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Low-occurrence strong wind speed in idealized building cases: Comparison of estimation methods

Wei Wang [1], Naoki Ikegaya [1]

[1]*Faculty of Engineering Sciences, Kyushu University, Fukuoka, Japan,*
wang.wei.530@m.kyushu-u.ac.jp, ikegaya@cm.kyushu-u.ac.jp

SUMMARY:
Understanding the low-occurrence strong wind speed (LOSWS) distribution at the pedestrian level in urban areas is important for pedestrian safety and comfort. However, the robustness of the statistical methods for estimating LOSWSs under different building-layout conditions remains uncertain. In this study, the performances of the Weibull distribution method and Gram–Charlier series (GCS) method were compared. Their accuracies for an isolated building and building array cases were analyzed in this study. A validated large-eddy simulation database of these idealized building cases was used in the statistical analysis. Regarding the estimation accuracy of LOSWSs, the two-parameter Weibull distribution (2W) and three-parameter Weibull distribution (3W) methods are superior to the GCS methods when the available orders of statistics are equal. If the estimation accuracy is the priority, high-order GCS methods are recommended more than the 2W and 3W methods. The present findings can serve as an illuminating reference for further applications of these statistical methods.

Keywords: Wind environment, Weibull distribution, Gram–Charlier series

1. INSTRUCTIONS

Pedestrian-level wind environment (PLWE) is an important concept that directly impacts human safety and comfort (Stathopoulos, 2006). Previous studies of PLWE have entailed an analysis of strong mean wind speed regions (Yoshie et al., 2007), and gust wind speeds (calculated using the mean wind speed and amplification factors) (Vita et al., 2020). However, these previous studies of PLWE basically focused on the mean wind speed. Considering the stochastic nature of turbulent flows, the instantaneous wind speed, particularly the low-occurrence strong wind speed (LOSWS), is a better measure than the mean wind speed within the context of PLWE studies.

Using large-eddy simulations (LESs) or particle image velocimetry (PIV), several studies have systematically analyzed the LOSWS at the pedestrian level of idealized building cases based on probability density functions (PDFs) determined via time-series data of wind speed (Hirose et al., 2022; Ikegaya et al., 2020). However, the large volume of time-series data adds to the difficulty of determining LOSWS, especially in actual urban cases. To conveniently obtain LOSWS distributions in urban areas, Wang et al., 2022; Wang and Okaze, 2022 developed statistical methods that facilitated the determination of LOSWSs using statistics. However, the performance of these statistical methods remains unclear for various building-layout conditions. Consequently, this study aims to compare the estimation accuracy of these statistical methods for idealized building cases, including isolated buildings and building arrays. Because of the length limitation of the abstract, only the brief result of an isolated building case was presented.

2. ISOLATED BUILDING CASE

The LES result of the isolated building case (Case-IB) was validated in Ikegaya et al., 2020; Okaze et al., 2021. Fig. 1 (a) shows the computational domain of the isolated building case. Fig. 1 (b) shows the probe point distribution at the pedestrian level (*z/H* = 1/16, where *H* = 0.2 m is the building height) around the building (probe point number *N* = 80 in total).

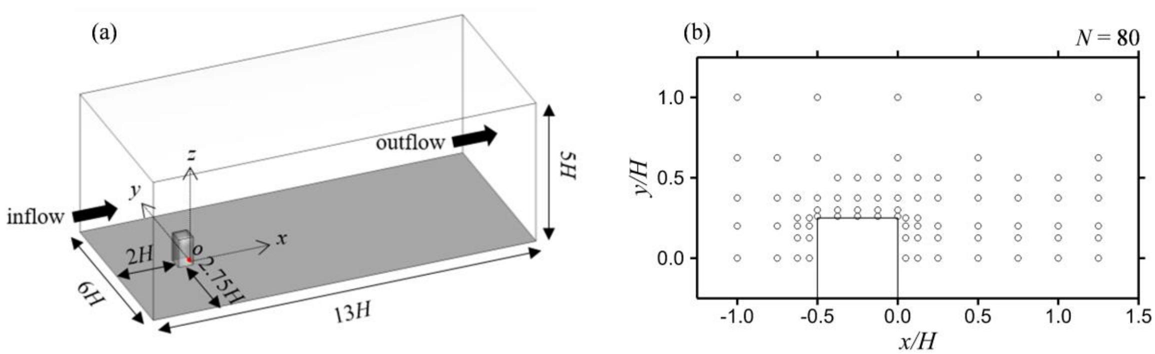

Figure 1. (a) Computational domain; (b) probe point distribution at the pedestrian level.

3. STATISTICAL METHODS

3.1. Weibull Distribution Method

The 2W and 3W methods (details can be found in Wang and Okaze, 2022) are based on the two-parameter and three-parameter Weibull distributions, respectively. The probability density function of the three-parameter Weibull distribution is shown in Eq. (1), where $\alpha > 0$ is the scale parameter, $\beta > 0$ is the shape parameter, and ζ is the location parameter. 2W is a special case of 3W when the location parameter $\zeta = 0$. The coefficient of variation σ/μ of 2W is expressed by Eq. (2), where $\Gamma(z) = \int_0^\infty x^{z-1} e^{-x} dx$ is the gamma function. The skewness γ of the Weibull distribution is expressed by Eq. (3). The required statistics for the 2W method are the mean and standard deviation of the wind speed and those for the 3W method are the mean, standard deviation, and skewness, as shown in the flow char in Fig. 2 (a). In Fig. 2 (a), the input parameter δ can be σ/μ or γ for the 2W and 3W methods, respectively, to estimate the peak factor K_q (Eq. (4)). The peak factor with specific exceedance probability q was derived with $K_q = (s_q - \mu)/\sigma$, where the LOSWS was denoted by s_q.

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\zeta}{\alpha}\right)^{\beta-1} \exp\left[-\left(\frac{x-\zeta}{\alpha}\right)^{\beta}\right] \tag{1}$$

$$\sigma/\mu = \frac{\left[\Gamma(1+2/\beta) - \Gamma^2(1+1/\beta)\right]^{1/2}}{\Gamma(1+1/\beta)} \tag{2}$$

$$\gamma = \frac{\Gamma(1+3/\beta) - 3\Gamma(1+2/\beta)\Gamma(1+1/\beta) + 2\Gamma^3(1+1/\beta)}{[\Gamma(1+2/\beta) - \Gamma^2(1+1/\beta)]^{3/2}} \tag{3}$$

$$K_q = \frac{[-\ln(q)]^{1/\beta} - \Gamma(1+1/\beta)}{[\Gamma(1+2/\beta) - \Gamma^2(1+1/\beta)]^{1/2}} \tag{4}$$

3.2. Gram–Charlier Series Method

The GCS method (details can be found in Wang et al., 2022) was applied to estimate the PDF of wind speed in this study. The PDFs based on the GCS method is expressed by Eq. (5), which has two terms $G(\varphi)$ and $R_i(\varphi)$. $G(\varphi) = \frac{1}{\sqrt{2\pi}}\exp\left(-\frac{\varphi^2}{2}\right)$ is the PDF of the Gaussian distribution (hereafter, G model) and $R_i(\varphi) = 1 + f_3 + \cdots + f_i$ is the revision term based on the statistics, where $f_3 = \frac{\gamma}{6}(\varphi^3 - 3\varphi)$, $f_4 = \frac{kt-3}{24}(\varphi^4 - 6\varphi^2 + 3)$, $f_5 = \frac{1}{12}\left(\frac{m_5}{10} - \gamma\right)(\varphi^5 - 10\varphi^3 + 15\varphi)$ and $f_6 = \frac{1}{720}(m_6 - 15kt + 30)(\varphi^6 - 15\varphi^4 + 45\varphi^2 - 15)$. $\varphi = (x - \mu)/\sigma$ is the standardized random variable, kt represents the kurtosis, and m_i represents the ith-order statistic. The GCS methods with the second to sixth orders were analyzed in this study. Note that the second-order GCS method corresponds to the Gaussian distribution. The flow chart of GCS method is shown in Fig. 2 (b). In the GCS methods, the LOSWS s_q is estimated from the predicted PDFs incorporating the statistics of γ, kt, m_5, and m_6.

$$p_i(\varphi) = G(\varphi)R_i(\varphi) \tag{5}$$

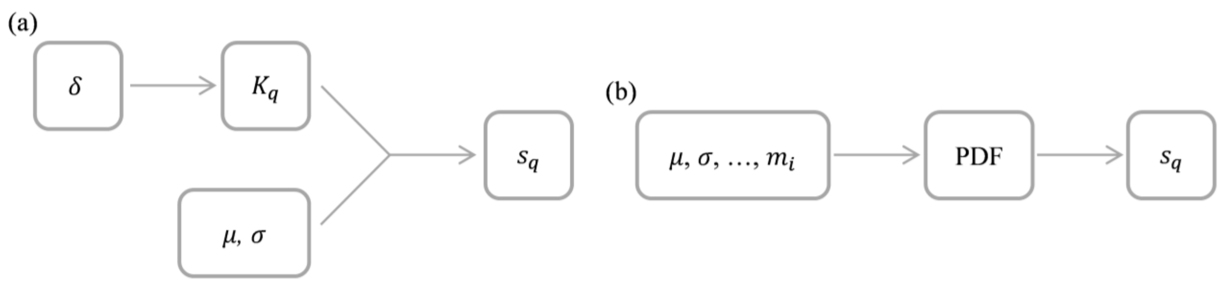

Figure 2. Flow chart. (a) Weibull distribution method; (b) GCS method.

4. ESTIMATION ACCURACY

Fig. 3 shows the comparisons of the LOSWSs with exceedance probabilities q = 10%, 1%, and 0.1% directly calculated from the LES time-series data (x-axis) and the values estimated by the statistical methods (y-axis) of Case-IB. It was found that although the orders were the same, the 2W method was more accurate than the G method, and the 3W method was more accurate than GCS-3rd. From Figs. 3 (c)–(g), the estimation accuracy of the GCS method gradually increases as the order increases. As shown in Fig. 3 (g), the relative errors of GCS-6th were within approximately 5% (more accurate than the 2W and 3W methods).

5. CONCLUSIONS

In this study, LOSWSs at the pedestrian level around an isolated building (Case-IB) were estimated using different statistical methods. The performances of the Weibull distribution method and the GCS method were compared. The LES data of Case-IB were used in the statistical analysis. It was found that if input statistics are up to the second or third order, the 2W and 3W methods are recommended more than the GCS methods. The estimation accuracy of the GCS method gradually increases as the order increases. For the LOSWS of Case-IB, GCS-6th is the most accurate. The results of idealized building array cases will be presented in future.

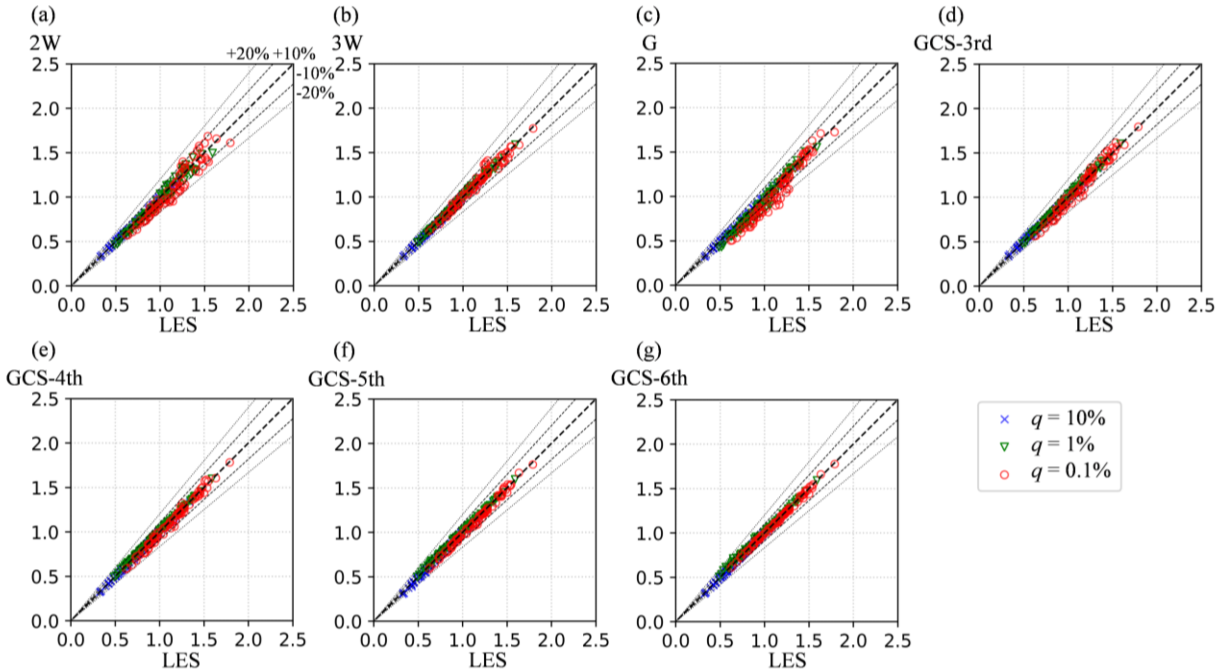

Figure 3. Estimation accuracy of the LOSWS. (a, b) 2W and 3W methods; (c–g) GCS methods.

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