Pressure factors for edge regions on low rise building roofs

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Abstract

Point and area-averaged pressures are presented for enclosed low rise (height (h) / breadth (b) = 1/3) building roof, based on 1:100 scale wind tunnel measurements obtained in a simulated suburban atmospheric boundary layer. Large magnitude mean and peak suction pressures were measured close to the leading edges under the separating shear layer. Significantly larger magnitude mean and peak pressures were measured on 0.2h (wide) by 1.0h (long) rectangular edge strips compared to the pressures on 1.5h by 1.0h roof sections. Pressure factors of the order 3.0 for suction pressures and 1.4 for positive pressures were obtained for these regions.

1. Introduction

Wind tunnel tests carried out on low rise (height (h) / breadth (b) < 1/3) building roofs by Kind [1] and Ginger [2] amongst others have shown that the largest pressures were experienced close to edge discontinuities (ie. leading edges), in regions of flow separation. Ginger [2] and Ginger and Letchford [3] also studied the spatial and temporal characteristics of the pressures in these regions.

Flow mechanisms over sharp edged roofs are characterized by shear layer separation and subsequent vortex formation. Ginger [2] measured large magnitude mean and fluctuating pressures under the 2D separation bubble for wind flow normal to the separating edge (ie. $\beta = 0^o$) and under the 3D conical vortex for oblique wind directions (ie. $\beta = 15^o$ to 75^o) in simulated suburban atmospheric boundary layer flow conditions. Large magnitude mean and peak suction pressures were measured within a 0.2h wide region from the separating edges. The largest magnitude point suction pressures were measured for $\beta \sim 30^o$ close to the apex of the 3D conical vortex.

Most wind loading codes (eg. AS1170.2 [4]), prescribe the quasi-static design approach for determining peak wind loads on low rise buildings. In this method the fluctuating surface pressures depend entirely on the fluctuating wind velocity in the atmospheric boundary layer. Although the quasi-static design is satisfactory for regions where the flow impinges directly, it is not suitable for determining peak pressures where flow separation and vortex formation takes place. Local pressure factors are prescribed to account for the highly intermittent larger magnitude pressures in the flow separation regions.

Ginger [2] and Ginger and Letchford [3] showed that fluctuating suction pressures were spatially well correlated over a length of 1.0h, on 0.2h wide rectangular strips along the separating edges under the 2D separation bubble and the 3D conical vortex. The larger magnitude pressure fluctuations under the 3D conical vortex for $\beta \sim 30^o$ to 60^o were better correlated than the pressure fluctuations under the 2D separation bubble for $\beta = 0^o$. Furthermore, for a particular wind direction, conditionally sampled data showed that the peak suction pressures were better correlated than the time averaged pressures. The regions appropriate for applying pressure factors on low rise building roofs in turbulent boundary layer flow conditions are identified as 0.2h by 1.0h rectangular edge strips along the separating edges.

2. Experimental procedure

Tests were carried out in the 3 m wide by 2 m high by 12 m long Boundary Layer Wind Tunnel in the Department of Civil Engineering, University of Queensland. A terrain category 3 (AS1170.2 [4]) z_o = 0.2m) boundary layer was simulated at a length scale of 1/100 as described by Ginger [2]. A 300mm by 300mm square planform 100mm high (h) flat roof enclosed building model with pressure tappings on the roof was tested in this flow. Area-averaged pressures were measured on six 100mm by 150mm panels (labelled A, B, C, D, E, F) using six uniformly spaced tappings, as shown in Figure 1. Area averaged pressures were also measured on 100mm by 20mm rectangular edge strips (labelled A_s to F_s) surrounding the parent panels using five uniformly spaced tappings also shown in Figure 1. The effect of wind orientation (β), was studied over the range 0° to 360°. The point and area-averaged pressure measurement systems had good frequency response beyond 100Hz at which point they were lowpass filtered and sampled at 250 Hz for 30s. The positive direction was defined as downwards. The results presented here are the average of five runs.

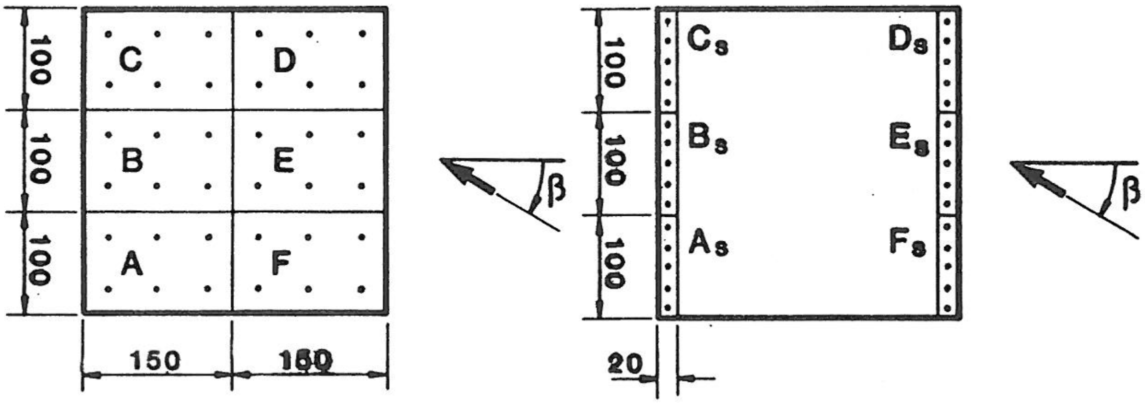

Figure 1. Roof panels A to F and edge strips A_s to F_s

3. Results

The mean pressure coefficient contour plots for $\beta = 0^{\circ}$ and 30° presented in Figure 2, identify the large suction pressure regions under the separated shear layers. The large magnitude mean and peak suction pressures are within a 0.2h wide region close to the leading edges for all wind directions.

Ginger [2] and Ginger and Letchford [3] also showed that the time averaged and peak suction pressures under the separated shear layer were well correlated over a distance greater than 1.0h and for $\beta = 30^{\circ}$ progressively larger suction pressures were shown to be progressively better correlated. The pressures were also increasingly better correlated with increased elongation of the separated shear layer in the axial direction of the 3D conical vortex, as the wind orientation was increased from 0° to 75°. The variation of mean, standard deviation, maximum and minimum area-averaged pressure coefficients with wind direction on the six panels (A to F) is summarized in two cases: a roof corner panel F and a roof middle panel E in Figures 3 and 4 respectively.

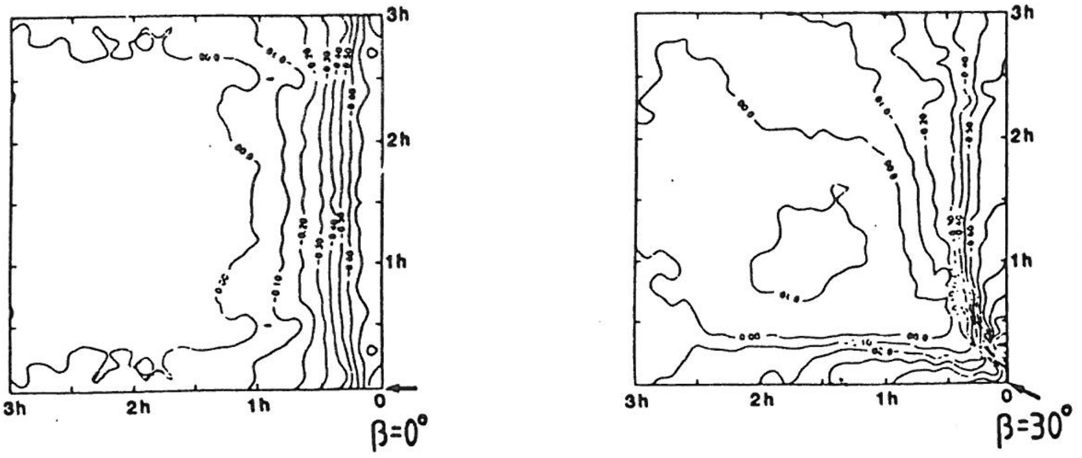

Figure 2. Mean pressure coefficient contours on building roof, β = 0° and 30° respectively.

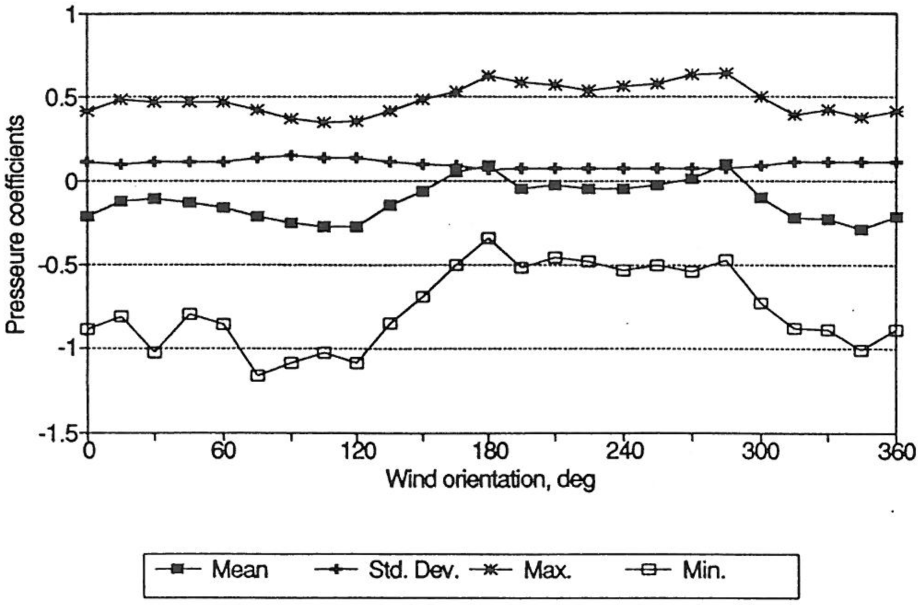

Figure 3. Pressure coefficient variation for roof corner panel F.

For roof corner section F, Figure 3 shows that the formation of a 2D separation bubble for β = 0° and 90° and 3D conical vortices for other wind directions generate large magnitude mean and fluctuating suction pressures. The location of the pressure tappings in relation to the flow separation regions generate the largest magnitude mean, maximum and minimum pressure coefficients of -0.29, 0.64 and -1.16, for β = 345°, 285° and 75° respectively.

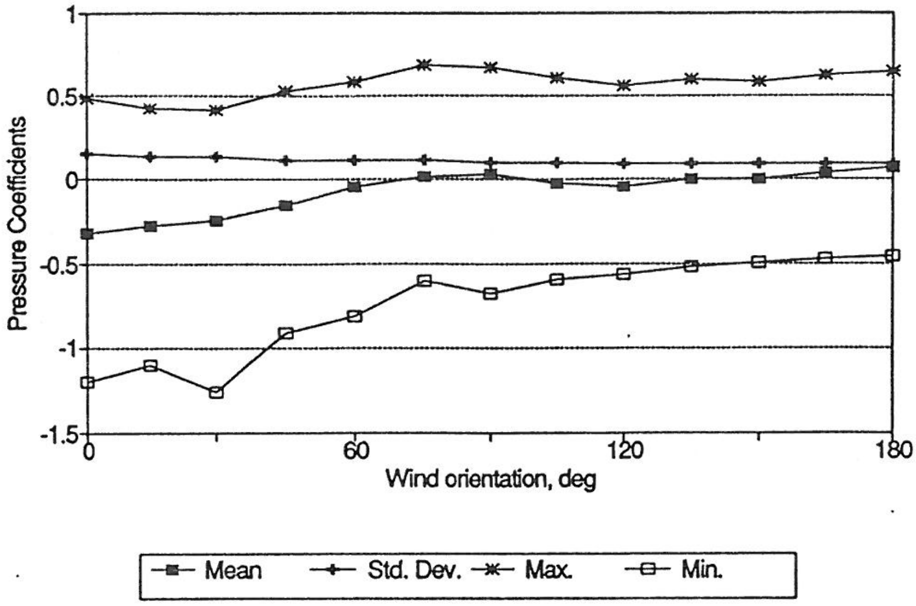

Figure 4. Pressure coefficient variation for roof middle panel E.

For roof middle panel E, Figure 4 shows that the formation of a 2D separation bubble for $\beta = 0^o$ and 3D conical vortices for other wind directions again generate large magnitude mean and fluctuating suction pressures. The largest magnitude mean, maximum and minimum pressure coefficients of -0.32, 0.68 and -1.26, were measured for $\beta = 10^o$,75^o and 30^o respectively. The variation of mean, standard deviation, maximum and minimum area averaged pressure coefficient with wind direction on the six edge strips (A_S to F_S) is summarized in two cases: a roof corner edge strip F_S and a roof middle edge strip E_S in Figures 5 and 6 respectively.

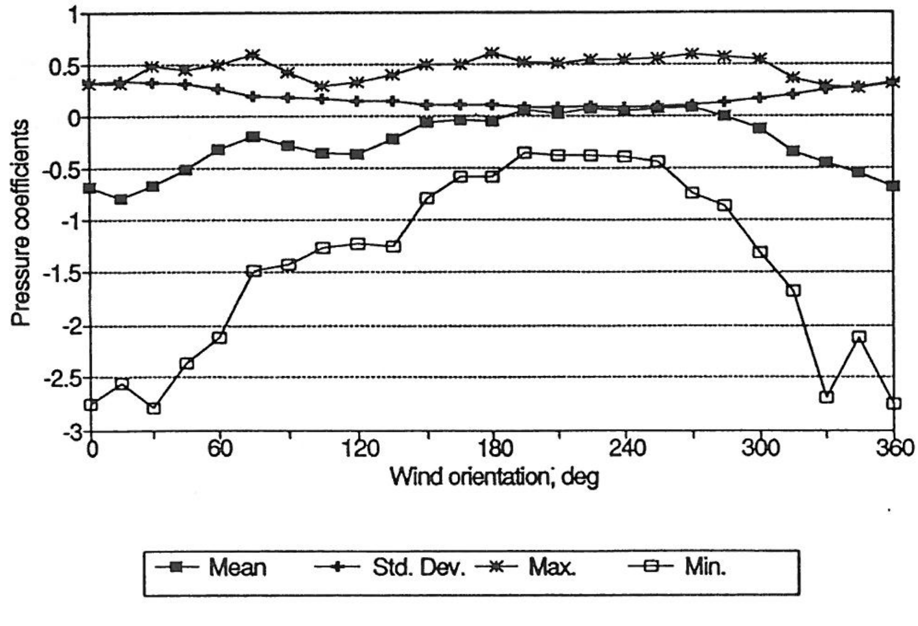

Figure 5. Pressure coefficient variation for roof corner strip F_S.

For roof corner edge strip F_S, Figure 5 shows the familiar formation of a 2D separation bubble for $\beta = 0^o$ and 3D conical vortices for other wind directions. The largest magnitude mean, maximum and minimum pressure coefficients of -0.79, 0.57 and -2.75 were measured for $\beta = 15^o$, 285^o and 0^o respectively.

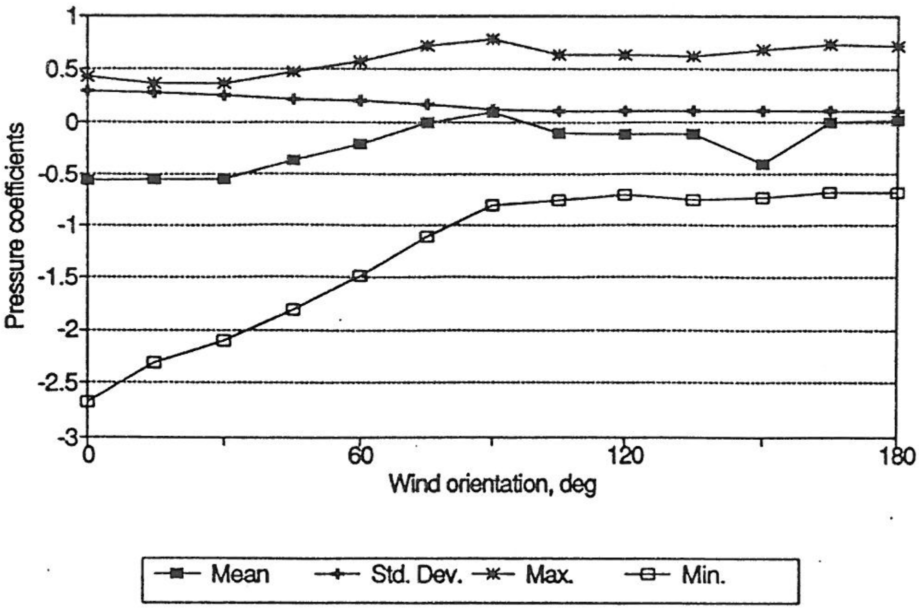

Figure 6. Pressure coefficient variation for roof middle strip E_s.

For roof middle edge strip E_s, Figure 6 again shows the formation of a 2D separation bubble for $\beta = 0^o$ and 3D conical vortices for other wind directions. The largest magnitude mean, maximum and minimum pressure coefficients of -0.56, 0.77 and -2.68 were measured for $\beta = 0^o$,90^o and 0^o respectively.

AS1170.2 [4] suggests a local pressure factor K_l of 1.5 for areas of size a^2 within a of the edge and 2.0 for areas of size $a^2/4$ within a/2 of the edge. The definition of a is the lessor dimension of 20% of plan dimension or the roof height. Here a takes the value 0.2 * 300mm = 60mm, and a^2 = 3600mm^2 and $a^2/4$ = 900mm^2. The pressure factors prescribed in AS1170.2 [4] are used with mean pressure coefficients and gust dynamic pressures, ie. *peak suction pressures* applied on the entire roof. This paper determines local pressure factors (K_l) for the 0.2h by 1.0h edge strips using the area-averaged pressure data on the parent panel. The strips shown in Figure 1 have areas of 2000mm^2, thus lying between the provisions of the code[4]. Values of K_l can be estimated from the ratios of the peak strip pressure to peak panel pressure (maxima/maxima and minima/minima) and are shown in Figures 7 and 8 respectively.

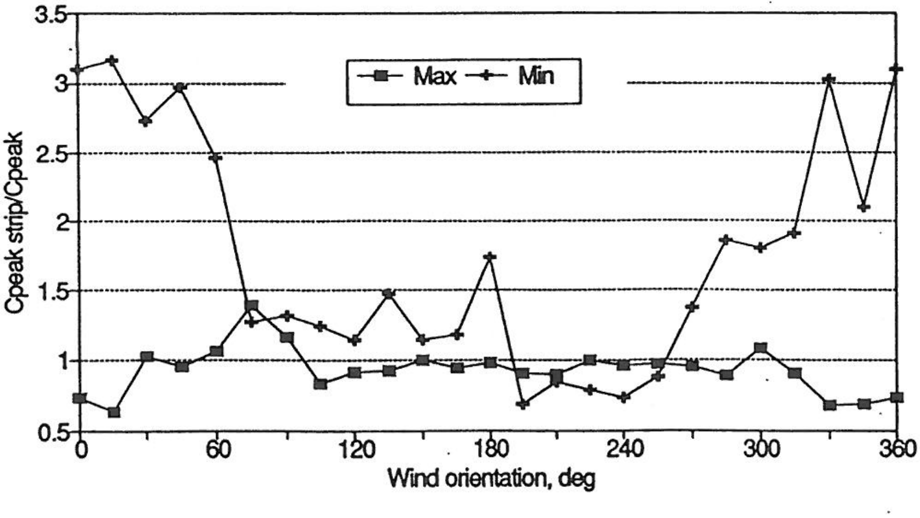

Figure 7. Estimated local pressure factors for corner strip regions

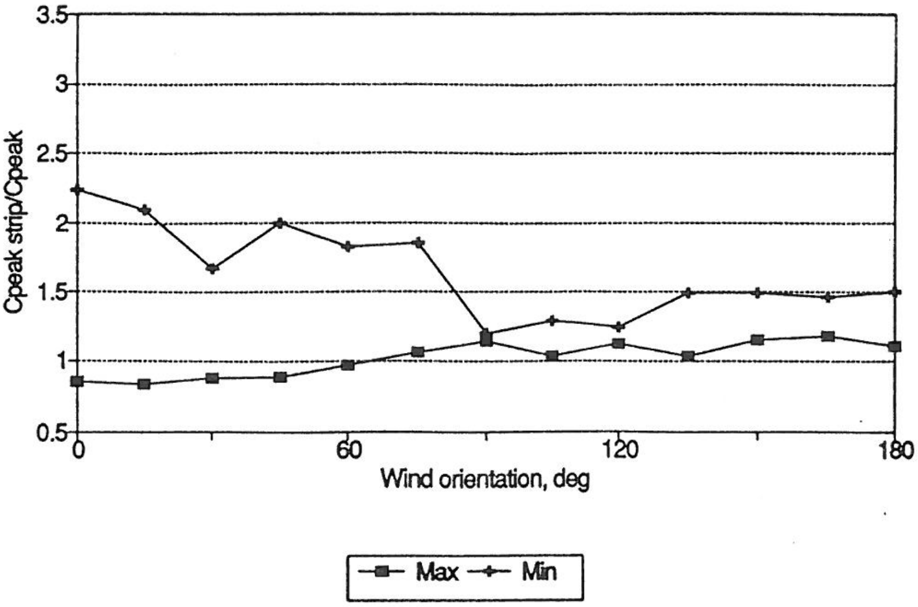

Figure 8. Estimated local pressure factors for middle strip regions

Figure 7 shows that a K_l of ~3.0 is appropriate for suction pressures for $\beta = 0^o$ to 60^o and ~1.4 for positive pressures for $\beta = 90^o$ for the roof corner edge strip regions. Figure 8 shows that a K_l of ~2.0 is appropriate for suction pressures for $\beta = 0^o$ to 60^o and ~1.2 for positive pressures for $\beta = 90^o$ for the roof middle edge strip regions. These pressure factors are to be used with peak suction pressures acting on 1/6 the roof area within which the respective edge strips are contained. It is important to note that the peak suction pressure acting on 1/6 the roof area is of a larger magnitude than the peak pressure acting on the entire roof. Thus the code [4] values appear to underestimate the pressure factors for suction pressures on 0.2h by 1.0h edge strips in separation regions.

4. Conclusions

Large magnitude mean and fluctuating pressures were measured within regions of flow separation on low rise building roofs. In turbulent boundary layer flows, the large magnitude mean and peak suction pressures were measured within a region 0.2h from the separating edge. These pressures were well correlated over a distance of 1.0h. In adopting a quasi-static design approach local pressure factors are required for separated flow regions along edges. Appropriate factors on 0.2h by 1.0h edge strips referenced to 1.5h by 1.0h roof panels encompassing these edge strips are 1.4 and 3.0 for positive and suction pressures respectively for the worst wind directions.

5. References

1. R.J. Kind, Worst suctions near edges of flat roof tops on low-rise buildings, J. Wind Eng. Ind. Aerodyn., 25, (1986) 31-47.
2. J.D. Ginger, Characteristics of large pressures in regions of flow separation on low rise building roofs, PhD Thesis, University of Queensland, 1992.
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4. Australian standard, SAA loading code Part 2: Wind loads AS1170.2 (1989).