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Prediction of Basic Wind Speed for Ayeyarwady

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Abstract**—** The paper presents a preliminary study on modeling & estimation of basic wind speed (extreme wind gusts) for the consideration of vulnerability and design of building in Ayeyarwady Region. The establishment of appropriate design wind speeds is a critical step towards the calculation of design wind loads for structures. In this paper the extreme value analysis of this prediction work is based on the anemometer data (1970-2009) maintained by the department of meteorology and hydrology of Pathein. Statistical and probabilistic approaches are used to derive formulas for estimating 3-second gusts from recorded data (10-minute sustained mean wind speeds).

Keywords**—** Basic Wind Speed, Building, Gusts, Statistical and probabilistic approaches

I. INTRODUCTION

RESIDENTIAL building can suffer extensive wind damage when they are improperly designed and constructed and when wind speeds exceed design levels. Wind loading competes with seismic loading as the dominant environmental loading for structures. They have produced roughly equal amounts of damage over a long time period, although large damaging earthquakes have tended to occur less often than severe windstorms. The damage of cyclone Nargis that hit in Myanmar was severe in Ayeyarwady Region and Yangon Region. Fig.1. shows the location of Nargis cyclone affected areas and damages in Ayeyarwady Region[5]. Most of the structural damages are not relating to wind induced structural damages because there were almost no reinforced concrete buildings in the affected area. But after Nargis, there are large numbers of reinforced buildings in that area and wind load effects become important in structural computation.

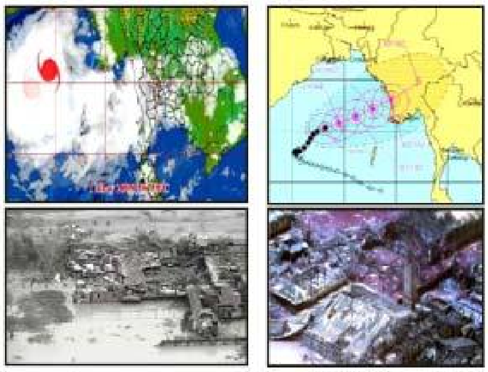

Fig. **1**. Cyclone aff**e**cted areas in **N**argis

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II. LOCATION OF THE STUDY AREA

Pathein is situated about 115 miles west of Yangon. It is the capital of Ayeyarwady region and one of the delta regions of Myanmar that are prone to seasonal storms. The area of Pathein is 14580 acres including extension quarter. The elevation of the town is 11.53' above mean sea level and is located on the bank of Pathein River and is existed 40 miles from the sea. In this study, the recorded wind data has been obtained from the department of meteorology and hydrology in Pathein weather station. Location of Ayeyarwady Region in Myanmar is shown in Fig. 2.

Fig. 2. Location of Ayeyarwady Region in Myanmar

III. METHODOLOGY

The paper describes an application of extreme value analysis to the prediction of design wind speeds. In particular, the Gumbel approach is described in detail and formulars for estimating 3-seconds from 10-minute sustained mean wind speeds (recorded wind speeds) are derived. 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. To quantiy the hazard of extreme gusts, monthly maximum 10-minute sustained mean wind speeds recorded from 1970 to 2009 at an anemometer station maintained by the department of meteorology and hydrology of Pathein in Ayeyarwady Region were collected. Statistical and probabilistic approaches are used to model the gust wind speeds. Predicted extreme gust wind speeds (basic wind speeds) are model by the extreme value analysis.

IV. 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. The basic wind speed is used in the determination of design wind loads on buildings and other structures. In most codes and standards, the basic wind velocity can be obtained from basic wind speed map. Table I summarizes the basic wind speed characteristics used, or recommended, in the codes and standards [4].

TABLE I
DEFINITIONS OF BASIC WIND SPEED

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

Source: 2001 John D.Holmes

V. STATISTICAL APPROACHES

Statistical and probabilistic approaches (normal distribution) are used to derive formulas for estimating 3-second gusts from 10- minute sustained wind speeds.

A. Normal distribution

The normal or Gaussian distribution is the most important of all the distributions since it has a wide range of practical applications. The cumulative distribution function of X can now be found by using the relation

$$F(z) = \text{probability } (Z \leq z) \quad (1)$$

$$= \text{probability } \left(\frac{X-u}{\sigma} \leq z\right) \quad (2)$$

$$= \text{probability } (X \leq u + z\sigma) \quad (3)$$

The full table of F(z) is given in Table I, Appendix B[3]. Some particularly useful values are also given in Table II.

TABLE II

z	0	1	2	2.81	3
F (z)	0.5	0.8413	0.9772	0.9975	0.9986

Source: Appendix B [3]

B. Formulas for converting 3-second gusts

For 3-second gust over a ten minute period, the probability is 3/600 or 0.5%, therefore from statistics [3] we have:

$$u_{3sec} = u_{10min} + 2.81\sigma_u \quad (4)$$

or

$$u_{3sec} = u_{10min} + [1 + 2.81\, \sigma_u/u_{10min}] \quad (5)$$

where u_{3sec} is the 3-second gust, $u_{10\ min}$ is the 10- minute sustained wind speed, and σ_u is the standard deviation of the $u_{10\ min}$.

In most cases the hurricane gust factor can be described using models developed for standard neutral boundary layer flow conditions [7].

$$\sigma_u = 2.5\, u_* \quad (6)$$

where σ_u is standard deviation and u_* is the friction velocity. Furthermore, according to Hsu ,

$$\frac{u_*}{u_{10min}} = \kappa p \quad (7)$$

where κ(= 0.4) is the von Karman constant and p is the exponent of the power-law wind profile [7] such that

$$\frac{u_*}{u_{10min}} = \left(\frac{z_2}{z_1}\right)^p \quad (8)$$

where u_1 and u_2 are the wind speeds at heights z_1 and z_2, respectively. Now, by substituting Eqs. (6) and (7) into (5), one gets:

$$u_{3sec} = u_{10min} + (1 + 2.81p) \quad (9)$$

Eq. (9) is the formula for estimating the 3-second gust from a 10-minute sustained speed.

In order for the engineers to have a better estimation of p from z_0, Fig. 3 is provided. For example, for an open terrain where $z_0 = 0.02$ m, $p = 0.155$.

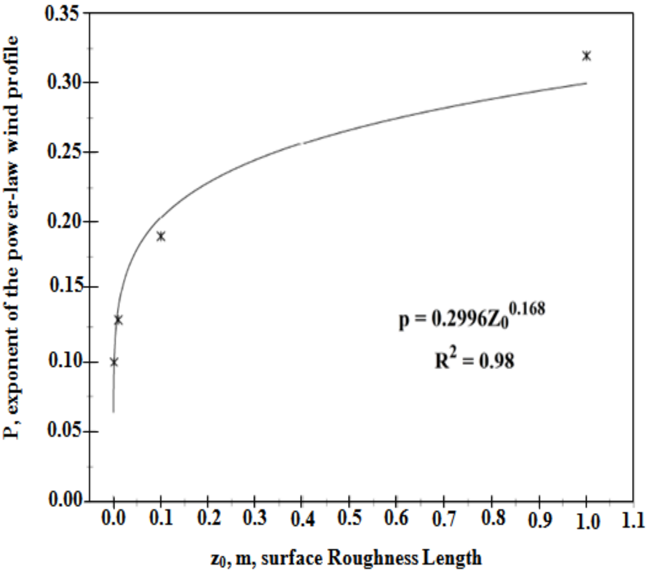

Fig. 3. The relationship between z_0 and p (data source: Justus, 1985, in neutral stability condition).

VI. MODELING OF GUST WIND SPEED

The gust speed is the highest sustained gust over a three second period of time. Model building codes have converted to three-second peak gust wind speeds because that means of measurement is now commonly used at wind speed reporting stations across the U.S. To predicted basic wind speed, it is necessary to estimate the 3-s gust from the collected data (10-min sustained speed).

A. Collected wind speed data from Pathein station

The annual maximum wind speed for the 40 calendar years from 1969-1970 to 2008-2009 are listed in Table III. The anemometer position has been constant throughout that period, and the height of the anemometer head has always been the standard meteorological value of 10 m.

TABLE III
COLLECTED WIND SPEED DATA (1970-2009)

Year	Maximum 10 min sustained wind speed (m/s)
1969-1970	5.41
1970-1971	7.47
1971-1972	8.94
1972-1973	6.21
1973-1974	4.83
1974-1975	34.51
1975-1976	16.99
1976-1977	5.45
1977-1978	5.36
1978-1979	8.18
1979-1980	5.72
1980-1981	5.45
1981-1982	5.99
1982-1983	4.92
1983-1984	6.44
1984-1985	6.17
1985-1986	5.45
1986-1987	6.44
1987-1988	8.94
1988-1989	7.15
1989-1990	5.36
1990-1991	9.07
1991-1992	6.26
1992-1993	6.44
1993-1994	7.15
1994-1995	5.36
1995-1996	4.83
1996-1997	5.36
1997-1998	4.83
1998-1999	5.36
1999-2000	5.36
2000-2001	4.83
2001-2002	5.36
2002-2003	4.83
2003-2004	4.47
2004-2005	4.83
2005-2006	8.94
2006-2007	4.29
2007-2008	17.88
2008-2009	7.51

B. Estimating 3-second gusts from the collected data

To predicted basic wind speed, formula for estimating the 3-second gust from a 10-minute sustained speed , Eq (9) is used. Different terrains can be categorized according to their associated roughness length, z_0. So, z_0 of open terrain is 0.02[2]. The converted annual maximum gust speed for the 40 calendar years 1970 to 2009 are listed in Table IV.

TABLE IV
ANNUAL MAXIMUM GUST SPEEDS (1970-2009)

Year	Maximum gust wind speed(m/s)
1969-1970	7.79
1970-1971	10.75
1971-1972	12.87
1972-1973	8.95
1973-1974	6.95
1974-1975	49.70
1975-1976	24.46
1976-1977	7.85
1977-1978	7.72
1978-1979	11.78
1979-1980	8.24
1980-1981	7.85
1981-1982	8.63
1982-1983	7.08
1983-1984	9.27
1984-1985	8.88
1985-1986	7.85
1986-1987	9.27
1987-1988	12.87
1988-1989	10.30
1989-1990	7.72
1990-1991	13.07
1991-1992	9.01
1992-1993	9.27
1993-1994	10.30
1994-1995	7.72
1995-1996	6.95
1996-1997	7.72
1997-1998	6.95
1998-1999	7.72
1999-2000	7.72
2000-2001	6.95
2001-2002	7.72
2002-2003	6.95
2003-2004	6.44
2004-2005	6.95
2005-2006	12.87
2006-2007	6.18
2007-2008	25.75
2008-2009	10.81

VII. PRINCIPLES EXTREME VALUE ANALYSIS

The use of extreme value analysis for design wind speeds lagged behind the application to flood analysis. Gumbel (1954) strongly promoted the use of the simpler Type I extreme value distribution for such analyses. In the 1950s and the early 1960s, several countries had applied extreme value analyses to predict design wind speeds.Gumbel (1954) gave an easily usable methodology for fitting recorded annual maxima to the Type I Extreme Value distribution [4]. The Type I distribution takes the form of equation (10) for the cumulative distribution $F_U(U)$:

$$F_U(U) = exp\{-exp[-(U-u)/a]\} \tag{10}$$

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:

$$R = 1/(1-F_U(U)) \tag{11}$$

Substituting for $F_U(U)$ from equation (11) in (10), are obtain:

$$U_R = u + a\{-\log_e[-\log e(1-1/R)]\} \tag{12}$$

In Gumbel's original extreme value analysis method, a probability of non-exceedence, p is derived by

$$p \approx m/(N+1) \tag{13}$$

where 'm' is the rank in ascending order.

A reduced variate, y, is formed from:

$$y = -\log_e(-\log_e p) \tag{14}$$

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:

$$p \approx (m-0.44)/(N+1-0.88)$$
$$= (m-0.44)/(N+0.12) \tag{15}$$

VIII. MODELING OF BASIC WIND SPEED

The gust wind speed is plotted against reduced variates, and a straight line is fitted. The results of this are shown in Fig. 4 and Fig. 5, for the Gumbel and Gringorten methods, respectively. The intercept and slope of these lines give the mode, u and slope, a of the fitted Type I Extreme Value Distribution Analysis.

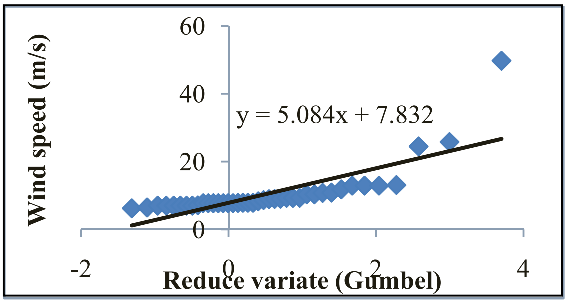

Fig. 4. Analysis of annual maximum wind gust , using the Gumbel method

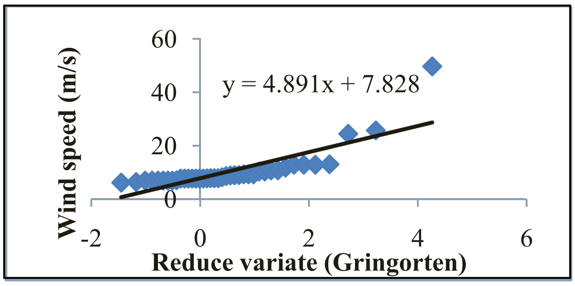

Fig. 5. Analysis of annual maximum wind gust, using the Gringorten method

Prediction of extreme wind speeds for various return periods can then readily be obtained by application of equation (12). In this case, Table V lists these predictions based on the two fitting methods.

TABLE V
PREDICTION OF EXTREME WIND SPEEDS FOR THE STUDY AREA

Return period (year)	Predicted gust speed (m/s)	
	(Gumbel)	(Gringorten)
10	19.3	18.8
20	22.9	22.4
50	27.7	26.9
100	31.2	30.3
200	34.8	33.7
500	39.4	38.2
1000	42.9	41.6

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 50- year mean recurrence interval (ASCE 7-05)[1]. In these two methods, basic wind speed is choosed as 27.7 m/s (62 mph) to be safe. This predicred basic wind speed data for various return period would be useful for designer to estimate the effect of wind load on building in delta region.

IX. CONCLUSION

On the basis of statistical and meteorological considerations, Eq.(9) is proposed for 3-second gust estimations from 10-minute sustained wind speed data. Under neutral stability conditions over the open terrain, the value of the 3-second gust over a 10-minute period is 1.44, that is the factor to multiply u_{10min}. For a better estimation of p from Z_0, Figure 1 is provided. In this study, basic wind speed is predicted to analyse and design the buildings in the study area. It would be beneficial for designer to get informed effect of wind load on building in Ayeyarwady region. In this region, the minimum value of basic wind speed should be 27.7 m/s (62 mph). More reliable results can be obtained by using historical wind speed data.

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