WIND LOADS ON BALUSTRADES

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Introduction

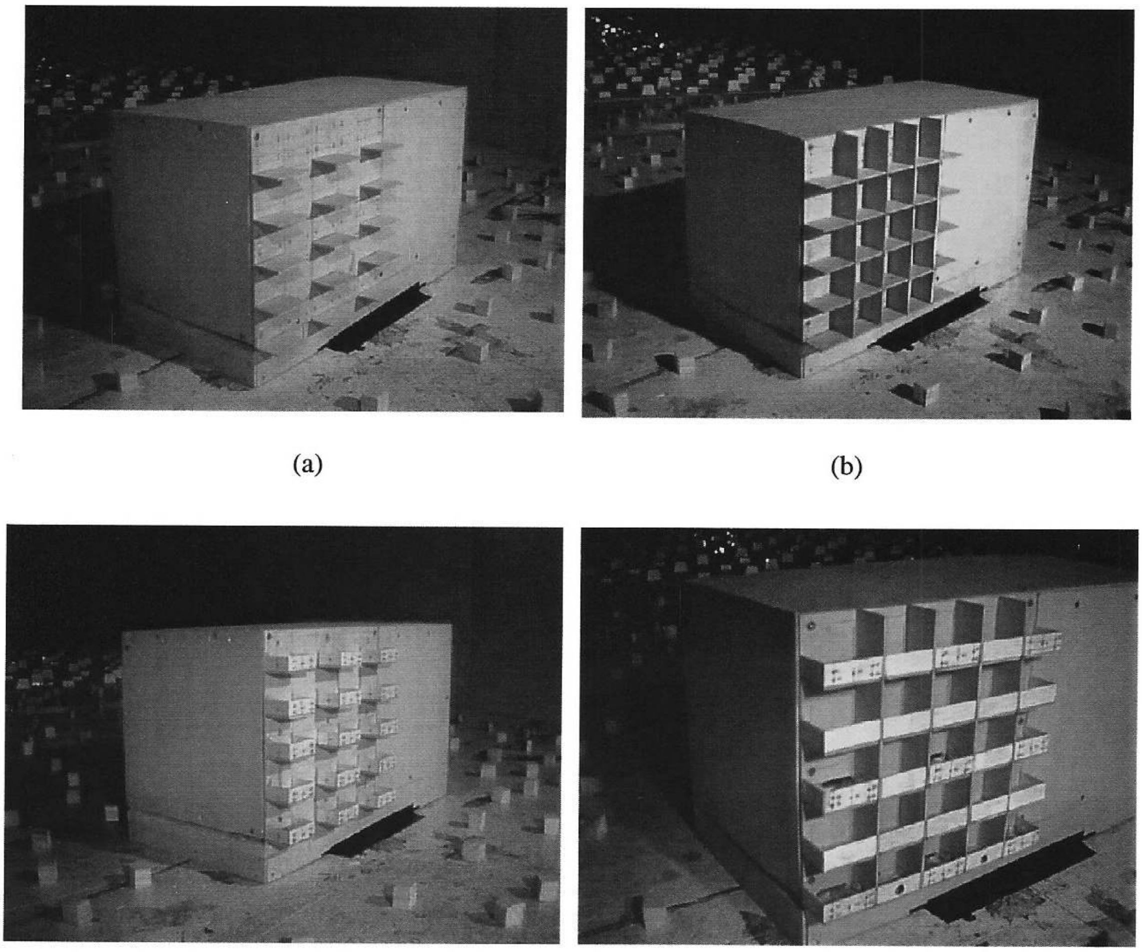
This paper presents the results of a recent wind tunnel study performed at Windtech Consultants that sought to directly measure the wind loading on balustrade members. Due to blockage restrictions in the wind tunnel and the minimum upwind fetch distance required to properly develop the atmospheric boundary layer, the geometric length scale for modelling a high-rise building, for example, is typically limited to a scale of 1:200 to 1:500. At this scale, the dimensions of the balustrade are too small to attempt to directly measure the pressures on the balustrade itself. Instead, the loading is generally estimated from pressures measured on the surface of the building without the balustrade in place, or inferred from measurements of the wind speed in the vicinity of the balustrade. This study was undertaken to assess the accuracy of these estimation techniques.

Experimental Setup

Wind tunnel tests were performed in Windtech's Blockage Tolerant Boundary Layer Wind Tunnel. Pressures were recorded on a 1:50 scale, flat roofed, building with plan dimensions of 15m by 30m and an eaves height of 20m. Two types of balustrade configurations were examined, an isolated balustrade and a uniformly distributed balustrade across the width of the building, as shown in Figure 1. In a separate study, wall pressures were measured with the balcony slab modelled, but without the balustrade members in place, in order to determine the wind loading on the nearby wall surface [1]. The latter represents the typical method for modelling balconies in wind tunnel tests. Pressures were measured on both the outer and interior surfaces of the balustrade members in order to determine the net loading across the balustrade member. Tests were repeated at two locations on the model, along the short (15m) building surface and along the long (30m) building surface. The model was placed in atmospheric flow conditions that simulated a suburban terrain (AS/NZS 1170.2:2002, Terrain Category 3 [2]) and tested over 360 degrees at 15 degree increments. The mean wind speed and turbulence profiles as well as the normalised power spectral density in the wind tunnel adequately matched the full-scale equivalent values for the terrain being modelled.

In total, 90 pressure taps were instrumented over nine balustrade members (i.e. 10 pressure taps for each balustrade). Of these, six pressure taps were positioned on the outer surface of the balustrade and four taps on the inner balustrade surface. As such, the positive pressures from the outer balustrade surface could be simultaneously combined with the negative pressures from the inner balustrade surface to determine the maximum and minimum net loading acting across the balustrade member. The pressure tap layout on the isolated balustrade case is shown in Figure 2. A similar pressure tap layout was adopted on the long wall face and for the continuous balcony configuration.

All pressures measured in the wind tunnel are referenced to the mean wind speed at a height located in low turbulence conditions situated well above the model. Pressures were sampled at 1024 samples per second for 64 seconds (equivalent to about 9 samples per second for 30 minutes in full-scale). The pressures signal was later low-pass filtered at 500Hz and re-referenced to the gust wind speed at eaves height.



(a) (b) (c) (d)

Figure 1 – Photographs of the test model while in the wind tunnel; (a) Isolated balcony with slab only, (b) Continuous balcony with slab only, (c) Isolated balcony with balustrade, (d) Continuous balcony with balustrade.

Experimental Results

Two separate load cases were examined in the study, the net loading across the front wall of the balustrade and the net loading across the side balustrade wall.

Net loading on the front balustrade wall

Figure 3 presents the maximum and minimum net pressure coefficients acting on the front face of balcony 'A', for the isolated balcony configuration. In addition, the wall pressure recorded immediately behind the balcony is also presented for comparison. The figure shows the peak balustrade loading occurred in the positive direction, or load acting in the direction towards the building, with a maximum positive coefficient, C_p, of 0.8 when referenced to the gust wind speed at

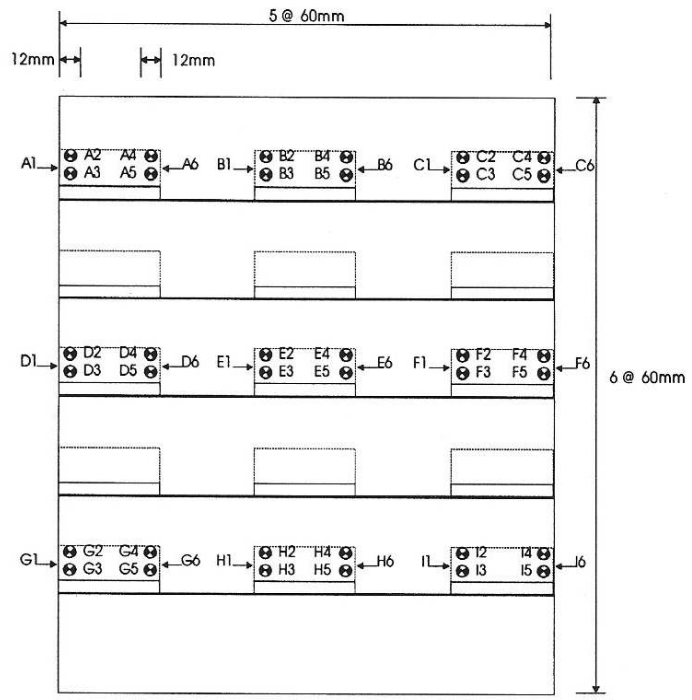


Figure 1 – Pressure tap layout for isolated balustrade model

eaves height. The figure also shows that this matches the positive wall pressures measured immediately behind the balustrade. Similar results were observed for the remaining upper level balustrades (Balconies A, B, C). It is believed that the positive wind loads recorded across the upper level balustrades and on the nearby wall are caused by the same flow phenomenon and hence the positive balustrade loads on the upper balconies can be estimated from the positive wall pressures. Similar results were observed on the continuous balustrade configuration, as shown in Figure 4.

However, the same can not be said for the medium and lower level balconies, where there is no relationship between the wall and balustrade pressures. The magnitude of the loading on the inner balustrades were also much lower, with a maximum positive coefficient, C_p, of approximately 0.4.

Net loading on the side balustrade wall

With regards to the isolated balcony case, a maximum loading coefficient of 1.4 was recorded on the inner side wall of balcony 'A' (When pressure tap A6 is combined with the corresponding inner wall tap), as shown in Figure 5. No direct relationship could be found between the pressures on the inner side wall of the balcony and a corresponding wall pressure tap, except that the extreme magnitudes of the coefficients appear to be similar (ie. +1.4 on the balustrade wall compared to -1.5 on the building wall surface).

Similarly for the continuous balcony case, a maximum net pressure coefficient of 1.4 was also recorded on the inner side wall of balcony 'A'. However, only a maximum wall pressure coefficient of 1.1 was recorded at any point on the building wall surface. Again, no direct relationship could be found between the pressures on the inner side wall of the balcony and a corresponding wall pressure tap (or combination of wall taps).

Design Recommendations for Balustrade Loading

Worst balustrade net pressures were recorded on the upper level balconies and, as such, all recommendations are based on these pressures.

Isolated Balustrades:

It is recommended that the balustrade members be designed using the minimum suction pressure coefficient measured on the building wall surface and not the maximum positive pressure coefficient. This applies to the net balustrade loading, which includes the contribution from the front and rear surfaces of the balustrade.

Continuous Balustrades:

It is recommended that the balustrade members be designed using the minimum suction pressure coefficient measured on the building wall surface multiplied by a factor of 1.2. This applies to the net balustrade loading, which includes the contribution from the front and rear surfaces of the balustrade.

References

Mans, C., Rofail, T. (2003) Effect of balustrades on building cladding pressures, *Proceedings for the Australian Society of Wind Engineers Conference*, Sydney, Feb 6-7 2003.

AS/NZS 1170.2:2002 (2002) *Structural design actions, Part 2: Wind actions*, Standards Australia, Homebush.

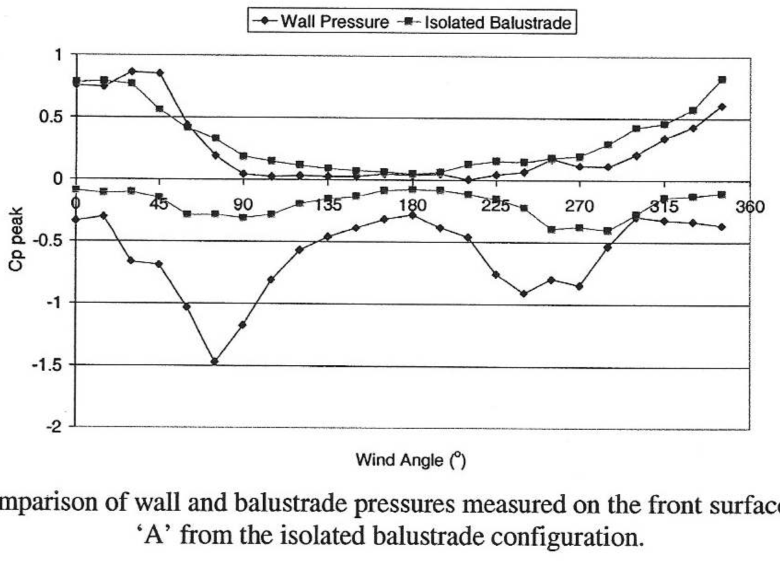


Figure 3 – Comparison of wall and balustrade pressures measured on the front surface of balustrade 'A' from the isolated balustrade configuration.

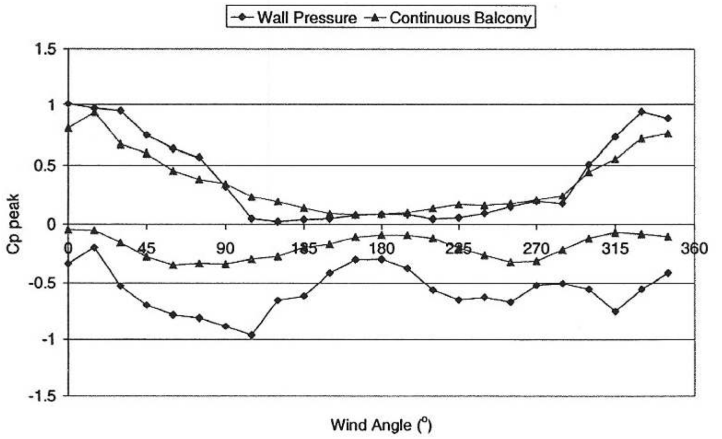


Figure 4 – Comparison of wall and balustrade pressures measured on balustrade 'A' from the continuous balustrade configuration.

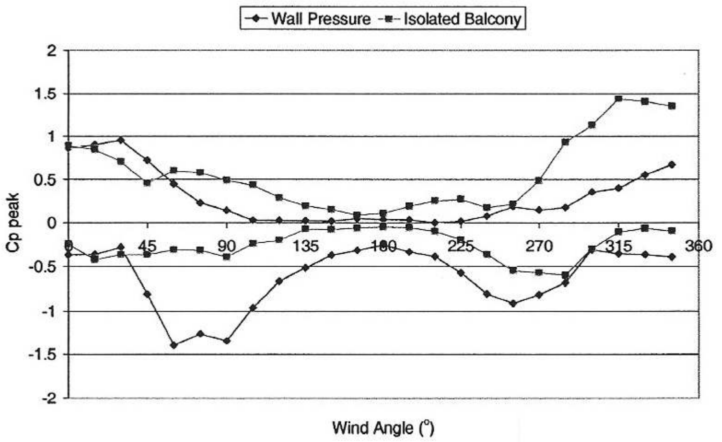


Figure 5 – Comparison of wall and balustrade pressures measured on the inner side wall of balustrade 'A' from the isolated balustrade configuration.