WIND TUNNEL STUDY OF NORTH-WEST WINDS OVER WELLINGTON CITY, NEW ZEALAND

Nicholas Locke and Paul Carpenter

Opus International Consultants, Central Laboratories
PO Box 30-845, Lower Hutt, New Zealand

Introduction

The current New Zealand wind loading code [1] and its replacement [2] do not include the sheltering effects of steep hills and ridges on areas that lie within the separation zones downwind of such terrain. The topographic multiplier is applied symmetrically, upwind and downwind of the hill/ridge crest implying that the flow remains attached over the downwind slope of the terrain, which does not occur in reality.

Much previous work has been done on wind speeds over hills and ridges but has generally focused on describing wind speeds over gently sloping terrain and speed increases near the crests of steep hills and ridges. This paper presents results from a wind tunnel study that investigated the sheltering effect of hilly terrain to the north-west of Wellington City, on wind speeds over the city and harbour during north-west winds. The effect of changes of surface roughness on wind speeds was also measured.

All measurements in the paper are given as full-scale distances in units of metres.

The Wind Tunnel Model

A 1:2500 scale topographic model of Wellington City was installed in the Central Laboratories wind tunnel whose test section measures 2.7m wide x 1.2m high. The topography around Wellington is illustrated in Figure 1. Also indicated in Figure 1 is the line along which wind speed profiles were measured. The sheltering effect of upwind hills was tested with the model surface uniformly covered with gravel (2-2.5mm in diameter, at model scale). This size of roughness element was found to maintain a category 3 boundary layer profile at the model scale [3]. The uniform roughness on the model was later altered to measure the effect of a surface roughness more representative of the real situation.

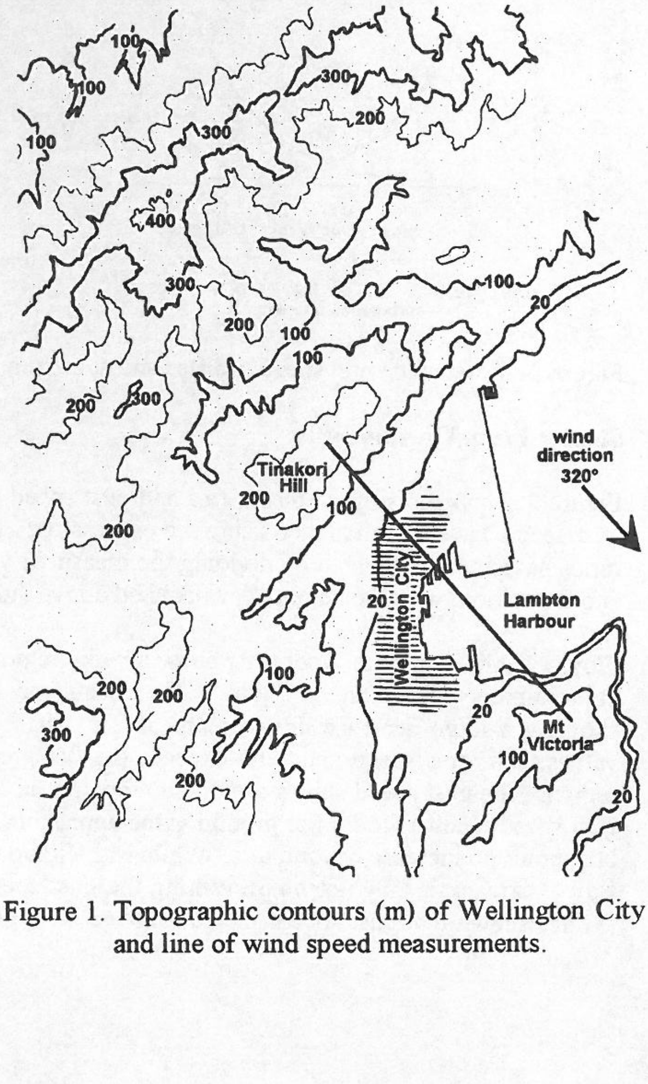

Figure 1. Topographic contours (m) of Wellington City and line of wind speed measurements.

Experimental Method

The model was orientated to a wind direction of 320° as this corresponds to a wind approximately normal to the ridgeline of Tinakori Hill. Wind speed measurements were taken in a vertical plane extending from the crest of Tinakori Hill to the crest of Mount Victoria, approximately 4km to the south-east. Stream-wise distances (X) are measured from the crest of Tinakori Hill, while heights (Z) are measured above sea level. Vertical profiles of wind speeds were measured at X= 0 (Tinakori Hill), 250, 500, 750, 1000, 1250, 1500, 1750, 2000, 2500, 3000, 3250, 3500 and 3750 (Mt. Victoria) metres.

Wind speed measurements were made using a hotfilm anemometer, with the wire mounted horizontally. The signal was sampled for 120 seconds at 1000Hz and low pass filtered at 450Hz. The wind tunnel test section has a blockage tolerant ceiling and so no blockage corrections were applied to the measurements.

A category 3 boundary layer simulation was used to generate the onset reference flow, and gave the velocity and turbulence intensity profiles shown in Figure 2. Reference profiles were measured along the empty test section, where the model was to be positioned, and were found to vary by up to 7%. As wind speed measurements were later non-dimensionalised using reference values interpolated from the streamwise reference profiles no direct correction was applied to the wind speeds for this variation.

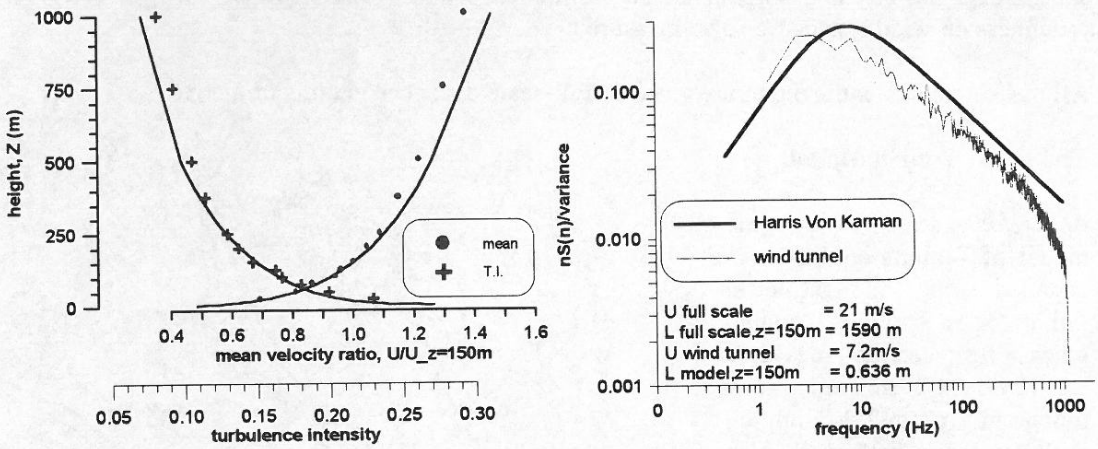

Figure 2. Reference wind speed profiles and spectrum measured at the centre of the test section.

Shelter From Upwind Hills

Figure 3 shows plots of the mean, rms and gust speed ratios along the measurement plane. The gust speed has been calculated using the expression, gust speed = mean + 3.7*rms. The speed ratios have been calculated by dividing the measured value by the reference value at the same X and Z position, with the height, Z, calculated above the local ground level

Flow visualisation with wool tufts show a wake region of separated wind flow extending from approximately X=500m to 900m. The mean speeds in Figure 3 reflect this observation, showing a large decrease downstream of Tinakori Hill, which never recovers to flat ground values. The rms speed generally exceeds the flat ground values except in the separated wake region. The gust speed shows a marked reduction in this wake region also. At 50m height, the gust speed recovers to its flat ground value approximately 2000m down stream of the hill crest, but shows no increase beyond this. While Mt. Victoria's influence undoubtedly effects the wind flow upstream, it may not be preventing the gust speed increasing further, as a previous study [4] has shown that gust speeds increase above level ground values downstream of a steep ridge (slope=0.5) but not behind a shallower ridge (slope=0.25). Tinakori Hill lies some where between these two ridges having an upwind slope of 0.24 and a downwind slope of 0.36. A further point that is apparent in both this study and the previous work [4] is that the gust speed shows a much quicker recovery to the flat ground values than does the mean speed. The gust speed recovers in around 60% of distance required for the mean speed to recover. This is of interest as it is contrary to step changes in ground roughness over flat terrain where the mean speed reaches equilibrium more quickly than the gust wind speed [5].

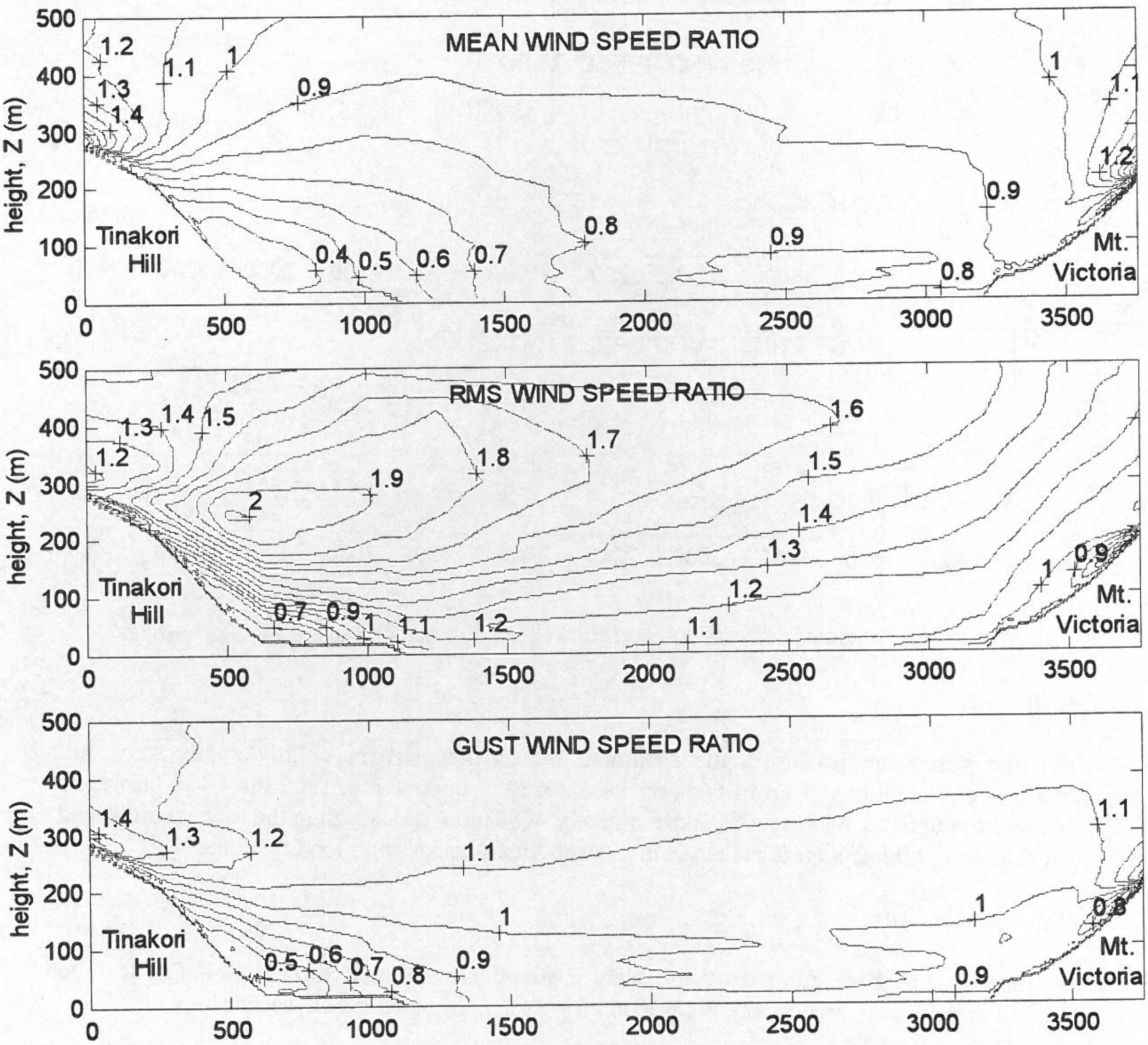

Figure 3. Mean, rms and gust wind speed ratios ($U_{hills} / U_{reference, \text{'flat ground'}}$) category 3 roughness.

Surface Roughness Changes

To measure the effect of surface roughness on the wind, the gravel that covered the Lambton Harbour area of the model was removed (X=1725m to 3100m) and 'generic buildings', 20m to 90m high, were added to the central city area (X=1050m to 1550m) shaded in Figure 1. Vertical wind profiles were measured at X=1250, 1500, 1750, 2000, 2500, 3000, 3250, 3500 and 3750 (Mt. Victoria) metres. The ratio of wind speeds measured with the above changes in roughness to those measured with uniform ('category 3') roughness are plotted in Figure 4. As expected, wind speeds over the city area decrease and speeds over the smoother harbour surface increase. The mean wind speed changes more rapidly than the gust speed, although neither appears to be in equilibrium at any point.

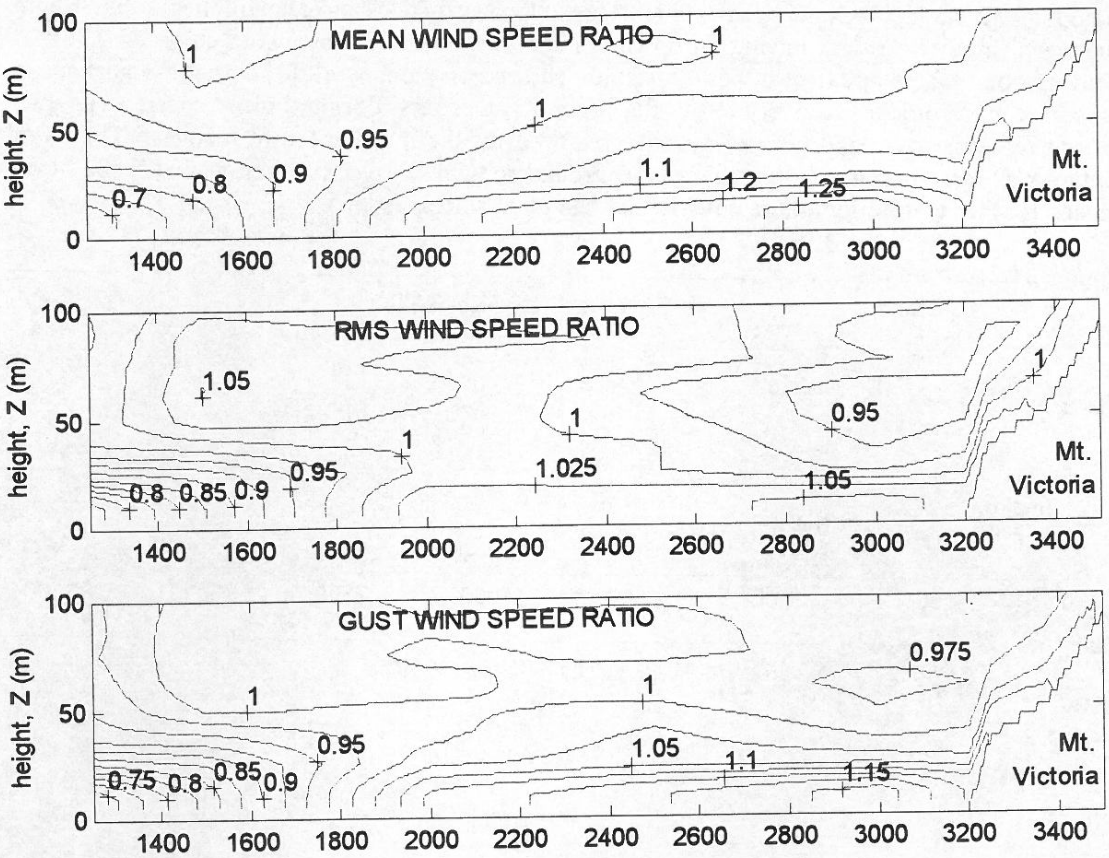

Figure 4. Surface roughness effects: speed ratios ($U_{changing\ roughness}$ / $U_{uniform\ roughness,\ category\ 3}$)

Conclusions

Mean and gust wind speeds in the separated region downstream of moderately steep hills showed large reductions of up to 60% of the onset flow upstream of the hills. The gust speed recovered to the onset wind speeds approximately 40% more quickly than the mean wind speed. Such sheltering effects are not reflected in current Australasian wind loading codes.

Acknowledgements

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References

1 Standards New Zealand, "NZS 4203:1992 Loadings Standard – Volume 1 Code of Practice", 1992.

2 Standards New Zealand, "DR 99419, Draft Australian / New Zealand Standard for Comment. Structural Design-General requirements and design actions, Part 2: Wind actions", September 1999.

3 Jamieson, N. "A Topographic Wind Tunnel Model Study of Wellington City – Experimental Methods and Results", Central Laboratories Report 91-29121, 1991.

4 Carpenter, P. and Locke, N. "Investigation Into Wind Speeds and Turbulence Over Hills", presented at the New Zealand Wind Energy Association meeting, 30 June 1997.

5 Standards Australia, "AS 1170.2-1989. SAA Loading Code. Part 2: Wind loads", 1989.