AT MICROFICHE REFERENCE LIBRARY
A project of Volunteers in Asia

Trees as an Indicator of Wind Power Potential

by: John E. Wade and E. Wendell Hewson

Published by:
Department of Atmospheric Sciences
Oregon State University
Corvallis, OR 97331 USA

Paper copies are $ 1.50.

Available from:
Department of Atmospheric Sciences
Oregon State University
Corvallis, OR 97331 USA

Reproduced by permission of the Department of Atmospheric Sciences, Oregon State University.

Reproduction of this microfiche document in any form is subject to the same restrictions as those of the original document.

TREES AS AN INDICATOR OF WIND POWER POTENTIAL

by

John E. Wade and E. Wendell Hewson
Department of Atmospheric Sciences, Oregon State University

INTRODUCTION

A necessary condition for utilizing wind energy is a knowledge of the strength and persistence of wind. This is particularly true here in the Pacific Northwest where in mountainous terrain the wind may vary considerably over distances less than a kilometer. Since power is proportional to the cube of the wind speed, it is crucial to know the strength of winds at sites being considered.

One of the first steps in determining the feasibility of utilizing wind as a source of energy should be a wind power survey, the purpose of which is to discover windy locations for wind power plant installation. This paper will describe a wind survey technique being developed by Oregon State University under a Department of Energy contract. The technique, called "Biological Wind Prospecting", uses plants as indicators of the strength of the wind. Plants provide a quick, at a glance, indication of strong winds and when calibrated by the degree of wind shaping provide a rough, first-cut assessment of wind power potential.

DEVELOPMENT OF THE TECHNIQUE

Putnam (1948) was the first to use vegetation as a tool in wind power surveys. He classified trees by various degrees of wind deformation which included:

(a) *Brushing*: the branches are bent to leeward only slightly, like the hair in a pelt which has been brushed one way.

(b) *Flagging*: the branches stretch out to the leeward and the trunk is bare on the windward side.

(c) *Wind clipping*: the leading shoots are suppressed and held to an abnormally low level. The upper surface is as smooth as a well kept hedge.

(d) *Tree carpets*: the tree is prostrate and spreading over the ground.

(e) *Winter killing and resurgence*: the leading shoots are killed during the winter.

(f) *Ice deformation*: the formation of ice on the branches in winter causes breakage, leading to a much branched "candelabrum" tree.

Putnam assumed that tree deformation was a function of the annual mean wind speed. He noted that some components of the annual mean wind speed may not contribute to tree deformation; for example, light winds will have little effect on tree form and occasional severe winds without breakage do not affect tree shape but contribute to the annual mean velocity. However wind turbines, he reasoned, react similarly using only speeds in a certain range. In addition, he found turbine output could be predicted from the annual mean wind speed because speed frequency distribution curves in New England are of the same statistical type. Therefore tree deformation should also be a function of the annual mean wind speed.

Putnam's technique, although based on fragmentary observations of trees and often only estimated wind data, showed good agreement between the degree of tree deformation and annual mean wind speed. Barsch and Weischet (1963) and Yoshino (1973) also found agreement between measured wind speeds and the degree deformation of trees. However, none of the above studies attempted to develop relationships between wind velocity and tree form.

In July 1976, Oregon State University initiated a similar study whose purpose was to calibrate in terms of wind characteristics various indices of wind effects on vegetation. These indices, when calibrated, could in turn be used as a first step in selecting sites for wind energy conversion systems.

The first year of the study began with the establishment of a library of information on the affects of wind on vegetation. In addition, five indices of wind affects on coniferous trees were developed and the calibration process was commenced. The results of the first year's research are described by Hewson et al. (1977) and Hewson and Wade (1977).

During the second year, the study of the relationship between the index values and wind characteristics was expanded to over 40 locations in Washington, Oregon, Nevada and California. The primary emphasis in this phase of the study was the calibration of two widely distributed species of conifers, Douglas-fir (Pseudotsuga menziesii) and Ponderosa Pine (Pinus ponderosa) in terms of annual mean wind speed.

Preliminary calibrations have been made on three indices:

Griggs-Putnam Index: a subjective rating scale similar to that developed by Griggs and used by Putnam (1948). The original index has been described earlier.

Deformation Ratio: an indicator of the degree of wind induced crown asymmetry and trunk deflection. The ratio is computed by measuring the angle formed by the crown and the trunk on the leeward side of the tree and dividing by the measured angle formed by the crown and the trunk on the windward side of the tree. The sum of this ratio and the quantity $\gamma/45$, where γ is the angle of permanent deflection of the tree trunk from the vertical, is defined as the deformation ratio, as illustrated in Figure 2.

Compression Ratio: a measure of the influence of wind on the formation of reaction wood and the resulting eccentric radial growth. The ratio is calculated by measuring the increment of growth on the lee side of the tree over some period of time during which winds have been measured and dividing by the increment of growth over the same period on the windward side of the tree (see Figure 3).

Two other indices have been examined but not calibrated. They are:

Shape Index: a measure of the relative influence of wind on apical (height) and radial growth. The index is computed by dividing the circumference of a tree at 1.5 m by its height.

Eccentricity: an indicator of the departure from circularity of the trunk of the tree. This index is computed by measuring the major and minor axes of the tree at 1.5 m and computing eccentricity.

These five indices are calculated from data collected in the field. At each experimental site wind data are being gathered so that the relationship between the wind and each index value can be determined. At many of the locations winds are being measured using recording anemometers and wind vanes, from which monthly averaged wind speeds and directions can be determined. The sites that have been chosen for study have been selected either because of the presence of wind deformed vegetation or because wind information and trees happen to be available in the same area. Wherever possible these shorter period wind measurements are being correlated with nearby longer period records to determine how representative the short period records are.

The procedure needed to develop index values for each tree involves first of all a physical examination of the tree and its environment which includes amount and direction of wind induced flagging, nearby sheltering vegetation which may affect tree form, and terrain influences that may affect stem shape. Measurements are made of tree trunk height and circumference for the Shape Index, major and minor axes of the trunk for the Eccentricity, and the altitude of the location where the tree is growing. A photograph is taken from a point perpendicular to the direction in which the tree is flagged for later laboratory analysis of the degree of wind flagging for determining the Griggs-Putnam Rating and the Deformation Ratio. For the Compression Ratio the tree is cored on the side facing the prevailing wind direction at breast height, 1.5 m, and also on the opposite side of the tree trunk. The two holes in the tree are plugged and the cores are mounted in blocks and labeled for laboratory analysis.

The final step in the field analysis may include the collection of needles, bark and a cone so that positive species identification can be made if necessary by a dendrologist. Up to the present time the study has concentrated on Douglas-fir and Ponderosa Pine, but eight other species of conifers have also been included.

The wind data are processed at Oregon State University to determine hourly, monthly and annual mean wind speed and the percent frequency of winds from each direction. Field data on each tree are processed and the indices defined earlier are calculated. Tree cores are sanded, polished, cross dated and measured for growth increment. The data on the tree rings are cross dated, as shown in Figure 4, to insure that the rings on each side of the tree are aligned and represent the year assigned.

RESULTS

Index values have been computed at 24 locations which have a year or more of wind data. Relationships between the indices G (Griggs-Putnam Index), D (Deformation Ratio), C (Compression Ratio) and $\overline{V}$ (the annual mean wind speed) are given in Table 1 along with r, the correlation coefficient, ME the mean error in the prediction of mean wind speed and P_{25} the percent of time the prediction error is likely to exceed ± 25%.

Table 1. Relationships between $\overline{V}$ and index values.

Index	Relationship	r	ME (%)	P_{25} (%)
G	$\overline{V} \approx 1.05G + 2.72$	.90	14	8
D	$\overline{V} \approx 0.9D + 3.00$	.88	15	21
C	$\overline{V} = 3.6C + 0.32$	.67	22	32

Mean predictive errors were calculated using a Jackknife statistical technique (see Quenouille, 1956 and Gray and Schucany, 1972). The technique involves dividing the sample into as many subsets as there are data points. Regression relations are calculated for each subset leaving out one of the data points. For each regression relation an error estimate is obtained for the point not included. In this way the mean predictive error for each data point is based on a regression equation which does not include that point. The mean error for all the data points is the mean error expected when using a regression relationship developed with all of the data points. In Table 2 and Figures 5 and 6 relationships are shown between the annual mean wind speed and the three indices.

Table 2. Relationship between the Griggs-Putnam Index (G) and the annual mean wind speed ($\overline{V}$) in m sec^{-1}.

G	$\overline{V}$
0	< 3.3
1	3.3 - 4.2
2	4.3 - 5.1
3	5.2 - 6.2
4	6.3 - 7.5
5	7.6 - 8.5
6	8.6 - 11.0*
7	> 11.0*

* Estimated since data are not available for these speed ranges.

Relationships have also been developed between the percent of useable winds P and the indices (see Table 3). The percent of useable winds is defined as the percent of time the winds occur in the range

3.6 - 22.3 m sec^{-1} which is the speed range at which many commercial wind turbines operate.

Table 3. The relationship between P (percent of useable winds) and $\overline{V}$ (the annual mean wind velocity) in m sec^{-1} (other parameters are the same as in Table 1).

Index	Relationship	r	ME (%)	P_{25} (%)
G	P = 12G + 29	.90	15	8
D	P = 10D + 33	.84	19	21
C	P = 18C + 32	.60	32	41

The C index obviously has the greatest amount of error because asymmetric growth may be the result of a number of other factors not related to wind. However, if a large number of trees (six or more) are sampled at each location this error should decrease.

We have also found that coniferous trees in windy locations are shorter, have a greater circumference, trunks are generally egg shaped in a radial cross section with the narrow end pointed in the direction of the prevailing wind, and the direction of the crown and trunk asymmetry are strongly correlated with the prevailing wind direction.

During the next year research will focus on extending these techniques to both other coniferous and deciduous trees. Work is also proceeding in developing techniques for identifying wind deformed vegetation from aerial photographs. The use of aerial photographs would speed the process of selecting sites with good wind power potential.

CONCLUSIONS

Tree deformation appears to be a sensitive indicator of annual mean wind speed and direction and trees may be used to estimate both the annual mean wind speed (mean error ± 17%) and percent of useable winds (mean error ± 22%). This technique could appropriately be used as a first stage in a wind survey prior to instrumentation with anemometers.

REFERENCES

Barsch, D., 1963: Wind, Baumform und Lanschaft: Eine Untersuchung des Windeinflusses auf Baumform und Kulturlandschaft am Beispiel des Mistralgebietes im französischen Rhonetal. In: Freiburger Geographische Hefte, Heft 1, edited by F. Bartz and W. Weischet. Freiburg.

Gray, H.L. and W.R. Schucany, 1972: The Generalized Jackknife Statistic, Marcel Decker Inc.

Hewson, E.W. and J.E. Wade, 1977: Biological Wind Prospecting. Third Biennial Conference and Workshop on Wind Energy Conversion Systems, Washington, D.C., September 1977

Hewson, E.W., J.E. Wade and R.W. Baker, 1977: Vegetation as an Indicator of High Wind Velocity. ERDA Report RLO-2227-77-2, June 1977.

Putnam, P.C., 1948: Power from the Wind. New York, Van Nostrand.

Quenouille, M., 1956: "Notes on bias estimation", Biometrica, 43, 353.

Weischet, W., 1963: Grundvoraussetzungen, Bestimmungsmerkmale und klimatologische Aussagemöglichkeit von Baumkronendeformation, in Studien sum Problem der Deformation von Baumkronen durch Wind. Freiburger Geographische Hefte, (1) 5-19.

Yoshino, M.M., 1973: Studies of wind-shaped trees: their classification, distribution and significance as a climatic indicator. Climatological Notes, 12, Dept. of Geography, Hosei University, Toyko, Japan, 52 pp.

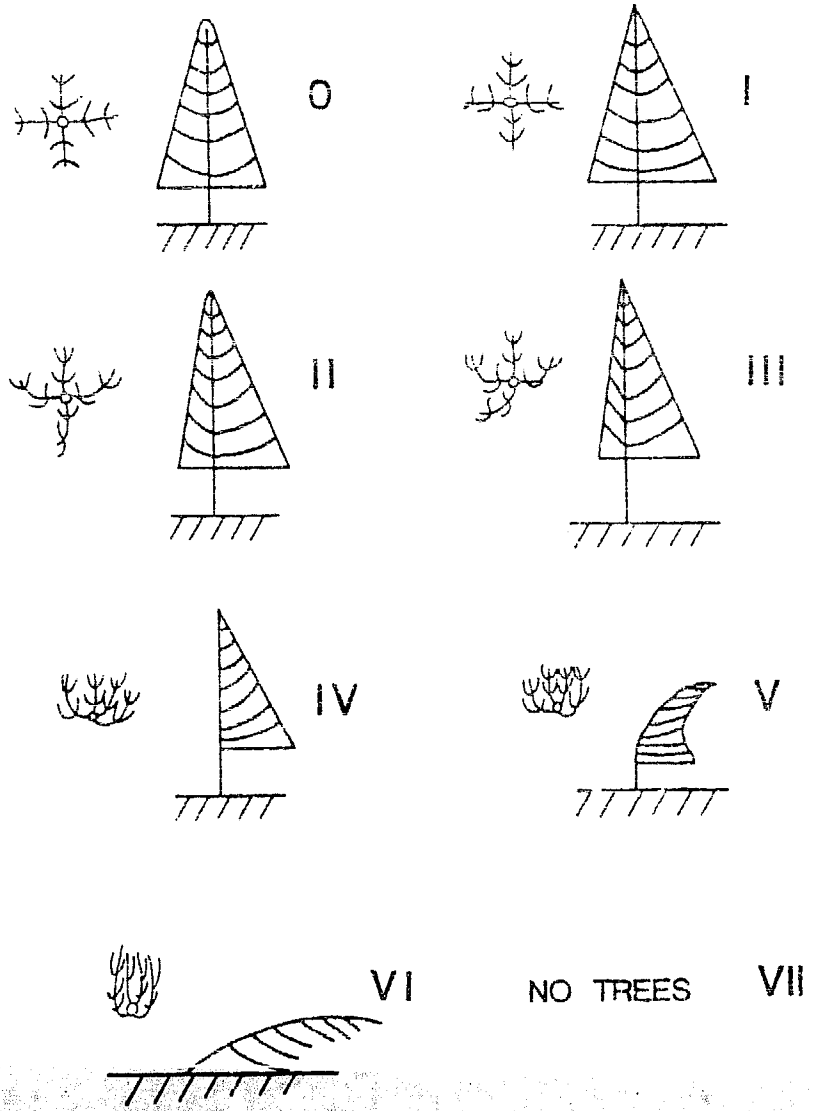

Figure 1. A representation of the Griggs-Putnam Index which is based on external wind deformation of coniferous trees.

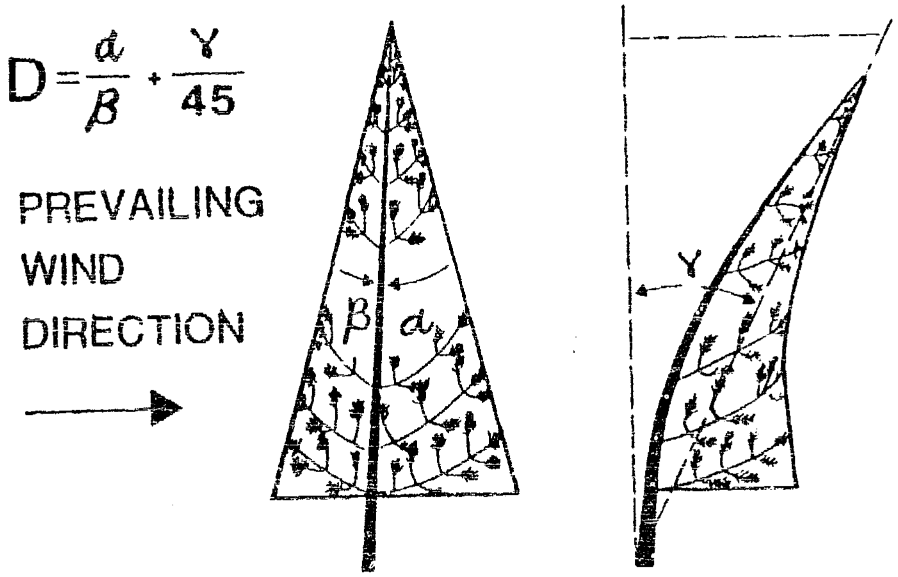

Figure 2. The Deformation Ratio measures the degree of wind induced crown asymmetry and tree trunk deflection. The ratio of α and β has a minimum value of 1 and a maximum value of 5.

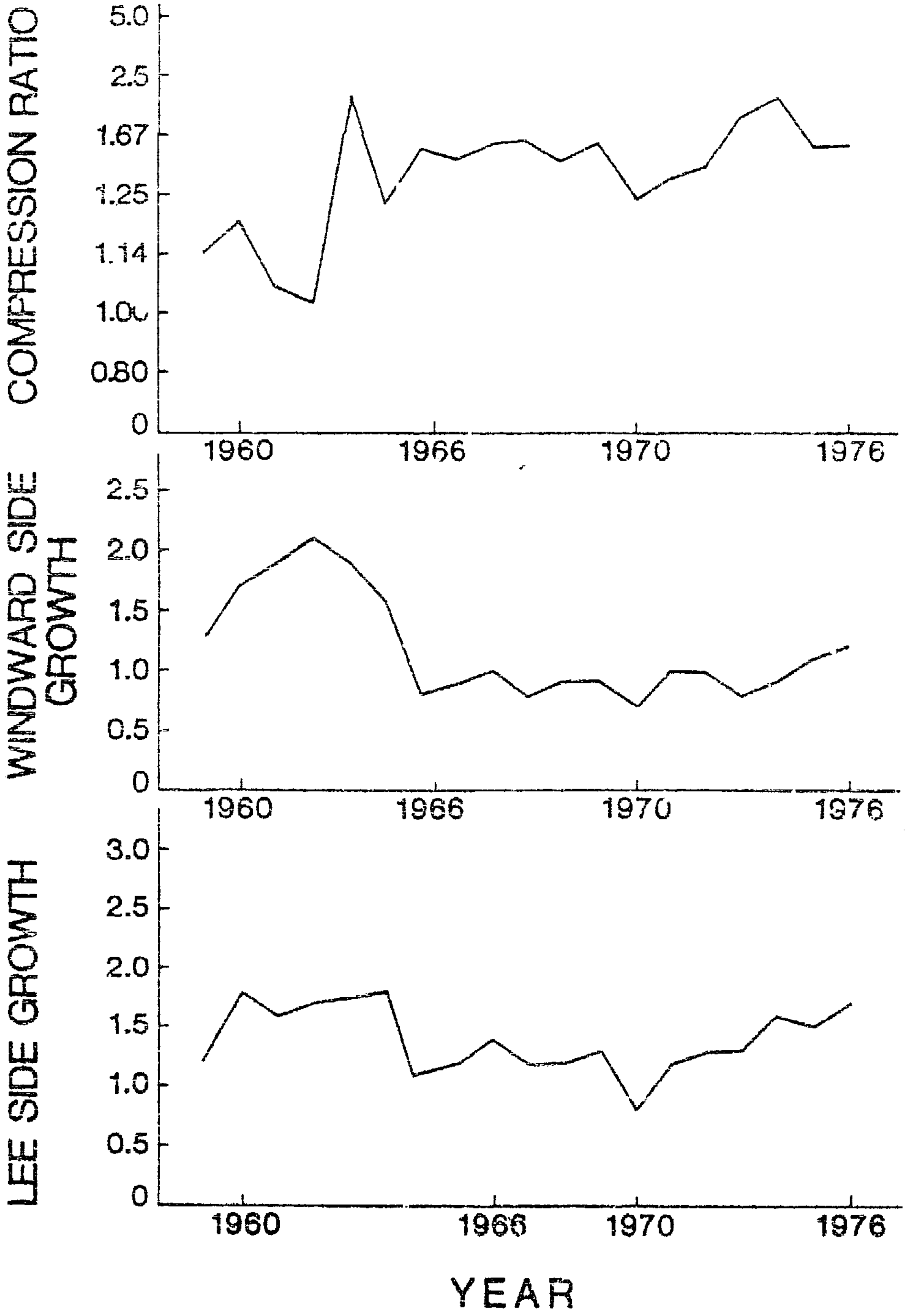

Figure 3. Shows a comparison of windward and leeward growth rate on a coniferous tree. The ratio of the two is called the Compression Ratio and measures the influence of wind on radial growth rate.

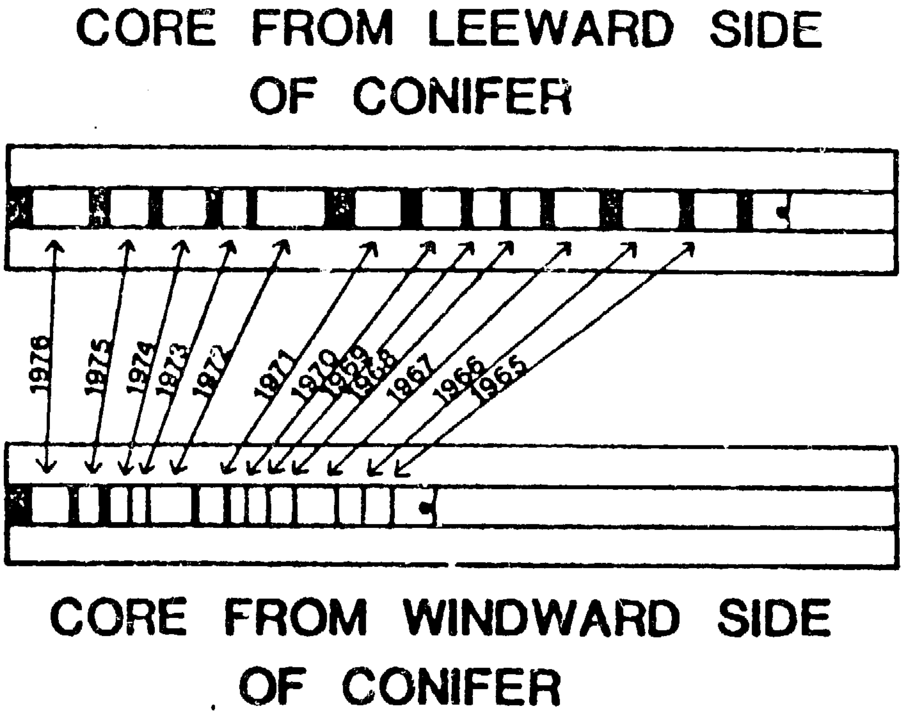

Figure 4. Tree cores are mounted, cross dated and then measured for annual growth increment on the windward and leeward side. Rings on the leeside are wider, and there is a greater proportion of latewood (darkwood). The wider rings are due to compressive stresses on the leeside causing the vertically aligned cells to be shorter and wider.

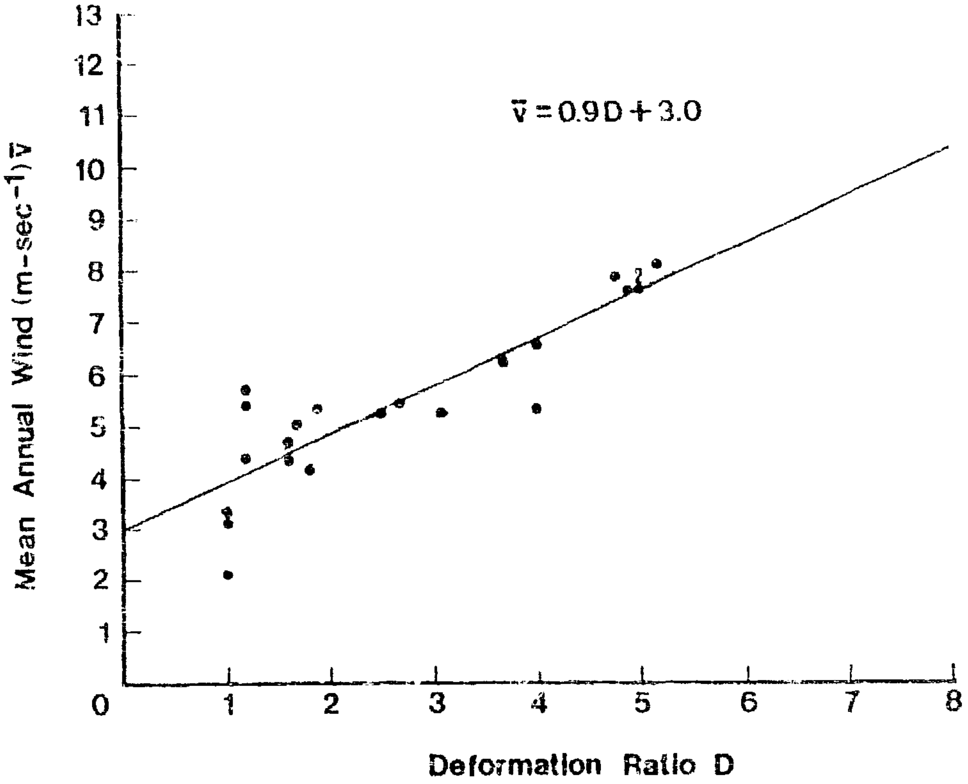

Figure 5. The relationship between the mean annual wind velocity and the Deformation Ratio.

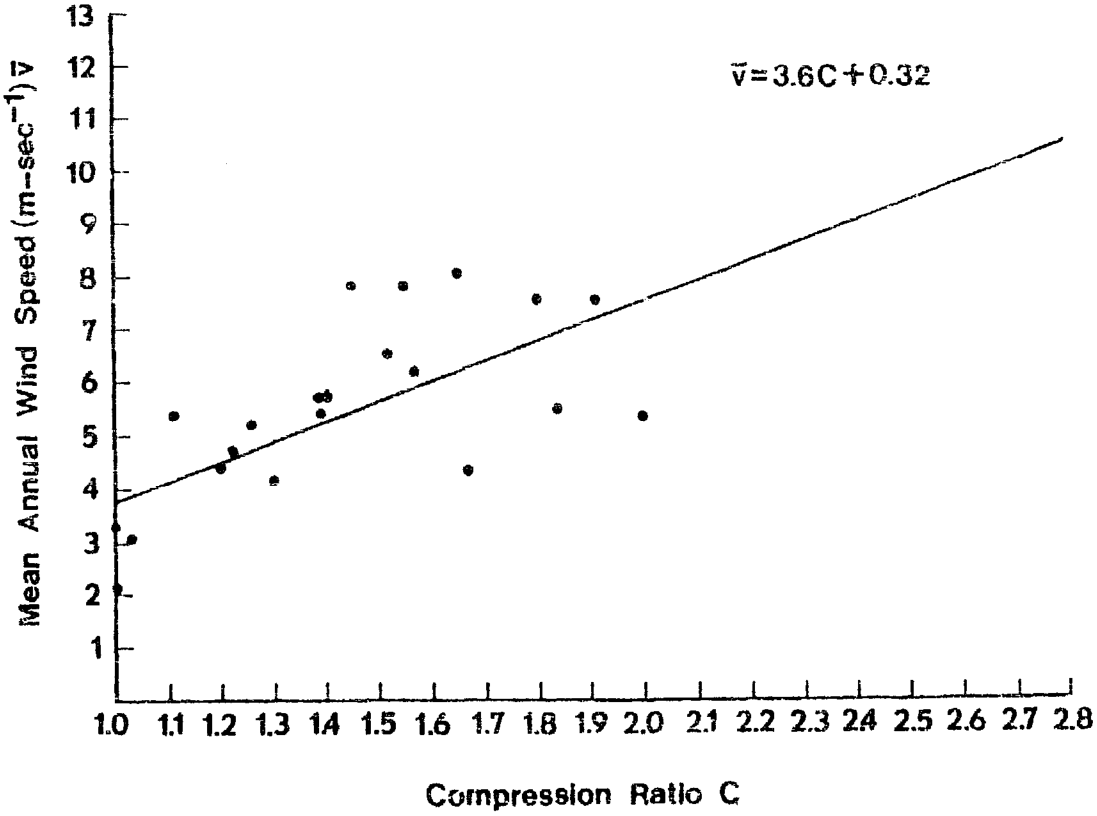

Figure 6. The relationship between the mean annual wind velocity and the Compression Ratio.