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Improving the resilience of the building envelope to wind driven rainwater ingress

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ABSTRACT

Investigations of damage to buildings and analysis of insurance claims data following severe wind events have shown that there are still problems with the performance of contemporary engineered buildings. Costly insurance claims arose from wind-driven rain entering buildings through flashings, doors and windows, even when there was no damage to the building envelope and with wind speeds lower than the ultimate limit states design level wind speed for buildings in the affected regions. 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 quantify water entry through windows at a range of wall wetting rates and windward wall pressures. A series of static pressure and realistic fluctuating wind pressure tests, utilizing the CTS Pressure Loading Actuators and calibrated rain nozzles were conducted on a sliding glass door and windows commonly found in Australia. Test results were used to develop relationships between applied pressures, wetting rates and the resulting water ingress. Thresholds of the degrees of water ingress were noted. Additionally, the results are also used to develop a suite of water ingress curves that can be used to assess the vulnerability of such windows to wind-driven rainwater ingress for various storm scenarios.

1. Introduction

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. Post-event damage surveys have shown that water ingress is a major source of damage around the world following tropical cyclones and thunderstorms (Walker, 1975; Boughton et al., 2011; Gurley and Masters, 2011; Boughton and Falck, 2020). These studies have noted that water ingress can occur through several building features such as flashings, gutters, roof cladding as well as closed and undamaged windows and doors. 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.

A survey of the literature available on the subject has shown that most tests available in Codes and Standards, as well as methods used by researchers, involve the application of a single uniform wetting rate and a single applied pressure to the test specimens. Applied pressures used during such tests are often significantly lower than what may be experienced during a windstorm.

Codes and Standards from various countries provide test methods with specified wetting rates and loading sequences for wind-driven rainwater ingress for example, AS 4420.1 (2016) in Australia and ASTM E331-00 (2009) in the United States. However, these are often simplified for practical reasons, generally using static or sinusoidal fluctuating pressures and a constant wetting rate. Several researchers have studied water ingress through windows, often following or adapting test sequences presented in Codes and Standards or applying fluctuating pressures using pressure loading actuators loading (Salzano et al., 2010; Van Straaten et al., 2010; Lopez et al., 2011). Such studies are similar to that of the current project being performed at the Cyclone Testing Station. However, these previous studies make use of a constant wetting rate.

This report presents the results from a study undertaken at the Cyclone Testing Station (CTS) in collaboration with the Insurance Institute of Business and Home Safety (IBHS). The project is aimed at quantifying the water entry through windows at different wall wetting rates and pressure levels so that standards can be developed related to the wind-driven rain risk experienced in different locations.

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. Considerable preparatory work was required to determine the combinations of wetting rates and applied pressures that were possible in the apparatus. Detailed tests were then conducted a cyclone-rated C2 sliding door and a non-cyclone N3 rated sliding glass window. 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 2. 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 et al., 2012). A spray rack is installed within the pressure chamber capable of applying a range of uniform wetting rates to the specimen.

The spray rack was supplied by a centrifugal pump from a reservoir, a flow meter was installed at the outlet of the spray rack to monitor the total volume of water passing through the spray rack. The pressure of each arm of the spray rack can be monitored separately and the pressure of each arm can be independently controlled with low-flow pressure regulators used for agricultural applications.

Figure 1. Wind driven rain simulator test apparatus

One of the test specimens in this study was an N3 rated, a two-panel sliding window of dimensions approximately 0.9 x 1.2 m (1.1 m^2), shown in Figure 3. A drain box was installed immediately under the sill of the window

Figure 2 N3 Sliding window installed in the WDRI simulator.

Design data for the test specimen according to AS2047 include:

ULS design pressure:
General areas: 1400 Pa
Corner windows: 2000 Pa
Serviceability design pressure:
General areas: 600 Pa
Corner windows: 800 Pa

Water penetration test pressure
Non-exposed areas: 150 Pa
Exposed areas: 300 Pa

3. Static Pressure Tests

Tests in Phase 1 were conducted under uniform static pressures. 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. A range of pressures was applied, up to the serviceability pressure of the window or door. A drain bucket is located at the base of the test specimen to collect water that exits the pressure chamber through the test specimen. The total volume of water was collected after each test.

Wetting rates were verified using a catch box system similar to that specified in ASTM E331-00 (2009). This catch box consisted of four separate chambers where water could be independently collected and measured. The catch box could be moved to different parts of the test area to determine whether the uniformity of spray was uniform across the entire test specimen area. ASTM E331-00 (2009) The spray rack produced reasonably uniform spray over the range of wetting rates. As the test specimens used during these tests mainly had water ingress occurring through weep holes at the bottom of the tracks it was judged that the uniformity of spray was adequate for the tests to be conducted in Phase 1. Three tests were 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, 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 wetting rate is shown in Figure 4. The level of water ingress increases with increasing pressure in the form of an s-curve shape, common to many vulnerability functions. A reasonably low level of variability was observed between the three tests for each wetting rate and pressure increment. 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.

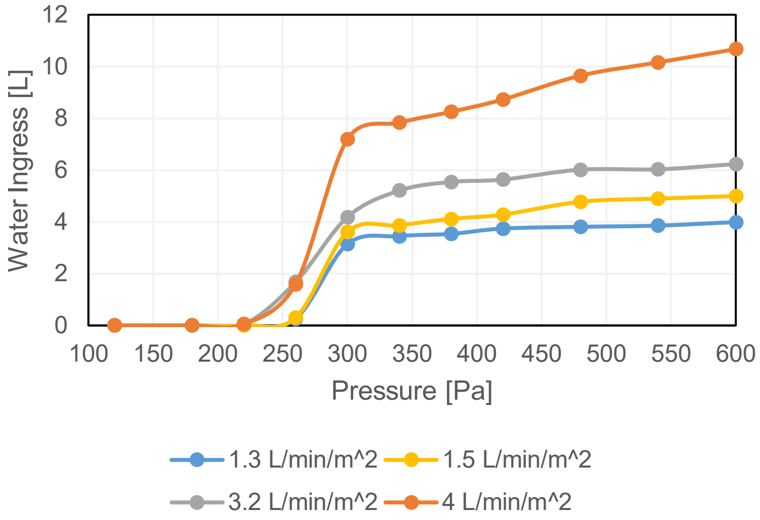

Figure 3. N3 Sliding Window - Total water ingress over 3 minutes for a range of applied pressures and wetting rates (mean of 3 tests)

4. Dynamic Pressure Tests

Static testing showed the levels of water ingress that would occur for a fixed wetting rate and a constant pressure over a duration of three minutes. However, during a windstorm, a window or door would experience fluctuating pressures and therefore a fluctuating wetting rate. Therefore, dynamic testing was conducted using wind tunnel data to create 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. Additionally, artificial dynamic traces were also applied to the test specimens to determine the mechanisms of water ingress during pressure fluctuations.

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. It was noted that there was an approximately two-second delay between water entering the chute and being deposited in the bucket. Preliminary results showed that water ingress occurred during ‘peak events’ of pressure during the dynamic trace. Such behaviour is shown in Figure 5, indicating water accumulating in the water collection bucket incrementally with each peak event.

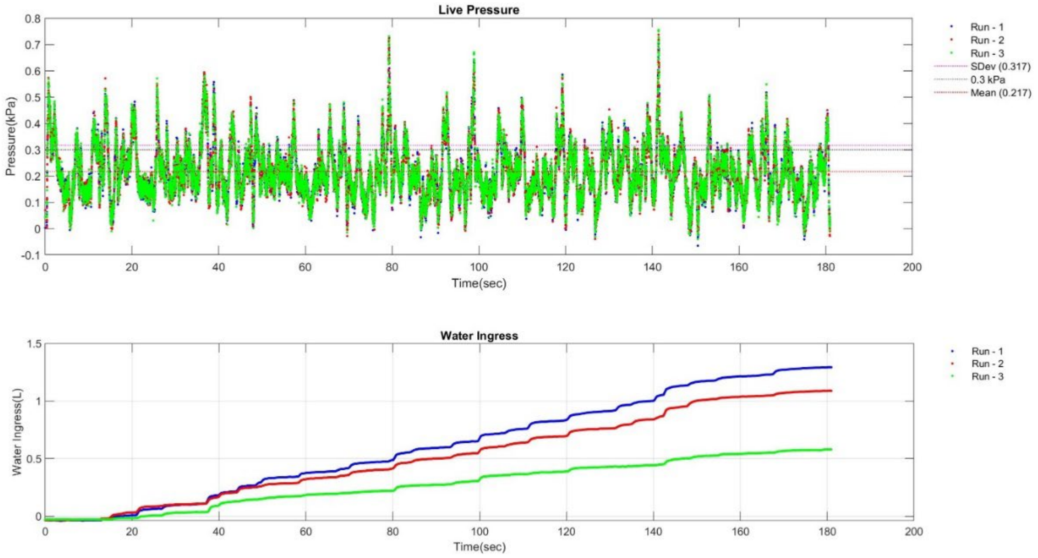

Figure 4. Example of fluctuating dynamic pressures applied to the test specimen (top), resulting water ingress through time showing water entering the collection bucket soon after peak events in the pressure time-history (bottom)

Further work is currently underway for the purpose of relating the static test behaviour to the dynamic test behaviour. This is being undertaken by applying a range of artificial dynamic pressures to the test specimen to determine the resulting water ingress. The resulting data will be used to convert the static water ingress curves shown in Figure 4 into a suite of Dynamic water ingress functions that can be used to estimate the level of water ingress based on a time history of pressure fluctuations and a given wetting rate.

4. Analysis and Discussion

From observations on-site and video footage, the primary mode of water ingress was through the weep holes in the lower track of the sliding window. Although small deflections were observed in the glass at higher pressures, no new modes of water entry were observed as the applied pressure was increased.

Uncontrolled water ingress, where water flows continuously over the window sill, for most wetting rates begins at approximately 300 Pa, which is the test pressure for water ingress according to AS 2047. This suggests that the window has been designed to meet the minimum requirements of the standard with no reserve capacity to resist water ingress.

Furthermore, thresholds for different degrees of water ingress behaviour can be identified from the data presented in Figure 4 along with an analysis of video footage.

These thresholds include:

- An initial stage of no water ingress where water begins to fill the track of the window at low-pressure increments without spilling over the track.
- An onset of water ingress where water begins to spill over the track, indicated by the lifting of the water ingress curve away from the x-axis.
- An onset of uncontrolled water ingress, where water begins to spill over the track in an uncontrolled manner, indicated by the change in slope of the water ingress curve.
- Finally, an onset of surging water ingress, where what appears to be air-entrained water surges upward at the weep hole location. For wetting rates 3.2 and 4 L/min/m^2, this threshold occurs when the slope of the curve begins to decrease before it becomes asymptotic. Surging water ingress does not occur for the wetting rate of 1.3 L/min/m^2

4. Conclusions

The following report has presented a test methodology for testing windows and doors for wind-driven rainwater ingress under a range of uniform wetting rates. A series of tests were conducted on an N3 sliding glass window commonly found in Australia. 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. Several thresholds of the degree of water ingress were noted. Data were also used to develop water ingress curves that are a first step in assessing the vulnerability of such windows to wind-driven rainwater ingress. Further work will involve relating water ingress behaviour under static pressures to fluctuating dynamic pressures and additionally relating the wetting rates and applied pressures to their corresponding rainfall rates and wind speeds.

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