WIND LOADS ON BALUSTRADES

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ABSTRACT: This paper examines the wind loading on impermeable balustrade members. In particular, the study focuses on the net pressure coefficients measured across a balustrade member located on an isolated balcony. Comparisons are presented with existing code recommendations pertaining to the design loading on a balustrade member. Results suggest that the highest positive net pressure coefficient of 1.8Cp (acting in the direction towards the centre of the balcony) occurs on the upper corner balcony members, specifically the side wall balustrade located adjacent to the edge of the building. The highest negative net pressure coefficient of –1.6Cp occurs on balconies situated adjacent to the side edges of the building. For design, the current Australian, British and Hong Kong standards specify that balustrade members are required to withstand the larger of either the net wind loading acting across the balustrade or a 1kN/m^2 live load. For the recommended live load of 1kN/m^2 to dominate over the highest net pressure coefficient of 1.8Cp, the eaves height 3-sec gust wind speed is required to be less than 30m/s. For wind speeds greater than 30m/s, the wind loading coefficient of 1.8Cp dominates over the live loading.

1 INTRODUCTION

Balustrade members are commonly found on low and high-rise residential apartment buildings. For design, the loading on a balustrade member is generally governed by either the worst design loading from wind pressures or from impact loading. For example, the current AS/NZS 1170.1-2002 [1] recommends that balustrades in private dwellings shall be designed to resist the worst loading from either the wind loading or a uniform loading of 1 kN/m^2 over the body of the balustrade. A similar live loading value is also recommended in the current British Standard and Hong Kong Building Regulations [2,3]. However, neither standard specifically specifies a method for determining the wind loading on the balustrade members. Assumptions must also be made regarding the application of pressure coefficients on the external and interior faces of the balustrade.

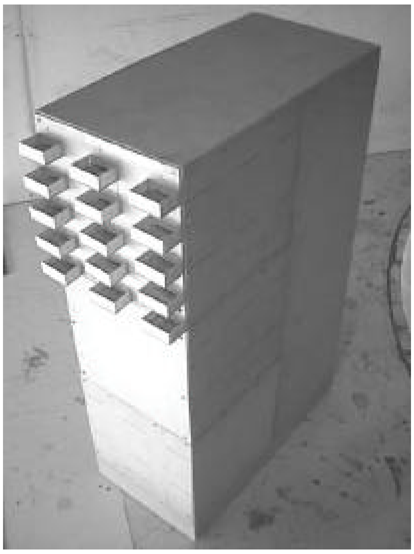
This paper presents the findings of a comprehensive study aimed at quantifying the wind loading on impermeable balustrade members through wind tunnel testing. The results are compared with the existing live loading recommendations provided in the Australian Code.

2 EXPERIMENTAL PROCEDURE

A variety of balustrade type and building configurations have been examined in this study. The focus of this study is to examine the wind loading on an isolated balcony located on both a low and high-rise building. The wind tunnel testing incorporated a 1:50 scale model building with full-scale plan dimensions of 15m and 30m. Tests were repeated for two building heights, being 18m and 48m. The balustrade dimensions are defined as 3m long with a depth of 2m in full scale. The height of each balustrade wall is 1.2m with a slab depth of 0.15m.

Tests were also repeated at two locations on the model, along the short building wall and along the long building wall for the 18m tall building. Tests on the 48m building were limited to the short building wall. Figure 1 shows photographs of the model identifying the two building geometries. The model was placed in atmospheric flow conditions that simulated a suburban terrain (AS/NZS 1170.2:2002, Terrain Category 3 [4]) 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 matched the full-scale equivalent values for the terrain being modeled.

a) Isolated balustrade, 18m tall bld



b) Isolated balustrade, 48m tall bld

Fig. 1. Photographs of the 1:50 scale model (H=18m and 48m) taken in the wind tunnel.

As shown in Figure 1, balustrade members were placed over a single 15m by 15m section of the building. 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 surface to determine the worst net loading acting across the balustrade member. Figure 2(a) presents the layout of the pressure taps used on the balustrade members. Pressure taps were positioned on nine balustrade members, labelled A through to I. In analyzing the pressure results, the balustrades were divided into three main zones: the top corner region (Balustrades A and C), the edge region (Balustrades B, D, F, G, I) and the mid-wall region (Balustrades E and H).

Testing was performed in Windtech's Blockage Tolerant Boundary Layer Wind Tunnel. All pressures measured in the wind tunnel were initially 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 for the 1:50 model (2048 samples per second for 16 seconds for the 1:400 model). The pressure signal was later low-pass filtered at 500Hz and digital filtering was applied for the range 0 to 500Hz. Unless otherwise specified, all pressure coefficients presented in this paper are referenced to the 3-sec gust wind speed at eaves height, H.

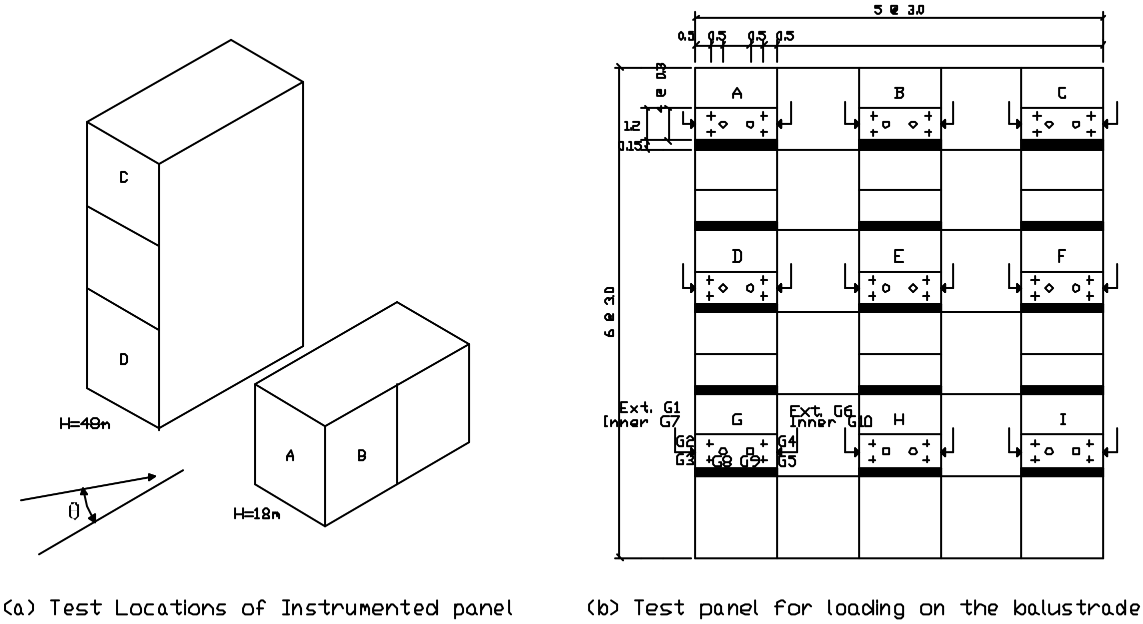


Fig. 2. Pressure tap layout used in the study. (a) Test locations of Instrumented Panel (b) Layout of pressure tap locations measured directly on the balustrade. The symbol '+' represents taps positioned on the outer balustrade surface and the 'o' symbol represents taps positioned on the inner balustrade surface

3 DISCUSSION

Table 1 presents the peak positive and negative net pressure coefficients measured on the balustrade members on the 18m tall building, referenced to the 3-sec gust wind speed at roof height, H. A positive net coefficient is defined as acting in the direction towards the centre of the balcony. Conversely, a negative net coefficient is defined as acting away from the centre of the balcony.

The coefficients are separated into three zones of the building surface: the top corner region, the edge region and the mid-wall region, as described in the preceding section. This is due to the unique flow characteristics expected to occur within the three regions. The results are further separated by examining the pressures measured on the side and main walls on each balcony. For example, the main balustrade wall is defined as running parallel to the building wall. The outer side wall represents the side balustrade wall adjacent to the edge of the building, while the inner side wall represents the side balustrade wall closest to the centre of the building.

Regarding the positive net pressure coefficients, the results suggest that the largest loading occurred in the top corner region of the building for both sides of the building. The table also suggests the largest positive loading occurred on the outer side walls of the balconies, for winds approaching roughly perpendicular to the test section, with a largest pressure coefficient of 1.82. At this wind angle the side balcony walls are directly inline with the approaching flow, but are also within the region of separated flow at the corner of the building. Significant positive net pressure coefficients of up to 1.3 were also recorded on the edge balustrades, while a peak net positive coefficient of 0.71 was recorded on the centre balustrades.

The largest negative net pressure coefficients were recorded on the edge balustrade members, with a largest coefficient of -1.6. Again, this was recorded on the outer side wall of the balustrade.

As the current wind loading standards do not provide any definitive recommendations for wind loading on balustrade members, comparisons with current live loading recommendations are presented. As defined by the current AS/NZS 1170.1 2002, balustrade walls are to be designed to withstand a net horizontal live loading of $1kN/m^2$. A similar value is recommended by the current British Standard and the Hong Kong Building Regulations.

Configuration	Location	$C_{p\,max}$	Corner Balcony			Edge Balcony			Midwall Balcony	
			Outer Wall	Inner Wall	Main Wall	Outer Wall	Inner Wall	Main Wall	Inner Wall	Main Wall
H=18m	Short Face	$C_{p\,max}$	1.58	1.27	0.93	1.29	1.05	0.55	0.71	0.59
		Tap	A1	A6	C7	G1	D6	B7	E1	E7
		θ	90	315	0	90	345	15	345	345
	Long Face	$C_{p\,max}$	1.82	1.30	1.00	1.07	1.15	0.63	0.51	0.49
		Tap	C6	A6	A7	F6	B6	B7	E6	E7
		θ	210	270	270	195	210	285	210	180

Configuration	Location	$C_{p\,min}$	Corner Balcony			Edge Balcony			Midwall Balcony	
			Outer Wall	Inner Wall	Main Wall	Outer Wall	Inner Wall	Main Wall	Inner Wall	Main Wall
H=18m	Short Face	$C_{p\,min}$	-0.57	-0.59	-0.45	-1.24	-1.03	-0.56	-1.31	-0.6
		Tap	C1	C6	C7	I1	I6	I7	E1	E7
		θ	75	0	300	0	105	285	90	75
	Long Face	$C_{p\,min}$	-0.81	-0.61	-0.65	-1.59	-0.78	-0.66	-1.16	-0.63
		Tap	C6	C1	C7	G1	I1	G7	E1	E7
		θ	180	0	180	285	60	285	90	285

Table 1. Summary of maximum and minimum net pressure coefficients recorded across balustrade members on the 18m building.

Table 2 presents a summary of the net pressures recorded on the balustrade members for both the 18m and 48m tall buildings. For simplicity, the highest net pressures are presented, irrespective of whether loading occurred on the side or main balcony wall and irrespective of the direction of the net loading. Along with the worst net pressure coefficients, the table presents the equivalent eave height wind speeds required for the balustrade wind loading to dominate over the recommended $1kN/m^2$ live load. Therefore, for design purposes, if the eave height wind speed exceeds that presented in Table 2, the balustrade should be designed according to the wind loading coefficients provided in Table 2. Conversely, if the eaves height wind speed is below that presented in Table 2, the balustrade member should be designed according to the $1kN/m^2$ live loading.

Regarding the isolated balustrade configuration, the table suggests that balustrades should be designed to withstand wind loading for an eaves height wind speed greater than 30m/s.

Building Height	Balustrade Configuration		Corner Balcony	Edge Balcony	Mid-wall Balcony
H = 18m H/B = 0.6	Isolated Balcony	C_p $V_{H\ 3\text{-sec gust}}$ (m/s)	1.82 30.1	1.59 32.2	1.31 35.5
H = 48m H/B = 1.6	Isolated Balcony	C_p $V_{H\ 3\text{-sec gust}}$ (m/s)	1.65 31.6	1.75 30.7	1.56 32.5

Table 2. Summary of worst net pressure coefficients (+/-) measured across the balustrade members and the equivalent eaves height 3-sec gust wind speeds required to exceed the AS/NZS 1170.1:2002 recommended 1kN/m^2 live loading.

4 CONCLUSIONS

A wind tunnel study was performed to directly measure the wind loading on balustrade members. Highest positive net peak pressure coefficients of up to 1.8, when referenced to the 3-sec gust wind speed at eaves height, were recorded on the top corner balconies. Highest negative net peak pressure coefficients of up to -1.6 were recorded on balconies adjacent to the edge of the building. The results suggest, for design purposes, balustrade members should be designed for wind loading if the 3-sec gust wind speed exceeds 30m/s, otherwise the balustrade may be designed for the 1kN/m^2 live load.

5 REFERENCES

1 AS/NZS 1170.1:2002, Structural Design Actions, Part 1: Permanent, Imposed and other Actions, Standards Australia, Homebush, 2002.
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