EFFECT OF BALUSTRADES ON BUILDING CLADDING PRESSURES

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Introduction

Balustrade members are commonly found on low and high-rise residential apartment buildings. However, possibly due to the relatively small size of the balustrades, little published information exists regarding their design wind loading or how they may affect the building cladding pressures. This is primarily due to the difficulties involved in correctly modeling a balustrade in typical wind tunnel tests. Due to blockage restrictions in a wind tunnel and the minimum upwind fetch distance required to properly develop the atmospheric boundary layer, the geometric length scale for modeling a high rise building, for example, is typically limited to a scale of 1:200 to 1:500. At these small scales, the dimensions of the balustrade members become very small and, as such, correctly scaling the Reynolds number for the flow around the balustrade becomes very difficult to achieve. In typical wind tunnel tests, building attachments are generally only modeled if they exceed 1.0m. As such, the balcony slab members are included in the model, but not the balustrade itself. Previous research has suggested that this is a reasonable approximation for modeling the balcony [1].

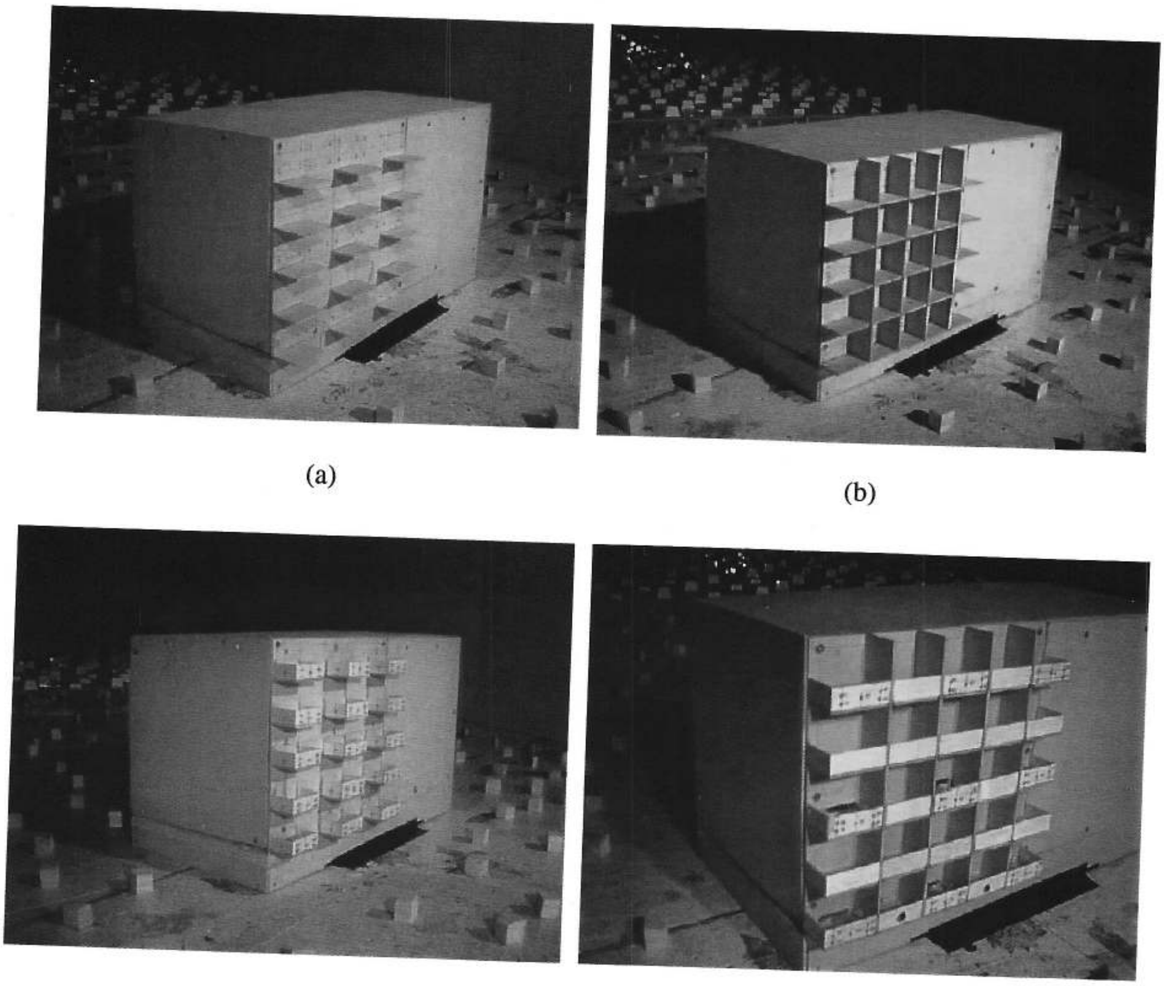
This paper is a portion of a recent wind tunnel study performed at Windtech Consultants. The study sought to measure the wind loads on the balustrade members themselves in order to determine methods for estimating the loading on the balustrade members from information on the corresponding façade pressures. The results of this aspect of the study are presented in a separate paper. This paper presents comparisons of the pressures measured on the wall surfaces behind a number of balustrade configurations. The importance of including the balustrade members in typical wind tunnel cladding studies is discussed.

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 each case, wall pressures were measured with the balustrade in place and with the balustrade removed, but with the balcony slab in place. The latter represents the typical method for modelling balconies in wind tunnel tests. A no balcony configuration was also included as a reference. 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 normalized power spectral density in the wind tunnel adequately matched the full-scale equivalent values for the terrain being modeled.

Pressures were simultaneously measured at 64 locations for each balcony configuration. Figure 2 describes the pressure tap layout for the isolated balcony configuration on the short wall face. 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.

Results and Discussion

Previous research has suggested that balconies may tend to increase the windward wall pressures by up to 60% at the top corner of the building, but decrease the minimum pressures on the side and rear walls [1]. The results from the current study appear to confirm these trends. Table 1 summarizes the worst maximum and minimum pressure coefficients recorded on the short wall surface for the three balcony configurations, along with the worst wind direction. The table suggests that the balcony elements tend to increase the positive pressure coefficients by up to 15%. These generally occurred towards the upper portion of the building and for winds approaching normal to the wall surface.

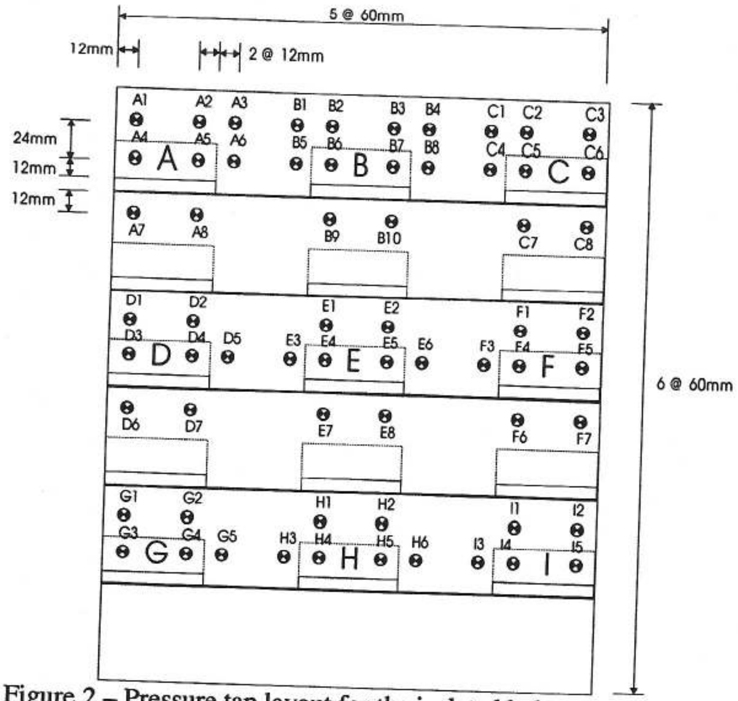


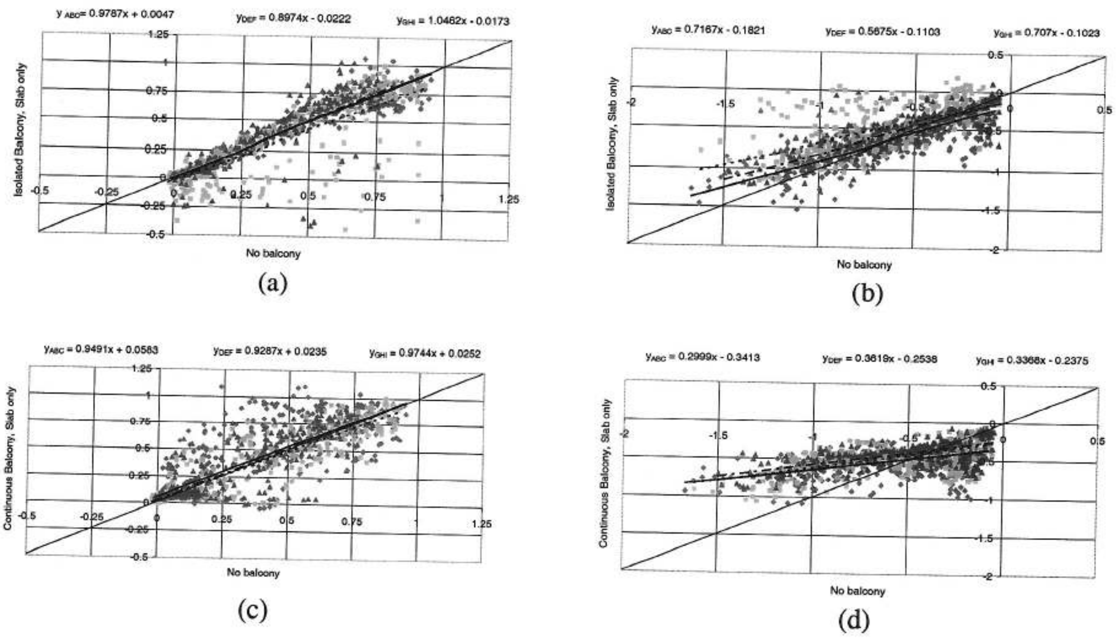
Figure 2 – Pressure tap layout for the isolated balcony configuration.

Configuration	Pressure Tap	$C_{p\,max}$	Wind Angle		Pressure Tap	$C_{p\,min}$	Wind Angle
No Balcony	B10	0.95	0		C3	-1.67	270
Isolated Balcony, Slab only	C2	1.06	345		C2	-1.53	300
Continuous Balcony, Slab only	A3	1.10	330		C8	-1.09	285

Table 1 Worst pressure coefficients measured on the short wall building surface referenced to the gust wind speed at eaves height.

Table 1 also suggests that balcony elements tend to reduce the worst minimum pressure coefficients by approximately 10% for the isolated balcony and by 30% for the continuous balcony. In each case, the worst coefficients occurred at the top corner of the building. The worst negative coefficients occurred when the building wall was at 90° to the approaching wind. Although not shown here, similar results were observed from measurements taken on the long building surface.

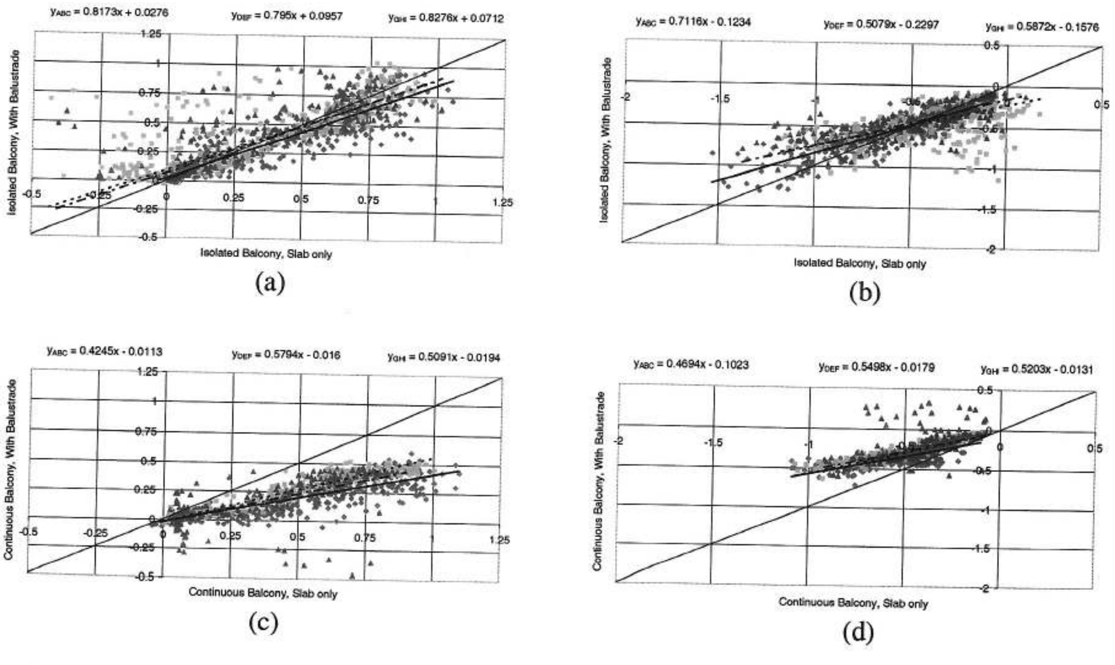
A useful indication of the effect of modeling the balcony slab members can be obtained by plotting the pressure coefficients in a scatterplot where, for each pressure tap, the pressure coefficients recorded from one configuration is directly plotted against the pressure coefficients recorded in a second configuration. For example, Figure 3(a) presents the maximum pressure coefficients measured on the no balcony case on the x axis versus the maximum pressure coefficients measured on the isolated balcony case on the y axis. If the pressure coefficients from the two tests were to match perfectly, the points in the scatterplot should fall on a straight line with the slope of the linear fit equal to unity and a y intercept of zero. For ease of presentation, the results are grouped into the three rows of balconies (See Figure 2 for balcony definition). With regards to Figure 3(a), there is a



(a) (b)

(c) (d)

Figure 3 – Comparison of Maximum and Minimum Pressure Coefficients recorded the building wall with no balcony present verses with the balcony slab attached.
◊ Balconies A, B, C; ⊖Balconies D, E, F; ∇ Balconies G, H, I.



(a) (b)

(c) (d)

Figure 4 – Comparison of Maximum and Minimum Pressure Coefficients recorded the building wall with the balcony slab attached verses with the balustrade attached.
◊ Balconies A,B,C; ⊖Balconies D, E, F; ∇ Balconies G, H, I.

degree of scatter on the middle balcony level, as indicated by the square markers. This was due to differences in maximum pressure coefficients on edge balconies D and F. The figure suggests modeling the isolated balcony slabs, particularly those located away from the middle part of the vertical edges, does not significantly alter the pressure coefficients on the surface of the building, as the linear fit slopes for all balconies are within +/-4% for the upper and lower balcony levels.

Figure 3(b) compares the negative pressure coefficients from the no balcony case and the isolated balcony case. Again, the figure shows the greatest scatter in pressures occurs around the middle balconies. The slopes of the linear fit also suggest that the presence of the balcony slab causes a uniform reduction in negative pressures by around 30%, likely due to the balcony slabs disrupting the flow around the corner of the building. In view of the scatter present in the negative pressure coefficients, it can be concluded that it is important to include the isolated balcony slabs on the pressure models. Similar comparisons are presented in Figures 3(c) and 3(d), but for the continuous balcony. In this case, the scatter and change in slope is more pronounced, suggesting that it is more critical to model the continuous balcony slabs. It is believed the differences in the positive coefficients may be attributed to a slight shift in the stagnation point of the flow on the front surface of the building. Again, the reduction in the negative coefficients is likely due to the balustrades aiding in disrupting the flow around the building and hence sheltering the wall surface from the surrounding flow field.

In order to determine whether the balustrades themselves should be included on the model, similar comparisons are presented in Figures 4(a) to 4(d). In this case, the maximum and minimum pressures from the slab only configuration are plotted on the x-axis against the peak wall pressures measured with the balustrade member included on the model on the y-axis. In general, the figures indicate a large degree of scatter and deviation from the ideal linear fit of unity, suggesting that it may be important to include the balustrade member on the model. With regards to the isolated balcony, the results appear to collapse reasonably well with the exception of the middle level balconies (square markers). The outlying markers represent taps where there is a marked difference in the flow field at that particular tap location. As the scatter in Figure 4(a) is mainly located above the line of best fit, the presence of the balustrade tends to increase the positive pressures at the balconies located at this middle region. However, the slope of the line of best fit suggests that, on the whole, the presence of the balustrade tends to reduce the positive pressure coefficients. In contrast, less scatter is observed for the negative coefficients as shown in Figure 4(b), but the pressures are, in general, reduced by 30 – 50%. With regards to the comparison for the continuous balustrade configuration, Figures 4(c) and 4(d) suggest that the balustrade members cause a general reduction in the wind loading by approximately 50% if the balustrade is included on the model. This reduction occurs for both the maximum and minimum pressure coefficients and for both the edge and centre balconies.

The results tend to suggest, that for both balustrade configurations, the introduction of the balustrade to the model tends to shelter the surrounding wall area from the flow field around the building, hence reducing the wall pressures. This was more pronounced for the continuous balustrade configuration, where the vertical fins and the balustrade members combine to significantly reduce the worst positive and negative pressure coefficients by around 50%.

References

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