GUIDE NO. AERB/NF/SG/S-3

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GOVERNMENT OF INDIA

AERB SAFETY GUIDE

EXTREME VALUES OF METEOROLOGICAL PARAMETERS

ATOMIC ENERGY REGULATORY BOARD

AERB SAFETY GUIDE NO. AERB/NF/SG/S-3

EXTREME VALUES OF METEOROLOGICAL PARAMETERS

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Mumbai-400 094
India

May 2008

Price

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FOREWORD

Activities concerning establishment and utilisation of nuclear facilities and use of radioactive sources are to be carried out in India in accordance with the provisions of the Atomic Energy Act 1962. In pursuance of the objective of ensuring safety of members of the public and occupational workers, as well as protection of the environment, the Atomic Energy Regulatory Board (AERB) has been entrusted with the responsibility of laying down safety standards and enforcing rules and regulations for such activities. The Board has, therefore, undertaken a programme of developing safety standards, safety codes and related guides and manuals for the purpose. While some of these documents cover aspects such as siting, design, construction, operation, quality assurance and decommissioning of nuclear and radiation facilities, other documents cover regulatory aspects of these facilities.

Safety codes and safety standards are formulated on the basis of nationally and internationally accepted safety criteria for design, construction and operation of specific equipment, structures, systems and components of nuclear and radiation facilities. Safety codes establish the safety objectives and set requirements that shall be fulfilled to provide adequate assurance for safety. Safety guides elaborate various requirements and furnish approaches for their implementation. Safety manuals deal with specific topics and contain detailed scientific and technical information on the subject. These documents are prepared by experts in the relevant fields and are extensively reviewed by advisory committees of the Board before they are published. The documents are revised when necessary, in the light of experience and feedback from users as well as new developments in the field.

The code of practice on Safety in Nuclear Power Plant Siting (AERB/SC/S) states the requirements to be met during siting of Nuclear Power Plants in India. This safety guide provides guidance for finding extreme values of meteorological parameters and outlines the methodology and procedures for carrying out analysis as applicable for implementing the relevant parts of the code. In drafting this guide the relevant documents developed by the International Atomic Energy Agency (IAEA) under the Nuclear Safety Standards (NUSS) programme, especially the Safety Guide on Extreme Meteorological Events in Nuclear Power Plant Siting, (50-SG-S11A, 1981) have been referred for implementing relevant sections.

Consistent with the accepted practice, ‘shall’ and ‘should’ are used in the guide to distinguish between a firm requirement, and a desirable option respectively. Appendix is an integral part of the document, whereas annexure and references are included to provide information that might be helpful to the user. Approaches for implementation different to those set out in the guide may be acceptable, if they provide comparable assurance against undue risk to the health and safety of the occupational workers and the general public, and protection of the environment.

This guide applies only for facilities built after the issue of the document. However during periodic safety review a review for applicability of current standards for existing facilities would be performed.

For aspects not covered in this safety guide applicable national and international standards, codes and guides, acceptable to AERB should be followed. Non-radiological aspects such as environmental protection and industrial safety are not explicitly considered in this guide. Industrial safety is to be ensured through compliance with the applicable provisions of the Factories Act, 1948 and the Atomic Energy (Factories) Rules, 1996.

This guide has been prepared by specialists in the field drawn from the Atomic Energy Regulatory Board, Bhabha Atomic Research Centre, Nuclear Power Corporation of India and other consultants. It has been reviewed by the relevant AERB Advisory Committee on Codes and Guides and the Advisory Committee on Nuclear Safety.

AERB wishes to thank all individuals and organisations who have prepared and reviewed the draft and helped in its finalisation. The list of persons, who have participated in this task, along with their affiliations, is included for information.

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Chairman, AERB

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1. DESIGN BASIS METEOROLOGICAL PARAMETERS

1.1 Introduction

Meteorological parameters like wind speed, rainfall intensity as well as total rainfall, storms, cyclones, maximum and minimum temperature play a major role in the design of the nuclear facilities (NFs) from the safety view point [1,2,3,4]. This guide aims to establish a methodology for derivation of extreme values of meteorological parameters (viz. wind speed, rainfall, temperature etc.). Rainfall forms an important input to other processes like estimation of maximum water level at the proposed site whereas wind speed is necessary to study structural safety particularly of tall structures like cooling towers, stacks, transmission line towers etc. These meteorological parameters are beyond human control. Structural safety requires that structures important to safety shall be designed to withstand the extreme values of these parameters likely to occur during the lifetime of the facility [1]. Parameters to be used as design basis should have a very low exceedance probability of occurring during the lifetime of the facility. This is achieved by using the extreme value analysis technique [5, 6, 7, 8]. NF design requires generation of such design basis values of the above parameters.

Lifetime of the NFs is normally about several tens of years. The NFs are to be designed in such a way that they can withstand the occurrence of extreme values of the above parameters during their life time. Due to the statistical nature of the variability of the parameters, the design value of a parameter considered in design should have a mean recurrence interval[1] (MRI) much larger than the life time of the facility. These design basis values of the environmental parameters mentioned above are often evaluated using the extreme value analysis which helps us to estimate a value of the parameter which has a very low probability of exceedance during the lifetime of the plant. This method helps to generate a value of meteorological parameter corresponding to a given MRI, based on the historical data available for these parameters. The probability that the value with the predicted MRI, say 'T' years, will exceed at least once in T years is around 63% for large values of MRI. The mean recurrence interval of the design basis value of any parameter is governed by the importance of that parameter to the safety of the plant. Atomic Energy Regulatory Board (AERB) has recommended in its siting code [1] for nuclear power plants, minimum values of MRI for various parameters and the same are given in Table 1.1

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1 The mean recurrence interval (MRI) is defined as the mean time between the occurrences of two events that are equal to or greater than a given magnitude.

1.2 Objective

The estimation of extreme values of meteorological parameters is an important aspect of the siting and design of a nuclear facility. The aim of this guide is to give various methodologies which can be used to carry out such estimations.

1.3 Scope

Projection of extreme values of environmental parameters likely to be encountered in the future using historically observed data is normally handled by different extreme value statistical methods. The methodology of estimating extreme values along with different approaches utilised in extreme value statistics are described in section 2 along with different extreme value distributions. This section also includes data requirements for the extreme value distributions. In case of nonavailability of site data, alternative choices for the data base are also discussed in this section. The application of these methods to different meteorological parameters of interest is discussed in section 3 giving emphasis to the type of data base for the specific parameters. Methodologies for generating extreme value parameters are given in Appendix I. Worked out examples for data sets using both numerical as well as graphical techniques are given in Annexure-A.

TABLE 1.1 : DESIGN BASIS PARAMETERS AND MEAN RECURRENCE INTERVALS[1]

Parameter	Data	Mean Recurrence Interval	Reference
Wind speed	(a) Extreme wind* (b) Severe wind	10000 Years 1000 Years	AERB/SC/S AERB/SC/S
Rainfall	Maximum daily rainfall	1000 Years**	AERB/SC/S
Cyclone pressure	Pressure drop	1000 Years	AERB/SC/S

* Wind induced missile effect to be considered

** For design basis flood

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1 For required size of database, see subsection 2.4.4

2. EXTREME VALUE METHODOLOGY

2.1 Introduction

Meteorological parameters follow a seasonal cycle and the continuous survey of any meteorological parameter reveals annual extreme values. It is also observed that this extreme value varies randomly from year to year. Purpose of the analysis is to predict a value of the parameter which is not likely to be exceeded during the lifetime of the plant such that the plant can be designed with regard to these parameters to function safely during its lifetime. On account of the randomness of parametric values, it is adequate to predict a value which will have a mean recurrence interval (MRI) of, say, N years. This does not mean that a higher value than this will not occur during any N year period. Confidence levels of the statistically derived value depend on the size of the data as well as the data scatter with respect to fitted probability distribution function. Statistically, one can also find out the probability of non-exceedance of the value in terms of a MRI, which is much higher than the lifetime of the plant. One can prescribe the MRI, which should be used for generating the design basis value of the parameter for a specified degree of risk.

2.2 Estimation of Extreme Value

The general procedure for estimation of extreme value for meteorological parameters comprises of the following steps:

(a) Study the representative data set for determination of extreme values and assessment of its quality from the reliability and completeness point of view.

(b) Selection of the most appropriate statistical distribution for the data set of extreme values.

(c) Processing of the data set to evaluate expected value, standard deviation and other probability distribution parameters for the purpose of derivation of extreme value of meteorological parameter.

2.3 Mean Recurrence Interval

Extreme value analysis is used for estimating value of the parameter having an MRI of N years. Probability that the event having N years MRI will occur in V years is given by the relation [5,14,15,16]

$$P(X_{N,V}) = 1 - [(1 - 1/N)^{V}] \quad (2.11)$$

where $P(X_{N,V})$ is the probability that a 'N' year MRI event 'X_N' or more will occur during 'V' years. Probability that a 'N' year event will occur in N years is thus 63.2% for large values of N. Table 2.1 gives the fractional probability of

N year event occurring in V years for various values of N and V. Probability that N year event will occur in a year is

$$P(X_N, 1) = 1/N \quad (2.12)$$

Probability that a N year event will not occur in one year is

$$\bar{P}(X_N) = 1 - (1/N) \quad (2.13)$$

This is the relation of non-exceedance probability and MRI.

2.4 Data Needs

The extreme value methodology has a specific requirement of the data. As the requirement of the extreme value parameters is at the planning stage, choice of observation station is also important. Data requirement is discussed in the following paragraphs:

2.4.1 Type of Data

Since the MRI is given in terms of years, the data used for the extreme value treatment is the annual data. The measurements of the meteorological parameters should be carried out round the clock. This database for a year should be analysed for generating a maximum or minimum value depending on whether extreme maximum or extreme minimum value is needed. For this purpose the referred year need not be calendar year. The beginning date for the yearly time interval for data analysis should be chosen such that the meteorological parameter of interest is not at the peak or valley of the annual cycle. Series of these extreme annual values over a continuous period of number of years makes the data set for the extreme value analysis. This presumes that necessary care is taken in selecting the site of the meteorological data station.

2.4.2 Representative

It is always preferable to have site data. Usually sufficient site data are not available, and consequently recourse is taken to data from nearby meteorological stations. The observation station selected has to represent the site. Though this can be done by comparing the topography, nearness to sea or large water bodies and such other parameters, it is always advisable to collect one year data at the site and compare this data with concurrent data collected at other nearby stations. The station which has a better matching will be the representative station and the data from this station can give more reliable estimates of parameters at the actual site. It may sometimes be seen that the trends of the data collected at site will match with a nearby station. Sometimes there may not be good matching, because of local variation of topography and other features though the trend is matching. In such cases, the representative site data, if corrected by a factor, will give a better matching. In such cases the representative site data should be appropriately modified using this correction factor before use.

2.4.3 Site Data

The collection of site data should continue during the lifetime of the plant including during decommissioning and safe storage, so as to permit possible reassessment of hazards during periodic safety review.

2.4.4 Size of Database

For a better reliability of estimates the amount of data needed should be commensurate with the need of MRI for which the estimates are needed. Normally for a few hundreds of years MRI, a minimum of 30 year data should be used. For higher MRIs, database of around 100 years is ideal. However, as such extensive database is normally not available, even 50 year database, if available, can be used for 1000 year MRI [1].

2.4.5 Missing Data

In an extensive database, some data for interim periods in the overall time span may not be available. For conservatism, it may be assumed that the missing values of the parameter were the highest observed during the entire period of data set in case of maximum extreme and lowest for minimum of the extreme. The ranking of the data should be done treating this period of observation as a part of the data set. The values corresponding to these observations are not to be plotted. The values of the extreme so derived will give a conservative estimate of the parameter for the required design basis MRI.

2.4.6 Quality Assurance Programme

A quality assurance programme should be established and implemented to cover those items, services and processes affecting safety. The quality assurance programme should be implemented so as to ensure that data collection, data processing, field and laboratory work, studies, evaluations and analyses, and all other activities necessary to achieve the objectives of this safety guide are correctly performed.

2.5 Selection of Appropriate Probability Distribution

2.5.1 Probability Distributions

The observed values of a parameter may follow any of the statistical distributions. However, the extreme value will normally be falling at the tail part of the particular distribution which the parameter will be following. In most of the statistical distributions individually followed by the meteorological parameters of interest, the extreme values of the parameters generally follow one of the following types of distributions

(i) Fisher-Tippett Type I which is also known as Gumbel distribution [9,10,11]

(ii) Fisher-Tippett Type II distribution (modification of this is known as Frechet distribution)[12]

Gumbel distribution or Frechet distribution is applicable for parameters having no upper bound value. Frechet distribution can be transformed to Gumbel distribution through logarithmic transformation of variable viz. using the natural logarithm of the actual variable as variable for Frechet distribution. Detailed equations are provided in Appendix-I of the guide.

2.5.2 Method of Selection

For selection of the appropriate distribution, the values of the variable (i.e., extreme values of meteorological parameter) are plotted on a special plotting paper. A Fisher-Tippet distribution results in a straight line when plotted on this paper. The transformed variable as described in earlier paragraph should also be plotted to check for Fisher-Tippet type II fit. The selection of distribution should be made after comparison of the extent of fit of the data set.

2.6 Generation of Distribution Parameters

Evaluation of the moments of the selection distribution can be carried out using the database of annual extreme meteorological parameter. Graphical method using least square fit as well as numerical method using order statistics approach may be used to evaluate the parameters of distribution. Numerical technique provides better accuracy. From distribution parameters, MRI for a particular extreme value of a meteorological parameter and associated confidence limit may be derived.

Details of both graphical approach and numerical technique are provided in Annexure-A.

TABLE 2.1 : PROBABILITY THAT AN EVENT EQUAL TO OR MORE SEVERE IN MAGNITUDE THAN THE N-YEAR EVENT WILL OCCUR IN V YEARS [2]

Number of Years	Mean Recurrence Interval N											
V	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1000**	**2000**	**5000**	**10000**
2	0.750	0.360	0.190	0.097	0.040	0.020	0.010	0.004	0.002	0.001	0.000	0.000
5	0.969	0.672	0.409	0.226	0.096	0.049	0.025	0.010	0.005	0.002	0.001	0.000
10	0.999	0.893	0.651	0.401	0.183	0.096	0.049	0.020	0.010	0.005	0.002	0.001
20	-	0.988	0.878	0.641	0.332	0.182	0.095	0.039	0.020	0.010	0.004	0.002
50	-	-	0.995	0.923	0.636	0.395	0.222	0.095	0.049	0.025	0.010	0.005
100	-	-	0.999	0.994	0.867	0.634	0.394	0.181	0.095	0.049	0.020	0.010
200	-	-	-	0.999	0.982	0.866	0.633	0.330	0.181	0.095	0.039	0.020
500	-	-	-	-	0.999	0.993	0.918	0.632	0.394	0.221	0.095	0.049
1000	-	-	-	-	-	0.999	0.993	0.865	0.632	0.394	0.181	0.095
2000	-	-	-	-	-	-	0.999	0.982	0.865	0.632	0.330	0.181
5000	-	-	-	-	-	-	-	0.999	0.993	0.918	0.632	0.393
10000		-	-	-	-	-	-	-	0.999	0.993	0.865	0.632

Note: An N-year event is an event which has a mean recurrence interval (MRI) of N years.

3. DATABASE

3.1 General

Extreme value methodology and data needed for extreme value analysis have been discussed in Section 2 together with the requirement of the quality and quantity of data. The details of the database corresponding to each parameter of interest will be discussed in the following sections.

3.2 Wind Speed

Wind data are required during the design stage for assessing the stability of the structures. Wind loading is of two types: Static loading and Dynamic loading. Static loading implies a wind pressure due to steady wind speed. Dynamic loading is especially needed in design of tall structures like cooling towers, transmission towers, communication towers, stack etc., where the height of the structure is more than five times the smallest dimension of the structure or buildings and closed structures whose natural frequency in the first mode is less than 1 Hz. They require investigation of dynamic effects of wind like wind induced oscillations including gust. A majority of structures in practice do not suffer wind induced oscillations and do not require to be examined for the dynamic effects of wind.

Requirement of the averaging period of the wind data for both these aspects is different as per IS:875 [4]. For dynamic loading calculations by Gust Effectiveness Factor method, hourly wind speed is required while for static loading where wind pressure calculations are used, three seconds averaging period wind data is essential.

3.2.1 Normalisation of Wind Data

3.2.1.1 Averaging Time

Wind data normally collected at existing meteorological stations of India Meteorological Department (IMD), which may be the main source of past data for a virgin site is of one hour average for continuous monitoring stations. If one has one hour average data then this data can be converted to shorter averaging time data using the modification factor which has been arrived at from statistical studies of the observed data. A graph giving the ratio of the short averaging period data to one hour average data against the averaging period is given in figure 3.1 [17]. Using this graph one can generate the data corresponding to required averaging period.

3.2.1.2 Standard Height

Data are some times available from different measurement heights. These data have to be converted to data observed at a standard reference height. This is normally taken as 10 m. However in case of tall structure the data are required sometimes at higher heights. Vertical profile of wind speed is dependent on the weather category. However, for higher wind speeds i.e. wind speeds more than 6 m/s the weather category is neutral. The profile formulation for neutral weather category can be used. This is given by

$$U(z_1)/U(z_2) = (z_1/z_2)^{0.14} \qquad (3.1)$$

Where, $U(z_i)$ - Wind speed at height z_i

Data will be available from nearby meteorological stations of India Meteorological Department (IMD). Some meteorological stations collect wind data twice a day at fixed time. This data is not useful as this may not necessarily record highest wind speed occurring in a day. Only those stations where round the clock data is collected should be chosen for the analysis.

3.2.2 Default Data

In the situation where a proper representative station is not available, recourse is to be taken to the methodology suggested in IS:875 [4]. This gives a map of India showing areas of different wind speeds for a 50 year MRI. The wind speed corresponding to the zone where the site is falling should be taken and should be corrected for the topography, MRI, terrain category, height, structure size using factors k_1,k_2,k_3 given in the code.

3.3 Rainfall

Rainfall data needed for design basis is either rainfall intensity i.e. hourly rainfall or daily rainfall. The first type of data are needed for designing the storm water drainage around the site while the other data in more detail are needed for generating design basis flood water level at inland sites which are often situated near a river course or dam [18]. Rainfall data of both the types will be available from IMD stations situated all over India. Hourly rainfall data can be used to generate a 24 hour running average data for the storm.

Although continuous recording raingauge is preferred, in cases where the continuous measurement of rainfall data is not available, measurements carried out over discrete time intervals (i.e. 1 hour etc.) may be made use of to arrive at running average data for any desired duration (e.g. 24 hours, if the point of interest is daily rainfall) [2]. An adjustment factor, which depends on the interval between successive measurements, will have to be applied to the observed sequential data set to arrive at the 24 hour running average rainfall data. These factors could be generated from the site data or in absence of site data, figure 3.2 may be used [26]. When the results of extreme value analyses are reported, a description of the meteorological stations and the geological setting should be included in the report. Any adjustment of data should be presented in conjunction with the results of the analyses.

For analysis of flood water levels during storm conditions, data from one station is not sufficient. It requires the data of isohytal profile of rainfall during the storm over a vast area. This goes to define a storm and this is to be used for generating the design flood water levels by using appropriate methodologies described in AERB siting guide 'Design Basis Flood for Nuclear Power Plants on Inland Sites' [18].

3.4 Air Temperature

Data normally needed for the temperature are maximum and minimum temperatures. Daily maximum and minimum temperature data are also available from IMD stations spread all over India. Annual maximum and minimum values of the temperature from the daily maximum and minimum data may be used for analysis.

3.5 Atmospheric Pressure

This data is specifically needed for generating the design basis flood level during the cyclone at coastal sites. Data regarding historical cyclones can be had from IMD. The parameter of interest is not the absolute pressure but the pressure drop at the centre of the cyclone which landfalls at the coastal region. After arriving at the design basis cyclonic depression, one can use it to generate the coastal flood water level using the methodologies described in AERB siting guide 'Design Basis Flood for Nuclear Power Plants at Coastal Sites' [19].

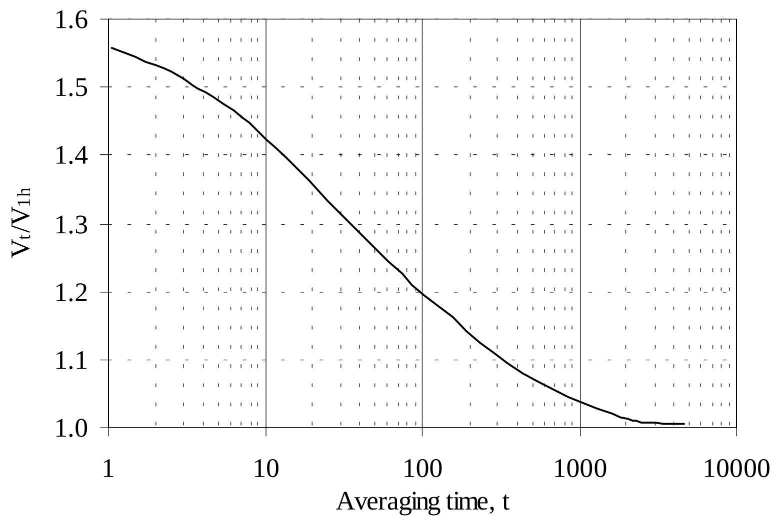

FIGURE 3.1 : CONVERSION OF WIND SPEEDS AVERAGED OVER DIFFERENT TIME INTERVALS INTO SPEEED AVERAGED OVER ONE HOUR

V_t: Velocity for averaging time, t sec.

V_{1h}: Velocity with averaging time one hour

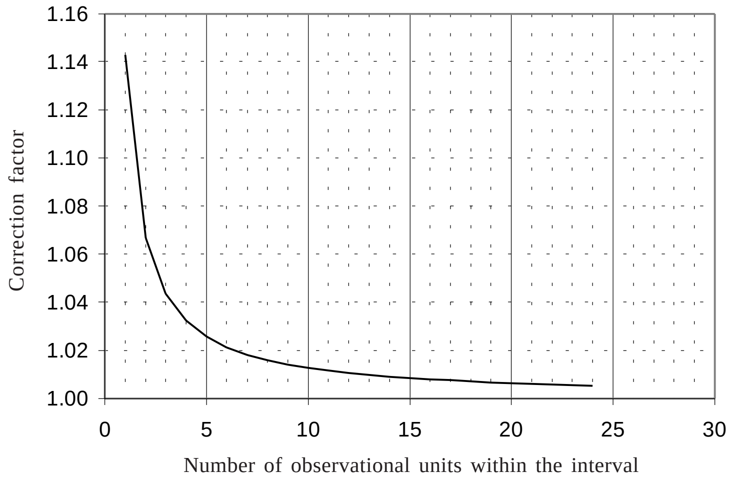

FIGURE 3.2 : ADJUSTMENT OF FIXED INTERVAL PRECIPITATION AMOUNTS FOR NUMBER OF OBSERVATIONAL UNITS WITHIN THE INTERVAL [26]

APPENDIX-I

METHODOLOGY FOR CALCULATION OF EXTREME VALUE PARAMETERS

I.1 Probability Distributions

I.1.1 Gumbel Distribution

Fisher-Tippet Type I distribution is generally known as Gumbel distribution. The data set which is used for this distribution is of the extreme or the highest value observed during a year. If x is the parameter value from such a set, probability P(x) that the value x will not be exceeded is given by

$$P(x) = \exp[-\exp\{-(x-a)/b\}] \qquad I(1)$$

Where a and b are the location and scale parameters respectively.

Replacing

$$Y = (x-a)/b \qquad I(2)$$

Where Y is the reduced variate in non-dimensional form

$$Y = (x-a)/b = -\ln[-\ln P(x)] \qquad I(3)$$

I.1.2 Fisher-Tippett Type II Distribution

Fisher-Tippett distribution also requires a data set similar to one for Gumbel Distribution. Probability that the value x will not be exceeded is given by

$$P(x) = \exp[-\{(x-a)/b\}^{(-g)}] \qquad I(4)$$

Where a and b are location and scale parameters respectively and g is the shape parameter.

I.1.3 Frechet Distribution

For a special case where value of location parameter a is zero the above distribution reduces to

$$P(x) = \exp[-(x/b)^{(-g)}] \qquad I(5)$$

Where b and g are scale and shape parameters respectively.

Replacing

$$Y = [g] \ln(x/b) \qquad I(6)$$

Where Y is the reduced variate

$Y = [\gamma] \ln (x/\beta) = - \ln [- \ln P(x)]$ I (7)

Frechet distribution can be transformed to Gumbel distribution through logarithmic transformation viz. using the natural logarithm of the actual variable as the variable for the transformed Gumbel distribution. Under this transformation

$X_G = \ln X_F$ I (8)

$\alpha_G = \ln \beta_F$ I (9)

$\beta_G = 1/\gamma_F$ I (10)

Where X_G, α_G, β_G are the variable and parameters of the transformed Gumbel distribution and X_F, β_F and γ_F are the variable and parameters of the original Frechet distribution.

The methodology for calculation of extreme value parameters using these probability distributions can be broadly classified in to two namely i) graphical method and ii) numerical method. The details of these methodologies are covered in subsequent sections.

I.2 Graphical Method

I.2.1 The data of annual extremes of a parameter are arranged in an increasing order of magnitude and ranking is given as 1,2,3...N to individual values for available N year data set. The non-exceedance probability for each data x_i of rank 'i' is then assigned using the relation

$P(x_i) = i/(N+1)$ I (11)

Value of reduced variate, Y_i, corresponding to assigned non-exceedance probability value for each reading, x_i, should be generated using the relationship for Gumbel distribution

$Y_i = - \ln [-\ln P (x_i)] = (x - \alpha)/\beta$ I (12)

Values of the variable x_i are plotted on 'Y' axis against the corresponding generated value of reduced variate on x-axis.

A linear regression using least square method should be done to generate slope and using this graph, values of distribution parameters can be generated from the relation

$$Y = \frac{1}{\beta}(x - \alpha)$$ I (13)

for $Y = 0$, $x = \alpha$ I (14)

Knowing this, one can find the value of distribution parameter α and β.

I.2.2 For finding out the value of the parameter for a desired MRI of N_R years, the following procedure should be followed.

(i) Find out the value of the non-exceedance probability i.e the probability that an N_R year MRI event will not occur in one year corresponding to a given MRI using the equation I(15)

(ii) Calculate the corresponding reduced variate value using the equation I(12).

(iii) Find out the value of the parameter corresponding to this reduced variate either from the equation I(13) or from the graph.

$$P = 1\text{-}1/N_R \qquad \text{I(15)}$$

The reduced variate scale can be converted to probability scale using the relation

$$P = \exp[-\{\exp-(Y)\}] \qquad \text{I(16)}$$

Where P is the non-exceedance probability and Y is the reduced variate.

This scale can also be converted to MRI scale using the relation

$$N_R = 1/(1\text{-}P) \qquad \text{I(17)}$$

Where N_R is the MRI for the non-exceedance probability value P.

I.2.3 If one has to use Frechet distribution fitting, the logarithmic transformation shall be used to convert it to equivalent Gumbel distribution i.e. plot values of '$\log_e$ x' against the reduced variate and the values of the Frechet distribution parameter can be generated from the distribution parameter of the resulting Gumbel distribution using the relations given in equations I(8), I(9) and I(10) in subsection I.1.3.

Method of Moments [20], Method of Maximum Likelihood [20], Method of Maximum Entropy [21,22], Method of Probability Weighted Moments [23] are some of the methods available for arriving at the values of a, location parameter and b, scale parameter[24]. Use of any one of the methods is acceptable.

I.2.4 A typical example is given in Annexure A.

I.3 Numerical Method

Lieblein Technique [14, 15, 24] :

Having satisfied that a particular distribution can be fitted to the data points by using a probability graph paper, the values of the distribution parameter a and b can be obtained more accurately by order statistics approach: The Lieblein Technique [14].

The necessary steps are given below:

I.3.1 Evaluation of Estimator for Gumbel (Fisher-Tippett Type-I)

(i) Use the original unranked chronologically arranged set of values X_R (R =1,2,......N)

(ii) Divide the data set into k subgroups of m elements each. If N is not a multiple of m there will remain some data. Let there be m' remainder data such that (k.m) + m' = N. The first set of elements (k.m) is called the main subgroup.

Example:

Let N =15, then following possibility may be considered.

Main subgroup	Remaining subgroup
k = 3, m = 5	m' = 0
k = 3, m = 4	m' = 3

(iii) From table I.3.1, find the combination of N, k, m and m' which gives the maximum efficiency E. Obtain the proportionality factors

t = k.m/N

t'= m'/N

The efficiency E is the main parameter which expresses the degree of optimisation of the partition and degree of minimisation of variance. It depends upon the choice of k.

(iv) Arrange the main subgroup into a matrix Y_{ij} of order k x m. The matrix of main subgroup having 15 elements with k = 3, m = 5 has the following form

m k	=	1	2	3	4	5
1	=	Y_{11}	Y_{12}	Y_{13}	Y_{14}	Y_{15}
2	=	Y_{21}	Y_{22}	Y_{23}	Y_{24}	Y_{25}
3	=	Y_{31}	Y_{32}	Y_{33}	Y_{34}	Y_{35}

(v) Arrange the elements in each individual row in ascending order and form another matrix X_{ij}. Each element of rearranged matrix should satisfy the criterion,

($X_{ij} <= X_{ij+1}$: j =1, 2, 3,...... m-1 ; i = 1, 2, 3, ...k)

For the above main sub-group of 15 elements, the rearranged matrix will have the following form,

m	=	1	2	3	4	5
k						
1	=	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}
2	=	X_{21}	X_{22}	X_{23}	X_{24}	X_{25}
3	=	X_{31}	X_{32}	X_{33}	X_{34}	X_{35}

X_{11} £ X_{12} , X_{12} £ X_{13} ,.......... £.X_{15}

X_{21} £ X_{22} , X_{22} £ X_{23} ,.......... £.X_{25}

X_{31} £ X_{32} , X_{32} £ X_{33} ,.......... £.X_{35}

In the rearranged matrix the magnitude of elements in each row is same but their position in each assigned individual row alters depending upon their magnitudes.

(vi) For each column of this rearranged matrix, find the sums

$$S_j = \sum_{i=1}^{k} X_{ij}$$, (where j = 1,2,...m)

In the above matrix

$S_1 = X_{11} + X_{21} + X_{31}$

$S_2 = X_{12} + X_{22} + X_{32}$

.

.

.

$S_5 = X_{15} + X_{25} + X_{35}$

(vii) Using the table I.3.2 obtain the weights a_{mi} and b_{mi}.

(viii) Obtain the distribution parameters as follows

$$a'_G = 1/k \overset{m}{\underset{j=1}{S}} a_{mj} S_j$$

$$b'_G = 1/k \overset{m}{\underset{j=1}{S}} b_{mj} S_j$$

(ix) If m' ¹ 0 i.e., the remainder group exists, Follow the steps (i) to (viii) with k = 1, m = m' and obtain a''_G and b''_G and evaluate

"

(x) $a_G = t\, a'_G + t'\, a''_G$

$b_G = t\, b'_G + t'\, b''_G$

(xi) If $m' = 0$ set $a'_G = a_G$ and $b'_G = b_G$

(xii) Now that a_G and b_G are evaluated, it is possible to evaluate the probability according to the Gumbel (Fisher-Tippett Type I) distribution for a specified value of the variate X_G or of the reduced variate

$Y_G = (X_G - a_G) / b_G$

$P_G(Y_G) = \exp[-\exp(-Y_G)]$

(vi) Obtain the mean recurrence interval using Eq. I(17)

I.3.2 Evaluation of Estimators for Frechet Distribution

(i) Make initial transformation of each element of the extreme value data set by taking natural logarithm, i.e. for a data set $X_1, X_2 .... X_N$, find $\ln X_1, \ln X_2 ..... \ln X_N$ to get the transformed data set.

(ii) Apply steps (i) to (xi) as given in I.3.1 to obtain a_G and b_G for the transformed data set.

(iii) Evaluate

$b_F = \exp(a_G)$

$g_F = 1/ b_G$

I.3.3 Evaluation of Variance, Efficiency and Standard Deviation

(i) Evaluate the proportionality factors

$q = t^2/k$

$q' = (t')^2$

(ii) Evaluate the variance, Var

$\mathrm{Var}\ (X_G) = q\, Q_m + q'\, Q_{m'}$

Where Q_m and $Q_{m'}$ are defined by following general form

$Q_n = (A_n Y_G^2 + B_n Y_G + C_n) b_G^2$

and A_n, B_n, C_n are given in Table I.3.3.

(iii) All variances may be related to a theoretically specified lower bound known as the Cramer Rao Lower Bound, Q_{LB} [2]

$Q_{LB} = Q_0 / N$

Where $Q_0 = (0.60793\, Y_G^{\,2} + 0.51404\, Y_G + 1.10566)\, b_G^{\,2}$

(iv) Determine standard deviation s_G and efficiency E, as given below

$s_G = [\mathrm{Var}\,(X_G)]^{1/2}$ and

$E = Q_{LB} / \mathrm{Var}\,(X_G)$

The standard deviation s_G may now be plotted for each X_G on extreme probability paper to obtain the shape of their confidence limit.

Then, if the sampling distribution of X_G is approximately normal.

(1) The $X_G \pm 1 s_G$ confidence interval will represent the limits within which the 68.27% of the events having a particular MRI will fall.

And for the maximum analysis case

(2) The $X_G + 1\, s_G$ upper confidence limit will represent the value which will not be exceeded by 84.13% of the events having a particular MRI.

(3) The $X_G + 2\, s_G$ upper confidence limit will represent the value which will not be exceeded by 97.72% of the events having a particular MRI.

(4) The $X_G + 3\, s_G$ upper confidence limit will represent the value which will not be exceeded by 99.87% of the events having a particular MRI.

For the Frechet distribution the confidence band width of $1s$ can be evaluated for each Y_F, using equation valid for Gumbel distribution

$(X_G \pm 1s) = a_G + b_G\,(Y_G \pm 1s)$

Now that X_G must be transformed back to actual X_F value.

$X_F = \exp\,(X_G)$ and $Y_G = Y_F$

Obtaining,

$(X_F + 1\, s) = \exp\,[\, a_G + b_G\; (Y_F + 1\, s)]$

It may be noted that in the case of Gumbel distribution, the upper and lower confidence limits are equidistant from the MRI value. However, in the case of Frechet distribution, these limits are not equidistant, because it is the logarithm of confidence limits that are equidistant from the natural logarithm of MRI value.

TABLE I.3.1 : GROUPING PROCEDURE FOR MAXIMUM EFFICIENCY [2]

Sample Size N	Partition (k)(m) + m′	Efficiency for P(x) = 0.01 (Probability that the variate will be exceeded)	Sample Size N	Partition (k)(m) + m′	Efficiency for P(x) = 0.01 (Probability that the variate will be exceeded)
1	---	---	26	(4)(6)+2	0.799
2	(1)(2)+0	0.540	27	(4)(6)+3	0.813
3	(1)(3)+0	0.687	28	(4)(6)+4	0.819
4	(1)(4)+0	0.759	29	(4)(6)+5	0.827
5	(1)(5)+0	0.803	30	(5)(6)+0	0.832
6	(1)(6)+0	0.832	31	(5)(5)+6	0.808
7	(1)(4)+3	0.727	32	(5)(6)+2	0.805
8	(2)(4)+0	0.759	33	(5)(6)+3	0.816
9	(1)(6)+3	0.777	34	(5)(6)+4	0.823
10	(2)(5)+0	0.803	35	(5)(6)+5	0.828
11	(1)(6)+5	0.819	36	(6)(6)+0	0.832
12	(2)(6)+0	0.832	37	(7)(5)+2	0.782
13	(2)(5)+3	0.773	38	(6)(6)+2	0.809
14	(2)(5)+4	0.791	39	(6)(6)+3	0.819
15	(3)(5)+0	0.803	40	(6)(6)+4	0.824
16	(2)(6)+4	0.813	41	(6)(6)+5	0.829
17	(2)(6)+5	0.823	42	(7)(6)+0	0.832
18	(3)(6)+0	0.832	43	(8)(5)+3	0.793
19	(3)(5)+4	0.793	44	(7)(6)+2	0.812
20	(4)(5)+0	0.803	45	(7)(6)+3	0.821
21	(3)(6)+3	0.808	46	(7)(6)+4	0.825
22	(3)(6)+4	0.818	47	(7)(6)+5	0.828
23	(3)(6)+5	0.826	48	(8)(6)+0	0.832
24	(4)(6)+0	0.832	49	(9)(5)+4	0.799
25	(5)(5)+0	0.803	50	(8)(6)+2	0.814

TABLE I.3.2 : WEIGHTS a_{mi} AND b_{mi} FOR CALCULATION OF DISTRIBUTION PARAMETERS CORRESPONDING TO DIFFERENT GROUP SIZES [2]

a_{mi} / b_{mi}	i					
	1	2	3	4	5	6
a_{2i}	0.916373	0.083627	-	-	-	-
a_{3i}	0.656320	0.255714	0.087966	-	-	-
a_{4i}	0.510998	0.263943	0.153680	0.071380	-	-
a_{5i}	0.418934	0.246282	0.167609	0.108824	0.058350	-
a_{6i}	0.355450	0.225488	0.165620	0.121054	0.083522	0.048867
b_{2i}	- 0.721348	0.721348	-	-	-	-
b_{3i}	- 0.630541	0.255816	0.374725	-	-	-
b_{4i}	- 0.558619	0.085903	0.223919	0.248797	-	-
b_{5i}	- 0.503127	0.006534	0.130455	0.181656	0.184483	-
b_{6i}	- 0.459273	- 0.035992	0.073199	0.126724	0.149534	0.145807

TABLE I.3.3 : VARIANCE DETERMINATORS FOR Q_n (Where n = m or m') [2]

n	A_n	B_n	C_n
2	0.71186	- 0.12864	0.65955
3	0.34472	0.04954	0.40286
4	0.22528	0.06938	0.29346
5	0.16665	0.06798	0.23140
6	0.13196	0.06275	0.19117

ANNEXURE-A

EXAMPLE OF APPLICATION OF VARIOUS EXTREME VALUE TECHNIQUES

A.1 Generation of Wind Speed Data Set

Hourly and 5 minute averaged extreme wind speed data observed at a typical site for the period 1969-1997 have been used to demonstrate the application of various extreme value techniques. These data are listed in Table A-1 for the above averaging times and different heights of measurements. 3 seconds-averaged extreme data are computed using the relation

$(V_{3s}/V_{1h}) = 1.52$ (read from the graph Fig. 3.1)

In this illustration, extreme wind speed data set of 29 elements is used. Cols. (i) to (v) give the data in original time sequence. Cols.(vi) to (viii) give the extreme data computed for standard 10 m height and different averaging periods. Partitioning of data is shown in Cols.(ix) to (xii). Cols.(xiii), (xiv) and (xv) give the ranking order, ranked data and probability plotting positions on Gumbel type extreme probability paper.

A.2 Evaluations of Estimators Using Lieblein Technique
(Data of 3s i.e., column viii of Table A1 is used.)

A.2.1 Partitioning of Data : Partition the original data set of 29 elements into k = 4 sub-groups and m = 6 elements called main sub-group and the remainder group i.e. k = 1 and m = 5 elements for maximum efficiency as given in Table I.3.1.

A.2.2 Plotting the Data : Rank the data in increasing order of magnitude and calculate Probability Plotting Positions as given in Cols. (xiii), (xiv) and (xv).

A.2.3 Calculation of Estimators

(i) Calculate proportionality factors:

$t = km/N = 4 \times 6/29 = 0.8276$

$t' = m'/N = 5/29 = 0.1724$

$q = (t)^2/k = 0.1712$

$q' = (t')^2 = 0.0297$

(ii) Arrange the extreme values in 4 x 6 matrix x_{ji} (see col. xi)

J	i = 1	i = 2	i = 3	i = 4	i = 5	i = 6
1	73.0	59.7	70.4	58.7	68.2	55.9
2	59.7	69.3	67.2	70.4	70.4	65.1
3	80.0	80.0	76.8	68.4	95.9	64.5
4	82.8	59.6	57.2	57.9	42.9	53.4

(iii) Arrange the elements of each row in ascending order (see col. xii Table A.I) and form another matrix x_{ij} for main sub-group as follows:

I	j = 1	j = 2	j = 3	j = 4	j = 5	j = 6
1	55.9	58.7	59.7	68.2	70.4	73.0
2	59.7	65.1	67.2	69.3	70.4	70.4
3	64.5	68.4	76.8	80.0	80.0	95.9
4	42.9	53.4	57.2	57.9	59.6	82.8

(iv) Form the sums of rearranged matrix in step (iii) for each column:

i.e. $S_j = \sum_{j=1}^{k} X_{ij} \quad (i = 1, 2, \ldots 6)$

(v) For the remainder group (m = 0) we have k = 1 and m' = 5.

(vi) Thus S_i and S'_i for the main group and remainder group are as follows:

Main sub-group

S_1	=	55.9	+	59.7	+	64.5	+	42.9	=	223.0
S_2	=	58.7	+	65.1	+	68.4	+	53.4	=	245.6
S_3	=	59.7	+	67.2	+	76.8	+	57.2	=	260.9
S_4	=	68.2	+	69.3	+	80.0	+	57.9	=	275.4
S_5	=	70.4	+	70.4	+	80.0	+	59,6	=	280.4
S_6	=	73.0	+	70.4	+	95.9	+	82.8	=	322.1

Remainder sub-group

S_1'	=	46.1
S_2'	=	47.7
S_3'	=	50.2
S_4'	=	57.5
S_5'	=	72.8

(vii) Using Table I.3.2, obtain the weights a_{mi}, b_{mi} (m = 6 and I = 1, 2, ..6)

	i = 1	**i = 2**	**i = 3**	**i = 4**	**I = 5**	**i = 6**
(a_{6i})	0.355450	0.225488	0.165620	0.121054	0.083522	0.048867
(b_{6i})	-0.459273	-0.035992	-0.073199	0.126724	0.149534	0.145807

And calculate for the main group the following:

$$\alpha_G = \frac{1}{k}\sum_{j=1}^{m} a_{mj} s_j = \frac{1}{4}\sum_{j=1}^{6} a_{6j} s_j = 62.588$$

$$\beta_G = \frac{1}{k}\sum_{j=1}^{m} b_{mj} s_j = \frac{1}{4}\sum_{j=1}^{6} b_{6j} s_j = 7.908$$

(viii) Using Table I.3.2, obtain the weights $a_{m'i}$ and $b_{m'i}$, m' = 5, I = 1, 2…5 for remainder group

	i = 1	**i = 2**	**i = 3**	**i = 4**	**i = 5**
(a_{5i})	0.418934	0.246282	0.167609	0.108824	0.058350
(b_{5i})	-0.503127	0.006534	0.130455	0.181656	0.184483

And calculate for the remainder group the following:

$$\alpha'_G = \frac{1}{k}\sum_{i=1}^{m'} a'_{mi} s'_i = \frac{1}{4}\sum_{i=1}^{5} a'_{5i} s'_i = 49.979$$

$$\beta'_G = \frac{1}{k}\sum_{i=1}^{m'} b'_{mi} s'_i = \frac{1}{4}\sum_{i=1}^{5} b'_{5i} s'_i = 7.542$$

(ix) Evaluate

$a_G = t\ a_G + t'\ a'_G = 60.414$

$b_G = t\ b_G + t'\ b'_G = 7.845$

A.2.4 Evaluation of variance, Standard Deviation and Efficiency

Using calculated values of q = 0.1712 and q' = 0.0297 [refer I.3.3 (i)] and the procedure outlined in I.3.3(ii), I.3.3(iii) and I.3.3 (iv), the variance, standard deviation and efficiency can be calculated. These are shown in Table A-2.

A.2.5 Plots for Frechet and Gumbell distribution as obtained by Lieblein Technique for this exercise are given in Fig.A1 and A2 while the least square fit (Graphical Method) for Gumbel distribution is given in Fig. A3.

A.3 Comparison of Expected Extreme Wind Speeds Using Different Techniques

Expected 3s-extreme wind speeds for the MRI 50 years, 100 years and 1000 years were evaluated using 29 years 3s-averaged wind speed data computed from hourly extreme wind data standardised to 10 m height and the following techniques for extreme value analysis:

(i) Lieblein technique for Gumbel type distribution (see Fig.A1)

(ii) Lieblein technique for Frechet type distribution (see Fig.A2)

(iii) Least square method for Gumbel type distribution (see Fig.A3)

(iv) IS code 875 (4) methodology using basic wind speed maps.

Table A-3 gives the comparison of expected extreme wind speed (kmphr) values and 1s values for the MRI 50 y, 100 y and 1000 y.

TABLE A-1 : TABULATION OF EXTREME WIND DATA SET

TABLE 1A								TABLE 1B				TABLE 1C			
Original Time Sequence & Extreme Wind Data and Standardised Data								**Partitioning of Data for Gumbel Type Distribution Using Lieblein Technique**				**Data for Plotting on Extreme Probability Paper**			
Year	Time Sequ-ence	Extreme Wind Data x_r (km/h) observed At height h(m) for averaging time			Calculated Extreme Wind Data x_r (km/h) at standard height of 10 m for the averaging time			Data (col. viii) partitioned for maximum efficiency (Table I.2.1) k = 4, m = 6 & m' = 5 and ranked within subgroups				Data arranged in ascending order			
		h(m)	1 hr.	5 min	1 hr.	5 min	3 sec.	J = 1, 2..k (= 4)	I = 1, 2..m (= 6)	x_{ji}	X_{ij}	Ranking Order M	Ranked Data X_M (M=1,2... ..N = 29)	Probability Plotting Position $f(M) = M/(N+1)$ (N = 29)	Reduced Variate $Y_G = -\ln(f(M))$
(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)	(xiii)	(xiv)	(xv)	(xvi)
1969	1	120	68.5	89.0	48.0	62.4	73.0	Main Group 1	1	73.0	55.9	1	42.9	0.033	-1.2241
1970	2	120	56.0	71.0	39.3	49.8	59.7		2	59.7	58.7	2	46.1	0.067	-0.9962
1971	3	120	66.0	81.0	46.3	56.8	70.4		3	70.4	59.7	3	47.7	0.100	-0.8340
1972	4	120	55.0	72.0	38.6	50.5	58.7		4	58.7	68.2	4	50.2	0.133	-0.7006
1973	5	120	64.0	85.0	44.9	59.6	68.2		5	68.2	70.4	5	53.4	0.167	-0.5832
1974	6	120	52.5	71.5	36.8	50.1	55.9		6	55.9	73.0	6	54.6	0.200	-0.4759
1975	7	120	56.0	73.0	39.3	51.2	59.7	2	1	59.7	59.7	7	55.9	0.233	-0.3752
1976	8	120	65.0	78.3	45.6	54.9	69.3		2	69.3	65.1	8	57.5	0.267	-0.2790
1977	9	120	63.0	87.0	44.2	61.0	67.2		3	67.2	67.2	9	57.9	0.300	-0.1856
1978	10	120	66.0	73.0	46.3	51.2	70.4		4	70.4	69.3	10	58.7	0.333	-0.0941
1979	11	120	66.0	79.0	46.3	55.4	70.4		5	70.4	70.4	11	59.6	0.367	-0.0033
1980	12	120	61.0	78.0	42.8	54.7	65.1		6	65.1	70.4	12	59.7	0.400	0.0874
1981	13	120	75.0	91.0	52.6	63.8	80.0	3	1	80.0	64.5	13	59.7	0.433	0.1788
1982	14	120	75.0	106.0	52.6	74.3	80.0		2	80.0	68.4	14	64.5	0.467	0.2716

TABLE A-1 : TABULATION OF EXTREME WIND DATA SET (CONTD.)

TABLE 1A								TABLE 1B				TABLE 1C			
(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)	(xiii)	(xiv)	(xv)	(xvi)
1983	15	120	72.0	94.0	50.5	65.9	76.8		3	76.8	76.8	15	65.1	0.500	0.3665
1984	16	120	64.1	84.0	45.0	58.9	68.4		4	68.4	80.0	16	67.2	0.533	0.4642
1985	17	120	90.0	121.0	63.1	84.8	95.9		5	95.9	80.0	17	68.2	0.567	0.5657
1986	18	120	60.5	80.0	42.4	56.1	64.5		6	64.5	95.9	18	68.4	0.600	0.6717
1987	19	15.5	58.0	74.0	54.4	69.5	82.8	4	1	82.8	42.9	19	69.3	0.633	0.7836
1988	20	30.0	45.9	74.0	39.2	63.3	59.6		2	59.6	53.4	20	70.4	0.667	0.9027
1989	21	6.5	40.0	53.0	37.6	49.8	57.2		3	57.2	54.6	21	70.4	0.700	1.0309
1990	22	6.5	42.0	60.0	35.9	51.3	57.9		4	57.9	57.9	22	70.4	0.733	1.1707
1991	23	6.5	26.5	51.0	28.2	54.2	42.9		5	42.9	59.6	23	72.8	0.767	1.3254
1992	24	6.5	33.0	59.0	35.1	62.7	53.4		6	53.4	82.8	24	73.0	0.800	1.4999
1993	25	6.5	29.5	51.0	31.4	54.2	47.7	Remainder	1	47.7	46.1	25	76.0	0.833	1.7020
1994	26	6.5	35.5	55.0	37.8	58.5	57.5	Group 1	2	57.5	47.7	26	80.0	0.867	1.9442
1995	27	6.5	31.0	61.0	33.0	64.9	50.2		3	50.2	50.2	27	80.0	0.900	2.2504
1996	28	6.5	45.0	68.0	47.9	72.3	72.8		4	72.8	57.5	28	82.8	0.933	2.6738
1997	29	6.5	28.5	47.0	30.0	50.0	46.1		5	46.1	72.8	29	95.9	0.967	3.3843

TABLE A-2 : VARIANCE, STANDARD DEVIATION AND EFFICIENCY FOR LIEBLEIN TECHNIQUE

I	$P_G(X_G)$	Y_G	X	X_G	$VAR(X_G)$	$SIG(X_G)$	Efficiency, E
1	0.033	-1.224	42.9	50.811	4.015	2.004	0.733
2	0.067	-0.996	46.1	52.599	3.337	1.827	0.761
3	0.100	-0.834	47.7	53.871	2.961	1.721	0.788
4	0.133	-0.701	50.2	54.917	2.719	1.649	0.815
5	0.167	-0.583	53.4	55.840	2.556	1.599	0.841
6	0.200	-0.476	54.6	56.681	2.448	1.565	0.866
7	0.233	-0.375	55.9	57.470	2.382	1.543	0.890
8	0.267	-0.279	57.2	58.227	2.351	1.533	0.911
9	0.300	-0.186	57.5	58.958	2.351	1.533	0.931
10	0.333	-0.094	58.7	59.676	2.379	1.543	0.948
11	0.367	-0.003	59.6	60.389	2.436	1.561	0.962
12	0.400	0.087	59.7	61.100	2.520	1.588	0.973
13	0.433	0.179	59.7	61.817	2.633	1.623	0.981
14	0.467	0.272	64.5	62.546	2.777	1.667	0.986
15	0.500	0.367	65.1	63.290	2.955	1.719	0.988
16	0.533	0.464	67.2	64.056	3.169	1.780	0.988
17	0.567	0.566	68.2	64.853	3.426	1.851	0.986
18	0.600	0.672	68.4	65.684	3.732	1.932	0.981
19	0.633	0.783	69.3	66.561	4.095	2.024	0.975
20	0.667	0.903	70.4	67.497	4.531	2.129	0.967
21	0.700	1.031	70.4	68.502	5.051	2.247	0.959
22	0.733	1.171	70.4	69.598	5.682	2.384	0.949
23	0.767	1.326	72.8	70.814	6.460	2.542	0.938
24	0.800	1.500	73	72.182	7.432	2.726	0.926
25	0.833	1.702	76.8	73.765	8.686	2.947	0.914
26	0.867	1.944	80	75.669	10.377	3.221	0.901
27	0.900	2.250	80	78.069	12.793	3.577	0.886
28	0.933	2.673	82.8	81.387	16.654	4.081	0.870
29	0.967	3.385	95.9	86.973	24.527	4.952	0.849

X = Ranked Observed Data

$X_G = a_G + b_G Y_G = 60.414 + 7.845 Y_G$

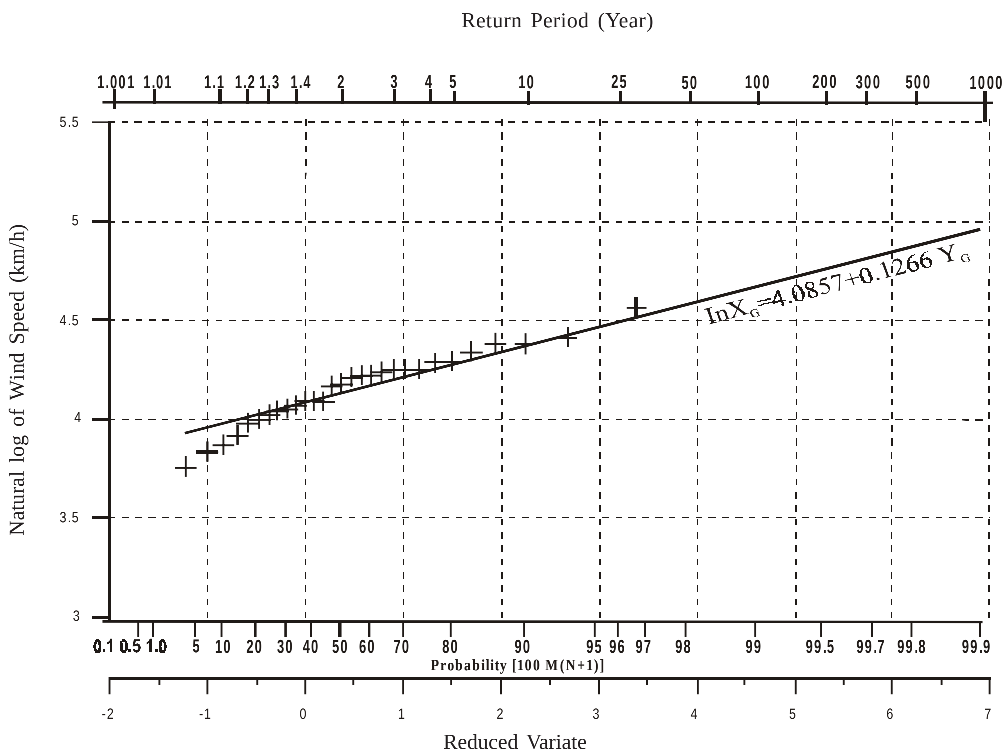

FIGURE A1 : PLOT OF FRECHET TYPE DISTRIBUTION ON EXTREME PROBABILITY PAPER USING LIEBLEIN TECHNIQUE

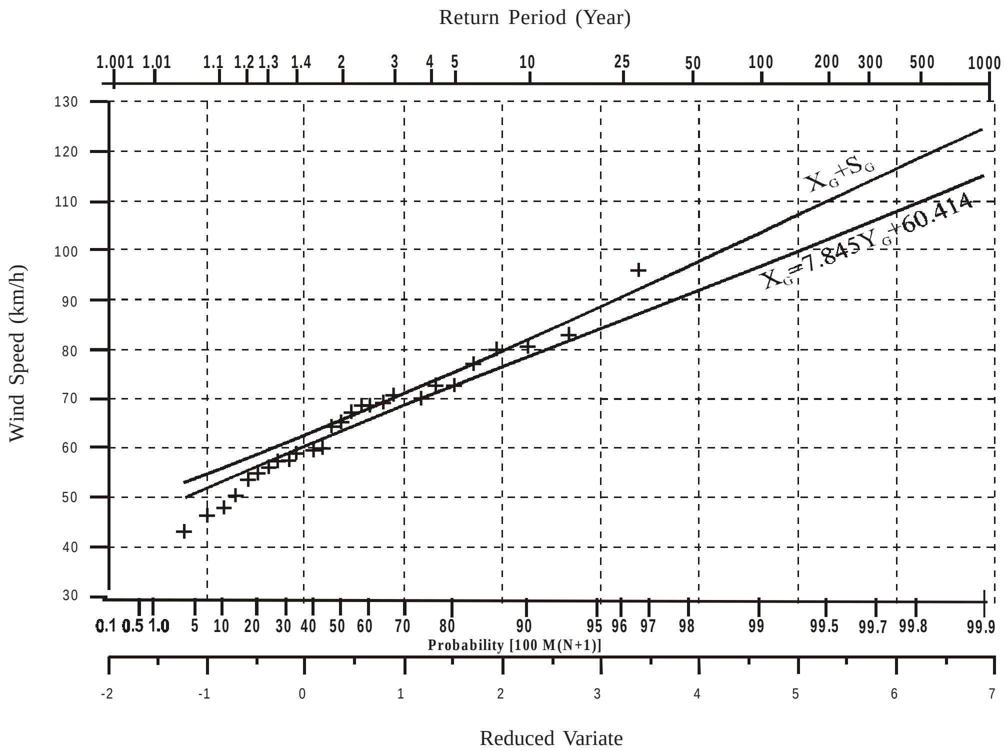

FIGURE A2 : PLOT OF GUMBEL TYPE DISTRIBUTION ON EXTREME PROBABILITY PAPER USING LIEBLEIN TECHNIQUE

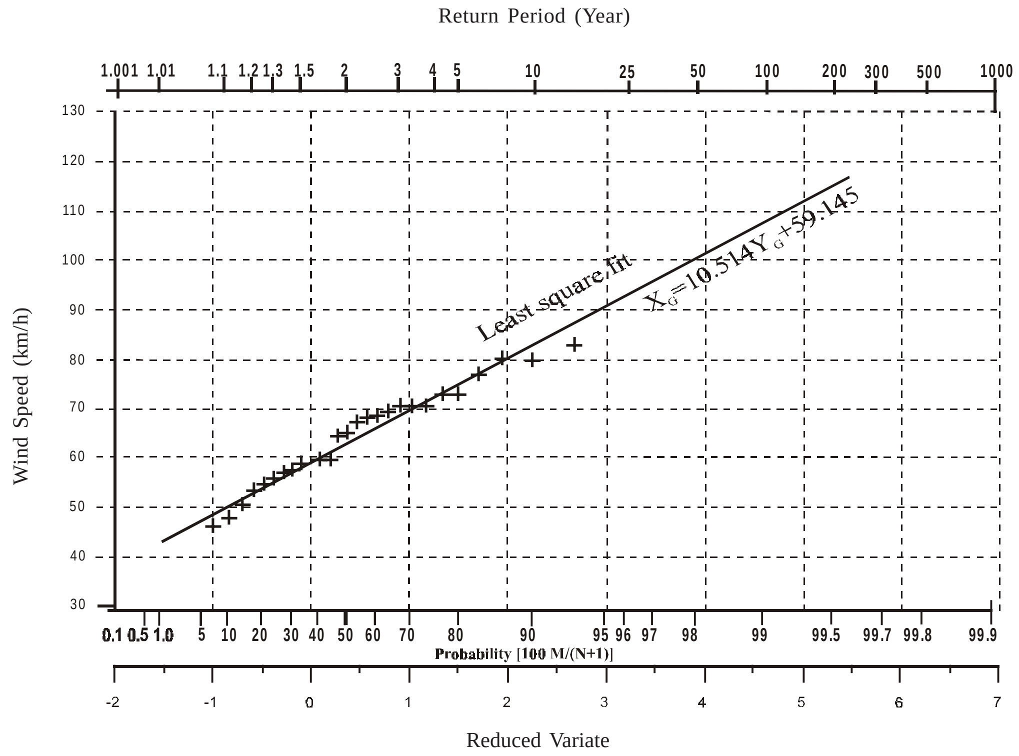

FIGURE A3 : PLOT OF GUMBEL TYPE DISTRIBUTION ON EXTREME PROBABILITY PAPER USING LEAST SQUARE METHOD

TABLE A-3 : EXPECTED 3S-EXTREME WIND SPEEDS (KM/H) AT A TYPICAL SITE FOR DIFFERENT EXTREME VALUE ANALYSIS TECHNIQUES

Mean Recurrence Interval (years)	Expected Mean Extremes for Distribution Type/Technique					
	Gumbel Type/ Lieblein		Frechet Type/Lieblein		Gumbel Type/ Least Square	
	Mean Value	Mean+1s Value	Mean Value	Mean+1s Value	Mean Value	Mean+1s Value
50	91.02	96.62	97.51	106.13	100.17	112.78
100	96.50	102.98	106.52	117.54	107.51	120.21
1000	114.6	124.02	142.67	164.67	131.77	143.77

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Published by : Atomic Energy Regulatory Board
Niyamak Bhavan, Anushaktinagar
Mumbai - 400 094
INDIA.

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