Revised power-law model to estimate the vertical variations of extreme wind speeds in China coastal regions

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1. Introduction

The tropical cyclones, known as the typhoons (GB/T 19201 2006) in the Northwest Pacific, are in association with strong winds, heavy rains and storm surges. In each year, around 7–9 typhoons make landfall onto the East and South coasts of China (China Meteorological Administration, 2014). They pose threats to coastal megacities of China and cause damages to industrial facilities, urban structures and infrastructures. For instance, it was reported that the economic losses in China coastal regions resulted from the Typhoon Meranti were estimated to be 11 billion RMB (US $ 1.8 billion) and at least 44 causalities were recorded during the passage of the particular typhoon. Therefore, the typhoon-resistant design is of great importance in the construction of buildings on China coastal regions.

Typhoons originated from the Northwest Pacific pose severe threats on the coastal megacities of China. Hence, the typhoon-resistance capability should be given priority in the building designs along the coastline of China. The wind profile model, which has been widely used to estimate the vertical variation of wind loads, is of importance due to its value in evaluating the structural safety of the buildings under extreme wind conditions. In practice, the classical power-law model with four specific exponents has been recommended by the load code (GB 5009-2012) of China to calculate the vertical profile of extreme wind speeds. Based on the results of a series of artificial typhoon simulations, which have been verified by both the track data of historical typhoons and observations obtained from three land weather stations, the classical power-law model with the exponents recommended by the code is evaluated. It has been found from the evaluation that the classical power-law model is insufficient to estimate the vertical variation of design wind speeds in the coastal area of China. Consequently, an empirical correction ratio and a scale factor are introduced to provide more reliable estimates of extreme wind speeds with any desired return periods.

Typhoons are in association with strong winds, heavy rains and storm surges. In China, typhoons result in economic losses estimated to be 11 billion RMB (US $ 1.8 billion) and at least 44 causalities. Hence, typhoon-resistant design is crucial in coastal building construction.

The classical power-law model is used to estimate the vertical profile of extreme wind speeds, but it is insufficient. An empirical correction ratio and scale factor are introduced to provide more reliable estimates of extreme wind speeds with any desired return periods.

Typhoons originated from the Northwest Pacific pose severe threats to coastal megacities. The classical power-law model is insufficient, so an empirical correction ratio and scale factor are introduced to estimate more reliable extreme wind speeds.

Typhoons, originating from the Northwest Pacific, cause severe threats to coastal regions in China. The classical power-law model is insufficient to estimate extreme wind speeds, so an empirical correction ratio and scale factor are introduced for more reliable estimates.
2. Extreme wind profile model

2.1. Power-law model

The power-law model, as recommended by the load code, is widely used to characterize the vertical variations of design wind speeds (China Association for Engineering Construction Standardization, 2012), and then used to estimate wind loads acting on structures (Davenport, 1960). The design wind speed, which is essentially the extreme wind speed with a specific return period, is assumed to be a power function of heights in the power-law model. In most cases, the extreme wind speed with 50 years return period $x_{50}$ is employed in the design of general buildings, and the power-law model shows,

$$x_{50}(h) = x_{50,10}(h/10)\alpha$$

In equation (1), $x_{50,10}$ is the extreme wind speed with 50 years return period at 10m level and $\alpha$ is the exponent of the power-law model, which is stipulated as 0.12, 0.15, 0.22 and 0.30 according to the surface roughness categorization (classes A, B, C and D) in the load code of China.

2.2. Extreme value distribution model

The probability distribution of extreme values, or the extreme value distribution, is widely employed to project the extreme wind speed with a desired return period based on a series of "samples" of extreme wind speeds. According to the extreme value theory (EVT) developed by Fisher and Tippett (1928), the extreme value distributions can be categorized into three types, namely the Fisher-Tippet I type (FT-I or Gumbel distribution), the Fisher-Tippet II type (FT-II or Fréchet distribution) and the Fisher-Tippet III type (FT-III or Reversed Weibull distribution). The load code of China specifies that the Gumbel distribution should be adopted for the projection of the extreme wind speed.

In practice, all three types could be generalized into a single model with a set of universal parameters, namely the generalized extreme value (GEV) distribution, as,

$$F(x|\mu, \sigma, k) = \exp \left\{ - \left[ 1 + \frac{x - \mu}{\sigma} \right]^{-k} \right\}$$

In equation (2.a), $k$ is the shape parameter, $\mu$ is the location parameter and $\sigma$ is the scale parameter. When $k > 0$, the GEV distribution transforms into the Fréchet distribution. When $k < 0$, it converts into the Reversed Weibull distribution. When $k = 0$, the GEV distribution reduces to the Gumbel distribution shown as,

$$F(x|\mu, \sigma) = \exp \left\{ - \exp \left( - \frac{x - \mu}{\sigma} \right) \right\}$$

Given the typhoon occurrence rate $\lambda$, the extreme wind speed exceeding probability $F_T$ corresponding to the desired return period $T$ is calculated as (Vickery et al., 2000),

$$F_T = 1 + \left( \frac{1}{\lambda} \right) \ln(1 - 1/T)$$

Provided the desired return period $T$, the corresponding extreme wind speed is derived from combing equations (2) and (3). More specifically, the extreme wind speed $x_{cr}$ with the return period of $T$ can be calculated as,

$$x_{cr}(h) = \mu(h) - [\sigma(h)/k(h)] \left\{ 1 - \left[ -\ln(F_T) \right]^{-k(h)} \right\}$$

According to the extreme value theory (EVT) (Fisher and Tippett, 1928), the parameters of $k$, $\sigma$ and $\mu$ are related to the mean $\langle x \rangle$ and the standard deviation $s$ of the given extreme value series as

$$\sigma = \mu + \frac{1}{k} \left\{ s - \left( \left\langle x^2 \right\rangle - \mu^2 \right) \right\}$$

In equation (5.a) $\mu$ represents the Gamma function shown as,

$$\mu = \Gamma \left( 1 - n(k(h)) \right)$$

When substituting equation (5) into (4), the extreme wind speed $x_{cr}$ is obtained from the mean of the extreme value series $\langle x \rangle$ as,
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