MEASUREMENTS OF TOPOGRAPHIC MULTIPLIERS AND FLOW SEPARATION FROM A STEEP ESCARPMENT

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Abstract

Wind tunnel measurements of topographic multipliers and flow separation from a tall, steep escarpment are compared with full scale measurements. Changes in mean wind speed, gust wind speed and turbulence over the escarpment are measured in both scales, with good agreement found. Results are compared with Australian code estimates and the results of other investigations.

1. Introduction

Full scale measurements have been performed previously by Holmes, Banks and Paevere (1996) on a large steep escarpment to verify code estimates of the 'topographic multiplier' and to investigate flow separation. The site chosen for this study was the Mt Dandenong escarpment in Melbourne, Australia (Figure 1). Cup anemometers and vanes were installed upon towers at the base and summit of the escarpment to measure wind flow perturbation over the topography. This paper will compare the results of this full scale work, for one wind direction, with a wind tunnel simulation.

A 1:1000 scale model of the Mt Dandenong escarpment was tested in the 2.4 m × 2 m boundary layer wind tunnel (BLWT) at the University of Sydney. Simulation of wind flow over the Mt Dandenong escarpment at a reduced geometric scale allowed flow to be measured more extensively over the entire escarpment rather than just the two full scale tower locations. Some of the problems associated with the wind tunnel test included the effects of model blockage and maintaining similarity criteria from prototype to model as has been discussed previously by Glanville and Kwok (1996).

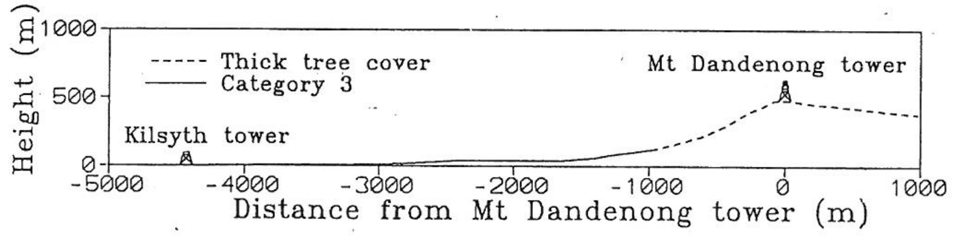

Figure 1: Cross section of the Mt Dandenong escarpment along a bearing of 308°

2. Results

2.1 Mean wind speed

A mean wind speed profile above the Mt Dandenong tower location is given in Figure 2. All model results have been scaled to full scale values in this paper. Good agreement is found between the model and prototype profiles which are both referenced to the 69 m level. Below about 50 m, mean wind speed is seen to drop in magnitude dramatically, clearly demonstrating separation of flow over the crest. Of particular interest is the constant mean velocity gradient above the 69 m level. It appears that the approach boundary layer is effectively 'levelled' by flow over the escarpment. Similar levelling has also been observed by Bowen and Lindley (1976), Bradley (1980), and Jensen and Peterson (1978) in other full scale and wind tunnel investigations.

Velocity gradients defining the mean shear layer over the Mt Dandenong escarpment are shown in Figure 3. Levelling of the boundary layer is clearly evident approaching the crest. Velocity gradients have been deleted where arbitrarily $\overline{u}(z)/\overline{u}(500) < 0.5$ to illustrate flow stagnation. A flow separation bubble from the leading edge of the escarpment is then easily recognised over the crest. It is observed that a new boundary layer gradually begins to form along the escarpment ridge well downstream of the crest. A smaller separation bubble on the windward face of the escarpment is also observed in Figure 3.

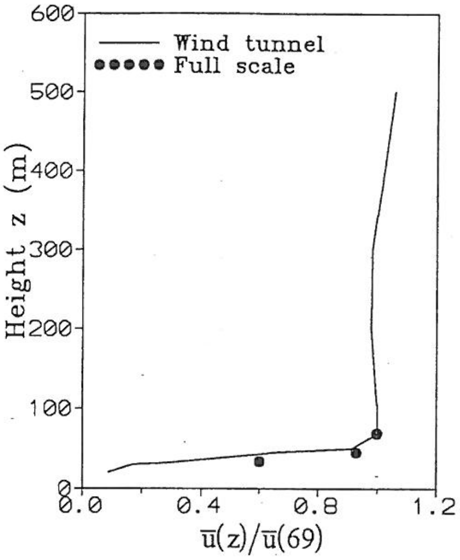

Figure 2: Vertical profiles of mean wind speed above the Mt Dandenong tower location (reference 69 m).

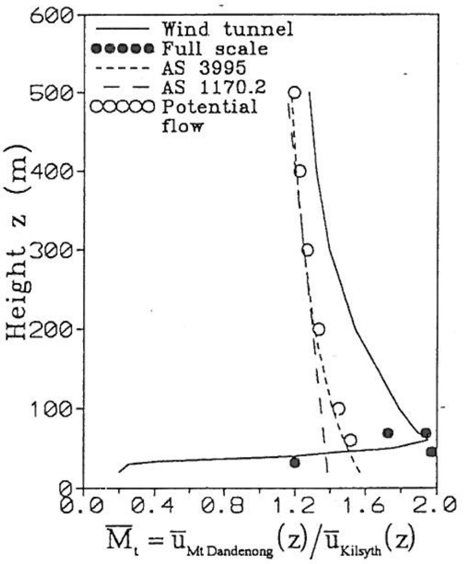

Figure 4: Topographic multipliers for mean wind speed (Kilsyth-Mt Dandenong towers).

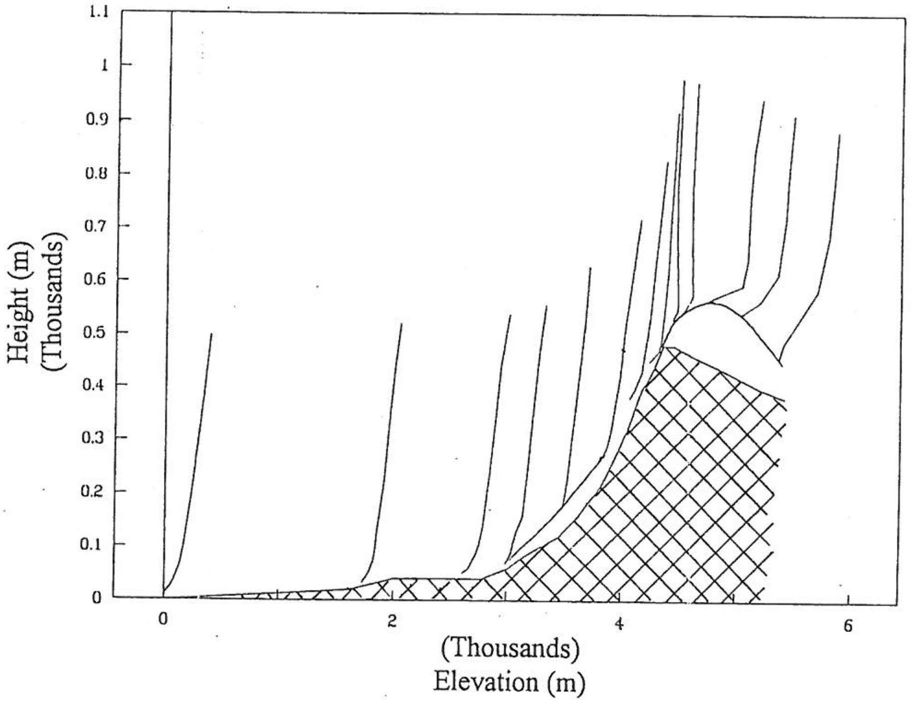

Figure 3: Change in longitudinal mean wind speed profile over the Mt Dandenong escarpment (reference 69 m).

Topographic multipliers for mean wind speed $\overline{M}_t$ (also known as speed up ratios) between the Kilsyth and Mt Dandenong tower locations are plotted in Figure 4. Model results are seen to agree well with the measured full scale multiplier values. Australian code estimates of the topographic multiplier are also plotted in Figure 4 and are seen to be considerably unconservative when compared to the measured results. The AS3995 code estimate is seen to make no allowance for flow separation, but is still more realistic than the AS1170.2 estimate at lower elevations.

Two points are noted from Figures 2, 3 and 4. Firstly, the wind speed gradient above the Mt Dandenong tower location is approximately constant between the 69 m and 500 m levels. Secondly, topographic multipliers at the 500 m level as obtained from the wind tunnel test and the codes are approximately equal in magnitude. A logical 'rule of thumb' extension from these observations on the Mt Dandenong escarpment might be that the velocity profile above the crest of an escarpment, having dimensions of similar magnitude to that of the approaching boundary layer, will be approximately constant and equal in magnitude to the approach wind speed at a height equal to the height of the escarpment, multiplied by the AS3995 code estimate of $\overline{M}_t$. This implies a mean topographic multiplier of the form:

$$\overline{M}_t \propto z^{-\alpha} \qquad (1)$$

where α is a power law exponent for the mean velocity profile in the approach flow. This argument will only hold outside areas of flow separation.

Potential flow theory was also used to estimate topographic multipliers based upon a uniform approach velocity profile. Potential flow estimates are plotted in Figure 4 between 500 m and a Jackson and Hunt (1975) lower depth level of 57 m. Within this range, flow remains relatively inviscid such that this approach is considered permissible as a first order estimate.

2.2 Turbulence

Longitudinal turbulence intensities $\sigma_u(z)/\overline{u}(z)$ at three different elevations over the escarpment are shown in Figure 5. Turbulence intensities along the Kilsyth plain remain almost constant having a greater magnitude at lower heights. Over the crest, turbulence intensities at all levels are seen to converge towards a constant magnitude; slightly lower than the upstream value at 500 m. Beyond the

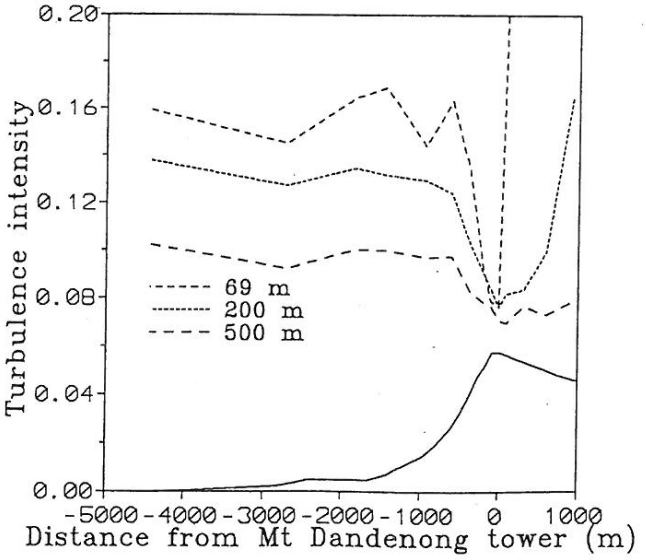

Figure 5: Variation in turbulence intensity over the Mt Dandenong escarpment at three different elevations.

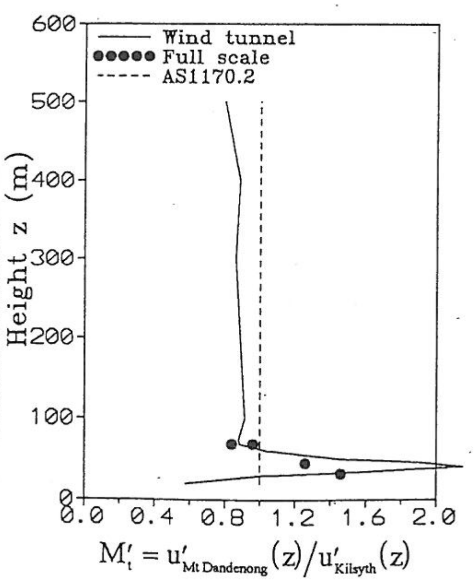

Figure 6: Topographic multipliers for longitudinal rms velocity (Kilsyth-Mt Dandenong towers).

crest, turbulence intensities are seen to increase dramatically at lower elevations, as these sites become engulfed in highly turbulent separated flow. Similar patterns of turbulence intensity distribution have been observed by Bowen and Hong Clucas (1992) and Bowen and Lindley (1976), during their wind tunnel investigations.

Inspection of topographic multipliers M'_t for rms longitudinal velocity in Figure 6 reveals that turbulence is slightly reduced over the crest outside areas of flow separation. This is evident in both model and full scales. Thus the reduction in turbulence intensity over the crest, that was observed in Figure 5, results from both an increase in the mean velocity component $\overline{u}$ *and* a slight reduction in turbulence σ_u. The implied AS1170.2 assumption for M'_t (ie: equal to unity) is seen to be conservative outside the separated region.

2.3 Gust wind speed

Model and full scale topographic multipliers for gust wind speeds between the Kilsyth and Mt Dandenong tower locations are plotted in Figure 7. It is noted that the gust wind speed multipliers in the model and full scales are slightly lower in magnitude than those mean wind speed multipliers of Figure 4. This is to be expected considering the decrease in turbulence intensity over the crest that was found in section 2.2. AS3995 code estimates are seen to lie close to the measurements for heights above the separated zone, but for the wrong reason. The incorrect assumption that the turbulent fluctuations are amplified by the same amount as the mean velocity compensates for the underestimate of the mean topographic multiplier in AS3995.

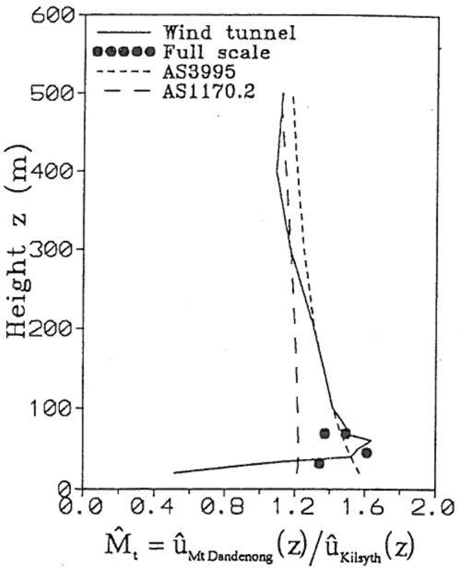

Figure 7: Topographic multipliers for peak gust wind speeds (Kilsyth-Mt Dandenong towers)

3. Conclusions

A 1:1000 scale wind tunnel investigation of wind perturbation over a tall, steep escarpment was presented and compared to full scale results. Good agreement was found between measurements of mean wind speeds, rms turbulence, gust wind speeds and flow separation at both scales. These results indicated that Reynolds number effects can be surmounted at a geometric scaling ratio of 1/1000 and that wind tunnel modelling is a valid method of obtaining design data.

A simplified estimate of the mean 'topographic multiplier' was proposed for escarpments having dimensions of similar magnitude to the approaching boundary flow. It was found that mean, rms and peak topographic multipliers in Australian codes need some adjustment.

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