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A REVIEW PAPER ON WIND CLIMATE MODELING

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Abstract-

India has a mixed extreme wind climate which is mainly affected by thunderstorms, cyclones, gales from Monsoon winds and localised storms. Different storms occur due to different geophysical reasons and their turbulent intensities are different. Mainly tall slender structures which are located in urban region of Indian coastal areas are strongly affected by extreme wind. Every year the statistics of damages clearly reveals that even today structures and structural components are not sufficiently wind hazard resistant. So extreme events from each storm type should be fitted in a separate extreme value distribution and later on a combination of probability distributions should be made in order to specify design wind speed for a target non exceedance probability. Most of the researchers conclude that the extreme value distributions include type I(Gumbel), type II(Fre'chet) and type III (Reverse Weibull) distributions. The design wind load is proportional to the square of the design wind speed. So the specification of design wind speed is a prerequisite for the specification of design wind load. The specification of design wind speed can be done by extreme wind climate modeling.

Keywords: Wind; Weibull distribution; Gumbul distribution; Design wind speed; Extreme value distribution.

I. INTRODUCTION

Yaojun Ge at. Al.[1] describe about the theoretical model of the joint probability distribution with directional independent coefficients are set up to describe joint distribution of wind speed and direction, and its application method is developed into three statistical steps, data processing of wind speed records, examination of joint distribution model and estimation of distribution model parameters. Ying et. al. [2] Find out a comparative assessment of methods for extreme value analysis of the US wind speed data using four different techniques, namely Standard Gumbel, Modified Gumbel, Peaks-Over-Threshold (POT) and Method of Independent Storms (MIS) and also give the estimates of design wind speed corresponding to 50-year and 500-year return period. [3] To investigates the probability distributions of extreme wind speed and its occurrence interval based on extreme wind speed data. The Type I extreme value distribution, three-parameter Weibull distribution and two-parameter Weibull distribution are adopted in this study to fit the wind speed data. The results found that, the three distributions are suitable for providing the probability distribution of the extreme wind speed data, the Type I and the three-parameter Weibull distributions are more appropriate than the two-parameter Weibull distribution. N. Lakshmanan [4] Using the Gumbel probability paper approach the extreme value quantiles have been calculated. A design basis wind speed for each site for a return period of 50 years has also been evaluated. M. Kasperski [5] describe that, the design wind load can be specified based on an appropriate small target value of the exceedance probability. Arnab Sarkar et.al.[6,14] determine about the method for finding the wind speed range till which Weibull model is appropriate and also to fit upper wind speed data in a suitable statistical distribution like extreme value distribution of type I (Gumbel). The hourly mean wind speed data of Ahmadabad has been used to validate the procedures.

[7] told that, Gumbel distribution using MLS is found to be appropriate for estimation of design wind speed for Vadodara region & also calculated that the values of estimated 3-sec average extreme wind speed adopting statistical distributions are compared with IS 875 procedures to get a design parameters. Vivekanandan. N [8] A comparative study of wind speed finding for different return periods, obtained using five methods of Gumbel distribution and with BIS code of practices is carried out; and results obtained. [9,13] Extreme wind climate in India is mainly influenced by thunderstorms and cyclones. This study is to improve the current design methodology and the national code of standards to make engineering structures in India less vulnerable to damage due to strong winds.

[10] Describe that, To provide the basic wind speed which will be used to design building. Data was then analyzed statistically using Gumbel method to determine the basic wind speed, from which wind pressure affecting a typical structure can be calculated.[11] Describe that Offshore wind resources are more abundant and stronger and they blow more consistently than land-based wind resources..The assessment shows that the study areas have high-strength wind power but are rarely subjected to extreme wind speeds, which told that it is suitable for wind farm construction. Yeli zet. al.[12] told

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that, Accurately modeling wind speed is critical in estimating the wind energy potential of a certain region. In order to model wind speed data smoothly, several statistical distributions have been studied. Truncated distributions are herewith defined as a conditional distribution that results from restricting the domain of statistical distribution and they also distribution, in modeling wind speed data and also in calculating wind power density. The obtained results indicate that upper-truncated Weibull distribution shows better performance than Weibull distribution in estimating wind speed distribution and wind power.

II. EXTREME VALUE STATISTICS

[23,24,25,26] Upper tail modelling of wind speed data can be done by extreme value statistics.

Extreme value theory has firstly been published in a comprehensive textbook by Gumbel.[15,17,18] He presented and discussed three basic types of extreme value limit distributions[20,21,22]: type I – Gumbel distribution; type II – Frechet distribution; and type III – Reverse Weibull distribution. The distributions of types II and III each form a family of curves with specific characters. Compared to the type I distribution, they show as special feature a certain curvature when plotted in Gumbel probability paper. Generally, a probability paper is a graph paper with one axis specially ruled to transform the distribution function of a specified function to a straight line when it is plotted against the variate as abscissa. While the curves for the type II distribution bend in a concave shape in respect to the axis of the reduced variate, the curves corresponding to type III show a distinct convex character (Fig. 1). These two types are separated by

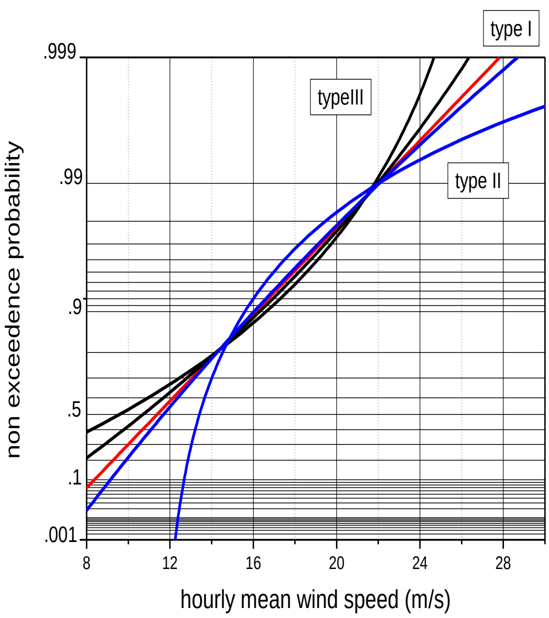

Fig. 1: Traces of the extreme value limit distributions in a Gumbel probability paper

cover base distribution. This study proposes, for the first time, the use of upper-truncated Weibull

the type I distribution which appears in the plot as a straight line.

The generalised extreme value distribution of a variate x can be given by the following form:

$$F(x) = \exp\left[-\left(f_1 - f_2.\frac{x-m}{\sigma}\right)^{\frac{1}{\tau}}\right] \quad (1)$$

In equation (1), m is the mean value, σ is the standard deviation and τ is the curvature parameter. The type III distribution is obtained for positive curvature parameter. The coefficients f_1 and f_2 which depend on the curvature parameter can be given in the following forms: $f_1 = \Gamma(1+\tau)$ (2)

$$f_2 = \sqrt{\Gamma(1+2.\tau) - f_1^{\,2}} \quad (3)$$

Γ - Gamma function

The extreme value is given by:

$$x_{\max} = m + \sigma.\frac{f_1}{f_2} \quad (4)$$

For τ = 0, the type I extreme value distribution is obtained and the equation (1) for the generalised extreme value distribution becomes equation (5):

$$F(x) = \exp\left[-\exp\left(-\left[\gamma + \frac{\pi}{\sqrt{6}}\frac{x-m}{\sigma}\right]\right)\right] \quad (5)$$

γ - Euler constant = 0.5772

Curvature parameter τ < 0 leads to the type II extreme value distribution. This distribution is defined for values x>0. In this case, instead of a finite upper tail, a lower limit is obtained.

III. RESULTS AND DISCUSSION

Wind loads need to be considered in the design of structures especially high-rise and light weight structures. Wind loads are usually specified as pressure due to the predicted maximum wind velocity. This necessitates accurate prediction of the maximum wind velocity that can be experienced over the design life of structures so that the design is carried out with these wind speeds in mind. Structural Engineers should be able to accurately predict all loads affecting structures. Consideration of wind loads is very important in the structural design especially in the design of high rise structures. This, among accurate prediction of other loads affecting a structure, ensures safe and economic design of structures. It is important to periodically review the wind speeds. This is because the wind speeds experienced could change due to changes in land use like deforestation to give way for infrastructure among other causes. Most structures are usually designed for a life period of 50 yrs, thus the basic wind speed will have a return period of 50 years. The objective of this study is to provide the basic wind speed which will be used to design building structures.

There are many coefficient estimation methods, for example, digital characteristics method, least-squares method, sequence statistics method, and maximum likelihood method. Among them, the maximum likelihood method has the highest estimation efficiency.[28,29]If possible, the maximum likelihood method is always suggested. But when it fails sometimes, the least-squares method can be used instead. The sample size considered in the POT and MIS methods depends on the threshold. The sample size decreases as threshold wind speed is raised. Results of the Gumbel methods (SG and MG) are independent of the threshold[27], as they utilize a complete sample of annual maxima. The standard Gumbel method appears to provide an upper bound estimate in most cases. In general, POT estimates the large variation with respect to the threshold speed. A possible reason for this variability is that the Pareto model is only applicable to a narrow and unidentifiable range of exceedence data. It can be clearly observed that the POT estimates are only reasonable while the threshold is raised up to a high enough level in line. In contrast with POT methods, MIS estimates follow a smoother trend with very limited variability with respect to the threshold speed.

The hourly wind database has been scanned for individual stations based on their specific identification number and the gust wind data pertaining to every available wind monitoring station have been separated into unique named files for statistical analysis. The histogram of probability density distribution for hourly mean wind speed data is shown. It is clearly understood that the theoretical model has a good agreement with the observed probability density distribution of hourly mean wind speed data. However, it is not at all clear that whether upper tail follows Weibull distribution or not.

For this purpose log (1-F(v)) where F(v) is the cumulative probability, is plotted with respect to hourly mean wind speed (v) in the Figure-3.

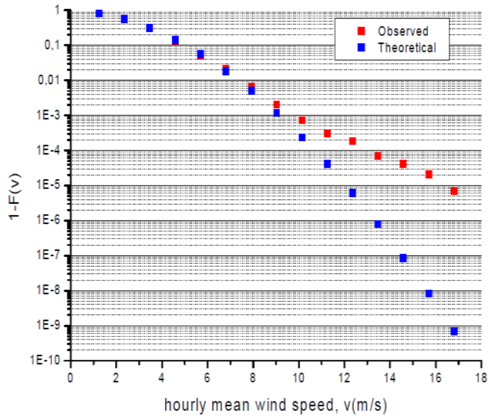

Figure 3: Probability distribution of hourly mean wind speed data for Ahmadabad

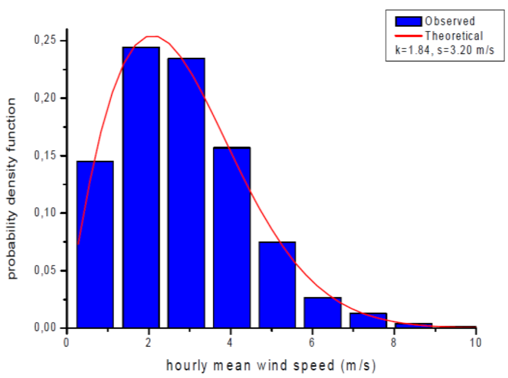

Figure 2: Probability density distribution of hourly mean wind speed data for Ahmadabad

In the figure 3, it is clearly observed that the upper tail is not following Weibull distribution. Now it becomes necessary to find the threshold value beyond which Weibull model is inappropriate. For this purpose with shape and scale parameters (k=1.84 ands=3.20 m/s) of Weibull distribution for wind speed data of Ahmadabad the mean of the distribution ($m_{weibull}$) can be calculated from equation and it has been found as 2.843 m/s whereas the arithmetic mean from the data has been found as 2.865 m/s. The under estimation of Weibull mean ($m_{weibull}$) is due to the fact that the upper tail of the Both actual and theoretical probability distributions are plotted in Gumbel probability paper. In Gumbel probability paper –ln(-ln p) vs. hourly mean wind speed are plotted for both actual and theoretical distributions. The graph is shown below in Fig. 4.

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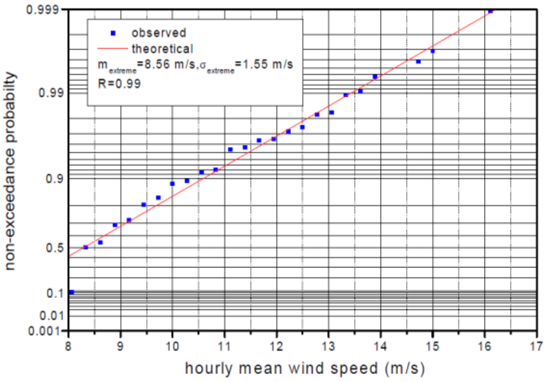

Figure 4: Non-exceedance probability of extreme hourly mean wind speed

In the Figure 4 it is interesting to note that the observed values closely follow the trend of theoretical probability. Since fitting is done only for the upper tail where Weibull model is inappropriate, x axis has been started from 8 m/s. The correlation coefficient (R) is found to be 0.99 which indicates that the linear fitting in the Gumbel probability paper seems to be appropriate.

Based on wind speed map given in IS 875, the basic wind speed for Vadodara region is found to be 50 m/ s; and the coefficients of A and B corresponding to the basic wind speed is 88.8 and 22.8 respectively. Based on GoF test results, Gumbel distribution using MLS is found to be appropriate for estimation of extreme wind speed for different return periods. The study suggested that the Mean+1SE value of 3-sec average extreme wind speed of 57.1 m/ s (205.4 km/ hr) related to 1000-yr return period may be adopted for design purposes in Vadodara region[8] By using the methodology, a computer program was developed and used to estimate the design wind speed for Delhi and Visakhapatnam regions. The study suggested that the Mean+SE values of 3-sec average extreme wind speed of 62.1 m/s (223.5 km/hr) and 77.1 m/s (277.5 km/hr) related to 1000-yr return period may be adopted for design purposes in Delhi and Visakhapatnam regions respectively.

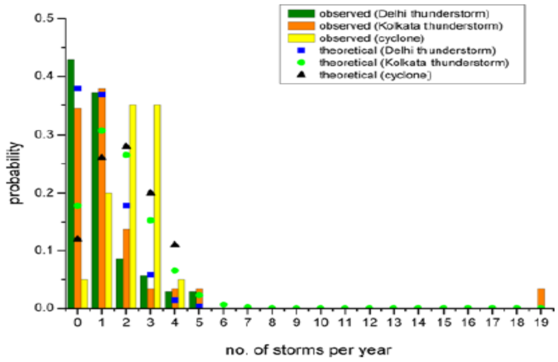

Fig. 5: Probability Density Distribution of Number of Storms per Year

The Weibull distribution [16,19] was the most appropriate distribution for fitting the annual wind speed at the study sites, and the wind energy potential analyses were all based on the Weibull distribution. The cumulative Weibull distribution enables us to estimate the probability of the wind speed within a given interval. For a given wind turbine with a cut-in speed and a cut-out speed v_o, the availability factor, which is the probability of the wind turbine operation, is calculated .according to the AIC criterion, TWD shows the best performance for all considered months and for the whole year.

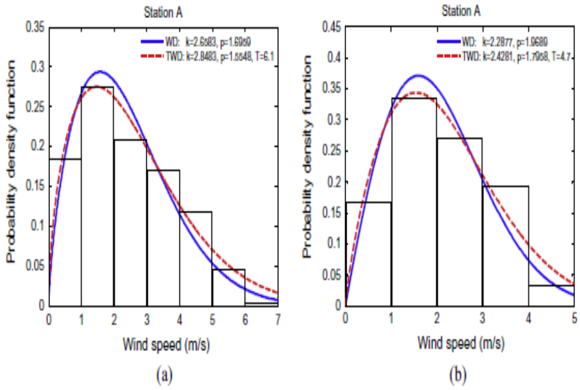

Fig. 6: Histogram and pdf graphs of WD and TWD for monthly wind speed data measured at Station A.

IV. CONCLUSIONS

The mean values and mean square deviations of wind velocities vary with directions and this should be considered in the definition of mean wind velocity. Probability distributions of "occurrence interval" can provide more realistic information on the statistical analysis of extreme wind speeds. In the analysis of extreme events, it is must to choose an appropriate threshold value in each case to ensure sufficient statistical stability. An inappropriate choice of threshold value will lead to a biased estimate. Thunderstorm modeling can be performed for each location, but cyclone modeling must be performed for a completely coastal area. In India, storm separation was not adopted and only type I distribution was used for extreme wind modeling for the design of existing structures. In this study, Weibull model has been found more popular with respect to others & it is able to describe wind climate. However, there is a threshold wind speed till which Weibull model is valid and above that wind speeds can be modeled by extreme value distribution. This threshold can be analytically determined for a particular location. In case of Ahmadabad upper tail of wind speed data beyond this threshold value have been fitted by Gumbel distribution.TWD is used first time to model wind speed data. A Monte Carlo simulation is carried out to find the best estimation method for TWD.

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