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Prediction of Basic Wind Speed in Mandalay Region

THET MON SOE[1], THET THET AYE[2], THINN THINN SOE[3]
[1] Department of Civil Engineering, Mandalay Technological University, Mandalay, Myanmar
[2] Department of Civil Engineering, Technological University (Kyaukse), Mandalay, Myanmar
[3] Department of Civil Engineering, Technological University (Mandalay), Mandalay, Myanmar

***Abstract* – Basic wind speed is very important for designer to develop new urban planning and new design buildings. The aim of this paper research is to predicate basic wind speed and to calculate wind directions in Mandalay city. The extreme value distribution such as Gumbel and Gringorten method are based on the anemometer data (1995-2015) obtained from department of meteorology Mandalay. Statistical and probabilistic approaches are used to derive formula for estimating 3 sec gust wind speeds from hourly wind speeds. The maximum wind direction in Mandalay region is calculated.**

***Indexed Terms-* Basic Wind Speed, Mandalay city, Statistical approaches, gust wind speeds**

I. INTRODUCTION

Wind is the term used for air in motion and is usually applied to the natural horizontal motion of the atmosphere. Motion in a vertical or nearly vertical direction is called a current. Movement of air near the surface of the earth is three-dimensional, with horizontal motion much greater than the vertical motion. Vertical air motion is of importance in meteorology but is of less importance near the ground surface. On the other hand, the horizontal motion of air, particularly the gradual retardation of wind speed and the high turbulence that occurs near the ground surface, are of importance in building engineering. In urban areas, this zone of turbulence extends to a height of approximately one-quarter of a mile above ground, and is called the surface boundary layer. Above this layer, the horizontal airflow is no longer influenced by the ground effect. The wind speed at this height is called the gradient wind speed, and it is precisely in this boundary layer where most human activity is conducted. Therefore, how wind effects are felt within this zone is of great concern. Wind generally flows from an area of high pressure to an area of low pressure. The Coriolis force, friction, pressure gradient, intensity of sunshine, and earth's temperature control wind movements and directions are factors that affect wind direction and speed. Wind direction is important for a lot of things such as sailing, aviation, wind farms, urban planning design and orientations of buildings.

The location of the study area is Mandalay region. The wind speeds are measured by using anemometer that is shown in Figure 1. The anemometer position has been constant throughout that period and the height of the anemometer head has been the value of 7.62m (25ft). The wind speed is usually recorded two times a day. These measuring times are 9:30 am and 3:30pm with an hourly wind speed. To predict basic wind speed, it is necessary to estimate the 3-s gust from an hourly wind speed.

Figure 1. Anemometer

II. BASIC WIND SPEED

Basic wind speed is based on peak gust speed average over a short time interval and corresponds to 10 m height above the mean ground level in an open terrain. A short time interval is about 3 s or 10 min. One of the primary steps to find the design wind load for buildings is to get the basic wind speed. The determination of the effective wind pressure is based on the basic wind speed. The value of basic wind speed must be established by meteorological measurement. Normally it is not necessary to actually do the measurement for a particular region. The values as suggested from published Wind Maps specified by the codes may be used. Basic wind speeds generally have been worked out for a return period of 50 yrs. Table 1 summarizes the basic wind speed characteristics used, or recommended, in the codes and standards.

Table 1. Definitions of Basic Wind Speeds [01Hol]

Code	Averaging Time	Return Period(s)
ASCE 7-98	3 s	50 years
Eurocode 1	10 min	50 years
AS 1170.2	3s	1000 years

In Myanmar, there is no reference map that included basic wind speed. The basic wind speed is used as assumption data. So, it is necessary to analyze the prediction of extreme wind speed based on historical climate data.

III. STATISTICAL APPROACHES

Statistical and probabilistic approach is used to derive formula for estimating 3 sec gust wind speeds from hourly wind speeds.

The cumulative distribution function of X can now be found by using the relation:

$$F(z) = \text{probability } (Z \le z)$$

$$= \text{probability } \left(\frac{(X-u)}{\sigma} \le z \right)$$

$$= \text{probability } \left(X \le u + z\sigma \right)$$

Some particularly useful F(z) values are also given in Table 2.

Table 2. Statistical Table [70Cha]

z	0	1	2	3	3.33
F (z)	0.5	0.8413	0.9772	0.9986	0.9996

For 3 sec gust over an hourly, the probability is 3/3600 or 0.083%.

From statistics approach,

$$z = \frac{X-\mu}{\alpha}, \ \alpha = 0.00083, \ \frac{\alpha}{2} = 0.000415$$

1- α = 0.9992

$$P(-z \le \frac{x-\mu}{\sigma} \le +z) = 0.9992$$

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

$$2\,F(z) = 1.9992$$

$$F(z) = 0.9996$$

So, the z value is 3.33 from the standard normal (Table 2) and the Equation can be written:

$$U_{3sec} = U_{1hr} + 3.33\sigma_u$$

Where U_{3sec} is the 3 second gust wind speed, U_{1hr} is the hourly wind speed, σ_u is the standard deviation of the hourly wind speed.

In most cases, the gust factor can be described as following Equation using models developed for standard neutral boundary layer flow conditions.

$$\sigma_u = 2.5u_*$$

Where σ_u is standard deviation and u_* is the friction velocity.

$$\frac{u_*}{U_{1hr}} = kp$$

Where k = 0.4 is the von Karman constant and p is the exponent of the power-law wind profile. Now, by substituting Equations, the following equation is obtained:

$$U_{3sec} = U_{1hr}[1 + 3.33P]$$

This equation is the formula for estimating the 3 sec gust wind speed from hourly wind speed. In order for the engineers to have a better estimation of p from Z_0 of Figure 2 is provided. For example, for an open terrain where Z_0 = 0.02m, p = 0.155 [08Hus].

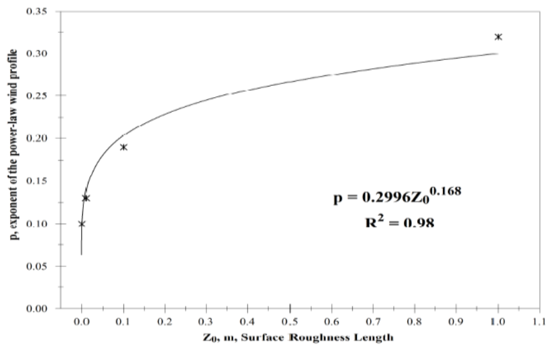

Figure 2. Relationship between Z_0 and p [08Hsu]

IV. PREDICTION OF BASIC WIND SPEED

A. Calculation of Annual Maximum 3sec Gust Wind Speeds from the Hourly Wind Speed

The annual maximum wind speeds for 21 calendar years from 1995 to 2015 are collected from meteorological stations in Mandalay. To predict basic wind speed, it is necessary to estimate the 3 sec gust wind speed from hourly wind and at the standard reference height of 10 m above ground level. Firstly, Converting of maximum 3sec gust wind speeds from hourly wind speeds are listed in Table 3.

Table 3. Converted Maximum 3 sec Gust Wind Speeds at 25 Feet Height

Year	Maximum hourly wind speed		Maximum 3 sec gust wind speed
	mile per hour (mph)	meter per second (mps)	meter per second (mps)
1995	12.6	6.01	9.11
1996	21.6	10.30	15.62
1997	17.2	8.20	12.44
1998	28.4	13.55	20.54
1999	18.7	8.92	13.52
2000	11.3	5.39	8.17
2001	10.8	5.15	7.81
2002	7.2	3.43	5.21
2003	12.8	6.11	9.26
2004	8.5	4.05	6.15
2005	8.4	4.01	6.07
2006	8.7	4.15	6.29
2007	7.8	3.72	5.64
2008	8.6	4.10	6.22
2009	10	4.77	7.23
2010	7	3.34	5.06
2011	8.6	4.10	6.22
2012	10.6	5.06	7.67
2013	8.2	3.91	5.93
2014	8.2	3.91	5.93
2015	16.2	7.73	11.71

B. Calculation of Annual Maximum 3 sec Gust Wind Speeds at the Standard Height 10 m (33-ft)

When the basic wind speed is estimated from regional climatic data, the basic wind speed shall be not less than the wind speed associated with an annual probability of 0.02 (50- year mean recurrence interval), and the estimate shall be adjusted for equivalence to a 3-s gust wind speed at 33 ft (10 m) above ground as specified ASCE 7-98. The following equation is used to calculate a 10 m height wind speed from the hub height wind speed every 3 sec with assuming roughness length (0.02) for an open terrain.

$$U_1 = U_2 \frac{\ln\left(\frac{H_1}{z}\right)}{\ln\left(\frac{H_2}{z}\right)}$$

Where,

H_1 = the height of the wind speed to be calculated (10 m)

H_2 = the height of the measured wind speed

U_1 = the wind speed to be calculated

U_2 = the measured wind speed

z = the roughness length (open, flat terrain)

The standard height above the surrounding vegetation for measuring open wind speed is 10 meters (33ft). The height of the anemometer head in Mandalay at 1995 is 7.26m. So, to convert wind speed at the standard meteorological value of 10m is needed. The converted maximum 3 sec gust wind speeds at the standard height 10 m (33-ft) are described in Table 4.

Table 4. Converted 3sec gust wind speeds at the standard height 10m (33-Ft)

Year	Annual Maximum 3 sec gust wind speed (m/s)	
	At 7.62 (25 ft) height	At 10 m (33ft) height
1995	9.11	9.61
1996	15.62	16.47
1997	12.44	13.11
1998	20.54	21.65
1999	13.52	14.26
2000	8.17	8.62
2001	7.81	8.23
2002	5.21	5.49
2003	9.26	9.76
2004	6.15	6.48
2005	6.07	6.40
2006	6.29	6.63
2007	5.64	5.95
2008	6.22	6.56
2009	7.23	7.62
2010	5.06	5.34
2011	6.22	6.56
2012	7.67	8.08
2013	5.93	6.25
2014	5.93	6.25
2015	11.71	12.35

C. Methods for Wind Estimation

Gumbel (1954) gave an easily usable methodology for fitting recorded annual maxima to the Type I

Extreme Value distribution. The Type I distribution takes the form of Equation 1 for the cumulative distribution $F_U(U)$:

$$F_U(U) = \exp\{-\exp[-(U-u)/a]\}$$

where u is the mode of the distribution, and a is a scale factor.

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

$$R = \frac{1}{[1-F_U(U)]}$$

Substituting for $F_U(U)$ from Equation 3.2 into 3.1, the following extreme wind speed equation is obtained;

$$U_R = u + a\left\{-\log_e - \log_e\left(1-\frac{1}{R}\right)\right\}$$

In Gumbel's original extreme value analysis method, the procedures are

1. The largest wind speed in each calendar year of the record is extracted.
2. The series is ranked in order of smallest to largest: 1, 2, m … to N.
3. Each value is assigned a probability of non-exceedence, p, according to

$$p \approx \frac{m}{N+1}$$

A reduced variate, y, is formed from:

$$y = -\log_e(-\log_e P)$$

The wind speed, U, is plotted against y, and a line of 'best fit' is drawn, usually by means of linear regression.

4. The intercept and slope of these lines give the mode, u, and slope, a.
5. Predictions of extreme wind speeds for various return periods can then readily be obtained by application of predication of extreme wind speed equation.

A simple modification to the Gumbel procedure, which gives nearly unbiased estimates for this probability distribution, is due to Gringorten (1963), Equation of a probability of non-exceedence is replaced by the following modified formula;

$$P = \frac{(m-0.44)}{(N+1-0.88)} = \frac{(m-0.44)}{(N+0.12)}$$

The value of 3sec gust wind speeds at the standard height 10m (33-Ft) from Table 4 are sorted in order to increasing magnitude show in Table 5 and assigned a probability, p, according to (i) the Gumble formula and the Gringorten formula and (ii) the substituting the value of probability Equation. And then these values are tabulated in Table 5.

The gust wind speeds are plotted against corresponding reduce variate, and a straight line is fitted as show in Figure 3 and 4, for Gumble and Gringorten Method, respectively.

Table 5. Calculation of reduced variate

Serial No:	3 sec gust Wind Speed (m/s)	Probability of non-exceedence, P (Gumble Method)	Probability of non-exceedence, P (Gringorten Method)	Reduced Variate, y	
				Gumble	Gringorten
1	5.34	0.05	0.03	-0.13	-0.20
2	5.49	0.09	0.07	-0.02	-0.05
3	5.95	0.14	0.12	0.06	0.04
4	6.25	0.18	0.17	0.13	0.11
5	6.25	0.23	0.22	0.19	0.18
6	6.40	0.27	0.26	0.25	0.24
7	6.48	0.32	0.31	0.30	0.29
8	6.56	0.36	0.36	0.36	0.35
9	6.56	0.41	0.41	0.41	0.41
10	6.63	0.45	0.45	0.47	0.46
11	7.62	0.50	0.50	0.52	0.52
12	8.08	0.55	0.55	0.58	0.58
13	8.23	0.59	0.59	0.64	0.65
14	8.62	0.64	0.64	0.71	0.72
15	9.61	0.68	0.69	0.78	0.79
16	9.76	0.73	0.74	0.86	0.88
17	12.35	0.77	0.78	0.95	0.98
18	13.11	0.82	0.83	1.06	1.10
19	14.26	0.86	0.88	1.20	1.25
20	16.47	0.91	0.93	1.38	1.48
21	21.65	0.95	0.97	1.69	1.93

The intercept and slope of these lines give the mode, u and slope, a of the Type I Extreme Value Distribution. From Figures 3 and 4, the mode, u are obtained 4.3379 and 4.7135, and then the calculated slopes, a are 8.8203 and 7.9922, respectively, for Gumbel and Gringorten method.

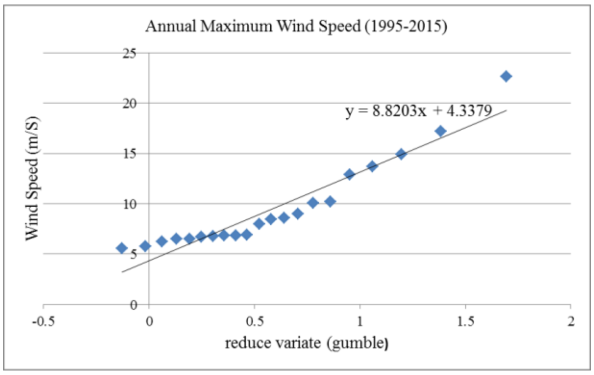

Figure 3. Analysis of Annual maximum Gust wind, Using Gumbel Method

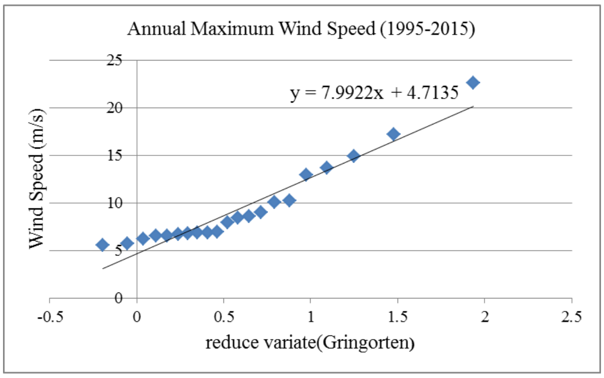

Figure 4. Analysis of Annual maximum Gust wind, Using Gringorten Method

And thus Basic wind speeds for various return periods can be predicted and are listed in Table 6.

When the basic wind speed is estimated from regional climate data, the basic wind speed shall be not less than the wind speed associated with 50 year mean recurrence interval (return period 50 year).

So, in this study, the wind speed for return period 50 year is chosen as minimum basic wind speed. Moreover, the wind speed of Gumbel's method is used as basic wind speed to be safe. The reason is that the value of Gumbel's method is greater than the value of Gringorten's method.

Table 6. Predicted of Wind Speed

Return Period(year)	Predicted Wind Speed			
	Gringorten Method		Gumble Method	
	(m/s)	(mph)	(m/s)	(mph)
2	8.88	18.62	8.94	18.74
5	12.81	26.87	13.28	27.84
10	15.42	32.33	16.15	33.86
20	17.92	37.56	18.91	39.64
50	21.15	44.34	22.48	47.13
100	23.58	49.42	25.15	52.73
200	25.99	54.49	27.82	58.32
500	29.18	61.16	31.33	65.69
1000	31.58	66.21	33.99	71.26

D. Wind Directions for Mandalay

The annual maximum wind speeds for 21 calendar years from 1995 to 2015 are collected from meteorological stations in Mandalay.

Figure 5 shows the histograms of wind direction from 1995 to 2015. The most frequency percentage of wind direction is south wind direction and the second most frequency percentage is south-east direction.

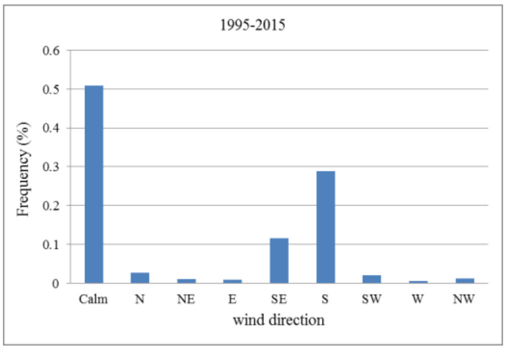

Figure 5. Histogram of Wind Directions

V. CONCLUSION

The minimum basic wind speed of Mandalay is 22.48 mps (47.13 mph). But this minimum basic wind speed is less than basic Wind Speed (3 sec Gust Wind Speed in mph) from Myanmar National Building Coad (2016) as value 38.16mps (80 mph). The maximum wind flow direction is South wind directions in Mandalay. In this research, the large value of wind speed is selected to safe design structures. The basic wind speed is used in the determination of design wind loads on buildings and bridge structures.

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