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# EXTREME PROBABILITIES OF WIND SPEED IN INDIA —A DESIGN AID FOR STRUCTURES

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## SYNOPSIS

The paper analyses the annual maximum gust speeds recorded so far in the meterological stations in South India and provides extreme probability chart for annual maximum wind speeds. The chart will serve as a good design aid for probabilistic approach.

## WIND STRUCTURE

Wind is induced by large-scale pressure gradients over the earth's surface. The wind pattern can be represented by a mean steady value with a fluctuating part superposed on it, such as 30 minutes mean, hourly mean, daily mean etc. The wind moving freely high above the ground unaffected by the frictional stresses of the ground surface is defined as the graident wind and its velocity, the gradient velocity $V_g$. The minimum height at which this height is attained is termed the gradient height $Z_g$. Within the boundary layer of the ground surface to the gardient height, the mean wind velocity follows a power law of the type:

$$\frac{V_z}{V_g} = \left(\frac{Z}{Z_g}\right)^{\alpha} \qquad \ldots.1$$

where $Z_g$ and $\alpha$ are functions of the ground roughness and the values will vary according to whether the wind is over sea, over open country or over a city with tall structures. $V_z$ is the wind velocity at a height Z. When the wind speed reaches a peak, it is called a gust and at its minimum speed, it is termed a lull.

## WIND INTENSITY

The wind intensity is defined in terms of its speed. The Beaufort scale offers a qualitative scale of wind force varying from 0 for calm to 12 for Hurricane.

## WIND MEASUREMENTS

A network of meteorological stations in India, continuously record the wind speed versus time in graphical form by anemometers installed at a standard height of 10*m* above ground level or the nearest practical height. These records known as anemograms contain the exact pattern of the wind velocities. Cup anemometers and wind anemometers indicate the velocity and these have to be read at any instant and noted down. They are generally connected to continuously totalling units by reading which the hourly, daily and monthly mean wind speed can be obtained. The mean values and the extreme values provide data for statistical analysis of the wind speeds. When wind speed patterns in fractions of seconds is required to be recorded graphically or otherwise, the ERA gust anemometer is used.

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## WIND PATTERN AND VELOCITY

Typical patterns of wind velocity and pressure with reference to time scale as recorded by anemograms of the Indian Meteorological Department for different stations in South India is indicated in Fig. 1. A pictorial representation of wind velocity profiles vide eqn. 1 is given in Fig. 2 (Davenport).

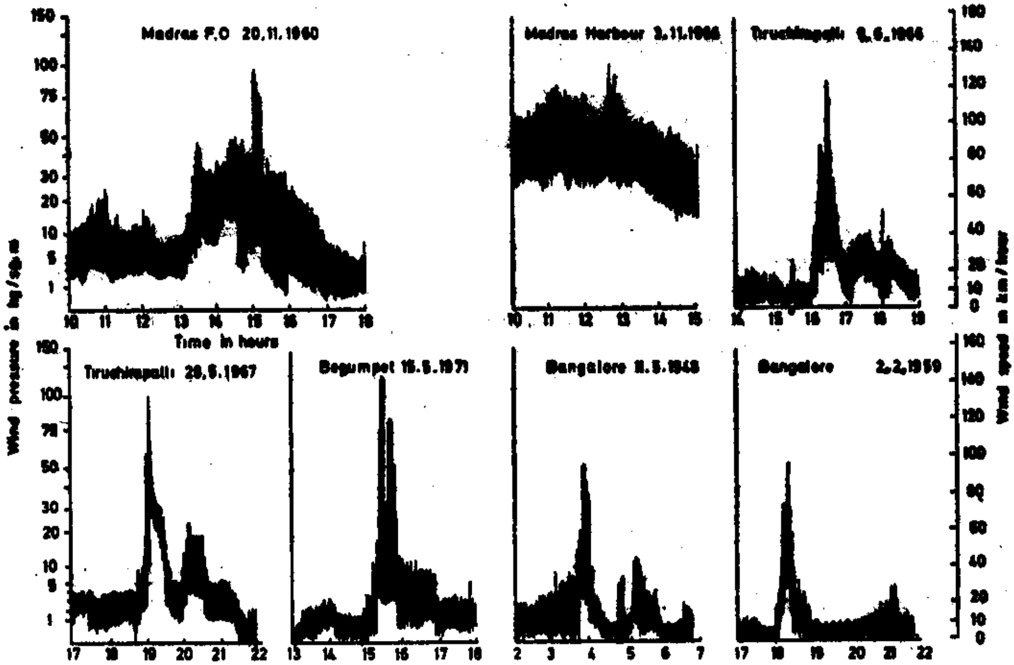


Fig. 1. Anemographic records of maximum wind speed of South Indian stations

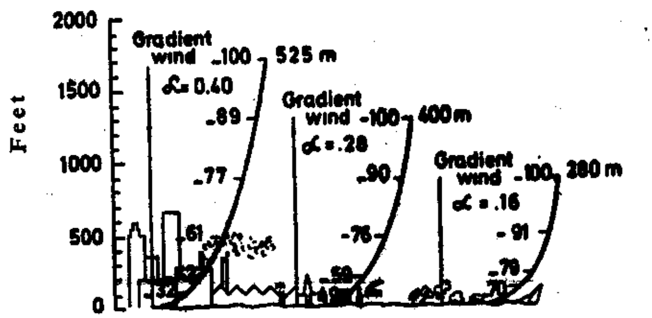


Fig. 2. Variation of mean velocity profile with surface roughness

## APPLICATION OF STATISTICAL THEORY OF EXTREMES.

The wind speed likely to be exceeded only once in any given number of years can be obtained by the application of statistical theory of extreme values to a series of annual extreme wind speeds. This is a more satisfactory basis for estimating design wind speeds because the procedure permits the anticipated lifetime of the structure to be taken into account. In calculating the maximum velocity for the design period, the maximum velocity is an average over several time periods T. Statistically, there exists for such a distribution a calculated risk of 63% that this design velocity may be exceeded. The calculated value of $V_{max}$ is obtained from the relation:

$$V_{max}=ay+b,\ y=-\log(\log p) \qquad \ldots\ 2$$

where $a$, $b$ are constants unique to every site

$y$ an intermediate variable and

$p$ the probability that the maximum wind velocity will not exceed the extreme value $V_{max}$.

This relation is plotted for $V_{max}$ and $y$, which is termed the reduced variate; $y$ is related to $p$ and therefore to the time period T, which is called the return period. The oft quoted example illustrating the procedure is the UK record at Cardington. The annual maximum gust speeds are listed and arranged in ascending order and they are assigned ranks starting from 1 for the lowest speed and $N$ for the highest speed where $N$ is the number of years of record. The probability (termed as "plotting position") $P$ is calculated for every year as: rank $(N+1)$. $y$ is calculated from eqn. 2. While for U. K. and U. S. A., such statistical charts analysed from meteorological wind data are available, for India no such analysis of meteorological data has been done so far. In the present work maximum wind speeds were analysed as above from the meteorological data of South Indian stations.

There is a percentage risk in selecting any design wind speed, but this decreases with increasing return period $T$.

**TABLE I**

Return Period (Years) Required for Various Design Lifetimes at Certain Risks.

| Desired life (years) | Calculated Risk | | | | |
|---|---|---|---|---|---|
| | 0.632 | 0.500 | 0·400 | 0.333 | 0.300 |
| 2 | 3 | 3 | 4 | 5 | 6 |
| 10 | 11 | 15 | 20 | 25 | 29 |
| 20 | 20 | 29 | 39 | 49 | 56 |
| 50 | 50 | 72 | 98 | 124 | 140 |
| 100 | 100 | 144 | 196 | 247 | 280 |
| | 0.250 | 0.200 | 0.100 | 0.050 | |
| 2 | 7 | 9 | 20 | 40 | |
| 10 | 25 | 45 | 95 | 196 | |
| 20 | 69 | 90 | 190 | 390 | |
| 50 | 173 | 224 | 475 | 975 | |
| 100 | 345 | 448 | 949 | 1950 | |

Table I gives design return periods for calculated risks for various structural lifetimes. Taking the example of a twenty year structural life, a 10% chance of destruction requires a design to a 190-year return period. For wind at Madras Harbour

T=20 years, $V_{max}$=156 kmph

T=190 years, $V_{max}$=210 kmph

The increase in design wind speed from 156 to 210 kmph is within the usual factor of safety. As an alternative, the designer may construct his structure for a particular wind speed and quote the calculated risks for a particular structural life time. In the absence of extreme probability chart of annual maximum wind speeds in India, the structural engineer has the limitation that he cannot assess the calculated risks inherent in his design for particular lifetimes. In other words, he can not estimate the dynamic wind loads, taking into account the return period of wind.

## RETURN PERIOD ANALYSIS

The annual extreme values of gust speeds at a network of meteorological stations in South India, viz. Madras Harbour, Madras Forecasting Office (Airport), Bangalore, Tiruchirapalli, Begumpet, Mangalore and Vizagapatanam were analysed by applying the statistical theory of extreme values. Typical results are given in Table 2 and Figs. 3. As

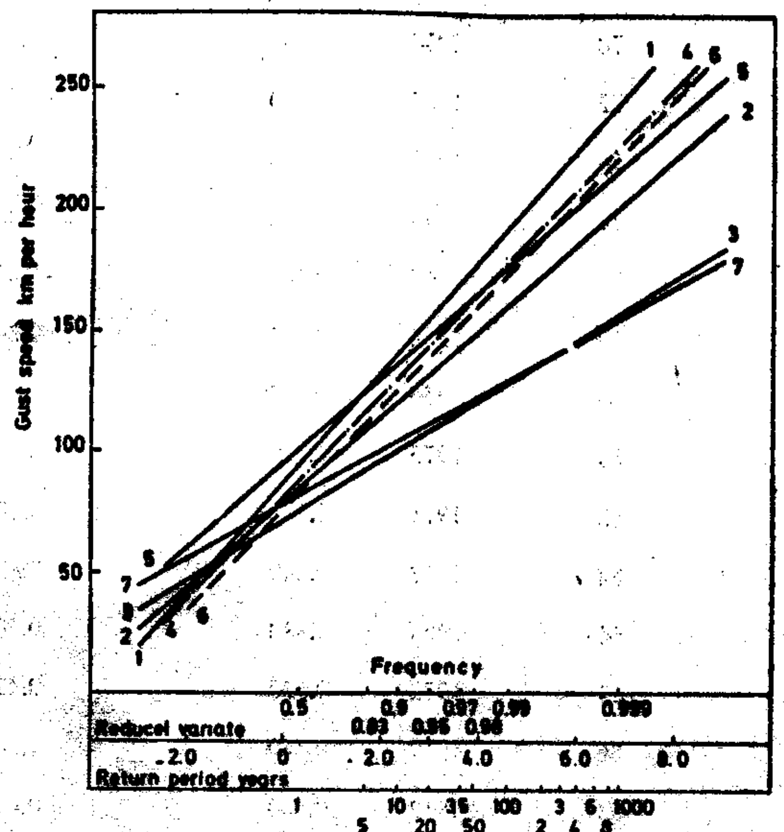


Fig. 3. Extreme probability chart of annual maximum wind speeds at South Indian stations 1946–75

an illustration, for a return period of 50 years the maximum gust speed in Madras F. O. is 148 km/Hr from Fig. 3, while according to the data for 24 years, the highest on record is 136 kmph.

**TABLE 2**

Annual Maximum Gust Speeds Analysed from Extreme Values

| Rank $m$ | Highest gust $x$ kmph. | Year | Probability or plotting position. $P=\frac{m}{N+1}$ | Reduced variate $y=-\log_e(\log_e P)$ |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| MADRAS AIRPORT | | | $N=24$ | |
| 1 | 51 | 1956 | 0.040 | –1.16 |
| 2 | 70 | 1974 | 0.080 | –0.92 |
| 3 | 72 | 1957 | 0.120 | –0.75 |
| 4 | 74 | 1962 | 0.160 | –0.60 |
| 5 | 76 | 1973 | 0.200 | –0.47 |
| 6 | 79 | 1965 | 0.240 | –0.35 |
| 7 | 80 | 1954 | 0.280 | –0.24 |
| 8 | 80 | 1955 | 0.320 | –0.13 |
| 9 | 80 | 1975 | 0.360 | –0.02 |
| 10 | 82 | 1971 | 0.400 | 0.08 |
| 11 | 84 | 1967 | 0.440 | 0.19 |
| 12 | 84 | 1968 | 0.480 | 0.30 |
| 13 | 84 | 1972 | 0.520 | 0.42 |
| 14 | 86 | 1959 | 0.560 | 0.54 |
| 15 | 88 | 1953 | 0.600 | 0.67 |
| 16 | 88 | 1958 | 0.640 | 0.80 |

TABLE 2 (Cont.)

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| 17 | [illegible] | 1964 | 0.680 | 0.96 |
| 18 | 89 | 1970 | 0,720 | 1,11 |
| 19 | 94 | 1969 | 0,760 | 1.29 |
| 20 | 104 | 1961 | 0.800 | 1,49 |
| 21 | 104 | 1963 | 0,840 | 1,74 |
| 22 | 117 | 1952 | 0.880 | 2.05 |
| 23 | 120 | 1966 | 0.920 | 2,48 |
| 24 | 136 | 1960 | 0.960 | 3.19 |

## RESULTS AND RECOMMENDATIONS

The consolidated results are presented in figure 9 as an extreme probability chart of annual maximum wind speeds (1946-1975), which chart provides the Vmax values for structural designs against any desired return periods. The authors recommend that the I. S. Code for wind loads should include extreme probability charts, calculated risks and return periods. The authors also recommend further research work on the meteorological data and that similar statistical analysis be done and extreme probability charts prepared for other regions in India.

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