# Effect of Aspect Ratio on Roof Wind Loads of Low-Rise Rectangular Buildings

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## SUMMARY

A wind tunnel study has been conducted to evaluate the effect of building aspect ratio on roof wind loads. Various rectangular building models with different aspect ratios and roof pitches were used to obtain mean and peak pressure co-efficients at various locations of the roof. A comparison of these pressure co-efficients with those obtained from the Australian Wind Loading Code (AS 1170.2-1989) suggests that the aspect ratio of buildings has a significant effect on roof wind loads.

## INTRODUCTION

The external pressures on various components (e.g. the walling, roofing etc.) of a low-rise enclosed structure such as a house can be readily calculated using a Standard or Code (for example, Australian Wind Loading Code, AS 1170.2-89). However, the effect of aspect ratio (= length/width) of buildings is not fully addressed by the Code. Measurements obtained on full-scale buildings (Hoxey and Moran, 1983) indicate that low rise building's roof pressure distribution is significantly affected by its length. However, the full-scale measurements were obtained at various sites and the site conditions may have some influence on the results. More recently, Holmes and Paterson (1992) conducted a computational study on arched-roof buildings which showed that increasing the aspect ratio of a building produces an increase in magnitude of positive and negative pressures on both windward and leeward walls as well as roof.

A systematic wind tunnel study is described here which investigates the effect of building aspect ratio on roof wind loads. Measurements of pressure co-efficients are presented for buildings with various aspect ratios and roof pitch angles for different wind directions. The measured pressures are compared to the Code values and the design implications are discussed.

## EXPERIMENTAL ARRANGEMENT

All the measurements were carried out in the Boundary Layer Wind Tunnel, James Cook University of North Queensland. The test section measurements are 17.5 m long, 2.5 m wide and 2 m high. A maximum speed of about 22 m/s can be achieved at the measurement location.

A scale of 1:200 was used for the wind tunnel models. All the models had same width and height (200 mm and 150 mm respectively) and their lengths were varied to 200 mm, 400 mm, 800 mm, and 1600 mm which provided aspect ratios of 1, 2, 4, and 8 respectively. The models were manufactured in modules so that their aspect ratios and roof pitch angles can be changed easily. Three different roof pitches (7.5°, 22.5° and 45°) were used in the present study. Each model was fixed on a 1.7 m diameter turntable which could be rotated through 360° to vary the relative angle of attack of the wind.

External pressures were measured using pressure taps distributed both at end and mid length sections of the models. Two Setra 237 pressure transducers mounted within "Scanivalves" were used for this purpose. The "Scanivalves" were mounted within the models and connected to the pressure taps using 450 mm long p.v.c. tubings, which incorporated two restrictors to get a flat frequency response within ± 10% up to 200 Hz. This response is adequate for the present testing.

The atmospheric boundary layer corresponding to terrain category 2 was simulated in the wind tunnel test section using a combination of tunnel floor carpet and a 300 mm high fence mounted across the entrance of test section. The mean velocity and turbulence intensity profiles, measured at the model location (without the model), are shown in Figure 1 and they are in good agreement with the corresponding profiles, computed using the semi-theoretical equations developed by Deaves and Harris (1978).

The velocity and turbulent intensity profiles were measured using a TSI 1210-10 hot film probe in conjunction with a TSI IFA 100 constant temperature anemometer. The anemometer voltages were linearised using TSI model 1072 lineariser before sampling. All the data were sampled at 1000 Hz for a duration of 32 Sec, which corresponds to about 60 minutes in full-scale.

Static pressure and freestream velocity were measured using a pitot-static tube, mounted about 1 m above the wind tunnel floor. The pitot-static tube was also used for calibrating the hot film probe at the beginning and end of each run.

## RESULTS AND DISCUSSION

### Effect of Aspect ratio

The measured external point pressures and "pneumatically averaged" pressures (obtained using manifolds) were reduced to non-dimensional pressure co-efficients to enable direct comparison with the Australian Wind Loading Code, AS1170.89. Due to space restriction, only point pressures are presented in this paper.

Figure 2 shows minimum pressure co-efficients measured at mid-length section along 7.5° pitch windward roof for 0° wind angle of attack. The Code recommended values are also plotted in this figure as solid lines. It can be seen that there ia a systematic increase in minimum pressure co-efficients as the aspect ratio of the building is increased from 1 to 8. For aspect ratios of 1 and 2, the measurements are well within those specified by the Code. When the aspect ratio is increased to 4, the pressure co-efficients are higher than for aspect ratios 1 and 2 but well within the Code limit except near the ridge. A further increase in aspect ratio to 8, increases the pressure co-efficients significantly; all the measured pressure co-efficients (between eaves and ridge) exceed the Code limit with the difference being small near the eaves and high around the midway point between eaves and ridge. The present results are generally consistent with the observations of Holmes and Paterson (1992). While increasing the aspect ratio of an arched roof building from 0.3 to 5, their computational study showed an increase in roof mean pressures by a factor of 2.7. In the present study, as can be seen from Figure 2, the minimum pressures increase by a factor of 3.4 while the aspect ratio is increased from 1 to 8.

### Effect of Roof pitch angle

The measured minimum pressure co-efficients for buildings with various roof pitch angles are plotted in Figures 3a and 3b for aspect ratios 4 and 8 respectively. The air flow is at an angle of attack of 0°. Several interesting observations can be made from these figures. In general, for a given building aspect ratio, as the roof pitch angle is increased the roof pressures decrease. In particular, when the roof pitch angle is increased from 7.5° to 22.5°, there is little or no reduction in pressures near the eaves. However, the roof pressures decrease linearly as the ridge is approached and substantial reduction occurs around the ridge. In contrast, when the roof pitch angle is increased from 22.5° to 45°, significant reduction in roof pressure occurs near the eaves with very little change near the ridge. This can be explained as follows: for both 7.5° and 22.5° roof pitches, flow separates at the leading edge, inducing higher suction pressures near the eaves. However, for 22.5° pitch angle, flow re-attaches earlier, as compared to 7.5° case, thus yielding a reduction in negative pressures (at locations away from the leading edge). When the roof pitch angle is increased further to 45°, the flow does not separate at the leading edge as evident from the small suction pressure near the eaves. The flow remains attached to about 75% of the length of the windward roof and has a tendency to separate near the ridge, especially for the higher aspect ratio building. All these observations are consistent with other earlier studies (e.g. Kanda and Maruta, 1992).

When the measured pressures were compared with the Code values (not shown), it was clear that *all measurements* were higher than the Code for a building with aspect ratio of 8 for roof pitches of 7.5° and 22.5°. However, for 45° roof pitch, only the ridge region experiences higher than Code recommended pressure. For a building with aspect ratio of 4 and 7.5° roof pitch, the minimum pressures are well within the Code's limit except near the ridge. For 22.5° pitch, the pressures are higher than the Code upto about midway between the eaves and ridge but becomes equivalent to the Code for the remaining length. For 45° roof pitch, all the measured minimum pressures are significantly lower than those provided in the Code.

### Effect of angle of attack of wind

Figures 4a and 4b show the measured minimum pressure co-efficients for wind directions 0° and 30° and for buildings with roof pitches of 7.5° and 22.5° respectively. These figures contain data obtained at mid length section of buildings with aspect ratios of 4 and 8. Both the figures show that roof pressures increase as the aspect ratio is increased,as noted previously. For buildings with roof pitches of 7.5° and

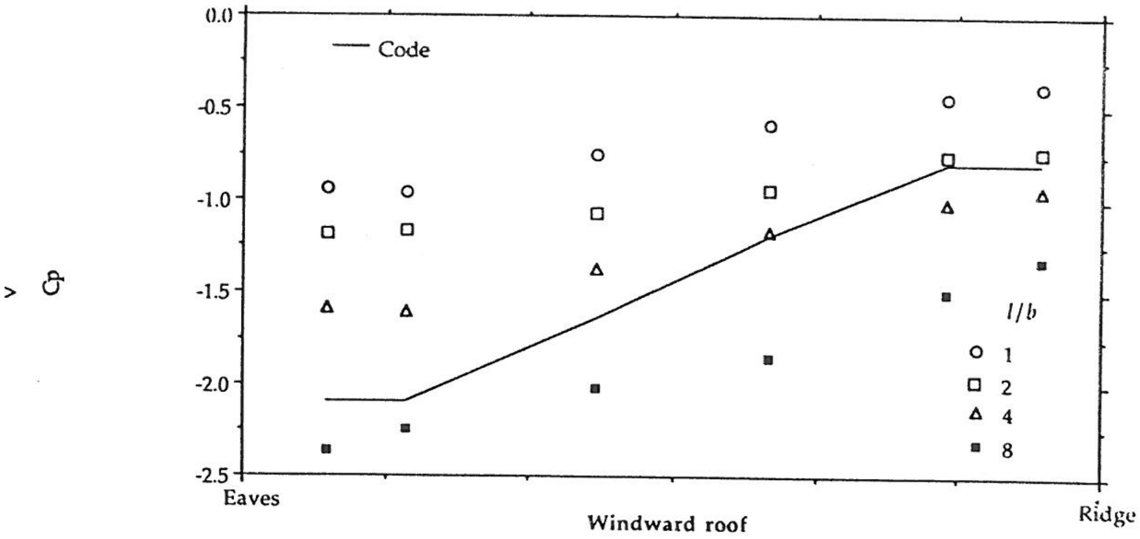

Figure 2. Minimum pressure co-efficients for a roof pitch of 7.5°
and a wind angle of 0°

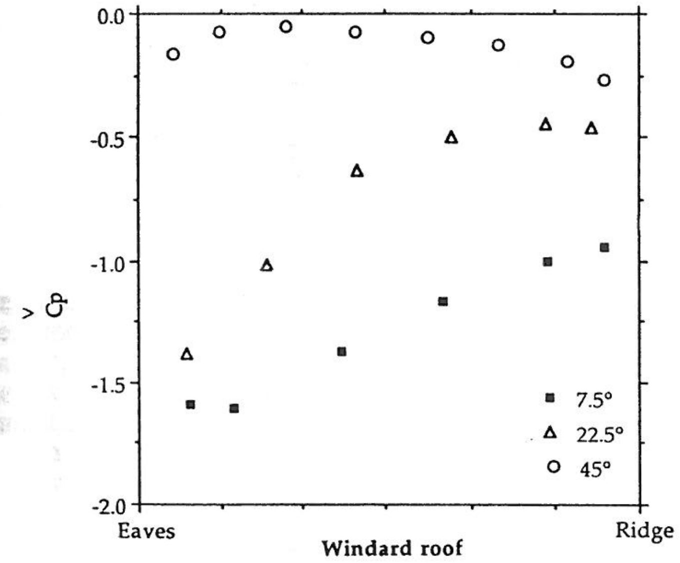

Figure 3a. Comparison of minimum roof pressure co-efficients
for various roof pitch angles. *l/b* = 4

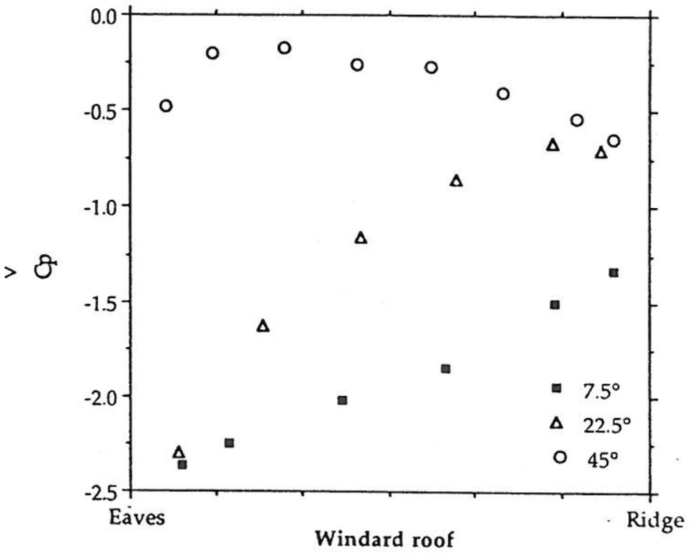

Figure 3b. Comparison of minimum roof pressure co-efficients
for various roof pitch angles. *l/b* = 8

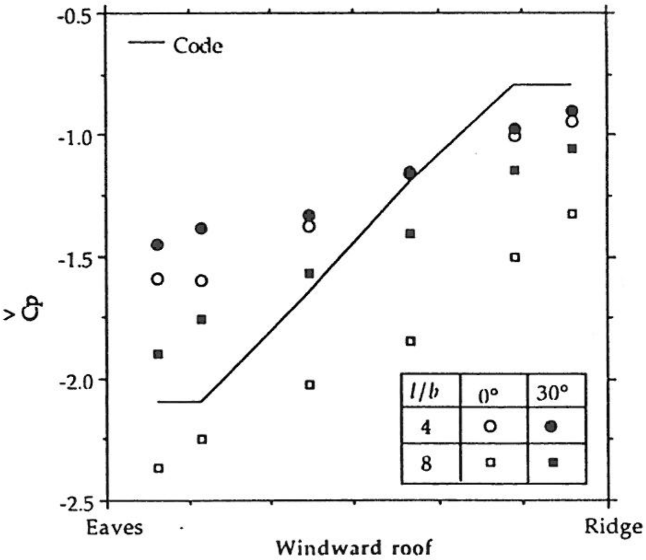

Figure 4a. Minimum pressure co-efficients for a roof pitch of 7.5°
and a wind angle of 30°

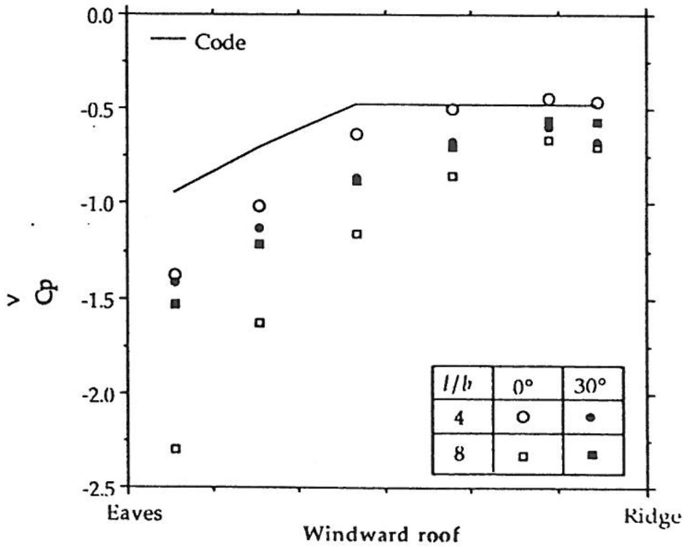

Figure 4b. Minimum pressure co-efficients for a roof pitch of 22.5
and a wind angle of 30°

22.5° and an aspect ratio of 8, as the wind angle of attack is increased from 0° to 30°, there is a smal reduction in roof pressures. When the angle of attack of wind is changed from 0° to 30°, for the model of aspect ratio 4, opposite trends are produced for roof pitch angles 7.5° and 22.5°. For a roof pitch o 7.5°, the roof pressures are slightly lower for 30° wind direction as compared to 0°. However, with roof pitch of 22.5° roof pressures for 30° wind direction are marginally higher than 0° wind. This observation is consistent with the conclusion of Kanda and Maruta (1992) that peak pressures on building roofs need not occur at 0° wind direction. It is conjectured here that the conical vortex originating from the leading edge of the building at oblique wind angles, may be increasing the roo pressures for the building with aspect ratio of 4 but may not be strong enough to influence the roof pressures at mid length section of the building with aspect ratio of 8. This aspect will be investigated in detail in a future study.

## CONCLUSIONS

A wind tunnel study has been carried out which explored the effect of building aspect ratio on roof wind pressures. Results of the study indicate significant increase in roof pressures as the building's aspect ratio is increased. However, for a given aspect ratio, the measured roof pressures decrease with an increase in roof pitch angle. When the measured pressures are compared to the Code, it is noted tha the Code does not adequately cover design pressures for large buildings with high aspect ratios (>8). Therefore, a wind tunnel investigation is required to obtain realistic design pressures for such buildings A comparison of peak pressures obtained for wind from various directions support the earlie suggestion that occurrence of critical pressures depends on various building parameters (such as the roof pitch angle, aspect ratio etc.) and does not always occur at 0° wind direction.

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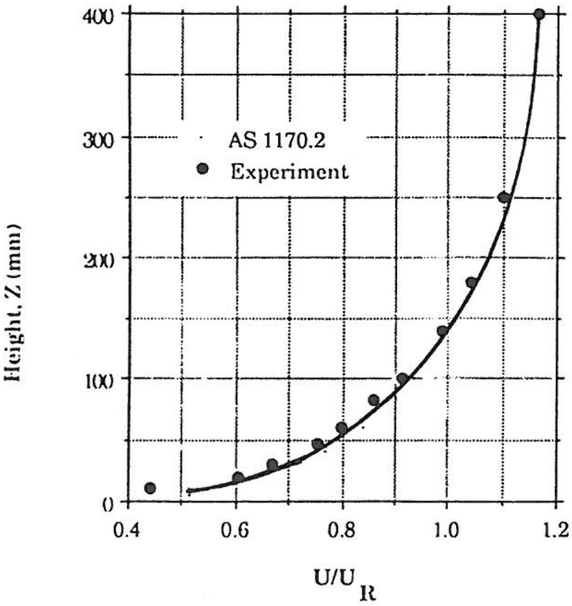

Figure 1a. Comparison of velocity profiles

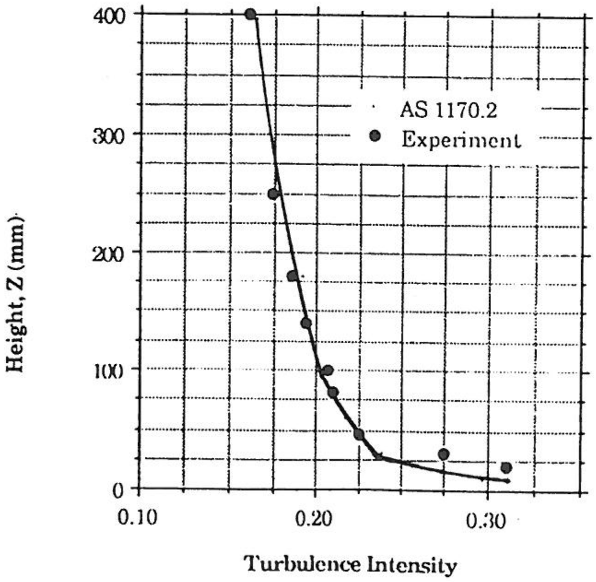

Figure 1b. Comparison of turbulence intensity profiles