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Prediction of Basic Wind Speed for Battambang Province

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Abstract

Basic wind speed is a very essential parameter used for conversion into wind loads on building structures. In Cambodia, the information of basic wind speed remains uncertain due to insufficient fundamental studies on the wind characteristics associated with regional climate. The aim of this paper is to predict the basic wind speed in Battambang, a northwest province of Cambodia using statistical and probabilistic approaches. The datasets have been collected from Mekong River Commission data portal in forms of hourly wind speed, and were then statically converted to 3-second gusts speed using Gaussian distribution transformation. The extreme value distributions such as Gumbel and Gringorten were used to analyze the extreme speed in accordance with a return period. The results showed that with a return period of 50 and 700 years, the basic wind speed was found to be 31.3 m/s, 41.1 m/s by Gumbel and 28.4 m/s, 36.1 m/s by Gringorten, respectively. These results provided a new look over traditionally uncertain basic wind speed selection and can be an alternative for estimation of wind loads for the design of building structures in Battambang.

Keywords

Basic wind speed, Statistical approach, Probabilistic approach, Battambang

1.Introduction

Wind load is an important loading type that affects the structures, in particular for tall and light weight building. The practical design method for wind load allows to use a basic wind speed represents a design limit state to ensure the safety and usability of the structures. The design for serviceability uses a return period that varies from 10 to 50 years, while a return period of 700 years is used for strength design [1]. The first essential parameter in the calculation of design wind loads starts with the selection of basic wind speed. In Cambodia, the absence of design code of building provides difficulty to engineers, which leads to use the uncertain wind speed for the design purpose. Thus, this study aims to provide the prediction of basic wind speed in Battambang, a northwest province of Cambodia as a case study. Battambang is a northwest province of Cambodia where attaches with the central lowland. The datasets were collection via historical record from a Mekong River Commission data portal [2] with code of identifier 130305 at coordinates 13.1°N, 103.2°E and altitude of 13m. The available datasets of wind speed were recorded from 2008 to 2012. Nowadays, this region has developed with high-rise buildings and other industrial structures that is convincing for the need of basic wind speed development. Thus, this study is very important as an initiative for expansion study of wind loads on building structures in Cambodia.

2.Methodology

In this study, a statistical approach known as, normal Gaussian distribution was firstly used to convert an hourly wind speed recorded by the station to a 3-second gust speed. After that, the probabilistic approach was used for the prediction of basic wind speed associated with extreme values [3] simply provides the “Type I Extreme Value Distribution” for such analysis corresponding to a return period.

2.1 Statistical Approach

The probability density function (PDF), $f(x)$ of a normal random variable x with mean value μ, and variance σ^2 is defined by

$$f_X(x) = \frac{1}{\sqrt{2\pi}\sigma} exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right], -\infty < x < +\infty \quad \text{(Eq. 1)}$$

The cumulative distribution function (CDF), $F_X(x)$ is the interval between $-\infty$ and x of $f_X(x)$. That is,

$$F_X(z) = \int_{-\infty}^{z} f_X(x)dx \quad \text{(Eq. 2)}$$

$$F_X(z) = \Pr\{-\infty < X < z\} = \Pr\{X < z\} \quad \text{(Eq. 3)}$$

$$F(z) = \Pr\left\{\frac{X-\mu}{\sigma} < z\right\} = \Pr(X \le \mu + z\sigma) \quad \text{(Eq. 4)}$$

A 3-second gust speed over one-hour wind speed, the probability is 3/3600 or 0.0833%. From statistic approach, the define parameter Z can be calculated as:

$$Z = \frac{X-\mu}{\sigma}$$

$$\Pr\left\{-z < \frac{X-\mu}{\sigma} \le +z\right\} = 1 - \frac{3}{3600}$$

$$F(z) - [1 - F(z)] = 0.9992$$

$$2F(z) = 1.9992$$

$$F(z) = 0.9996$$

$$\Rightarrow z = 3.34$$

Table 1. Values Standard Normal Distribution [4]

z	0	1	2	3	3.34
$F(z)$	0.5	0.8413	0.9773	0.9987	0.9996

2.2 Estimation of 3-second gust wind speed

As can be seen in Table 1, $z = 3.34$ was used in standard normal distribution. Then, the equation can write as follows.

$$u_{3sec} = u_{1hr} + 3.34\sigma_u \quad \text{(Eq. 5)}$$

where:
$\boldsymbol{u_{3sec}}$ = 3-second gust speed
$\boldsymbol{u_{1hr}}$ = one-hour sustained wind speed
$\boldsymbol{\sigma_u}$ = standard deviation of the $\boldsymbol{u_{1hr}}$

In most cases, the gust factor can be described as shown in Eq. 6 using a model developed for standard neutral boundary layer flow conditions [5].

$$\sigma_u = 2.5u_*$$ (Eq. 6)

where:
u_* = friction velocity. Furthermore, according to Hsu [6],

$$\frac{u_*}{u_{1hr}} = kp$$ (Eq. 7)

where:
$\mathrm{k} = 0.4$ von Karman constant [7]
p = exponent of the power-law wind profile [8]

$$\frac{u_2}{u_1} = \left(\frac{Z_2}{Z_1}\right)^p$$ (Eq. 8)

where:
u_1 and u_2 = wind speeds at heights Z_1 and Z_2, respectively.

By substituting Eq.6 and Eq.7 into Eq.5, the 3-second gust speed can be written as follows.

$$u_{3\sec} = u_{1hr}\left(1+3.34p\right)$$ (Eq. 9)

The Eq.9 is used to convert an hourly wind speed to a 3-second gust speed. In order to have a better estimation of p from Z_0 , Fig.1 is provided. For an open terrain with $z_0 = 0.02m$ and $p = 0.155$.

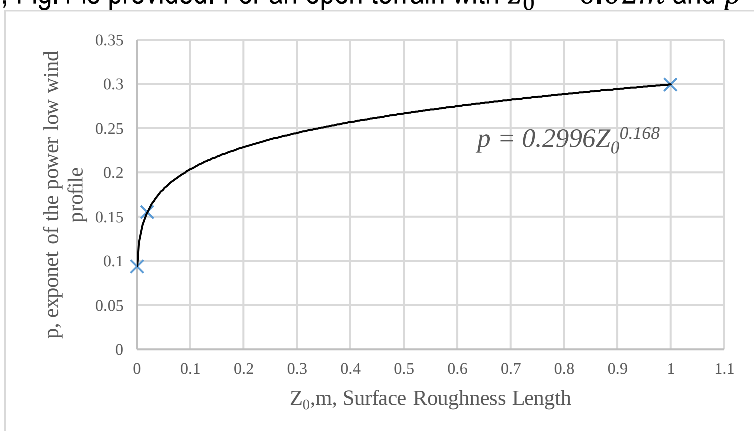

Figure 1. Relationship between z_0 and p [8]

2.3 Standard Height

A basic wind speed is a 3-second gust speed at 10m above the ground in Exposure C (Open terrain) [1]. Eq.8 can be used to convert a wind speed at any height to the standard height of 10m.The annual maximum wind speeds for 10 years at a height of 15m were determined and are shown in table 2 below.

Table 2. Annual maximum wind speed data and 3-second gust speed (m/s)

Years	Hourly at 13m	3-sec gust at 13m	3-sec gust at 10m
2008	16	24.3	23.3
2009	10	15.2	14.6
2010	14	21.2	20.4
2011	12	18.2	17.5
2012	12	18.2	17.5

2.4 Principles Extreme Value Analysis of wind speeds

The Gumbel's original extreme value analysis method applied to flood prediction.Gumbel [3] provide a simple method for fitting recorded annual maximum value to the Type I Extreme Value distribution [9]. The Type I Distribution uses the form of Eq.10 for the cumulative distribution as shown below.

$$F_U(U) = \exp\left\{-\exp\left[-\frac{U-u}{a}\right]\right\} \quad \text{(Eq.10)}$$

where:
u = the mode of the distribution
a = a scale factor

The return period, R, is directly related to the comulative probability distribution, $F_U(U)$, of the annual maximum wind speed at a site as follows.

$$R = \frac{1}{1-F_U(U)} \quad \text{(Eq.11)}$$

By substituting $F_U(U)$ from Eq.11 into Eq.10, we obtain,

$$U_R = u + a\left\{-\ln\left[-\ln\left(1-\frac{1}{R}\right)\right]\right\} \quad \text{(Eq.12)}$$

For the large values of return period, R, Eq.12 can be written as:

$$U_R = u + a\ln R \quad \text{(Eq.13)}$$

In Gumbel's original extreme value analysis method, the following procedure is adopted:

- In each calendar year of the record is given the largest wind speed
- The series is ranked in order of the smallest to the largest: 1, 2,…,m,…to N.
- Each value is assigned with a probability of non-exceedance, p, shown as:

$$p \approx m/(N+1) \quad \text{(Eq.14)}$$

- A reduced variate, y, is formate from:

$$y = -\ln\left[-\ln(p)\right] \quad \text{(Eq.15)}$$

- y is an estimate of the term {} brackets in (Eq.12)
- The wind speed, U_R, is plotted against y, and a line of 'best fit' is drawn with form $y = ax + u$

A simple modification to the Gumbel procedure, which gives nearly unbiased estimate for this probability distribution, is due to Gringorten [10]. Equation of probability of non-exceedance is replaced by the following modified formula:

$$p \approx (m-0.44)/(N+1-0.88) \quad \text{(Eq.16)}$$

Table 3. Computation of reduced variation

Series	3-sec gust at 10m	Probability of non-exceedance	Reduce Variate
1	14.6	0.11	-0.79
2	17.5	0.30	-0.17
3	17.5	0.50	0.37
4	20.4	0.70	1.01
5	23.3	0.89	2.16

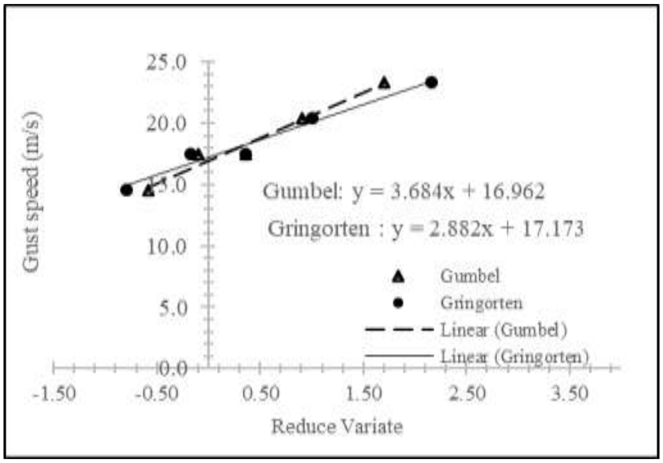

Figure 2. Analysis of the annual maximum wind gusts at Battambang using Gumbel method

The design basic wind speed for various return periods was predicted and is listed in Table 4 below.

Table 4. Computation of reduced variation

Return Period	Predicted gust speed (m/s)	
	Gumbel	Gumbel
10	25.3	23.7
20	27.9	25.7
30	29.4	26.9
50	31.3	28.4
100	33.9	30.4
200	36.5	32.4
500	39.9	35.1
700	41.1	36.1
1000	42.4	37.1
1700	44.4	38.6

Results and Discussion

The basic wind speeds in Battambang were predicted by converting the hourly wind from the raw datasets to the 3-second gust wind using Normal or Gaussian Distribution Function. Moreover, the 15m height was then converted into a standard heigh of 10m, as illustrated in table 2. It is clear that the 3-second gust wind increased compared with the hourly wind speed. More than that the basic wind speed degraded respect to lower height. That represents the natural properties of wind speed profile along the buildings. As probabilistic approach was performed, the design basic wind speed can be captured in relations with a return period, as shown in table 4. The results showed that with a return period of 50 and 700 years, the basic wind speed was found to be 31.3 m/s and 41.1 m/s by Gumbel and 28.4 m/s and 36.1 m/s by Gringorten, respectively. These results provided an initiative establishment

of the design basic wind speed in Battambang, but needs further design validation for existing buildings to ensure the reliability.

Conclusions

In order to provided reliability for the design buildings under wind load with safely and cost-saving, basic wind speed in Battambang was determined in this research paper. The minimum value of basic wind speed this area should be 31.3 m/s and 41.1 m/s for the design of building with a return period of 50 and 700 years, respectively.

Acknowledgments

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