Wind Loads on Sun-Shade Attachments and Parent Building

George Holland and John Ginger
Cyclone Testing Station, School of Engineering, James Cook University, Townsville, Qld 4811

Introduction

Building designs for tropical climates frequently incorporate sun-shading attachments in order to reduce solar loads. These can protrude up to 5m from the building face. Wind load standards such as AS/NZS 1170.2 (2002) do not provide wind load data for the design of multiple attachments on buildings, and designers have to use data from similar wind load studies or specialist publications. Stathopoulos and Zhu (1988) showed that 2m to 4m balconies reduce positive pressures on the windward wall, particularly near the top of a building, and negative pressures on side and leeward walls, when compared to the building without attachments. Rofail and Kwok (1999) tested the effects of attachments that extended further from the face of the building, and showed that a quasi-steady external pressure coefficient (Cp_e) of 0.8 was applicable for the windward wall of a building except for the top edges, regardless of whether there was a roof above the top balcony. They also concluded that at the top edges, the Cp_e is higher by about 50% than that for the same building without attachments. Cook (1990) states that balconies without walls (i.e. horizontal plates) distributed all over the face of a building, has little effect on the face pressures of the parent building, and hence the balconies are subjected to very small loads. Based on other studies, the maximum loading of balconies was considered to occur near the top edge of the building.

The effects of shading attachments on the cladding pressures on the parent building and the pressures experienced by these attachments are presented in this paper. Two attachment configurations projecting 3m and 5m from the building face are analysed in this study.

Wind Tunnel Tests

The wind tunnel tests were carried out in the 2.0m high × 2.5m wide × 22m long Boundary Layer Wind Tunnel at the School of Engineering, at James Cook University. The approach wind flow was satisfactorily simulated to between terrain category 2 and 3 (as per AS/NZS 1170.2) at a length scale of 1/100. A 30 × 15 × 50m base building was constructed at a length scale of 1/100, to which plates of 3m and 5m protrusions, representative of sunshades were attached to levels 1 to 9, at 5m intervals, as shown in Figure 1. Figure 1 also defines the direction of the approach wind with respect to Faces A, B and C on the parent building. Tests were performed to determine the following: external pressure coefficients on the base building (i.e. parent building with no attachments), external pressure coefficients on the parent building with 3m and 5m attachments, and the net (i.e. top – bottom) pressure coefficients on the 3m and 5m attachments. External pressures acting toward the building surface are defined as positive and net pressures acting downwards on the attachments are defined positive.

External pressures on the faces of the base building and net pressures on the attachments were obtained for approach wind directions (θ) of 0° to 90° at intervals of 15°. Pressure taps were connected to Honeywell pressure transducers via Scanivalves and a calibrated tube and restrictor system. The pressure signals were low-pass filtered at a frequency of 250Hz, and sampled at 600Hz for 20s for a single run. The pressures were analysed to give mean, standard deviation, maximum and minimum pressure coefficients as;

$$C_{\bar{p}} = \bar{p}\big/\left(\tfrac{1}{2}\rho \overline{U}_h^{\,2}\right),\quad C_{\sigma_p} = \sigma_p\big/\left(\tfrac{1}{2}\rho \overline{U}_h^{\,2}\right),\quad C_{\hat{p}} = \hat{p}\big/\left(\tfrac{1}{2}\rho \overline{U}_h^{\,2}\right) \text{ and } C_{\breve{p}} = \breve{p}\big/\left(\tfrac{1}{2}\rho \overline{U}_h^{\,2}\right)$$

where, $\frac{1}{2}\rho\overline{U}_h^{\,2}$ is the mean dynamic pressure at average roof height h = 50m. The results were obtained from averaging the data from three separate runs.

Results and Discussion

The results from wind tunnel testing have been summarized in the following three sections; the base building, buildings with 3 m and 5 m attachments and the attachments themselves. In general, the pressure coefficient contours for wind directions of $\theta = 0^\circ$, 45° and 90° are presented. The complete set of results from this study are given in Holland (2002).

Contour plots of mean, minimum and maximum pressure coefficients for the base building are shown in Figures 2, 3, and 4 respectively for a wind direction of $\theta = 0^\circ$. These pressure coefficients are for a rectangular enclosed building and compare satisfactorily with data given in AS/NZS 1170.2 (2002).

The effects of the attachments on the parent building are analyzed by comparing pressure coefficients on the base building and on the building with the addition of attachments, using the change in pressure coefficient $K = C_{pe}^{A} - C_{pe}^{B}$, where C_{pe}^{A}, and C_{pe}^{B} are the pressure coefficients on the building with attachments and the base building respectively. Hence an increase in positive pressure coefficient or a reduction in negative pressure coefficient with the inclusion of attachments will result in a positive value of K. The effects of the 3m attachments, K_3 and the 5m attachments, K_5 from selected tests are shown in Figures 5, 6 and 7. The K_3 and K_5 contours show very similar trends. At $\theta = 0^\circ$ in Figure 5, the top corners of the windward wall show positive K values indicating an increase in peak positive pressure coefficients. At these corners, the peak pressure coefficient is up to 1.5 times larger with the addition of attachments. The reduction in suction pressures on the side walls in Figure 6 (Face A at 90°) and Figure 7 (Face B at 0°), indicated by the positive K values in these areas, are greatest at the windward edges with $K = 1.4$.

The net pressure coefficients on the attachments of buildings with 3m and 5m attachments, for approach wind directions of 0° and 90° are shown in Figures 8 and 9. Each figure contains pressure coefficients for the attachments at levels 1, 3, 5, 7 and 9. Each attachment is divided into three areas with the maximum, minimum and mean net pressure coefficients listed in column form for each area.

Areas on the sides of attachments near a windward edge experience the largest net pressure coefficients at $\theta = 0^\circ$ due to flow acceleration occurring around the building. Also, the uppermost attachment at level 9 experiences large upward net pressures, with the effect more pronounced for the larger attachment size. At $\theta = 90^\circ$, there are generally much larger fluctuating pressures at the leeward ends of the attachments with the exception at level 9 where downward pressures were larger at the windward edge.

Conclusions

Wind tunnel model studies were carried out at a length scale of 1/100 to determine the wind loads on sunshade attachments that protrude from the face of a building and the effect of these sunshades on the pressures on the base building. The following conclusions were reached:

The design external pressure coefficients on the parent building with attachments and without attachments (i.e. base building) were generally within AS/NZS 1170.2 values for rectangular enclosed buildings.

Although peak external pressure coefficients were generally reduced by the inclusion of attachments on the building, larger fluctuating pressures were experienced in the upper regions. An increase in windward wall peak positive external pressure coefficients of about 50% occurs at the top corners of the base building with the addition of attachments. Peak pressure coefficients on the sidewalls were reduced significantly at windward edges with the addition of attachments on either the windward wall or sidewall.

Net upward design pressure coefficients on the top attachment compared closely with the corresponding pressure coefficients given for a single sunshade attachment in AS/NZ 1170.2 (2002). However, the design net pressures on the attachments below were generally smaller than the values in AS/NS 1170.2.

Based on the results of this study the following quasi-steady pressure coefficients are recommended for sunshade type attachments on medium to high-rise buildings:

- Net downward pressure coefficients of 0.7 and 0.8 for 3m and 5m attachments.
- Net upward pressure coefficients of 0.9 and 1.5, for 3m and 5m attachments at the top level, and net upward pressure coefficients of 0.6 and 0.65 for 3m and 5m attachments at the levels below.

References

Australian and New Zealand Standard, *SA/SNZ Loading Code, Part 2: Wind Actions AS/NZS1170.2*, Standards Association of Australia, Sydney, 2002

Cook, N. J. *The designers guide to Wind Loading of Building Structures, Part 2: Static* Structures, Butterworths: BRE, Sydney, 1990.

Holland G. G. *Wind Pressure on Attachments and its Effects on the Parent Structure*, B.E. Thesis, School of Engineering, James Cook University, 2002.

Rofail, A. W. & Kwok, K. C. S. 'The effect of sunshading elements on cladding pressures', *Wind Engineering into the 21st Century: Vol 2*, 1999. pp 1159-1164

Stathopoulos, T. & Zhu, X. 'Wind pressures on buildings with appurtenances', *Journal of Wind Engineering and Industrial Aerodynamics*, 31(1988) pp 265-281

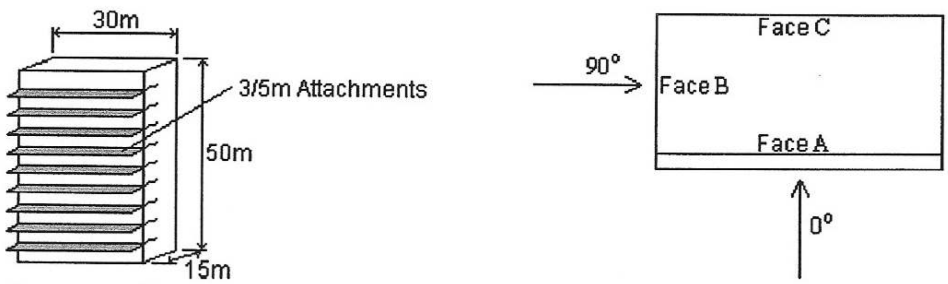

Fig 1. Attachment configuration and approach wind directions in plan with respect to Faces A, B and C

Base Building

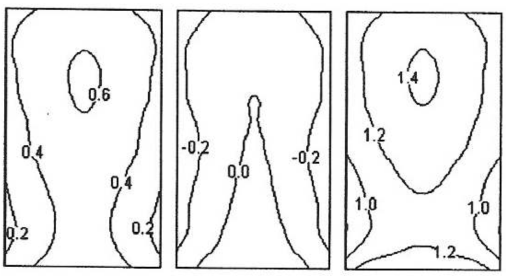

Fig 2. Mean, minimum and maximum windward wall pressure coefficients respectively (θ = 0°).

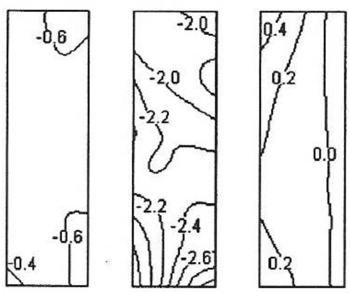

Fig 3. Mean, minimum and maximum side wall pressure coefficients respectively (θ = 0°).

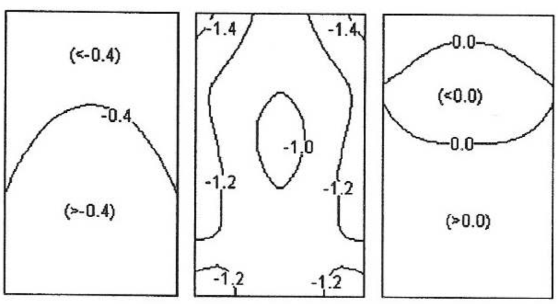

Fig 4. Mean, minimum and maximum leeward wall pressure coefficients respectively (θ = 0°).

Building with 3m and 5m Attachments

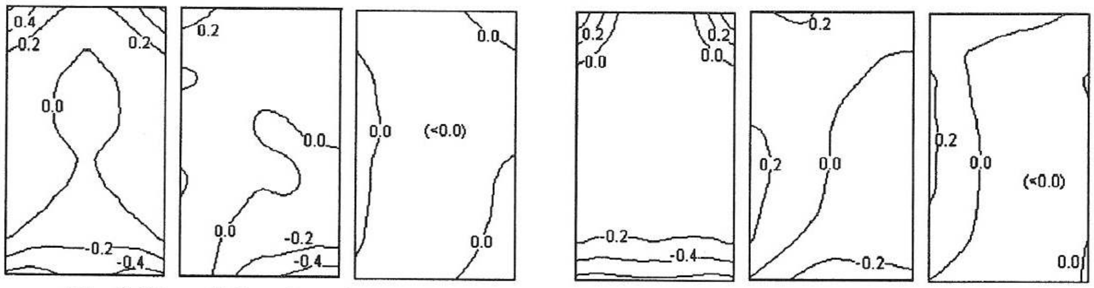

Fig 5. K_3 and K_5 values for $\theta = 0$, 45 & 90 degrees respectively (Face A, maximums).

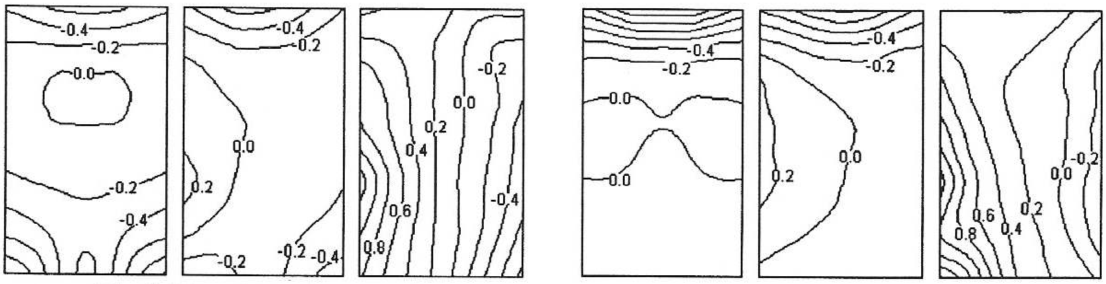

Fig 6. K_3 and K_5 values for 0, 45 & 90 degrees respectively (Face A, minimums).

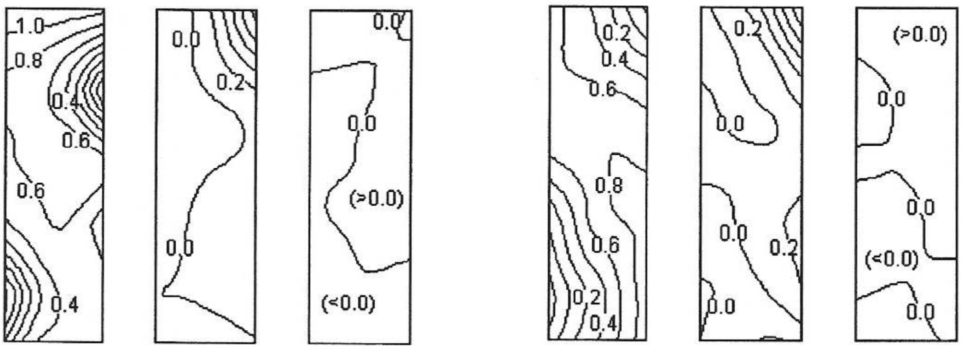

Fig 7. K_3 and K_5 values for 0, 45 & 90 degrees respectively (Face B, minimums).

Level 9	0.508 -1.575 -0.397	0.398 -1.308 -0.460	0.536 -1.410 -0.422	0.685 -3.417 -0.501	0.183 -2.027 -0.710	0.429 -3.553 -0.577
Level 7	1.036 -0.529 0.098	0.900 -0.424 0.032	1.111 -0.605 0.090	0.884 -0.682 0.104	0.817 -0.520 0.032	0.814 -0.580 0.053
Level 5	1.520 -0.493 0.211	1.161 -0.328 0.110	1.314 -0.665 0.181	1.287 -0.516 0.235	1.206 -0.412 0.223	1.041 -0.662 0.189
Level 3	1.565 -0.576 0.254	1.206 -0.219 0.164	1.641 -0.644 0.296	1.261 -0.551 0.242	1.246 -0.442 0.177	1.414 -0.594 0.185
Level 1	1.504 -0.339 0.258	1.136 -0.285 0.119	1.786 -0.489 0.272	1.441 -0.356 0.260	1.179 -0.408 0.165	1.235 -0.578 0.175

Fig 8. Net *Cp* on 3m and 5m attachments, $\theta = 0°$

Level 9	1.440 -0.757 0.103	1.504 -0.462 0.166	0.894 -1.385 -0.193	1.459 -0.493 0.167	1.349 -0.680 0.198	1.078 -1.869 -0.169
Level 7	1.177 -1.050 -0.011	0.589 -1.102 -0.013	1.363 -0.933 0.087	1.037 -0.809 0.035	1.088 -0.993 0.013	1.500 -1.138 0.028
Level 5	0.760 -1.524 -0.057	0.525 -1.057 -0.023	1.263 -1.110 0.044	0.550 -0.569 0.029	0.730 -0.804 0.068	2.046 -1.168 0.230
Level 3	0.824 -1.072 -0.038	0.833 -0.719 0.050	1.505 -1.062 0.050	0.626 -1.611 -0.004	0.715 -1.028 0.003	2.046 -1.210 0.194
Level 1	0.448 -0.820 -0.038	0.395 -0.875 -0.022	1.413 -0.956 0.092	0.493 -1.109 0.003	0.583 -1.004 0.030	1.532 -1.252 0.107

Fig 9. Net *Cp* on 3m and 5m attachments, $\theta = 90°$