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Re-analysis of extreme wind gusts in Region D

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ABSTRACT

Recorded and corrected extreme wind gusts exceeding 22 m/s from eight coastal stations in Region D, as currently defined in AS/NZS 1170.2, have been processed as a group, and for 3 individual stations with long records. These indicates that the extreme value distribution in the draft standard DR AS/NZS 1170.2:2020 is quite adequate, without any additional factors, but the predicted extreme wind speeds for Carnarvon are well under the Region D specifications. The calculated wind direction multipliers for Region D show higher values for the north to south-east sectors; this can be explained by the wind directions generated by the clockwise rotations created by the cyclonic vortices, as the storms cross the coastline, or as they pass along the coastline at near full strength.

1. Introduction

A 50-kilometre wide strip between 20° S (just north of Port Hedland) and 25° S (just south of Carnarvon) has been designated as 'Region D' in the Australian/New Zealand Standard for wind actions, since 1989 (Standards Australia, 2011). This Region incorporates the northern part of the Gascoyne coast, as well as the Pilbara coast. The design wind speeds for buildings and other structures in this Region are the highest in Australia, and are higher than any other parts of northern Australia.

Observations by the Bureau of Meteorology (BoM) have improved greatly in recent decades with better information on cyclone tracks resulting from geo-stationary satellite observations, and new automatic weather stations (AWS) providing more surface wind data. This paper makes use of more than fifty years of observations by the BoM on recorded daily maximum gust speeds and their directions during cyclones, to critically review the requirements in the current, and draft revised, Standard for wind loading, AS/NZS 1170.2 (Standards Australia, 2011, 2020).

Another paper in this Workshop (Holmes, 2021) describes an analysis of cyclone tracks and landfalls on the Pilbara and Gascoyne coasts by severe tropical cyclones during the period 1970-2020; this information was also used to identify recorded high gusts from tropical cyclones, and separate them gusts due to other events such as thunderstorms.

2. Database of recorded wind gusts from cyclones

Daily maximum gust data is available for the stations in Region D listed in Table 1. Long records are available from Port Hedland and Carnarvon. Onslow Airport is also a long-established station, but daily gust data is missing for several years. The older stations have a mixture of gusts from Dines pressure-tube-float anemometers and 3-second moving averaged gusts from cup anemometers associated with automatic weather stations (AWS). The newer stations only have AWS data, from stations installed in the 2003-4 period.

Table 1. Anemometer stations in Region D and years available

Station No.	Name	Lat.	Long.	Years	Notes
4032	Port Hedland	20.37°S	118.63°E	1954-2020	Dines & AWS
4083	Karratha	20.71°S	116.77°E	2003-2020	AWS only
4090	Roebourne	20.76°S	117.16°E	2003-2020	AWS only
5007	Learmonth	22.24°S	114.10°E	1978-2020	Dines & AWS
5008	Mardie	21.19°S	115.98°E	1984-2020	Dines & AWS
5017	Onslow	21.67°S	115.11°E	1943-2020	Dines & AWS (1975-2002 missing)
5084	Thevenard Is.	21.46°S	115.02°E	2003-2020	AWS only
5094	Barrow Is.	20.87°S	115.41°E	2003-2020	AWS only
6011	Carnarvon	24.89°S	113.67°E	1953-2020	Dines & AWS
200100	Varanus Is.	20.66°S	115.58°E	2004-2020	AWS only

3. Corrections for terrain and gust duration

3.1 Corrections for terrain

Corrections for terrain are required to adjust the gust data to the standard open country terrain (Terrain Category 2 in AS/NZS 1170.2). For the AWS data, correction factors were derived using gust factors (3-second gust/10-minute mean) derived from data recorded by the BoM at half-hourly interval. These values were averaged over many thousands of values for sixteen direction sectors. Then averaged turbulence intensities were calculated using theoretical peak factors, leading to estimates of aerodynamic roughness lengths, and thence effective terrain categories in AS/NZS 1170.2. The full methodology for this process was described by Holmes (2016).

Table 2 shows the correction factors derived for eight stations, determined from the AWS half-hourly data as described above. The correction factors are mostly less than 1.0 as the terrain is generally very open, with all the stations located at airports. In the case of Varanus Island, the anemometer is exposed to open water for nearly all directions. The minimum 10-minute mean wind speed used for the gust factor analysis was 26 km/h (7 m/s) for the stations on land, and 51 km/h (14m/s) for Varanus Island, since the roughness of the over-water fetch is more sensitive to wind speed.

The Dines anemometer data were corrected for terrain using factors developed by Dorman in the 1980s, (Dorman, 1983).

3.2 Corrections for gust duration

The AWS data were also corrected for gust duration to adjust the recorded 3-second (moving average) gusts to the 0.2-second duration used in AS/NZS 1170.2 (Holmes and Ginger, 2012). The correction factor for the 3-second gust to a 0.2-second peak gust is a function of the wind speed itself. Using peak factors from the method described by Holmes *et al.* (2014), the empirical correction formula of Equation (1) was obtained, (for gusts at the standard height and terrain).

$$V_{0.2s} = -(2.67 \times 10^{-7}){V_{3s}}^4 + (4.298 \times 10^{-5}){V_{3s}}^3 - (1.411 \times 10^{-3}){V_{3s}}^2 + 1.137V_{3s} \quad (1)$$

No corrections for gust duration were made for the data recorded by Dines anemometers. The high-speed version of the Dines, used in cyclonic regions from the 1970s, closely recorded a peak gust with a 0.2-second duration (Holmes and Ginger, 2012). The adjacent AWS and Dines anemometer that were located at Learmonth Airport during Cyclone 'Vance' in 1999 provides a check of Equation (1). A maximum gust of 74 m/s was recorded by the Dines, and 63 m/s by the cup anemometer of the AWS (Reardon *et al.,* 1999). The measured ratio of 1.17 corresponds to a ratio of 1.15 for ($V_{0.2s}/V_{3s}$), at a value of V_{3s} of 63 m/s, given by Equation (1).

Table 2. Correction factors for terrain from gust factor analyses

Wind direction	Port Hedland	Karratha	Roebourne	Learmonth	Mardie	Onslow	Carnarvon	Varanus Is.
22.5	0.93	0.91	0.91	0.95	1.00	0.94	1.00	0.99
45	0.94	0.91	0.91	0.98	1.00	0.94	0.98	0.95
67.5	0.97	0.91	0.91	0.99	0.99	0.92	0.99	0.86
90	1.00	0.92	0.92	0.98	0.99	0.90	1.00	0.86
112.5	1.01	0.95	0.95	0.98	0.98	0.91	1.00	0.86
135	0.99	0.97	0.97	0.98	0.99	0.92	0.99	0.89
157.5	0.96	0.96	0.96	1.01	1.01	0.94	0.98	0.92
180	0.97	0.97	0.97	1.01	0.99	0.95	0.96	0.87
202.5	0.97	0.97	0.97	1.00	1.01	0.95	0.94	0.86
225	0.97	0.94	0.94	0.99	1.04	0.95	0.96	0.86
247.5	0.96	0.88	0.88	0.98	1.00	0.98	0.98	0.86
270	0.94	0.86	0.86	0.98	0.98	0.94	0.98	0.86
292.5	0.91	0.92	0.92	1.00	0.96	0.91	0.97	0.87
315	0.91	0.93	0.93	1.03	0.98	0.91	0.97	0.87
337.5	0.92	0.95	0.95	1.01	1.02	0.93	0.99	0.88
360	0.92	0.98	0.98	0.96	1.05	0.95	0.98	0.94

4. Extreme-value distribution fits

4.1 Fits to the combined data for Region D

Of the ten stations listed in Table 1, Thevenard Island and Barrow Island were regarded as redundant, as those stations were too close to Onslow and Varanus Island respectively to provide sufficient statistical independence. The peak gust data from tropical cyclones recorded at the 8 stations listed in Table 2 gave 202 corrected values greater than 22 m/s, from 82 separate cyclones, recorded in 346 station-years.

The combined corrected data is plotted as a function of average recurrence interval in Figure 1. The equation of best least-squares fit to the data (the dashed line in Figure 1) is given by Equation (2). The average recurrence interval (ARI) is the average time between exceedances of an extreme wind speed.

$$V_R = 151.7 - 137.9 R^{-0.1} \qquad (2)$$

R is the ARI, and V_R is the predicted gust associated with it.

Equation (2) is a form of the Type 3 Generalized Extreme Value Distribution (GEV) with a shape factor, *k*, of 0.1. Equation (2) is similar in form to that used AS/NZS 1170.2:2011, but the coefficients are different. The equation for Region D in the Standard is Equation (3):

$$V_R = F_D . (156 - 142 R^{-0.1}) \qquad (R \geq 5 \text{ years}) \qquad (3)$$

In which F_D is an 'uncertainty factor' with a value of 1.10.

Equation (3) is shown on Figure 1 as a solid blue line. It is seen to be conservative with respect to the data, and to the fit of Equation (3).

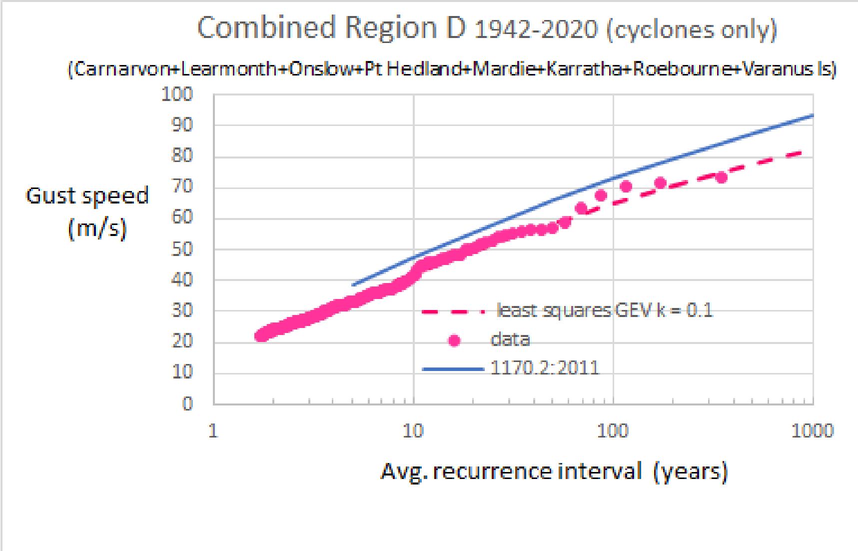

Figure 1. Best fit to the combined gust data from 8 Region D stations

The main reason for the conservatism in Equation (3) is the factor F_D. The uncertainties in the predictions when that factor was introduced in the 2002 and 2011 versions of AS/NZS 1170.2 have largely disappeared, with the availability of much more data from more anemometer stations in Region D.

In the draft revision of the Standard DR AS/NZS 1170.2:2020, the F_D factor has been removed. In addition a reduction will be introduced for the distance from the smoothed coastline. Figure 2 shows the specified distribution for locations 10km inland in Region D; this is approximately the average distance inland for the 7 mainland stations. The specified distribution is very close to that given by Equation (2); for example, V_{500} is 78 m/s in Equation (2), and 77 m/s in DR AS/NZS 1170.2:2020 for locations 10km from the coastline.

A 'climate change' multiplier of 1.05 has been included for Regions C and D in DR AS/NZS 1170.2:2020, but since this is intended to account for the effects of future climate change, that multiplier has not been applied in Figure 2.

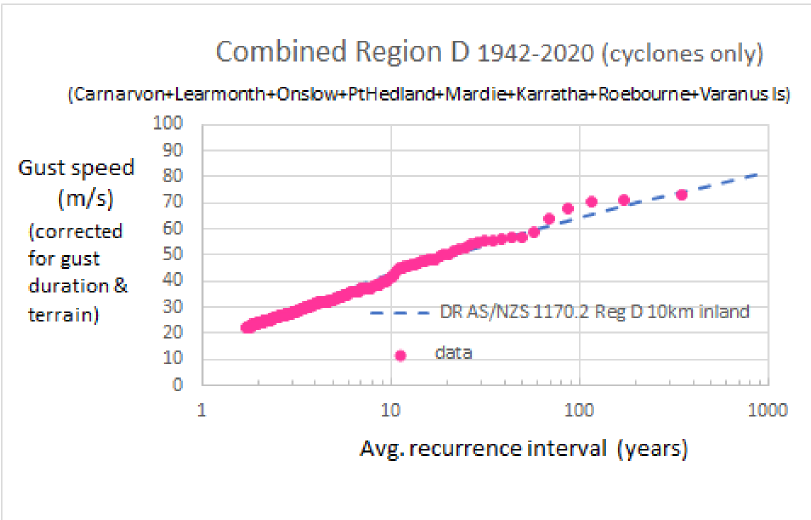

Figure 2. Recorded data from 8 stations compared with proposed distribution for Region D (10 km inland) in DR AS/NZS 1170.2:2020 ($R \geq 5$ years)

4.2 Fits to data for individual stations

Use of combined data from several stations, as described in Section 4.1, significantly reduces the uncertainty (sampling errors) in predictions of extreme wind speeds for Region D in general. However, there is considerable variability in the frequency of impacts from severe tropical cyclones at different locations along the coastline of the Region (Holmes, 2021).

Three stations: Port Hedland, Onslow and Carnarvon, with 66, 78 and 67 years of data respectively, have long enough records to enable the spatial variability in the predicted extremes to be determined. Figure 3 shows fitted lines for data from those three stations, plotted with the proposed line in DR AS/NZS 1170.2 for locations 10km inland. This figure shows that Region D line in the draft Standard represents the data from Onslow and Port Hedland well, but is very conservative for Carnarvon. In fact, even the line in the draft Standard for Region C is conservative.

This is hardly surprising as there have been no landfalling severe cyclones in the latitude range 24.0^o to 24.9^{o}S in the last five decades (Holmes, 2021). Cyclone 'Olwyn', a category 3 storm which passed along the coast offshore from Carnarvon, and produced a corrected gust of 45 m/s, was the only storm to affect Carnarvon significantly since 1960. There is a clear case for Carnarvon to be down-graded to Region C in a future amendment to AS/NZS 1170.2.

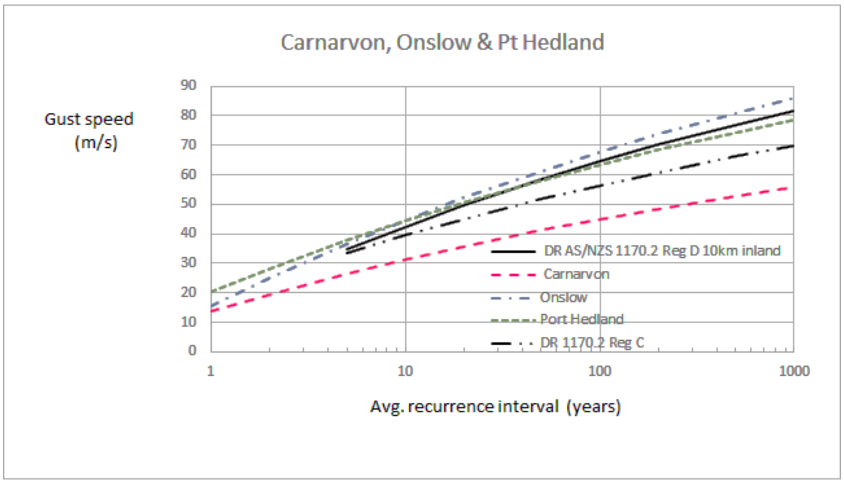

Figure 3. Fitted lines to Carnarvon, Onslow and Port Hedland data compared with DR AS/NZS 1170.2

5. Directional multipliers

For the recorded gust data from the eight combined Region D stations that were used for Figures 1 and 2, wind direction multipliers were calculated in a similar way to that used for other wind regions in Australia as described by Holmes (2020). Wind directions from corrected gusts greater than 22 m/s were used to calculated directional probabilities for sixteen directional sectors, and direction multipliers for eight sectors using Equation (4).

$$M_{d,i} = \frac{C - D[2R.p(\theta_i)]^{-0.1}}{C - D[R]^{-0.1}} \quad (4)$$

for i = 1 to 8

$p(\theta_i)$ is the probability of a high wind gust (> 22 m/s) coming from the direction sector, i, and R is the targeted average recurrence interval. C, D are the parameters in the Type 3 GEV distribution fitted to the extreme gust wind speeds.

The calculations for Region D with the target ARI, *R*, taken as 500 years, are summarized in Table 3. This Table shows that there is a higher probability of cyclonic wind gusts in Region D coming from the N to SE range, with the highest probability for the NE sector. This can be understood when considering the wind direction produced by the cyclonic vortices at their maximum intensity on landfall or travelling along the NE-SW Pilbara coast at full strength.

Table 3. Calculations of wind direction multipliers, M_d, for combined Region D stations

Wind direction	$p(\theta)$	M_d calculated	M_d rounded	M_d DR AS/NZS 1170.2
N	0.134	0.874	0.90	0.90
NE	0.274	0.945	0.95	0.90
E	0.179	0.903	0.90	0.90
SE	0.153	0.887	0.90	0.90
S	0.103	0.846	0.85	0.90
SW	0.061	0.788	0.80	0.90
W	0.037	0.730	0.75	0.90
NW	0. 061	0.788	0.80	0.90

In the draft revision DR AS/NZS 1170.2:2020, a constant value of M_d of 0.90 has been specified for Region D, for consistency with Region C which covers the whole of the northern Australian coastline, with a wide variety of cyclone tracks and coastal orientations. Based on Table 3, this could be reviewed in the future, to allow designers to take account of the reduced probability of extreme gusts from westerly sectors from cyclones in Region D.

5. Conclusions

- Extreme value analysis of combined gust data from eight anemometer stations in Region D suggest that the distribution in the draft Australian Standard DR AS/NZS 1170.2:2020 is a good fit.
- The recorded gust data for Carnarvon strongly suggests that the town should be located in Region C, not Region D.
- Analysis of directional probabilities and wind direction multipliers for the combined Region B stations, indicate a slight bias to winds from the north through to south-easterly sectors.

References

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