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Tropical Cyclone Olwyn
Damage to buildings in Exmouth, Western Australia

CTS Technical Report No 61

March, 2015

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Tropical Cyclone Olwyn
Damage to buildings in Exmouth, Western Australia

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Tropical Cyclone Olwyn: Damage to buildings in Exmouth

Executive Summary

Tropical Cyclone Olwyn (TC Olwyn) made landfall near Exmouth, Western Australia in the early hours of Friday 13 March, 2015. The measured wind speeds at Learmonth (32 km south of Exmouth) showed peak 3 second gusts of 180 km/h. The estimated peak gusts in Exmouth were around 185 km/h, which is equivalent to 67% of the Region D ultimate design wind speed for housing (allowing for the conversion of 3 second gusts to design wind speeds). The wind pressures were estimated to be 45 % of the ultimate design wind pressure for Region D. The wind speeds at Exmouth were close to design wind speeds for the serviceability limit state.

New buildings and houses that were repaired and retrofitted after TC Vance (1999) experienced little structural damage. This is expected, as the wind speeds in TC Olwyn were significantly lower than both the design wind speed and those recorded in TC Vance.

Although the wind speeds were around the level at which buildings should remain serviceable, there was significant damage to houses and buildings from wind-driven rain entering through flashings, windows and doors. Water damaged plasterboard ceiling and wall linings, carpets, and timber floors. Many people reported they had tried to deal with the volumes of water entering their house during the cyclone and had put themselves at risk of serious injury while working in front of windward windows or doors.

The report suggests some strategies to reduce water ingress from wind-driven rain. These are applicable to buildings in all wind regions. The strategies include improving the performance of flashings, doors and windows.

To remain effective, all surfaces of roof flashings must be anchored with at least the same fasteners and spacing of fasteners that are required for the adjacent roof. In high winds, flashings must also exclude upward-moving water, especially at valley gutters, ridges or flashings with walls.

Windows should be rated to the appropriate site wind classification. Weep holes in windows should prevent large volumes of water being forced from the outside to the inside of the building during severe wind events. Where possible, soft rubber seals that are pushed against a frame by windward wall differential pressure should be used. Building owners should regularly check and replace damaged, deteriorated or incomplete seals. It is recommended that the test requirements in AS 2047 and the test method in AS 4420.5 should be revised to more accurately reflect the conditions that cause water ingress during tropical cyclones.

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1. INTRODUCTION

1.1. TC Olwyn

Tropical Cyclone Olwyn (TC Olwyn) formed at 2:57 pm on Wednesday, 11 March, 2015 approximately 500 km North of Karratha and 660 km N-NE of Exmouth in Western Australia. On Friday, 13 March, 2015 at approximately 1:00 AM TC Olywn crossed the West Pilbara coast near Exmouth as a Category 3 cyclone. The BoM anemometers recorded maximum 10 minute mean wind speeds of 137 km/h with gusts (3-second average) up to 180 km/h at Learmonth Airport south of Exmouth around 1:30 am on 13 March, 2015. TC Olwyn continued south over Coral Bay, reaching Carnarvon as a Category 2 system at about 1:30 pm the same day. By the time TC Olwyn reached Geraldton in the early hours of Saturday morning, it had weakened further with wind speeds less than Category 1 intensity.

Figure 1.1 shows the track of TC Olwyn based on bulletins from the Australian Bureau of Meteorology (BoM). Times are given in Australian Western Standard Time (AWST) and Category designations are from the BoM (Table 1.1).

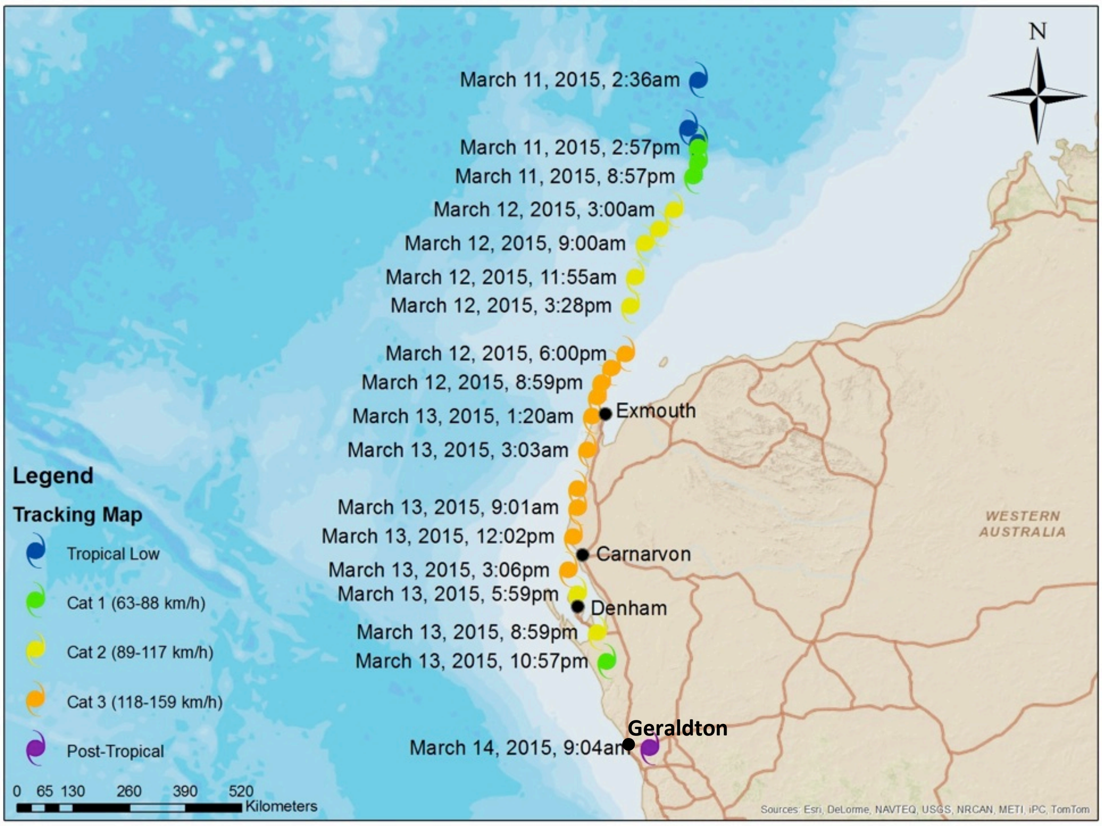


Figure 1.1 – Track and intensity information for Tropical Cyclone Olwyn (Image from TC Olwyn Rapid Assessment Report V2 16_03_2015)

Table 1.1 Tropical Cyclone wind speed categories – Australian Bureau of Meteorology

Cyclone Category	km/h	
	10-min Sustained	**3-sec Gust**
Category 1	63-88	**91-125**
Category 2	89-117	**125-164**
Category 3	118-159	**165-224**
Category 4	160-200	**225-279**
Category 5	>200	**>279**

Exmouth is in wind Region D as defined in AS 1170.2 and shown in Figure 1.2 and Table 1.2, with regional design gust wind speed in standard conditions for Importance Level 2 buildings of 88 m/s (316 km/h). Residential structures designed in WA since the mid-1980s for Region D should meet design wind speeds defined in different ways in the varying standards but with an ultimate wind speed equivalent always near 310 km/h or 86 m/s. Hence the recorded peak gust in the cyclone at Learmonth was around 64% of the design ultimate wind speed for residential buildings in that location (allowing for the conversion of 3 second gusts to design wind speeds).

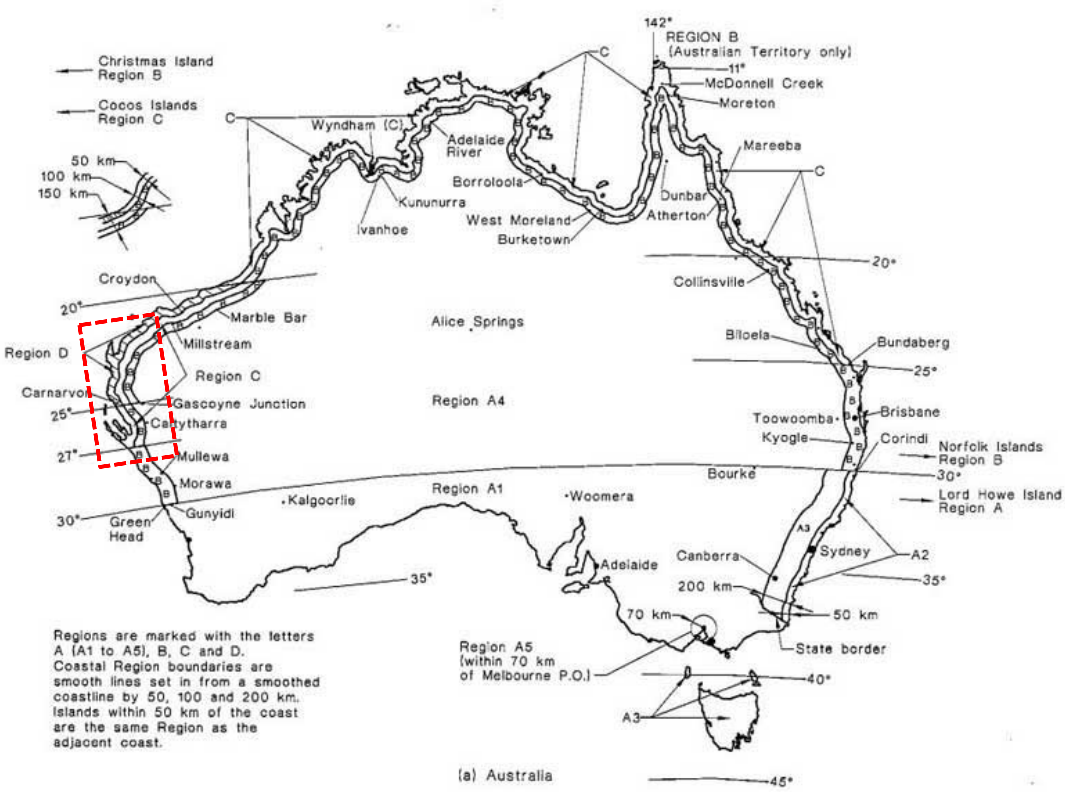


Figure 1.2 – Wind regions from NCC 2015 BCA Volume 2

(The area affected by TC Olwyn is highlighted by the rectangle.)

Table 1.2. Ultimate design regional wind speeds by region for 1/500 annual probability (appropriate for housing and other Importance Level 2 structures

Regions	V_u (m/s) AS 1170.2:1989	V_{500} (m/s) AS/NZS 1170.2:2002	V_{500} (m/s) AS/NZS 1170.2:2012
A	50	45	45
B	60	57	57
C	70	69	69
D	**85**	**88**	**88**

(Source: Australian Standard AS 1170.2:1989 to AS/NZS 1170.2:2012)

1.2. Field investigation

Reports from the Department of Fire and Emergency Services WA, Bureau of Meteorology (BoM) and media were used to guide decisions on where to focus the investigation.

Although the media reported extensive damage to the agricultural industry in the Carnarvon, particularly to banana plantations and vegetable crops, and DFES received many calls for assistance, the structural damage in the area was mainly to older houses or from trees falling on buildings. Similarly, the damage reported in Coral Bay, a small community south of Exmouth, was also mainly to trees and 30 to 40 year old houses. Government employees who visited the town immediately after the cyclone reported only minor flashing and gutter damage to newer houses. Previous CTS damage investigations have documented the problems associated with the structural performance of older houses, so it was decided that the team would focus on an investigation of damage to newer construction in Exmouth.

An investigation in Exmouth also provided the opportunity to compare the performance of buildings in TC Vance (1999) to that during TC Olwyn, check the performance of newer construction, and investigate the causes of damage from wind-driven rain.

The field study commenced on Wednesday 18 March, 2015 and concluded on Friday 20 March, 2015. The investigation:

- Examined contemporary buildings to determine whether their performance was appropriate for the estimated wind speeds they experienced. Where damage was greater than that expected, common failures were documented in sufficient detail to allow recommendations for changes to regulations or construction methods as appropriate.
- Focused on damage to houses and buildings from water ingress to determine the elements or systems that enable significant volumes of wind-driven rain to enter buildings during severe wind events. The CTS team sought out houses that had features that may have led to water ingress and asked the occupiers whether they had any water damage during the cyclone.
- Investigated water damage to new buildings. After TC Vance, there were many buildings that didn't have structural damage, but were uninhabitable due to the loss of ceilings, wall claddings and damage to soft furnishings. Since TC Vance other damage investigations have shown that damage from wind-

driven rain still requires a significant recovery effort and cost even without serious structural damage.

- Examined patterns of damage to determine whether there are any building envelope elements or systems that appear to have systematic weaknesses.
- Evaluated the performance of structures that had been repaired following TC Vance (1999) to determine whether the repair methods had any weaknesses.

As part of the investigation, the CTS team also met with the Shire of Exmouth manager of buildings, building supervisor, council members, and local builders. The discussions included building issues relevant to the Exmouth area, wind forces on buildings, damage caused during tropical cyclones and severe storms, and possible causes of damage, particularly causes of water ingress. Feedback was sought on building products, codes and standards.

1.3. Purpose of the report

This report presents the outcomes of the CTS field investigations into the effects of TC Olwyn on buildings and houses in the Exmouth area. It focuses on the following issues that are important to the continuing safety of buildings in cyclone-prone regions of Australia:

- Structural performance of buildings constructed under the current regulations. This helps to examine whether the current regulations are targeting an appropriate level of structural safety.
- Structural and weather-proofing details that may need to be addressed through codes and standards to ensure their performance is adequate. The emphasis of this report is on identifying elements and systems that caused significant damage to buildings and houses due to penetration of wind-driven rain.
- The performance of buildings that had been repaired after structural damage in a previous tropical cyclone. Buildings in Exmouth sustained significant structural damage and damage from water ingress during TC Vance (1999). The investigation provided an opportunity to evaluate the effectiveness of these repairs.

2. WIND SPEEDS RELATED TO DAMAGE

2.1. Analysis of Bureau of Meteorology anemometer data

Data was available from the following anemometers associated with BoM Automated Weather Stations (AWS):

- **Learmonth:** The anemometer is located at the Learmonth Airport, 32 kilometres south of Exmouth. The measurement height is the standard 10 metres on flat topography. The BoM buildings are relatively small and approximately 43 metres from the anemometer at a bearing of 60 degrees. The anemometer and direction vane appeared to function correctly during the event. The peak gust recorded had a direction of approximately 20 degrees so was unlikely to have been affected by the Bureau buildings.
- **Carnarvon:** The anemometer is located at the Carnarvon airport. The AWS 3-cup anemometer head is at a height of 10 metres in flat, open terrain. While the airport is close to the town, the anemometer is 600 m from the nearest town buildings.
- **Denham:** The BoM provided AWS records for TC Olwyn. The AWS anemometer located at the airport is at a height of 10 metres and the airport is surrounded by relatively flat topography.
- **Geraldton:** Data was available from an AWS anemometer at a height of 10 metres in flat, open terrain.
- **Pearce:** Data was available from an AWS anemometer at a height of 10 metres in flat, open terrain at the airbase.

Figure 2.1 shows the AWS Anemometer at Exmouth looking towards the Bureau buildings. (The approximate direction of the peak gust is shown as a red arrow.)

Figure 2.1 – AWS anemometer at Learmonth airport

Table 2.1 shows the maximum values of 10-minute mean wind speed, 3-second gust wind speed and direction and times of occurrence, during the passage Cyclone Olwyn for each of the recording stations.

Table 2.1 Readings from BoM anemometers

Station (Region)	Max 3-sec gust (km/h)	Dir'n	Time of max gust (WST)	Est 0.2 sec gust (m/s)	Design gust speed (m/s)	% Design speed	% Design pressure
Learmonth (D)	180	NNE	13/03/15 2:32	57.5	88	65.3%	42.7%
Carnarvon (D)	146	NE	13/03/15 13:30	46.6	88	53.0%	28.1%
Denham (C)	120	ESE	13/03/15 16:40	38.3	69	55.5%	30.9%
Geraldton (B)	76	ESE	14/03/15 4:03	24.3	57	42.6%	18.1%
Pearce (A)	50	E	14/03/15 8:48	16.0	45	35.5%	12.6%

Note: The values in Table 2.1 have had no corrections applied to them as the terrain was near standard, and it is assumed that the anemometers indicate accurately at these speeds.

Figure 1.1 shows that the passage of TC Olwyn was very close to the coast after it had made landfall at North West Cape. The lowest recorded barometric pressure at sites near the centre increased steadily as the tropical cyclone moved south. The track from satellite observations indicated that TC Olwyn passed just to the west of Exmouth, Learmonth and Carnarvon; over Denham; and just to the east of Geraldton as an ex-tropical cyclone. The track shows that each of these stations would have been positioned in the eye wall very close to the eye at some stage of their record. This meant that each station recorded winds close to the maximum gust in that area.

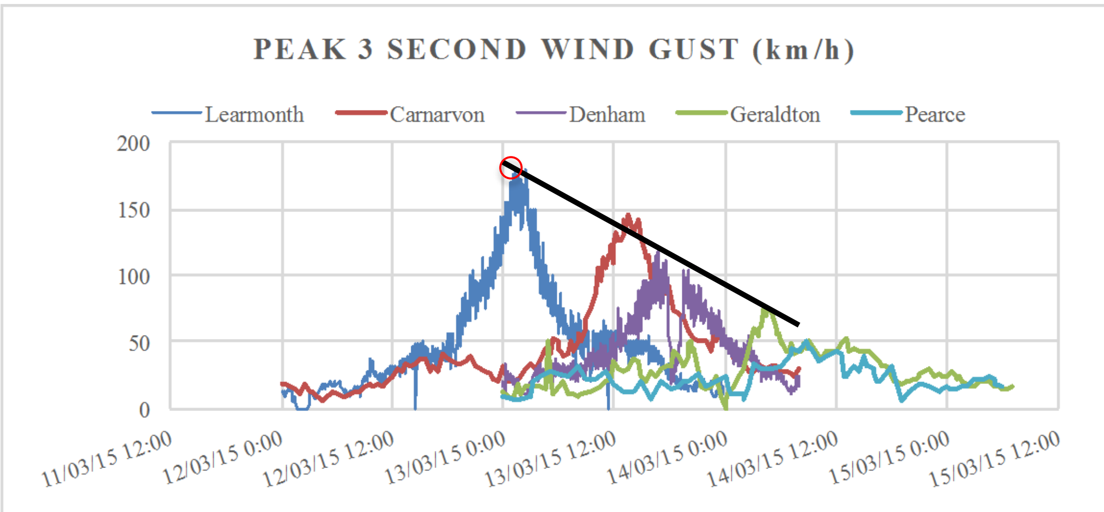


Figure 2.2 – Peak 3 second wind gust (km/h) time-histories for BoM automatic weather stations during TC Olwyn

Figure 2.2 shows the anemometer 3 second gust data from the AWS shown in Table 2.1. The Learmonth AWS is 32 km south of Exmouth, so to estimate the wind speeds at Exmouth, it is necessary to extrapolate Figure 2.2 in the area shown by the red circle. Figure 2.2 shows:

- The wind speed at Denham had a sharp drop and rapid increase as the cyclone passed over, suggesting that it experienced they eye. This is confirmed by reports from residents.

- No drops were recorded at other stations, indicating that the cyclone eye missed each of them. Reports from residents confirm that the eye was not experienced at Exmouth, Learmonth, Coral Bay and Carnarvon.
- Wind direction changes at Learmonth and Carnarvon were close to 180°, which confirmed that the eye was very close to the station.
- While the event was no longer classified as a tropical cyclone as it passed Geraldton, the anemometer data had a small peak accompanied by a change in direction compatible with a close pass to the east of the town by the remnants of the tropical cyclone.
- There is a reasonably linear decrease in peak gust wind speed over time (and hence distance travelled by the tropical cyclone) recorded at stations that experienced winds in or near the eye wall.

The indicated reduction in 3 second gust wind speed averages is around 10 km/h per 100 km of cyclone travel.

2.2. Other anemometers close to Exmouth

Many people in Exmouth mentioned reports that two anemometers located approximately 13 km to the NNE of the town had measured gust wind speeds in excess of 220 km/h. The CTS team was given permission to visit the anemometers and discuss the wind speeds noted during TC Olwyn. Neither anemometer recorded data, but operators reported the following:

- Anemometer on a building roof – approximately 1.5 m above the roof and approximately 12.8 metres above the ground –
  - Operators reported that the wind speed indicator had a stop at 120 knots (~220 km/h) and the anemometer rested against the stop for a period of some minutes before becoming active again as the wind speed reduced after the eye wall had passed.
  - Analysis of the acceleration of the wind over the roof indicates an acceleration multiplier of 1.45 for the anemometer height giving a corrected speed greater than 152 km/h.
- Anemometer on a mast at a height of 277 metres above flat open terrain –
  - Operators indicated that they saw a maximum gust of 115 knots on the read-out, but at the time of the peak winds, the operators were occupied with other duties so may not have observed the highest gust speed. This is a lower bound on the peak gust wind speed at that height.
  - The appropriate profile multiplier for gust winds at this height is 1.30, giving an equivalent corrected speed at 10 metres above ground of greater than 164 km/h.

The corrections to these anemometers readings for their location indicate that the maximum wind speed at the site 13 km north of the town of Exmouth was likely to be greater than 164 km/h. This is compatible with the measured maximum 3 second wind speed at Learmonth airport (32 km south of Exmouth) of 180 km/h.

2.3. Wind speed and direction in Exmouth

In comparing wind speeds at Exmouth and Learmonth; there was no appreciable difference in the damage to native vegetation at Exmouth and Learmonth and the few planted trees near Learmonth appeared to have been denuded to the same extent as those in Exmouth. This indicates that there was not a significant difference in wind speeds recorded at Learmonth and those experienced in Exmouth.

The reduction in wind speed with distance travelled calculated in Section 2.1 was around 10 km/h per 100 km travelled, so in 32 km between Exmouth and Learmonth it is reasonable to expect that gust wind speed in Exmouth may be 3 to 4 km/h higher than those in Learmonth. This is also consistent with gusts at 10 m above ground of greater than 161 km/h some 13 km north of Exmouth.

This report uses a peak 3 second gust wind speed in Exmouth of 185 km/h to allow for a small loss of intensity as the cyclone moved from Exmouth to the anemometer site at Learmonth. However, as this value is an extrapolation, there is likely to be an error of around 5%. The indicated range of gust wind speeds in Exmouth is therefore 176 km/h to 194 km/h for ±5%. It is unlikely that the wind speed in Exmouth is less than that recorded further south in Learmonth, therefore it is expected that the peak 3 sec gust wind speed was between 180 km/h and 195 km/h with 185 km/h used as a representative wind speed.

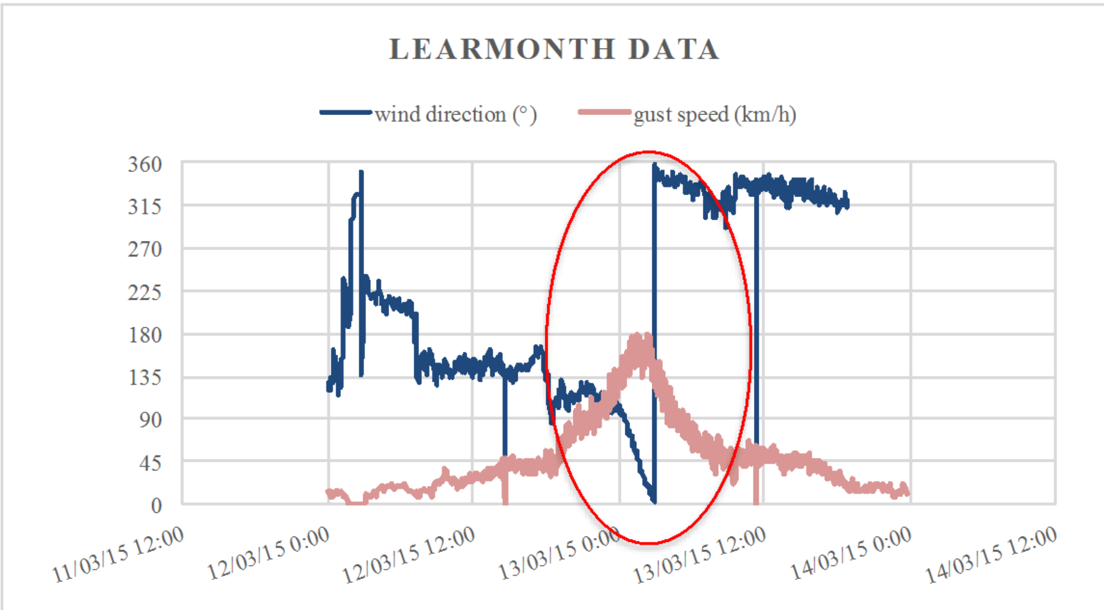


Figure 2.4 Wind direction (°) and 3 sec gust speed time-histories for BoM Learmonth automatic weather station during TC Olwyn

Figure 2.4 shows the wind data from the Learmonth AWS, which is a reasonable proxy for the wind behaviour at Exmouth. It shows wind gusts exceeding 90 km/h from 8:30 pm (2030) on 12 March, 2015 with the winds from the ESE. The wind direction changed gradually to NNE at around 2:30 am on 13 March, 2015 for the peak gusts. After this time the wind speed decreased steadily with the winds generally from the NNW. The gust wind speed did not fall below 90 km/h until 5:30 am on 13 March, 2015.

Table 2.2 summarises the estimated wind speeds and directions at various times in Exmouth derived from Figure 2.4 with the following transformations:

- The peak wind speeds in Exmouth would have been observed around 1 hour before they were observed in Learmonth.
- The peak gusts in Exmouth may have been 5 km/h higher than those measured in Learmonth.

Table 2.2 shows that the peak wind gust at Exmouth was at around 1:30 am on 13 March, 2015 from the NNE and at around 67% of the design ultimate wind speed. The peak gust applied around 45% of the design ultimate pressures to surfaces. This gust has a return period of around 27 years (calculated using the Australian wind loading standard AS/NZS1170.2) and is therefore close to a serviceability event. (The serviceability wind speed is often taken as 1/25 annual probability.)

The timing of the peak gust correlated with the reports of relative wind speed we received from people in Exmouth who had experienced the event.

Table 2.2 Expected wind speeds and directions in Exmouth

Time and date	Max 3-sec gust (km/h)	Dir'n	Est 0.2 sec gust (m/s)	% Design speed	% Design pressure	Return period (y)
12/03/15 19:00	82	ESE	26.3	29.9%	8.9%	2
12/03/15 19:30	101	ESE	32.2	36.6%	13.4%	3
12/03/15 20:00	87	ESE	27.9	31.7%	10.1%	2
12/03/15 20:30	98	ESE	31.2	35.5%	12.6%	3
12/03/15 21:00	107	ESE	34.2	38.8%	15.1%	4
12/03/15 21:30	109	ESE	34.8	39.6%	15.6%	4
12/03/15 22:00	120	E	38.4	43.7%	19.1%	5
12/03/15 22:30	134	E	42.7	48.5%	23.5%	7
12/03/15 23:00	143	E	45.6	51.9%	26.9%	9
12/03/15 23:30	160	E	51.2	58.2%	33.9%	14
13/03/15 0:00	175	ENE	55.8	63.4%	40.2%	20
13/03/15 0:30	185	NE	59.1	67.2%	45.1%	27
13/03/15 1:00	177	NNE	56.5	64.2%	41.2%	21
13/03/15 1:30	185	NNE	59.1	67.2%	45.1%	27
13/03/15 2:00	150	N	47.9	54.5%	29.7%	10
13/03/15 2:30	154	N	49.3	56.0%	31.3%	12
13/03/15 3:00	136	NNW	43.3	49.3%	24.3%	7
13/03/15 3:30	109	NNW	34.8	39.6%	15.6%	4
13/03/15 4:00	96	NNW	30.5	34.7%	12.0%	3
13/03/15 4:30	103	NNW	32.8	37.3%	13.9%	3
13/03/15 5:00	80	NNW	25.6	29.1%	8.5%	2
13/03/15 5:30	74	NNW	23.6	26.9%	7.2%	2

3. DAMAGE TO BUILDINGS IN EXMOUTH

The population of Exmouth was approximately 2200 in the 2011 census. Around 20 buildings were reported in the media as needing SES attention. Figure 3.1 shows a satellite image of the town with the newer sub-divisions that were the focus of the investigation highlighted.

Figure 3.1 Exmouth town (Map from Google Earth)

An assessment of site wind classification to AS 4055 showed that no houses in Exmouth were more than 500 m from open water (TC 1.5) or open country (TC2). Therefore, all houses in Exmouth are C3 if fully shielded or C4 if not shielded. Partially shielded sites are C4 if they are within 500 m of the ocean or C3 if they are not.

3.1. Comparison of wind damage from TC Vance and TC Olwyn

Tropical Cyclone Vance passed through the town of Exmouth on 22 March, 1999, almost exactly 16 years before TC Olwyn. The Learmonth AWS recorded a maximum wind gust of 225 km/h in TC Vance (Reardon, Henderson and Ginger, 1999), which was 1.25 times the speed recorded at the same location in TC Olwyn:

- Wind speed in TC Olwyn was 80% of that in TC Vance.
- Wind loads in TC Olwyn were 64% of the loads in TC Vance.

Survival of a building or type of building in TC Olwyn and damage of the building or same type of building in TC Vance could not be taken as evidence of improved performance. However, damage in TC Olwyn with little damage of the same type of building in TC Vance could be taken as evidence of decreased performance.

Drive-by observations of more than half of the streets in Exmouth north of Nimitz St were aimed at finding damage to buildings in TC Olwyn to compare with the same types of buildings damaged in TC Vance.

There was little evidence of damage in TC Olwyn to the same types of buildings that had significant damage in TC Vance.

3.1.1. "Norwesters"

Figure 3.2 shows an example of this type of building.

Figure 3.2 – Restored "Norwester"

In TC Vance, the following observations were made about this type of housing.

- Many "Norwesters" experienced batten loss in TC Vance. Many of these buildings had nailed batten-to-rafter connections. The overbatten above the wall arrested the damage in some cases, and in others, the ridge capping

flattened as the roofing carried uplift loads in tension across the ridge after internal damage to batten-to-rafter connections.
- Window frames had come away from the house frame due to inadequate fastening.

There was no sign of either of these two types of failures after TC Olwyn. At least two of these houses had recently installed roofing, but no overbattens (see Figure 3.3). Presumably an alternative anchorage system had been installed at the time of roof replacement.

(a) Norwesters with overbattens

(b) Norwesters without overbattens

Figure 3.3 – Roofs on Norwesters

3.1.2. Dravo houses

Figure 3.4 shows an example of this type of building from the CTS investigation of damage to houses in Exmouth following TC Vance in 1999 (Reardon, Henderson and Ginger, 1999). The Dravo house was susceptible to damage after an opening was created on the windward wall. In some cases roof panels were removed, and in others, end walls were blown out. Figure 3.4 shows both types of failure.

Figure 3.3 – Dravo house after TC Vance

It is likely that the wind speeds in TC Olwyn did not reach a damage threshold for the Dravo house, so it was not possible to say whether systematic strengthening of the Dravo houses had been successful. Because of the sensitivity of the house to internal pressures, good door furniture and effective window protection are very important.

3.1.3 Damage for reasons highlighted after TC Vance

Some houses that experienced TC Vance were damaged in TC Olwyn.

3.1.3.1 Window frame fixing

A window frame in one of the houses investigated was only fixed to the building using four screws and each penetrated around 10 mm into the jarrah building frame (see Figure 3.4). This damage was a feature of many of the “Norwesters” after TC Vance. (Reardon, Henderson and Ginger, 1999). An example of inadequate fixing of the window frame after TC Vance is shown in Figure 3.5. The Australian Window Association (AWA) has published a window fixing guide that is available on their website to illustrate appropriate installation practices. (AWA 2010)

Figure 3.4 – Window frame failure in an older house during TC Olwyn

Figure 3.5 – Window frame failures in “Norwesters” during TC Vance

3.1.3.2 Deterioration of structural elements

In many cases some deterioration in structural elements was noted. Figure 3.6 shows deterioration in the ends of rafters that allowed withdrawal of coach screws that had been used to attach a pergola in 2000 (after TC Vance). In this case, the loss of the pergola led to some roof damage on the same building. The roofing itself was in poor condition, which over many years may have let water into the timber, and led to its deterioration.

Figure 3.6 – Deterioration of rafter ends at pergola fixing point and corrosion of cladding.

3.1.3.3 Batten to rafter or truss connections

The report on TC Vance (Reardon, Henderson and Ginger, 1999) indicated that a significant problem in older houses was the single nail used to secure battens to trusses or rafters. In many of the older houses, an angle iron overbatten above the external walls secured the whole roof structure to the walls. (The overbatten is shown in Figure 3.3(a).) However in TC Vance, battens separated from the trusses closer to the ridge and this allowed significant damage to roofs in spite of the overbattens still remaining. After TC Olwyn, at least one older house was seen in which battens had separated from trusses that were fastened by only one nail. Figure 3.7 shows a truss with the single nail connector remaining after the batten had been pulled over it.

Figure 3.7 – Single nail batten to truss fixing after TC Olwyn.

3.1.4 Garage doors

At the time of TC Vance, most houses in Exmouth had carports and most garage doors failed. In a few cases, significant damage to the rest of the structure was caused by the rapid increase in internal pressures following the failure of the garage door.

Only one badly damaged roller door was seen in the investigation following TC Olwyn, shown in Figure 3.8.

Figure 3.8 – Failure of an older conventional roller door in TC Olwyn.

However a number of roller doors and panel lift doors that faced the direction of maximum winds sustained minimal damage and are illustrated in Figure 3.9:

- Roller doors with wind locks on nearly every slat performed well.
- Temporary braces fixed between holes in the floor and brackets above the door head were used to strengthen both roller and panel lift doors.

(a) Wind locks *(b) Temporary brace* *(c) Fixings for temporary braces*

Figure 3.9 – Satisfactory performance of garage doors in TC Olwyn.

A number of garage doors in Exmouth are over 3 m in height, but appeared to have been supplied to the same standard as the doors of maximum height 3 m (for which AS/NZS 4505 is mandatory). There was no noticeable difference in the performance of doors with different heights.

3.2. Structural performance of recent construction

Recent construction is characterised by variety in:

- Architectural styles;
- Roof type – hip, skillion, nearly flat, curved or very steep;
- Wall material – steel framed with lightweight cladding; timber framed with lightweight cladding; transportable systems that used steel frames; transportable systems that used structural insulated panels; rammed earth; magnesium oxide panels; concrete tilt-up panel systems; concrete sandwich panels;
- Window styles – sliding, awning, louvre and multi-fold;

However, there was little variety in roof material; nearly all roofs were sheet metal. Few recent houses were fitted with debris protection screens.

Figure 3.11 shows some examples of recently constructed housing in Exmouth.

There was very little structural damage to recent construction, but a number of buildings experienced damage to flashings. Performance of flashings is discussed further in Section 3.3. With wind speeds at around 67% of the ultimate design wind speed and pressures at around 45% of the ultimate design wind pressure, the good structural performance of buildings was not surprising. However, where envelope elements had failed, significant volumes of water entered the building causing damage to contents, flooring and linings as detailed in Section 4.1.

3.2.1. Structural damage to roofs

Almost all recently constructed buildings have sheet metal roofs. Some corners of roofing had lifted where the flashing had been lost. Figure 3.10 is a typical example. In this case, and others like it, the problem was associated with the extra loads applied to the partially connected flashing after connections of the vertical surface failed. The failure did not progress beyond the area near the loss of the flashing. There were sufficient reserves of strength in the roofing fasteners to stop the sheeting from detaching at the low loads experienced.

Figure 3.10 – Lifting of roofing at loss of flashing

3.2.2. Structural damage to walls

There was no sign of structural damage to any wall systems, but their water tightness varied.

Figure 3.11 – Examples of recently constructed houses in Exmouth

3.2.3. Structural performance of windows and glass doors

Four windows or glass doors were noted where failure of glass or the frame on the windward side of the building led to breach of the building envelope. In each of these cases, significant water ingress followed the development of the opening. In two cases, the internal pressure that developed caused failure of windows on leeward or side walls.

3.2.3.1 Electrically operated entrance doors in a public building

Figure 3.12 shows failure of entrance doors in a large public building. These doors were on the windward face of the building in the early part of the cyclone. Security vision showed that they failed before the peak gust was experienced. The same vision shows that after they failed, they were blown at least 5 metres into the building and substantial volumes of water were allowed in over a tiled floor. Following the loss of the doors, air currents within the building moved papers and blew over potted plants in other parts of the interior space.

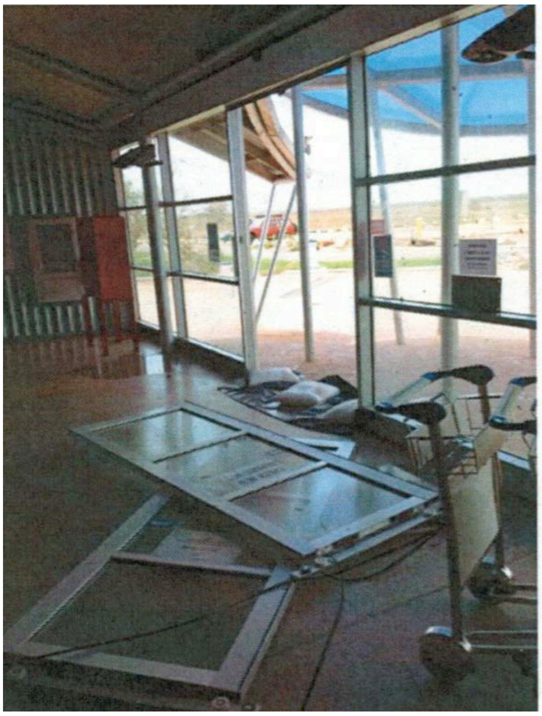


Figure 3.12 – Failure of entrance doors (photo Jenny Kox, Shire of Exmouth)

3.2.3.2 Double-hung inward-opening glass doors

The glass in these doors had failed (Figure 3.13). It appeared to be toughened glass and the fragments were measured at 5 mm thick. Each panel was 820 x 1800 mm and was protected by an expanded metal debris screen on the outside. There was no evidence that the debris screen had been struck by debris. It appeared that both panels had broken under wind loads. It is unlikely that glass of this thickness was appropriate for the exposed hilltop location in which it had been fitted.

Following failure of the doors, water and wind-driven sand was admitted to the carpeted area behind them. Five suspended ceiling panels were blown upwards into the ceiling space and the underside of the roof sheeting would have experienced internal pressure from the dominant opening.

Figure 3.13 – Failure of toughened glass in doors

3.2.3.3 Failure of window frames under wind loads

Three houses were seen in which sliding sashes had come out of their frames. In each of these cases, the frames had deflected under the windward wall pressures towards the inside of the house. The sashes detached from the frames and blew into the house. Figure 3.14 shows a damaged frame in house almost ready for handover that had previously held two full height glass sliding door sashes. The frame had permanently deformed at both the top and bottom. Once the sliding door sashes had blown in and lost their glazing, the internal pressures caused some windows on a side wall to also distort the frame (Figure 3.15) and blow out of the building. There was no label that indicated the window rating visible on this window.

Figure 3.14 – Inward failure of glass door frames

Figure 3.15 – Outward failure of glass door frames

3.2.4. Swinging front door failures

Several houses inspected had openings created after front doors failed.

- Home-owners reported they had attempted to hold the doors closed by leaning against them or moving furniture in front of them. Activity close to a windward wall posed a significant risk to their safety.
- After failure of the doors, large volumes of water entered the building, causing damage to floor coverings, furnishings and walls.

3.2.4.1 Double front doors

Inward opening, double front doors on windward walls that had no bolts or inadequate bolts into the door header and floor failed in several houses (Figures 3.16 and 3.17) at the latches due to the prising forces as the doors are forced inwards.

Figure 3.16 – Failure of double front door

Figure 3.17 – Failure of latches on double front door

3.2.4.2 Single front doors

The door latch on single doors is not subjected to the same prising forces as the latch in double swinging doors. However, bolts top and bottom reduce the shear forces on the latch and improved the performance of the doors.

3.3. Damage to ancillary items

In general, there was little damage to ancillary items such as solar hot water systems, solar PV panels, externally-mounted air conditioners, satellite dishes, antennae and fences, which was not surprising given that the wind speeds were significantly less an the design wind speeds.

However, there were a number of ceiling fans in outdoor areas that were damaged or that caused damage to the linings of alfresco or balcony areas. An example is shown in Figure 3.18.

Figure 3.18 – Loss of ceiling fan and damage to soffit

Figure 3.19 – Damage to glass spa fence

There were also a few cases where glass fencing was damaged. (Figure 3.19) This glass had the potential to become lethal debris.

3.4. Water damage to buildings and contents

While there was little structural damage to recently constructed houses in Exmouth, many occupiers indicated that there were significant volumes of water entering houses and causing damage to contents, chattels and the building itself. Section 4 details the types of failures or features that led to water ingress.

4. WIND-DRIVEN RAIN

Water ingress was the main cause of damage to buildings in Exmouth during TC Olwyn. Wind-driven rain passed through the building envelope at openings such as windows and doors (even if closed), around flashings, or where flashings had been damaged.

Wind-driven rain has been mentioned in most previous damage investigations following major storms (Reardon, Henderson and Ginger, 1999; Henderson et al, 2006; Leitch et al, 2009, Boughton et al 2011). In some cases, water ingress affected the structural elements of the building (e.g. complete or partial ceiling collapse).

The focus of this section is wind-driven rain entering buildings that have not had damage to structural elements such as windows, doors and roofing or been struck by wind-borne debris. Although there was little structural damage, insurance claims for damage from water entering new buildings are likely to be substantial. Most people interviewed in this investigation indicated that they expected some water to get into their homes, but were surprised at the large volumes of water they needed to mop up and were distressed at the amount of damage it caused.

4.1. Consequences of rain-water damage

4.1.1. Damage to floors and floor coverings

Once inside the building, water moved downwards and eventually reached the floors (Figure 4.1).

(a) water on floor (Photo Toby Scholl)

(b) cupping of overlay timber floors

(c) carpet staining

(d) skirting board damage

Figure 4.1 – Water damage to floors

Even small quantities of water irreparably damaged furnishings, floor coverings and personal belongings. The following floor damage was observed in the investigation:

- Mould growth and staining of carpet;
- Cupping of overlay timber floors; and
- Swelling of medium density fibreboard skirtings.

For some of this damage, replacement of the floor will be particularly expensive. In many cases, the replacement process will significantly inconvenience residents.

The consequences of damage from wind-driven rain can be minimised by:

- reducing the volume of water ingress;
- using floor coverings that are less affected by inundation with water

4.1.2. Damage to Ceiling and wall linings

Some wall and ceiling linings such as plasterboard are particularly sensitive to water ingress. Where the ingress was above a ceiling, water pooled on the ceiling or soaked insulation that saturated ceilings. People reported water running from light fittings (Figure 4.2 (a)) and smoke detectors. In some cases, the water also ran down wall cavities, causing damage to plasterboard wall linings.

(a) Water through light fittings (Photo Shannon Bailey) (b) Damage to wall lining
Figure 4.2 – Water damage to ceiling and wall linings

In some cases, plasterboard ceilings collapsed under the weight of the water during the event, affecting furniture, floor coverings and belongings. Figure 4.3 shows some examples of ceiling collapse. Although there were no reports of people being injured in this event by a ceiling collapse, several people reported near misses and relief that the outcome wasn't different.

Water damaged ceilings in the following circumstances:

- Water directly entering a roof space, and
- Water affecting a second storey floor, seeping downwards and damaging the ceiling below.

As the ceiling acts as a structural diaphragm to redistribute lateral loads to the tops of bracing walls in severe wind events, structural performance may be compromised by loss of the ceiling. There were no cases of structural performance being affected by diaphragm loss reported to the investigators.

Figure 4.3 – Examples of water damage to ceilings

Wet insulation also holds water in the roof space and can prolong the high humidity conditions that encourage the growth of mould. Houses and buildings that have suffered no structural damage can be unusable for many weeks until the problems are rectified. Within one week of the TC Olwyn, mould had grown in saturated plasterboard ceilings and wall linings.

Water ingress into ceilings and walls can also damage electrical wiring, and this needs to be checked, and repaired or replaced if necessary. An electrician's certificate may be required before a house that has had extensive water and / or structural damage can be reconnected to the grid. One Exmouth resident reported that a short circuit in a saturated junction box had caused continual tripping out once the power was reconnected.

There is also the potential for water to create conditions that lead to accelerated corrosion of connections and other metal components in buildings, which could reduce their strength in future events. (Refer Section 3.1.3.2)

The consequences of water ingress that damages ceilings and wall linings can be minimised by:

- reducing the volume of wind-driven water ingress;
- using linings that are less affected by water (fibre cement ceilings and wall linings in garages didn't fail despite being affected by water ingress).

4.1.3. Safety of people

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 case, they had put themselves at risk of injury by being directly in front of windward wall windows and glass doors (Figure 4.4). One home-owner broke her arm when she slipped while removing soaked towels from the floor.

Figure 4.4 – Mopping up water in front of windows (photos taken during cyclone)

4.2. Entry points for wind-driven rain

Strong winds produce a high differential pressure on the windward wall from outside to inside, which can force water entrained in the wind through gaps and spaces that it would otherwise not penetrate.

The airflow around and over a building in a cyclone can drag water upwards over the building envelope. Flashings are designed to channel downward-moving water away from the building, but during a cyclone, water is driven upward and into the building.

Home-owners and builders reported that significant volumes of water entered the windward side of undamaged buildings through the following:

- Around doors and windows. – Water was driven through the small gaps around doors and windows and upwards through weep holes in windows and glass sliding doors.
- Under flashings. – Wind-driven rain moving upwards against the building envelope was pushed under flashings and into the building.

The extent of the water ingress problem experienced by owners was a function of a number of factors:

- The exposure of the house to wind-driven rain. – Water ingress was more significant in houses with less shielding on the windward side.
- Different types of flashing or windows. – These variations are explored in the following sections.

4.2.1. Water ingress through undamaged windows and doors

Some occupants reported a steady spray of water from the base of windows into rooms on the windward side of the house.

Figure 4.5 – Water ingress through weepholes (Photos Toby Scholl)

The extent of water ingress through undamaged windows and doors was affected by:

- The type of window (closing and opening mechanism);
- The type of seals (soft rubber seemed to allow less water than wool pile or mohair); and
- The manufacture of the window or door.

4.2.1.1 Sliding windows/doors

Water ingress through sliding windows and doors was greater than for most other types of windows. The water entered through:

- Weepholes in the frame (Figure 4.1) and
- Around seals between the moving sash and the frame.

Weep holes

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 in high winds, Figure 4.6 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). Some people reported that the water was spurting two metres from the window, and compared the jet of water with a garden hose.

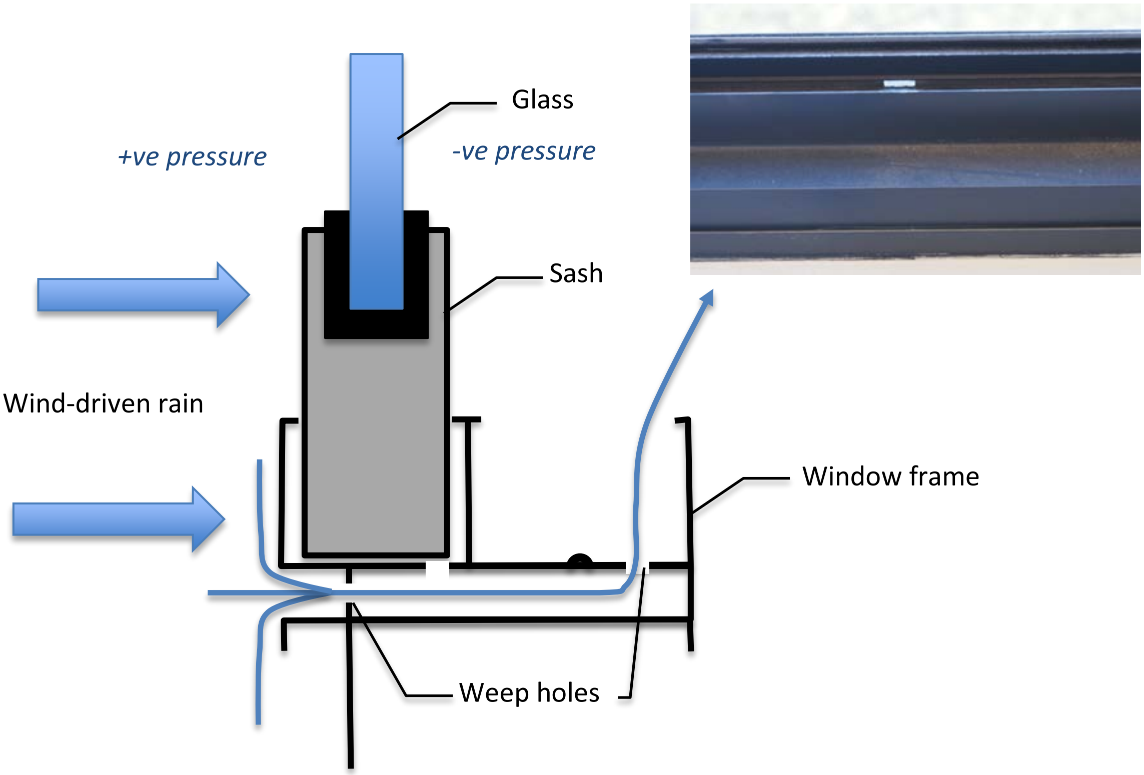


Figure 4.6 – Weep holes in sliding window assembly

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 almost no water entered their homes through windows. However, this option is not always available as:

- Some manufacturers' windows have weep holes in the bottom of the frame or recessed so that they can't be taped up, and
- Other windows on some buildings, such as windows on the second floor, are inaccessible.

One type of sliding window had a rubber flap on the outside of the frame that covered the weep holes. This successfully reduced water ingress on a recently constructed house in this event. However, some minor deterioration in the rubber was noted. If the seals deteriorate further, performance of the windows in future cyclones may be affected. (Figure 4.7)

Figure 4.7 – Weepholes covered by rubber flap

In order to drain moisture to the outside of the building under normal conditions, and prevent water ingress during high wind events, durable seals or internal one-way valves should be fitted to weep holes.

Seals on sliding sashes

Some home-owners also reported that water entered around the wool pile or mohair seals of the sliding sash section of windows, or when the sashes of sliding glass doors flexed inward from the wind pressure (Figure 4.8).

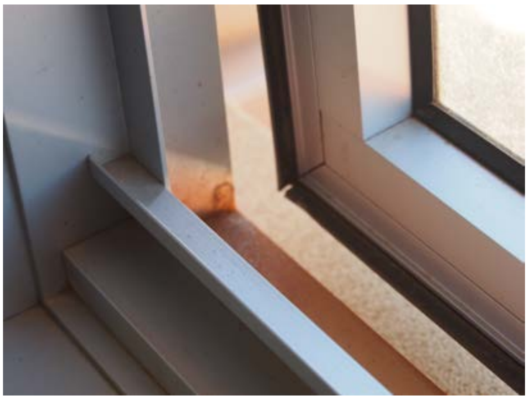
Figure 4.8 – Gap opened between flexible sashes

Windows that are correctly rated for the site wind classification have sufficient rigidity to prevent flexing of the sash that allows large volumes of water into the building. Further research is needed to develop water-tight seals for sliding windows and doors.

4.2.1.2 Awning windows

In general, awning windows with rubber seals performed better than those with wool pile or mohair seals as shown in Figure 4.9.

(a) Damage from water ingress through wool pile or mohair seals



(b) rubber seals

Figure 4.9 – Awning windows

However, significant water that had passed through or around the seals, penetrated through the opening mechanism in some awning windows, as shown in Figure 4.10.

Figure 4.10 – Water ingress through opening mechanism in awning window (Photo Shannon Bailey)

Water ingress through awning windows can be minimised by using rubber seals and ensuring that they are in good condition. (More leakage occurred where seals had pulled away from corners.)

4.2.1.3 Louvre windows

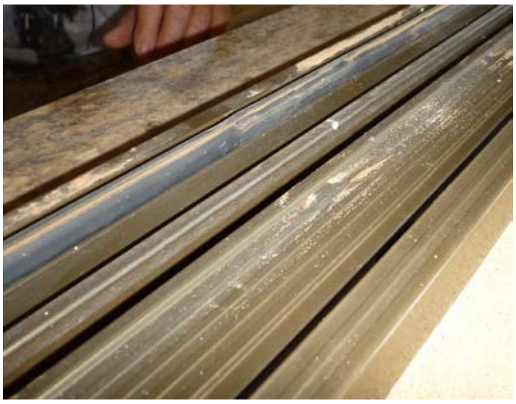
In general, contemporary louvre windows performed well during TC Olwyn. Home-owners reported that only small amounts of water leaked into houses either between the panes or over the bottom lip of the louvre frame as shown in Figure 4.11.

Figure 4.11 – Water ingress through louvres

4.2.1.4 Bi-fold windows and glass doors

Two houses that were inspected as part of the investigation had outward opening bi-fold windows on windward walls. These windows both had soft rubber seals and let in less water than sliding windows in similar locations on other houses. This may be because wind pressure pushes the sashes against the seals located at the back of the frame and bottom of the windows, preventing wind-driven rainwater from entering the building. (This appeared to be effective in limiting water being driven through the weep holes into the house.)

(a) Bi-fold windows



(b) Soft rubber seal on bi-fold window frame

Figure 4.12 – Bi-fold windows

Owners of a commercial building reported that a large volume of water entered through their outward opening bi-fold doors. The seals of these doors (Figure 4.13) had been damaged before the event by workers moving furniture in and out of the building.

Figure 4.13 – Damaged seals in multi-fold doors

No houses with inward opening bi-fold doors were inspected, but it is likely that for these doors, pressure on the windward wall would push the sashes away from the seal and allow significant water ingress.

4.2.1.5 Swinging doors

The investigation showed that water entered around swinging doors due to:

- Flexibility in the door allowing the top and bottom edges of inward opening doors to move away from the frame and seals under wind pressure. Once the door had moved away from the seal, a leakage path between the door and the seal was established. This type of leakage was not reported where there were strong bolts at the top and bottom of doors.
- Incomplete seals in either outward or inward swinging doors allowed water to enter the house. (Figure 4.14)
- Damage to door furniture that allowed the doors to swing fully or partially open (see Section 3.2.4)
- Damage to seals and frames due to wind action. (Figure 4.15)

Figure 4.14 – Leakage paths through gaps in seals on swinging doors

(a) Damaged seal near lock *(b) Good seal at bottom of door*

Figure 4.15 – Damaged frames and seals in swinging doors

Figure 4.15(b) shows an outward swinging glass door with a good seal at the bottom. Wind pressure pushed the door against this seal and prevented water ingress around the bottom of the door through the weep holes. However, this door had a single opening panel that latched into a bi-fold door and the fluctuating wind pressure damaged the frame at the lock (circled in Figure 4.15(a)) and allowed the door to move enough to damage the seals, which allowed water to come into the house.

4.2.1.6 Comparison of wind pressures and water penetration resistance test pressures for windows

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).

Windows on windward walls that may have been classified using AS 2047 as non-exposed were not shielded during TC Olwyn as the rain was driven horizontally.

As indicated in Section 2.3, the estimated wind velocity at Exmouth (standard height and Terrain Category 2) was 185 km/h. Representative differential pressure across windows could be calculated for different site wind classifications and compared with AS 2047 test pressures:

- Windward wall C_{pe} = 0.7
- Assumed C_{pi} = –0.3 (appropriate for buildings with no openings)
- Terrain and shielding multipliers as given in App A of AS 4055 (compatible with AS/NZS 1170.2)
- All sites in Exmouth are either C3 or C4.

Table 4.1 presents the ratio of calculated differential pressure across windward wall windows during the peak gusts estimated for Exmouth in TC Olwyn to the test pressures in AS 2047. It shows that during TC Olwyn, for both site wind classifications, the estimated wind pressures were over two times the test pressures used to demonstrate resistance to water penetration in AS 2047.

Table 4.1 – Ratio of wind pressure at Exmouth in TC Olwyn to AS 2047 test pressures

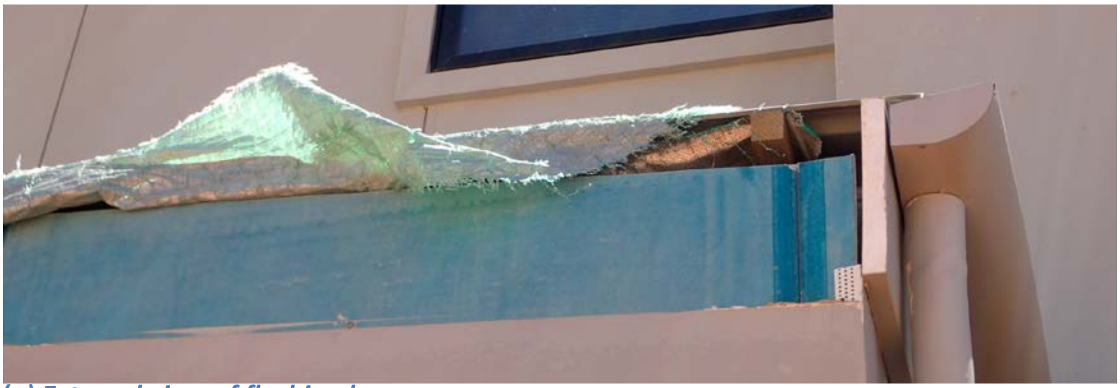
Site wind classification	Ratio of AS2047 Non-exposed test pressure to derived pressure from TC Olwyn	Ratio of AS2047 Exposed test pressure to derived pressure from TC Olwyn
C3	3.80	2.53
C4	3.15	2.36

Water penetration test pressures given in AS 2047 are significantly less than serviceability pressures and do not give a clear indication of water penetration resistance of windows in realistic wind conditions. Higher test pressures are needed together with acceptance criteria that allow some controlled water ingress at the higher pressures. 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 test methods in AS 4420.5 should better reflect the conditions that caused penetration of wind-driven rain through unbroken windows during high wind events.

4.2.2. Water ingress through damaged flashings

Loss of flashings due to wind loads where flashing is inadequately fastened can cause partial loss of roof sheeting, and allow significant amounts of water into the building. As flashings are often used above the ceiling, the loss of the flashing causes damage to ceilings as shown in Figure 4.16.



(a) External view of flashing loss

(b) Internal view of flashing loss *(c) Ceiling damage from flashing loss*

Figure 4.16 – Loss of flashings on one of the houses in the investigation

Figure 4.17 shows a building that had lost flashing from all windward edges of the roof.

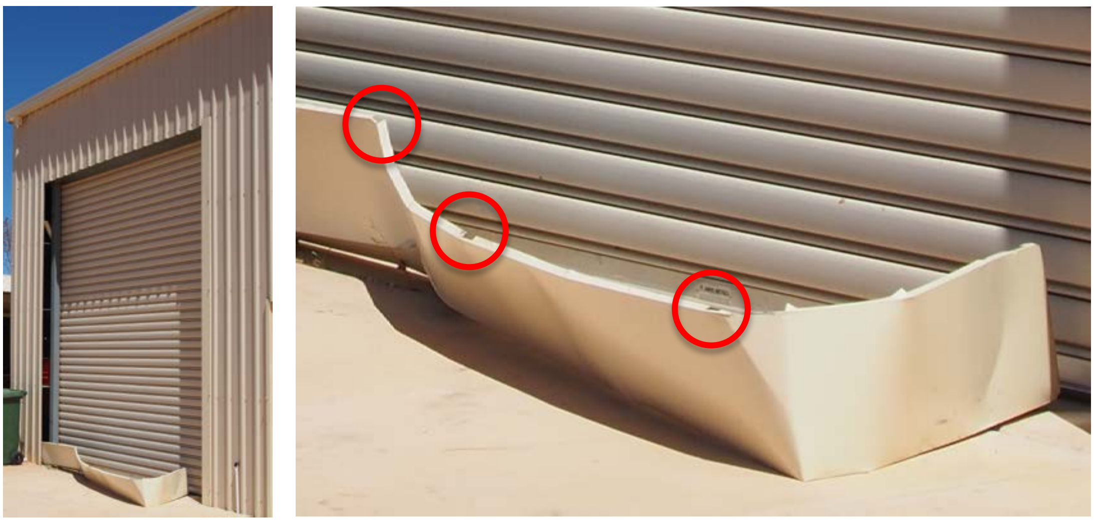
Figure 4.17 – Extensive loss of flashings

Figure 4.18 shows a house with loss of flashing and other minor roof damage. The same flashing across the width of the house on the leeward side was fixed to the eaves with only four pop rivets. It was fixed to the upper surface with the roofing screws, but as the flashing on the windward side peeled back under wind loads, some screws pulled out of the battens (shown on corner in the larger photo) and others pulled through the flashing.

Figure 4.18 – Flashings fixed with rivets

(Inset photo shows pop rivet in the same flashing remaining on the leeward side of the house.)

(a) Flashing on houses



(b) Flashing on light-industrial building

Figure 4.19 – Flashings fixed with rivets at close centres

Figure 4.19(a) shows flashing fixed to the edge beam of an alfresco area with pop rivets at 300 mm centres. Because flashings are always in the higher loaded corner and edge regions of buildings, connections for flashings should have at least the same capacity as fasteners for the adjacent roofing. Similar damage was also seen on light industrial buildings as shown in Figure 4.19(b).

Figure 4.20 shows roof flashing that had been inadequately connected to the concrete wall below. However, because the ribs in the roof sheeting were at an acute angle to the wall and hence flashing, fastening to the roofing at every rib meant that the fasteners were too far apart. A number of buildings had this problem.

Figure 4.20 – Flashings at an acute angle to the ribs of the roof sheeting

The New Zealand Department of Building and Housing has published guidelines on flashings for weather tightness as Acceptable Solution E2/AS1 (Department of Building and Housing 2011). This information includes:

- materials suitable for flashings;
- corrosion resistance;
- length of overlaps;
- details for finishing concealed edges of flashing;
- details for finishing exposed edges of flashing; and
- fixing requirements.

4.2.3. Water ingress through undamaged flashings

As rain is entrained in the wind during a tropical cyclone, when the wind moves up over a building, the water is also driven upwards. In many cases the wind directs water under flashings on the windward side of the building.

4.2.3.1 Valley gutters

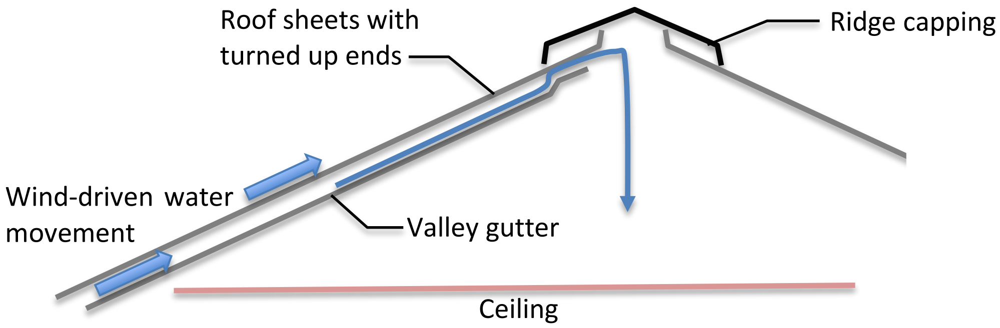
Figure 4.21(a) shows dampness in a ceiling (highlighted with an oval) during TC Olwyn from water driven up a valley gutter. This can be contrasted with Figure 4.21(b), which shows more extensive ceiling damage in a similar house under higher wind speeds in TC Vance (Reardon, Henderson and Ginger, 1999).

(a) During TC Olwyn

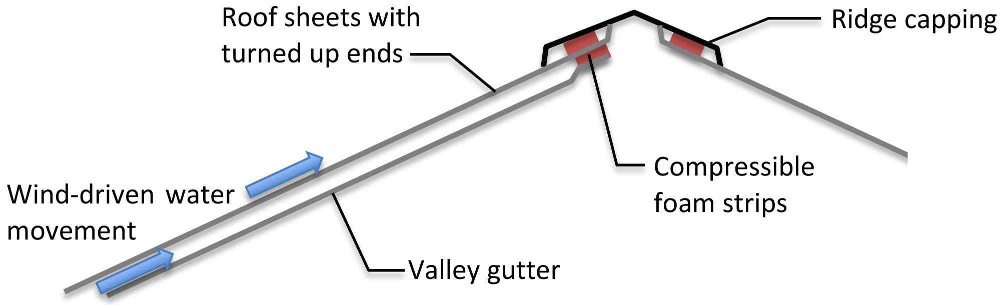
(b) During TC Vance

Figure 4.21 – Damage to ceiling from water entering through flashing above valley gutter

Figure 4.22(a) illustrates the water path going up the valley gutter, under the roof sheeting at the top and overflowing the edge of the valley gutter sheeting into the roof space.



(a) Path of water at the top of valley gutter.



(b) Compressible foam at the top of valley gutter.
Figure 4.22 – Sketch section showing leakage at the top of valley gutter.

One of the builders interviewed had used a compressible foam strip around the top of the valley gutter under the roof sheeting to seal the top of the gutter on a number of houses (Figure 4.22(b)). Some of these valley gutters were on the windward face of the house for the peak gusts during TC Olwyn, and did not overflow. The seals appeared to be successful in preventing upward-moving water from continuing over the top of the end of the valley into the roof space. Similar strips under the ridge capping could prevent water from being driven upward under the roof capping.

4.2.3.2 Interface between upper surface of roof and wall

Figure 4.23 shows a common detail on many skillion-roofed houses in the marina area. In this case, the roof sheeting runs between the eaves and a wall that continues above the roof panel.

Figure 4.23 – Flashing between roof and wall panel

Wind had driven water up the roof panel, under the flashing and over the end of the roof sheeting (even though the sheeting had been turned up at the edge). The water then entered the wall cavity, ran down the wall and into the ceiling space. In some cases, wall linings were damaged. In most cases, parts of ceilings collapsed. Figure 4.24 is a cross-section through the roof indicating the water path.

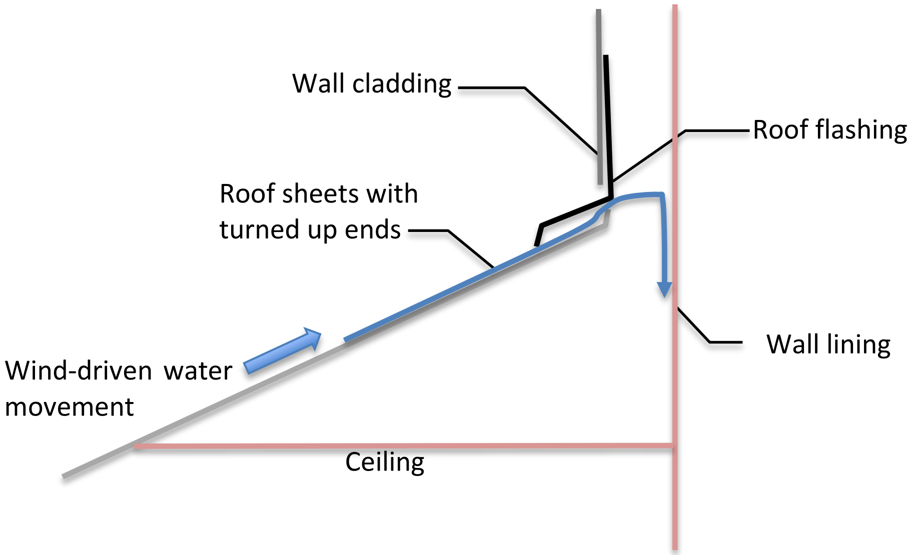
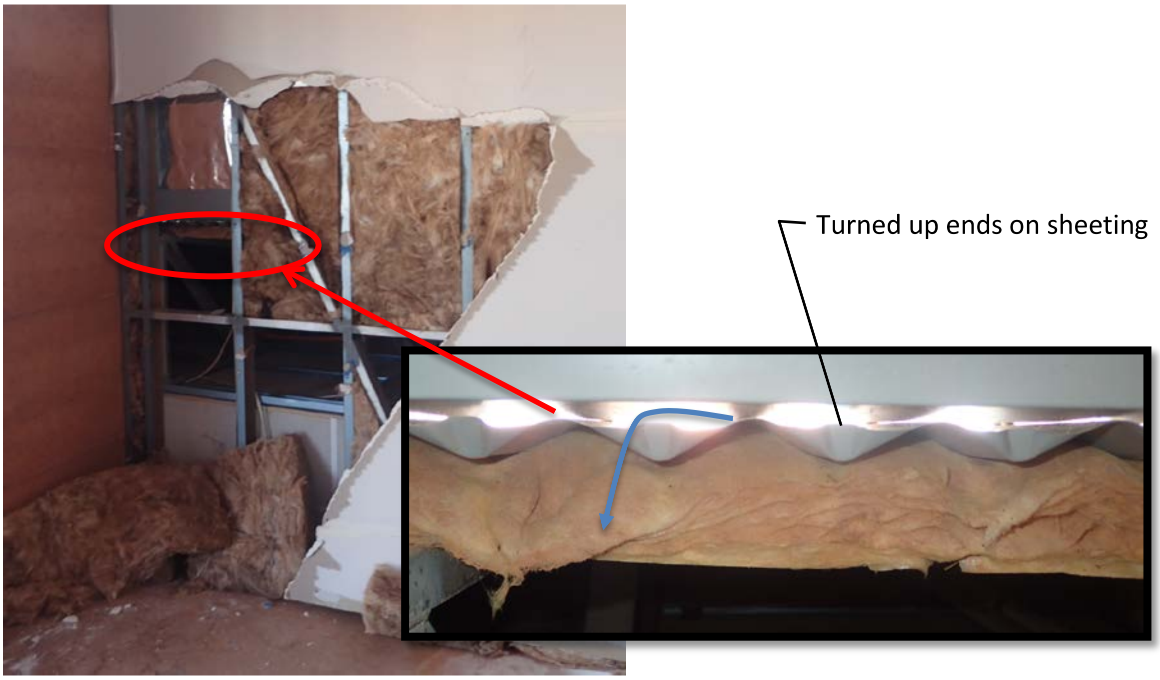


Figure 4.24 – Sketch of water path under flashing between roof and wall panel

Figure 4.25(a) shows a house in which the insulation in the wall held the water and saturated the plasterboard internal wall linings. Figure 4.25(b) shows an external view of a different house, which shows the rainwater entry points under the flashing. Plasterboard ceilings were damaged in both houses.



(a) Views from inside a house with corrugated roofing

(b) Views from outside a house with ribbed roofing
Figure 4.25 – Water ingress between roof and wall panel

In addition to the use of hooks and hems on concealed edges as detailed in Department of Building and Housing (2011), compressible foam can prevent wind-driven water ingress under the flashing.

Compressible foam underneath the flashing, illustrated in Figure 4.26, may limit air movement due to differential pressure and therefore could stop wind-driven water entry. It would still be necessary to turn up the pans of the roof sheeting even if the foam strip is used. The turned up edge would also stop the foam strip being blown into the roof space by the differential pressure.

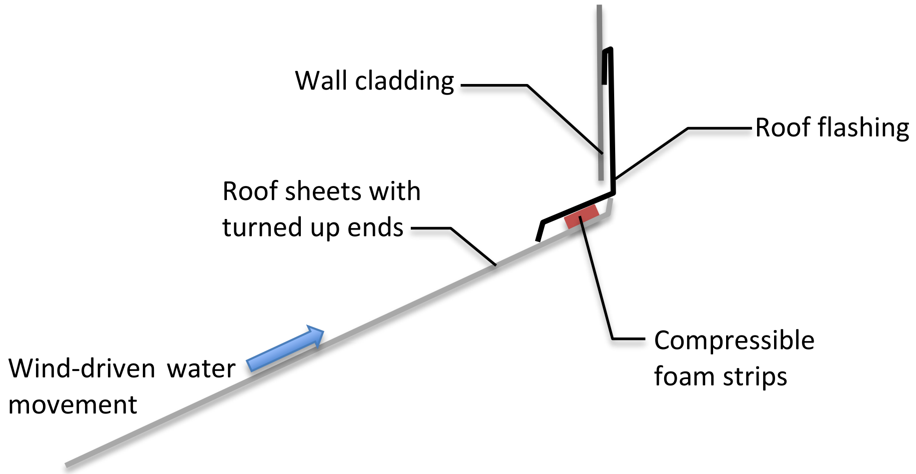


Figure 4.26 – Sketch of suggested compressible foam under flashing between roof and wall

4.2.3.3 Interface between lower surface of roof and wall

Figure 4.26 shows a building that had compressible foam seals (Figure 4.27) between the flashing and the underside of the roof sheeting. However, the sheeting was continuous over the foam and wind pressure forced the foam from the gap. The reverse slope of the sheeting also channelled horizontally driven rain into the building through the gap. Although there was no external damage, this building had significant internal damage as a result of the water ingress.

Figure 4.26 – Building with flashing failure (inset photo shows ceiling damage)

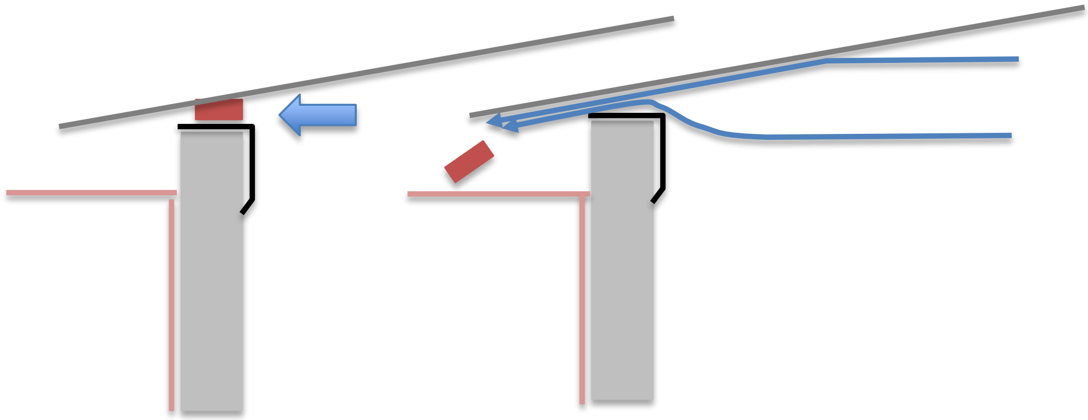


Figure 4.27 – Sketch of detail in Figure 4.26

This problem may have been solved by turning up the back edge of the flashing and installing a screw as shown in Figure 4.28. The principle is to lock the foam in place so that it can't move in either direction in response to wind pressure.

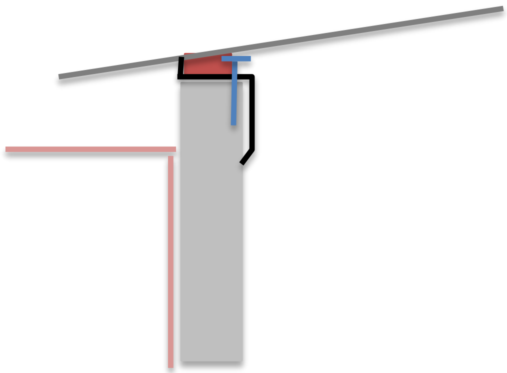


Figure 4.28 – Sketch of recommended detail

4.2.4. Water ingress through eaves and soffits

Failure of soffits was also observed in some houses. Figure 4.29 shows damage to soffits under the eaves that allowed water to enter the inside of the house.

Figure 4.29 – Damage to soffits

There is an increasing trend for houses and other buildings to have large outdoor areas such as alfrescos and balconies. Where these are not lined with resilient materials, there is potential for water damage to the linings themselves and for water ingress into the ceiling space behind them. Extensive soffit and eave damage was reported following Cyclone Yasi (Boughton et al, 2011). AS4055 was amended to include design pressures for these components of a house.

Figure 4.30 shows loss of plasterboard lining in a breezeway and damage to timber linings in alfrescos.

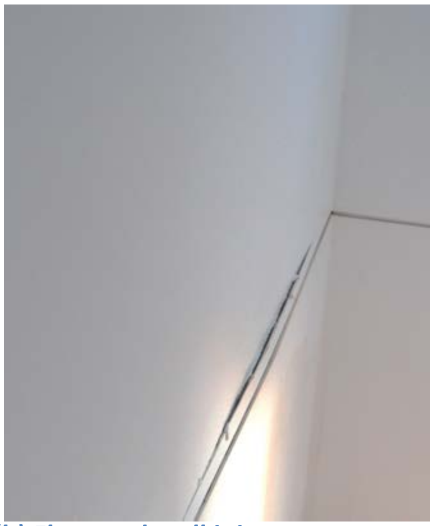
Figure 4.30 – Damage to soffits in breezeway and above alfresco

4.2.5. Water ingress between wall and floor

Differential pressure across the windward wall forced water into the building at the junction between wall envelope elements and the floor.

4.2.5.1 Construction joint between floor and wall

Figure 4.31 shows penetration of water through the wall immediately above the floor. In Figure 4.31(a), water passed along a crack above a concrete slab and caused damage to the skirting board, wall lining and floor on the inside. In Figure 4.31(b), water was driven under a timber frame above a timber floor and caused damage to linings in a stairwell. In both cases, appropriate flashings and damp proofing should have prevented the problems.



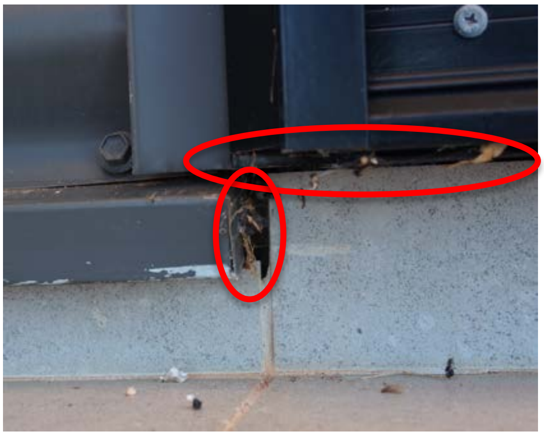
(a) Joint between wall and concrete floor slab (inset shows damage to skirting board) *(b) Floor and wall joint*

Figure 4.31 – Water ingress between wall and floor interface

4.2.5.1 Under full-length windows and glass doors

Some home-owners reported that water came into their houses between the window frame and the floor. Figure 4.32(a) shows a gap between tiles and a window frame on a second floor balcony that allowed water into a ceiling space. This problem could have been avoided by sealing these gaps.

Figure 4.32(b) shows a sliding glass door that had been fitted immediately above the floor joists of a balcony. As it was not possible to have a flashing under the bottom of the frame in this installation, water was driven between the bottom of the door frame and the timber floor.



(a) Gaps between tiles and door frame *(b) No flashing under door frame*

Figure 4.32 – Water ingress between wall and floor interface

5. Conclusions

TC Olwyn crossed the West Pilbara coast near Exmouth as a Category 3 cyclone on Friday, 13 March, 2015 at approximately 1:00 am. The BoM anemometers recorded 3-second average gusts up to 180 km/h at Learmonth Airport, south of Exmouth. TC Olwyn continued south over Coral Bay, Carnarvon and Denham.

5.1. Estimated maximum wind gusts

The estimated maximum 3 second wind gust at Exmouth was 185 km/h, with an error expected to be ± 5%. This wind speed is 67% of the design wind speed for Region D after correction for gust duration, and resulted in wind pressures around 45% of design wind pressures.

Wind speeds measured during TC Olwyn were around 80% of those measured during TC Vance using the same anemometer.

5.2. Structural performance of buildings

There were the usual problems with older buildings; minor roof loss associated with deterioration, and poor batten to rafter connections. Many older houses had been retrofitted with improved structural details following TC Vance. The only cases where battens separated from trusses were buildings that had not been damaged in TC Vance, and had not been retrofitted with improved batten-to-truss connections.

There was little structural damage to recently constructed buildings in Exmouth. There was no evidence of loss of roof sheeting or battens. However, a number of buildings showed the following damage:

- loss of flashing;
- failure of windows, glass sliding doors or aluminium frames; or
- failure of locks or fixings of double front or swinging doors.

Few garage doors failed in recently built houses. Some home-owners used additional temporary wind braces that were fitted in preparation for the cyclone, to protect their garage doors.

Because peak gust wind speeds in TC Olwyn were less than the peak gusts in TC Vance and the design wind speeds, it is not possible to say whether the good structural performance demonstrated either improvement following TC Vance or satisfactory performance against codes and standards.

5.3. Water ingress

Almost all recently built houses in Exmouth showed evidence of varying amounts of wind-driven rain entering through windows and doors, or water ingress under flashings. In some cases, water ingress lead to extensive damage to floors, walls and ceilings as well as contents. The consequences of water ingress were:

- Water damage to plasterboard ceilings and collapse of ceilings during the event;

- Water damage to plasterboard wall linings causing separation from the wall frames;
- Water damage to flooring including carpets, overlay timber floors; and
- Safety concerns for occupants mopping up water in front of windward wall windows and glass doors.

The wind speeds during TC Olwyn were only 67% of the ultimate wind speed for Region D with an annual probability of occurrence of only 1/25 to 1/30 (similar to that for serviceability). At these wind speeds, rain was driven nearly horizontal, covering all windward surfaces. The differential pressure across windward walls and roofs forced air, and the rainwater and sand entrained within it, through small gaps.

The main points of entry for wind-driven rain were identified and recommendations (See Section 6) have been made on steps to reduce the effects in future events:

- Broken windows and doors;
- Weep holes in windows and glass door frames
- Wool pile or mohair seals or damaged rubber seals;
- Windows or doors with flexible sashes;
- Opening mechanism of awning windows;
- Locks in swinging doors;
- Around flexible, inward opening swinging doors;
- Damaged or lost flashings;
- Valley gutters;
- Under flashings at wall to roof interface, wall to loor interface or around windows
- Damaged soffits and eaves.

Research is required to determine appropriate levels of wind driven rain and pressure differentials to develop appropriate economical test methods for a range of envelope products. The benefits of this research will help reduce recovery costs to the community. As well as the direct costs of repairs, there are additional indirect costs associated with owners' distress during event, possible relocation during repair, implications for jobs and tourism.

5.4. Codes and Standards

The water penetration resistance test pressures in AS 2047 *Windows and external glazed doors in buildings* are much lower than pressures for the serviceability limit state and do not adequately represent the pressures applied during wind events (even in events with wind speeds significantly less than the design wind speeds).

The test method for water penetration resistance in AS 4420.5 *Windows – Methods of test Method 5: water penetration resistance test* do not reflect the conditions that cause wind-driven rain ingress.

AS/NZS 4505 *Garage doors and other large access doors* applies to domestic garage doors up to 3 m high. Many of the recently installed garage doors in Exmouth were higher than 3 m to accommodate large boats.

6. Recommendations

Buildings repaired, refurbished or constructed after TC Vance (1999) generally had adequate structural performance at the lower wind speeds of TC Olwyn. However, the investigation has confirmed some structural issues that have been raised in reports on other damage from cyclones, reached some new conclusions on wind-driven rain ingress and has made the following recommendations:

6.1. Structural performance

- Structural elements in older houses should be checked to ensure that they have sufficient capacity for the wind classification and that they have not deteriorated. Any elements or details that are insufficient or have deteriorated e.g. corrosion of connections and roof sheeting, need to be retrofitted or replaced;
- When replacing roofs, either following damage or for refurbishment, check connections in the whole roof structure. Any elements or details that are insufficient or have deteriorated need to be retrofitted or replaced. In addition, to improve water tightness, flashings should be checked and upgraded as indicated in section 6.2.3.
- Windows and glass doors are required to comply with AS 2047 and need to be rated for the appropriate site wind classification. This rating applies to the frames, sashes and glass.
- Double swinging and double sliding doors require bolts at the top and bottom of each door to reduce loads on the latches between the doors. The frames require sufficient strength to carry loads from the bolts. (In the case of automatic sliding doors, these bolts could be temporary measures used only in preparation for tropical cyclones.)
- Soffits should be designed to resist ultimate wind forces. AS 4055 gives design pressures for soffits in Table 3.3.
- Outdoor ceiling fans should be designed for easy removal. Procedures for building preparation before tropical cyclones should include removal of outdoor fans.

6.2. Water damage from wind-driven rain

Water damage was the largest contributor to the cost of damage in Exmouth during TC Olwyn. Nearly all recently constructed buildings experienced some level of damage due to water ingress.

6.2.1. Windows

- Windows should be rated to the appropriate site wind classification to ensure sufficient stiffness, to prevent deflection of sashes that open gaps and allow water to enter.
- Weep holes should be fitted with some device (eg. flaps or one-way valves) that prevents large volumes of water being forced from the outside to the inside of the building during severe wind events.

- Where possible, use soft rubber seals that are pushed against a frame by windward wall differential pressure. The woolpile or mohair seals that are currently used on sliding surfaces do not appear to work at serviceability pressures. The condition of seals should be checked prior to the cyclone season. In particular, seals should meet at corners. Damaged, deteriorated or incomplete seals should be replaced.
- Bi-fold windows and doors should be outward opening so that windward wall pressures push them back onto a rubber seal in the frame.

6.2.2. Doors

- Inward opening doors should be appropriately bolted at top and bottom, to reduce water entry around the top and bottom of the doors.

6.2.3. Flashings

- Department of Building and Housing (2011) presents comprehensive guidelines on flashings. A similar document should be developed for Australian buildings, which would include the following additional requirements for cyclonic regions.
- Anchor all surfaces of roof flashings with at least the same fasteners and spacing of fasteners that are required for the adjacent roof. This is also necessary for the fixing of edge flashings to vertical surfaces.
- For an effective seal against rain driven by high winds, most flashings must also exclude upward-moving water. This is particularly the case for flashings at the top of roof surfaces such as valley gutters, ridges or flashings with walls. The underside of the flashing should also be sealed. A compressible foam strip may be effective in these cases. Such strips need to be anchored in position to resist wind pressures. Turned up edges of roofing and hems and hooks on flashings are required to achieve weatherproofing and also anchor the foam strips.

6.2.4. Ceiling and wall lining materials

- Where the recommended improvements in water proofing requirements are not adopted, buildings can be made more resilient to the effects of wind-driven rain by selection of materials for linings that do not deteriorate when they get wet.

6.3. Codes and Standards

6.3.1. AS 2047 Windows and external glazed doors in buildings

- Water penetration test pressures given in AS 2047 are significantly less than serviceability pressures and do not give a clear indication of water resistance of windows. Higher test pressures are needed together with acceptance criteria that allow some controlled water ingress at high pressures.
- This investigation showed that windows under large overhangs had similar levels of leakage to those that were not protected by the overhangs. Wind driven rain is nearly horizontal, so overhangs do not reduce the level of exposure. It is recommended that all windows be considered as “exposed”.

6.3.2. AS 4420.5 Windows – Methods of test, Part 5: water penetration resistance test

The currently described test inadequately models conditions in high wind events. Observations in this wind event showed that the dam in the frame did not fill as wind pressure removed water from it into the building. Research into developing an appropriate revised test method is required.

6.4. Education

Many of the above recommendations can be addressed by education that targets product manufacturers, builders and home owners. The issues that are suitable for targeted education through technical reports, seminars, or information on appropriate websites are summarised below:

6.4.1. Window manufacturers

- Comply with strength requirements for wind ratings
- Indicate the wind rating on window labels (in accordance with AS 2047–2014)

6.4.2. Designers and Builders

- Ensure ratings on windows and doors match the wind classification for the site;
- Fasten flashings with appropriate connectors;
- Seal flashings against wind driven rain;
- Upgrade deficient or deteriorated connections in the roof structure; and
- Ensure bolts and door furniture and their connection to the door has sufficient strength for the wind rating.

6.4.3. Home owners/occupiers

- Quality of flashings and the importance of their role in preventing water ingress;
- Check gutters flashings and roofing on a regular basis to ensure that structural elements in the house stay dry and do not slowly deteriorate;
- Check and maintain seals on windows and doors;
- As part of preparation for cyclones tape up weep holes in windows and sliding doors; and
- Follow emergency service recommendations during the event eg. sheltering in small rooms, not standing in front of windows during the event.

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