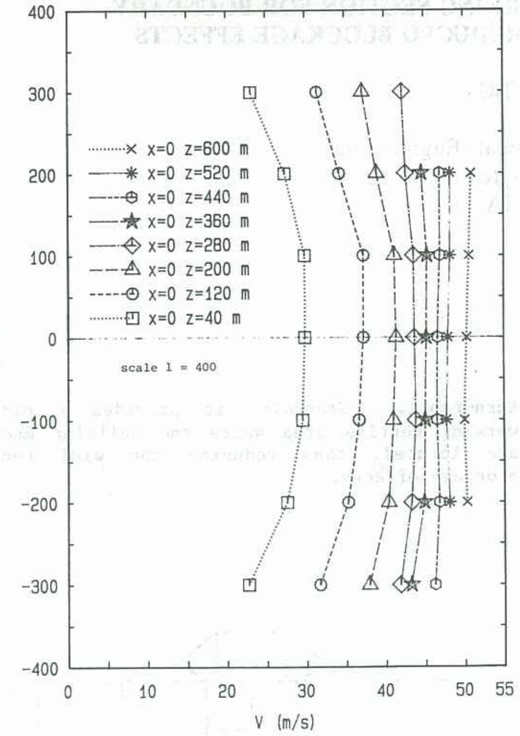


Figure 2 Mean Velocity Profiles (horizontal), scale 1:400
$\overline{V}$ = 40 ms^{-1} at x=0 y=0 z=160 m
Configuration CN 1:400

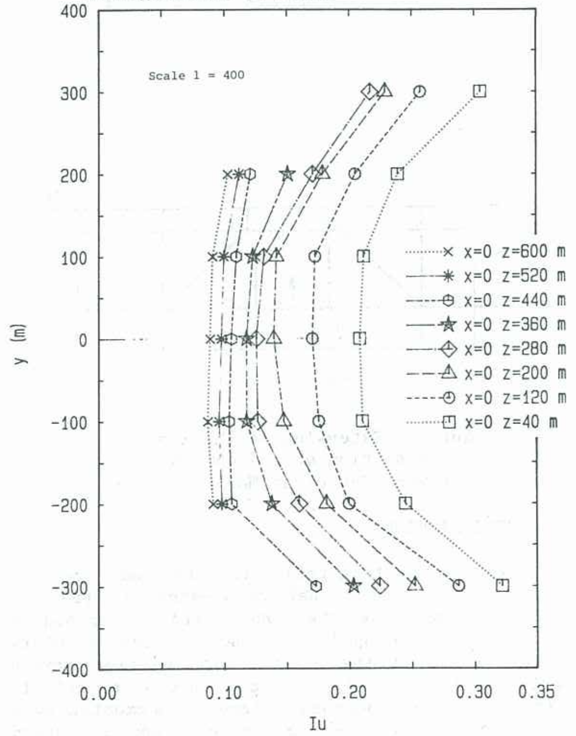


Figure 3 Turbulence Intensity Profiles (horizontal), scale 1:400
$\overline{V}$ = 40 ms^{-1} at x=0, z=160m
Configuration CN 1:400

Using the method of boundary layer development, relatively high speed flows with very large scales of turbulence can be obtained in the test working section without stalling the wind tunnel fan. The requirement of a relatively short fetch of roughness elements to generate natural wind models used by this technique allows the remaining length of the wind tunnel to be used for an insertable working section for high speed aerodynamic work. The new extension of the working section, designated Configuration CN, to accommodate the enlarged turn-table, can be covered with in-fill boards to revert back to a square test working section, designated Configuration SQ, for more conventional model studies. Using different combinations of various sizes of vorticity generators and floor roughness elements, 1/150 and 1/400 scale models of the natural wind to meet the requirements of the Standards Association of Australia Wind Loading Code AS1170 for Terrain Category 3 have been developed for the SQ and CN Configurations. The mean velocity and turbulence intensity vertical profiles at the centre of the working section for these wind models, expressed in terms of the full scale heights, are given in Figures 4 and 5.

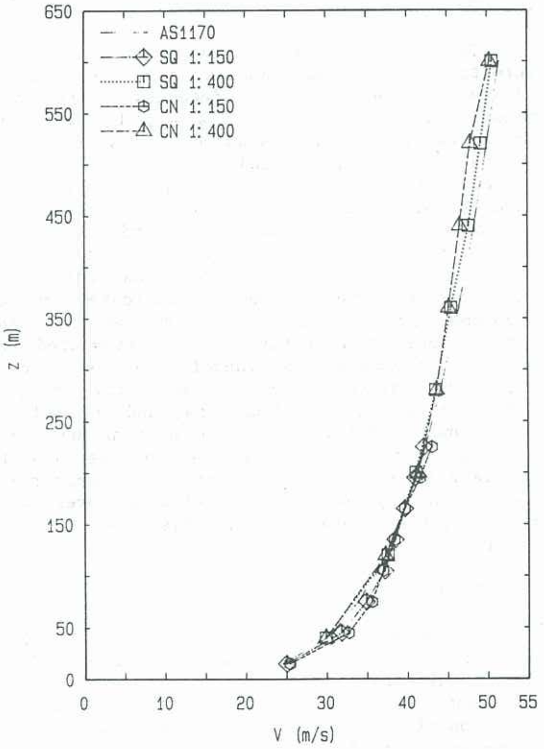


Figure 4 Mean Velocity Profiles
V = 40 ms^{-1} at 160 m
(Terrain Category 3)

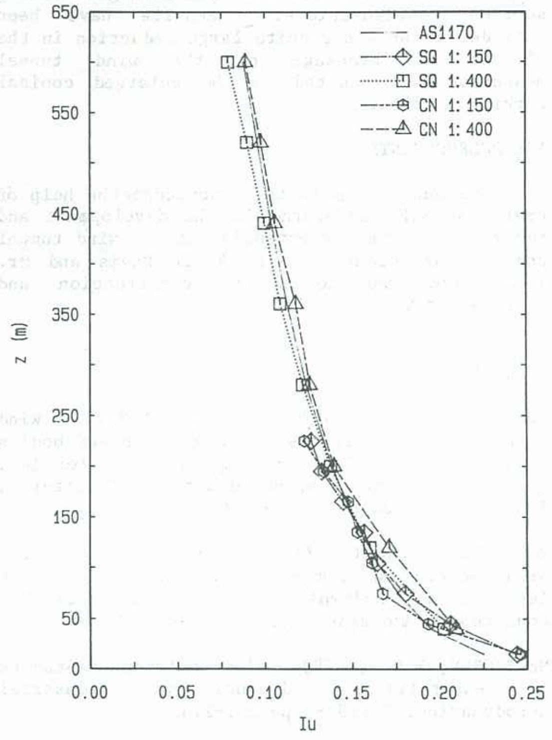


Figure 5 Turbulence Intensity Profiles
$\bar{V} = 40\ \mathrm{ms}^{-1}$ at 160m
(Terrain Category 3)

MEASUREMENTS OF BLOCKAGE EFFECTS

Environmental wind speed studies, pressure measurements and aeroelastic model tests were carried out for 1/150 and 1/400 scale models of a 40 m x 40 m x 160 m high building in both the SQ and CN Configurations for wind directions $\beta = 0$ to 180°. The critical results for each of these experiments will be compared with respect to blockage effects, and although data for only two blockage ratios are so far available, it is known that the effect is relatively linear (McKeon and Melbourne 1971), and hence some important conclusions can be drawn.

For the environmental wind speed studies, wind velocity pressure ratios at the base of the building were measured with reference to that at the height of the top of the building, i.e. $(\bar{V}_{local}/\bar{V}_h)^2$. The experimental technique has been given by Melbourne (1978). The results for the most critical case at the corner are plotted against blockage ratio, defined as the ratio of the model frontal area to the cross-sectional area of the working section, as shown in Figure 6. It can be seen that the blockage correction slope has been nearly halved by the use of the enlarged working section.

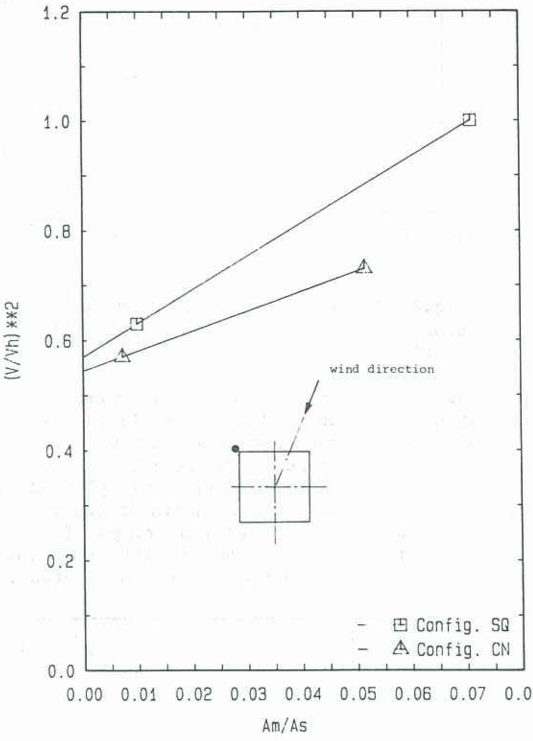


Figure 6 Comparison of Environmental Studies
Blockage Ratio v.s. Velocity Pressure Ratio

The technique for measuring surface pressure on tall buildings has been described by Melbourne (1988). The highest negative peak pressure coefficients on the side wall for the two configurations (same scaled pressure tapping point) are shown plotted in Figure 7. The effect of the enlarged conical working section is even more marked with respect to these critical pressure measurements in that the blockage correction slope has reduced by a factor of 2.5. For models up to 2% blockage ratio the correction on the highest peak pressure coefficents is less than 5%, whereas in the conventional working section the correction would be greater than 10%.

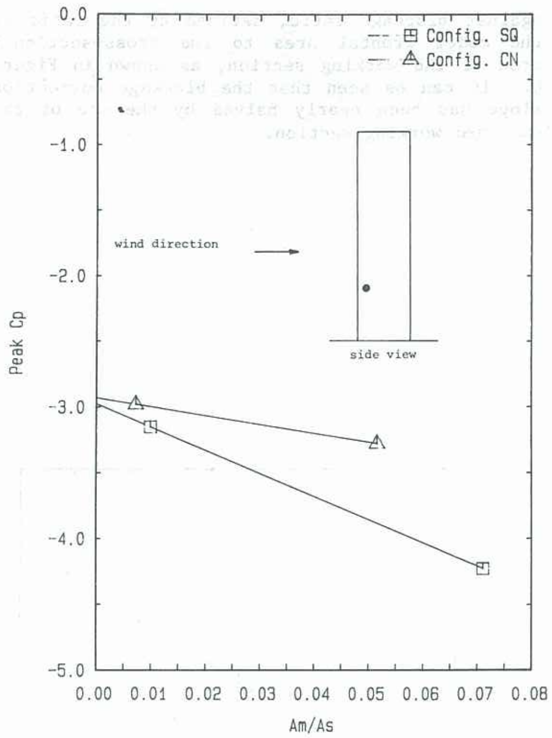


Fig.7 Comparison of Pressure Measurements Blockage Ratio v.s. Negative Peak Pressure Coefficient

Description of the aeroelastic model testing principles is given by Melbourne (1981). Along-wind and cross-wind responses were measured for the building with density 150 kg/m^3, but only the highest cross-wind responses are plotted in Figure 8 for illustration. Again it can be seen that the blockage correction slope for the enlarged working section is significantly lower than that for the conventional working section.

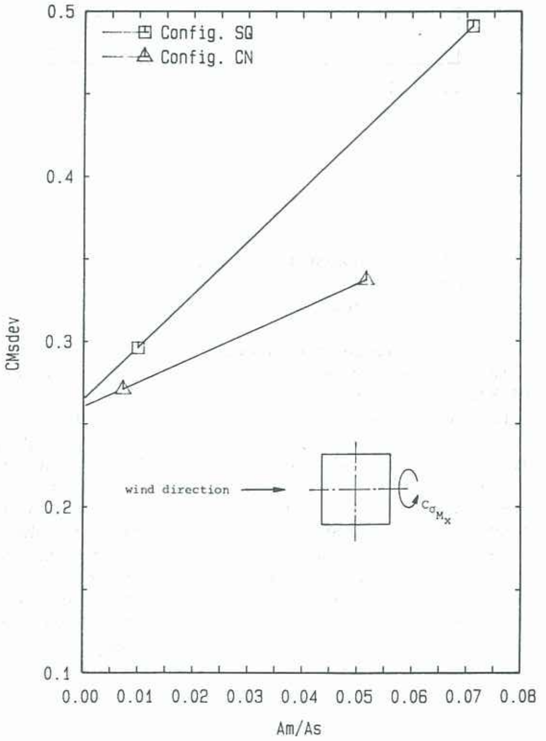


Fig. 8 Comparison of Aeroelastic Tests Blockage Ratio v.s. Crosswind Response

CONCLUSION

The development and the performance of the enlarged conical working section with an enlarged turn-table for boundary layer wind tunnel tests have been described. The different scale model mean velocity and turbulence intensity profiles are presented and shown to compare closely with the required full scale characteristics. Environmental wind speed studies, pressure measurements and aeroelastic model tests were carried out for the original and enlarged working section configurations. Results have been included to show the quite large reduction in the effects of blockage on the wind tunnel measurements conducted in the enlarged conical working section.

ACKNOWLEDGEMENTS

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