Estimation biases of design wind speed due to mean occurrence rate in the Poisson process assumption

Chung-Lin Fu [1], Yuan-Lung Lo [2], Jenmu Wang[3]

[1]*Tamkang University, New Taipei, Taiwan, fcl@mail.tku.edu.tw*
[2]*National Taipei University of Technology, Taipei, Taiwan, yllo@mail.ntut.edu.tw*
[3]*Tamkang University, New Taipei, Taiwan, wang@mail.tku.edu.tw*

SUMMARY:
This study intends to discuss the estimation biases caused by converting the non-exceedance probability from the event-based Gumbel curve to the yearly-based Gumbel curve due to the Poisson process assumption. The maximum sample of each typhoon from 1961 to 2022 in Taiwan's meteorological stations was selected for the event-based Gumbel distribution fitting. The Poisson process assumption was then applied to convert the event-based Gumbel curve to the yearly-based Gumbel curve by setting different threshold windspeed values for different mean occurrence rates. Finally, design wind speeds for multiple-year return periods were obtained by interpolating the yearly-based Gumbel curve. Results showed that fewer extreme samples were left for fitting the Gumbel distribution when the threshold wind speed value was higher. Thence, the mean occurrence rate of typhoon events decreased. Several stations showed that when the coefficient of variation of the scale parameter was significant, the consistency of the design wind speeds based on different threshold wind speed values was worsened. The coefficient of variation of the design wind speeds was from 4% to 10% when the fluctuation of the scale parameter was larger than 10%. The choice of the threshold wind speed depends on how stable the assumption of the mean crossing rate can be maintained while applying the Poisson process.

Keywords: Design wind speed, Gumbel distribution, Poisson process

1. INSTRUCTION

To evaluate the wind-induced response of a structure, the first step is to estimate the design wind speed correctly. Based on the failure scenario the designer would like to define, the design wind speed is given in terms of return period length. Most codes or standards provide design wind speeds in tables or maps with a 50- or 100-year-return period, such as Japan, Taiwan, Korea, and so on. The local meteorological information plays a vital role in the extreme value analysis process to accurately estimate the design wind speed according to the specific return period length. For south-eastern countries like Taiwan, typhoon events are the primary source to induce damage to buildings or bridges. Therefore, a proper estimation process for the design wind speeds requires a good-quality fitness of extreme value distribution and an adequate estimation of the mean occurrence rate of typhoon events during observation years utilizing the Poisson process assumption. This study intends to discuss how the mean occurrence rate of typhoon events affects the formation of the extreme value distribution. It thence disturbs the interpolation of specific non-exceedance probabilities for determining design wind speeds. First, the long-term records of thirty meteorological stations in Taiwan are utilized to collect those maximum 10-minute mean wind speed samples among all typhoon events (event-based maxima). By setting different threshold wind speed values, filtered samples are fitted with the Gumbel distribution and then converted to a yearly-based distribution based on the mean occurrence rate. Finally, the design wind speeds according to specific return periods are obtained by interpolation. To compare the general features of these thirty meteorological stations, non-dimensional quantities such as coefficients of variations are given.

2. GUMBEL DISTRIBUTION AND POISSON PROCESS ASSUMPTION

The Gumbel distribution is defined as Eq. (1), where x the extreme samples, μ the location parameter, and α the scale parameter.

$$F(x) = exp\left\{-exp\left[-\left(\gamma + \frac{\pi}{\sqrt{6}}\frac{x-\mu}{\alpha}\right)\right]\right\} \qquad \gamma = 0.577216 \tag{1}$$

In Eq. (1), if the extreme samples are fitted, the obtained distribution curve is an event-based curve (distribution). Since the specific return period corresponds to the non-exceedance probability according to Eq. (2), it is necessary to convert the event-based curve to the yearly-based one. For instance, a 50-year-return period means a non-exceedance probability of 98% in the distribution.

$$F\left(x_{des,MRI}\right) = 1 - \frac{1}{MRI} \qquad MRI = Mean\ Reccurence\ Interval\ (return\ period) \tag{2}$$

To convert the event-based distribution to the yearly-based distribution, the concept of the Poisson process can be applied by assuming that all the typhoon events are (almost) uniformly distributed among the observation years. Therefore the mean occurrence rate, λ, of typhoon events can be substituted into Eq. (3) for curve conversion.

$$F_{yearly}(x) = exp\left[-\lambda\left(1 - F_{event}(x)\right)\right] \tag{3}$$

Fig. 1 shows the event-based maxima of Taipei Station from 1961 to 2022 and its two distributions. It is seen that the 98% non-exceedance probability locates a higher design wind speed of a 50-year-return period along the converted distribution (red) rather than the unconverted blue one. In this example, a difference of 4 m/s may lead to roughly 27% underestimation in design wind loads.

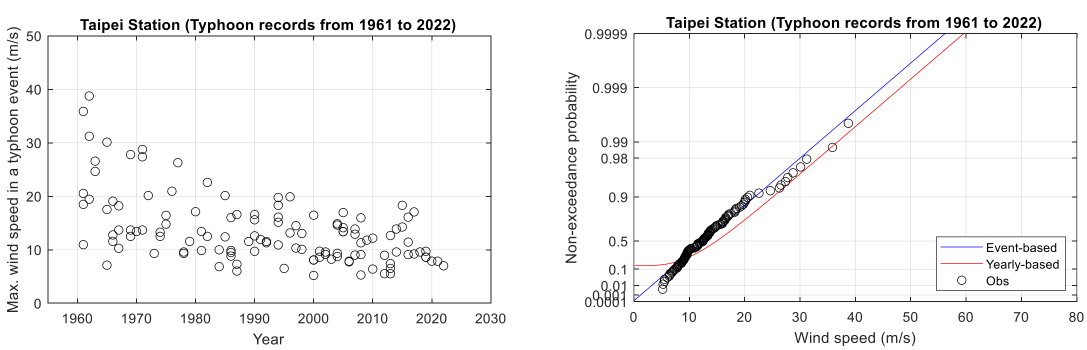

Figure 1. Event-based maxima of Taipei Station and its two distributions

3. EFFECTS OF MEAN OCCURRENCE RATE ON DESIGN WIND SPEEDS

In the subsequent section, we attempt to discuss how the mean occurrence rate affects the determination of design wind speeds. In the Peaks Over Threshold approach, the event definition is strictly made regarding how the threshold value should be assumed for an actual event. In most Asian-Pacific countries, a threshold of 17.2 m/s wind speed is considered a good indicator of a light typhoon. By filtering out those smaller samples than this threshold value, event-based maxima are genuinely qualified for the Gumbel distribution fitting. However, due to limited field monitoring information, most stations cannot afford to provide enough eligible samples for good-quality fitness. For those areas that belong to typhoon-prone regions but lack sufficient data, it becomes a critical task to determine how immense the threshold value should be and, thence, what the mean occurrence rate is. Fig. 2 shows the event-based maxima of Taitung Station. Together with Taipei Tation in Fig. 1, these two stations show a similar trending distribution of maxima, i.e., the maxima decrease with the year. This descending phenomenon could be due to the urbanization process. However, if examined carefully, most maxima in Taipei Station distribute more uniformly than those in Taitung Station (see the green area in Fig. 2).

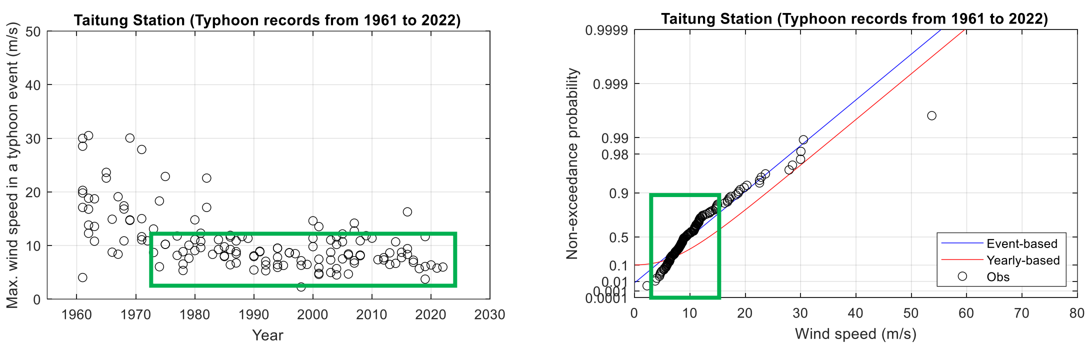

Figure 2. Event-based maxima of Taitung Station and its two distributions

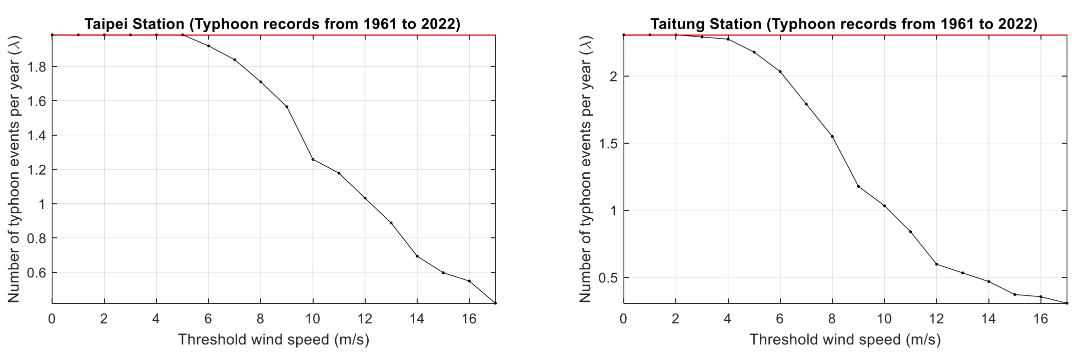

Figure 3. Relations of mean occurence rate and threshold wind speed of Taipei and Taitung Stations

By setting different threshold wind speeds from 0 to 17 m/s, the mean occurrence rate λ of typhoon events among the observation years can be calculated and plotted in Fig. 3. The drop in the mean occurrence rate variation in Taipei Station is from 2.0 (no threshold) to 0.4 (17 m/s threshold) and is from 2.3 to 0.3. The two stations are similar qualitatively and quantitatively. Fig. 4 shows the variations of the location and scale parameters concerning the mean occurrence rate. It is found that both stations have a decreasing feature when the mean occurrence rate is high. This is reasonable since smaller samples are included in calculating the location parameter when a low threshold value is. The scale parameters in both stations have different patterns since one has a more uniform distribution of smaller maxima, and the other's smaller maxima concentrate more below the 10-m/s range. When the threshold wind speed is linearly decreased, a linear reduction in the mean occurrence rate is desirably expected to maintain the Poisson process assumption. Fig. 5 shows the estimation results of the design wind speeds of the 50-year-return period.

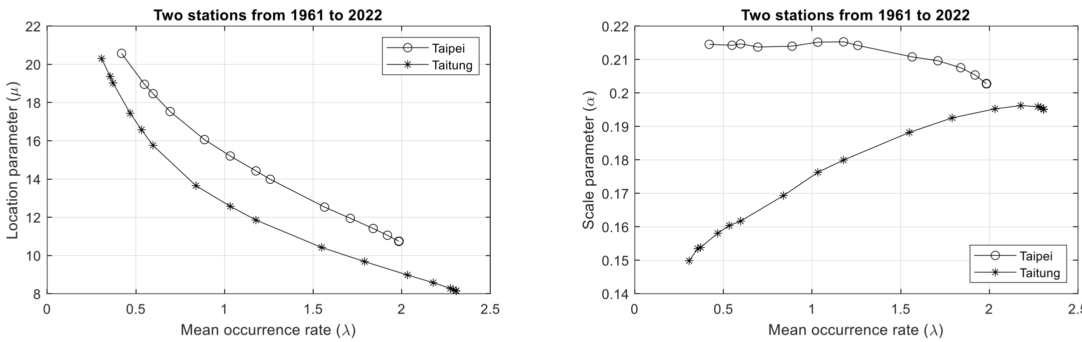

Figure 4. Location and scale parameters in terms of mean occurrence rate for Taipei and Taitung

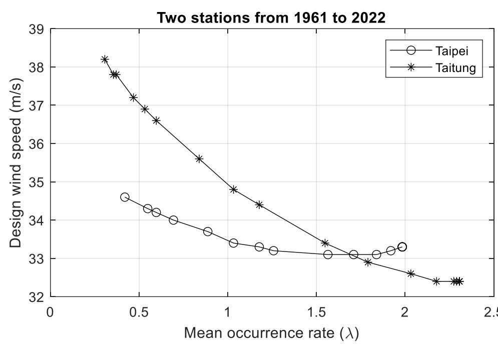

Figure 5. Design wind speed estimations for Taipei and Taitung

4. CONCLUSION

Results show that when the coefficient of variation of the scale parameter is significant, the consistency of the design wind speeds based on different threshold wind speed values is worsened. The coefficient of variation of the design wind speeds is from 4% to 10% when the fluctuation of the scale parameter is larger than 10%. The estimation bias can be reduced to 1% when the scale parameter is stable, i.e., the coefficient of variation of the scale parameter is less than 10%. More detailed information will be presented in the full paper. The choice of the threshold wind speed depends on how stable the assumption of the mean occurrence rate can be maintained while applying the Poisson process. The oral presentation will explain an estimation approach for a proper threshold wind speed.

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