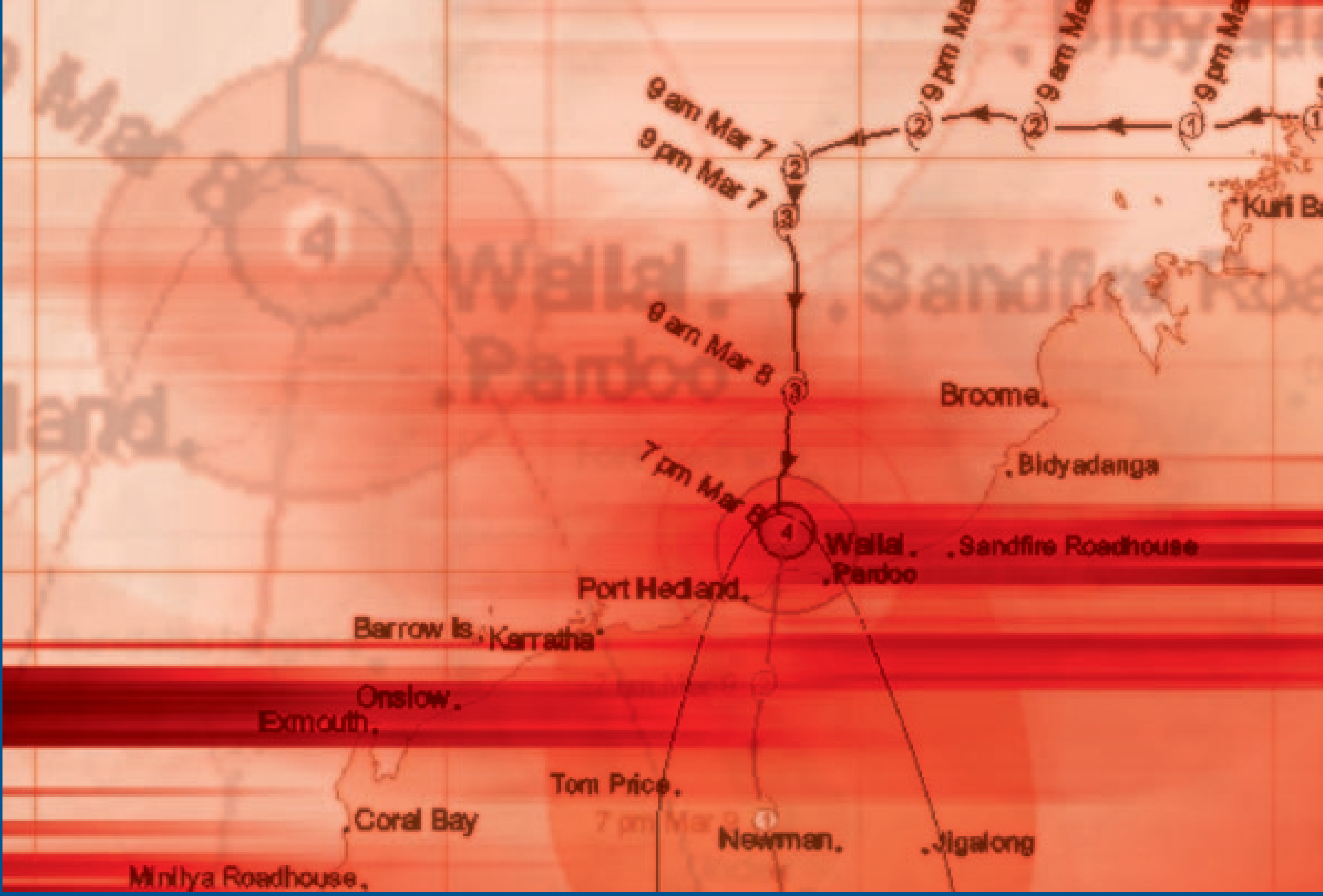

Tropical Cyclone George

Damage to buildings in the Port Hedland area

Report: TR52

April, 2007

ABCB

CYCLONE TESTING STATION

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TECHNICAL REPORT NO. 52

Tropical Cyclone George
Damage to buildings in the Port Hedland area

April 2007

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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 Geoff Boughton and Ms Debbie 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 travel from Perth to investigate the damage following Cyclone George than a CTS team travelling from Townsville. The CTS is most grateful to Geoff and Debbie for preparing this report and also to the Australian Building Codes Board for supporting this work.

TimberED Services Pty Ltd

Tropical Cyclone George
Damage to buildings in Port Hedland Area

Executive Summary

Tropical Cyclone George crossed the Pilbara coast east of Port Hedland in the late evening of Thursday 8th March 2007. The peak gust speeds in Greater Port Hedland standardised at 10 m height in Terrain Category 2, were estimated at up to 200 kph (~55 m/s). The damage appeared to have been caused by winds within the quadrant South-East through to South-West. The period of maximum winds lasted for four to five hours. Estimates of the maximum wind gust speed in the eye wall, ~20 km to East of Port Hedland, were up to 270 kph (~75 m/s) closer to the design wind speed for region D of 88 m/s.

The report details the results of studies of damage in the Greater Port Hedland area and a few stations and communities close to Port Hedland only. It focuses on structural damage, though some comments are made about water damage. Less than 2% of buildings sustained structural damage. The low damage figure relates to the fact that the estimated wind speed was 65% of the current design wind speed for the area. The worst structural damage observed was loss of the major part of the roof structure. This type of damage was only observed in Port Hedland, and only in older buildings. Structural damage was caused by:

- deterioration of older structural elements;
- inappropriate re-roofing practices. In a significant number of cases, re-roofing removed the prime tie-down system without replacing it with other systems;
- not following current practice for this area;
- failure of non-structural elements such as flashings and trims. Where these were fixed to roof sheeting, then the loss of the trim led to the loss of some roofing as well; and
- pressurisation of roof space through roof vents (in gables and in some cases by rotating vents).

Most buildings constructed to current codes and standards performed well though there were some concerns about light gauge metal trusses and battens. It is important that these codes and standards be followed for all reconstruction work.

Independent of the structural damage, there was water damage to plasterboard linings. Plasterboard had been used in most recent housing. Water ingress occurred around flashings or through cracked sealant. Where there was roof or gable damage, or the roof space vented, water was blown directly into the ceiling space.

Recommendations were made covering the following points:

- inspection and regular maintenance of all buildings is important for them to retain adequate performance under high wind loadings;
- when re-roofing buildings there is an excellent opportunity to bring the structural capacity of the entire roof up to current standards;
- design and construction recommendations for Wind Region D must be followed in order to deliver satisfactory performance.

Tropical Cyclone George
Damage to buildings in Port Hedland Area

Table of Contents

1. Introduction

Tropical Cyclone George crossed the Pilbara coast in North West Western Australia around 10 pm on 8 March 2007 and caused damage to buildings and other infrastructure in the region of Port Hedland.

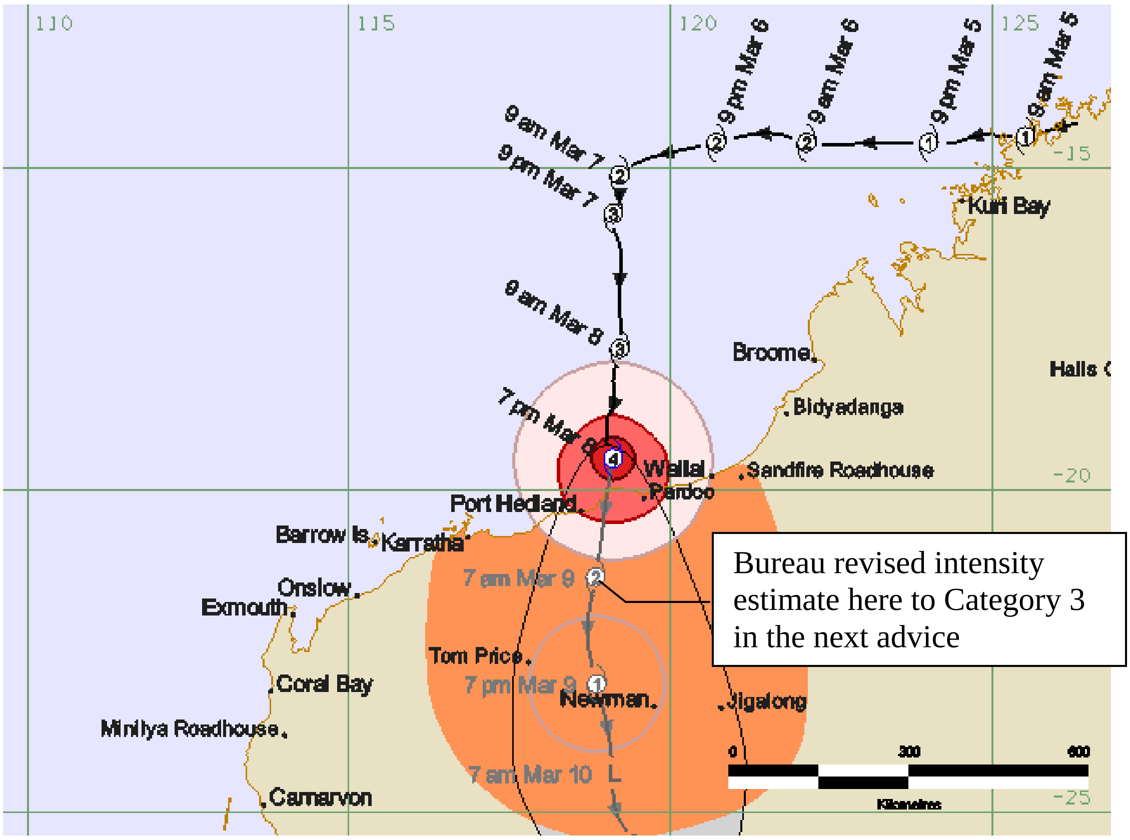


Figure 1.1: Tropical Cyclone George threat map 8th March 2007 2100 (BoM) and location map (Geoscience Australia)

1.1 Objective

This report was commissioned by the Cyclone Testing Station within 24 hours of TC George's landfall. It had the following overall objective:

To investigate structural wind damage to buildings in the Greater Port Hedland area.

The study focused on housing, though some commercial and public buildings, and some sheds were also investigated.

More specifically the study sought to:

- estimate the wind speed caused by the cyclone throughout the study area;
- determine whether the extent and type of damage could reasonably be expected from the estimated wind speeds;
- determine whether buildings that had been built in accordance with BCA96 [1] performed adequately;
- document types of construction that appeared to be more vulnerable to wind damage than others;
- ascertain the adequacy of current codes and standards; and
- provide possible reasons for failures to damaged building components and where possible, provide recommendations for upgrading these details.

An investigation of the mining camp (approximately 100 km inland from Port Hedland) where two deaths occurred was not possible. Those buildings are not covered in this report.

1.2 Strategy

The damage in Greater Port Hedland was relatively light and another Tropical Cyclone (Jacob) was expected within a few days, so a rapid clean-up was required. A small team was sent to Port Hedland on the first available commercial flight:

- the first priority was to obtain information from detailed studies of buildings of interest before debris was cleared away. This study aimed at establishing the elements at which failure was initiated, and any factors that may have contributed to poor performance of buildings. The location of the damaged buildings was supplied by Fire and Emergency Services (FESA WA) and supplemented by other observations where possible; and
- simple structures (mainly road signs) were investigated to estimate the wind field.

1.3 Greater Port Hedland

Greater Port Hedland has three distinct centres:

- Port Hedland (post code 6721) – comprising the old town associated with the wharf and the localities of Spinifex Hill, Cooke Point, and Pretty Pool;
- South Hedland (post code 6722) – mainly housing and commercial premises and comprising the localities of Walnut Grove, Lawson, Shellborough, Cassia and Koombana; and
- Wedgefield (post code 6723) – comprising mainly light industrial buildings, but with a few residences on larger industrial blocks.

Figure 1.2 shows the town layout. The path of Tropical Cyclone George was to the East of the town and there did not appear to be a significant difference between the wind speeds experienced in the three centres.

Through the remainder of this report, Greater Port Hedland refers to the three centres, and Port Hedland refers to the centre marked in Figure 1.2.

Figure 1.2: Greater Port Hedland (Google Earth)

2. Estimates of Wind Speed and Direction

In order to analyse the structural performance of the buildings, it is first necessary to estimate the wind field (i.e. wind speed and direction) in the study area. In particular, it is necessary to determine the relationship of the estimated wind speed to the current design wind speed.

The study area included:

- Port Hedland, South Hedland and Wedgefield, all of which did not experience the eye of the Tropical Cyclone and were to the North West of the cyclone path and
- an indigenous community East of Port Hedland that experienced the eye wall.

A number of sources were used to estimate and verify peak wind speeds in the study area including:

- advice from the Bureau of Meteorology; and
- investigations of simple structures.

The cyclone categories according to the Bureau of Meteorology are shown in Table 2.1.

Table 2.1 Bureau of Meteorology Cyclone Categories

Category	10m Terrain Category 2 Gust Wind Speed		Central Pressure
	km/h	m/s	hPa
1	<125	<35	990
2	125-170	35-47	970-985
3	170-225	47-63	950-965
4	225-280	63-78	930-945
5	>280	>78	<925

2.1 Characteristics of Tropical Cyclone George (from BoM)

The following is a report on TC George that appeared on the Bureau of Meteorology (BoM) web site [2] within five days of its occurrence.

Severe TC George was both very intense and physically large. During the event, gales were reported on or near the coast as far north as the Northern Territory border on Sunday 4 March as the cyclone moved across from the NT, and as far west as Karratha on Thursday 8 March. The cyclone intensified to a Category 4 system as it approached the coast, but post-analysis may indicate intensity of Category 5 at landfall. The wind impact was greatest between Wallal and Whim Creek with a mean wind of 195 km/h (equivalent to gusts of 275 km/h) being recorded offshore at Bedout Island. At Port Hedland Airport, gusts of 154 km/h were recorded around 10:30pm prior to equipment failure. It is likely that stronger winds were experienced around midnight, on the edge of the very destructive core.

TC George produced large amounts of rainfall in the Northern Kimberley and the Northern Territory earlier in its lifecycle, before moving offshore and intensifying into a significant cyclone. Upon approaching the Pilbara coast, substantial falls occurred, however the lack of previous rainfall limited the potential for flooding. No significant flooding was recorded.

Port Hedland escaped direct impact from storm surge as the cyclone passed to the east of the town.

Reported impacts include three fatalities and numerous injuries at mining camps south of Port Hedland. Considerable damage was reported from Port Hedland with at least 10 houses losing roofs, despite solid construction practices in the Region. The Bureau's Port Hedland radar dome was damaged.

Tropical Cyclone George was the most destructive cyclone to affect Port Hedland since TC Joan in 1975.

Coastal Crossing Details

Crossing time:	10pm WDT Thursday 8 March 2007 50km ENE of Port Hedland
Category when crossing the coast:	4 (to be confirmed on post-analysis)

Extreme values during cyclone event (estimated)

Note that these values may be changed on the receipt of later information

Maximum Category:	4 (to be confirmed on post-analysis)
Maximum sustained wind speed:	195 km/h (measured)
Maximum wind gust:	275 km/h (estimated)
Lowest central pressure:	910 hPa (estimated)

Figure 2.1 shows the track of the event as deduced from radar images, satellite data and wind direction mapping from damage to vegetation and structures.

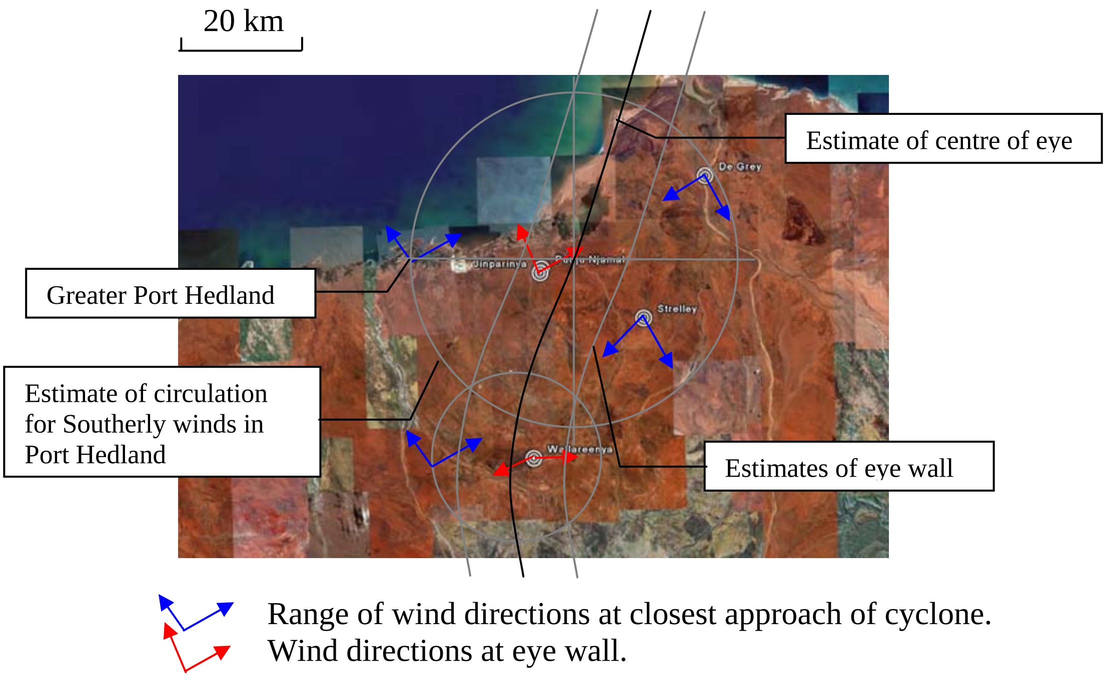


Figure 2.1: Track of TC George (Background image Google Earth)

Figure 2.1 shows that TC George's closest approach to Port Hedland was around 30 km to the East of Port Hedland. This would have been its position at around midnight, the time that residents reported the maximum winds. These winds would have been primarily from the South, and would have shifted towards the West as the Tropical Cyclone progressed in a SSW direction.

Figure 2.2 shows one of the last captures from the Port Hedland radar before it stopped reading during the passage of the cyclone. It shows a strong rain band between the eye and Port Hedland and that on the basis of the track shown in Figure 2.1, and the geometry of the system in Figure 2.2, the eye wall would have been around 20 km from Port Hedland at its closest point.

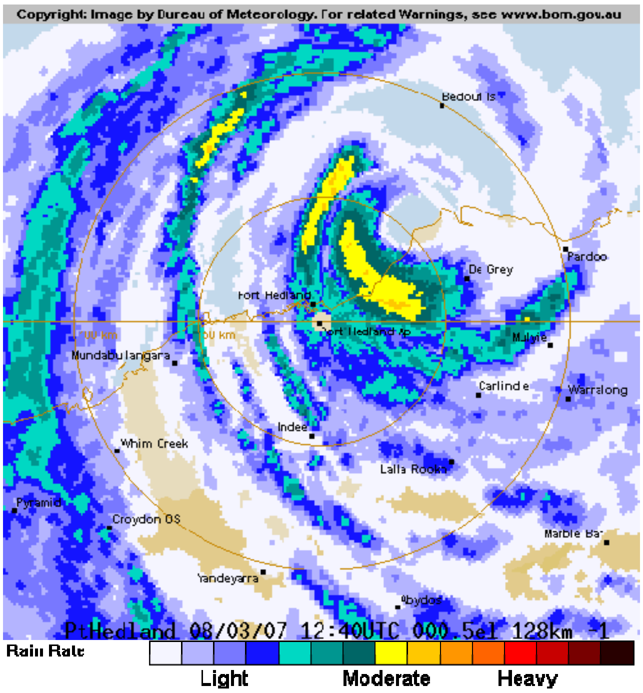


Figure 2.2: Radar capture as TC George crosses the coast

2.2 Wind speed Estimates for the Study Area

Unfortunately, the Automatic Weather Station at Port Hedland did not record wind speeds during the closest approach of TC George. Therefore, road signs were used to estimate upper (U) and lower (L) bounds of peak gust wind speeds at different locations in the study area. These signs are generally flat plates that are attached to one or more cantilevered posts as shown in Figure 2.3, and located in clear exposed approach terrain adjacent to the road. The wind loads acting on these plates can be determined with confidence, and wind speeds deduced from the sign damage can be regarded as plus or minus 5%. The methodology used to estimate wind speeds was the same as used in the report on TC Larry which affected the Innisfail region of North Queensland [3].

The analysis of different road signs was used to derive upper and lower bounds as shown in Figure 2.3:

- signs that had a plastic hinge in the posts indicated that the maximum bending moment had exceeded the plastic moment capacity. A sign in this condition could be used to estimate a lower bound on the wind speed providing the sign was free of evidence of impact damage, and the direction of fall was normal to the axis of the sign;
- the cross section and steel grade of the posts could be used to establish the plastic moment capacity;
- the dimensions of the sign could be used to infer the load that would have been required to exceed the plastic moment capacity; and
- the load could be used with the height of the sign and the upwind terrain and topography to deduce the wind speed that was exceeded to cause failure of the posts.

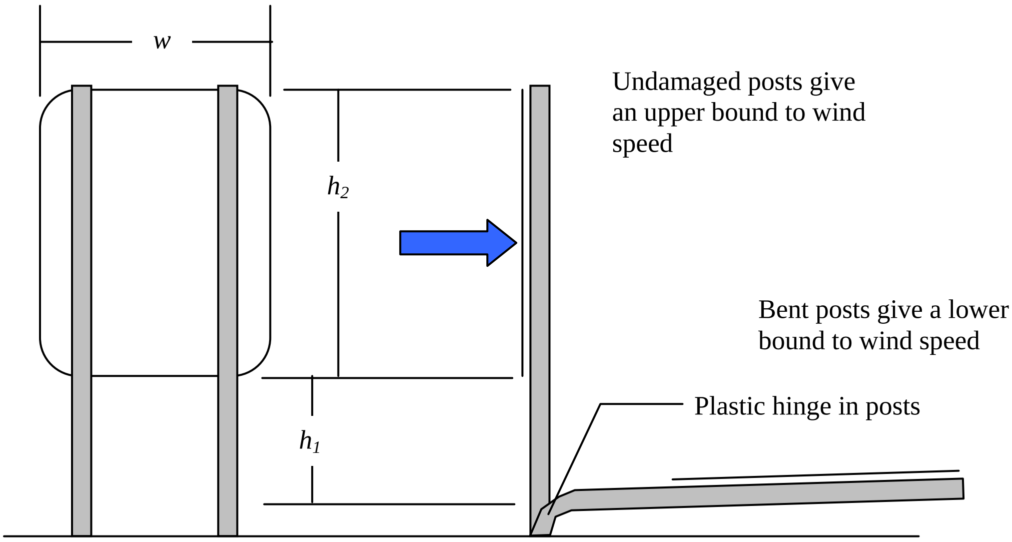


Figure 2.3 Road sign analysis – upper and lower bounds to wind speed

A number of road signs were examined during the study, and from these several were selected as providing the most reliable wind speed information. Figure 2.4 shows a map indicating locations of road signs selected for analysis, corresponding lower (L) or upper (U) wind speeds at 10 m height in terrain category 2, in kph, and the approach direction. The approach direction is shown as a triangle. The legs of the triangle show the wind direction for which the pressure coefficient used is valid. It represents a range which for most signs was from South to West – the range of directions as the eye wall passed Greater Port Hedland.

The wind speed calculated for South Hedland was in the range 200 to 240 kph. As the lower bound sign had just established plastic hinges, it was assumed that the peak gust was close to the lower bound speed – 200 kph or 55 m/s.

The wind speed calculated for the eye wall region – near Tabba Tabba Cr was in the range 130 kph to 270 kph (36 to 75 m/s). It is suggested that the likely speed was near to the top of that range from relating vegetation damage between Tabba Tabba Ck and the Strelley R to the damage in Greater Port Hedland.

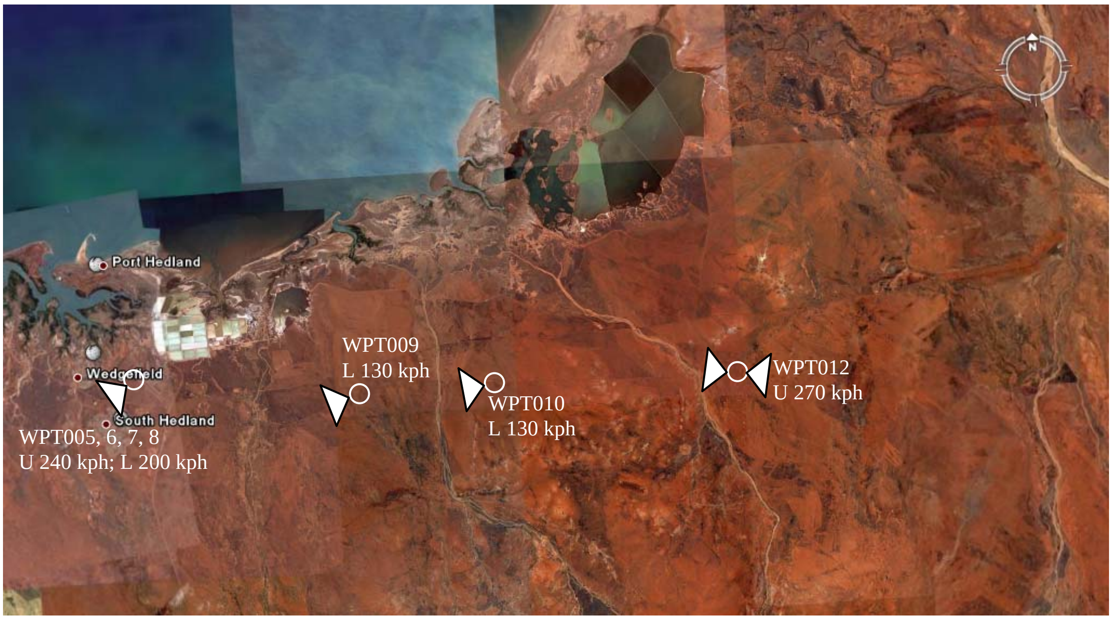


Figure 2.4: Location of road signs used for wind speed assessment
(Background from Google Earth)

3. Housing Stock in Study Area

This section contains a short description of the relevant housing stock in the study area. Houses have varying degrees of exposure to wind forces, with those dwellings located in a suburban environment gaining shelter from surrounding structures as distinct from those exposed houses near the sea or in open terrain. Topographical features such as hills can concentrate or divert wind flow. Wind speeds impacting on a community will vary according to a tropical cyclone's intensity, size and distance from the community. Therefore an assessment of the wind resistance of housing requires knowledge of house types and their distribution throughout the community.

Typical of all towns, Greater Port Hedland has a mixture of house types. Differences in size, shape, window size, cladding type, roof shape, age, and methods of construction can have an effect on the resilience of the house to resist wind forces. A variety of houses were studied in the course of the investigation. They are classified by estimated age of original construction, and have been categorised into three main groups. Many have undergone refurbishments at different times.

Table 3.1 Age categories used for housing

Age class	Features
Pre 1960	Rectangular buildings with single ridge line (predominantly hips), often with screened windows, fibre cement external linings, masonite internal linings. Hardwood structural framing with extensive use of nails (originally roofing was nailed). Roofs incorporated straps or over-battens for tie-down. Few remaining.
1960s and 1970s	Mainly rectangular plans with some irregularities(mixture of hips and gables with a main ridge line), often with screened windows, fibre cement external and internal linings. Hardwood framing, roofing screwed (large washers), often use over-battens and external tie down rods. A number have had roofing replaced and other renovations. Some of houses in this era had decromastic steel roof tiles.
Contemporary	Many different styles have been built. The floor plans are more complex than previous houses and result in more complex roofs (involving some valley gutters). Plasterboard has been used as an internal lining in this era. Structural systems include brick veneer construction with steel or timber frames, steel framed construction with a variety of light weight claddings. Nearly all houses built since 1990s have steel framing.

Note: The dates for the cut-off are only approximate. There is a gradual transition between each type that may be as long as 10 years.

Much of the housing stock in Port Hedland was built by either the government or by the mining companies. In either case, engineered specifications were used to ensure wind resistance before it was included in the WA Building By-laws and later the Building Code of Australia.

Figure 3.1: An example of pre 1960s house

Figure 3.2: An example of 1960 - 1970s house

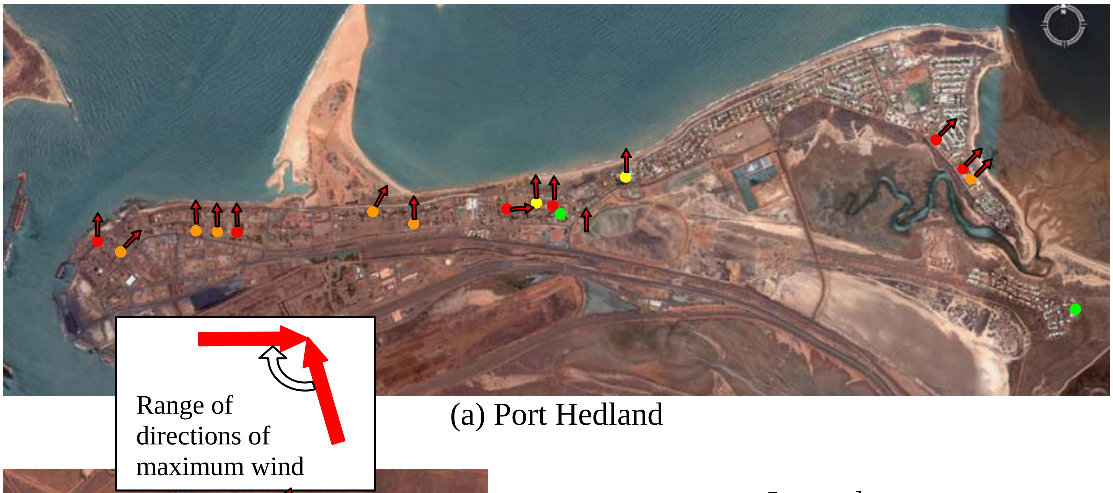
Figure 3.3: An example of a contemporary house

- Few transportable homes were seen. However, transportables are often used as offices or caretakers residences in the Wedgefield light industrial area.
- Many houses in Greater Port Hedland have cyclone screens. Window glass is thicker than normal for windows in Region D. Few cases of broken windows were observed.
- There are few roller doors (even on light industrial buildings). Most houses have carports rather than garages and most industrial buildings have large sliding doors.
- South Hedland is very flat and only a few streets in Port Hedland have topography that would modify the design wind speed.
- There are very few high-set houses in the study area. All of those seen dated from the 1960s and appeared to have performed well.
- There are very few flat roofs on houses in the study area. However, many commercial and public buildings such as the Civic Centre, schools, shopping centres, police stations and the hospital have flat roofs. There was some trim damage on these buildings and problems with water ingress, but few structural problems.
- The roof slope on houses appears to be 15 degrees or more for the older houses, around 15 degrees for the houses from the 1960s and 1970s and higher than 15 degrees for contemporary housing.

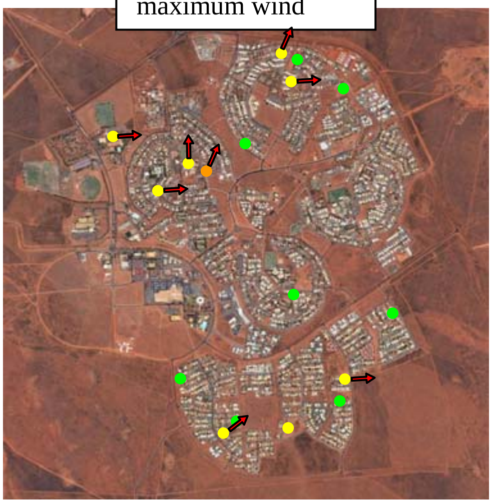
4. Performance of Buildings

The damage was spread throughout the investigation area. There were no concentrations of damage. As estimations of the wind speed in Tropical Cyclone George were significantly less than the design wind speed for the region (approximately 65%), it was expected that there would be little or no damage.

Figure 4.1 shows the extent of roof damage of the buildings inspected in Port Hedland and South Hedland. There seems to be little concentration of damage, and the worst damage appears to be in Port Hedland where buildings are generally older.



(a) Port Hedland



Legend

Code	Damage
● (green)	Nil roof damage
● (yellow)	Damage to trim or sheeting
● (orange)	Loss of battens
● (red)	Loss of rafters or trusses
↗	Wind direction that caused the roof damage

(b) South Hedland

Figure 4.1: Roof damage on buildings inspected

4.1 Housing

In each case, a reason for bad performance of housing could be established.

Good performance could be directly related to the use of appropriate details for the gust wind speeds (which were appreciably less than the design wind speed). In some cases, renovations had given an opportunity for structural aspects of older buildings to be upgraded. (In some cases renovations had decreased performance as discussed in Section 4.1.3.)

Poor performance could generally be attributed to the use of one or more inappropriate details for the gust wind speeds. In some cases, deterioration due to lack of maintenance had rendered once good detailing, ineffective.

There appeared to be few pieces of debris released into the wind stream, so there was not much debris damage in the Port Hedland area. Specific failure types are listed in the sections below:

Table 4.1 presents a summary of the structural damage observed in housing.

Table 4.1 Structural Damage to Housing

Roof Damage		Port Hedland		South Hedland	
Index	Description	*n*	*n* (Over-Batten remv'd)	*n*	*n* (Over-Batten remv'd)
0	No roof damage	1		4	
3	Roofing lifted <10%	0	0	5	0
4	lost roofing <50%	0	0	1	0
5	lost battens <50%	3	2	1	0
6	lost battens >50%	3	2	0	0
7	lifted rafters <50%	5	4	0	0

- *n* is number of houses
- *n* over-batten remv'd is the number of houses in the previous column that have had their over-batten removed (it is a subset of *n*)

4.1.1 Batten to rafter connection

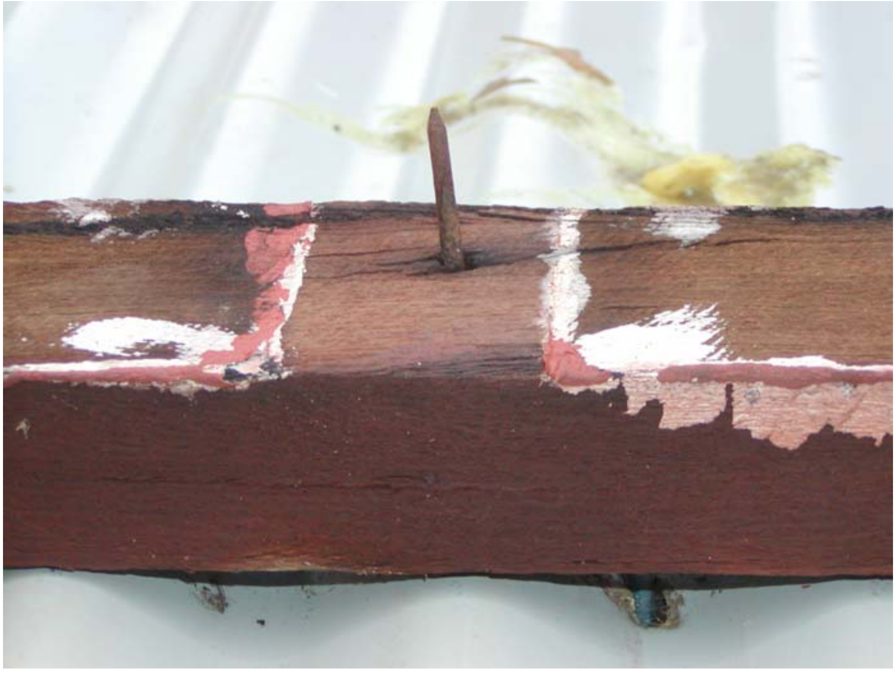
The most obvious damage in a number of older houses that had lost substantial portions of roofing was failure of the batten to rafter connections. In a number of houses, the roofing had been replaced and stronger roofing connectors installed as opposed to the spring head nails used during initial construction. However, no attempt had been made to increase the capacity of other elements in the roof structure. Figure 4.2 illustrates this type of failure.

Where these connections had failed, the rafters remained attached to the remainder of the house, but the battens were removed with the roof sheeting. The main details that had failed were simple nailed connections with one or two nails per batten to rafter connection. Current practice would require a screw, strap (locally called a pap-strap) or a framing anchor.

Two houses were observed where framing anchors had been used, but failures still occurred:

On one, framing anchors had been used only on the edge batten, and uplift forces on the remainder of the roof had caused failure that eventually overloaded the other anchorages in the system – in parts of the roof, roofing screws, and in other parts, the framing anchors.

On the other, framing anchors had only been installed on battens in the centre portion of roof, and the higher uplift forces at the edge of the roof had caused failure of the batten to rafter connections, firstly at the edge, and spreading rapidly to the rest of the roof. Both of these cases highlight the need for the use of the appropriate fasteners throughout the roof.



(a) nail failed

(b) framing anchors remained intact

(c) failure of nails in rotting timber at framing anchor

Figure 4.2: Failure of batten-to-rafter connections

Two flat roofed transportable houses lost a substantial portion of secret fixed cladding ("Kliplok" or similar) after failure of a batten to rafter connection. In this case, short lengths of batten were fixed over the rafters by framing anchors, but the outer batten had rotted near its end grain and compromised the framing anchors. The loss of the batten caused a number of sheets of roofing to “un-clip” across the roof. Figure 4.2(c) shows the failure.

4.1.2 Rafter to top plate/wall frame connection

Before the 1970s, many roofs in Port Hedland were anchored to the top of walls with skew nails. Where the batten to rafter connection had sufficient strength to transmit the forces to the rafters and where there were no other systems in place to hold the roof down, the skew nails did not have sufficient capacity to resist the wind loads. Figure 4.3 illustrates this type of failure.

Figure 4.3 Failure of Rafter to Wall Connection

However, a number of roofs were seen where the rafters were still attached to the walls with only skew nails even though the battens had separated from the rafters. In these roofs, the rafter to wall connection may have been ‘protected’ by prior failure of a weak batten to rafter connection. Had the battens remained attached to the rafters, the loading on the rafter to wall connection may have been in excess of its capacity.

4.1.3 Use of over-battens

Over-battens have been used in the North West of Western Australia for many years as the principal tie down system for the roof structure. Typically, the over-batten is a galvanised equal angle that sits on top of the roofing. It is connected to the floor structure by heavy bolts that pass by the battens and rafters, through the top wall plate and within the wall frame, through the bottom plates to the underside of the floor joists. Figure 4.4 shows a section that illustrates the system. The over-batten secures the battens and the rafters at the line of the external wall.

Previous cyclones in WA [4] have shown that where the roofing outside the over-batten (over the eaves) lifts due to either failure of the sheeting anchorage or the batten to rafter connections, the damaged roof folds back over the over-batten, but the main body of the roof remains attached, as shown in Figure 4.5(a). In this way, the over-batten assists batten-to-rafter connections and rafter-to-wall connections, allowing these to function with two nails each.

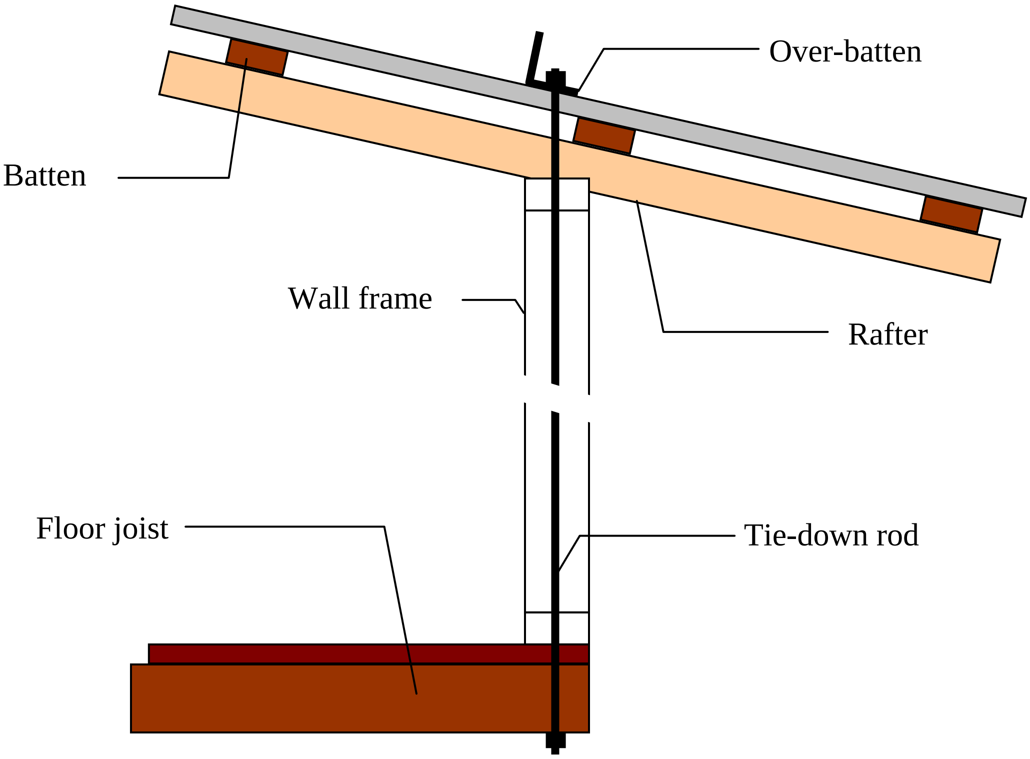


Figure 4.4: Over-batten in original configuration

Figure 4.5(b) shows the over-batten installed on a house. On the left of the photo, the over-batten is above an external wall frame, and on the right of the photo, it is above a verandah beam with steel posts that function as the tie-down rods.

Figure 4.6 shows the same system used over a fibre-cement roofing system. Here the over-batten is smaller, and the anchorages are closer together.

(a) roof failure arrested by over-battens

(b) large angle over-battens

Figure 4.5: Over-batten on steel roof sheeting

Figure 4.6: Over-batten on fibre-cement sheeting

Seven roofs of the twenty three houses with some structural damage had been built using over-battens, but the tie-down rods had been oxy-cut in the past. These houses had each been re-roofed at some stage, but the over-battens had not been replaced, and no other tie-down system had been installed in any of these houses. Figure 4.7 shows a roof failure with the cut tie-down rods highlighted. In this case, the rafters had detached from the walls but the hip rafters which were independently anchored had remained.

Figure 4.7: Removal of Over-batten on re-roofing led to roof failure

Many of the batten-to-rafter failures and the rafter-to-wall failures listed in Table 4.1 were due to the removal of the over-battens. It is imperative that where a tie-down system is significantly changed, a replacement load path is installed.

Detailed recommendations on re-roofing older homes that address these issues have been provided in Section 6.

4.1.4 Deterioration of crucial structural elements

Regular inspection and maintenance of older structures is essential for adequate structural performance. In many other damage inspections after tropical cyclones eg [3] and [4], it was observed that deterioration of structural elements was instrumental in contributing to failure. There were similar cases observed in this study as well.

Most of the older buildings in Port Hedland used hardwood framing with jarrah the favoured species. Although jarrah is resistant to termite activity, the voracious termites in Northern Australia have been known to attack it.

Figure 4.8 shows some rafters that had been seriously compromised by termite activity. This led to partial roof loss, and caused safety issues for workers installing tarpaulins during the response phase.

Figure 4.8: Termite-damaged rafters led to partial roof loss

Figures 4.9 and 4.10 show some rot and corrosion in timber framed structures. There were also many instances of corroded roofing, though in most of these, the corrosion was not the prime cause of the failure.

Figure 4.9: Rot-damaged rafters led to partial roof loss

Figure 4.10: Corroded fasteners contributed to partial roof loss

4.1.5 Steel-framed construction

More recent (post 1990) house construction in Greater Port Hedland uses steel wall and roof framing. There were few structural failures in this type of housing observed.

One type of standard house uses a 600 mm cantilever on the end of a deep top hat batten. This is more than the design recommendations suggest for this region. Figure 4.11 shows the failure of this cantilever.

Figure 4.11: Failure of cantilevered top-hat battens

An aboriginal community that experienced the eye wall wind speeds (estimated at less than 75 m/s) had two identical houses that lost all of the roof battens. These battens had pulled their fasteners out of the light gauge truss elements as shown in the inset in Figure 4.12.

Figure 4.12: batten loss from steel roof trusses
(inset shows detail of truss top chord)

The batten fasteners had worked their way out of the trusses which appeared to have a steel thickness of around 1 mm. The truss steel had locally deformed at the anchorage (highlighted by the circles in the inset). A number of the trusses showed signs of buckling at the batten anchorage also highlighted by a circle in the main photo. As the wind speed did not exceed the design speed for this house, the performance of the connection was of concern. Further investigation of anchorage of light steel battens into light steel trusses is required.

A third failure in a modern light gauge steel framed roof is illustrated in Figure 4.13. This building was also in an area that experienced the eye wall wind speeds. Although the steel trusses appeared to use a slightly thicker gauge steel than the trusses illustrated in Figure 4.12, debris damage initiated failure of batten to verandah rafter connection, causing progressive failure of the remaining batten to rafter anchorages. A circle in Figure 4.13 shows that the batten screws remained in the RHS verandah rafters, and the screws pulled through the 0.75 mm thick battens. In the trussed portion of the roof, the screws pulled out of the trusses as shown in Figure 4.12.

Figure 4.13: batten loss from steel framed roof

The batten spacing on the verandah was 450 mm which performed well at this wind speed on an identical house next door. However, once one anchorage had been lost, the load on adjacent anchorages increased beyond their capacity. This system is sensitive to damage caused by debris or irregularities in anchorage installation.

This failure also highlights concerns about the performance of very light gauge steel elements in roofs at less than the design wind speed.

4.1.6 Roof sheeting failures

There were a few instances in which roofing became separated from the battens as the primary cause of failure.

In one case, a trim became detached from a barge board and dragged two sheets from the roof when they might otherwise have stayed attached. This type of failure is shown in Figure 4.14. (The soffit damage evident was a secondary failure.) Similar damage to trim was also observed in schools.

Figure 4.14: Failure of trim

There were cases of fatigue in roofing observed, but none of these were the primary cause of failure of a roof. They all were fasteners that had been over-loaded by the loss of adjacent fasteners. The loss of individual fasteners appears to have had a number of origins including:

- breakage of fasteners at some stage prior to the cyclone (fracture surface corroded);
- breakage of fasteners during the cyclone (fresh fracture surface). This was always a secondary failure – possibly as the roofing impacted the ground; and
- fasteners missing or not having been driven into a batten.

4.1.7 Water damage to linings

A number of houses lost only small portions of the roof. Where the ceiling lining was fibre-cement sheeting, it remained intact but let water through to cause damage to carpets, furniture and contents. This was the case for older buildings built prior to the 1970s or 1980s.

Figure 4.15: Water damage to plasterboard ceilings

Plaster ceilings suffered water damage, even if the roofing was only very slightly damaged. Also, damage to gable panels allowed water entry to the roof space and caused damage to ceilings as shown in Figure 4.15.

In a number of houses, fine mesh was installed in place of bird boards between the trusses to provide ventilation into the roof space, as shown in Figure 4.16. Unfortunately, wind borne rain was driven through the mesh, ponded on the plasterboard ceilings, and lead to collapse of the ceiling.

Figure 4.16: Mesh ventilation to roof space
Inset: Water damage to plasterboard ceiling

Figure 4.16 shows soil that has been blown onto the underside of the roof and onto the wall cladding on the windward wall. The soil and water were blown through the mesh shown between the top of the cladding and the underside of the battens. Where such ventilation is used, resilient lining materials must be installed. Alternatively, where plasterboard or other water sensitive lining materials are installed, roof space ventilation openings are not recommended.

4.2 Public and Commercial Buildings

There was little damage to public and commercial buildings. Many shops were able to open on the day following the passage of Tropical Cyclone George. Power was restored to the Greater Port Hedland area very quickly which meant that there was little commercial disruption. The minimal disruption would not have been possible had the structures not performed well.

4.2.1 Wind damage to ceilings

Pressurisation of the roof space through gable ventilators caused downward pressure on ceilings and a number of dry ceiling collapses were due to this effect. An example of this type of damage was seen in motel rooms, illustrated in Figure 4.17. In each case in which this was observed, there was no opening that could develop dominant internal suction in the affected rooms, though any leakage through doors and windows would have been from suction surfaces. The affected rooms were not adjacent to the windward wall, but were some distance from it. Any water blown in through the vent landed on ceilings closer to the vent.

Figure 4.17: Collapse of dry plasterboard ceiling due to roof space pressure

4.2.2 Damage to roof trim and flashings

A number of school buildings and the Civic Centre had some damage to the roof that appeared to originate at flashings on the windward edge of the roof. In each case, the flashing seemed very large (around 600 mm wide). Flashings are not normally regarded as structural elements, but in this case, the flashing takes loads comparable to loads on roof sheeting that is regarded as a structural element. The flashings are located in a local pressure zone, which can double the loads on specific fasteners.

Figure 4.18: Damage to wide flashings roofing and trim on windward edge of roof

As this type of detail appears to be quite common in public buildings of this age, it may be advantageous to have the structural adequacy of the wide flashings verified by structural engineers. (Wide flashings and trim can be treated in the same way as roofing.) If needed extra fasteners should be fitted to this detail wherever it occurs in the cyclone regions (C or D) [5].

4.3 Industrial Buildings

The heavy industrial buildings at the ore handling and treatment plants appeared fine from the boundary fences. No inspection of these structures was undertaken.

Light industrial buildings are concentrated in the port area and in Wedgefield. There was little structural damage to observe. Few roller doors are used on these structures – most buildings use heavy sliding doors in place of roller doors. One undamaged commercial roller door that faced the West was seen, and another with some track damage was noted. Sliding doors seemed to perform well, though some trim damage at the top was seen on two and one had been dragged from its track at the bottom – see Figure 4.19 (a).

Roller doors were rarely used in house garages with carports the favoured shelter. Two exceptions were seen, and both of these doors were undamaged and operational. They are shown in Figure 4.19(b). Neither had been fitted with any special anchorages.

(a) Industrial doors

(b) Undamaged Domestic roller doors

Figure 4.19: Roller and sliding doors

5. Conclusions

Tropical Cyclone George crossed the Pilbara coast east of Greater Port Hedland in the late evening of Thursday 8th March 2007. While the town did not experience the eye or the inner eye wall of the tropical cyclone, peak gusts estimated to be up to 200 kph (~55 m/s) would have been experienced through all of the study area. These gusts would have been within the quadrant South through to West. The period of maximum winds lasted for four to five hours.

Generally, there was little structural damage within Greater Port Hedland. This is to be expected as the estimated gust wind speed was approximately 65% of the design wind speed. The observed damage could be explained by deterioration of structural elements, inappropriate refits, or inappropriate detailing. Most of the structural damage occurred in older buildings.

Independent of the structural damage, there was water damage to plasterboard linings. Plasterboard had been used in most recent housing. Water ingress occurred around flashings, or through cracked sealant and through roof space ventilation. Where there was roof or gable damage, water was blown directly into the ceiling space.

The study team inspected all buildings that had been reported to the State Emergency Service as having some structural damage, and any other structural damage observed while travelling in the area. Less than 2% of buildings sustained structural damage. The worst structural damage observed was loss of the major part of the roof structure. This type of damage was only observed in Port Hedland, and only in older buildings. Structural damage was caused by:

- deterioration of older structural elements. Inspection and regular maintenance of all buildings is important for them to retain adequate performance under high wind loadings;
- inappropriate re-roofing practices. When re-roofing buildings there is an excellent opportunity to bring the structural capacity of the entire roof up to current standards. In a significant number of cases, the re-roofing removed the prime tie-down system without replacing it with other systems;
- not following current practice for this area. Design and construction recommendations for Wind Region D [6], [7] must be followed in order to deliver satisfactory performance;
- inadequate batten to truss screw fixings in very light gauge steel battens and trusses. Tearing of battens and withdrawal from light gauge truss top chords contributed to unsatisfactory performance of a number of recently constructed houses;
- failure of non-structural elements such as flashings and trims. Where these were fixed to roof sheeting, then the loss of the trim led to the loss of some roofing as well; and
- pressurisation of roof space through roof and gable vents.

Many buildings constructed to current codes and standards performed well. However, recently constructed buildings in Greater Port Hedland experienced less than 65% of their design load. In a number of Aboriginal communities that experienced the eye wall where wind speeds were estimated to be around 85% of the design wind speed, failures occurred in all light gauge steel framed buildings built within the last five years. It is important that the building industry undertakes testing to establish correct procedures for anchoring light gauge steel battens to light gauge steel trusses.

6. Recommendations

While the damage sustained in Greater Port Hedland was relatively light, it is clear that the most vulnerable structures are the older ones. This highlights the need for regular inspection and maintenance of structural elements.

Damage to older buildings that had been re-roofed highlighted the following recommendations. When re-roofing older homes, builders should:

- inspect for signs of rot, termite damage or member corrosion and replace damaged elements;
- check that the batten-to-rafter connections and rafter-to-wall connections comply with current recommendations in the appropriate framing standard; (This step is easy to achieve when the roofing has been removed.)
- upgrade with extra anchorage (eg pap straps or framing anchors) where connections do not meet the current standard; and
- ensure that tie-down rods are linked to the roof anchorage system. If the over-battens are replaced, the tie-down rods need to connect with them, if other anchorage is used, then the tie-down rods must be incorporated in the new anchorage system.

Where possible and practical, current codes and standards for this area should be followed for all reconstruction work. Documents such as AS1684.3 [6] and HB132.2 [7] provide guidance and load capacities.

Failures in connections between light gauge steel battens and truss chords of recently constructed houses, at wind speeds estimated to be less than the design criteria, highlight the need for a program of research and education into the anchorage of light gauge battens under cyclonic wind loads. Such a program is recommended to ensure that new houses built with lighter gauge metal structural components will have sufficient strength to withstand design wind events.

As the wind speed near the eye wall in Cyclone George was estimated at around 75m/s, approximately 30 km from its landfall, it is likely that the maximum gust wind speed in the entire event may have been above 80 m/s. It is recommended that the design wind speed for Region D presented in AS/NZS 1170.2 [5] remain near 88 m/s.

Cyclone George appears to have continued as a severe event beyond the current cyclone regions boundaries detailed in AS/NZS1170.2. There is also anecdotal evidence following some previous events to suggest that other severe tropical cyclones in WA have shown similar behaviour. It is recommended that research be undertaken to determine if the boundaries need to be widened in this region of WA.

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