Studies of Topographical Effects on Hong Kong Wind Climate

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1. Introduction

The effects of topography, such as hills, ridges and escarpments, on local wind climate have been investigated through wind tunnel model studies, full-scale measurements and numerical simulations (Goliger and Milford, 1991, Ferreira et al., 1995, Holmes et al., 1997, Glanville and Kwok, 1997, Ishihara et al, 1999, and others). Many wind codes also provide guidance for the determination of speed-up effects caused by topography.

In Hong Kong, the combined effects of complex topography and typhoons may amplify already strong winds which can have a significant impact on tall buildings and other structures. The objective of this study is to investigate wind characteristics at locations significantly affected by local topography. First of all, the variation and development of the wind profiles, including the mean wind speed and turbulence intensity, over the selected topographical features are investigated by wind tunnel model study. Second, the wind speed-up effects measured from the wind tunnel tests are compared with those predicted from four international wind codes.

2. Wind Tunnel Experiments

A number of sites with topographical features typically found in Hong Kong were studied in detail in a series of wind tunnel experiments. Site 1 is a ridge approximately 600 m above sea level and 560 m above a plain to the west. This type of ridge is commonly found in Hong Kong and its terrain profile is shown in Figure 1, having an upwind slope near the crest of about 0.47 and a downwind slope of about 0.57. The experimental results were used to compare with those predicted from wind codes. Measurements were also taken along the ridge line with a terrain profile shown in Figure 2, having an upwind slope near the crest of about 0.72 and a downwind slope of less than 0.05.

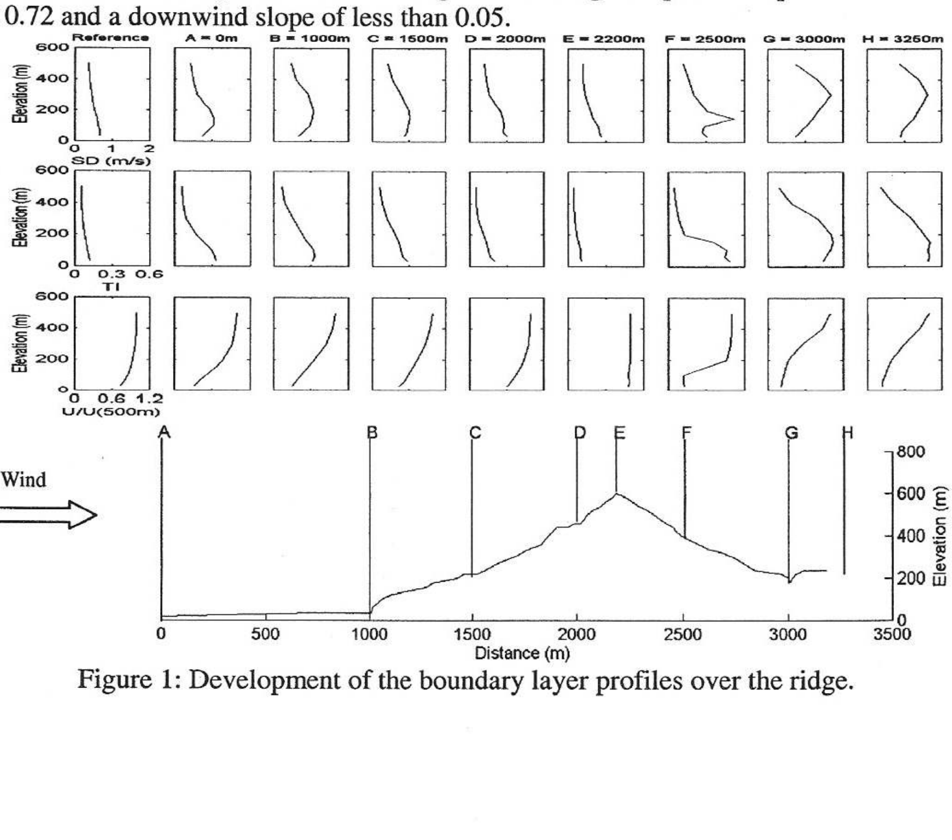


Figure 1: Development of the boundary layer profiles over the ridge.

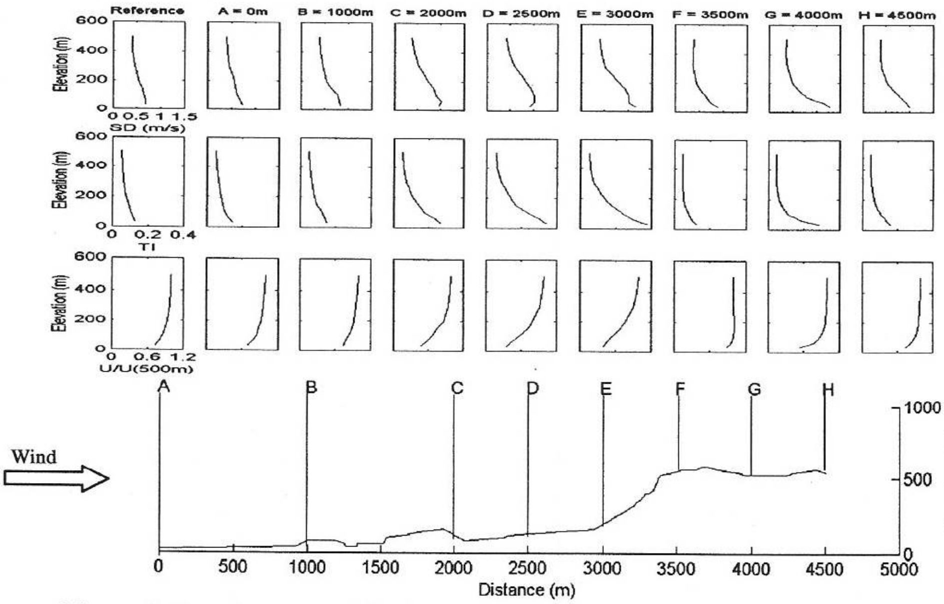


Figure 2: Development of the boundary layer profiles along the ridge line.

Wind tunnel measurements were made on topographical models constructed at a 1:2000 linear scale in the high-speed section of the CLP Power Wind/Wave Tunnel Facility at the Hong Kong University of Science and Technology using constant temperature hot wire anemometers.

Measurements were taken at eight measurement locations along the site. At each measurement location, the wind characteristics were measured at heights 30 m, 60 m, 100 m, 150 m, 200 m, 300 m, 400 m and 500 m above the local hill surface. The hot wire signals were low-pass filtered at 1000 Hz and sampled for a 65 second period at a rate of 2000 Hz.

3. Results and Discussions

3.1. Development of Boundary Layer Profiles

Mean wind speed profiles at locations near the crest of Site 1 are shown in Figure 3. At the crest of the ridge, the mean wind speed in the lower regions accelerates, producing a nearly uniform mean wind speed profile with α close to zero. Speed-up effect is clearly shown. However, at locations C & D on the upwind slope, wind speeds decrease below approximately 200 m with topographical multipliers smaller than 1.

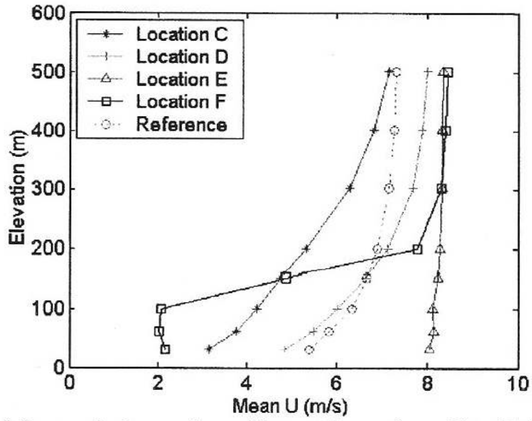


Figure 3: Mean wind speed profiles at Locations C to F for the ridge.

In addition, downstream of the crest, at Location F, the mean wind speed at elevation below 100 m is very slow. After that, the speed sharply accelerates from 100 m to 200 m and keeps nearly constant. This is the result of flow separation occurring near the crest as shown in Figure 4. In this region, the topographical multipliers are significantly less than 1 at elevations below approimately 200 m.

Behind the ridge, the sharp decrease in mean wind speed with the increase in the standard deviation of the measured wind speed results in significant increases in the turbulence intensity. This suggests flow separation at the crest. In addition, the large increase in turbulence intensity persists over 1 km downstream of the crest, which indicates that flow separation at the crest of a high mountain affects a very large area downstream of the crest.

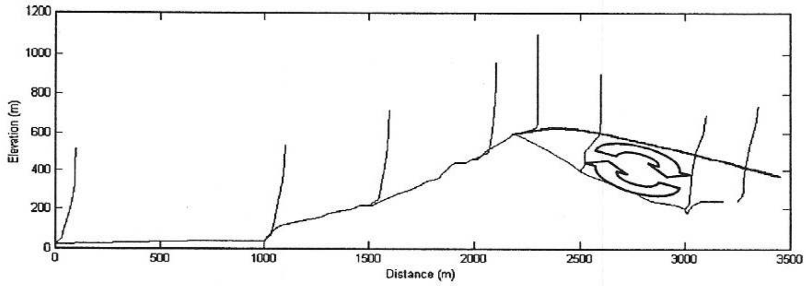


Figure 4: Flow separation behind the crest of the ridge.

Along the ridge line, the mean wind speed profiles at locations near the crest are shown in Figure 5. At the crest (Location F), the speed-up effect is most significant as might be expected. The mean wind speed in the lower regions accelerates significantly, producing a nearly uniform mean speed profile ($\alpha \approx 0$) at heights in excess of approximately 100 m above the local ground level.

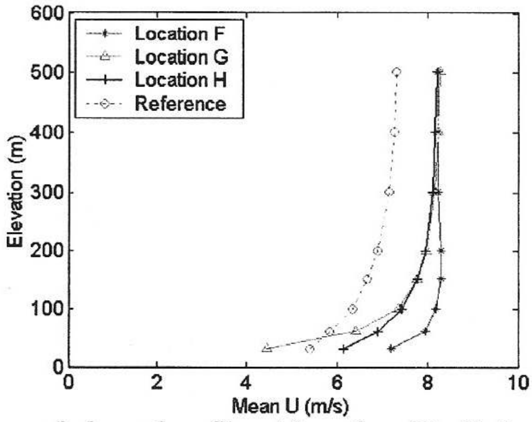


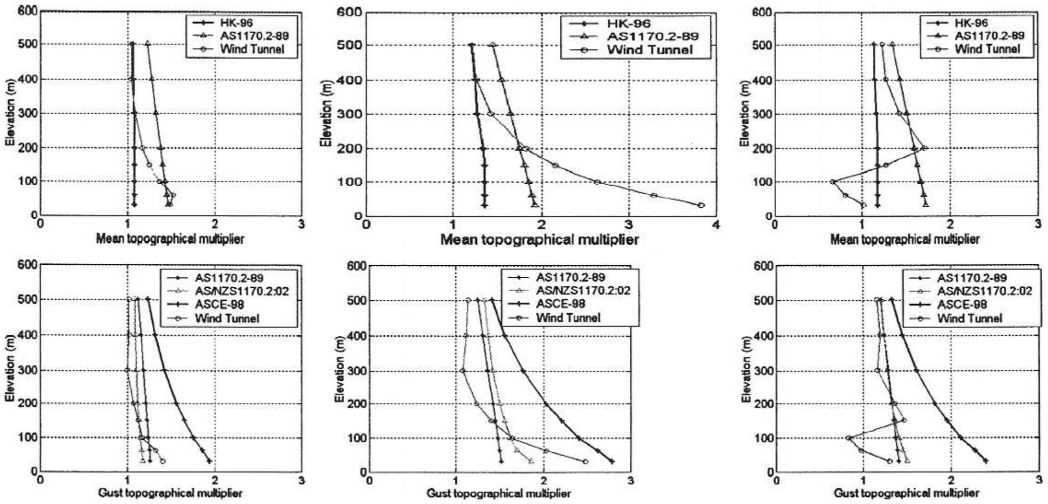
Figure 5: Mean wind speed profiles at Locations F to H along the ridge line.

It is observed that the magnitude of the speed-up effect decreases with distance downstream of the crest as shown from the measurements at Locations G & H. Furthermore, there is a significant increase in turbulence intensity upstream of the crest, which is believed to be due to the two small hills in front, at approximately 80 m and 160 m in height respectively.

3.2. Topographical Multipliers

The wind tunnel test results of the ridge (Site 1) were compared with topographical multipliers suggested in four wind codes: AS1170.2-1989, AS/NZS1170.2:2002, ASCE-98 and Hong Kong draft code 1996. In this study, the topographical multiplier is defined as follows and Figure 6 shows the results of both gust wind and mean wind multipliers:

$$Topographical\ multiplier = \frac{\text{(Wind speed at height z above the mountain)}}{\text{(Wind speed at height z above the flat ground upwind)}}$$



(a) Location C (b) Location E (c) Location F

Figure 6: Topographical multipliers at Locations C, E & F over the ridge.

In general, the mean wind topographical multipliers measured in the wind tunnel are larger than those suggested by the Hong Kong draft 1996 wind code and smaller than those suggested by the AS1170.2-1989 wind code which tends to be conservative. The AS1170.2-1989 and AS/NZS1170.2:2002 give similar gust wind topographical multipliers to that of the wind tunnel measurements except those at the crest where the wind tunnel measurements give larger values at elevations below 100 m. The topographical multipliers recommended in ASCE-98 are much larger than those suggested by the other codes considered in this study.

Near the crest of the ridge at Location E where there is a maximum speed-up, the values of topographical multiplier decrease with increasing height. Some wind code predictions do not account for the effect of flow separation behind the ridge, such as at Location F and this results in overestimating mean wind speeds within the separated zone.

4. Conclusions

Wind speed-up effects close to the crest of a ridge were studied in a program of wind tunnel model tests. Comparisons were made between topographical multipliers determined from the wind tunnel measurements and wind code predictions. There are reasonable agreements between the wind tunnel results and the Australian wind codes up to the point where separation takes place. The topographical multipliers suggested in ASCE-98 are much larger than those suggested by the other codes considered in this study.

References

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