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Water Penetration into Buildings with no Structural Damage during High Winds

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Abstract

Damage investigations following extreme wind events in all regions of Australia have consistently shown that significant volumes of water enter buildings through the building envelope at winds significantly lower than the ultimate design wind speed. This paper details the findings from an investigation of buildings in Exmouth, WA following Tropical Cyclone Olwyn in March 2015 where winds were around the serviceability wind speed, but a significant number of new houses that had no structural damage were affected by rainwater ingress.

Detailed studies of water penetration through windows, doors, flashings and gutters were undertaken. Water entry was caused by air entry through the building envelope where water was entrained in the air stream. This mechanism allowed water penetration at roof to wall junctions, valley gutters, and windows. Few of these elements have tests that assess water tightness, but water still entered through windows that had passed water penetration tests.

Satisfactory performance was observed where measures had been taken to restrict air entry through the building envelope. Some cases where sealing elements had been successfully applied are discussed. A comprehensive solution to wind-driven water penetration involves considering the differential pressure between the windward wall external cladding and cavities, the roof shape and slope, and the design of elements such as windows and door furniture.

Introduction

Damage investigations following a number of extreme wind events in all wind regions of Australia have consistently shown that significant volumes of water enter structurally sound buildings through the building envelope at winds significantly lower than the ultimate design wind speed. (Leitch et al, 2009; Henderson et al, 2006; Boughton et al, 2011; Boughton et al, 2015).

Tropical Cyclone Olwyn crossed the WA coast near Exmouth (Region D) in March, 2015. Wind speed data was collected from the Learmonth Automatic Weather Station (AWS) 32 km south of Exmouth. After correction for the location and averaging by the AWS, the maximum 0.2 second (peak) gust at Exmouth was estimated to be 59 m/sec:

- Annual probability of exceedance = 1/27;
- 67 % of ultimate design wind speed;
- 45% of the design wind ultimate pressures; and
- 111% of the 1/25 serviceability limit states wind speed.

Although the winds were close to the serviceability wind speed, a significant number of new houses that had no structural damage were affected by wind-driven rain. The Cyclone Testing Station investigated the mechanisms of rainwater entry.

Consequences of wind-driven rainwater entry

Damage to linings

Once water breached the building envelope, it moved through wall and ceiling spaces, pooled on ceilings and ran down wall linings, affecting furniture, floor coverings and belongings. In some cases, plasterboard ceilings collapsed under the weight of the water during the event (Figure 1). As the ceiling and walls act as structural diaphragms, there is potential for structural performance to be compromised by loss of ceilings.

Figure 1. Water damage to linings

Safety issues

Most people interviewed during the investigation reported that they spent hours during the cyclone mopping up wind-driven rain that had entered their homes. In some cases, they had put themselves at risk of injury by being directly in front of windward wall windows and glass doors.

Observations of damage

Water entry through windows and doors

The weep holes in windows (small drain holes in the frame) are designed to allow condensation and minor leakage around seals to pass through to the outside of the building. However many people reported that the water was spurting up to two metres from the window, and compared the jet of water with the spray from a garden hose.

Figure 2. Water penetration through weep hole in window (photo by home owner)

Some home-owners reported that water entered around the wool pile or mohair seals of the sliding sash section of windows and doors, or when the sashes of sliding glass doors flexed inward from the wind pressure.

Water entry through flashings

Loss of flashings due to wind loads where flashing was inadequately fastened allowed significant amounts of water into the building. As flashings were often used above the ceiling, the loss of the flashing caused damage to ceilings.

Figure 3. Loss of barge flashing

Even where flashings remained intact, in some cases water was driven under the flashing and into cavities. This included water driven under apron flashings into wall cavities on second storeys, water driven up walls under barge flashings and water driven up valley gutters under ridge flashings. Figure 4 illustrates water being driven up a valley gutter, under the roof sheeting at the top, and overflowing the edge of the valley gutter sheeting into the roof space.

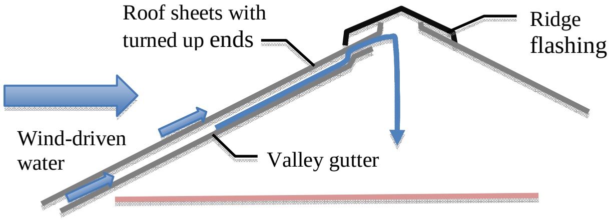

Figure 4. Water driven up valley gutter under ridge flashing

Mechanisms of water entry

Differential pressure

Strong winds produce a high differential pressure across waterproofing elements in the building envelope on the windward wall. For windows and doors, the differential pressure is the difference between external windward wall pressure and internal pressure inside the building. For flashings, the differential pressure is the difference between external windward wall pressure and the pressure inside the wall and roof cavities.

Where the building has no structural damage (including doors and windows) both internal pressure and wall and roof cavity pressures are determined by the average pressure on all surfaces, which is dominated by the negative pressures on side walls and leeward walls. Typically, the area averaged external pressures lead to C_{pi} of –0.2 to –0.3 for internal pressures and wall cavity pressures; and C_{pi} of –0.4 to –0.5 for roof space pressures (Standards Australia, 2011).

$$C_{pn} = C_{pe} - C_{pi} \tag{1}$$

Equation 1 indicates that the differential pressure coefficient (C_{pn}) is 0.9 to 1.0 for windows, doors and wall flashings, and 1.1 to 1.2 for roof and apron flashings leading to differential pressures (Δp) at serviceability wind speeds presented in Table 1.

Wind class	$V_{h,s}$ (ms^{-1})	Δp (wall) kPa	Δp (roof) kPa
N1	26	0.37	0.45
N2	26	0.37	0.45
N3	32	0.55	0.68
N4	39	0.82	1.00
C1	32	0.55	0.68
C2	39	0.82	1.00
C3	47	1.19	1.46
C4	55	1.63	2.00

Table 1. Serviceability differential pressures across building envelope

This differential pressure can force air through small openings in the building envelope such as weep holes in windows and glass doors, seals around windows and doors, and gaps under flashings. If water has accumulated near these gaps, it can be entrained in the moving air and driven through the external building envelope.

Water movement

Flashings and drainage paths such as weep holes in windows are designed to divert downward moving water away from gaps in the building envelope. At high wind velocities, the rain approaches the building nearly horizontally. The airflow around and over a building at winds near the serviceability limit state can drag water upwards and over the building envelope (Figure 4).

Weep holes are usually located in recesses in the window frame that can allow water that is running up or down the window to accumulate around the weep holes. Figure 5 shows that on windward walls, horizontally driven rain is forced through the weep hole by the air pressure (in the opposite direction to its intended path). Water bubbling through the weep hole, as shown in Figure 2, is consistent with water entrained in moving air.

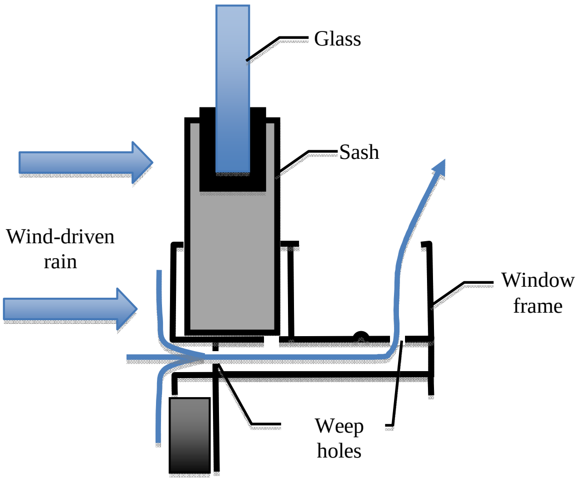

Figure 5. Water driven through weep holes in windows

Conditions that enable water penetration

Water penetration through the building envelope requires three conditions:

- *A gap in the external building envelope.* Seals around windows and doors help to close gaps around the edges. However, other gaps are designed into the building envelope eg weep holes in windows balance pressure across the window and provide drainage of minor leakage or condensation; and guidelines for installation of flashings recommend a 2 to 5 mm gap under apron and similar flashings. Rainwater will be driven through these gaps in high wind events unless details are installed to prevent it.

- *Accumulation of water near a gap in the external building envelope*. Wind flow across the windward surfaces of the building may drive rainwater towards the gaps. For example, water is driven up valley gutters as shown in Figure 4 and up windward walls towards weep holes in windows. This water can then be driven through the gaps into the building.

- *Airflow through the gap*. Airflow caused by differential pressure across the building envelope entrains the available water and drives it through the gaps into the building. Expected differential pressures at the serviceability wind speed are presented in Table 1.

Water penetration test pressures in AS 2047.

AS 2047–2014 Table 2.4 specifies test pressures for resistance of window assemblies to water penetration. It gives two pressures for each site wind classification; for windows that are exposed and non-exposed (protected by a large verandah, alfrescos and balconies or other features of the building that provide shielding).

The test pressures in AS 2047 are around 27% for non-exposed windows and 37% for exposed windows of the values in Table 1. These low test pressures are not representative of realistic wind conditions in serviceability events. Significant volumes of water entered through weep holes in tested window systems:

- Many window manufacturers provide sills with a height that enables the test pressure to be resisted by hydrostatic pressure, so higher differential pressures than the test pressure will result in uncontrolled leakage through the weep holes.

- A number of windows on windward walls that may have been classified using AS 2047 as non-exposed as they were under a verandah or balcony were subjected to horizontally driven rain during TC Olwyn and were effectively exposed.

Test pressures and criteria in AS 2047 should address community expectations of water tightness. Most people would expect a small amount of water to enter their homes during severe wind events, but do not accept the volumes of water that have passed through windows that comply with the current standard. The Standard should be amended to require higher test pressures, and include acceptance criteria that allow reduced and controlled water ingress at the higher pressures.

Options for reducing flow

Windows and doors

In order to prevent water passing through gaps around windows and doors with air movement, seals must be airtight and in good condition. Windows with fibre (eg. mohair) seals allowed air, and therefore water, to move through the seal.

Two home-owners said that they had taped up the weepholes in their sliding windows as part of their preparation for the approaching cyclone. They reported that very little water entered their homes through windows during TC Olwyn. However, a more effective option is to detail weep holes to allow water to drain out of the building, but prevent air movement into the building:

- Some sliding windows in Exmouth had a rubber flap on the outside of the frame that covered the weep holes. This successfully reduced water ingress on recently constructed houses.

- One of the houses investigated had windows with ball valves in weep holes (Figure 6). The home-owner reported that leakage was minimal.

Figure 6. Window frame with ball valve (inset) in weep hole

Flashings

Many flashings are located in areas affected by high local pressure factors, but even the most comprehensive installation manuals (e.g. Lysaght, 2014, Department of Building and Housing, 2011; Standards Australia, 2012) provide limited guidance on fastening. Flashings must be securely fixed with screws (not pop rivets) to both sides of the gap.

Flashings generally require gaps for expansion and isolation of metal elements. In places where water can accumulate at the flashing, these gaps may need to be sealed. Some builders in Exmouth had used well-secured compressible foam strips at the top of valley gutters, under ridge flashings or under apron flashings (Figure 7) to prevent wind-driven rainwater entering roof spaces and damaging ceilings.

These strips reduced airflow through the gaps under the flashings so that water was not entrained in the air. Where the foam strips had not been well secured, the differential pressure forced them into the cavity and allowed water to enter the building.

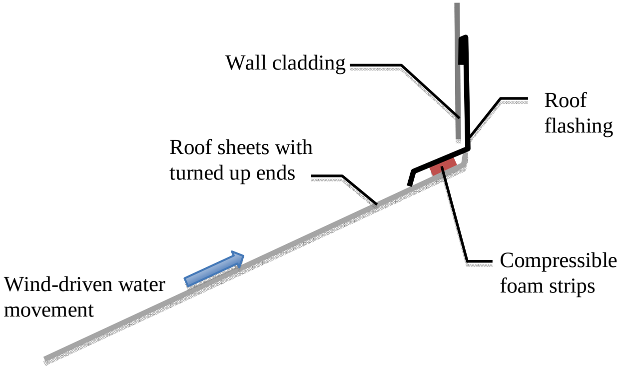

Figure 7. Compressible foam strip under apron flashing between second storey wall and first storey roof

Conclusions

The investigation of damage to buildings by wind-driven rain in the absence of structural damage in TC Olwyn concluded that:

- wind-driven rainwater entering buildings caused extensive damage to linings and contents, and contributed to risky behaviour of home-owners who tried to clean it up;

- where wind drag over the building surface caused water to accumulate near gaps in the building envelope, water entered the building where air movement produced by high differential pressures through the gap entrained the water.

- water ingress occurred at gaps around window and door seals; through weep holes in windows and doors; at the tops of valley gutters; under apron flashings at the junction of second storey walls and first storey roofs; and under ridge and barge flashings.

In order to minimise water penetration in future wind events near the serviceability wind speed:

- seals around doors and windows must be air tight;
- weep holes in windows and doors should have a mechanism such as a flap or ball valve to prevent airflow (and wind-driven water penetration) from the outside to the inside of the building;
- compressible foam strips or similar methods of sealing gaps under flashings near where water can accumulate, such as at the top of valley gutters, should be used;
- flashings must be adequately fastened (screwed) on both sides. Further research and publication of detailing for flashings is required; and
- the water penetration test methods in AS 2047 should better reflect the public expectations of performance of windows and doors under differential pressure at serviceability wind speeds.

Detailing buildings to limit air penetration under differential pressure through the windward wall and flashings will minimise water penetration into buildings.

Recommendations

Industry produce revised guidelines on flashings to include:

- detail on anchorage of flashings, in particular anchorage of barge flashings to both barge and roof surfaces;
- improved water-tightness of flashings at the top of roofing surfaces (apron flashings, ridge flashings and valley gutters).

The water penetration test for windows should be reviewed to give a better indication of the volumes of water ingress likely at wind pressures near the serviceability wind speed.

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