Tropical Cyclone George
Wind penetration inland

Report: TR53
February 2009

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TECHNICAL REPORT NO. 53

Tropical Cyclone George
Wind penetration inland

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LIMITATIONS OF THE REPORT

PREFACE

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

Logistically it was far more expedient for the TimberED team to travel from Perth to investigate and assess the wind speeds along the track of 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 Bureau of Meteorology and the Australian Building Codes Board for supporting this work.

ABCB

CYCLONE TESTING STATION

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Tropical Cyclone George
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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 previously 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.

Wind speeds in the region affected by the first 120 km of the cyclone's track after landfall were estimated from damage to simple structures and to vegetation.

All of the estimated wind speeds were less than the design wind speeds presented in AS1170.2-2002 with the relevant F_D and F_C factors. This event has shown no cause to modify the modification factors F_D and F_C.

The cyclone crossed very close to the northern extremity of wind region D, with estimated wind speeds at landfall close to the design wind velocities for that region. Had the crossing been in region C, the design wind speeds would have under-estimated the winds caused by the event. Consideration should be given to moving the boundary of region D further northward.

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Wind Penetration Inland

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Acknowledgements

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- Bureau of Meteorology and in particular, Andrew Burton who arranged transport and logistics for the site visits.
- FMG who gave permission for us to study the piling rig, toilet block and Rail Camp 1. Staff at the Rail Camp were also prepared to be interviewed and share their experiences.
- Staff at BHP Billiton who gave permission for us to use the rail access road.
- Australian Building Codes Board for funding assistance.
- Staff at Wodgina mine.
- People at Strelley, Jinparinya communities and De Grey Station.

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. Technical Report 52 [1] studied the damage within Greater Port Hedland. However, significant damage occurred in more remote communities East and South of Port Hedland.

1.1 Objectives

This study sought to establish wind speeds at various distances from the coast after the Tropical Cyclone made landfall. The estimated reduction in wind speed with distance from the coast could then be compared with the design winds for this region of Western Australia presented in AS/NZS1170.2 [2].

1.2 Strategy

Technical Report 52 [1] made use of simple structures to assess wind speeds in the Greater Port Hedland area and similar techniques will be used in this study. However, there were few simple road signs that could be used in the more remote areas, so other techniques were used:

- Relative damage to river gums could be used to compare damage at different sites with the damage at sites for which evaluations of simple structures had been undertaken.
- Other simple structures such as vehicles, transportable buildings and masts were used as “windicators” using the techniques outlined in the Cyclone Testing Station report on Tropical Cyclone Larry [3].

2. Establishment of track of TC George

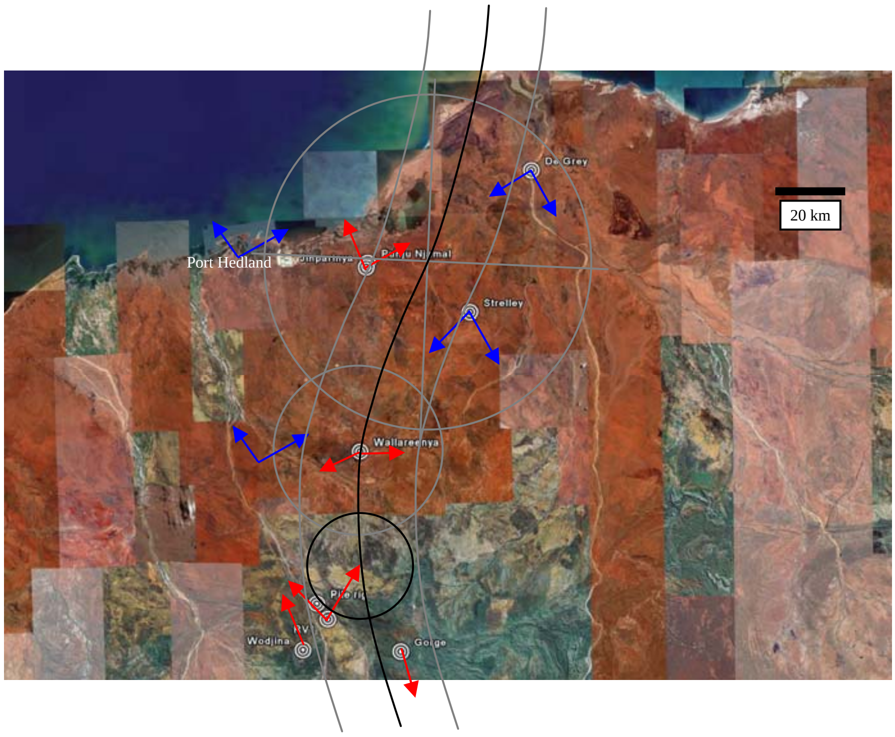
The early estimates of cyclone track published soon after the event by the Bureau of Meteorology were established using a combination of scientific methods including:

- radar images from both the Port Hedland and Dampier radars
- microwave imagery
- satellite imagery
- observation of wind damage to buildings and vegetation

This report makes use of the initial track estimated by the Bureau and refines it using ground observations of wind damage to vegetation and debris paths. Discussions with people who experienced the event were able to estimate the position of the eye. The plot makes a number of simplifying assumptions:

- The eye is assumed to be circular, whereas in reality it changed shape a number of times.
- The track plotted is the “ground level” track which may differ slightly from the position of the event deduced from satellite images. Due to the sparseness of data for this “ground truthing”, the track is necessarily smoothed. In reality, the track may have had a number of small deviations from the shown smoothed path.
- Errors in estimation could be 5 to 10 km.

The resulting track (Figure 2.1) shows the centre of the eye at ground level passing near to Jinparinya settlement and Wallareenya station. The eye also passed over FMG Rail Camp 1, and the Wodjina camp and mine.



indicates the two directions of peak winds before and after the eye crossed the site
indicates the range of high wind directions where the eye did not cross the site

Figure 2.1: Estimated Track of Tropical Cyclone George after landfall.

The diameter of the eye at landfall was around 20 - 25 km as determined by the Bureau of Meteorology from radar images

The eye diameter increased as the system moved further South of Wallareenya station and weakened. The Bureau of Meteorology estimated that it may have been 30 to 35 km in diameter by the time it reached FMG Rail Camp 1 (also known as Rail Village 1 – sometimes abbreviated to RV1 and RC1).

Personnel from Wodjina camp and mine indicated that there was a lull during the passage of the cyclone that lasted for around half an hour. This description is compatible with the passage of the eye, debris paths indicated little change of direction after the passage of the eye, compatible with a position close to the edge of the eye.

Personnel from FMG Rail Camp 1 reported a lull of 40 to 45 minutes and the change in direction of the debris path was consistent with the centre of the eye being closer to the Rail Camp than to Wodjina camp and mine.

Likewise, a gorge to the east of Rail Camp 1 (RV1) shown on Figure 2.1 showed vegetation damage caused by winds that were close to North-North-Westerly winds only. This would have placed it on the eastern edge of the eye.

3. Estimations of wind speed

The wind speed was estimated at a number of locations. In each case, the wind speed is reported as an estimated regional wind speed – height of 10 metres above ground in Terrain Category 2. Each estimate draws inferences from damage to either structures or vegetation. There are errors in these inferences that are related to the complexity of the structure and other factors. Where the structure is simple, then reliability is "good" and the estimates could be within +/- 5%. Where the structure is complex or inferences are drawn from tree damage, the reliability is "moderate" and estimates are likely to be within +/- 10%. The estimates are detailed below:

3.1 Wind speeds in greater Port Hedland

Wind speeds in Greater Port Hedland were estimated at approximately 200 kph or 55 m/s in Technical Report 52 [1]. A number of road signs were measured and a lower bound estimate on a sign that had only just developed plastic hinges at the base of the poles was used for this estimate. It is shown in Figure 3.1. The reliability of the simple structure, and the fact that plastic hinges had only just started to form gave this estimate a reasonably high level of reliability. It has an estimated range of +/- 5%.

As well for this area, the range between lower and upper bounds of wind speed was quite small. The indicated wind speed was greater than 200 kph and less than 230 kph. The plastic hinges in the sign that gave the lower bound (shown in Figure 3.1) were only just deformed indicating that the wind speed was very close to the speed required to generate the plastic hinges.

Figure 3.1: slight bend in posts of lower bound sign in Port Hedland

Figure 2.1 of the Cyclone track shows that Port Hedland did not experience the eye and the winds in the eye wall were also some distance from the town. The wind speeds estimated for Port Hedland were significantly less than the maximum winds generated by Tropical Cyclone George. However, this estimate was of value in assessing damage to buildings in Greater Port Hedland. [1] The damage to trees at known 200 kph winds could be compared with tree damage at other sites where the wind speed was not known.

3.2 Peak wind speeds east of Port Hedland.

A number of road signs on the Great Northern Highway were used to estimate the wind speed within the eye wall when the cyclone was East of Port Hedland [1]. These road signs were close to the location of Jinparinya in Figure 2.1.

A number or road signs in this vicinity were used to evaluate lower and upper bounds of wind speed, but the two bounds did not converge particularly well. The range of indicated speeds was greater than 130 kph and less than 270 kph. Because this area would have experienced higher wind speeds than Port Hedland, it is reasonable to use the estimate of wind speeds in Port Hedland as a lower estimate of wind speeds at this location. This gives the range of possible maximum wind speed as 200 to 270 kph. The tree damage in river basins (comparing like species) at this location was significantly more severe than that in Port Hedland, suggesting that the wind speeds were higher than the 200 kph estimated in Port Hedland.

The estimates of 270 kph gust wind speed after around 50 km of overland travel confirms that Tropical Cyclone George was at least a strong Category 4 event at landfall, and probably a low Category 5 event.

The estimate of 270 kph can also be taken as the gust wind speed that would have affected communities near the eye East of Port Hedland. This includes the communities of Jinparinya and Punju Njamal both of which experienced an eye for around 25 minutes.

3.3 Wind speeds East of the eye and East of Port Hedland

The community of Strelley did not experience the eye of the cyclone, but maximum wind speeds associated with the eye wall impacted the community.

A radio mast at Strelley station was damaged by wind pressures and the plastic hinge gave an estimation of the gust wind speed. The mast is shown in Figure 3.2. It appeared to have been damaged by North-Easterly winds. While there was some debris wrapped around the base of the mast, this was below the level of the plastic hinge (as shown in Figure 3.2). The smaller members in the antenna would almost certainly have been bent by debris if it had impacted the aerial above the level of the hinge.

While at this location, there was only one structure on which to base the wind speed estimate, it was a lower bound to the wind speed, and the plastic hinge was not very advanced, suggesting that the wind speed was very marginally higher than the value required to develop the plastic hinge. The estimate was likely to be close to the maximum gust speed at this location. The height of the aerial was close to the 10 m of the standard regional gust speed measurement, so would not incorporate any errors associated with the correction of the measurement height to the standard height. However, this structure has a more complex drag compared with many of the other simple structures, due to the non-uniformity of the aerials and potential shielding of the downwind aerial by the upwind aerial. For this reason less accuracy can be attached to the gust speed estimation from this structure.

The dimensions of the mast were used to estimate a lower bound for the wind speed that caused the bending of the Circular Hollow Sections (CHS). At 10 m above terrain category 2, the lower bound of the wind speed was estimated at between 230 kph and 280 kph. This range is based on the range of sizes and dimensions estimated from ground level, the errors in pressure coefficients for the aerial, and sensitivities to the wind direction at the time the failure hinge was formed.

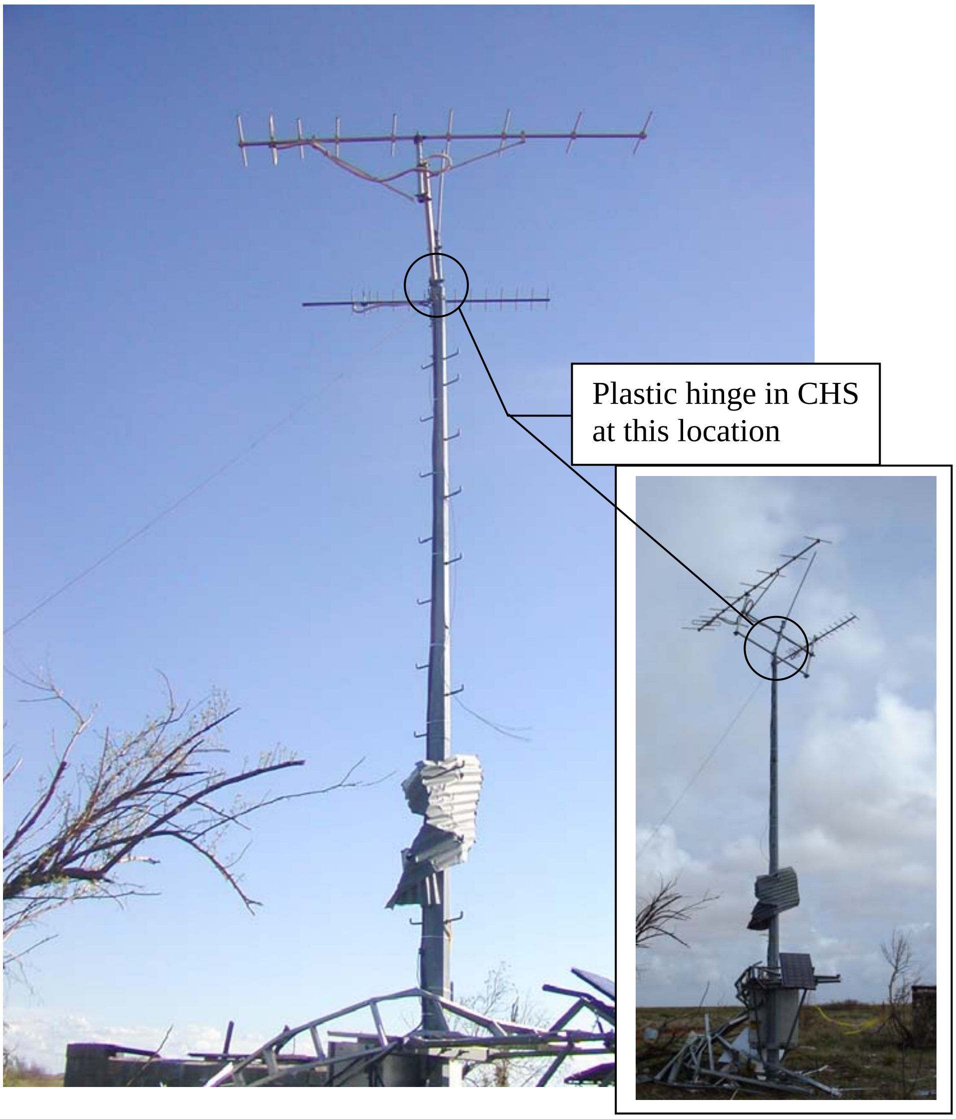


Figure 3.2: small plastic hinge in radio mast at Strelley community

The range of likely wind speeds overlapped the wind speeds inferred from the road signs near Jinparinya. The two sites would have each experienced winds in the eye wall at about the same time and give ranges of 230 to 280 kph or 200 to 270 kph. Vegetation damage indicates wind speeds significantly higher than 200 kph which suggests that the peak wind speeds were in the upper part of the ranges. It confirms that the eye wall wind speed soon after landfall was close to 270 kph.

3.4 Wind speeds near the eye South of Port Hedland

The Mount Newman Rail access road runs Southward from Port Hedland and passes quite close to the FMG Rail Camp 1. The estimation of the track in Figure 2.1 shows that the eye wall intersects that road approximately 40 km South of South Hedland (around 50 km from the coast line).

There are a large number of road signs along this road, but they are not concreted into the ground. Many of them had been blown over, but the failure was by rotation in the ground rather than formation of a plastic hinge in the poles. However, one sign did exhibit a plastic hinge in one of the two poles supporting it. The lower bound wind speed to cause failure of that sign could therefore be calculated.

The analysis of this sign was complicated by the fact that only one plastic hinge had formed in the legs. However, it is reasoned that the foundation failure of the straight leg occurred at the same time or after the formation of the hinge:

- If the straight pole had been pulled from the ground first, then the sign would have "weather-cocked" With one pole supporting it on one end only, the wind pressure on the sign would have rotated the sign on the remaining pole so that the long dimension of the sign would have been parallel to the wind. This would have relieved pressure on the remaining leg. There was no evidence of "weather-cocking" and so this scenario cannot have occurred.
- The straight leg had not been dragged in the down-wind direction. This suggests that the wind pressure on the sign was relieved as the straight pole was withdrawn from the ground. This is a scenario compatible with earlier or simultaneous failure of the bent leg.

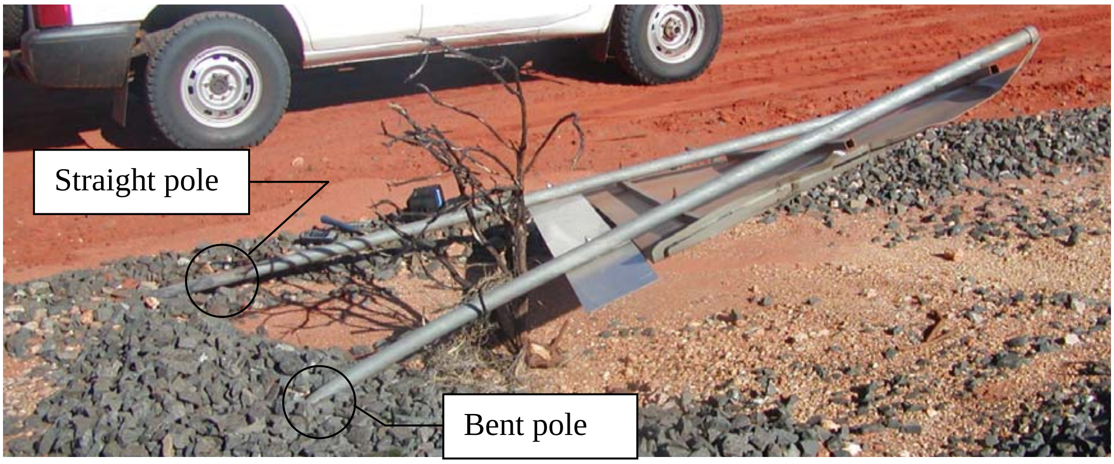


Figure 3.3: sign on rail access road

The sign fell as a result of winds in the quarter from South East to South West, compatible with the wind directions in the passage of the cyclone eye wall at this location. The analysis of the sign yielded a lower bound of the wind speed (standardised to 10 m height and terrain category 2) of 200 kph. Thus at the point where the eye wall crossed the road (around 40 km south of South Hedland) the Southerly winds would have been in excess of 200 kph.

Damage to river gums at this location indicated wind speeds of around 220 kph. The extent of defoliation and the damage to branches of about 50 mm diameter or more were similar to the type of damage to this species observed in locations where road signs had indicated wind speeds of around 220 kph. The tree damage at this location was greater than that observed in greater Port Hedland where wind speed was estimated at 200 kph, and less than that observed in the Tabba Tabba River near Strelley with estimated wind speeds of up to 270 kph. At Strelley, the extent of the defoliation was similar, but larger branches (up to 75 mm) had been broken.

Figure 3.4 shows tree damage in the area around 40 km south of South Hedland.

Figure 3.4: Damage to river gums East Turner River
(near eye wall south of Port Hedland)

3.5 Wind speeds near to FMG Rail Camp 1

Some investigations of wind speed at FMG rail camp 1 were commissioned by the WA Coroner. These involved assessing the wind speed necessary to establish plastic hinges in steel poles supporting basketball rings and backboards. Our own investigations involved the assessment of some other simple structures.

3.5.1 Hose reel

Figure 3.5 shows a hose reel that was completely undamaged in the middle of the camp. At the commencement of the cyclone, it may have had considerable shielding from surrounding buildings, but by the time the winds reached their maximum, the sheltering buildings had all been moved or removed. (Two substantially damaged buildings are shown behind the reel in Figure 3.5.)

Figure 3.5 shows that the face of the reel was free of scratches from debris impact. It also faced directly into the winds that seemed to inflict the most damage on the camp.

Figure 3.5: Hose reel at Rail Camp 1

The hose reel itself was a simple structure suitable for consideration as a "windicator" [3] and its undamaged condition made it possible to estimate the upper bound wind speed. However, the rigidity of this structure simply indicated that the wind had a velocity of less than 300 kph.

3.5.2 Piling rig

A 27 m high pile driving rig at the Turner River was blown over during the passage of the tropical cyclone. The rig was approximately 5 km North of FMG Rail Camp 1. Photographs of the toppled rig and a drawing of the rig is shown in Figure 3.6.

While the aerodynamic drag on of the rig can be evaluated from the drag coefficients for cylinders and the drag on the body, the forces required to topple the rig are complicated by the softness of the ground under the leeward track.

Under conditions expected in tropical cyclones high winds are accompanied by driving rain. The rain can easily saturate the soil under the rig and cause softening that may allow deformation. Table 3.1 shows the expected wind velocity to topple the rig under various soil deformations under the leeward track.

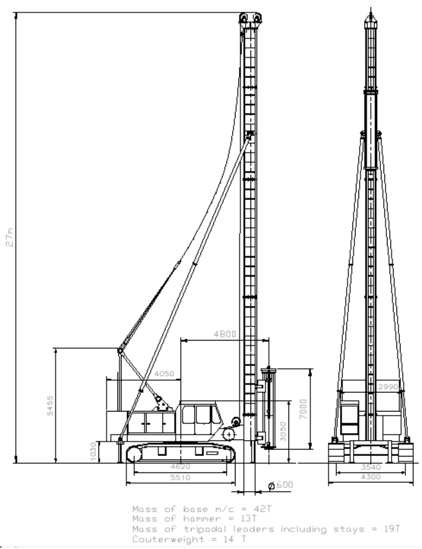


Figure 3.6 Pile Driving Rig
(Drawing from FMG Group)

Table 3.1 Wind velocity to topple rig

Deformation under leeward track (mm)	Angle due to deformation (deg)	Lower bound wind velocity (kph)
0	0	199
44	0.65	194
88	1.33	189
200	2.95	176

A deformation of the soil of 88 mm under the very outer edge of the track corresponds to a change of angle of around 1.3 degrees, and represents 1 mm deformation per tonne. It is likely to be a lower limit to the deformation. 200 mm under the edge of the track is more likely. This range of deformations gives a lower bound wind speed of between 176 and 189 kph.

3.5.3 Transportable toilet block

A transportable toilet block near the Turner River (around 4 km North of FMG Rail Camp 1) was overturned by the winds. Figure 3.7 shows a photograph of the overturned building with the large concrete block used to secure it.

Figure 3.7 Overturned toilet block North of Rail Camp 1

The toilet block had heavy concrete blocks on 3 corners, but in the direction from which the wind was blowing there was only one concrete block which could counter the wind forces. It had lifted off the ground.

For this case, there were some other variables to be considered:

- The slack in the anchor chains would have allowed some lifting of the toilet block before the weight of the concrete block could start to restrain overturning. In this case, the height of the centre of gravity was relatively low compared with the distance between the supports. This made the derived wind speed more tolerant of the angle of rotation before the slack in the chain was taken up.
- The volume of fluid in the underfloor tank contributed weight to the structure which assisted the stabilising forces. A number of different scenarios were run. The level in the tank of the adjacent toilet block was used as a guide to the likely volume.

The results of the various scenarios are shown in Table 3.2.

Table 3.2 Lower bound wind speeds from overturned toilet block

Tank fraction	Slack (m)	Angle (deg)	V10 (kph)
0.2	0	0.0	198
0.2	0.3	8.5	178
0.2	0.6	16.7	162
0.2	0.9	24.2	148
0.3	0	0.0	205
0.3	0.3	8.5	184
0.3	0.6	16.7	167
0.3	0.9	24.2	153

Fortunately, Table 3.2 shows that the estimated lower bound wind speed is not highly dependent on the volume of fluid in the tank. Also measurements of the length of the chain securing the concrete block indicates that the slack would be close to 0.3 metres. This indicates a lower bound wind speed of around 180 kph.

Two different structures indicate lower bound wind speed in this region of about the same value. While it was a lower bound, it was reasoned that the wind would not have been much greater than this value. At the Turner Bridge site, there were two pile drivers and only one had toppled. Also the extent of the tree damage indicated that the wind speed was less at this site than at Port Hedland. It was therefore likely that the peak gust was near 180 kph.

The wind speed at FMG Rail Camp 1 would have been much the same as the wind speed at both the Turner River Bridge site and the toilet block. Both sites indicate a lower bound wind speed of around 180 kph.

3.6 Estimations of wind speed near De Grey station

De Grey station was the closest site in this study to the landfall of the cyclone. Attempts were made to estimate the wind speed from vehicles that had been blown over. These vehicles included:

- An old bus used as storage for some irrigation equipment.
- Some empty cattle trailers

These vehicles are illustrated in Figure 3.8. Attempts to use them as "windicators" [3] were unsuccessful as the flexibility of the tyres and suspension was unknown, and proved critical in the calculations. As well the drag on the cattle trailer was difficult to determine due to the porosity of the sides.

Best estimates at the calculation yielded lower bound wind speeds of around 145 kph. The other damage at De Grey station was commensurate with wind speeds well in excess of this value.

Tree damage to river bank gum trees of a similar type to those at the Tabba Tabba River was more pronounced than the tree damage at the Tabba Tabba River near Jinparinya. Larger branches had been broken, and the vegetation damage indicated wind speeds well in excess of 270 kph estimated for eye wall wind speeds at Jinparinya near the Tabba Tabba River.

(a) overturned bus

(b) overturned empty cattle trailer

Figure 3.8 Overturned Vehicles at De Grey Station

The tree damage shows that the expected wind speeds at De Grey Station would have been a little higher than the wind speeds estimated at Jinparinya. It is difficult to say how much higher the winds at De Grey were than those near Jinparinya, but estimates of maximum wind speeds between 280 and 300 kph would be reasonable.

4. Penetration of wind speeds inland

Wind speed was estimated using a number of relatively simple structures. In the main, these were lower bound wind speed estimates. However, in many of these cases, the extent of the damage indicated that the winds were only just greater than the speed required to cause the damage. This means that the peak gust would have been only marginally greater than the lower bound estimate.

Also in a number of cases damage to trees could be linked with the estimate of the wind speed from simple structures. This enabled that estimate to be transferred to other locations with similar damage to similar species.

The estimates are listed in Table 4.1.

Table 4.1 Estimates of wind speed

Location	**Est Wind speed**	**Windicator**	**Reliability**
De Grey station	> 145	Overturned vehicles	poor
De Grey station	> 270	Trees	moderate
Strelley	230 – 280	Radio mast	good
Jinparinya	270	signs	good
Port Hedland	200	signs	good
40 km South of South Hedland	> 200	signs	good
40 km South of South Hedland	> 220	Trees	moderate
FMG Rail Camp 1	> 180	Overturned building and piling rig	moderate
FMG Rail Camp 1	< 200	Trees	moderate

The De Grey station was not in the eye, but was probably close to the region of maximum winds in the eye wall as the cyclone passed. It was likely that the wind speeds there were in excess of 270 kph (75 m/s). They may have been between 280 and 300 kph based on an extrapolation of the tree damage to wind velocity relationships observed.

Likewise the Strelley settlement experienced winds generated by the eye wall, and the estimates of the wind speed were in the same order as those at De Grey – 230 to 280 kph. At roughly the same time as the winds of this speed were experienced at Strelley, the winds in Port Hedland were approximately 200 kph and the winds in the eye wall at Jinparinya were around 270 kph. Figure 2.1 shows that Strelley was significantly closer to the eye of the cyclone than Port Hedland.

Later, when the cyclone had moved further to the south, wind speeds as the eye wall reached the Mt Newman Railway Line were estimated at around 200 to 220 kph.

The cyclone had moved significantly to the south by the time the eye wall had reached FMG Rail Camp 1 (around 90 km due south of Port Hedland, but around 140 km along the cyclone’s track). Estimates of these wind speeds from two simple structures put the wind speed near 180 kph.

All of these estimates were commensurate with the damage to nearby gum trees in stream lines.

These wind speed estimates could be compared with the design wind velocity for similar locations.

- Within 50 km of the coast, the design wind velocity for this region is 88 m/s (including the F_D factor) or 317 kph. Measured wind speeds were all less than this value, though expected wind velocity in the eye wall soon after landfall may have been near to this value. However, the estimated peak wind speed near landfall exceeded the design wind velocity for Region C (69 m/s or 249 kph). Also, the estimated wind speed near landfall exceeded the design velocity if the F_D multiplier was taken as 1.0.
- After travelling over land for 50 km, the measured winds near the eye were around 200 to 220 kph. The wind code gives a step reduction after 50 km over land from 88 m/s to 69 m/s (or from 317 kph to 249 kph).
- After a further 50 km of overland travel, wind speeds were estimated at around 180 kph. The code at 100 km after landfall has a further step reduction in design wind speed from 69 m/s to 57 m/s (or from 249 kph to 205 kph).

The details are summarised in Table 4.2.

Table 4.2 Estimates of wind speed compared with design values

					by distance from landfall				**by location**		
Locn	**Reliability**	**Eye**	**Wind speed (kph)**	**wind speed (m/s)**	**Dist from landfall**	**Region**	**Design no F_D F_C**	**Design with F_D F_C**	**Region**	**Design no F_D F_C**	**Design with F_D F_C**
Landfall	*estimated*	*yes*	*300*	***83***	*0*	*D*	*80*	*88*	*D*	*80*	*88*
De Grey station	moderate	no	>270	**>75**	10	D	80	88	D	80	88
Strelley	good	no	270	**75**	35	D	80	88	D	80	88
Jinparinya	good	yes	270	**75**	40	D	80	88	D	80	88
40 km south Sth Hedland	moderate	yes	220	**61**	90	C	66	69.3	D	80	88
FMG Rail camp	good	yes	180	**50**	140	B	57	57	C	66	69.3

In Table 4.2, each row represents the best estimate of wind speed from simple structures and vegetation damage, except for the first row (shown in italics). This has been extrapolated from the estimate of wind speed at De Grey station from tree damage only. Table 1 also shows comparison of the estimated wind speed with design wind speeds with two interpretations:

- By distance from landfall – measures the distance along the deduced track of the cyclone. This distance has been evaluated to compare wind speeds with the design wind speed had the same event crossed the coast at right angles and proceeded directly inland. This evaluation is purely academic to test the AS/NZS1170.2 model of decrease of wind velocity with distance from landfall.
- By location – relates the wind region to the actual location (distance from smoothed coastline). This applies directly to the design winds used for structures at that location in accordance with AS/NZS1170.2-2002.

The two analyses are illustrated in Figure 4.1. The wind speed estimates are at about 50 km intervals along the path of the cyclone, but the design wind speed at each location is given by the direct distance from the smoothed coast line. The first two points are in wind region D, even though the path of the cyclone has covered 100 km overland by the time it reaches the region D / region C boundary.

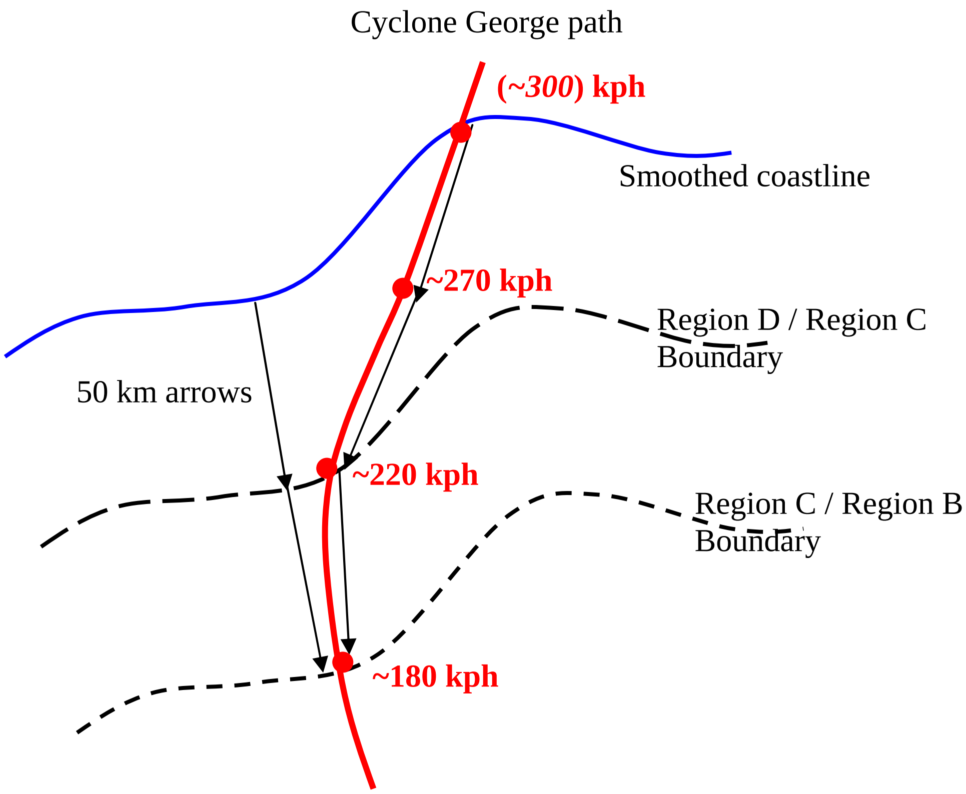


Figure 4.1 Estimated peak wind speeds after overland travel

4.1 AS/NZS1170.2-2002 regional wind speeds

The columns headed "By distance from landfall" could be used to compare the AS/NZS1170.2 [2] wind region velocities with the estimated wind speeds for the hypothetical case of the same event crossing the coast at right angles. These showed that for the two locations in the eye, the estimated wind speeds were each a little lower than the design wind speed with an F_D and F_C multiplier.

However, if the F_D multiplier is not used for the design wind velocity at landfall, then the design wind velocity is less than the estimated wind velocity. This indicates that the F_D and F_C factors are an important feature of the design wind velocity.

For the hypothetical case of a cyclone with the same characteristics as Cyclone George but crossing the coast at right angles, then the estimated wind speed could be compared with the design wind speeds as shown in Figure 4.2. The blue line represents the wind speeds and distance from landfall indicated in Table 4.2, and the red lines the design wind speeds for this scenario. The full red line is the design wind speed including F_D and F_C and the dotted red line is the wind speed if the F_D and F_C factors are removed from the standard.

Figure 4.2 shows that the current design wind speeds are a little conservative for nearly all distances from the coast. (There are only very small excursions of the blue line below the full red line near the region boundaries.) However, the dotted red line shows a significant portion below the estimated wind speeds within the first 100 km of overland travel.

It appears that the code models of cyclone penetration of wind speed (including the F_D and F_C factors) after landfall would have led to appropriate predictions of wind speed for this event. This confirmed that the F_D and F_C factors are a necessary feature of the design wind velocity.

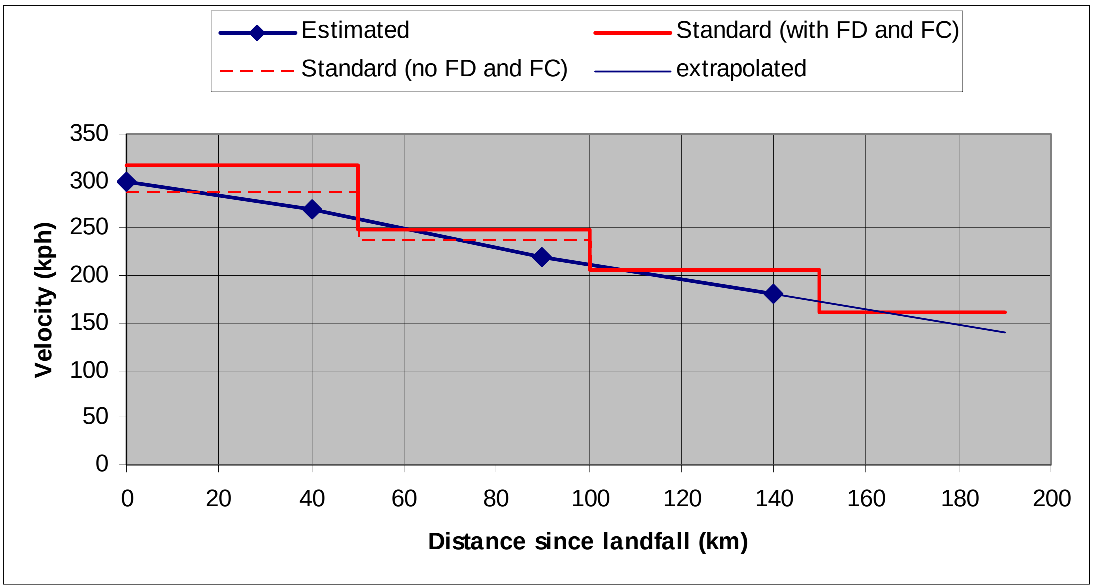


Figure 4.2 Design wind speeds plotted against estimated wind speeds with distance after landfall

4.2 Comparison with design wind speed by location

The columns headed “By location” in Table 4.2 could be used to compare the AS/NZS1170.2 wind region velocities with the estimated wind speeds for each site. This is important in comparing the estimated wind speed with the actual design wind speed for each site. These figures showed that for all but the estimate of wind velocity at landfall, the estimated wind speeds were each a little lower than the design wind speed with an F_D and F_C multiplier. The current wind standard could be expected to provide an adequate basis for design for all locations in the study area.

4.3 Region D boundary

The recorded landfall was very close to the 20 degree South parallel of latitude. This makes it coincident with the boundary between Region D and Region C. Had the landfall been in Region C, the estimated peak wind velocity of 83 m/s would have been considerably higher than the region C design wind velocity of 69 m/s.

This would suggest that it may be prudent to move the northern boundary of region D further north. Other severe tropical cyclones have crossed north of the path of cyclone George in the past decade. These include [4]:

- Cyclone Kirsty (1996) – high Category 4 Crossing at Pardoo 19.5 degrees South
- Cyclone Chris (2002) – Category 5 Crossing at Wallal 19.2 degrees South, and
- Cyclone Rosita (2000) – Category 5 Crossing at Bidyadanga, 18.8 degrees South.

5. Conclusions

Estimated peak gust wind speeds at various locations in the study area were as follows:

- Greater Port Hedland – 200 kph with good reliability
- De Grey station – >270 kph with moderate reliability
- Strelley – 270 kph with good reliability
- Jinparinya – 270 kph with good reliability
- East Turner bridge (~40 km South of South Hedland) – 220 kph with moderate reliability
- FMG Rail Camp 1 – 180 kph with good reliability

Design wind speeds with the F_D and F_C multipliers gave conservative estimates of the peak wind speeds estimated at each location.

If a cyclone with the same characteristics as TC George had crossed the coast at right angles, then the design wind speeds with the F_D and F_C multipliers would have given an accurate representation of the wind at each location. If the F_D and F_C multipliers were not included, then the design wind speeds would have been unconservative in this scenario.

As this event crossed the coast at a latitude of just more than 20 degrees south, the landfall was at the northern limit of wind Region D. At least three other severe tropical cyclones that would have exceeded the Region C design wind velocity have crossed the coast north of the Region D boundary in the last decade. Consideration should be given to moving the northern Region D boundary northwards.

6. References

[1] Cyclone Testing Station “Tropical Cyclone George – Damage to Buildings in the Port Hedland area” TR52, Cyclone Testing Station, James Cook University, NQ.

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

[3] Cyclone Testing Station “Tropical Cyclone Larry – Damage to Buildings in the Innisfail area” TR51, Cyclone Testing Station, James Cook University, NQ.

[4] Bureau of Meteorology reports on annual Tropical Cyclone activity. Web address (*bom.gov.au*)