Re-analysis of typhoon wind speeds in Hong Kong

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1. INTRODUCTION

Hong Kong experiences the effect of typhoons from the South China Sea at the rate of one to two storms per year. The territory is fortunate in having excellent records of the extreme winds generated by these events since the nineteenth century. Extreme winds from tropical storms and typhoons should be separated from those generated by other wind types, before attempting an extreme value analysis of wind speeds for design purposes. In this paper, recorded typhoon wind speeds from two stations have been analysed using the 'peaks over threshold' approach, which can be regarded as a method of fitting the Generalised Extreme Value distribution, and is an ideal method for including all relevant storm data in the analysis.

The series of largest winds (mean and gust) from each recorded storm from both the Hong Kong Observatory (1884-1957) and Waglan Island (1953-1999) are available and have been used in the present study. Due to the different topographic location of the two stations, they have been analysed independently.

2. PEAKS OVER THRESHOLD APPROACH

The peaks over threshold approach has been applied to the analysis of extreme floods by Davison and Smith, (1990); to extreme winds in the United States by Lechner *et al* (1992); and to extreme thunderstorm winds in Australia by Holmes and Moriarty (1999).

The method makes use of all wind speeds from independent storms above a particular minimum threshold wind speed, u_0 (say 20 m/s). There may be several of these events, or none, during a particular year. The basic procedure is as follows.

i) several threshold levels of wind speed are set : u_0, u_1, u_2, etc. (e.g. 20, 21, 22 …m/s)

ii) the exceedences of the lowest level u_0 by the maximum storm wind are identified, and the rate of crossing of this level (number per year, λ), is calculated

iii) the differences ($U-u_0$) between each storm wind and the threshold level u_0 are calculated and averaged (only positive excesses are counted)

iv) (iii) is repeated for each level, u_1, u_2 etc, in turn

v) the mean excess is plotted against the threshold level and a straight line fitted

vi) a scale factor, σ, and a shape factor, k, are determined from the slope and intercept of the line by the following equations (Davison and Smith 1990) :

$$\text{slope} = \frac{-k}{(1+k)}$$

$$\text{intercept} = \frac{\sigma}{(1+k)} \qquad (1)$$

The scale and shape factors are parameters of the generalised Pareto Distribution (Hosking and Wallis, 1987) fitted to the excesses calculated as described above. Prediction of the R-year return period wind speed, U_R, can then be made from :

$$U_R = u_0 + \sigma[1-(\lambda R)^{-k}]/k \qquad (2)$$

In Equation (2), the shape factor, k, is normally found to be positive for extreme wind data (usually in the range +0.1 to +0.3). As R increases to very large values, the upper limit to U_R of $u_o+(\sigma/k)$ is gradually approached.

The shape factor, k, corresponds to that in the Generalised Extreme Value (G.E.V.) distribution for the largest value in a defined epoch (e.g. annual maxima) (Davison and Smith, 1990). The equation for the cumulative distribution function in the G.E.V. is :

$$F_U(U) = \exp \{-[1 - k\,(U-u)/a]^{1/k}\} \qquad (3)$$

where u is a location parameter, and a is a scale factor.

3. HONG KONG OBSERVATORY ANALYSES

The Hong Kong Observatory (formerly the Royal Observatory of Hong Kong) is situated in central Kowloon. Data on the largest mean and gust data from all typhoons affecting the Observatory anemometers between 1884 and 1957 was extracted from the hard copy records by Melbourne (1984). No records were kept during the war years 1942 to 1945. Although records have continued to be obtained since 1957, the growth of the surrounding urban environment after that time, has been such as to make the data unreliable. Although the anemometer had been moved several times during the period, Melbourne (1984) corrected both hourly mean and gust data to a constant reference height of 50 metres, using wind-tunnel test measurements.

For the analysis of the hourly mean data by the peaks over threshold approach, the lowest threshold (u_0) was taken as 16 m/s. All 83 recorded values are greater than this threshold. The average annual rate, λ, of crossing of this threshold is 1.19 (83/70). The threshold was gradually incremented in 2 m/s increments. The average positive excesses above each threshold was calculated and found to decrease with increasing threshold. For thresholds of 28 m/s and above, fewer than 10 values produced a positive excess, so these averages were not included in the subsequent analysis.

The plot of the average excess against the threshold is shown in Figure 1. This plot gave a slope of -0.24 and an intercept of 5.55. Application of Equation (1) gives a scale factor, σ, of 7.3 m/s, and a shape factor, k, of 0.315. Then by Equation (2), predictions of annual maximum wind speeds due to typhoons at the station can be made for various probability levels. This is done in Table I.

A similar analysis has been carried out for the peak gust wind speeds at the Observatory. The data corrected to 50 metres height by Melbourne (1984) have also been used. In this case the lowest and highest thresholds used were 28 m/s and 46 m/s, respectively. The resulting scale and shape factors were 12.2 m/s, and 0.255 respectively. The results of the predictions as a function of return period are also listed in Table I.

4. WAGLAN ISLAND ANALYSES

Waglan Island is a small steep rocky island on the southern extremity of Hong Kong. Meteorological data has been recorded there since 1953. Extreme wind data from typhoons is available from that time up to the present, although there have been several moves of anemometer during the period. For a two-year period (1964-66), the anemometer was very close to the lighthouse on the island, and strongly affected by the wake of that building for a large range of wind directions. Data from this two-year period was not used. The remaining data comprised 75 storms in 45 years.

In the case of the Waglan data, corrections were made to the hourly mean data, to a height of 200 metres, using wind tunnel measurements made at the CLP Power wind tunnel at the Hong Kong University of Science and Technology (Figure 2). Recent measurements indicate that this height is at, or above, the gradient height for the strongest winds near the centre of typhoons and other forms of tropical cyclone (e.g. Amano *et al*, 1999). For the peak gust data, corrections were made to a height of 50 metres using the corrections of Melbourne (1984) for anemometer positions up to 1993. For the current anemometer position (since 1993), corrections derived from the HKUST measurements were used.

Similar peaks over threshold analyses were made for the Waglan Island data, as for the Observatory data. The results of the analyses are listed in Table I. The shape factors of 0.18 (means) and 0.14 (gusts) are slightly lower than those obtained from the Observatory data.

5. DISCUSSION

The results of the predictions for 20, 50, 200 and 1000 year return periods are summarised in Table I. This Table illustrates a number of features :

- The gust values from the Observatory are somewhat less (about 3 m/s at 50 year return period) than those from Waglan Island. This is not surprising considering the more sheltered location of the Observatory in Kowloon, although it may also be related to the different historical periods of the records.

- the gust speeds at 50 year return period at the Observatory and Waglan Island are reasonably consistent with the gust *pressures* given for 50 metres height in the Hong Kong Code (Building Department, 1983) for 'built-up' and 'exposed' terrains, for this return period.
- The 50 year return period gusts at 50 metres for both the Observatory and Waglan Island are both lower than earlier predictions by Chen (1975) and Melbourne (1984) who used a combination of Observatory and Waglan data.
- The predicted mean wind speed at 200 metres from the Waglan Island data (e.g. 50-year return period value of 47.3 m/s) is consistent with the predictions of gradient wind obtained by Davenport *et al* (1984) by Monte Carlo simulation.
- The 50 year return period prediction of a mean wind speed of 47.3 m/s is much less than the value of 64 m/s for gradient height mean wind speed given in the Hong Kong wind tunnel testing protocol.

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Table I. Results of peaks over threshold analyses

	Observatory means (50 m)	Observatory gusts (50 m)	Waglan I. means (200 m)	Waglan I. gusts (50 m)
lowest threshold, u_0 (m/s)	16	28	20	24
rate (/year), λ	1.19	1.16	1.44	1.42
scale, σ (m/s)	7.3	12.2	9.2	11.8
shape, k	0.31	0.25	0.18	0.14
20 year R.P. (m/s)	30.6	54.5	43.1	55.5
50 year R.P.(m/s)	32.8	59.0	47.3	61.8
200 year R.P. (m/s)	35.0	64.0	52.5	69.9
1000 year R.P. (m/s)	36.7	68.1	57.1	77.6

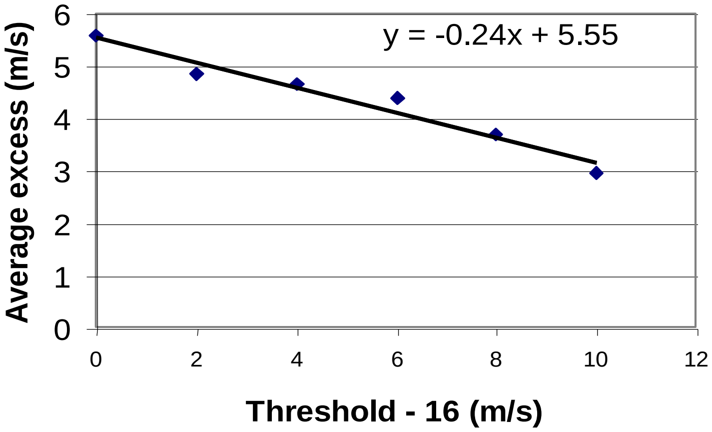

Figure 1. Average excess versus threshold for hourly mean data (at 50 metres height) from Hong Kong Observatory (1884-1957)

Figure 2. Model of Waglan Island used to determine anemometer corrections in the wind tunnel of the Hong Kong University of Science and Technology