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Wind Loads on Buildings with Balcony Glass Handrails

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Abstract

Balcony glass handrail systems for architectural and safety purposes need to be designed for wind loading, as well as being considered when estimating the wind loading on the building itself. However, current building codes and standards do not provide a precise methodology for estimating wind effects on buildings with glass railings. This paper investigates the wind effects on a 15-story residential mid-rise building with balcony glass handrail systems. Scaled model experiments were performed in the Wall of Wind facility at Florida International University. Two sets of experiments were performed by using building models without and with balcony handrail systems. Wind effects on both continuous and discontinuous balconies were studied. Results showed that the balconies can change the flow pattern around the building and consequently the pressure distribution on the walls. Pressure coefficients on the balcony handrail systems reported in this paper and in follow-up studies will help to achieve more reliable design guidance for railing systems that will improve safety of the residents.

Introduction

Failures of balcony glass railing systems have been a frequent occurrence during past hurricanes. Such failures pose dangerous life safety issues for the residents. The current methodology for establishing the wind effects on building facades involves determining the design load using the wind provisions of codes and standards such as the ASCE 7. However, the current methodology does not provide accurate guidance on the wind loading affecting balcony glass hand railings in mid- and high-rise buildings. Therefore, the engineer must interpret the wind provisions for the building walls and their application in ways that may not be truly representative of real loading on the balcony handrail systems, possibly underestimating effects of localized peak pressures. Moreover, the effects of glass handrail systems on the aerodynamic loading on the wall cladding elements are generally not considered.

Wind loading research on balcony railings and their effects on the wind load distribution on buildings' façade have been limited. Atmospheric boundary layer wind-tunnel measurements of wind-induced surface pressure on the facades of a medium-rise building were conducted by Chand [1] in an open-circuit wind tunnel. Results showed that balconies can affect the peak and mean surface pressure distributions on building walls and roof. Montazeri and Blocken [2] using Computational Fluid Dynamics showed that the presence of building balconies can change the wind pressure distribution on windward facades, because the balconies introduce multiple areas of flow separation, recirculation, and reattachment. Corner balconies can not only act as an architectural feature, but also as a passive aerodynamic device acting as general roughness elements disrupting formation of strong vortex shedding and thereby reducing cross-wind response of tall buildings. It was found that corner balconies that extend out could reduce the cross-wind loads by about 10-30% [3].

The objective of this paper was to (1) investigate wind loads on balcony glass hand railings of a residential mid-rise building under simulated wind loads; and (2) study the balcony effects on the wind loads on the building's façade. A 15-story mid-rise building was selected for the experiments. Pressure taps were installed on the balcony handrail systems and the building walls. The resolution of pressure taps on the balcony structure was higher in the critical corner areas. Three different model scales (1:180, 1:67 and 1:25) were used to study the effect of scaling. The focus of this paper is to estimate the net loading on the glass handrail system and the effect of the handrail system on the wall pressures. Selected results from the 1:180 model are presented in this paper.

Experiments

Wind Testing Facility

Experiments were performed at the 12-fan Wall of Wind (WOW) open jet facility at Florida International University. The WOW can generate wind speeds up to a Category 5 Saffir–Simpson Scale hurricane and reasonably replicates mean wind speed and turbulence characteristics of those of real hurricane winds. A set of triangular spires and floor roughness elements (figure 1) were used to generate turbulence and boundary layer characteristics. Figure 2 shows the mean wind profile for open terrain simulation. Detailed information about the Wall of Wind flow conditions is presented in [4].

Figure 1. Spires and floor roughness elements in WOW.

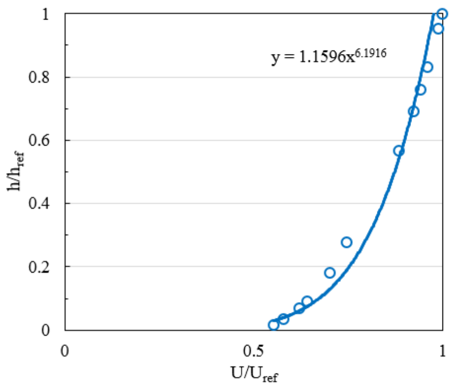


Figure 2. Mean wind speed profile in WOW.

Test Building Model

A 15-story mid-rise building was selected for the experiments. The building dimensions at full scale are shown in figure 3.

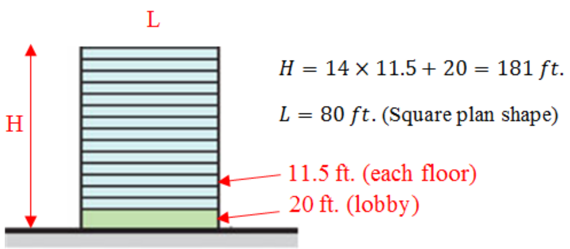
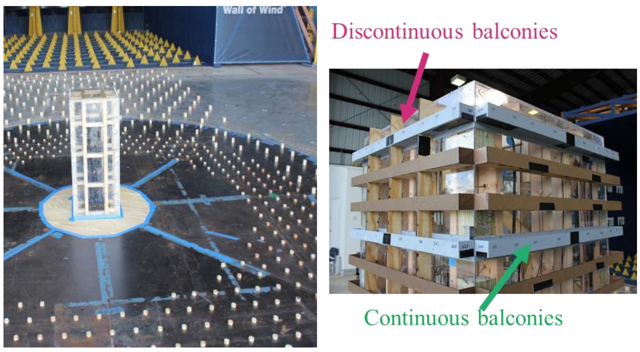


Figure 3. Full scale building dimensions.

In order to study the effect of balconies and glass handrails on the wind pressures on the building, two sets of experiments were performed by using building models without and with balconies and handrail systems. Wind effects on both continuous and discontinuous balconies were studied. Continuous balconies stretch from one side of the building to the other, while discontinuous balconies have partitions in between. Only the balconies located in the 15th, 12th, and 9th floors were instrumented and the rest were dummy balconies.

Pressure taps were installed on both surfaces of the balcony handrail elements as well as on the building walls. A 512 channel Scanivalve Corporation pressure scanning system was employed for pressure measurements. On-site calibration was conducted to assure the highest level of accuracy in the measurements. Pressure data were acquired at sampling frequency of 520 Hz for a period of one minute and were low pass filtered at 120 Hz. Figure 4 shows an example of the models that were tested for this study.



a) Building without balcony b) Building with Balcony

Figure 4. Scale building models

The wind direction convention is shown in figure 5.

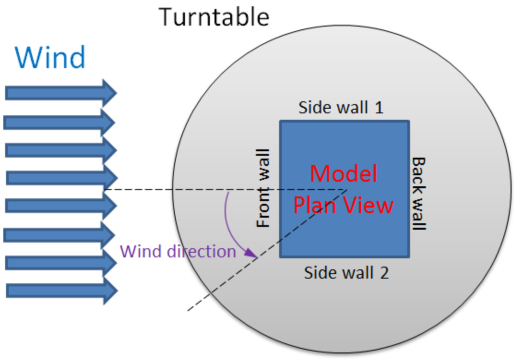


Figure 5. Wind direction convention.

Data Analysis

The results from pressure measurements are presented in the form of pressure coefficients. The mean pressure coefficient at any location was obtained as:

$$C_{p\ mean} = \frac{P_{mean}}{\frac{1}{2}\rho U_{mean}^2} \tag{1}$$

where P_{mean} is the mean pressure, ρ is the air density at the time of the test and U_{mean} is the mean wind speed measured at the building roof height. The peak pressure coefficient was obtained as:

$$C_{p\ peak} = \frac{P_{peak}}{\frac{1}{2}\rho U_{3\ sec}^2} \tag{2}$$

where P_{peak} is the peak pressure, and $U_{3\ sec}$ is the peak 3-s gust at the reference height.

The net pressure coefficient (equation 3) for the handrail system can be obtained using the instantaneous pressure difference between the pressures on its exterior and interior sides:

$$Cp_{net} = Cp_{exterior} - Cp_{interior} \tag{3}$$

Results

Figure 6 shows the surface plots of the mean pressure coefficients (Cp_{mean}) for the 1:180 model with and without balconies for wind direction of 0 degrees. It can be observed that the balcony handrail systems affect the pressure distribution on the building surface, which implies that the flow patterns were affected by the systems' presence. For example, the area subjected to high positive pressures was larger for the building with balconies. Figures 7-8 show the positive and negative peak pressure coefficients (Cp_{peak}) on the front and a side wall of the building. According to these plots, the presence of the handrail systems resulted in some local increase in the positive peak pressures on the front wall (figure 7), and in an overall attenuation of the peak negative pressures on the side wall (figure 8).

Figure 9 shows the non-directional pressure coefficients (largest pressure coefficients (in magnitude) obtained from all wind directions considered). It can be seen that while the positive pressures were not affected significantly, the negative pressures were reduced over most part of the building wall due to the presence of the balcony handrail system.

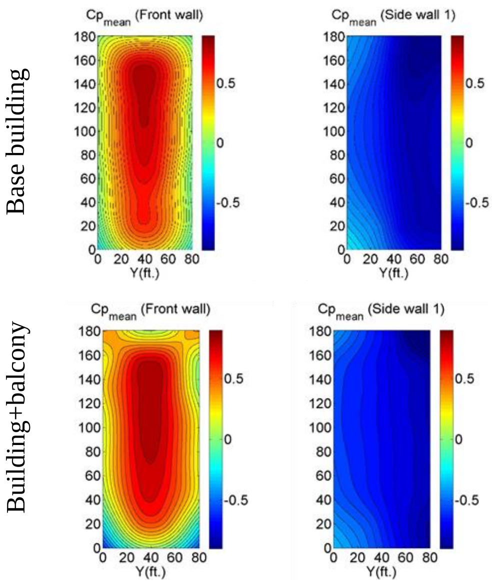


Figure 6. $\boldsymbol{Cp_{mean}}$ for 1:180 scale.

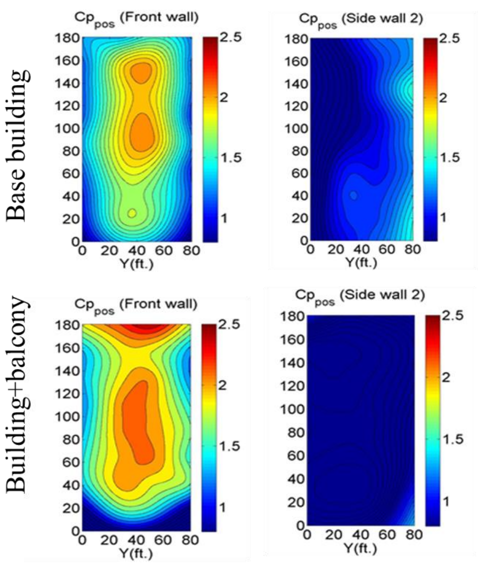


Figure 7. Peak $\boldsymbol{Cp_{pos}}$ for 1:180 scale.

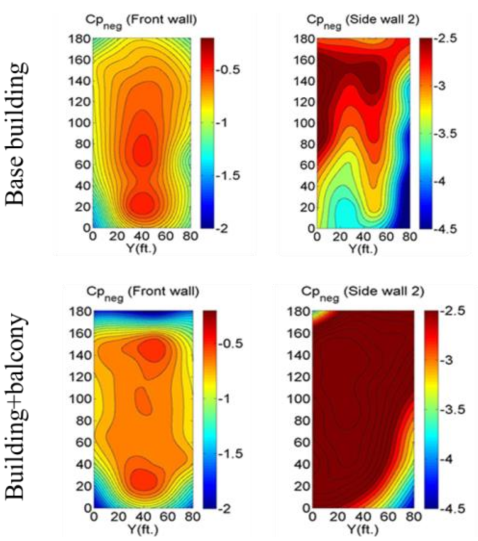


Figure 8. Peak $\boldsymbol{Cp_{neg}}$ for 1:180 scale.

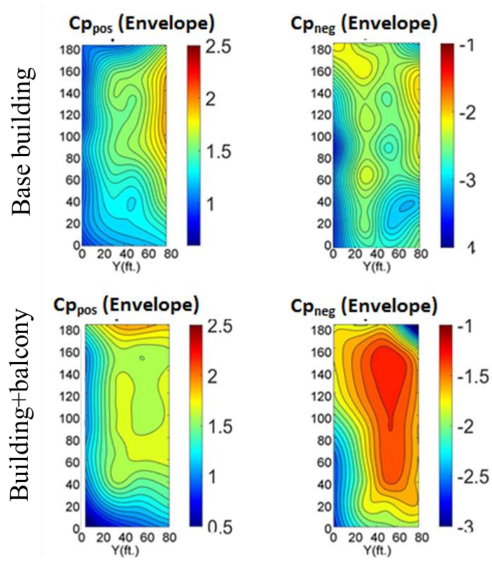


Figure 9. Envelope results

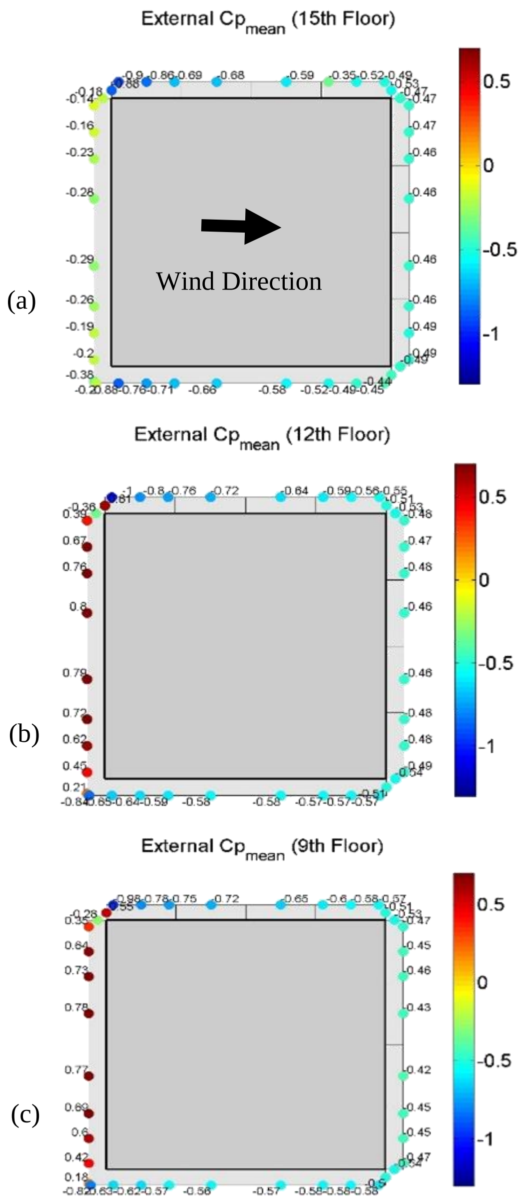


Figure 10. External $\boldsymbol{Cp_{mean}}$ on the balcony handrails

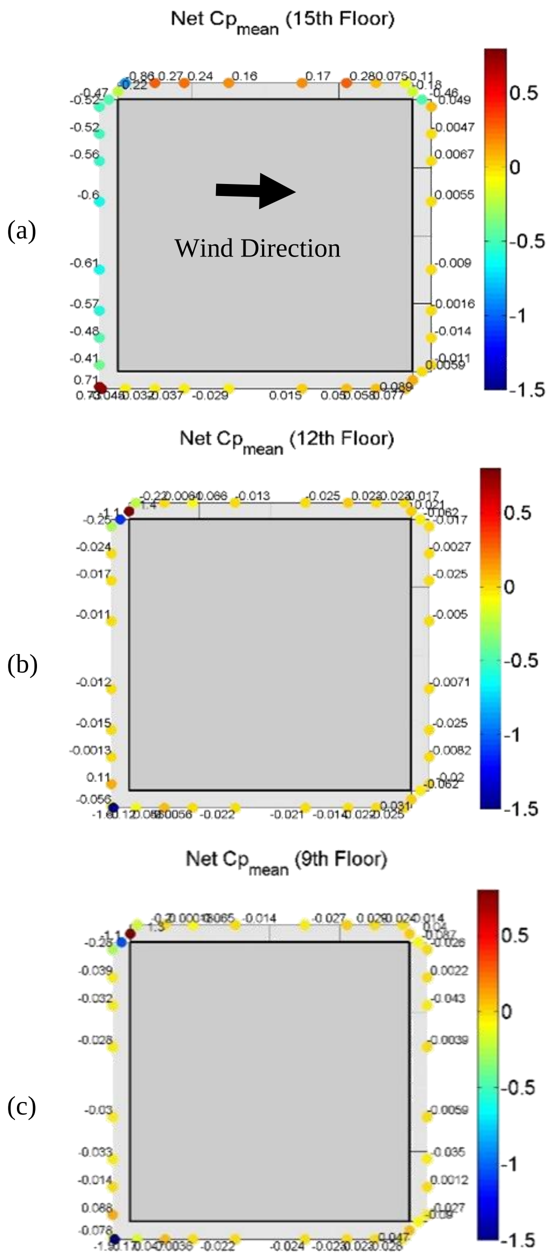


Figure 11. Net Cp_{mean} on the balcony handrails

Figure 10 shows the external Cp_{mean} of the pressure measurements on the balcony handrail systems located at different floors. The plots indicate that the windward handrails of the 12th and 9th floors experienced positive external pressures, as expected for windward surfaces. However the 15th floor handrails show a completely different loading pattern. The negative values for the 15th floor handrail systems are believed to be caused by the flow separation occurring near the top of the building. On the other hand, after hitting the front wall a portion of the flow may have circulated down into the narrow space between the handrail system and the building wall, resulting in pressurization of the windward handrail interior surfaces. For the 15th floor handrails, this would cause an increase in the net pressure, as shown in figure 11a. For the lower floors, this resulted in a significant pressure equalization across the handrails (as shown by the low net pressure coefficients shown in figure 11b-c). This equalization was also observed on the leeward and side wall handrail systems, for which very low net pressure coefficients were estimated at all balcony levels. Analyses for the other wind directions are underway.

Conclusions

Results of testing building models with and without balcony handrails in the WOW showed that the wind flow and pressure distribution along the building walls are significantly affected in the presence of balcony handrail systems. An overall increase of the peak positive pressure coefficients was observed, which can be attributed to the flow channeling in the space between handrail systems and the building wall. For wind direction of 0 degrees, the pressures on the exterior surfaces of the balcony handrail systems were dependent of the floor level, with balcony handrails at the top floor experiencing negative pressures. Net pressures on the windward handrails at the top level were higher, while for the other levels a reduction was observed because of pressure equalization across the handrail surfaces. Analyses of net pressures for the other wind directions are underway.

The results suggest that the wall pressures obtained from the codes and standards need to be used with caution for designing buildings with balconies. The current study can be further expanded to modify code provisions for wind design of such buildings. Pressure coefficients on the balcony handrail systems reported in this paper and in follow-up studies will help to achieve more reliable design guidance for railing systems that will improve safety of the residents. Adequate design will also preclude the generation of wind-borne debris during hurricanes. Future studies pertaining to the effect of different balcony geometries and terrain exposures on the wind loads on buildings are necessary. The distance of the balconies from the edge is a parameter that also warrants additional study.

Acknowledgments

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