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Shoalwater and Roleystone WA tornadoes
Wind damage to buildings

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TECHNICAL REPORT NO. 54

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PREFACE

Publication of this technical report continues the long standing cooperative research between the Cyclone Testing Station and TimberED. The authors Prof Boughton and Ms Falck have collaborated on other CTS damage investigations. Prof Boughton was formally a research fellow at the Cyclone Testing Station.

Logistically it was far more expedient for the TimberED team to investigate the wind damage in suburban Perth than for a CTS team to travel from Townsville. The CTS is most grateful to Geoff and Debbie for preparing this report and also to the WA Department of housing and Works for supporting this work.

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Shoalwater and Roleystone WA Tornadoes – Wind damage to buildings

Table of Contents

Acknowledgements

The Authors are grateful to a number of people who assisted in the study. These included:

- The Bureau of Meteorology WA, and in particular, Joe Courtney.
- People of Roleystone, Shoalwater and Rockingham WA who allowed us to visit their houses and take photographs, and freely discussed their building damage with us.
- Department of Housing and Works WA for part funding of the work.

1. Introduction

At around 7.40 am on Monday, 9 June, 2008, a tornado caused localised damage in the Shoalwater and Rockingham areas. The path of the tornado stretched for approximately 7 kms and damage was noted over the first 6 kms from the coast.

At around 2.30 pm on Friday 27th June, 2008 another tornado caused localised damage in the Roleystone area. This tornado passed over undulating terrain and its path of damage was around 2.5 km long.

1.1 Objectives

This study estimates wind speeds during the event and investigates the damage to buildings in the area. The estimated wind speed is compared with the design winds for this region of Western Australia presented in AS/NZS1170.2 [1] and AS4055 [2].

2. Meteorological aspects

2.1 Shoalwater tornado 9th June 2008

The Shoalwater tornado was embedded in a cold front. Figure 2.1 shows a satellite image of the cold front as it crossed the South West of WA. The red circle shows the locality that was affected by the tornado. The same event is shown in Figure 2.2, as a radar image, and again, the location of Shoalwater is shown by the red circle.

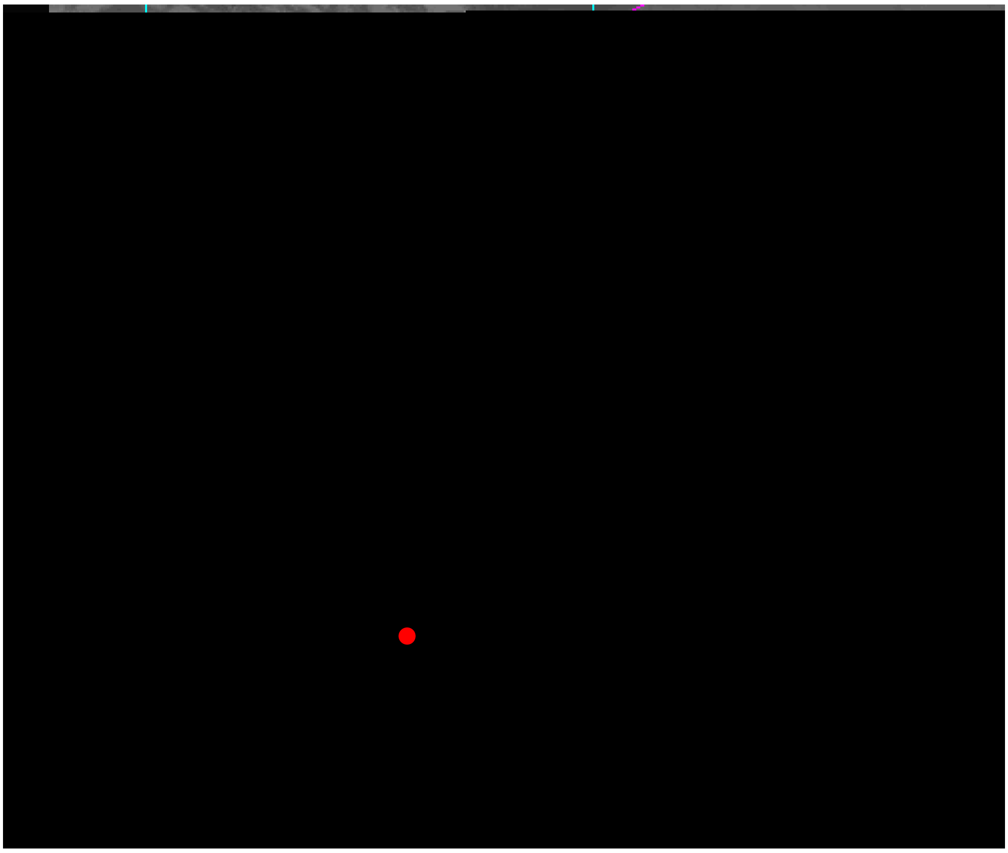


Figure 2.1 Satellite image 09/06/08 (Bureau of Meteorology WA)

Both the Bureau of Meteorology investigation and the structural investigation covered in this report noted strong evidence in the damage of a rotating column of air. This was confirmed by eye witness accounts of the same event. There is no doubt that the damage was caused by a tornado, and the diameter of the funnel was estimated to be about 30 m. This tornado was narrow enough to affect one house and leave the houses on either side completely unscathed.

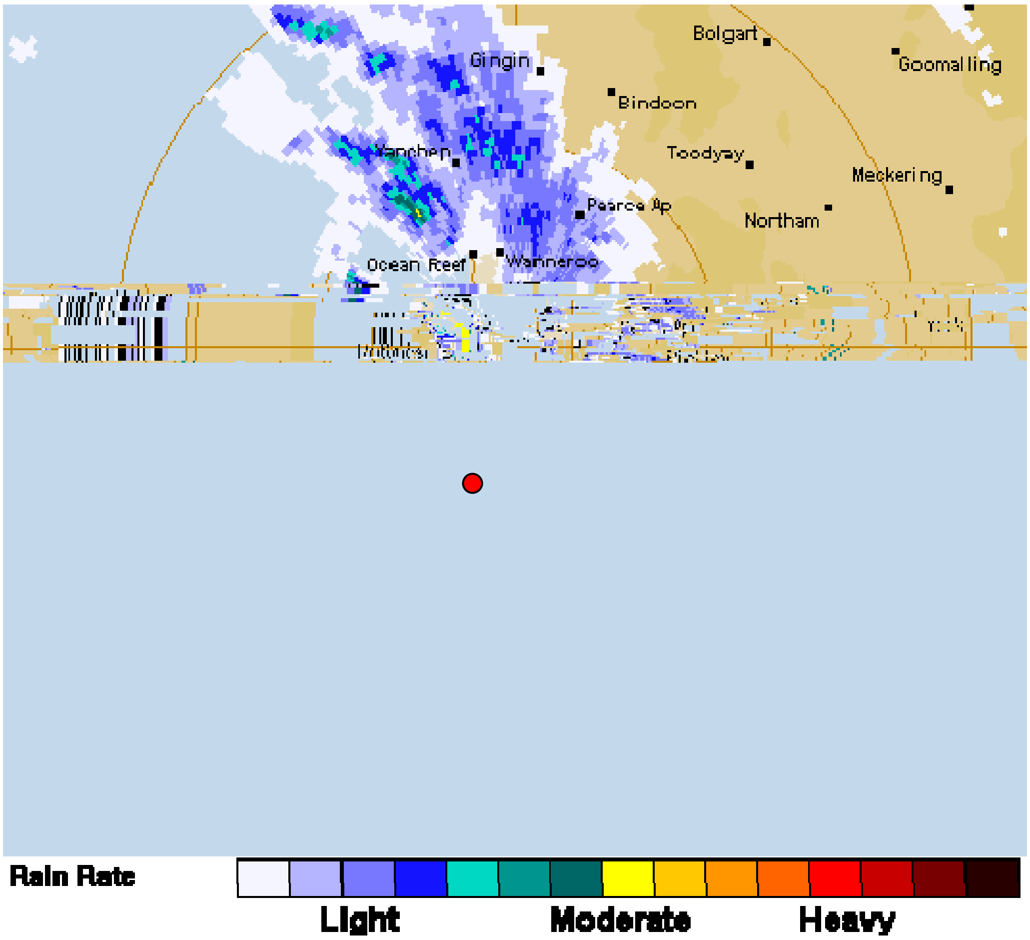
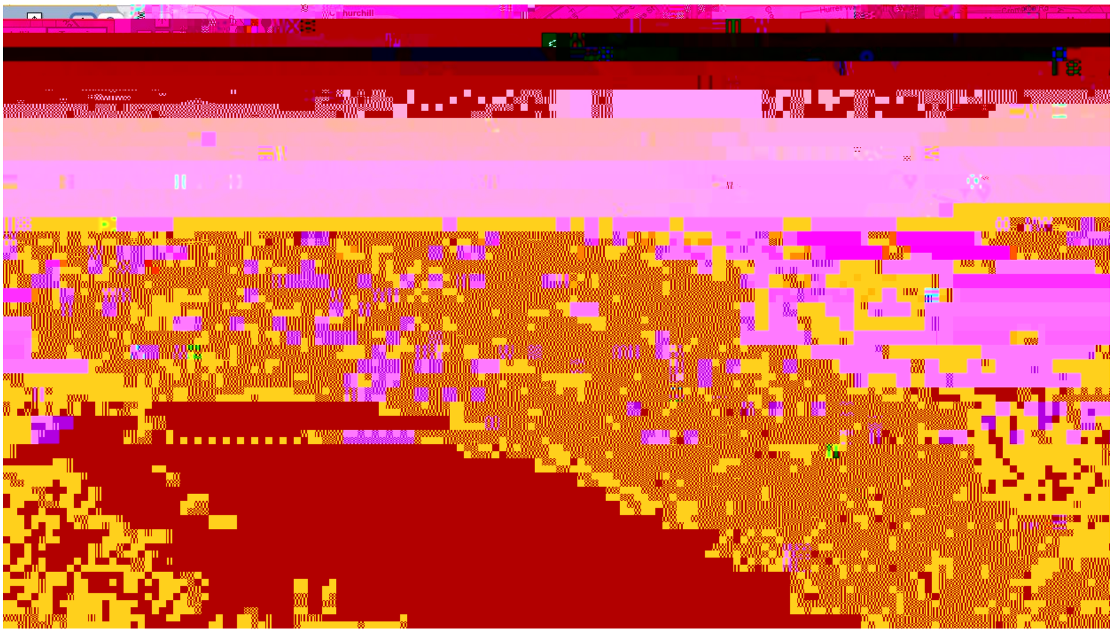
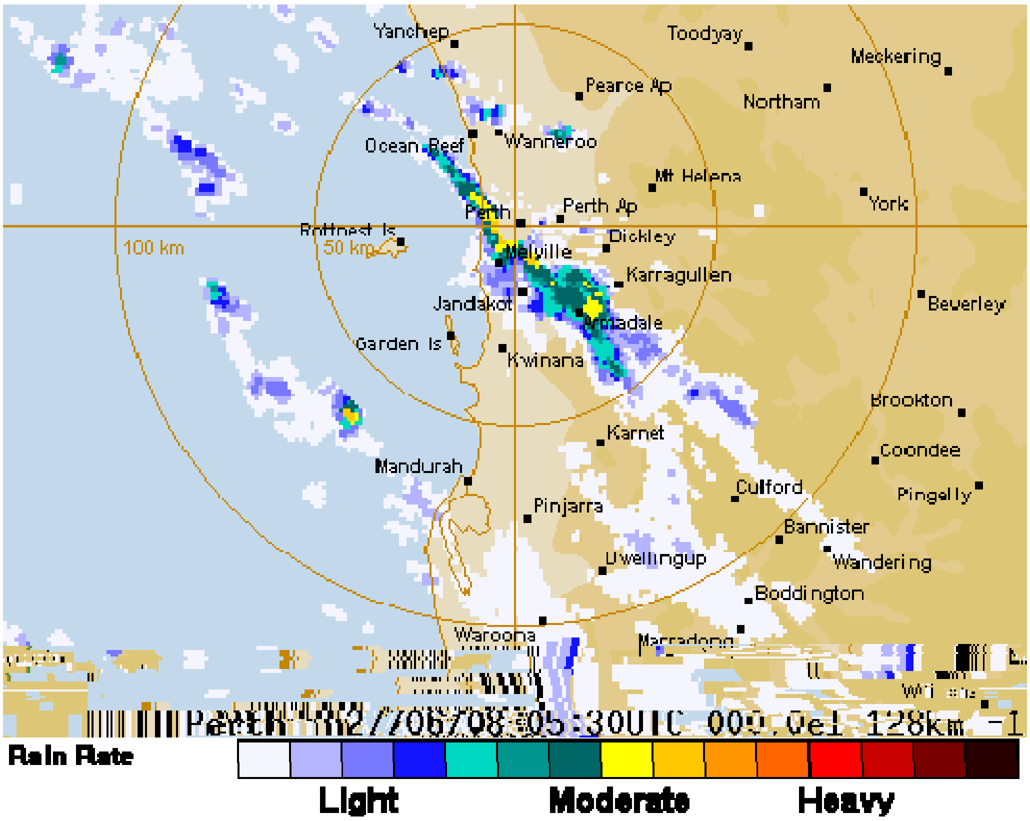


Figure 2.2 Radar capture 09/06/08 0740 WST (Bureau of Meteorology WA)

Figure 2.3 is a map of the tornado's path through the Shoalwater Bay area, highlighting some areas of damage. The fu




Yanchep
Toodyay
Meckering
Pearce Ap
Northam
Ocean Reef
Wanneroo
Mt Helena
York
Perth
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Rottnest Is
Dickley
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50 km
Melville
Karragullen
Beverley
Jandakot
Armadale
Garden Is
Kwinana
Brookton
Karnet
Coondee
Mandurah
Culford
Pingelly
Pinjarra
Bannister
Dwellingup
Wandering
Boddington
Waroona
Rain Rate
Light
Moderate
Heavy

This damage will be examined in more detail in section 4.

- The lower bound wind speed was estimated from the relatively simple structural system of roofing tied to battens which separated from the rafters. The failure required failure of approximately 30 nails at the batten to rafter

3.3 Wind speeds compared with design wind speeds

3.3.1 Shoalwater tornado

The range of wind speeds estimated in the Shoalwater tornado for both houses was similar. The best estimate indicated in Section 3.1 is 120 km/h (34 m/s) at roof height, which is close to the design wind speeds at roof height for a single storey house in flat suburban terrain in Region A given in AS/NZS1170.2 [1] and AS4055 [2]. (In AS4055 [2], the ultimate limit state wind speed for an N1 house is 34 m/s and for N2, 40 m/s.)

This estimate of wind speed is compatible with damage to trees which unless damaged by flying debris was restricted to broken branches and uprooting of very shallow rooted species.

The event could be classified as an F1 tornado according to the Fujita scale for tornado wind speeds as indicated in Table 3.1 [4].

Table 3.1 Fujita Scale for measuring Tornado intensity (Bureau of Meteorology)

F number	Wind Speed	Damage
F0	64-116 kph	Some chimneys damaged, twigs and branches broken off trees, shallow-rooted trees pushed over, signboards damages, some windows broken
F1	117-180 kph	Surface of roofs peeled off, mobile homes pushed off foundations or overturned, outbuildings demolished, moving autos pushed off the roads, trees snapped or broken;
F2	181-253 kph	Roofs torn off frame houses, mobile homes demolished, frame houses with weak foundations lifted and moved, large trees snapped or uprooted, light-object missiles generated
F3	254-332 kph	Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted, heavy cars lifted off the ground and thrown, weak pavement blown off the roads
F4	333-418 kph	Well-constructed houses leveled, structures with weak foundations blown off the distance, cars thrown and disintegrated, trees in forest uprooted and carried some distance away
F5	419+ kph	Strong frame houses lifted off foundations and carried considerable distance to disintegrate, automobile-sized missiles fly through the air in excess of 300 feet, trees debarked, incredible phenomena will occur

Figure 2.3 shows that the buildings used to estimate the wind speed in the event were in the region with the maximum damage and quite early in the track of the Shoalwater tornado. Damage levels to buildings and trees alike were much lower for the last one third of this tornado, and no structural damage was observed for the last kilometre of its track.

The maximum intensity of the Shoalwater tornado appeared to be F1, and it is likely that it was F0 for the last two or three kilometres of its track.

3.3.2 Roleystone tornado

The first half of the Roleystone tornado passed over a large number of houses, and in this half, the wind speeds were estimated to be less than the wind speeds in the Shoalwater tornado. The tornado was likely an F0 event for this portion of its path.

In the second half of the Roleystone tornado, after the path had crossed a forested ridge, the intensity appeared to increase to a high F1 or low F2. There were no houses in the direct path of the tornado in this region, but some just outside the path were significantly affected. The wind speeds at those locations were difficult to estimate.

3.3.3 Wind speed at houses compared with design wind speed

The Scope of AS/NZS1170.2 [1] excludes its use for determining wind speeds and resulting wind actions caused by tornadoes. This is because of the following uncertainties in tornado wind actions:

- Both the variation of wind speed with height and turbulence intensity are not known for tornadoes, so the $M_{z,cat}$ term used to establish gust wind speed at the structure from the regional wind speed cannot be evaluated.
-

the Shoalwater tornado was across flat topography and all but the start of the path, the terrain category would have been classed as Terrain Category 3. The shielding varies, but in the recent housing, it was sparse enough to be regarded as partial shielding. For only a small part of its track, could the housing be regarded as fully shielded. The entire path is in wind region A.

- The design wind speed of 34 m/s given in AS4055 [2] is the ultimate wind speed for N1 housing corresponding to the design conditions outlined above.
- The design wind speed of 33 m/s given in AS/NZS1170.2 [1] is the ultimate (500 year return period) wind speed for 3 metre high buildings designed for the conditions outlined above including partial shielding.

The estimated peak wind speed in the tornado was very close to the design wind velocity for all of the modern housing in its path.

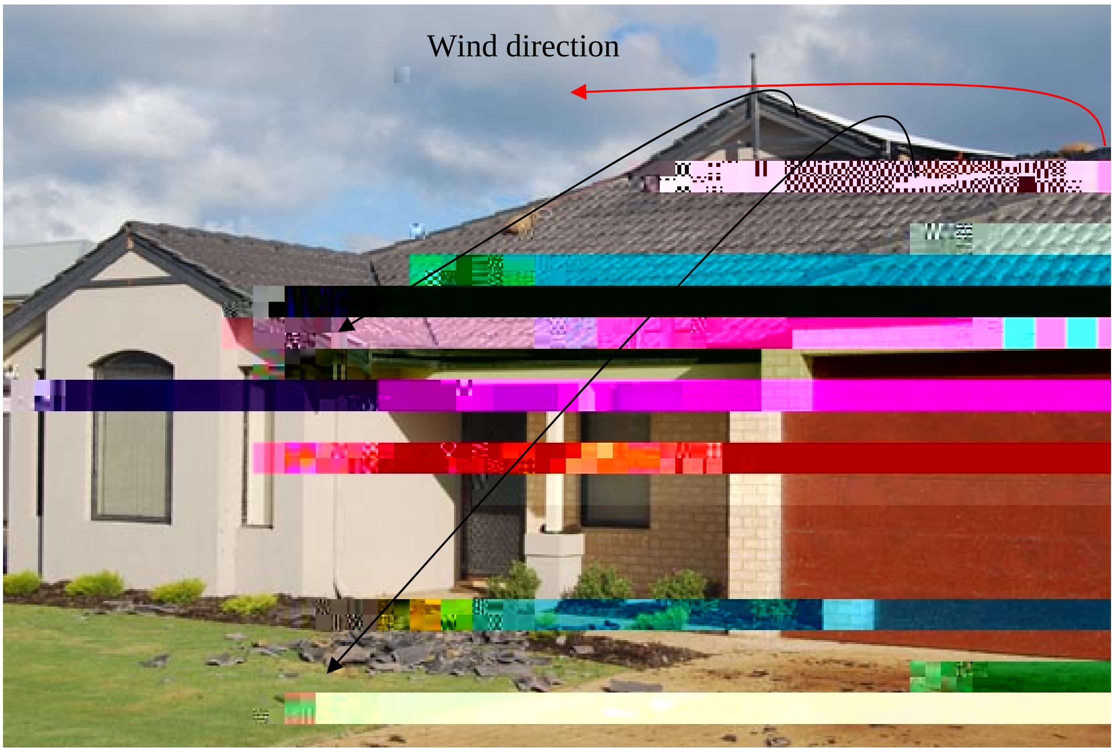
The path of the tornado in Roleystone passed over undulating topography. Many of the houses had topography class T2 and partial shielding. This put them into wind classification N2 and N3. Their construction details should have been matched to wind speeds of 40 m/s or 50 m/s, well in excess of the wind speeds in the first half of the tornado. (In the first half of the Roleystone tornado, the wind speed was estimated to be significantly less than 34 m/s.) Hence, even houses in N1 locations on this path should not have experienced winds near their design wind speed, 34 m/s.

4. Damage to buildings

The damage indicated that the tornado had a width of around 30 m. It was estimated that over the 7 km of the track that it affected over 200 houses, and the State Emergency Service respondth o20 1 Eergen0 calls from the suburbs that includth ohe tornado path. Even ohough some of these mayhave been oo deal with fallen orees, ohe figure is large enough oo indicate that ohere were more houses affected by the tornado than ohose that were in its direct path. The SES also reported that 1 Eerg15 houses had been 'unroofed', ohough this statistic may includt a number that had lost less than half of the roof or roofing.

The roof damage observed was commensurate with wind pressures and suctions from high speed wind. The study did not ttempt oo examine each damaged building, but sought oo examine in some detail damagethat was seen as quite typical.

4.1 Wind damage to modern oiled roofs



(a) oiled roof with wind damage

A number of tiled roofs suffered some damage. In the Perth metropolitan area, standard practice is to nail down every second tile, and every attempt is made to stagger the pattern at each row. Each tile that is not anchored has an anchored tile on either side of it, and in most cases, an anchored tile above and below it.

In a few cases, the damage could be entirely attributed to wind pressures alone. In most cases, the damage was associated with debris impact on the tiles.

Figure 4.1 shows a roof with incidental tile damage in areas of the roof that would have experienced very high suctions under wind actions alone. In the affected area, there was no sign of debris impact and many of the tiles had been removed with little breakage. In some cases, the nail used to anchor the tile was still in place in the tile.

The tiled roof used for wind speed estimation and illustrated in Figure 3.2 also experienced wind damage to tiles. In all of these cases, relatively small areas of roof were affected by the tile damage. It was only parts of the roof close to the intersections of roof planes (hips and ridges) that were subjected to tile loss. This indicates that at the design load, the highest loaded regions of the roof are close to their capacity.

Figure 4.2 shows a roof panel that experienced particularly high suctions, and it can be seen that while the tiles just below the ridge are still intact, they have almost lifted off. The tiles near the hip have been lifted by the wind.

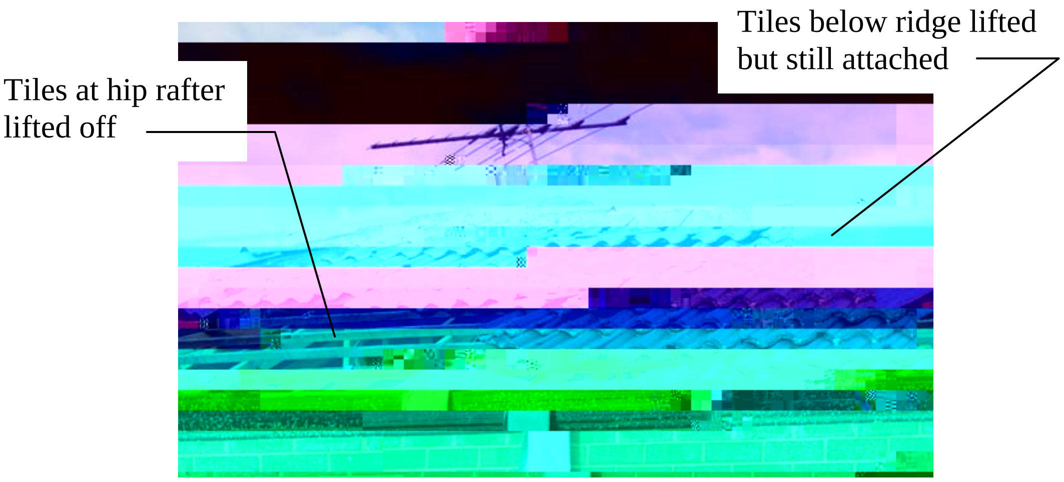
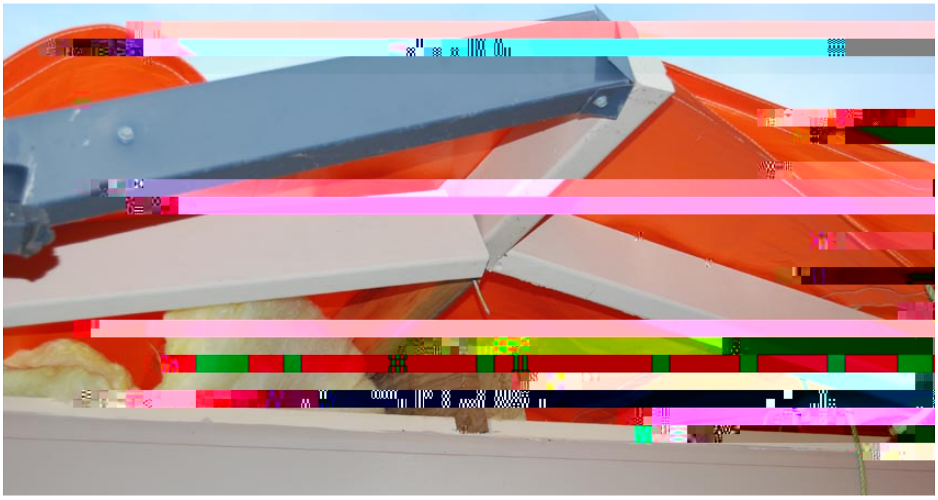


Figure 4.2 tiles in high uplift regions of the roof.

The estimated tornado wind speed was sufficient to lift individual tiles under external suctions. As the estimated tornado wind speed was close to the design wind speed for this location, the design wind speed is also sufficient to lift individual unfastened tiles. In peak suction areas of hip roofs, uplift forces exceed the weight of the tile at gust wind speeds of between 25 and 30 m/s.

In this case, the battens were light gauge top hat sections, and the light gauge steel tore over the batten fasteners. The trusses were nailed into timber top plates which were anchored by direct nailing to the brickwork and steel straps. Figure 4.8(b) shows that the top plate has lifted in some places, but the straps had held sufficiently to keep the roof attached to the top of the walls.

Figure 4.8 showed a house that had very recently been occupied and where the trusses were tied to brick walls. Figure 4.9 shows details of a house that had been occupied for around two years and the trusses had been anchored to framed walls.



(a) failure of truss anchorage

(b) lifted roof battens near corner of roof

Figure 4.9 Truss loss from framed walls

In Figure 4.9, all of the trusses had lifted a little from the walls. For two trusses, the lifting had not been stopped, but in all of the others, once the slack had been taken out of the connection, the upward movement stopped in a few mm. Figure 4.9(a) shows one of the truss heels that had lifted.

The main cause of the loss of roofing was the two nail connection between battens and rafters. On this house a bugle head screw had been used for the edge batten to rafter connection. Many of these connections were adequate, but the rest of the roof used two nails and in some cases, loss of the rest of the battens had increased load on the bugle head screws to cause them to withdraw as well. Figure 4.9(b) shows the corner of the roof where all of the battens had lifted but the roof had not completely detached in this area.

For this house, the topographic class from AS4055 was higher than T1, and this should have been taken into account in the design of the house. Its wind classification was N3.

In considering the construction details used for this house, AS1684.2 [5] Table 9.14 showed that the required batten to rafter force was 2.3 kN within 1200 mm of the edge of the roof and 1.2 kN in the remainder of the roof. AS1684.2 [5] Table 9.25 shows that two nails have a capacity of 0.64 kN, and one bugle head screw has 4.5 kN.

Thus in this roof, the edge batten had excess capacity 4.5 kN to meet an uplift demand of 2.3 kN, but the next batten in from the edge (also within the edge zone), had a connection capacity of only 0.64 kN to m

It is well accepted that in Tropical Cyclone prone areas, designers must assume full internal pressurisation. This has been differentiated from other strong winds by the duration of the event. However in this event, the extreme winds lasted only a few seconds and internal pressure still played a significant role in structural damage.

4.4 Debris damage

Debris damage is not often considered for short duration wind events, but there are references to debris damage in tropical cyclones in the Australian wind code AS1170.2 [1].

However, there were a number of houses that were damaged by debris in both tornadoes. In some cases, the debris was released from the rotating column of air and struck buildings that were not directly in the path of the tornado.

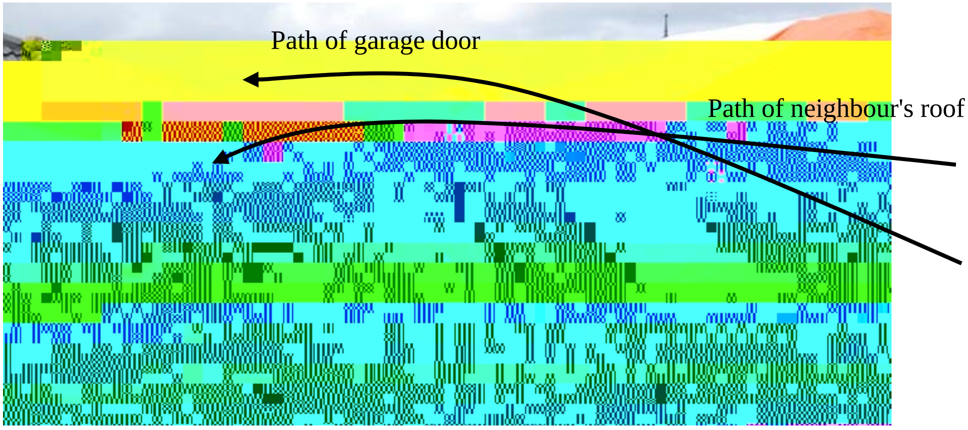


Figure 4.13 Debris damage to tiled roofs

In Figure 4.13, the house on the left was clear of the tornado's path, but sustained debris damage to both the roof and window from sections of a neighbour's roof. The

Figure 4.14 shows debris from just one house that produced at least five large sections of roof. Three of these can be seen in this photo together with some of the roof insulation. It is fortunate that this house was located in a rural setting, as it is clear that the debris generated would have substantially damaged any building it struck. However, in suburban areas, windows were broken by flying debris as shown on the left of Figure 4.13.

This report has demonstrated that short duration wind events generate debris. In a number of houses, wind borne debris broke windows that contributed to full internal pressurization.

4.5 Racking failure

A garage in the direct path of the tornado, shown in Figure 4.15, failed due to racking at loads well below the appropriate design load for the location.

The failure was due to inadequate fastening of the bracing. The bracing appeared to have been intended for squaring the garage during construction. rather than for resisting the wind forces. The single skin cladding was a weatherboard type product ee oofferin

5.3 Roof structure connections – struts, underpurlins and strutting beams

Poor performance of underpurlin, struts and strutting beam connections contributed to loss of the entire roof structure under sheet roofing in the Shoalwater tornado. The information required to correctly select and apply this detail is clearly outlined in AS1684.2 [5]:

- The wind classification of the house is found from AS4055 [2].
- Table 9.12 in AS1684.2 [5] can be used to select a force from the roof type, wind classification, roof load width, and fixing spacing.
- Table 9.23 in AS1684.2 [5] can be used to select appropriate connections to resist wind uplift forces. Even in N1 houses, skew nails do not offer enough resistance in softwood members for most sheet roofs. Looped straps are required.

5.4 Top plate to masonry connection

Failure of the top plate to masonry connection was noted in a number of houses with sheet roofs, and may have occurred in others where there was no visible external damage, but the cornices or ceilings were cracked.

Nailing the top plate to the top row of bricks does not offer sufficient resistance to uplift for any sheet roof. Straps anchoring the top plate must be secured to a sufficient depth of brickwork as indicated for rafters or trusses to external walls in Clause 3.3.3.3 of the BCA [7].

The BCA covers anchorage of rafters and trusses to external walls, but in stick-built roofs, there is also a need to anchor the base of struts and strutting beams that carry

5.5 Verandah details

In some cases, verandahs are not designed or constructed as rigorously as the rest of the house. Where verandahs are constructed under the main roof and verandah details have insufficient capacity to resist wind loads, failure of the verandah can lead to failure of sections of the house roof.

Verandah roofs can experience higher uplift loads than the remainder of the house roof. Verandahs always have full windward wall pressure pushing upwards on the underside of the roofing together with peak suction pressure on the upper surface of the roofing.

5.5.1 Batten and rafter spans

Figure 5.1 shows a verandah with batten spacings of 1.2 m when the house to which it was attached had spacings of 0.9 m.

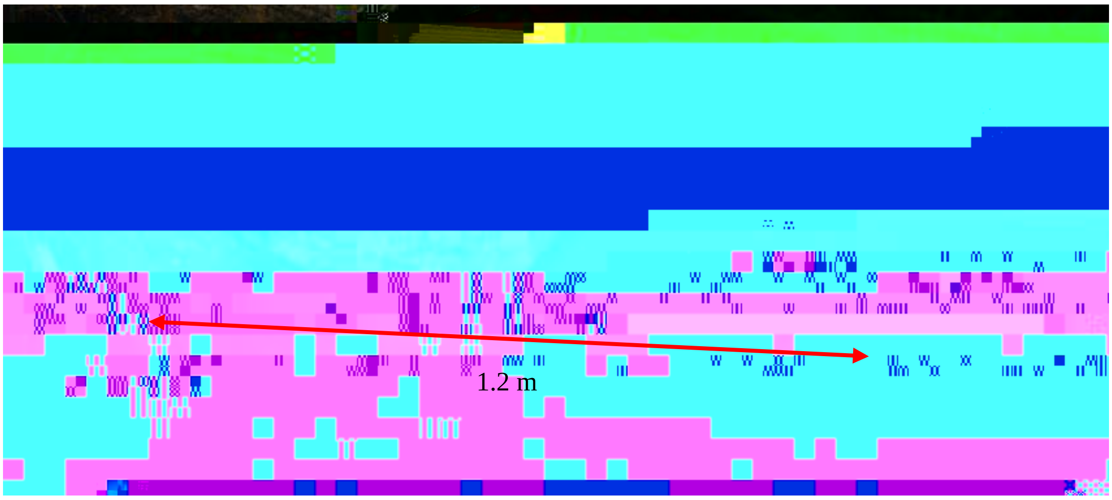


Figure 5.1 Batten spacing on verandah

The spacing of verandah battens and rafters must be smaller or equal to the spacings used in the main roof. Batten to rafter connections must have the same or greater capacity as the batten to rafter connections in the main roof.

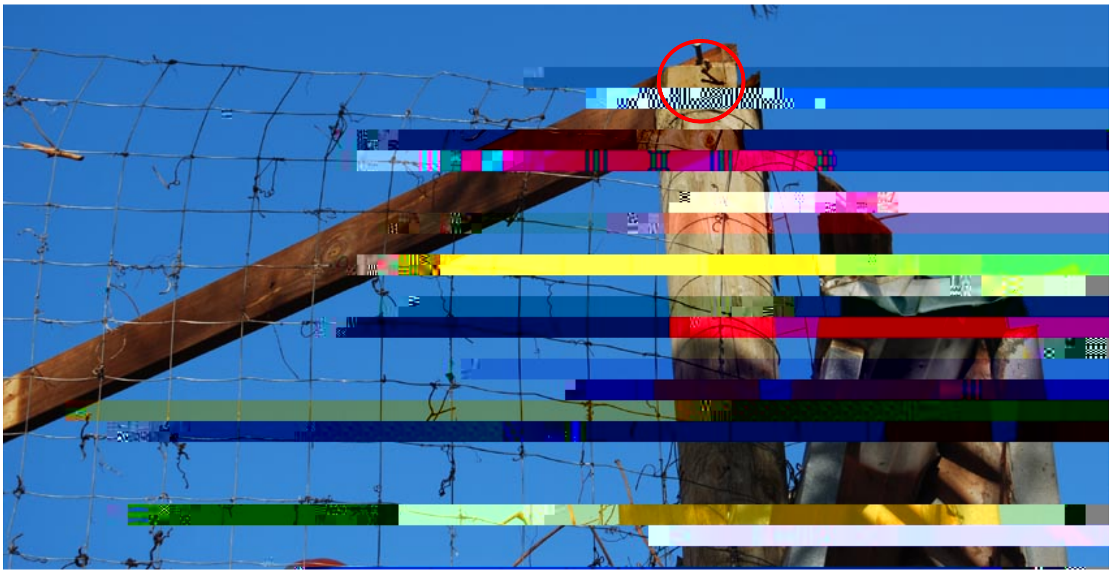
5.5.2 Beam to post connection details

Figure 5.2 shows a verandah beam to post connection that failed under wind load leading to loss of both the verandah and main roofs. This connection was made with two nails, but two M16 bolts are specified in AS1684.2 [5].

The information required to correctly select and apply this detail is outlined in AS1684.2 [5]:

- The wind classification of the house is found from AS4055 [2].
- Table 9.13 in AS1684.2 [5] can be used to select a force from the roof type, wind classification, roof load width, and spacing between beam to post connections.
- Table 9.20 in AS1684.2 [5] can be used to select appropriate connections to resist wind uplift forces.

(a) Verandah beam



(b) Verandah post

Figure 5.2 Verandah beam to post connection

5.6 Wind Classification

A number of houses on sloping ground were in the direct path of the Roleystone tornado and sustained no structural damage. If these houses had been correctly classified as N3 houses, the construction details would have been more than adequate to resist the winds estimated for that event. However, in the same location, damage was caused to some buildings that had details more appropriate for N1 housing.

full internal pressurization. Standards Australia should give consideration to amending clause 5.3.2 in AS/NZS1170.2 [1] to include buildings in all regions.

7. References

[1] Standards Australia (2002) “AS/NZS 1170.2 – Structural design actions, Part 2: Wind actions”, Standards Australia, Sydney NSW

[2] Standards Australia (2006) “AS4055 – Wind loads for housing", Standards Australia, Sydney NSW

[3] Xu, Y.L., and Reardon, G. F., (1998) "Variations of wind pressure on hip roofs with roof pitch", Journal of Wind Eng. Ind. Aerodyne. 73 pp. 267-284.

[4] Bureau of Meteorology (2008) Notes on tornadoes. Web address (*bom.gov.au*)

[5] Standards Australia (2006) “A