RISK ANALYSIS OF CYCLONIC WIND DATA

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Introduction

Cyclonic storms, also known as hurricanes in North America and typhoons in the Pacific, are produced by extreme winds of long duration. Every year they cause irreparable damage to all types of structures resulting in collossal loss of life and property in several parts of the world. An understanding of the hazardous forces on structures exposed to these disastrous cyclones is very essential for safe design and economical construction of structures, particularly, with regard to the high-rise and flexible constructions that are being built now-a-days. Equally important is the problem of safety of low cost houses, low-rise residential and public buildings, which serve to house a large proportion of the population in the cyclone prone rural and semi-urban areas. Eventhough it is uneconomical to design these structures for total safety against cyclonic wind forces, their effect cannot be completely disregarded. The structures in the cyclonic prone zones should be designed so that they cannot be damaged to an irreparable extent. In this context, from the structural design view point, the estimation of magnitudes of extreme winds due to cyclones and the risk of their being exceeded is an essential part of the assessment of wind loads on structures.

Wind Data

The wind data of cyclones which hit the east coast of South India between latitudes 8°N and 20°N during the period 1891 to 1983 were collected from the India Meteorological Department. The histogram of the severe cyclonic wind speeds greater than 62 knots (115 kmph) which are generally known to cause structural damages is shown in Fig.1.

Analytical Models of Cyclonic Winds

Since the data of these severe cyclones covered only a limited number of years, Monte-Carlo simulation technique was used to increase the data base. To propose a probability distribution which fits well with the data under investigation for predicting the cyclonic wind speed at a given risk level, Gumbel, Frechet and log-normal distributions have been separately tested. The parameters of the respective distributions were estimated using the method of moments.

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To verify the fitness of these three probability models determined empirically, their frequency distributions also are plotted in Fig.1. Eventhough the visual comparison of these distributions show that all the three models appear to be plausible probability distributions, Kolmogorov-Smirnov goodness-of-fit test showed that the Gumbel distribution given in Eq.1 is the best fit at 5% significance level.

$$F(x) = e^{-e^{-\alpha(x-u)}}$$

where $\alpha = 0.06 \text{ knots}^{-1}$ and $u = 77.03$ knots (1)

Risk Level

It can be shown that for a structure with a given life period, N, the probability of cyclonic wind speed exceeding the given value x in N successive years is given by : [1]

$$P_N(X > x) = 1 - \left[1 - \frac{1}{\bar{T}(x)}\right]^N \quad \ldots\ldots \quad (2)$$

where $\bar{T}(x)$ is the mean return period of wind speed x and is given by:

$$\bar{T}(x) = \frac{1}{1-F(x)} \quad \ldots\ldots \quad (3)$$

Eliminating $\bar{T}(x)$ and $F(x)$ from Equations 1, 2, and 3, the following relationship between x, N, and $P_N(X > x)$ is obtained:

$$x = 77.03 - \frac{1}{0.06}\left\{\ln\left[-\frac{1}{N}\ln\left(1-P_N(X > x)\right)\right]\right\} \ldots\ldots (4)$$

Eq.(4) for N = 50 years is plotted in Fig.2. The curve in Fig.2 indicates that (i) the risk level $P_N(X > x)$ decreases as the wind speed x increases and (ii) the reduction in the risk level per unit wind speed (i.e.) the slope of the curve, varies from zero at lower values of x to a maximum value and again decreases gradually approaching zero at extreme values of x. Hence, for maximum advantage, the wind speed at which the reduction in the risk level is maximum should be considered, and such an optimum wind speed is arrived at by maximising the reduction in the risk level. Mathematically this may be expressed by the condition:

$$\left[\frac{d}{dx}\left\{\frac{d}{dx}\left(P_N(X > x)\right)\right\}\right] = 0 \quad \ldots\ldots\ldots \quad (5)$$

This condition gives

$$x_{optimum} = u + \frac{1}{\alpha}\ln N \quad \ldots\ldots\ldots \quad (6)$$

where u and α are the same as defined in Eq.1. Substituting Eq.6 into Eq.4, the optimum risk level is given by:

$$P_N(X > x_{optimum}) = 0.63 \quad \ldots\ldots\ldots \quad (7)$$

This is the same as the risk level which is generally recommended for the design of structures against extreme winds in standard codes of practice [2, 3, 4]. For $\overline{T}(x) > 10$ years, the risk level represented by Eq.7, is the same as the probability of experiencing a cyclonic wind whose mean return period is equal to the life-period of the structure. Thus it is seen that while the variation of the risk level with N and $\overline{T}$ (x) given by Eq.2 is highly statistical [5], Eq.7 implies that to strike a balance between safety and economy, the structure may be designed for a wind speed whose mean return period is equal to its life-period and the corresponding wind speed represents the optimum wind speed. For structures of different life-periods, the optimum wind speeds may be obtained using Eq.4.

Conclusions

1. The distribution of wind speeds of severe cyclones which hit the east coast of South India between 8°N and 20°N latitudes may be best represented by Gumbel model with shape and scale parameters equal to 77.06 knots and 0.06 knots^{-1} respectively.
2. The optimum wind speed at which there is a maximum reduction in the risk for unit increase of wind speed, corresponds to a risk level of 0.63. For normal structures of 50 years of life period, the optimum wind speed, for the coast under investigation was found to be 141.1 knots (260.9 kmph).

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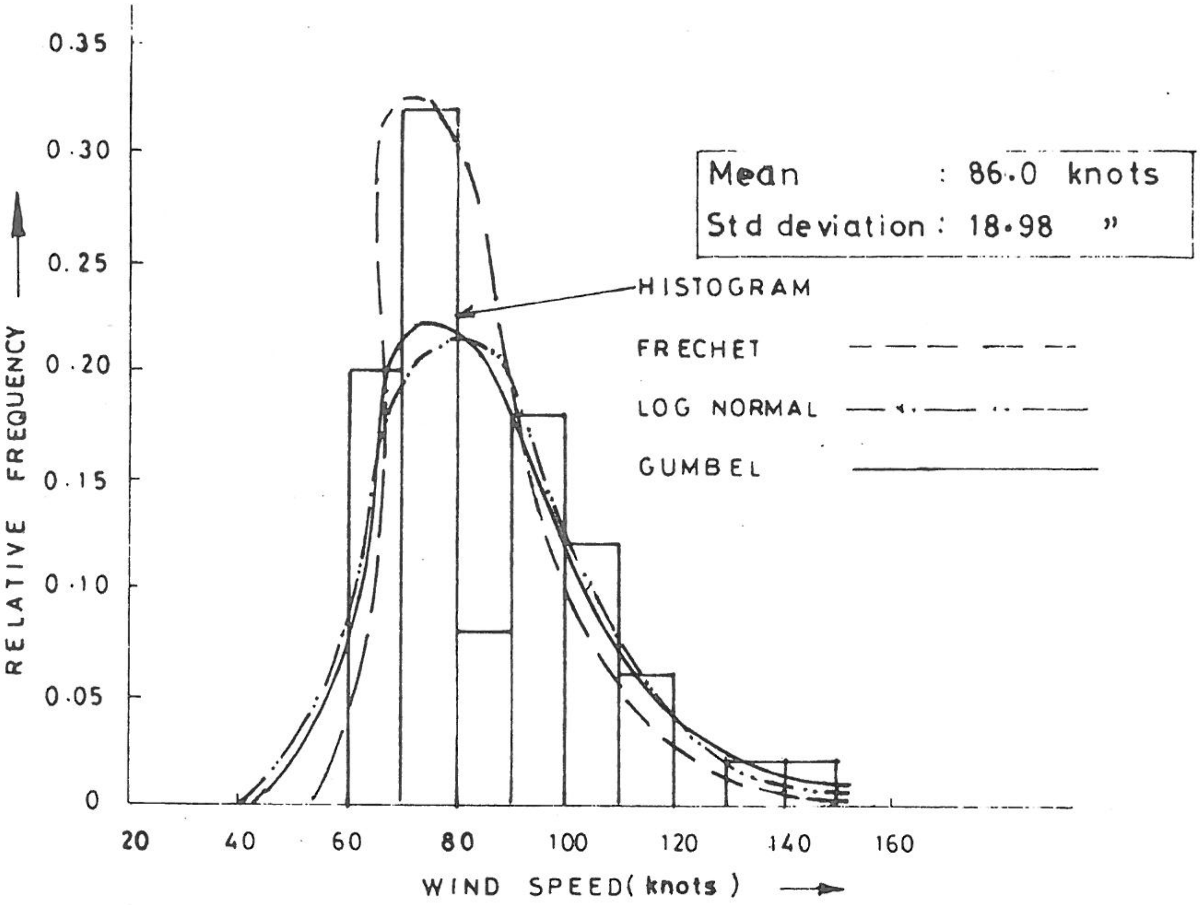

FIG.1 HISTOGRAM OF CYCLONIC WIND DATA WITH FITTED PROBABILITY MODELS

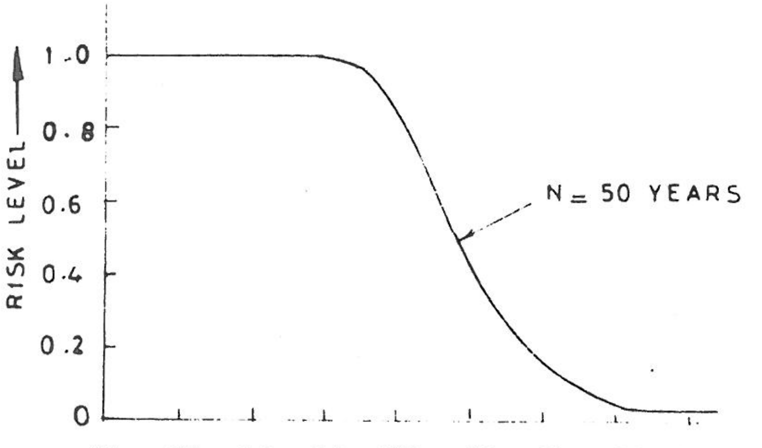

FIG.2. VARIATION OF WIND SPEED WITH RISK LEVEL