Wind Induced Vibration(WIV) and Wind Driven Rain (WDR) Effects on Glazed Curtain Wall Systems

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SUMMARY:
Vertical protruding elements are generally used with glazed curtain walls for building aesthetics and solar shading. Double Closed cavity double skin curtain walls (CCF) have also been recently developed to reduce energy demand, maintenance cost and water penetration vulnerabilities. However, no sufficient design guidelines are available yet for wind loading on curtain walls with vertical protrusions. Also, there is no guidance on the load sharing ratio (LSR) between the two glass walls of the CCF, as its cavity is not fully pressure equalized nor fully closed. The effect of cavity permeability in CCF on load sharing is yet to be fully understood. Current water penetration test standards do not replicate realistic wind or co-occurring wind and rain events, and some studies linked this to poor performance of some units under extreme weather events. Hence, in this work, experimental wind tunnel tests (i.e., WDR and Wind only) on full-scale Single skin façade (SSF) and CCF were carried out. The results indicate vertical protrusions can increase wind loads and dynamic amplification on curtain walls. Also, the SSF unit showed more vulnerability to water penetration in comparison to the CCF unit. Lastly, permeability in CCF units affects the LSR, reducing the wind loads on the internal glass.

Keywords: Water penetration, Cavity permeability, Vertical protrusion

1. INTRODUCTION

Glazed curtain walls are non-structural building envelopes that primarily separate and protect the building interior and its contents and/or occupants from the exterior environment. However, historically, glazed curtain walls have experienced failures (i.e. water penetration, glass breakage due to flying debris, and joint damage due to excessive façade panel vibrations) in hurricane winds. This has led to multimillion-dollar insurance claims for damages, especially to the building's interior. With the increase in water damage claims the question regarding the sufficiency of current standard water penetration tests in representing realistic wind and rain, especially for hurricane-prone areas has been raised. Consequently, current water penetration tests including AAMA 501.1-

05 (2005), and fabrication and quality testing methods need further assessment and improvement to enhance the resiliency and sustainability of curtain wall systems.

Solar heating is a major consideration for buildings with glazed curtain walls, due to its transparency, which affects the overall building's energy demand (Sayed and Fikry, 2019). Therefore, with the growing need for energy-efficient buildings, modern glazed curtain walls such as single skin facades (SSF) are typically incorporating vertical or horizontal shading devices that are usually protruding from the building's wall. However, there are only a few studies (i.e., Stathopoulos and Zhu (1990) and Chand and Bhargava (1997)) on the impact of these protruding devices on the wind loads on the curtain wall, most of which are conducted using reduced geometry models (e.g., length scales in the range of 1:300 to 1:400). Also, there are few investigations on the contribution of these devices to the wind-induced vibrations (WIV) of curtain wall systems (Alawode et al., 2023).

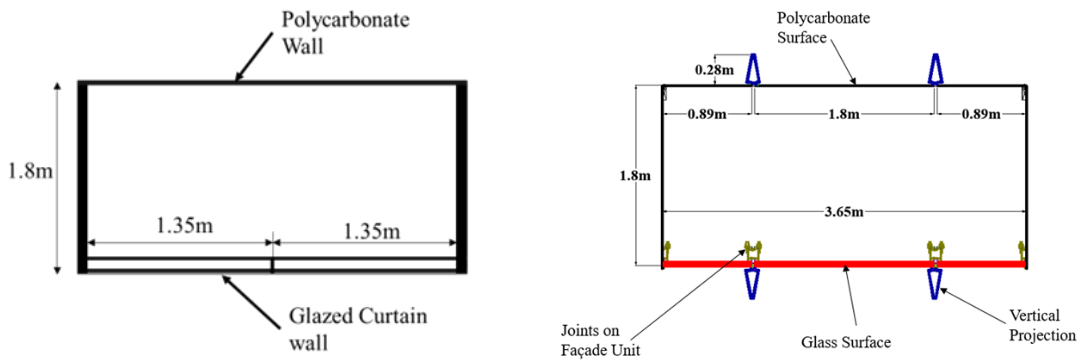
Closed cavity double-skin curtain wall (CCF) is another innovation of the fenestration industry to reduce water penetration and building energy consumption. However, the effect of the permeability (e.g., openings, defects) of the cavity in CCF units on water penetration and load sharing between the two layers of glass is yet to be investigated. While it is known that vibration in curtain walls could lead to fatigue in the framing elements and create openings within the system, there are no studies correlating WIV and water penetration due to wind-driven rain (WDR). This paper, therefore, focuses on understanding the wind and water penetration performance of glazed curtain wall systems through experimental methods.

2. METHODOLOGY

The experimental study was carried out at the Wall of Wind Experimental Facility (WOWEF) Atmospheric Boundary Layer (ABL) wind tunnel for ABL winds and wind-driven rain (WDR) simulation on a full-scale CCF and SSF units. An open terrain ABL with a roughness length of 0.08m with wind pressures referenced to the model roof.

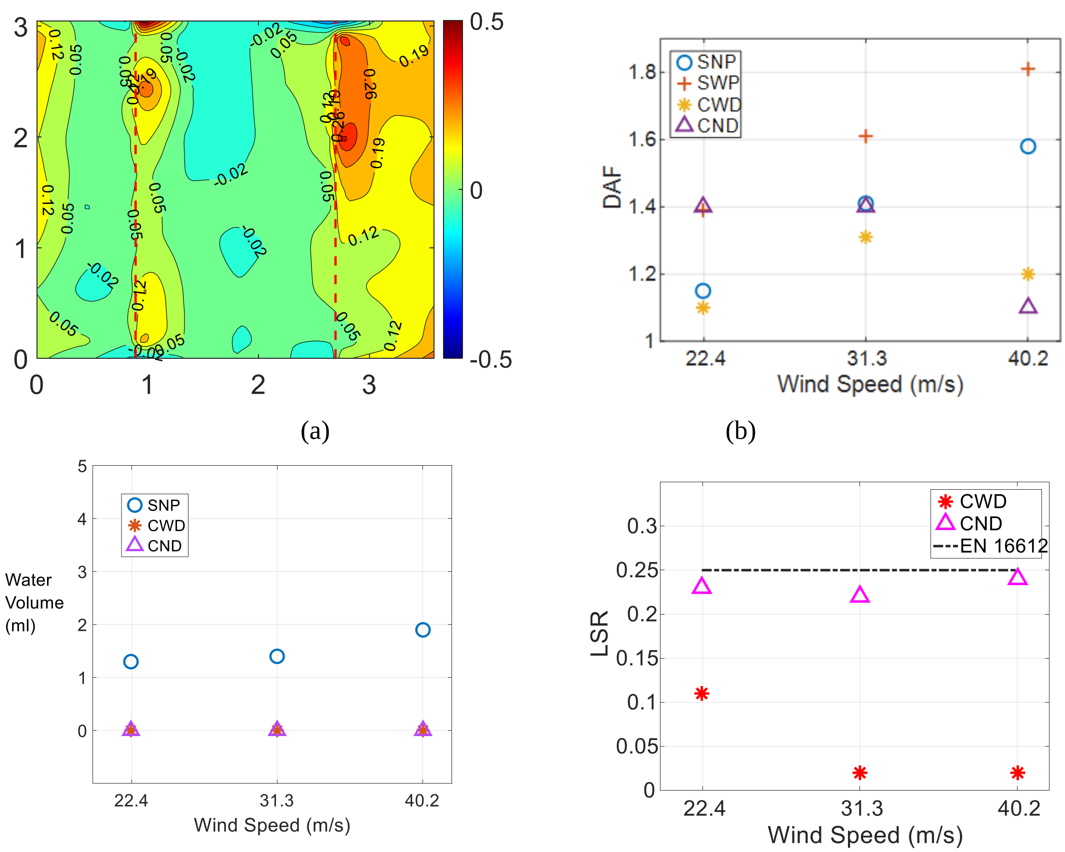
Two configurations for each full-scale curtain wall system were tested, namely, SSF with vertical protrusions (SWP), SSF without protrusions (SNP), CCF without defect (CND) and CCF with defect (CWD). The protrusions were 2 V-shaped vertical fins while the defect was a 10mm diameter hole on the side of the DSF that leads into the curtain wall cavity. For each configuration, the full-scale curtain walls were on one side with a polycarbonate wall on the opposite side (this was to measure pressure with pressure taps). The built-up model was supported on a steel structure bolted to the turntable. Figure 1 shows a cross-section of the DSF and SSF models. Accelerometers and strain gauges were attached to the unit (glass and mullion) and pressure taps were on the polycarbonate wall. The pressure tests (Winds directed at the polycarbonate side) and dynamic tests (Winds directed at the curtain wall side) were carried out for all configurations at 22.35 m/s, 31.30 m/s and 40.23 m/s wind speeds

A full-scale (1:1) raindrop size with matching characteristics was developed in the WOW EF. To ensure accuracy and to replicate realistic hurricane rain characteristics, the gamma model developed using three real hurricanes of Alex, Charley and Gaston by Tokay et al. (2013) are utilized as a base model to match rain characteristics. To obtain the correct Rain Size Distribution, 3-D printed nozzles were installed in front of the WOW fans. The WDR tests were carried out for both model configurations at 22.35 m/s, 31.30 m/s and 40.23 m/s wind speeds



(a) (b)

Figure 1. Schematic Plan of Models (a) DSF (b) SSF



(a) (b)

(c) (d)

Figure 2. Results (a) Cp Difference between SNP and SWP (b) DAF of external glass for SNP, SWP, CWD and CND at wind perpendicular to the glass surface (c) WDR penetration (d) LSR for CWD and CND

3. RESULTS

The vertical protrusions tend to increase the pressure coefficient (Cp) around the location of the protrusions. Figure 2(a) shows the Cp difference from the envelope Cp (i.e., 0° to 180° wind direction), with up to 0.35 difference. The dynamic amplification factor (DAF) (i.e., ratio of the peak response to mean plus background response) for all four configurations at 0° wind direction is shown in Figure 2(b). The plot indicates higher DAF in SWP compared to SNP indicating protrusions could cause higher vibration on the glazing. Also, CND had higher DAF compared to CWD, indicating that the permeability of the cavity reduces the vibration on the external unit. Generally, the results show that curtain walls which have natural frequencies above the 1Hz limits in ASCE 7-22 (2022) can experience dynamic wind excitation.

The WDR test results are shown in Figure 2(c), indicating the volume of water beyond the internal glass. The SSF showed a higher rate of water penetration while the DSF had none. Figure 2(d) shows the load sharing ratio (LSR) (i.e., the ratio of wind pressure on internal glass to the ratio of wind pressure on the entire unit) between the external and internal glass layers of the CCF unit. The results show that the CND has LSR values close to the EN 16612 specification for insulating glazing units (IGU) which have no vents/permeability. However, the CND LSR values are far off, which indicates current guidance does not apply to CCF with permeability in the cavity.

4. CONCLUSION

In conclusion, Vertical protrusions can increase wind loads and dynamic amplification on curtain walls. Current results indicate curtain walls can experience dynamic wind amplification despite having natural frequencies above 1Hz. Also, the SSF unit showed more vulnerability to water penetration in comparison to the CCF unit. Lastly, permeability in CCF units affects the LSR.

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