August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering
ICWE 16

Development of improved test methods for wind driven rainwater ingress through windows and doors

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SUMMARY:
Investigations of damage to buildings and analysis of insurance claims data following severe wind events have shown that there are ongoing problems with the performance of contemporary engineered buildings. Costly insurance claims arise from wind-driven rain entering buildings through flashings, doors and windows, even when there is no damage to the building envelope and with wind speeds lower than the ultimate limit states design level wind speed for buildings. The paper will detail studies undertaken at the Cyclone Testing Station (CTS) in collaboration with the Insurance Institute of Business and Home Safety (IBHS) to characterize water entry through windows and doors at a range of wall-wetting rates and windward wall pressures. Results of such tests will be used to characterize water ingress behaviour and inform the creation of new test methods for use in codes and standards that are more representative of coincident wind and rainfall during severe weather events.

Keywords: Wind-Driven Water Ingress, Vulnerability Studies, Tropical Cyclones

1. INTRODUCTION

Post-event damage surveys have shown that Wind-driven rainwater ingress (WDRI) through undamaged fenestrations such as windows and doors can result in significant damage during severe weather events and financial damage to buildings where no structural damage occurred (Boughton, Henderson et al. 2011, Gurley and Masters 2011). Often through weep holes or window tracks, a combination of the pressure differential across the window and wind-driven rain incident on the window or the wall above can lead to many litres of water entering a building over the course of a windstorm.

This paper presents progress on an ongoing research initiative by the Insurance Institute for Business & Home Safety (IBHS) and the Cyclone Testing Station (CTS) on wind-driven rainwater ingress through building envelopes. At a high level, this project consists of three aspects, which include:

1. Quantifying the hazard: e.g. derive hazard maps for rainfall, wind and water ingress. Determine the drivers of wetting rate, e.g. rainfall rate, angle, droplet size, building geometry
2. Quantifying vulnerability in a normalized manner: relate hazard magnitude to hazard impact i.e. determine relationships between wetting rate and water ingress rate

3. Quantifying hazard impacts: e.g. determine levels of unacceptable water ingress for different building materials, building usage and structural systems.

Currently, this project has been focusing on the second aspect, that is, quantifying the vulnerability of windows and doors to wind-driven rainwater ingress. Current test methods provided in several codes and standards as well as previous research generally use a single constant wetting rate and often, the application of only static pressures (ASTM E331-00 2009, AS 4420.1 2016). As such, objectives of the current project include the testing of windows and doors under static pressure as well as fluctuating pressures under a range of uniform wetting rates. Results of such tests will be used to characterize water ingress behaviour and inform the creation of new test methods for use in codes and standards that are more representative of coincident wind and rainfall during severe weather events.

2. METHODS

Tests were carried out to determine relationships between the levels of water ingress with increasing applied pressures, for a range of wetting rates. Detailed tests were then conducted on a cyclone (C2) rated sliding door and a non-cyclone (N3) rated sliding glass window from Australia. Additionally, a PG20-rated single-hung window from the United States was also tested. Results presented in this paper are limited to that of the N3 sliding window. Tests were carried out using the wind-driven rainwater ingress (WDRI) simulator at the Cyclone Testing Station at James Cook University, shown in Figure 1. A window or door specimen can be installed on the opening of a vertical pressure chamber that is pressurized using a pressure-loading actuator (PLA) (Kopp, Morrison et al. 2012). A spray rack is installed within the pressure chamber capable of applying a range of uniform wetting rates to the specimen.

Figure 1. Wind-driven rain simulator test apparatus, C2 sliding glass door installed,

3. STATIC PRESSURE TESTS

Applied pressures consisted of a 15-second ramp-up followed by a three-minute uniform constant pressure followed by a ramp down to zero pressure. Three tests were then performed for each wetting rate and pressure increment. Pressure increments, up to the serviceability pressure for a general area window included: 120, 240, 295, 350, 400, 455, 510, 560, 680, and 800 Pa. Wetting rates included: 1.3, 3.2 and 4 L/min/m2. The average total amount of water ingress for each of the three tests for each pressure increment and the wetting rate is shown in Figure 2. For a given wetting rate, these curves describe a range of pressures that cause zero water ingress, followed by a point of onset of water ingress where small changes in pressure cause large increases in water ingress. The slope of the curve then decreases and tends towards an asymptote, indicating that further pressure increases do not cause a significant increase in water ingress for that wetting rate.

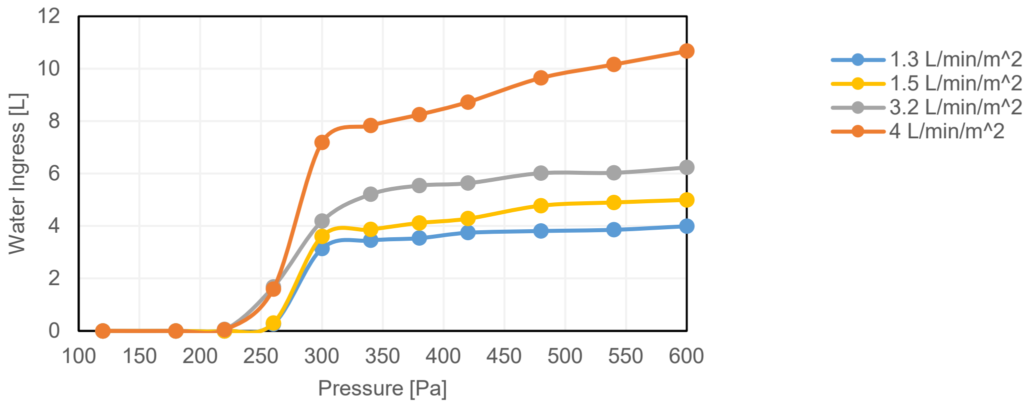

Figure 2. N3 Sliding Window - Total water ingress over 3 minutes for a range of applied pressures and wetting rates (mean of 3 tests)

4. DYNAMIC PRESSURE TESTS

Dynamic testing was conducted using fluctuating dynamic pressure traces that were applied to the test specimen using a Pressure Loading Actuator (PLA) based on wind tunnel data of pressures on a windward wall of a low-rise building. A water collection chute and bucket were installed below the test specimen, with load cells fitted to the bucket to allow the measurement of water throughout the test sequence. Preliminary results showed that water ingress occurred during 'peak events' of pressure during the dynamic trace, shown in Figure 3. Additionally, a range of artificial peak events consisting of triangular waveforms of a range of amplitudes and periods were used to qualitatively assess the response of the window to fluctuating pressures.

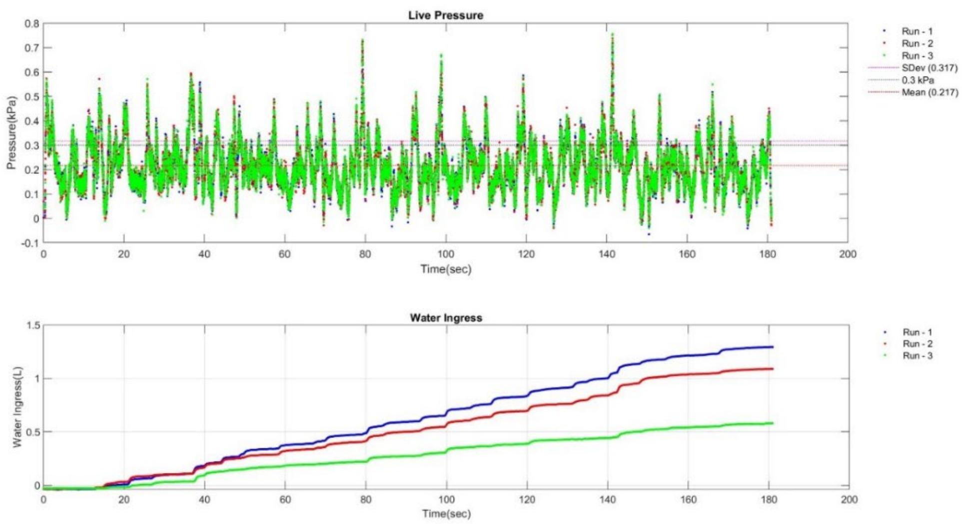

Figure 3. Example of fluctuating dynamic pressures applied to the test specimen (top), resulting in water ingress through time showing water entering the collection bucket soon after peak events in the pressure time history (bottom)

6. DISCUSSION AND CONCLUSIONS

This study presents a test methodology for testing windows and doors for wind-driven rainwater ingress under static and fluctuating pressures while subject to a range of uniform wetting rates. Test results were used to develop relationships between applied pressure, wetting rates and the resulting water ingress. Water ingress occurred mainly through the weep holes in the lower tracks of the windows.

Tests conducted under fluctuating pressures indicated that water ingress is a complex process that is influenced by several parameters in addition to the applied pressures and the applied wetting rates. Water ingress is driven by the level of the mean pressure during pressure fluctuations, which determines whether water ingress occurs during peak events, or continuously during the time history. The number of, and the loading rate of the peak events also determine the amount of water ingress that would occur. Additionally, the current water level in the window tracks and the time for tracks to empty and fill with water influences the amount of water ingress that occurs during each peak event.

Water ingress during realistic wind and rain conditions is therefore difficult to model, and this study has highlighted the importance of full-scale laboratory testing. Selecting representative time history pressures and wetting rates is therefore essential for the development of standardized test methods. Thus, further work on the project will involve analyzing coincident wind and rainfall data to determine such representative test sequences.

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