CYCLONE
TESTING
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Investigation of Townsville Tornado, 20 March 2012

Report: TR58
June, 2012

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SCHOOL of ENGINEERING and PHYSICAL SCIENCES
JAMES COOK UNIVERSITY

TECHNICAL REPORT NO. 58

Investigation of Townsville Tornado, 20 March 2012

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June 2012

Bibliography.
ISBN 978-0-9808572-6-9 (pbk)
Series: Technical report (James Cook University, Cyclone Testing Station); 58
Notes: Bibliography

Henderson, D. J. (David James), 1967-.
Investigation of Townsville Tornado, 20 March 2012
1. Tornado 2. Buildings – Natural disaster effects 3. Wind damage
I. Ginger, John David (1959-) II. Kim, Peter (1982 -) IV. Sumant B. (1983 -) V. James Cook University. Cyclone Testing Station. VI. Title. (Series : Technical Report (James Cook University. Cyclone Testing Station); no. 58).

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Acknowledgements

We acknowledge the support and assistance of the Qld Dept of Community Safety, Bureau of Meteorology, and the Mayor and officers of the Townsville City Council during this damage investigation. We also acknowledge the ongoing support of the Qld Dept of Public Works.

The CTS is very grateful to the residents who generously assisted this survey by volunteering information, answering questions and on occasions inviting the authors into their houses to inspect damage.

The CTS appreciates the assistance and advice from;

Kevin Anderson (Queensland Fire and Rescue Service)
Jim Davidson, Bruce Gunn, Jeff Callaghan, Doug Fraser, Mats Einerman (Bureau of Meteorology)
Bruce Harper (GHD)
Matt Mason (Macquarie University)
Mick Chay (CPP)
Yetta Gurtner (James Cook University)
Anne Henderson (CSIRO)

Contents

1. Introduction

Severe winds impacted areas of Townsville in the morning of 20 March, 2012, damaging houses and commercial properties. Damage to buildings ranged from minor such as loss of guttering to the loss of complete roof structure and some walls.

The Cyclone Testing Station (CTS) conducted a damage survey across parts of suburbs in Townsville (Garbutt, Vincent, Gulliver, Aitkenvale and Annandale), commencing on the day of the event. Detailed inspections were conducted on several properties. The investigation did not assess damage to other infrastructure such as power or communications. In addition the Queensland Fire and Rescue (QFRS) provided data from their rapid response street survey.

2. Wind speeds

An estimate of the wind speeds and storm type is required in order to evaluate the resilience of housing and other buildings subjected to these winds.

2.1 Meteorology

The Bureau of Meteorology operates an Automatic Weather Station (AWS) and a Dines anemometer at the Townsville airport in open terrain. The gust and mean wind speed measured at 10 m height, along with wind direction are given in Figure 2.2. The barometric pressure and corresponding approach wind direction (i.e., from the North is 0° and from the East is 90°), are presented in Figure 2.3. The 3 second average gust wind speed measured was 111 km/h (31 m/s) at 5:07 am, accompanied by a rapid change in wind direction. The Dines anemometer located adjacent to the AWS 3-cup anemometer measured a peak gust of 135 km/h (38 m/s).

Following an analysis of the available meteorological data including radar, the Bureau of Meteorology assessed that the destructive winds were likely caused from a tornado, and summarises the event as follows:

<u>Summary of event</u> *(courtesy of Bureau of Meteorology#)*

On Tuesday morning 20 March, a monsoon low was located over northwest Queensland. Rainbands were observed on the southern and eastern sides of the system and warnings indicated that damaging wind gusts were expected in these areas. At around 5am a storm embedded within a rainband affected suburbs near and south of Townsville Airport. On radar the storm showed signs of organised structure, suggesting strong updrafts were present. The morning wind sounding from Townsville airport showed moderate to strong lower atmospheric winds of 30 to 40 knots and very strong helicity, or potential for rotation, in the lower atmosphere. These factors suggest that the environment was favourable for formation of a tornado, and that this is the most likely phenomena to have caused the observed damage.

Other points of note:

- *Maximum wind gust of 135kmh at the Townsville Dines anemometer, the system was likely stronger further south than this.*
- *The storm wasn't a classic supercell, as would normally expect to spawn tornadoes. However, there was a large area of thunderstorms, multi-cell of mesoscale convection system (MCS) which showed organisation as thunderstorms developed within it.*
- *Separate reports of 50kt winds from a ship at sea and of estimated wind gusts to 90kmh and a trampoline blown into a property at Saunders Beach at around 4:07am suggest that the broad environment was favourable for waterspouts or tornadoes over much of the broader Townsville region.*

(26/3/2012)

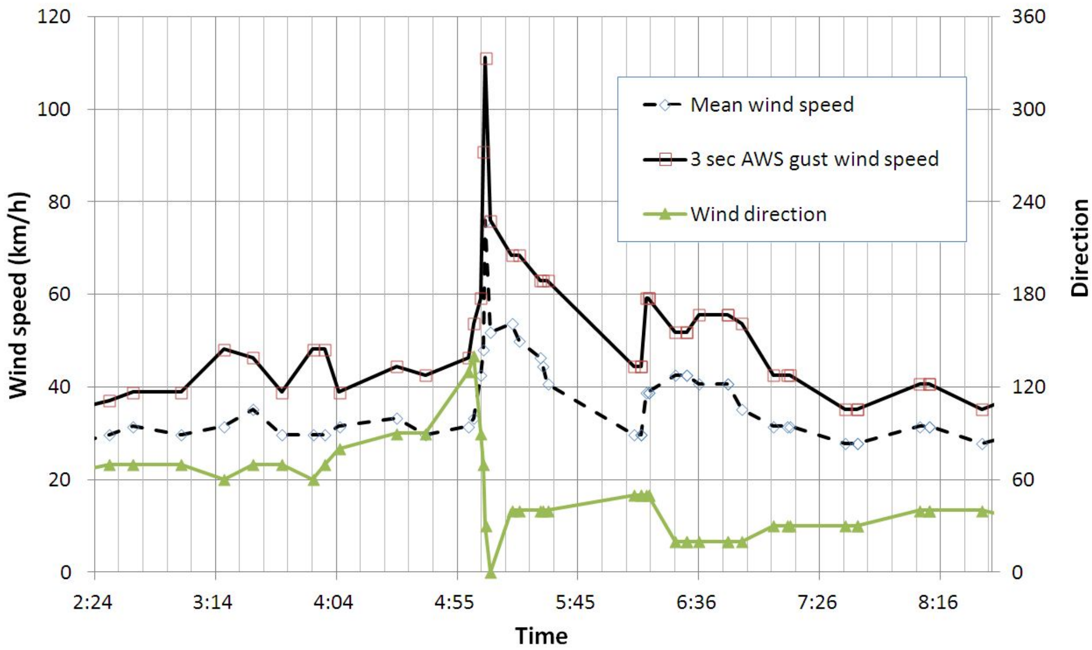

Figure 2.1: Wind speed and direction measured at the AWS-Townsville Airport
(Data courtesy of Bureau of Meteorology)

Figure 2.2: Gust and mean wind speeds measured at the AWS-Townsville Airport (Courtesy of Bureau of Meteorology)

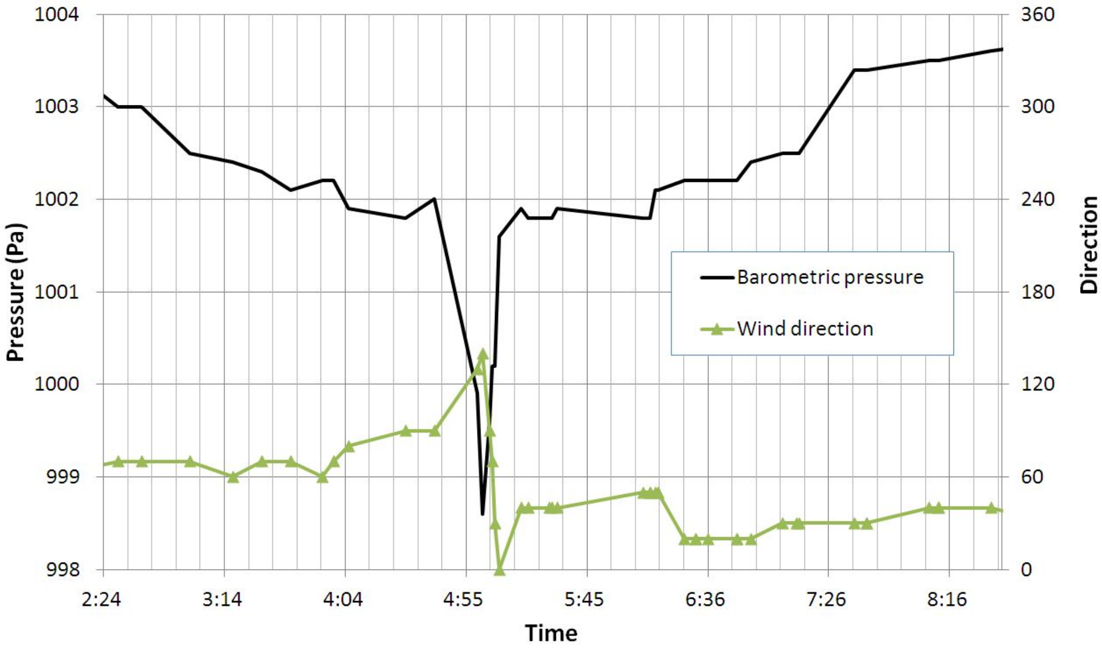

Figure 2.3: Pressure and air temperature measured at the AWS-Townsville Airport
(Data courtesy of Bureau of Meteorology)

2.2 Storm size

An overview of the observed damage footprint is shown in Figure 2.4. The storm track is devised by analysing the observed building damage and windborne debris patterns. The path runs for approximately 7 km in a NNW to SSE direction from Garbutt to Annandale. Vegetation damage (e.g. snapped and uprooted trees) was in a corridor of less than a kilometre wide with the observed structural damage in an inner 0.5 km band within this path.

Residents reported the event occurring between 5:05am to 5:30am, and lasting from a few minutes to half an hour. Some residents noted that the wind seemed to quickly change direction over the course of the event. Some residents from the severely impacted areas indicated that wind first came from a northerly direction. A resident whose property was approximately 100 m to the west of severely damaged houses in Vincent noted that the winds came from the south and then returned from the north-west. Residents told of water (wind driven rain) being jetted into the house from different directions.

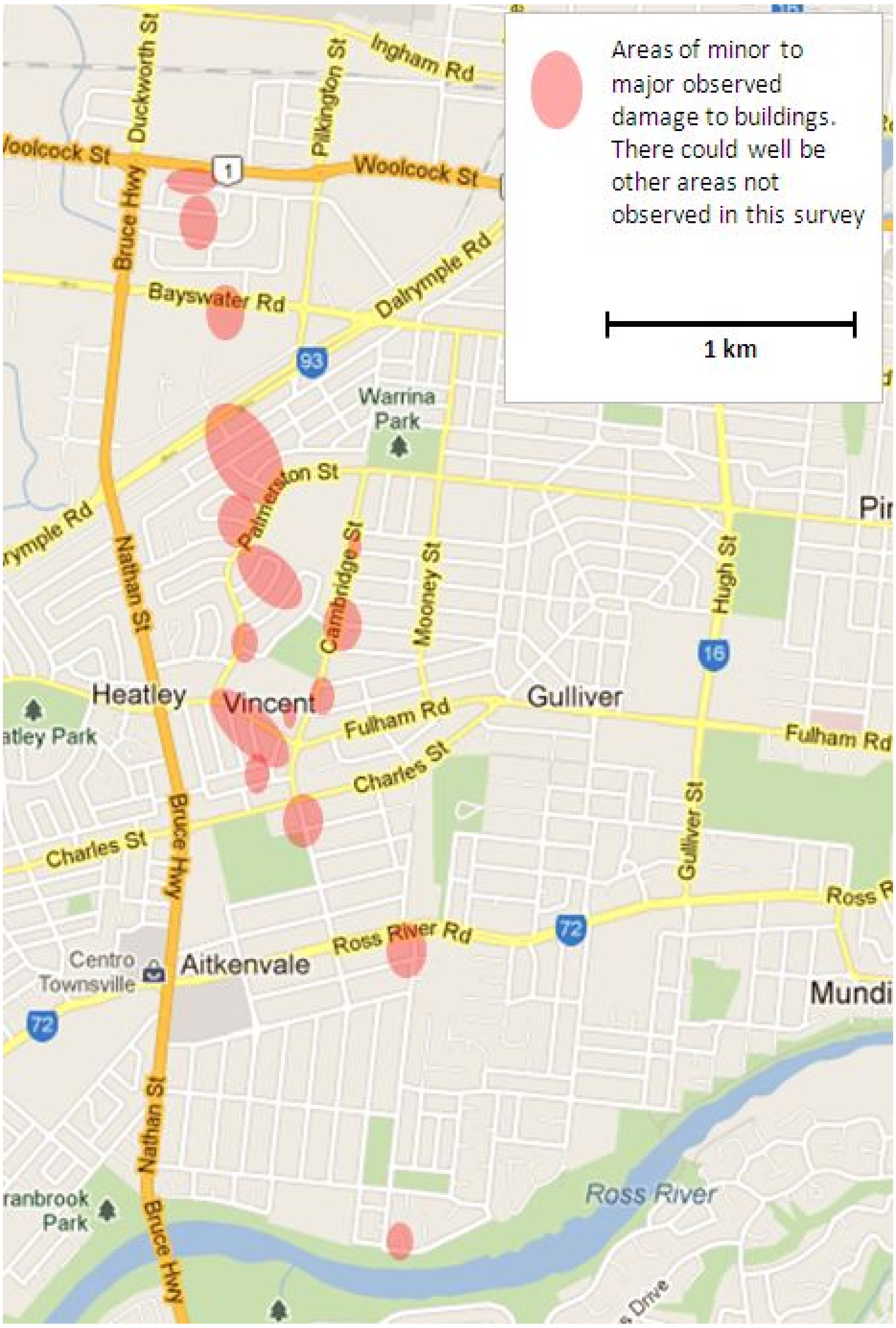

Figure 2.4: Overview of damage footprint
(Base image reference: Google Maps, 2012)

2.2.1 Wind direction

The damage survey also tracked windborne debris and snapped and fallen trees to determine wind directions during the event. Changing wind directions during the event will cause the debris to move in a composite path, thus only giving a general wind direction at a location of interest. The wind directions, summarised in Figure 2.5, are based on building damage, bent road signs, debris locations and vegetation damage.

The oval shown in Figure 2.5 highlights a region of tree damage along Dalrymple Rd (diagonal road running NE across near the top of figure). These trees are a mix of similar species planted in the same periods and were subjected to “similar” approach terrain winds. There is a pattern of tree damage directions (mix of up-rooting and snapping) pointing towards the centreline of the storm track (where the major damage to housing occurred). This indicates convergent wind direction associated with a tornado passage unlike divergent flows which might be expected in a thunderstorm down-burst event (ref: email correspondence; B. Harper and M. Mason, April 2012).

There was also substantial damage to trees near the river (Aitkenvale and Annandale sides) and adjacent to University Road. The extent of damage did not appear as severe as in Vincent.

2.2.2 Estimate of gust wind speeds

Cantilevered road signs (Windicators) provide a means of obtaining a measure of the gust wind speeds in the surveyed areas. These signs are generally flat plates that are attached to one or two cantilevered posts and located in exposed flat terrain adjacent to the road. The wind loads acting on these plates can be calculated and upper (U) and lower (L) bound wind speeds from signs that were bent-over and those that remained upright, as described by Ginger et al (2007).

An analysis of road signs in the Garbutt and Vincent areas, were used to estimate the gust wind speeds required to bend the signs. The analysis indicates peak gust wind speeds in the order of 50 m/s (referenced to 10 m height in open terrain). Due to the small geographic scale of the event and the sodden ground, only a few road signs were suitable to use as windicators. In addition, characteristic wind profile in thunderstorm and tornado events vary from those in tropical cyclones and gales. Therefore estimates of gust wind speeds here are based on limited data and have greater uncertainty than calculations based on tropical cyclone winds.

From the analysis of windicators and based on experience from the observations of damage to housing and other buildings it is estimated that the gust wind speeds referenced to 10m height in open terrain were in the range of 45 to 55 m/s (160 to 200 km/h). These intense wind speeds are variable over the area of impact of the storm, with this variability also evident in the patchy damage to buildings and vegetation.

Figure 2.5: Wind directions estimated from debris locations and tree damage
(Red oval marking the tree fall/damage along Dalrymple Road; Base image reference: Google Maps, 2012)

2.3 Design wind speeds

The Australian Building Codes Board (ABCB) publishes the Building Code of Australia (2011) which stipulates design parameters for the majority of buildings in Australia These requirements are met by compliance with a range of Standards relating to building construction (e.g. AS/NZS1170.2:2011). Codes and standards have been used in the design and construction of engineered structures in Australia, for several decades. However the wind loading standard excludes tornados from its design provisions (Holmes et al. 2012).

Houses in Townsville and Darwin suffered significant damage during Cyclone Althea and Cyclone Tracy, respectively in the 1970s. This precipitated the development of the Home Building Code of Queensland (1981) as an Appendix 4 to Standard Building by-laws, which was in widespread use by the mid 1980s. This required houses to be categorised by a site design wind speed, and it contained deemed to satisfy structural detailing for the houses in each category.

Townsville is located in Cyclone Region C as defined in AS/NZS1170.2:2011, where the ultimate limit state design wind speed (at 10m elevation in flat open terrain) is 69 m/s. The design wind speed at the roof height of the building is factored to account for the terrain, height and the topography. This factored design wind speed impacting on the building can be related to the pressures exerted on its elements through a series of coefficients defined in the wind loading standard, AS/NZS1170.2:2011.

Clause 5.3.2 of AS1170.2:2011 requires that in cyclonic regions of Australia internal pressure from a dominant opening shall be applied unless the building envelope can withstand a specific windborne debris impact along with the appropriate design net pressure. In addition, current houses are typically designed to AS4055 “Wind loads for housing” (2006) which states that housing in cyclonic regions are designed assuming a dominant opening can occur resulting in a large design internal pressure. Therefore with the estimated gust wind speed for the event being less than the regions design wind speed, minimal structural damage should be observed in housing constructed to current building standards, notwithstanding the differences in wind and pressure field between a tornado and typical boundary layer wind flow.

3. Damage to buildings

An analysis of the street survey data sets collected by the QFRS and by the CTS, showed that approximately twenty houses suffered significant damage with loss of all or sections of roof, while approximately 90 houses suffered moderate to minor damage including damage from windborne debris. At least a dozen commercial buildings suffered significant damage. The CTS street survey provides an overview of types of damage observable from the street, however, damage to the rear of a structure may be missed. The street survey therefore provides an overview of overall damage types and extents. By end of March, the Townsville Bulletin (25/3/2012 and 29/3/2012) reported that nearly 400 houses had suffered some form of damage with 33 houses suffering significant damage.

3.1 Houses

The windstorm's path through Vincent and Aitkenvale impacted on areas containing housing built prior to the 1980s, before the introduction of current housing design criteria.

Damage ranged from windborne debris impact to walls and windows, wind driven water ingress, loss of guttering, to the loss of roof cladding and roof structure.

Typically, the loss of roofing consisted of the timber battens attached to the cladding as shown in Figure 3.1. In these cases the battens were only nailed to the rafters and the nailed connections did not have sufficient load carrying capacity. Building standards for current construction require the roof battens to be screw fixed or strapped to the rafters as detailed in AS1684.3 (2005).

Loss of roof structure in one of the houses was observed at the timber over-batten. The timber over-batten appeared to have failed at the large checked recess as shown in Figure 3.2. This recess is required for the embedment of the end of the steel tie down rods as shown in Figure 3.3. This is a connection type used in some older housing prior to the introduction of current standards.

Inspection of this same two storey house also revealed that the house had translated at the floor bearers on the ant caps to the south by approximately 50 to 80 mm. The house was supported on concrete stumps, typical for its age. The perimeter piers had cranked tie down rods to the floor bearer, as shown in Figure 3.4(a). These connectors had rotated in direction of house movement. No hold-down rods were observed in any of the interior concrete piers as shown in Figure 3.4(b).

Many of the severely damaged houses had a windward dominant opening. For one case where the house had lost its roof, all windward windows and door appeared intact. However the resident noted that a few windows were left open to allow a breeze during the night. The suddenness and early hour of the storm precluded the resident having sufficient time to shut them during the event.

There was a pattern of extensively damaged houses which were exposed to the storm approaching from the northerly direction across open spaces (e.g. parks). These houses were subjected to higher wind speeds than those located downwind and afforded some shielding.

Reinforcing the patchy nature of the observed damage along the storm's path, housing of similar age to those in Vincent, to the south of Vincent, at the ends of the parks near Anne St, and Charlotte St suffered less damage.

Figure 3.1 Roof cladding attached to battens (battens were only nailed to rafters)

Figure 3.2 Checked recess in overbatten for rafter tie down

Figure 3.3 Tie down rods that were connected to the overbatten

Figure 3.4 (a) Rotated cranked rod, (b) House shifted on piers

3.2 Commercial buildings

Several commercial and light industrial buildings were damaged in both the Garbutt and Aitkenvale areas. Damage ranged from windborne debris impact, roller door failure, cladding loss and damage to structural members.

Sections of roof cladding were removed from at least four light industrial sheds. The sheds had portal frames spanning nominally E-W with the apex running N-S. Two sheds had failed doors one a failed large window, while the other shed was open at either end. All sheds had suffered damage from debris impact.

One large shed shown in Figure 3.5 said by the owners to be at least 30 years old with substantial roofing failure was inspected in detail. Its corrugated roof cladding was screwed to the purlins in a 3-4-3 pattern which is indicative of fixing patterns used prior to the current building standards. This fixing pattern has less than half the capacity during dynamic loading than current installation methods with screws in every alternate crest. The windward portal was clad from apex to knee and the leeward was clad from apex to approximately half frame height. Both these windward and leeward end "walls" were bowed due to the wind load. Several of the simple-span (i.e. non-lapped) cold formed Z purlins were buckled from a combination of axial loading and wind uplift. The purlins had no bridging.

An adjacent shed, shown in Figure 3.6 of similar size was subjected to a windward dominant opening from loss of roller door and debris damage from an old awning structure from across the road. The shed had a minor amount of roof cladding peeling up at locations along eaves with the cladding fixed to the purlins at every alternate crest.

Several examples of failures of large doors were observed as shown in Figure 3.7. The majority of these were roller doors. Failure of sliding doors on one shed was observed as shown in Figure 3.8. One roller door that had been replaced after Cyclone Yasi and was fitted with wind locks, generating large membrane forces to be developed which transferred the failure to the mullions as shown in Figure 3.9.

Figure 3.5: Loss of cladding and buckled purlins

Figure 3.6: Debris damage and broken roller door on “windward” wall, and failed translucent wall cladding and peeled roofing on side wall


Figure 3.7: Damaged roller doors

Figure 3.8: Impact to end wall, roof and failure of sliding doors and roof cladding

Figure 3.9: (a) Bend windward wall column, (b) Distortion of end portal frame and loss of roller door

3.3 Ancillary items

There were examples of items such as awnings, guttering and roof vents that had failed on houses across the damage path. Inadequate design and deficiencies in the attachment of elements such as fascias, guttering and awnings can lead to structural damage, increased water ingress and contribute to wind borne debris. Several garden sheds had failed, with some roof or wall elements adding to the wind borne debris.

An un-reinforced masonry block wall used to enclose underneath a pre-1980s highset house was knocked over. Reinforced core-filled masonry block construction is required in cyclonic regions.

Failure of commercial illuminated signage was observed. The “plastic” inserts had fractured or popped out of the frames exposing the lighting inside. These inserts and the overall structure should be designed for structural adequacy for cyclonic regions.

3.4 Water ingress

Many residents commented that wind driven rain sprayed into the house around the closed windows and doors. One resident said it felt like being in a washing machine with the water spray quickly coming from all directions.

3.5 Wind borne debris

Failed elements, such as roofing, awnings, guttering, flashings etc, were blown by the wind. In some cases roof cladding was found approximately 500 m from source building. Sections of a fibreglass pool (had been empty, not installed and sitting above ground) were found approximately 250 m from its original location. Examples of the windborne debris and impact on buildings are shown in Figure 3.10.

The suddenness (and rarity) of this event did not afford preparation time; however the community should have carried out tree pruning and maintenance of the house as part of being prepared for the season. The removal or securing of potential objects and structures that could become wind borne debris plays a part in minimizing damage.

Figure 3.10: Wind driven debris and impacts on housing

4. Conclusions and discussion

The analysis of debris field and advice from the Bureau of Meteorology indicates that a severe thunderstorm and a tornado with erratic and partial touchdowns caused the severe damage to housing and commercial properties in Townsville on 20 March 2012.

The peak gust wind speeds referenced to 10m height in open terrain were in the range of 45 to 55 m/s (160 to 200 km/h). These intense wind speeds were variable over the area of impact of the storm, with this variability also evident in the patchy damage to buildings and vegetation.

Tornados are classified using the Fujita or Enhanced Fujita scale. These scales use as part of the classification process indicators from damage to houses and other structures. These amounts and types of damage are based on North American construction styles and codes, much of which is different to Australian building methods and codes. Therefore, care should be exercised in relating Australian building damage to the F or EF scales.

Harper (1997) analysed severe thunderstorm activity in South East Queensland from the 1960s to 1990s. Ten tornados were documented in that time interval with one of those being classified as an F4 (extremely destructive) on the Fujita scale. Even with documented occurrences and expanding urban footprint, AS/NZS1170.2 (2011) does not provide design data, as part of its scope, for winds generated by a tornado. However, the peak wind speeds are estimated to be less than the regional design wind speed, as discussed in Section 2. Therefore, this windstorm should have produced negligible structural damage to buildings correctly constructed to current standards, notwithstanding differences in the wind and pressure field.

The Federal Emergency Management Agency in the USA has published guidelines for in-house and standalone shelter systems for housing for sheltering from tornadoes. Interestingly they are advocating the use of common details used in house construction for hurricane regions to promote resilience up to F3 tornadoes as well as better performance for structures on the periphery of more extreme events. In an Australian context, the design loads and design method in AS4055 (wind loads for housing standard), which currently does not require designing for a dominant opening or protecting openings for non-cyclonic regions, be assessed with respect to tornado occurrence, wind field and potential for debris attack.

The severe storm carried wind borne debris. Some of this debris impact was instrumental in creating a dominant opening and resulting large internal pressurization, which in turn lead to significant structural damage, in pre-80s houses. Houses in cyclonic regions, built to standards since early 1980s are typically more resilient since they should be designed for these large internal pressures.

5. Recommendations

It is recommended that the following issues be considered:

- Reconstruction and repairs should be carried out in accordance with relevant Standards.
- For the rebuilding or upgrading of older housing, the complete load path from roofing to foundations, and not just from roof cladding to battens, needs to be considered. This may not always be feasible so at the very least (pragmatic approach for partial solution) upgrade from roofing to top plates of walls. This includes the rafter to top plate connection and strapping from rafters and ridge plates to ceiling joists and tops of internal walls. Reference should be made to documents such as the Standards Australia handbook for the upgrading of older housing HB132.2 (1999)
- Domestic and commercial roller doors including mullions etc. should be designed and installed so that they can support design wind loading.
- Regular inspection of structural elements (including in the roof space) should be carried out to look for signs of deterioration (e.g. corrosion, rot, etc). The CTS brochure “Is your house prepared for a cyclone?” contains further information;
  http://www.emergency.qld.gov.au/emq/css/pdf/cyclonebrochure-house.pdf

It is also recommended that housing along the storm’s path should be inspected for areas of potential hidden damage, for example partial withdrawal of batten nails into rafters where the roof structure seems “springy” to walk on. This partial loss of resilience has been observed following events such as Cyclone Yasi (Boughton et al. 2011), Cyclone Larry (Ginger et al 2007) and Cyclone Vance (Boughton 1999). The inspections should be conducted prior to the start of the upcoming cyclone season.

6. References

BCA. (2011). "Building Code of Australia." A. B. C. Board, ed., ABCB, Canberra.

Boughton, G. (1999). "Tropical Cyclone Vance - Damage to buildings in Exmouth." Dept of Local Government, Perth.

Boughton, G., Henderson, D., Ginger, J., Holmes, J. D., Walker, G., Leitch, C., Sommerville, L., Frye, U., Jayasinghe, C., and Kim, P. (2011). "Tropical Cyclone Yasi Structural damage to buildings." *TR57*.

Ginger, J. D., Henderson, D. J., Leitch, C. J., and Boughton, G. N. (2007). "Tropical Cyclone Larry: Estimation of wind field and assessment of building damage." *Australian Journal of Structural Engineering*, 7(3), 209-224.

Harper, B. (1997). "Severe thunderstorms in South East Queensland." Systems Engineering Australia, Brisbane.

Holmes, J. D., Ginger, J., and Melbourne, W. (2012). *Wind loading handook for Australia and New Zealand*, Australasian Wind Engineering Society, Sydney.

Queensland-Home-Building-Code. (1981). "Appendix 4." Queensland Government, Australia.

Standards Australia (2002), "AS/NZS1170.2:2002 Structural design actions Part 2: Wind actions." AS/NZS1170.2:2002, Standards Australia, Sydney NSW, Australia.

Standards-Australia. (1999). "HB132.2:1999 Structural upgrading of older houses - Part 2: Cyclone areas." Standards Australia, Sydney, NSW.

Standards Australia. (2005). "AS 1684.3:2005 Residential Timber-framed Construction – Part 3 Cyclonic areas." Standards Australia, Sydney NSW, Australia.