CYCLONE
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Damage investigation of buildings at Minjilang, Cape Don and Smith Point in NT following Cyclone Ingrid

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Cyclone Testing Station
School of Engineering
James Cook University
Queensland, 4811

Phone: 07 4781 4340
Fax: 07 4775 1184

www.eng.jcu.edu.au/cts/

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SCHOOL of ENGINEERING
JAMES COOK UNIVERSITY

TECHNICAL REPORT NO. 50

Damage investigation of buildings at Minjilang, Cape Don and Smith Point in NT following Cyclone Ingrid

By
David Henderson and Cam Leitch

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Contents

1. Summary

During March 2005, Cyclone Ingrid travelled across parts of Queensland, the Northern Territory and Western Australia before degenerating into a rain depression. The Bureau of Meteorology classified this cyclone as varying in intensity between Category 5 and Category 3 during its erratic path across the 3 states. Fortunately, most of Cyclone Ingrid's track was across sparsely populated areas and so the potential for damage to housing and infrastructure was quite limited.

Cyclone Ingrid was classified as a Category 5 cyclone, prior to crossing the coast at Croker Island. Croker Island is located about 220 km North East of Darwin. The investigation focussed on the small Minjilang community of about 300 residents, located on Croker Island and involved an estimation of wind speeds and direction, a survey of both damaged and undamaged housing and comments on probable causes of failure. The CTS team also inspected structures at Coburg Peninsula.

Findings from the damage survey include;

- Best estimate of "Ingrid" Wind speeds at Croker Island is about 200 - 250 km/h (approx cyclone category 4 wind speeds)
- Most houses resisted wind forces. This should be the case as the winds were less than the design wind speed.
- Residents were able to shelter in buildings that didn't fail; hence no injuries.
- Where failures were observed, the damage was attributed to inadequate, missing or corroded structural components in nearly all cases.
- Extensive tree & vegetation damage
- Corrosion of components initiated failure in many cases.

2. Acknowledgements

The authors gratefully acknowledge the support given by the NT Department of Infrastructure Planning and Environment and for arranging access and providing transport to the Coburg Peninsular and Croker Island. Without the NT DIPE help of Mr Lyle Campbell and Mr Fabio Finnochario and their teams we would not have been able to conduct the damage survey. They are grateful to Mr Neil Clarke (Irwinconsult) and Mr George Curran (NT DIPE) who conducted damage inspections at the same time and through discussions helped reinforce some of the findings of this report. Thanks also to Mr Mike Foley of the Bureau of Meteorology, Darwin for discussions and data.

Finally the authors are extremely grateful to the residents at Minjilang, Cape Don and Smith Point who generously assisted this study by volunteering information, answering questions and on occasions inviting the authors into their houses to inspect damage.

3. Cyclone Ingrid

Cyclone Ingrid impacted the coast line of Queensland, Northern Territory and Western Australia as a severe Category 4 and 5 event, during its 10 days as a cyclone. The Bureau of Meteorology track is shown in Figure 1.

On the 13th March 2005, Cyclone Ingrid then reported as an extremely destructive Category 5 cyclone, made landfall at Croker Island. The Cyclone Testing Station (CTS) team arrived five days later to conduct damage investigations of housing and similar structures at Croker Island and Coburg Peninsular, shown in Figure 2. As noted by the Bureau, Cyclone Ingrid although very intense had a small eye diameter. For this reason, communities only a 100 km from Ingrid's path were only minimally affected by the winds.

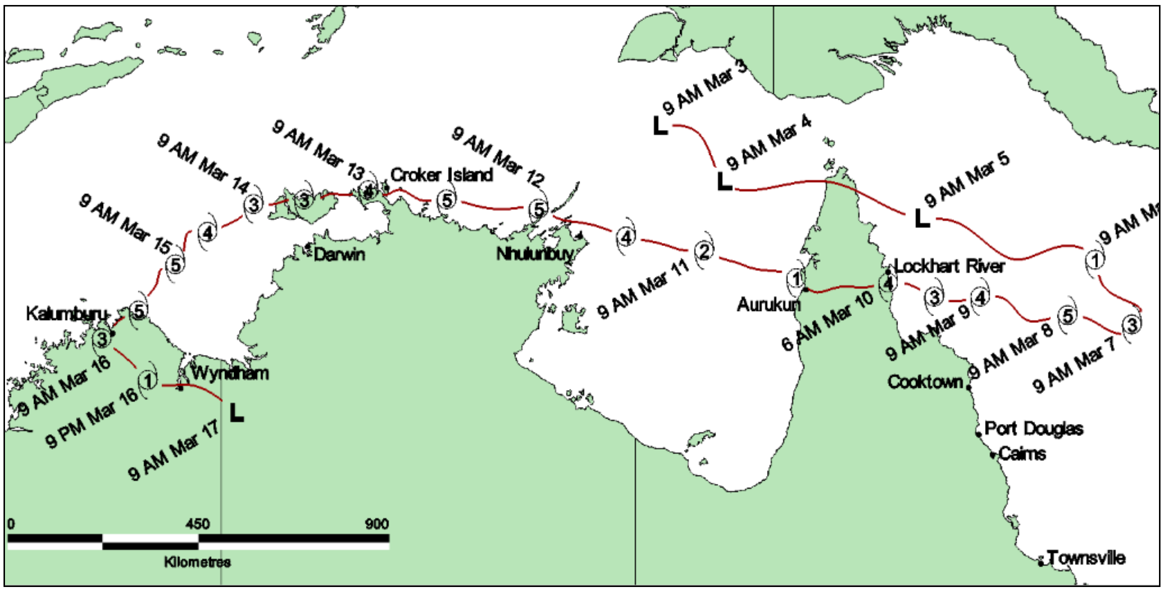

Figure 1: Track of Cyclone Ingrid (times in CST) (image from Bureau of Meteorology)

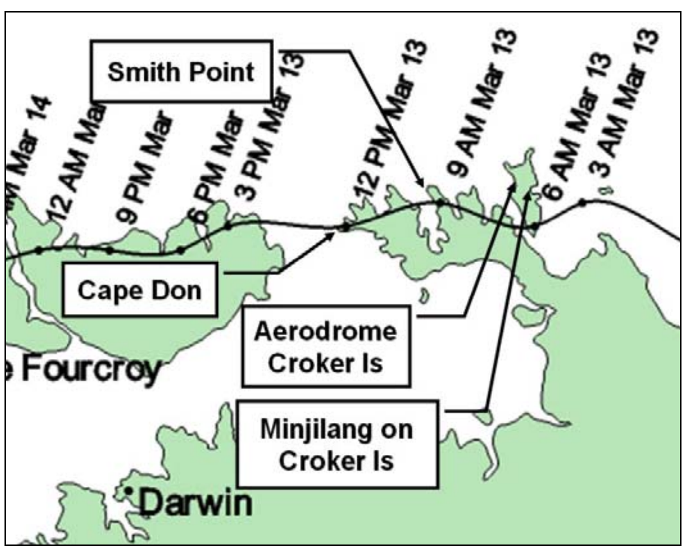

Figure 2: CTS Damage investigations at Croker Island, Cape Don and Smith Point.

4. Minjilang

Minjilang is a small community on the Eastern side of Croker Island. The spread of building included two school buildings, community centre, workshops and approximately 50 houses. As the community is roughly 10 m above sea level, storm tide had minimal direct impact.

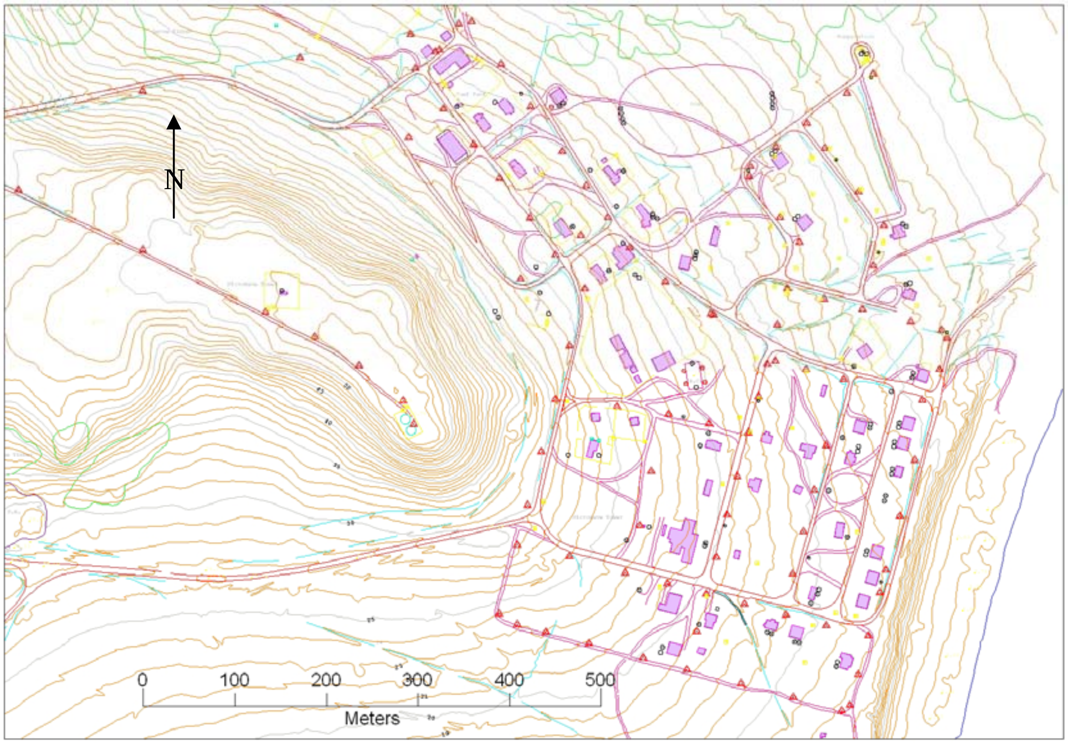

Figure 3: Map of Minjilang

4.1 Wind direction

The community of Minjilang on Croker Island was in the path of Cyclone Ingrid. In talking with residents at Minjilang, they observed that the severe winds came from a Westerly direction, then a lull of about 20 minutes, followed by the winds from a Northerly direction. By mapping the location of the wind driven debris during the CTS damage survey, the wind directions have been approximated to WSW and N (refer Figure 4). This places the centre of the cyclone eye to the South of the town. For the winds in the eye wall, a wind inflow angle 10 to 20 degrees inwards can be assumed [1].

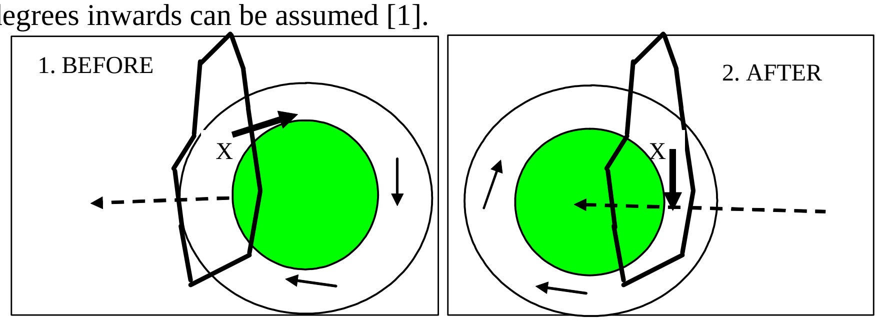

Figure 4: Schematic of wind directions as eye wall passes over Minjilang (marked as X)

4.2 Wind speed

As there was no anemometers near the town, estimates of peak winds need to be determined by calculating wind loads required to fail simple structures such as signs or hoardings. Being a small community there were few of these suitable ‘windicators’ to use (Figure 5). However from the few simple structures analysed, including a laterally displaced and overturned empty shipping container (Figure 6), it is estimated that the peak gust wind speed impacting on Croker Island aerodrome was in the order of 65 to 70 m/s (250 km/h) at 10 m height in open terrain. This estimate of peak winds correlates with the Bureau of Meteorology’s reanalysis of Cyclone Ingrid at landfall on Croker Island. From their review of data they suggest that Ingrid was a Category 4 system with wind gusts to 140 knots (260 km/h) when it impacted Croker Island [1].

The wind loading standard AS1170.2:1989 [2] gives a strength limit state design wind speed of 70 m/s referenced at 10 m height in open terrain, for the cyclonic regions of the Northern Territory. The damage investigation estimated the peak wind speeds to be approaching this design value. This implies that structures designed to the wind loading standard should be structurally adequate for the wind forces generated from Cyclone Ingrid. The 1989 version rather than the 2002 edition of the wind loading standard has been used as a reference because the 1989 version would have been used for the design standard for the majority of structures.

Figure 5: Footing failures - poor ‘windicators’

Figure 6: Empty container (lifted and overturned as no drag marks observed)

Topography and terrain affected the wind speeds impacting Minjilang. The surrounding terrain and the town itself with its buildings generally well spaced with open areas throughout the town, would be tending towards a Terrain category 2.5 classification. It is estimated that the peak wind speeds at 10 m height in Minjilang would have been in the order of 60 m/s (220 km/h).

As shown in Figure 7 the 54 m high hill lying to the West provided some shielding from the Westerly winds for the older houses and workshop building in the North of the town. For the Northerly winds, roughly a third of the houses were provided with some form of shielding from neighbouring houses.

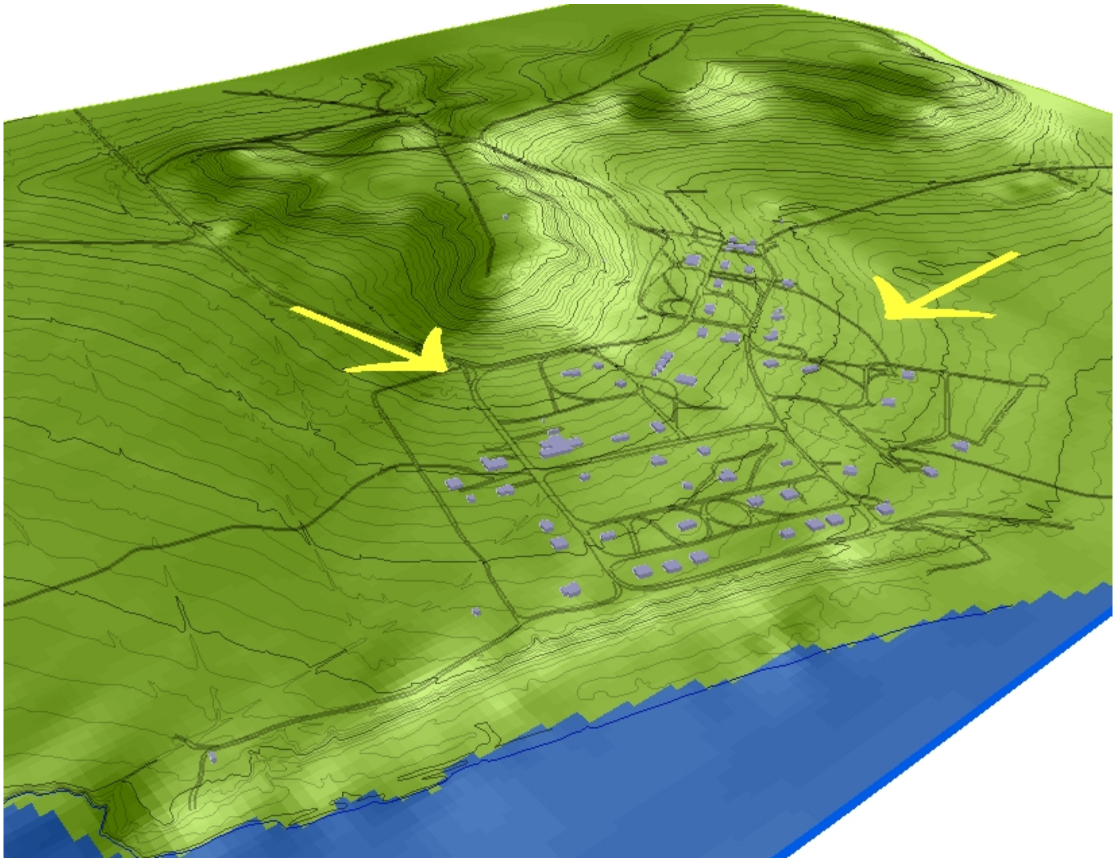

Figure 7: WSW and N wind directions impacting on Minjilang

4.3 Damage survey of Minjilang

Inspections (post mortems) were conducted on the few damaged structures. However, in order to obtain a clear overview of the extent, both in number and location, of the damage to the township, an external feature survey quantifying the types of construction and the amount of damage was carried out. The survey covered the majority of the town. Data collection involved a visual assessment of each building while walking along the street.

The damage classification system was based on the one developed by Leicester and Reardon [3] for Darwin after cyclone Tracy. It ranks the amount of visible structural damage with the categories ranging from negligible or non-structural damage such as broken soffits or loss of flashing to the extreme loss of all walls and roof structure.

The damage categorisation system relates only to structural damage visible from outside the buildings. The lack of dense gardens or fences typically allowed the observation of the two side walls and front facing wall. It is likely that some lower level damage such as debris impact or even damaged roofing would have been missed. Therefore the survey results should be taken as being indicative of the damage trends. Definitions of the damage categories are given in Table 1.

As only one damage category is allotted to each house, the most severe one is reported. If a house has sustained impact damage (2) to a windward wall and also suffered loss of some roofing battens (4), only the damage category of 4 is presented in the data summary.

Table 1: Description of damage categories

Category		Description
1	Negligible	Includes minimal damage such as the damage to elements which are not part of the main structural framework, such as guttering, soffit lining, or fascias.
2	Impact	Impact from wind driven debris. Examples would be a bent debris screen or indentations of external cladding.
3	Roofing	Loss of some roofing, but where battens and roof structure are left substantially intact.
4	Roof battens	Failure caused by inadequate fixing of roof battens to rafters, so roofing and battens were blown off. The rest of the roof structure is in place.
5	Half roof	A significant portion of the roof structure has been blown away.
6	All roof	All of the roof structure would need to be replaced.
7	Half walls	Loss of most of the roof structure and loss of some walls.
8	All walls	Loss of most of the walls and roof structure.

There were approximately 50 houses at Minjilang with the older houses to the North and the newer houses to the South. Of the 40 houses surveyed, only 20 % had sustained damage with partial loss of roof cladding through to loss of roof structure. The majority of the buildings performed well structurally. However all houses were subjected to water ingress, but the lack of linings such as plasterboard and carpets in the majority of the housing reduced the water ingress impact on those linings.

Figure 8 shows a graph of the distribution of damage for all houses in the survey. In any form of statistics care should be exercised when working with small sample sizes. However it is interesting to note that the proportion of undamaged to damaged houses (shape of Figure 8) is similar to the damage survey of houses in Exmouth following Cyclone Vance [4]. Both surveys show the improvements in house design and construction since Cyclone Tracy [3].

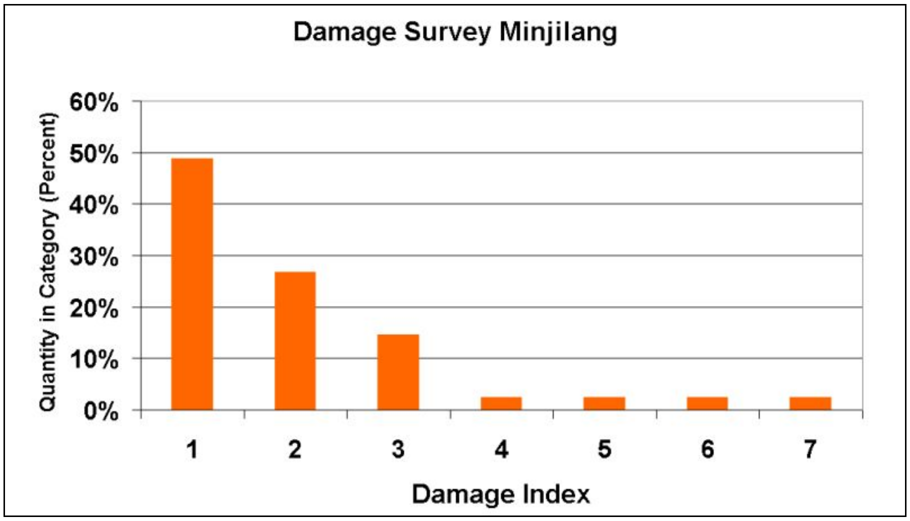

Figure 8: Figure of survey results

4.4 Recent house construction

Typically housing that was constructed in the past 10 to 15 years survived with minimal structural damage from wind loads observed (Figure 9 and Figure 10). Impact from wind driven debris, fallen trees, flashing loss (Figure 11) and soffit loss was noted.

One noted exception was a reinforced masonry block house that was built within the last couple of years (Figure 12). Part of the roof had peeled back, as shown in Figure 13, from the windward edge. It is postulated that a missing nut on a rafter hold down allowed the edge rafter to lift over the hold down rod.

Figure 9: Recent construction

Figure 10: Minor tree damage to post Tracy houses

Figure 11: Minor loss of flashing

Figure 12: Roof structure damage to new house (windward wall)

Figure 13: View of damaged roof on new house

4.5 Pre Tracy retro-fitted highset house

The highset fibro clad rectangular plan house suffered loss of roof cladding and battens (Figure 14 and Figure 15). It was advised that the house had been retrofitted as per some of the houses in Darwin that survived Cyclone Tracy.

The house was constructed from both aluminium and hardwood wall framing members lined with fibre cement cladding. The hardwood trusses were at 900 mm centres with hardwood battens at 600 mm centres over eaves and nominally 900 mm centres internally. The roof cladding was corrugated colorbond fixed with screws using cyclone assemblies.

Failure was initiated by missing hold down connectors between the battens and trusses. Corrosion of batten straps along the exposed eaves (Figure 16) and some batten to truss fixings not installed in the body of the roof space were observed. A truss to top plate hold down Z bracket was lying on the ceiling (Figure 17). So if the cladding had held on, part of the roof structure may have been blown off due to inadequate truss hold down. A section of the roof from this house was found 200 m to the South East (Figure 40).

Figure 14: East face (photo looking NW)

Figure 15: West face (photo taken looking SE)

Figure 16: Corroded batten hold down straps

Figure 17: Truss hold down brackets not installed to a couple of trusses

4.6 School

The high set school lost all top storey wall and roof structure as the wall frame was unable to resist the uplift forces (Figure 18 and Figure 19). It was advised that the classrooms were a 1950s aluminium framed 'kit' structure which was built on the elevated timber framed floor.

The roof of the building had been re-roofed with corrugated G550 cladding and fixed to the existing aluminium I beams with Type 17 screws with cyclone assemblies. No other post Cyclone Tracy retrofitting was evident. The classrooms wall and roof framing members were made from aluminium. The top plate and bottom plates were riveted to the studs via aluminium T sections. Figure 20 and Figure 21 show sheared rivets in a T connection and a corroded bottom plate hold down bolt.

Figure 18: Elevated school platform (roofing screwed to I beams)

Figure 19: Remains of classrooms

Figure 20: Aluminium inverted T brackets and rusted hold down bolt

Figure 21: Aluminium inverted T bracket showing sheared rivets

4.7 Early Childhood building

The brick single storey early childhood centre (Figure 22) acted as a shelter for some of the residents including teaching staff. Although structurally withstanding the severe wind forces, we were advised that the water ingress added to the trauma of the situation.
Minor structural damage was observed;

- loss of some flashings,
- damage to the brick skin adjacent to a gable truss end where a satellite dish was attached, and

- damage to polycarbonate cladding which was adding some wind and water protection along the central glass louvred skylight.

Figure 22: Early childhood building

Figure 23: Failure of mounting point for satellite dish

4.8 Workshop

The portal framed shed in the North of the town suffered loss of roller doors, and minor cladding and flashing loss with resultant water and wind damage to contents. Tearing of the wall cladding around some fasteners was observed, however the fixing spacings were found to be larger than typical manufacturer's specifications.

Figure 24: Wind ward wall (North face) Note openings have been covered with plastic

Figure 25: Roller door failure (Photo from DIPE)

Figure 26: Leeward wall cladding and flashing failure

5. Cape Don

Cape Don is located at the western end of the Coburg peninsular. The buildings consisted of three large residential buildings (lodges), a few small sheds and out buildings, and a lighthouse built in 1916. A Sutron automatic weather station was located near the lighthouse. However the Bureau of Meteorology subsequently advised that the AWS failed during the cyclone when the anemometer cups were blown off. The Bureau estimates Cyclone Ingrid to have impacted Cape Don as a category three cyclone with peak gusts in the order of 215 km/h.

Due to the topography of Cape Don, winds from the Northerly direction would be increased due to the open 1 in 10 slope. An estimated increase in wind speed from flat open terrain could be in the order of 10 % based on the topographic multipliers in AS1170.2.

5.1 Cape Don Lodge buildings

The major structural damage to one of the residential buildings (guest lodge) is in stark contrast to the structural performance of the retrofitted structure of the staff lodge. The lodges were of similar vintage to the lighthouse.

The guest lodge suffered major loss of roof cladding (Figure 27). Some of the screws fixing the corrugated asbestos cement cladding had corroded. Severe corrosion was also noted in the batten fixings and rafter connections (Figure 28). It was advised that the cleanup and removal of the asbestos cladding was going to be a major undertaking (Figure 29).

In comparison, the retrofitted staff lodge suffered no loss of roof cladding (Figure 30). Corrugated metal roof cladding was screw fixed with cyclone assemblies to timber battens at nominally 600 mm centres. The battens were strapped to nominally every second rafter (Figure 31). The rafters were spaced at nominally 450 mm centres. The loss of fascia, guttering and damage to some awning cladding was observed.

Figure 27: North face of guest lodge

Figure 28: Corroded and inadequate batten fixings

Figure 29: Rear of guest lodge with scatter of corrugated asbestos cladding

Figure 30: New roof on staff lodge

Figure 31: New batten straps on staff lodge

6. Common observed damage features

6.1 Attachments and ancillary elements

Inadequate design and attachment of elements such as fascias, awnings and soffits can lead to damage to structure, increased water ingress and contribute to wind driven debris. Figure 32 (a) shows the failure to truss top chord eaves from the awning being peeled back.

Figure 32 (a) and (b): Failure of eaves, awnings and associated damage to structures

Figure 33 (a) and (b): Soffit damage at Smith Point and Minjilang

Figure 34: Water ingress at Ranger house on Smith Point

Figure 35: Loss of guttering, fascia and awnings at Cape Don (photo from DIPE)

6.2 Tree damage

There was extensive tree damage caused by the cyclone. The National Parks advised that there would be an increased fire risk when the fallen timber dried out (Figure 38) [5].

Figure 36: Fallen trees at Minjilang

Figure 37: House damaged by tree at Minjilang

Figure 38: Defoliation of canopy across Coburg Peninsular

6.3 Wind driven debris

Wind driven debris poses a risk to life and property. Correct design and installation of materials is required.

Figure 39: Examples of wind driven cladding (predominantly with battens attached)

Figure 40: Part of roof from highset house in Minjilang

6.4 Corrosion

Many of the failures observed were initiated from structural elements suffering severe corrosion. Correct specification and installation of materials to suit the level of exposure along with ongoing maintenance is required for structures. The ongoing maintenance is particularly important in cyclone regions as it may be many years until a severe cyclone impacts the building.

Figure 41: Corrosion of frames, battens, fixings and claddings

Figure 42: Detail of corrosion of top hat batten

Figure 43: Corroded screws and cladding at Minjilang

7. Conclusions

Overall, the buildings performed well for the wind speeds endured. Where failures from wind forces (not falling trees) were observed they were associated with older buildings that had not been upgraded, or corrosion of fixings, or incorrect construction practice on newer structures. Therefore we (designers, builders, certifiers, regulators and owners) need to ensure that structural details are both appropriately specified, and regularly inspected and maintained so that our houses and buildings can provide us shelter.

The main conclusions from this CTS damage survey are:

- Best estimate of Cyclone Ingrid peak gust wind speed at Croker Island is 200 to 240 km/h (cyclone Cat 4)
- Most houses resisted wind forces. This reflects achievements since Cyclone Tracy.
- However it should be expected that the houses should be structurally adequate as the impact wind speeds were estimated to be less than the design wind speed.
- Residents were able to shelter in buildings that didn't fail.
- Failures attributed to inadequate, missing or corroded structural components.
- Extensive tree & vegetation damage (possible future fire hazard)
- Failure was initiated at corroded components in many cases.

8. Recommendations

It is recommended that the listed issues be considered:

- Specify and use appropriate materials suitable for the site exposure conditions.
- Undertake regular inspection and maintenance of housing, especially the structural components.
- Ensure strength upgrades are completed on all structural components of the wind load resistance system. This includes the batten to truss/rafter connection.
- Use water resilient internal linings, if practical.
- Review (& upgrade strength if needed) storm resistance of Automatic Weather Stations.

9. References

1 Conversation with M. Foley, Bureau of Meterology

2 Standards Australia SAA Loading Code Part 2: Wind Loads. AS 1170.2-1989.

3 Leicester R. H. and Reardon G. F. (1976) "A statistical analysis of the structural damage by cyclone Tracy." Civil Engg Trans. I.E.Aust. Vol CE18, No 2, pp 50 – 54.

4 Reardon G, Henderson D and Ginger J. (1999) "A Structural Assessment of the effects of Cyclone Vance on houses in Exmouth" TR48 Cyclone Testing Station JCU

5 Conversation with B. Scott, National Parks