Wind Loads on Hillside Sites

Neil Jamieson
Central Laboratories, Opus International Consultants
P.O Box 30-845, Lower Hutt

1. Introduction

This paper presents results from a preliminary wind tunnel study to investigate the effects of topography on the wind loads on low-rise pitched roof buildings. In particular, we were interested in quantifying the changes to the wind loads on the roof caused by wind flow angles, relative to the roof, being modified by the upwind topography.

2. Background

A hilly site, more than any other design consideration, has a very large influence on the wind loads that a building is designed for. In the New Zealand Loadings Standard, NZS 4302:1992, the hill-shape wind speed multiplier increases the wind loads by a factor of up to 2.4, corresponding to a wind speed multiplier of 1.54. This is a much bigger factor than that produced by most of the other wind speed multipliers, such as the terrain multiplier or the regional wind speed.

In NZS 4203, it is assumed that the wind direction is horizontal. However, for wind blowing up a slope the angle of the wind flow relative to the building surfaces can be much different, particularly on pitched roof buildings, as shown in Figure 1.

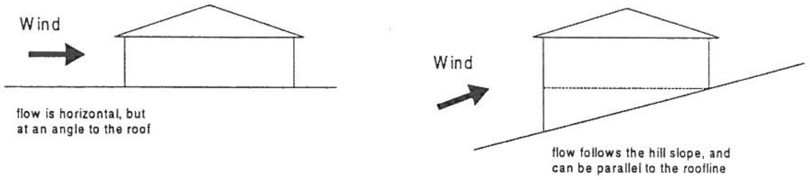


Figure 1: **Wind Flow Relative to a Building**

How significant an impact does the angle of the wind flow relative to the building surfaces have on the wind loads? Current information, as given in NZS 4203, shows that the highest loads typically occur on the roof for low pitch angles, when the wind flow is approximately parallel to the plane of the roof. This is much the same situation that can arise when a building with a pitched roof is located on a steeply sloping site. The aim of our wind tunnel model study was to investigate how much the loads could be affected.

3. Wind Tunnel Study

3.1 Model

A 1:100 scale pressure tapped model of a representative New Zealand hip roofed house was constructed. This had equivalent full-scale dimensions of 15m by 10m, an eave height of 3m, a roof pitch of 20°, and eaves 0.6m wide. Fifteen pressure tap locations were chosen, as shown in Figure 2; three each on the windward and leeward walls, six on the upwind roof slope, and three on the downwind slope.

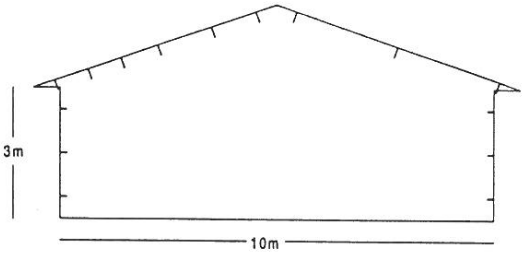
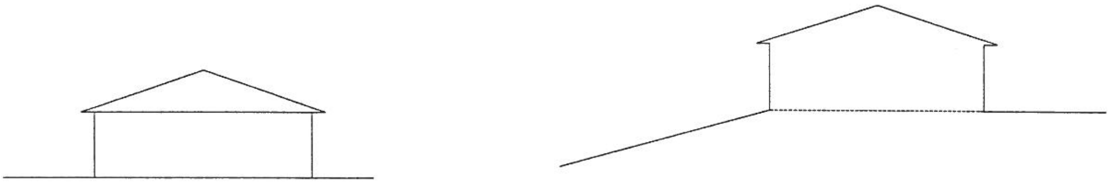


Figure 2: **Pressure Tap Locations**

A 1:100 scale model of an escarpment, with an upwind slope of 20° and a crest height of 40m, was constructed. This was to allow comparative tests to be done with the house model located on, (1) flat ground, and (2) on the crest of the escarpment model, as shown in Figure 3.



(1) (2)

Figure 3: **(1) Flat Ground, and (2) Escarpment, Model Configurations**

3.2 Wind Tunnel

The boundary Central Laboratories boundary layer wind tunnel is an open circuit type, with a 2.74m wide by 1.2m high test section. Velocity and turbulence profiles were set up to match the flow over suburban terrain, i.e. Terrain Category 3 as specified in NZS 4203.

3.3 Pressure Measurement System

A total of sixteen individual Honeywell pressure transducers were used for the study. Fifteen of these were connected, via PVC tubing, to the pressure taps in the building model. The system had been designed to obtain linear amplitude and phase responses for frequencies up to 500Hz. The remaining pressure transducer was used to measure the mean reference dynamic pressure.

3.4 Data Acquisition System

The pressure transducer output voltages were filtered at 450Hz to remove any high frequency noise and interfaced to a PC based data acquisition system. Each tap was sampled for 128 seconds at 1000Hz. A computer program analyses the data and presents the results as pressure coefficients. The results include conventional analyses of the mean, standard deviation, and the single maximum and minimum measured values. Also an analysis of the distribution of the sub-peaks in the sample is used to obtain the estimated maximum and minimum values that would be obtained if the pressure tap were sampled repeatedly. These estimated maximum and minimum values are also adjusted to correspond to a sampling period of one hour at full-scale. For this series of tests, the pressure coefficients were defined in terms of the mean dynamic pressure at the top of the model.

4. Results

4.1 Pressure Coefficients

Wind pressures in this preliminary study were measured only for wind flow normal to the long wall of the building model. These measurement configurations included the model being located on (1) flat ground, and (2) on the crest of an escarpment, as described in Section 3.1. Referencing in each to the roof height of the building allows direct comparison of the loading for these two configurations. Figure 4 shows the minimum pressure coefficients that dominate the loading for the roof and leeward wall sections, and the maximum values that dominate the windward wall loading.

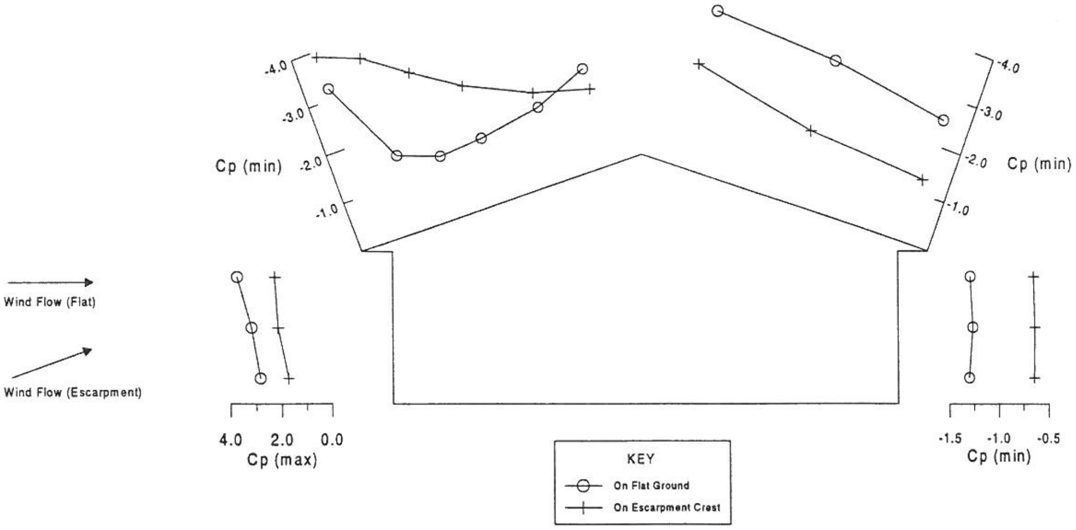


Figure 4: **Peak Pressure Coefficients – Flat Ground and Escarpment**

Looking at the roof sections, the minimum negative pressure coefficients measured for the house on the crest of the escarpment are significantly higher on the windward roof section than those measured on flat ground. In contrast, the reverse is true for the leeward roof section. On both windward and leeward walls, the pressure coefficients on flat ground are significantly larger than for the escarpment. As the reference height in each case was taken as the roof height of the building, the differences in the pressure coefficients can be ascribed to, either the relative levels of turbulence for each situation, or the angles of the wind flow relative to the building surfaces.

4.2 Design Pressures

To see how these differences in pressure coefficients might translate into design pressure loads, we decided to chose a typical design wind speed and determine the resulting pressures. Taking the Wellington regional wind design speed of 48m/s, we calculated the corresponding mean wind speeds at the roof height of the building for both flat ground and escarpment configurations, based on the factors given in NZS 4203. These were then used to convert the peak pressure coefficients to design loads. The resulting loads on the windward roof section at the crest of the escarpment are not only higher than those measured for the same area on flat ground, they are considerably higher than the corresponding loads derived from NZS 4203 (Figure 5). On the leeward side of the roof, the pressures derived from the wind tunnel measurements are smaller than those specified by NZS 4203. This is because the standard also includes pressures from a wider range of wind directions. The wind tunnel measurements shown are for the wind blowing directly on to the front face, and larger pressures occur on the leeward roof section for quartering winds.

These results show that the angle of the wind flow relative to the roof has a significant impact on the roof design loads for buildings located on sloping ground. One question is how, or if, this should be dealt with by the wind loading code. Perhaps for sloping terrain it may be best to consider the effective roof slope to be the difference between the actual roof angle and the angle of the upwind terrain.

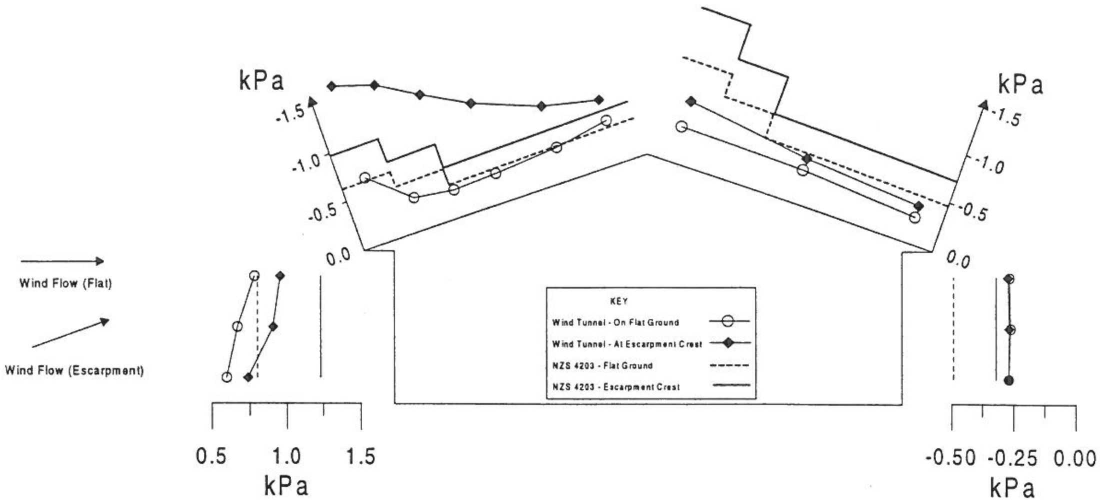


Figure 5: **Typical Design Pressures - Flat Ground and Escarpment**

5. Conclusion

This research has demonstrated the very large potential impact of a hilly site on the resulting wind loads on a building, particularly on the windward roof of a pitched roof building. In this area, pressure coefficients, and consequently the design pressures, were found to be significantly higher for sloping terrain than on flat ground. This is due to the differences in the relative angle of the wind to the building surface that can occur between these situations. Careful adherence to the procedures in NZS 4203 can, in theory, lead to the calculation of wind forces which are considerably too small.

Acknowledgement

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Reference

NZS 4203:1992 Code of Practice for General Structural Design and Design Loadings for Buildings, Wind Load Provisions