TC Coast-Crossing Wind Gust Hazard in Australia Using Satellite-Based Data

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1 INTRODUCTION

The Dvorak technique [8] is commonly used for tropical cyclone (TC) intensity estimation from satellite-based imagery. Since the 1984–85 cyclone season the maximum wind speed estimated by the Dvorak technique has become available; therefore, it provides a source of wind gust data for gust hazard estimation for the purpose of structural design. This abstract presents the TC coast-crossing gust hazard in Australia estimated by the Weibull distribution of the largest value using the satellite-based data maintained by the Australian Bureau of Meteorology (BoM) (http://reg.bom.gov.au/weather/cyclone/tc-history.shtml) from the 1984–85 to the 2006–07 cyclone seasons, a period of 23 years.

The BoM recorded the 10-min. mean wind speed at 10 m above the surface, whereas the regional wind speed specified in the Australian structural design standard, AS/NZS 1170.2:2002 [1], is based on 3-second gust wind speed at the same height. Consequently, a gust factor is needed to convert the 10-min. mean wind speed to 3-second gust speed. Harper et al. [3] recommended the following 10-min. to 3-second gust factors for updating the present forecasting advice in the WMO Global Guide to Tropical Cyclones — At sea (offshore > 20 km): 1.23; Off-sea (onshore winds at a coastline): 1.38; off-land (offshore winds at a coastline): 1.52; inland (roughly open terrain): 1.66. With a lack of published studies on TC gust factor for the Australian TC basin, a gust factor of 1.4 is chosen for calculating the gust speeds at land crossing and over the ocean.

2 HAZARD ESTIMATION METHODS

The gust speeds recorded in a zone regarded as of uniform climatology are considered by the superstation concept [6]; i.e. each TC gust is treated as the maximum gust speed recorded at the coast-crossing location by an imaginary anemometer over the period of data record. Then all the gust speeds in the zone are analysed for hazard estimation as described in the following.

2.1 Empirical Probability Distribution

Let $v_i, i = 1, \ldots, N$, be *N* statistically independent gust speeds arranged in ascending order recorded in a zone over a period of *T* years. The *T*-year empirical cumulative distribution function (ECDF) of the *i*th observation is determined by a probability plotting position formula as follows,

$$\mathrm{ECDF}_{T,i} = i/(N+1) \tag{1}$$

It has been shown [4] that Eq. (1) gives the mean of the cumulative probability distribution of the *i*th observation and is distribution-free.

Each gust speed v_i may be regarded as the maximum gust speed at the coastal-crossing site in *T* years. By the theory of total probability and statistical independence among the gust speeds, the annual ECDF of v_i can be estimated by

$$\mathrm{ECDF}_{1,i} = \left[i/(N+1)\right]^{1/T} \tag{2}$$

The empirical return period, ER, determined by the annual ECDF in Eq. (2) is then given by

$$\mathrm{ER}(v_i) = 1\Big/\left\{1 - \left[i/(N+1)\right]^{1/T}\right\} \tag{3}$$

2.2 Weibull Distribution of the Largest Value

The Weibull distribution of the largest value is expressed as follows,

$$F_V(v) = \exp\left\{-\left[(v_{\max} - v)/\sigma\right]^{1/k}\right\} \tag{4}$$

where v (m/s) is the gust speed, $v_{\max}$ (m/s), σ (m/s), and k are the location, scale, and shape parameters, respectively, of the distribution. With a Weibull distribution of the largest value, the gust speed v_R associated with a given return period R (years) can be estimated by

$$v_R = v_{\max} - \sigma\left\{T\ln\left[R/(R-1)\right]\right\}^k \tag{5}$$

The current world record for TC wind gust is 408 km/h (~113.3 m/s) recorded during TC Olivia on 10 April 1996 at Barrow Island, Western Australia [9]. Therefore, if we assume $v_{\max} = 120$ m/s, then σ and k can be readily determined by regression analysis.

3 COAST-CROSSING GUST HAZARD ESTIMATION

Since the Dvorak-technique estimated TC data recorded only the eyewall gust speeds, the results presented in this study represent only the gust hazard contributed by the eyewall wind gusts. This is equivalent to assuming that the wind field is a step function with the maximum gust speed in the eyewall region but with gust speed of zero beyond the eyewall. As a result, consideration of only the eyewall gust speed gives a lower-bound estimate of the actual gust hazard.

From the 1984–85 to the 2006–07 cyclone seasons, a period of 23 years, there were 142 TC coast crossings, as shown in Fig. 1, in which a hollowed circle represents a crossing. The TC-stricken coast from Geraldton, WA, extending north to Bundaberg, QLD, is divided into seven coastal zones (Fig. 1): (I) from Coral Bay, WA, extending south to Geraldton, WA; (II) from Coral Bay extending to 123°E, about north of Broome, WA; (III) from 123°E extending to 128°E, around the state boundary between WA and NT; (IV) from 128°E extending east to 137°E, around Borroloola, NT; (V) from 137°E extending east to 142.5°E, around the tip of Cape York Peninsula, QLD; (VI) from 142.5°E extending southeast to north of Bowen, QLD; and (VII) from Bowen to Bundaberg, QLD. Also shown in Fig. 1 are the landfalling locations of TC Monica 2006 (Zone IV) and TC Barry 1996 (Zone V), the gust speeds of which are significantly higher than the rest of TCs in their respective zones, as shown in Fig. 2.

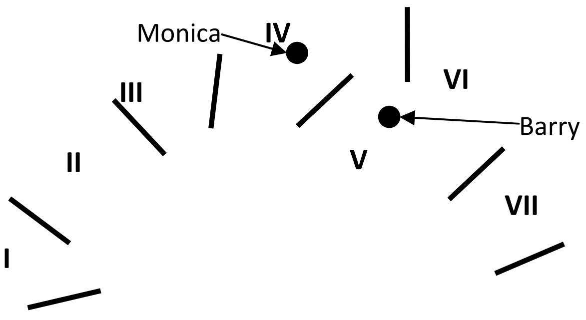

Fig. 1 TC coast-crossing locations and coastal hazard zones.

Zones I and VII, respectively, experienced only 5 and 4 crossings for the 23-year dataset, hence they are not considered further in this study.

The empirical coast-crossing gust speed hazards in Zones II to VI are computed by Eq. (3) and shown as dot points in Fig. 2. The 2006 TC Monica (98 m/s) in Zone IV and the 1996 TC Barry (79 m/s) in Zone V have significantly larger gust speeds than the rest of TCs in their respective zones and may be manifestation of 'sampling errors' due to short data records [7]. From statistical standpoint, they may be classified as outliers; i.e. the 'actual' return periods of these gust speeds are likely to be higher than that indicated by the empirical distribution. The scale and shape parameters of Eq. (4) are estimated by a robust regression method called MM-estimate using the bisquare weight function with efficiency coefficient of 0.85 [5]. Compared with the classical least-squares regression, the MM-estimate is advantageous in having high breakdown-point and high efficiency under normal errors, thus less sensitive to outliers.

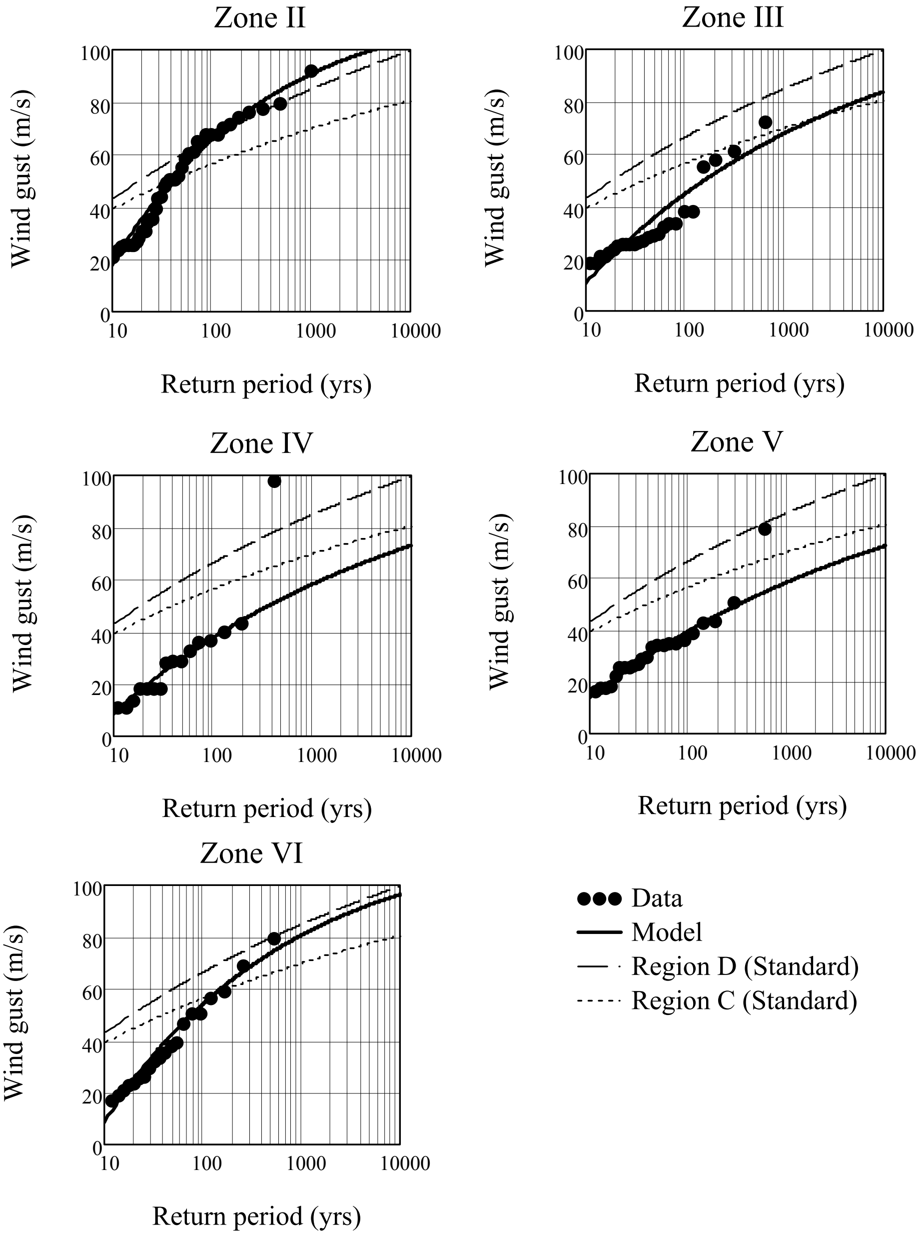

Fig. 2 Estimated coast-crossing gust hazard.

Also plotted in Fig. 2 for comparison are the wind gust hazards of Regions C and D specified in AS/NZS 1170.2:2002 [1]. It is seen that, for the return periods of engineering interest (i.e. about 500 to 2000 years), the estimated hazards of Zones II and VI exceed that of regions D and C, respectively, specified in the Standard, while the Zone-III hazard is close to the Region C hazard. The hazards of Zones IV and V are notably below that of Region C when the influences of TCs Monica and Barry are discounted by the MM-estimate in regression analysis. If the least-squares criterion is used, however, the estimated hazard of Zone IV will be close to that of Region D.

The slopes of estimated TC eyewall gust hazard curves in Fig. 2 in the lower return period range (say, < 300 years) are consistently greater than that of the Standard-specified hazard curves, but they are roughly the same in the higher return period range. This is attributed to the exclusion of gusts outside the eyewall region and of non-cyclonic wind events such as tornadoes, thunderstorms, and synoptic winds. This suggests that the hazard of engineering interest (< 500-year return period) is dominated by the eyewall wind gusts.

4 CONCLUDING REMARKS

Using the satellite-based wind gust data, the TC coast-crossing gust hazard along the Australian coast is estimated and shown to exceed the hazard specified in the structural design standard for wind actions, AS/NZS 1170.2:2002, in Zone II (northwest coast, WA) and Zone VI (northeast coast, QLD). This suggests that the Standard may need to be reviewed to differentiate the hazards at coastal front bearing the impact of landfalling wind gust from that of more inland areas by either increasing the specified regional design speed or refining the widths of the coastal hazard regions, or both.

Regardless of the concerns on the accuracy of Dvorak technique [2], existing studies on gust factor concentrate on the Atlantic and Eastern and Central Pacific basins; hence the gust factor of 1.4 used in this study may need to be validated by studies concerning the Australian region.

It is noted that only a period of 23 years of satellite-based data is used, the inherent uncertainty related to sampling errors in the estimated hazard may be significant. Datasets with longer period of time will alleviate the extent of such uncertainty.

5 REFERENCES

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