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Damage to low rise buildings during Tropical Cyclone Yasi

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Abstract

Severely destructive Tropical Cyclone Yasi impacted coastal and inland communities of North Queensland in February 2011. CTS conducted a street survey of over 2000 houses, and more detailed studies of around 100 more severely damaged houses. Houses built prior to the introduction in the early 1980s of engineered prescriptive requirements suffered higher levels of damage compared to houses built to current standards. Damage to engineered buildings such as sheds was also investigated.

Introduction

Tropical Cyclone Yasi (TC Yasi) was a severe tropical cyclone with a relatively large diameter that crossed the Queensland coast near Mission Beach in the early hours of Thursday 3 February 2011, as shown in Figure 1. Cyclone Yasi produced structural storm surge damage and structural wind damage at various locations between Innisfail and Townsville. There were evacuations of low-lying areas between Cairns and Townsville. Many houses were also evacuated as people made decisions as to which of their friends' houses looked and felt strongest. There were no deaths caused by wind damage to structures or storm tide. The Insurance Council of Australia (2011) reported that by December, over 72000 claims for a total value of $1.33 Billion had been lodged from this event. The reconstruction and repair of houses and other buildings is still ongoing in the affected communities.

This paper presents a summary of the Cyclone Testing Station (CTS) surveys investigating wind field and damage to low-rise structures (mainly housing) from wind loads. Findings from the storm tide damage investigation are reported in a separate paper (Walker, 2012). A detailed report on the estimated wind field, wind loading damage surveys and storm tide investigation is contained in CTS report TR57 (Boughton *et al*, 2011).

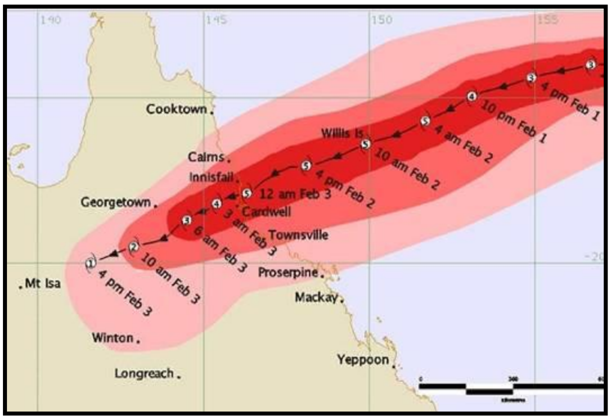

Figure 1: Track and cyclone intensity
(Courtesy of Bureau of Meteorology)

Estimated wind field

Knowledge of the wind speeds impacting our communities during cyclonic events is critical to governments and the wider community in understanding the vulnerability of housing and the effectiveness of current design standards and building regulations. Due to the scarcity of anemometers located along the tropical coast, there were no Bureau of Meteorology anemometers in the eye of Cyclone Yasi's path during its crossing the coast. As in previous damage investigations estimates of wind speeds were derived from the analysis of wind loads on simple structures such as road signs that had either failed or survived. A detailed analysis that demonstrates the robustness of using road signs for estimating wind loads is given by Ginger *et al* (2012). These speeds were incorporated with a Holland wind field model to estimate, across the study area, the 0.2 second gust wind speeds, as used in AS/NZS1170.2. The method and underlying assumptions are described by Boughton *et al* (2011) and updated by Holmes (2012). The estimates of peak wind speeds are shown in Figure 2. These values have an estimated uncertainty of around -10%.

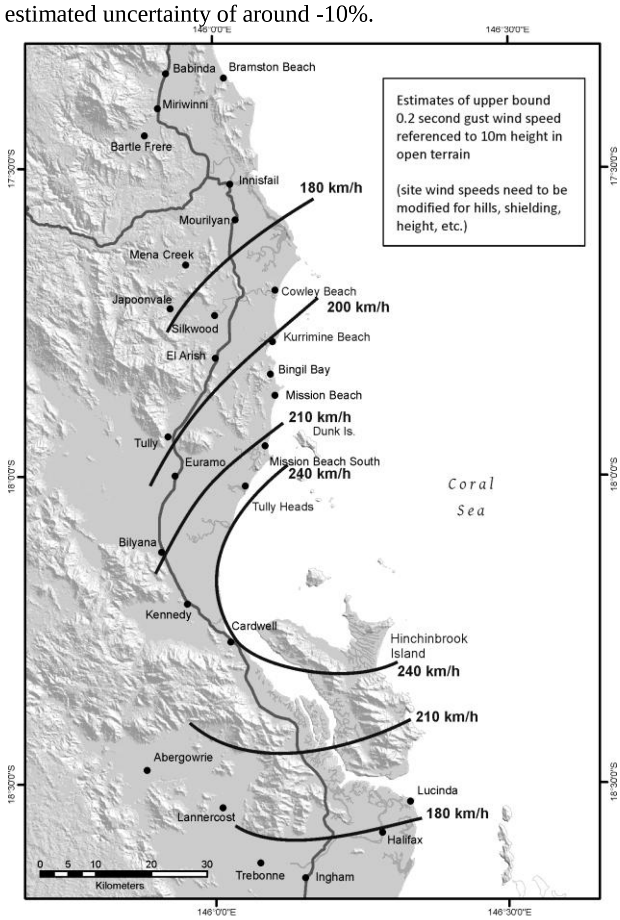

Figure 2: Estimate of 0.2s gust wind speeds

As shown in Figure 2, the estimated upper bound maximum gusts were 240 km/h. These upper bound estimates are approximately 5% less than the regional design wind speed of 250 km/h for 10 m height in open terrain.

Damage - overview

An external survey of nearly 2000 houses was conducted in order to obtain an overview of the extent of the damage to housing. The survey enabled quantification of the housing stock and the types of damage sustained, in terms of three damage classes for damage to roof, openings and walls as detailed in Table 1. An example of output using the rating system is shown in Figure 3 with the percentage of damage to roofs. The classification of houses into Pre and Post 1980s construction relates to the introduction of revised engineering deemed to comply provisions in Appendix 4 of the Queensland Home Building Code (1981).

Table 1: Three category Damage Index

	Roof (R)	Openings (O)	Walls (W)
0	None	None	None
1	gutters downpipes	debris not pierced	debris not pierced
2	debris damage to roof	debris pierced	debris pierced
3	lifted < 10%	windows/doors leaked	carport /verandah damage
4	lost roofing < 50%	windward broken < 30%	one wall panel fallen
5	lost battens < 50%	frames lost < 30%	> 1 wall panels fallen
6	lost battens > 50%	windward broken 30%-70%	racking damage, cladding attached
7	lost battens > 50% and lifted rafters	Windward broken > 70%	racking damage and lost cladding
8	lost battens > 50% and damaged tie-down	windward broken > 70% and suction loss	only small rooms intact
9	lost roof structure > 50% including ceiling	100% broken / missing	no walls remaining

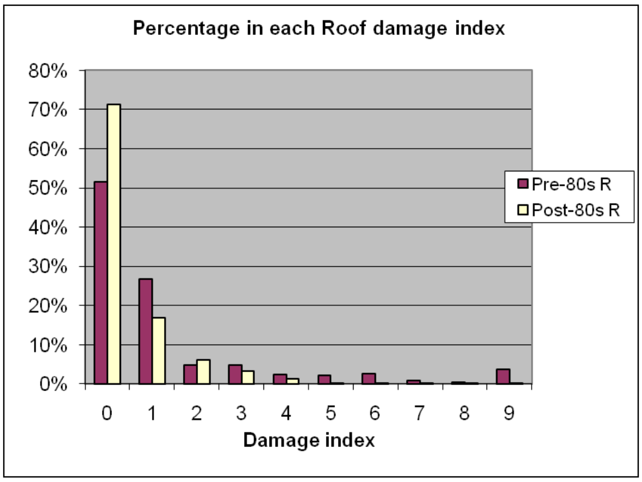

Figure 3: Damage to roof

Most of the contemporary houses (Post-80s) were slab-on-ground houses, with reinforced masonry walls. Figure 3 shows that more than 70% of Post-80s buildings sustained no roof damage compared with just 50% of Pre-80s buildings. Significant roof damage has a Damage Index of 4 or more with the Pre-80s buildings consistently having a greater frequency of severe roof damage when compared with Post-80s buildings. These results from the street survey are the average across the whole study area, and show that around 12% of Pre-80s buildings sustained roof damage at DI 4 or more compared with around 2% of Post-80s buildings. For some communities, this damage to older housing was as high as 20%.

It was observed in many cases that roofing on Pre-80s housing had been re-fixed with screws (including cyclone assemblies) but that this retro-fitting had not extended to elements and connections within the roof structure. The survey data shows roof damage % is similar for DI 4, as well as 5, 6 and 9. This indicates that high percentages of failures in older construction were also associated with loss of battens and failure of roof tie-down to walls. Guidance in the upgrading of these details can be found in documents such as AS1684 and HB132.2.

Detailed inspections were carried out on many buildings. Over 20 of these were on houses damaged and previously inspected following Cyclone Larry (Henderson *et al*, 2006). These houses were subjected to similar wind speeds (but different wind direction). The post TC Yasi survey highlighted reconstruction and repair issues. Six of the houses had loss of roofing or roofing with battens. One of these houses lost a major portion of its roof, including a section replaced following TC Larry. In four other houses, failures were observed in doors, windows and latches from wind loads exceeding capacity which caused consequential internal damage. The failures were caused by use of inadequate fixings, components or installation in reconstruction. Education and awarness of these issues is required for buildiers, regulators and insurers.

Damage to components and systems

Common trends in damage were observed. Some examples are presented here with additonal details on issues such as; metal cladding systems not installed to manufacturer specifications, degradation (e.g. corrosion or rot) of building components, ingress of wind driven rain, and building penetration by wind-borne debris, presented in TR57 (Boughton *et al*, 2011).

Garage doors:
The street survey showed for houses with roller doors, 29% had door failure. Apart from the formation of a dominant opening with the potential for greatly increasing wind loads on the structure, other consequences of door failure observed included water ingress, consequent damage to structure, cladding and contents from the whipping of the door curtain, or becoming wind-borne debris.

Figure 4 shows a roller door with wind locks that has remained attached to the door guides. Unfortunately the guides were not adequately fixed to the wall. Where wind locks are active, wind loads induce large catenary forces within the door and its supports. These loads need to be taken account of in the design of connections and frame.

Figure 4: Roller door guide failure

The roller door design standard AS/NZS4505 does provide design pressures for cyclonic regions. It is not refered to in the BCA so is not a regulatory requirement. Even so, since the doors are a part of the building envelope they must be designed and installed to resist the applied wind loads.

Tile roofs:
For Post-80s construction, damage to tile roofs was overrepresented when compared to other forms of roofing. Figure 5 shows the poorer performance of tiles compared to sheet roof for various AS4055 wind speed classifications (associated with exposure and topography). Failure modes of the tiles were loss of ridge capping (both apex and hip tiles), loss of tiles near gable ends, and cut tiles associated with hips. On most houses that had lost ridge capping, no mechanical fixings such as clips or screws on the ridge tiles were observed (Figure 6). The fixing method appeared to be flexible pointing adhesive. Examples were noted of failed or dislodged tiles that had clips attached to battens. It is unknown if the clips were correctly engaged with the tile prior to the wind loads or if the tiles disengaged during the wind loading. The dislodgement of the ridge or other tiles generally led to additional damage to the tile roof and to adjacent structures through wind-borne debris. The study has shown that improvement is required in fixing practices of roof tiles.

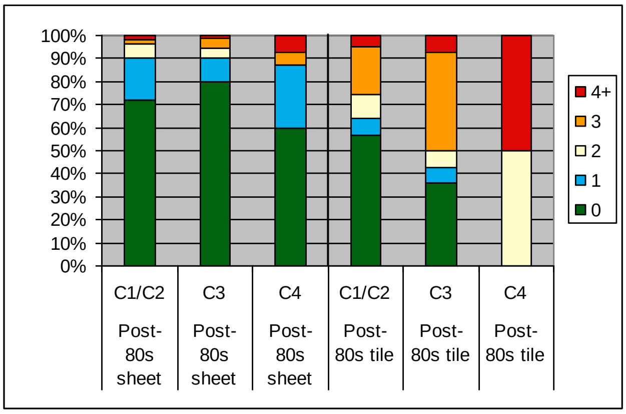

Figure 5: DI for sheet and tile post-80s roofs
(Refer Table 1 for Damage Index values)

Figure 6: Failure of ridge capping

Sheds:
There were a range of failure modes and performance issues observed in both back yard and light-industrial sheds (typically cold-formed construction). These modes include; Damage to the inside of the roof and walls with failure of roller door; Structural damage to sheds with two or three walls caused when the winds aligned with the shed opening direction and resulted in buckled purlins and cladding loss as shown in Figure 7; Failure of windward walls with buckling of purlins and cladding due to combined action on purlins and no compression bracing; Inadequate connections with observed missing bolts or screws; Corrosion of purlins as well as connections of major framing elements; And inadequate footing details with complete shed frames being lifted clear of the ground with resulting large impact damage on adjacent buildings.

The damage caused by shed failure can be compounded if they are located adjacent to other structures. Catastrophic failures can lead to the entire structure impacting adjacent buildings which are otherwise intact, as shown in Figure 8. This type of wind borne debris is not considered in the design of structures.

Figure 7: Buckling and loss of purlins with cladding

Figure 8: Failure of shed and impacted house

Conclusions and recommendations

The report by Boughton *et al* 2011 made the following conclusions and recommendations.

The upper-bound estimate of peak wind speed was 240 km/h (10m height, in open terrain), indicating that the wind speeds were less than the regional design wind speed (AS/NZS1170.2).

The survey showed that 10 to 20% of houses built prior to the introduction of current building regulations (i.e. Pre-80s) suffered significant roof damage for the worst affected communities. Comparing this to the survey findings of low incidence of damage to contemporary construction shows that the current building practices are able to deliver a satisfactory outcome for most of the building structure. However, this should be expected since the wind speeds were less than the regions design criteria. Where significant damage to contemporary construction was investigated, it was observed that the failures were attributed to errors in selection of design parameters, limitations of assumptions in AS4055, poor construction practice and degradation of materials.

Findings from the survey highlight the need for:

- Designing to the required ultimate limit states design pressure for the whole building envelope including all doors, windows, and eaves linings.
- Better community education targeting owners, insurers, designers and builders in the repair of damaged buildings to ensure that current building requirements are met.
- Community education on the need for regular maintenance of buildings to prevent loss of capacity.
- Changes to current standards, including AS4055 in relation to calculation of topographic classes, and AS/NZS4505 and AS2050 for improvements to performance of roller doors and tiled roofs.
- Development of construction requirements for buildings within a storm surge zone in order to improve resilience of affected buildings and improvements in land use planning to reduce the risk of structural damage in future events.
- Suggestions for inclusion of strengthened compartments within houses as means of shelter from possible large debris impact.
- Improvements in water tightness requirements including envelope fenestration and flashing details and/or appropriate selection and use of water resilient internal linings to mitigate damage and loss of amenity from wind driven rain.
- An effective anemometer network for reliable measurements of wind speeds impacting communities allowing for better assessment of building regulations and emergency response planning.

Update on recommendations

Various organisations and industry bodies have commenced addressing some of the issues raised in the findings of the damage investigation. These include;

- AS4055: A revision to the latest draft includes changes to the topography classification removing the slope averaging as well as the inclusion of explicit design pressures for soffits and eaves linings.
- Storm tide: Guidelines for the reconstruction of housing in storm tide affected regions released by Qld Reconstruction Authority. http://www.qldreconstruction.org.au/publications-guides/resilience-rebuilding-guidelines
- Education: Seminars and road shows were undertaken by several agencies including CTS, Timber Qld, Master Builders and QBSA. Continuing education and awarness for builders and certifiers in selection of appropriate components and forms of construction needs to be effectively implemented. CTS consulted with QRA and assisted in preparation of guideline documents to facilitate reconstruction.
- Anemometers: Prototype deployable anemometers based on TTU Sticknet design being investigated by CTS and RF.
- Upgrading of older housing: Issues were raised at implementation workshop and a letter was sent on behalf of participants being to the Qld Premier's office reccommending retrofitting options for older (more vulnerable) housing.
- Tile roofs: Revisions were proposed for AS2055 to no longer allow flexible pointing as a means of fixing ridge tiles and requires part tiles to be mechanically fixed to battens.
- Solar panels: Pressure coefficients on panels from wind tunnel tests will be included into AS/NZS1170.2.
- Garage doors: An industry working group was formed to promote awarness in the industry and revise AS/NZS4505 for inclusion into the Building Code of Australia.
- Sheds: An industry group is actively providing a certification process for best practice design and fabrication of cold formed steel sheds. This includes design of robust ridge and knee joints as well as awareness of designing for C_{pi} of 0.7 for internal pressure.

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