EVALUATION OF WIND DATA RECORDS TO PREDICT EXTREME EXTREME WIND SPEEDS IN TANZANIA

by

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ABSTRACT

The progress made towards evaluation of local wind data records to predict extreme values of wind speeds in Tanzania is being presented.

Records of wind data, stored continuously since 18 years, have been compiled and statistically processed. Extreme value theory of Fisher-Tippet Type I has been fitted into the data to abstract extreme values of wind speeds for locations at which the wind data records were obtained.

A reliable wind map of Tanzania containing basic wind speeds at 18 locations across the country has been produced. The basic wind speeds are being recommended for design against wind-induced failure of structures.

This paper forms an input to the authors' project to introduce design specifications against wind loads for Tanzania based on local climatic conditions.

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2. List of Symbols

v = wind speed

$\bar{v}$ = mean wind speed

V = extreme gust speed

μ = statistical value: the mode

σ = statistical value: the dispersion

$p(v)$ = probability of a certain wind speed v not being exceeded

T^0 = observation period

T = projected period

G = gust factor

1. Introduction

For structural engineers wind-induced failure of structures is certainly one of the most common product of a natural disaster. A close estimate of wind action on structures and effective application of design prescriptions provide reliable means to minimize the risk of structural failure due to wind-induced forces.

Effective use of design prescriptions is presently gaining more attention in Tanzania due to increasing activities in the construction sector, which can be observed not only in Dar es Salaam but also in regional headquarters.

While safe and economic design of these structures is guided through the British Code of Practice, the effective use of the design code is greatly hindered for lack of local inputs so that design against wind action is based on rough assumptions with regard to wind-induced forces.

A close estimate of wind-induced forces on a structure is predominantly governed by the maximum wind speeds likely to occur during the life time of the structure. The absence of proper investigations with regard to local climatic conditions has persistently led to estimation of maximum wind speeds on basis of the climatic extremes of Britain /3/.

While the general principles applied in the British design standards /4/ remain applicable in Tanzania, its application is only relevant if local wind climate is appropriately incorporated. In the work presented herein maximum wind speeds, likely to occur during the projected life of the buildings, have been predicted through statistical data processing of local historical wind records available.

2. Existing Wind Data Records

The common instruments used for wind data recording in Tanzania are the rotating cup anemometers mounted on 10 m masts. The anemometer sites are located at airfield stations. The recording can therefore be accepted to correspond to a meteorological standard of a common height and terrain , i.e. 10 m above flat or gently undulating open country with very few obstructions.

The existing wind data in Tanzania are hourly records dating back to 1972 /7/. Data records of earlier dates are either non-existent or were not transferred to Dar es Salaam from Nairobi in the wake of the break up of the East African Community.

Attempted efforts to acquire and compile reliable information from the existing, not well efficient data bank system resulted in attaining full data records on 16 recording stations and incomplete rather scattered records on 2 stations. It is under these constraints, therefore, that wind data records of only 18 site locations throughout the country have been evaluated, notably:

Arusha, Bukoba, Dar es Salaam, Dodoma, Iringa, Kigoma, Mbeya, Morogoro, Moshi, Musoma, Mtwara, Mwanza, Shinyanga, Songea, Sumbawanga, Tabora, Tanga and Zanzibar.

3. Methodology

The maximum wind speeds can be predicted through statistical investigations based on local historical wind data. Extreme value theories of Fisher Tippet Type I or II are usually fitted into the data.

From the parent record the monthly maxima have been extracted for the analysis. The employment of largest monthly speeds for the analysis follow recommendations in a study presented in /5/, for cases where short term records are available.

The maxima are most usefully presented in terms of the Cumulative Distribution Function (CDF), p(v), which quantifies the probability of a certain wind speed, v, not being exceeded.

It has been verified in /1/ that the CDF of extremes will always converge asymptotically towards the Fisher-Tippet Type I distribution which has a fixed shape and is given by

$$p(v) = \exp(-\exp(-y)) \quad (1)$$

so that

$$y = -\ln[-\ln p(v)] \quad , \quad (2)$$

where y is called the reduced variate and is given for the extreme wind speed, v, by:

$$y = (v - \mu)/\sigma \quad (3)$$

with

μ = the mode
σ = the dispersion.

The values of μ and σ can be easily determined from the observed data. These parameters play a similar role in the Type I distribution as the mean, $\bar{v}$, and standard deviation s in the Gaussian distribution /2/. Thus the mode μ corresponds to the location of the steepest part of the CDF and is given by:

$$\mu = \bar{v} - .5772\,\sigma \quad . \qquad (4)$$

The dispersion σ represents the spread of the CDF and is therefore a measure of variability:

$$\sigma = \sqrt{6}(s/\pi) \quad . \qquad (5)$$

So equation (1) takes the form

$$p(v) = \exp[-\exp(-(v - \bar{v} + .5772\,\sigma)/\sigma)] \quad . \qquad (6)$$

In the appendix, fig. II, the CDF of the 18 locations in Tanzania are shown. It is seen that the distribution of wind data approximates fairly well with the Type I probability distribution model. However, marked deviations are observed especially for Sumbawanga and Shinyanga due to insufficient data quantity. Otherwise for the marked 16 site locations the model can confidently be used to estimate wind speeds from wind data at hand.

4. Estimation of Extreme Values

The probability, p(v), in equation (6) is obtained using the observed data. It represents a probability of a certain wind speed, v, not being exceeded in any one year of the observation period, T°. It is shown in /5, 6/ that the probability can be conveniently presented in terms of the observation period, T°, used to abstract the extremes from the parent:

$$p(v) = (1 - 1/T^{\circ}) \quad . \qquad (7)$$

Equation (7) still holds if the observation were continued for the next, say, T years so that

$$p(v) = (1 - 1/T) \quad . \qquad (8)$$

Knowing the probability, p(v), equation (6) can be re-arranged to give the value of the extreme wind speed, v, that should not be exceeded in any one year of the projected period T:

$$v = \bar{v} - \sigma \left[\ln \{ - \ln p(v) \} + .5772 \right] \quad , \tag{9}$$

or

$$v = \bar{v} - \sigma \left[\ln \{ -\ln (1/T) \} + .5772 \right] \quad . \tag{10}$$

It is verified in /6/ that for a sufficiently large observation period (return period), say T>10,

$$\ln \left[-\ln \left(1 - 1/T \right) \right] = - \ln T \quad , \tag{11}$$

so that equation (11) takes the final form:

$$v = \bar{v} + \sigma \left(\ln T - .5772 \right) \quad . \tag{12}$$

For the results presented herein a standard return period of T=50 years has been adopted.

Since the observed wind data satisfy the meteorological standard base by virtue of choosing appropriate site locations for wind data recording, the extreme wind speed, v, obtained in equation (12) represent the basic wind speed.

5. Extreme Gust Speeds

For design purposes it is necessary to convert the basic wind speeds, v, to that of extreme gusts, V, of the shorter duration.

Due to lack of fast response anemometers to measure the gust wind speeds we shall assume the extreme gust duration of about 3 seconds at the standard height of 10 m above the zero plane. For practical purposes, supported by measurements of atmospheric winds /5/, the extreme gust speed, V, will be estimated as a constant proportion of the basic wind speed, v, with a gust factor :

$$G = 1.9 \quad ,$$

which correspond to a landscape with many wind breaks or equivalently the outskirts of large cities, so that

$$V = 1.9 \, v \quad .$$

Following is the map of Tanzania, Fig. I, showing the basic wind speeds as extreme gust speeds to be used for design of buildings for the locations indicated on which investigations have been carried out.

Fig. I

Map of TANZANIA showing basic wind speed in m/s

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6. Conclusions and Recommendations

A significant development towards introducing design specifications against wind loads for Tanzania incorporating local climatic features has been achieved. The information on wind data records which was found to exist in Tanzania has been assessed and evaluated.

The wind data, extracted from the parent record as maximum monthly speeds, was found to closely fit into the Fisher-Tippet Type I distribution so that the results obtained can be relied upon.

The basic wind speeds have been presented in a map as extreme gust speeds and are being recommended for application in the design of buildings.

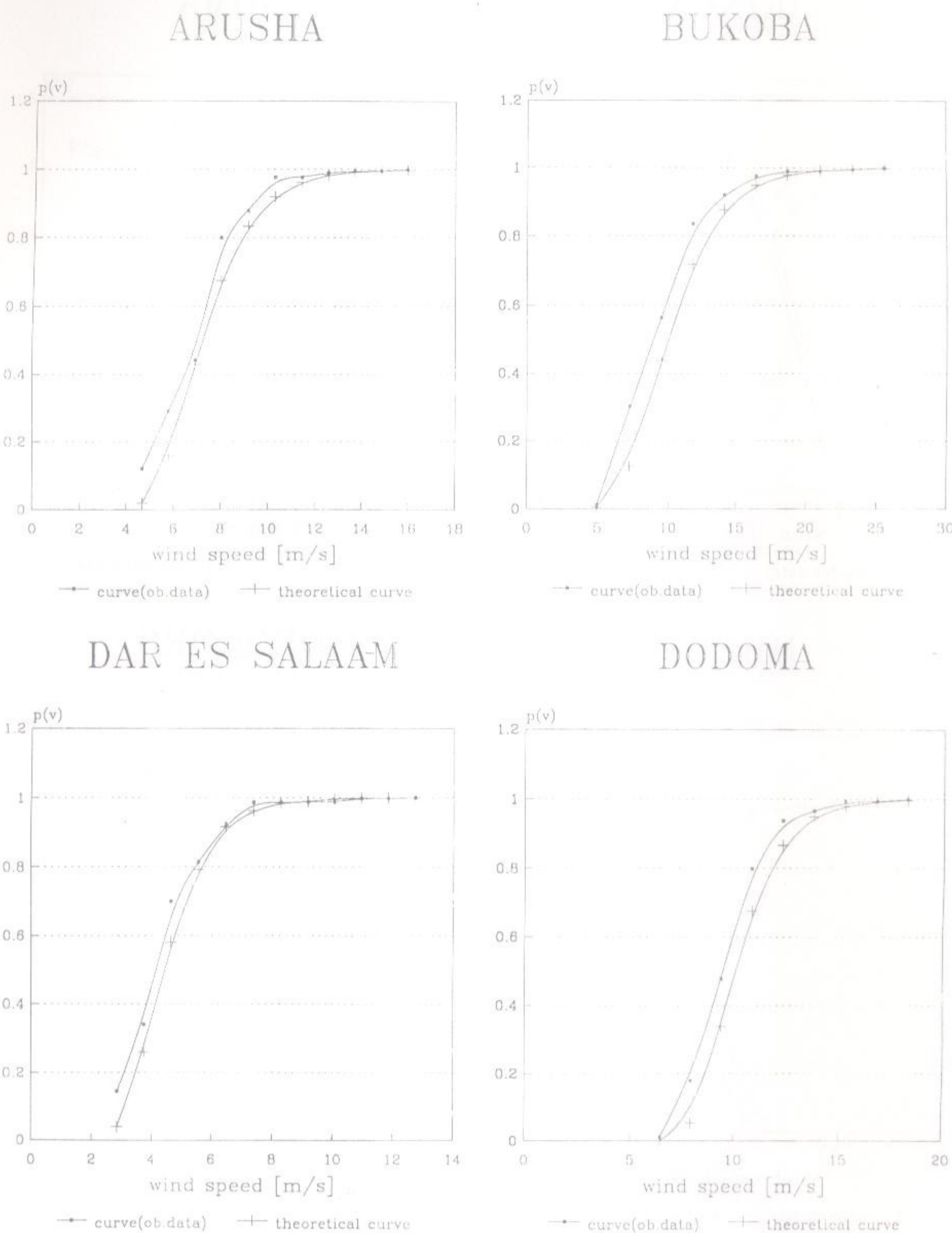
The values of basic wind speeds presented on the map are valid for the townships from which the data were analysed. A complete wind climate map in form of isopleths (lines of equal wind speeds), to include all remote areas outside the townships, will need extended recording stations.
However, since construction activities are almost exclusively concentrated in regional headquarters, the wind climate map presented herein will sufficiently satisfy design requirements in the foreseeable future.

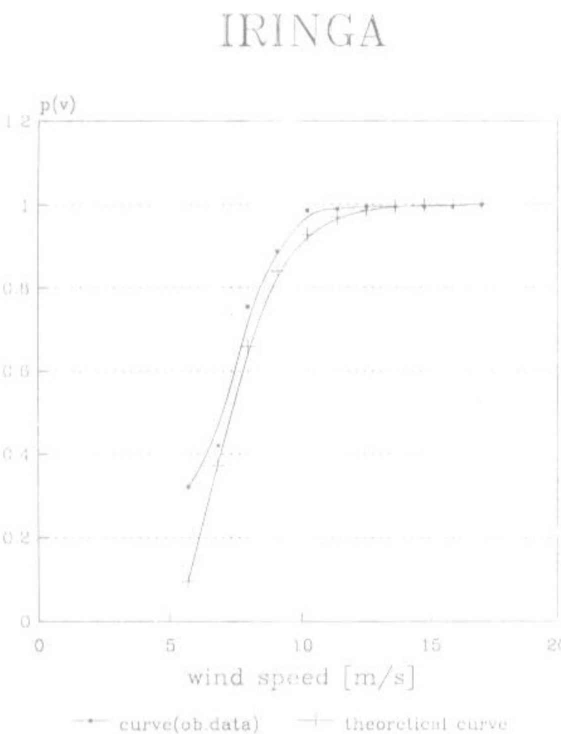
It is being observed that wind data records are non-existent at four regional headquarters, namely Chake Chake, Kibaha, Lindi and Singida. Further installations of meteorological facilities should therefore take preference of the four stations.

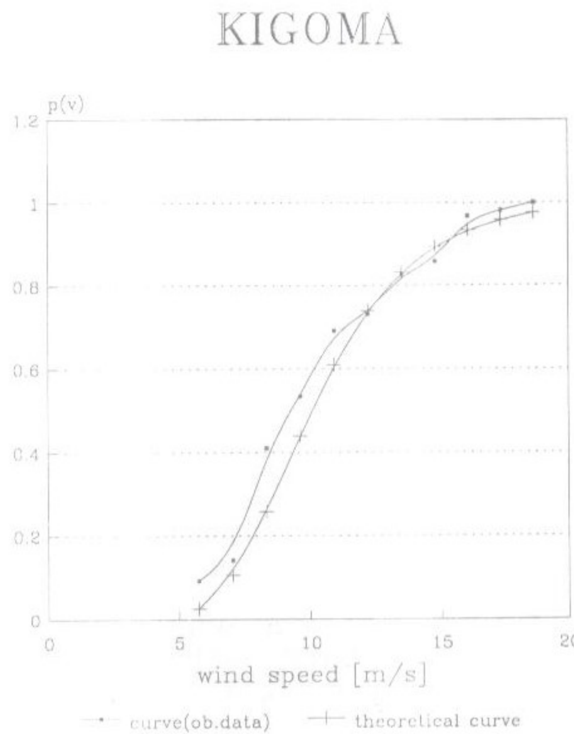
It is further being recommended that a follow up analysis of wind data records for Sumbawanga and Shinyanga should be carried out as soon as sufficient records are made available.

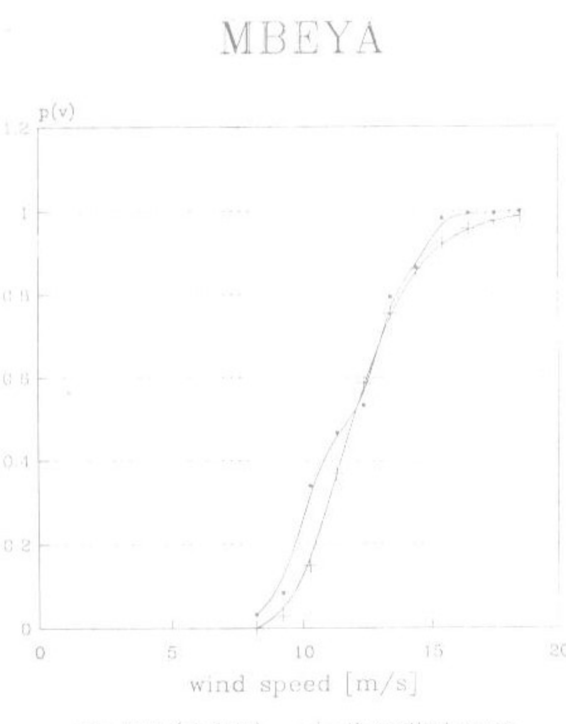
Fig. II

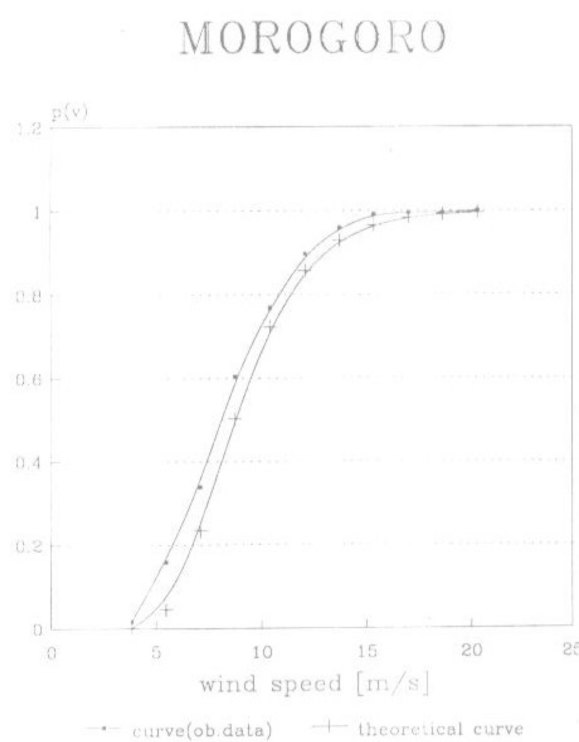
CUMULATIVE DISTRIBUTION FUNCTIONS



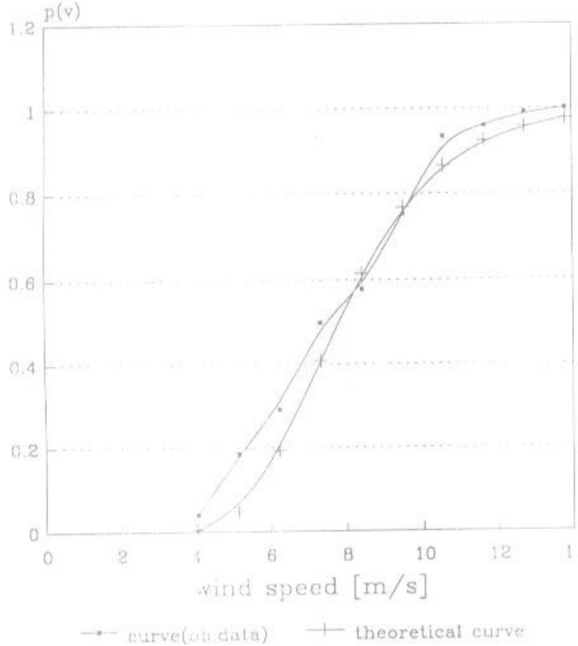

IRINGA
p(v)
wind speed [m/s]
curve(ob.data)
theoretical curve


KIGOMA
p(v)
wind speed [m/s]
curve(ob.data)
theoretical curve

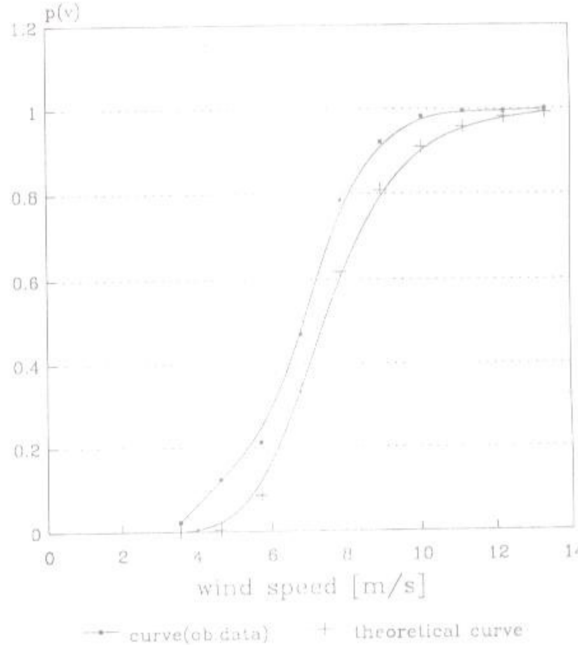

MBEYA
p(v)
wind speed [m/s]
curve(ob.data)
theoretical curve


MOROGORO
p(v)
wind speed [m/s]
curve(ob.data)
theoretical curve

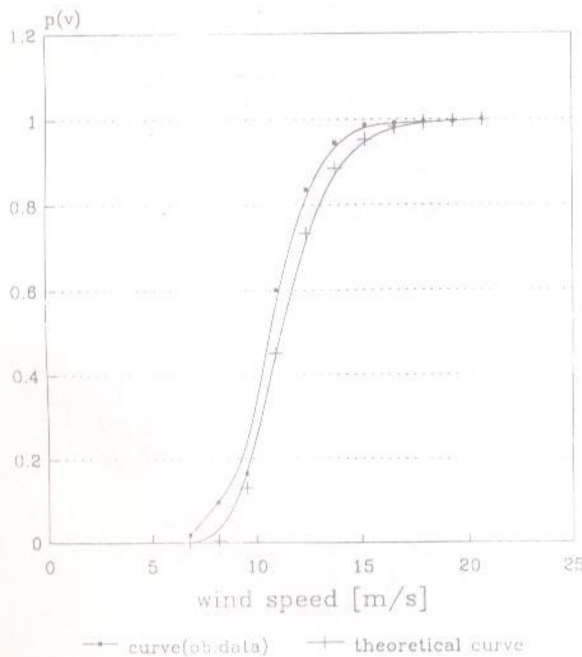
MOSHI



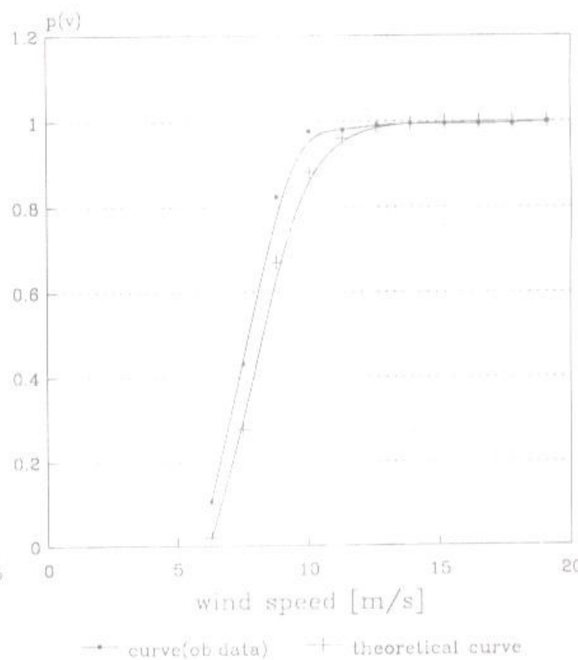
MUSOMA



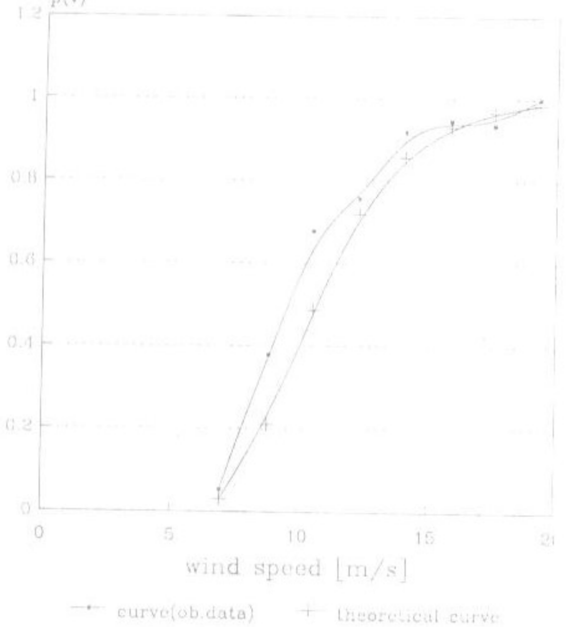
MTWARA



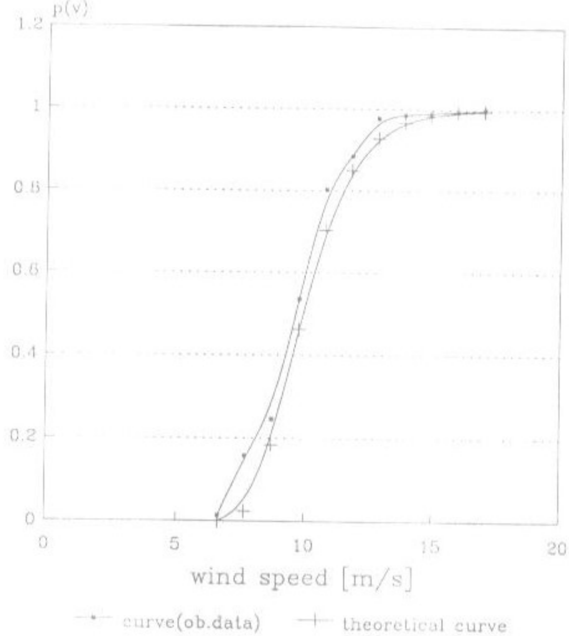
MWANZA



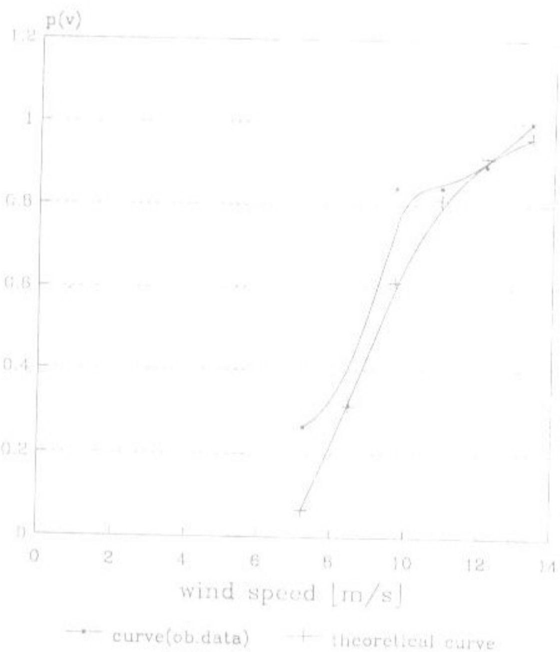
SHINYANGA



SONGEA



SUMBAWANGA



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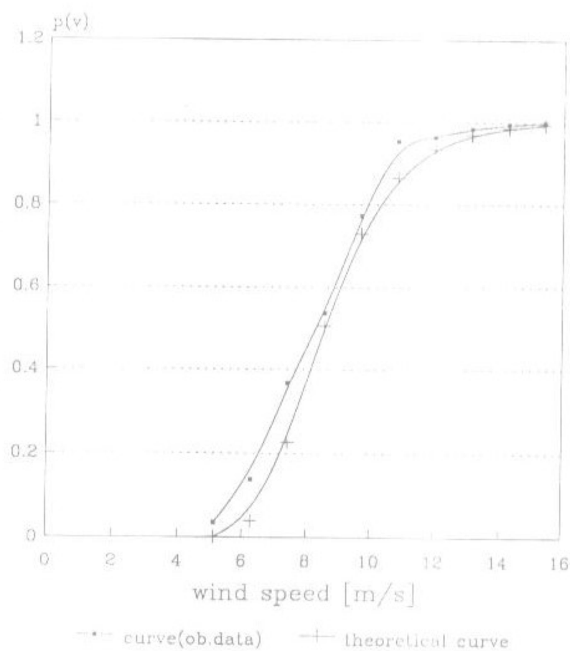

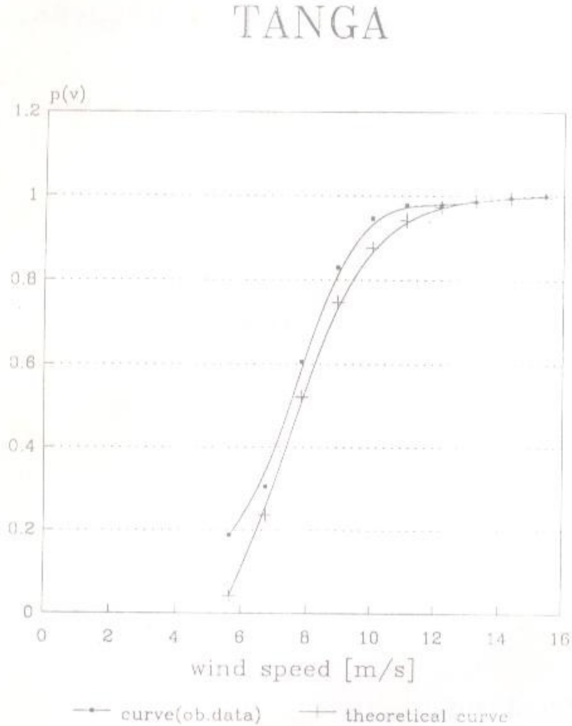

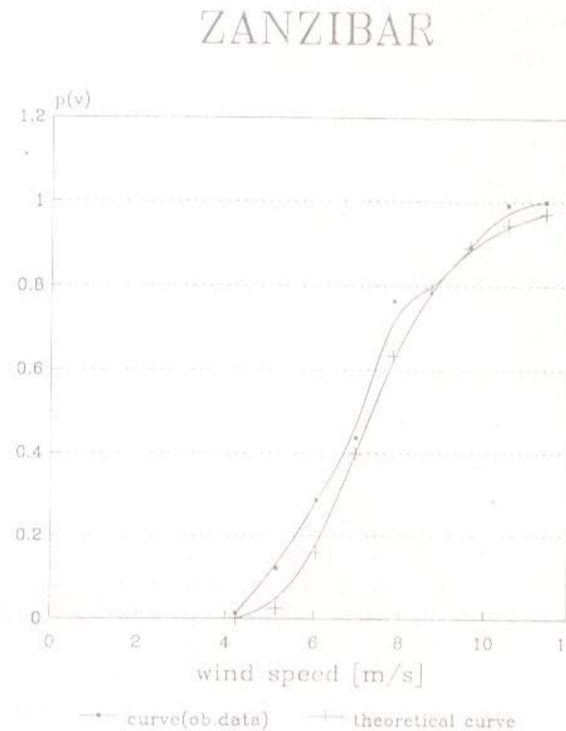

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/3/ BRU Technical Guideline No. 2
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