Extreme wind over a pine coastal forest established for sand-control at Aoyama of Niigata in Japan

Jiaojun ZHU* Takeshi MATSUZAKI** Yutaka GONDA**

Abstract
Ten-minute mean windspeed, maximum windspeed (gust speed) and the corresponding directions above the top of a sand-control forest of Japanese black pine (Pinus thunbergii Parl.) were recorded continuously over a 20-month period. The maximum 10-minute windspeed recorded was 13.0 m s⁻¹; prevailing wind direction ranged 145°-180° north true. Gust factor changed with mean windspeed in linear function, and averaged at 1.92. The profile parameters of roughness length and displacement height over the sand-control forest canopy averaged at 0.52 m and 5.6 m. The cumulative distribution of windspeed was found to follow the Weibull distribution over the sand-control forest. The coefficients of the two-parameter Weibull model were k=1.36 (an exponent) and c=2.56 m s⁻¹ (a constant). According to the method developed by building design purpose, the parameters of Gumbel distribution (Type I extreme value) for describing the conditional cumulative distribution of the annual extreme (10-minute mean windspeed) were estimated. The most likely extreme windspeed over the sand-control forest in a 50-year period was calculated to be 14.2~15.7 m s⁻¹. Relationships between mean windspeed and gust factor showed that the data were normally distributed about the gust factor versus the regression line of mean windspeed. The relationships can be used to estimate the probability that a gust speed of given wind magnitude will be equaled or exceeded during a period when the mean windspeed is known. The results obtained in this study are very useful in understanding the general wind regime over the sand-control forest areas. It can be concluded that these observations are important for the establishment and management of the sand-control forests nearby the sea because there were few long-term measurements in the strong blown sand areas.

Key words: sand-control forest, extreme wind, Gumbel distribution, gust factor, Weibull distribution

1. Introduction

Wind not only has a great deal of influences on building design but also has more effects on extensive damage to trees and agricultural crops and their growth, form and ecology (Finnigan & Brunet, 1995; Dyrbye & Hansen, 1996). Extreme winds, as natural hazards facing human beings, have extracted their toll of destruction in various parts of the world. The estimates of risk of wind in plant crops and the management of forest require information on the maximum windspeeds likely to occur over a certain period (Milne, 1992). The likely maximum mean windspeeds and the values of gustiness over the rough surface of forests will be not only useful in regard to such classic problems as wind damage, blown sand control, the dispersion and transport of pollutant and nutrient but also significative for establishment and management of the sand-control forests. In a word, the prediction of the wind climate is the cornerstone of any prediction of response to wind (Davenport, 1982).

The meteorological offices all over the world publish data and maps of windspeeds at their recording stations. Before 1964, the wind data from meteorological stations usually took the form of hourly means, and after 1965, 10-minute means are taken (Suzuki, 1968; Takeuchi, 1997). Although these raw data are available, for example, one can obtain the wind data from NCDC Web site (http://www.ncdc.noaa.gov or ftp enh.nist.gov) in USA and from library in Japan freely, only summaries are published in easily accessible form. The summaries usually provide annual means, the distribution

* Graduate School of Science and Technology, Niigata University ** Faculty of Agriculture, Niigata University
of hourly mean windspeeds and the extreme hourly mean windspeeds. Over a period of several decades the extreme windspeeds can be analyzed using extreme value statistical methods such as Gumbel (type I extreme value), Fréchet (type II extreme value) and reverse Weibull (type III extreme largest values) distributions (Simiu & Heckert, 1996; Galambos & Macri, 1999). The usual approach is to use the Gumbel method to fit a Fisher-Tippett distribution to the occurrence of annual extreme hourly mean windspeeds (Cheng & Chiu; 1985) and hence to estimate the extreme hourly mean windspeed which is most likely to occur during a 50-year return period. Alternatively, the probability of occurrence of any value of hourly-mean windspeed can be described by a Weibull distribution fitted to the entire record of hourly values (Galambos & Macri, 1999; Quine, 2000).

However, these analyses seldom include the measures of gustiness, and the data from meteorological office stations are strongly biased toward smooth areas (Quine & Reynard, 1990; Milne, 1992). Although the methods have been developed to standardize the recorded data and the theories used to develop the standardizing technique can also be invoked to predict the wind regime at non-measurement sites, these predictions have not been tested for the roughly typical forest. Furthermore, there is little information on the sand-control forests even though the determination of the wind regime is an important aspect for the establishment and management of the sand-control forests. The purpose of this study is therefore to add to such data and to investigate the wind characteristics above the sand-control forest in order to provide the basic references for the construction and management of the sand-control forests nearby the sea.

2. Materials and Methods

2.1 Sand-control forest and site description

The sand-control forest as a part of the SABO system along the shorelines, represents a very important aspect of the natural environment. Besides the main function of sand-control, the forest nearby the sea can also provide a lot of benefits through preventing the blown sand such as serving as an area of recreation for the people suffering from the noise, air pollution in urban regions, filtering of air and water, leaving of climatic extremes, improving ecological environment, reducing and ameliorating the potential conflicts that may arise etc. (Murai et al., 1992; Grob, 1993; Matsuzaki, 1994). These illustrate that questions regarding the stability and continuity of the sand-control forest system are absolutely necessary. Extreme wind is one of the basic studies for this purpose.

Measurements of wind were made above a pine sand-control forest at Aoyama in Niigata prefecture of Japan near the Japan sea (at N 37°52'41.3", E 138°56'16.8") during the period of November 1998~July 2000. The sand-control forest is composed of Japanese black pine (Pinus thunbergii Parl.), which was established about 35 years ago. The site is slightly sloping down toward the sea (about 4° slope). The sea-side edge of the sand-control forest stretches along a road in about 30° in E—W (about 60° from the true north) to several kilometers. There is a 50-m wide zone of young pine trees between the sand dune nearby the sea and the road. The distance from the shoreline to the road, i.e., the edge of the sand-control forest is about 120 m. The sand-control forest extends about 300 m towards land-side. Further away from the site, there is more variation in topography with buildings. A survey before this measurement showed that the average tree density was 3300 stems ha⁻¹. The canopy had reached a maximum height of 8.5 m in 1999, and the median tree height was 7.8 m. The stem basal area of the plantation was 26 m² ha⁻¹.

2.2 Instrumentation

In order to get the continuous wind data, two observation towers of 10-m height (Tower 1 and Tower 2) were established apart from about 60 m inside the sand-control forest stand. The distance from the sea-side edge of the sand-control forest to the towers is about 80 m. Two sets of propeller anemometers were mounted on a 1-m pole on the top of the towers. The instruments were of light-weight construction (Young Model 05103-16 B, R. M. Young Company, USA, 18 cm diameter 4-balde helicoid) with lower threshold sensitivity and a distance response constant of 2.7 m for 63% recovery. The manufacturer’s calibrations were used because the instruments were new when deployed. The electrical signals of windspeed and wind direction from these instruments were sampled and recorded at an interval of 5 s using data loggers (Kona DS-64 K 2, Kona Sapporo Ltd. Japan). 10-minute mean windspeed and wind direction were recorded. The wind direction
was recorded in sixteen-22.5° compass sectors. Besides the mean values of windspeed and wind direction, the maximum (gust) windspeed, moving windspeed and the corresponding directions in 10-minute period were also recorded. Data used in this analysis were mostly from Tower 2. During the collection of data logger from Tower 2, the wind data collected from the other instrument in Tower 1 were used to fill in the missing times in the database. In all, 87696 sets of 10-minute wind data were collected without break.

During the period of data collection, several weeks of intensive measurements were made at the top of the towers using three-dimensional sonic anemometer (Kaijo Denki DA-600-3 TV, Kaijo Cooperation, Japan). Wind velocity components (longitudinal u, lateral v, vertical w wind velocity) and temperature (T) were sampled and digitized at a rate of 10 Hz by a data-logging system (TR-62 TX, Kaijo Cooperation, Japan) with a data appending system controlled by a computer (PC-9801 NS/L, NEC, Japan). Instantaneous data were put onto the hard disk of the computer in the field. The computation was based on a run of time series of 8192 points over an 819.2 s period.

2.3 Data process

Initial data analysis consists of running through the entire data loggers into a computer. Then, removing wild points (when the battery was nearly used up, the data signals were prone to change greatly) and filling in the missing times in the database for the times when data logger was collected and the wild point appeared. Wind data were sorted by velocity, wind direction and date for calculating.

The daily mean windspeed was estimated as the arithmetical mean (equation 1). The sample number of one day is $6 \times 24$.

$$U_{\text{daily}} = \frac{\sum U_{\text{mean}}}{6 \times 24} \tag{1}$$

where $U_{\text{daily}}$ is daily mean windspeed (m s$^{-1}$), $U_{\text{mean}}$ is 10-minute mean windspeed (m s$^{-1}$).

Gust is defined as a sudden significant increase or rapid fluctuation of windspeed. Generally, the peak windspeed must reach at least 8 m s$^{-1}$ and the variation between peaks and lulls is at least 5 m s$^{-1}$, and the duration is usually less than twenty seconds (http://www.weather.com Copyright ©1999, The Weather Channel Enterprises, Inc. View). Gust factor is defined as the ratio of 10-minute mean windspeed and the maximum windspeed,

$$K_{\text{gust}} = \frac{u_{\text{gust}}}{U_{\text{mean}}} \tag{2}$$

where $K_{\text{gust}}$ is gust factor (non-dimension), $u_{\text{gust}}$ is the maximum windspeed (gust speed) in a 10-minute period (m s$^{-1}$).

In this study, the gust factor was calculated using the wind data to meet the criteria that gust speed and 10-minute mean windspeed in the database could not fall below 8.0 m s$^{-1}$ and 5.0 m s$^{-1}$ respectively. If either of these criteria were not met within the interval, the data would be discarded from the database for gust factor calculation.

Calculation of wind profile parameters obtained from the time series measurements of sonic anemometer is defined later.

3. Results

3.1 General characteristics

During the measurement period, the largest 10-minute mean windspeed recorded was 11.0 m s$^{-1}$ in 1998, 12.8 m s$^{-1}$ in 1999 and 13.0 m s$^{-1}$ in 2000. The daily means over the period are shown in Fig. 1. The daily maximum windspeed was 8.1 m s$^{-1}$ (on January 10 of 1999). There were 15 days occurred when 10-minute mean windspeed over 10 m s$^{-1}$, the corresponding wind directions ranged between 247.5°–360 degree from north true, and more than 75% ranged between 270°–290 degree from north true. There were three storms when the 10-minute mean windspeed exceeded 10 m s$^{-1}$ and lasted for one hour or more. Of the three strongest storms, the first occurred on March 22 of 1999, it started at 06:00 GMT+9, lasted about 10 hours and had a maximum 10-minute mean speed of 12.8 m s$^{-1}$. Gust windspeeds were greater than 20 m s$^{-1}$ for 1% of the time. The next major storm started at 12:30 GMT+9 on 3 January of 2000 and lasted 8 hours. It had a maximum 10-minute mean windspeed of 11.3 m s$^{-1}$, and the gust windspeeds were greater than 20 m s$^{-1}$ for 2% of the time. The last major storm started at 2:40 GMT+9 on 9 February of 2000 and lasted 5 hours. This storm contained the maximum 10-minute mean windspeed of 13.0 m s$^{-1}$ and the gust speeds were greater than 20 m s$^{-1}$ for 30% of the time.

The wind directions recorded over the 20-month period were summarized as the percentage of time that the wind was recorded in each of the sixteen compass
sectors (Fig. 2 A), and as the weighted average of the 10-minute mean windspeed (m s$^{-1}$) over the recording period in each of the sixteen compass sectors (Fig. 2 B). The prevailing direction was in the 145$^\circ$–180$^\circ$ (S–SW) sector. However, the stronger winds come from the opposite sectors (WSW–NNW) (Fig. 2 B). It is more clearly showed when using the wind data that were greater than 4 m s$^{-1}$ (Fig. 2 A). All of the three major storms described above had the directions ranging WSW–NNW sectors. The data show that the sea breeze and local wind-systems are typical for the prefecture of Niigata, Japan.

3.2 Estimation of the profile parameter ($u_*, d$ and $z_0$)

Estimation of the wind profile parameters ($u_*$, $d$ and $z_0$) over the observation plane was made normally by fitting the logarithm law profile in equation (3) to the windspeed over the plane (Abtew et al., 1989; Zhu et al., 2000).

$$\frac{u_*}{u} = \frac{1}{\kappa} \ln \left( \frac{z - d}{z_0} \right)$$

where $u_*$ is windspeed at height $z$ (m s$^{-1}$), $z$ is the height above the observation plane (m), $u_*$ is friction velocity (m s$^{-1}$), $\kappa$ is von Karman’s constant ($\approx 0.40$), $d$ is zero-plane displacement (m); $z_0$ is roughness parameter (m).

Since few levels of windspeed measurements above the canopy of the sand-control forest were available, it is obvious that no real test of equation (3) was con-
ducted in this study. However, this factor is not critical, for the actual measurement of $u_*$ was directly observed with the sonic anemometer. The friction velocity $u_*$ is calculated as,

$$u_* = \sqrt{-u'w'}$$

where $u'$ is longitudinal velocity fluctuation (m s$^{-1}$), $u' = u - \bar{u}$, $\bar{u}$ is mean streamwise velocity (m s$^{-1}$), and $w'$ is vertical velocity fluctuation (m s$^{-1}$), $\bar{w} = 0$, $w' \approx w$, $\bar{w}$ is mean vertical velocity (m s$^{-1}$).

Total 114 runs of sonic anemometer data were used to calculate the parameters of $d$ and $z_0$. There is considerable variation in the estimation of both displacement height and roughness length. The displacement height $d$ varies between 7.7 and 1.3 m, and the roughness length $z_0$ varies between 2.06 and 0.18 m. The most reliable estimates of $d$ and $z_0$ in this experiment probably came from those observations which the airflow blew from the sea (windward direction). From which, the average values of $d$ and $z_0$ are 5.6 m and 0.52 m respectively. This gives the values of $d/h=0.72$ and $z_0/h=0.07$ (h is the median tree height, m). The mean values of $d/h$ and $z_0/h$ are very similar to those obtained by other researchers in other forest areas (Landberg & James 1971; Milne, 1992; Gardiner, 1994).

### 3.3 Distribution of 10-minute mean windspeed

During the measurement period, the frequency of occurrence of 10-minute mean windspeeds greater than 2 m s$^{-1}$ is shown in Fig.3. Various statistical distributions have been suggested to describe the wind climate, while it is commonly assumed that the cumulative distribution of windspeeds can be described by the Weibull distribution (Milne, 1992; Quine, 2000). The two-parameter Weibull equation is expressed as,

$$P_w = \frac{k}{c} \left( \frac{x}{c} \right)^{k-1} e^{-\left( \frac{x}{c} \right)^k}$$

where $P_w$ is the probability of occurrence of windspeed greater than mean windspeed $V$ (m s$^{-1}$), an exponent $k$ (dimensionless) and a constant $c$ (m s$^{-1}$) are parameters of Weibull distribution. The parameters $k$ and $c$ can be used to derive the parameters (mode and dispersion) of extreme value distribution (Simiu & Filliben, 1980, 1982; Simiu et al., 1985). This distribution was fitted to the 10-minute mean windspeed data using a weighted non-linear fitting procedure (Fig. 3). The fitting data were limited to windspeeds greater than 5 m s$^{-1}$ to minimize the effect of the poorer accuracy of the 10-minute means at low windspeeds. The distribution was fitted to have $k=1.36$ and $c=2.56$ m s$^{-1}$ in this study (Fig. 3).

### 3.4 Probability distribution of 10-minute extreme windspeed

Assume that, at a given location, the highest windspeed that is subject to random fluctuation only, follows a probability distribution. Over a period of observation, a data set conforming to the Weibull distribution will have a cumulative distribution of its annual extreme values (Galambos & Marcri, 1999). The distribution of extreme values, which is usually used for building design purpose, is described by a Fisher-Tippett Type I distribution (Miller, 1982; Grigoriu, 1984; Cheng & Chiu, 1985; Gusella et al., 1991; Milne, 1992; Galambos & Marcri, 1999; Quine, 2000) of the form,

$$P_G(x) = e^{-y/\alpha}$$

where $y$ is a reduced variate given by,

$$y = \frac{1}{\alpha} (x - U_G)$$

$P_G(x)$ is the probability that an extreme value will be less than value $x$ in any one year, $U_G$ is the mode of the distribution (i.e. the most likely value of $x$) and $1/\alpha$ is the dispersion, i.e., a measure of the width of the distribution of $x$ (Milne, 1992; Simiu & Heckert, 1996; Quine, 2000).

The extreme windspeed, $U_{ext}$ corresponding to a recurrence interval or return period, $T$ (in years) is given by,

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![Fig. 3 Probability of occurrence of different 10-minute mean windspeeds at Aoyama, Niigata prefecture, Japan. The measured data and the Weibull distribution fitted to these measurements are compared](image-url)
In equation (7), it has been found that equating $x$ to the square of windspeed ($U_{10}^2$) rather than windspeed ($U_{10}$) gives a better fit to the windspeed maximum (Milne, 1992; Quine, 2000). Thus, integrating equations (6), (7) and (8), the extreme windspeed ($U_{10}$) corresponding to an observation period of $T$ years can be calculated from,

$$U_{10}^2 = U_C \cdot \frac{1}{\alpha} \ln \left( -\ln \left( 1 - \frac{1}{T} \right) \right) \quad \text{(9)}$$

The parameters $U_C$ and $\alpha$ can be estimated according to the method using Weibull parameters $k$ and $c$, which is suggested by Milne (1992), that is, $(U_C)^{1/2}/c$ is a simple function of $k$, and $\alpha U_C$ is approximately constant for an area. In this study, the function of $(U_C)^{1/2}/c$ is derived by a third order polynomial of $k$ (equation 10) as suggested by Quine (2000) and $\alpha U_C \approx 5.0$.

$$(U_C)^{1/2}/c = -0.5903k^3 + 4.4345k^2 - 11.8633k + 13.5690 \quad \text{(10)}$$

Applying this function to $k$, an estimate of $U_C^{1/2} = 10.6$ and $1/\alpha = 22.6$ at Aoyama, Niigata prefecture. From equation (9), the extreme 10-minute mean windspeed for a 50-year return period was calculated to be 14.2 m s$^{-1}$ at the measurement height at Aoyama sand-control forest area.

### 3.5 Gust speed and 10-minute mean windspeed

Wind load on forest trees and other structures is determined both by sustained wind and the gusts contained within them (Weggel, 1999). Gust factor as a

<table>
<thead>
<tr>
<th>Windspeed range (m s$^{-1}$)</th>
<th>Gust factor</th>
<th>Sample size</th>
<th>Mean windspeed (m s$^{-1}$)</th>
<th>Mean gust windspeed (m s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U &lt; 5$</td>
<td>1.96</td>
<td>439</td>
<td>5.00</td>
<td>9.85</td>
</tr>
<tr>
<td>$5 &lt; U &lt; 6$</td>
<td>1.95</td>
<td>3635</td>
<td>5.50</td>
<td>10.75</td>
</tr>
<tr>
<td>$6 &lt; U &lt; 7$</td>
<td>1.92</td>
<td>2475</td>
<td>6.52</td>
<td>12.51</td>
</tr>
<tr>
<td>$7 &lt; U &lt; 8$</td>
<td>1.89</td>
<td>1571</td>
<td>7.49</td>
<td>14.16</td>
</tr>
<tr>
<td>$8 &lt; U &lt; 9$</td>
<td>1.85</td>
<td>692</td>
<td>8.45</td>
<td>15.61</td>
</tr>
<tr>
<td>$9 &lt; U &lt; 10$</td>
<td>1.83</td>
<td>191</td>
<td>9.40</td>
<td>17.18</td>
</tr>
<tr>
<td>$10 &lt; U &lt; 11$</td>
<td>1.79</td>
<td>46</td>
<td>10.40</td>
<td>18.66</td>
</tr>
<tr>
<td>$11 &lt; U &lt; 12$</td>
<td>1.76</td>
<td>10</td>
<td>11.52</td>
<td>20.23</td>
</tr>
<tr>
<td>$12 &lt; U &lt; 13$</td>
<td>1.69</td>
<td>5</td>
<td>12.56</td>
<td>21.18</td>
</tr>
<tr>
<td>Weighted Mean</td>
<td>1.92</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
the mean windspeed, it showed that the gust factor decreased with increasing mean windspeed (Table 1); i.
the gust speed is a smaller fraction of the mean windspeed for higher windspeeds. Fig. 5 shows the plot
of gust factor as a function of mean windspeed in the 20-month period of observation over the sand-control
forest at Aoyama, Niigata prefecture. An equation of the form
\[ K_{\text{gust-p}} = a \mu_{\text{mean}}^{b} \]
has been suggested by Weggel (1999), which can be
fitted to the data as the predicted value of the gust factor \( K_{\text{gust-p}} \). But in this study, we find that linear re-
gression expressed as equation (12) can be predicted
the gust factor very well over the sand-control forest
plane.
\[ K_{\text{gust-p}} = -0.0348 \mu_{\text{mean}} + 2.1459 \]
The determination of coefficient \( R^2 \) of equation (12) is
0.987, \( p=0.000 \).

Gust factor also changes with wind direction, the
grouped values by wind direction are summarized in
Table 2. The result shows that the gust factor is very
stable around 1.90 during the sea-side winds (W~N).

4. Discussion

4.1 Extreme 10-minute windspeeds

The most detailed methods for extreme estimations
are those published for the engineering and building in-
dustries. Generally, over a period of \( n \) days, data were
collected for the highest windspeeds, while these obser-
vations are not independent. A method is suggested by
Simiu and Heckert (1996) and examined by Galambos
and Marcri (1999) for modifying the data to achieve
stochastic independence. According to Simiu and Heck-
ert's method, the relationships between the Gumbel dis-
bution parameters \( U_{G} \) and \( a \) and the expected value
\( E(u) \) and standard deviation \( s(u) \) are,
\[ U_{G} = E(u) - 0.57722 \left( \frac{\sqrt{6}}{\pi} \right) s(u) \]
\[ a = \left( \frac{\sqrt{6}}{\pi} \right) s(u) \]
The parameters of the Gumbel distribution were esti-
mated in this way. Applying this function to the re-
corded data over the sand-control forest provided an es-
imate of \( U_{G}^{1/2} = 11.8 \) and \( 1/a = 27.7 \) at Aoyama, Niigata
prefecture. From equation (9), the extreme 10-minute
mean windspeed at the measurement height at Aoyama for a 50-year return period was calculated to be 15.7 m s\(^{-1}\). The result shows that the approximation involved in both methods is in reasonable agreement. The probability that the extreme will be up to 25 m s\(^{-1}\) in any 1-year period was calculated from equation (6) and are presented in Fig. 6. This result suggests that it is a reasonable estimate over the sand-control forest areas to use the method for engineering.

4.2 Statistics of distribution of gust factor

If the differences between the predicted values of \( K_{gust-p} \) from equation (12) and the values of \( K_{gust} \) calculated from the actual data (equation 2) were ranked and assigned a probability using the plotting position equation. The probability, \( P(X) \), while \( X > x \), is expressed as,

\[
P(X \geq x) = \frac{m}{N + 1}
\]

where \( m \) is number of data, which are over a given criteria \( x \), \( N \) is the total number of data.

The resulting values of the differences and the exceedance probabilities were plotted in Fig. 7. This figure shows that the data fit the normal distribution well over most of the ranges except for at the low end of the distribution. Fortunately, the points at the low end of the distribution are unimportant for most applications since they are for low mean windspeed where the gust speed is relatively higher to the mean windspeed. Consequently, the normal distribution appears to provide a satisfactory model for the distribution of the difference between \( K_{gust-p} \) and \( K_{gust} \), and it is assumed that \( K_{gust} \) is normal distributed. The mean and standard deviation (\( \sigma \)) of the original Aoyama data are \( K_{gust}=1.92 \), and \( \sigma=0.179 \). The assumption that \( \sigma \) does not depend on the value of \( K_{gust-p} \) allows one to estimate the gust factor over the sand-control forest using the value of \( \sigma \) derived from the original data obtained at Aoyama, Niigata prefecture.

The relationship developed above can be used to estimate the probability that a wind gust of a given wind magnitude will be equaled or exceeded in the period when the mean windspeed is taken. For example, what is the probability that the wind gust exceeds 22 m s\(^{-1}\) if the 10-minute mean windspeed is 10 m s\(^{-1}\) over the Aoyama sand-control forest?

\[
K_{gust} = \frac{U_{mean}}{U_{gust}} = \frac{22}{10} = 2.2
\]

For a mean windspeed of 10 m s\(^{-1}\), \( \sigma=0.179 \), \( K_{gust-p} = 1.796 \), which is calculated from equation (12), then,

\[
\frac{K_{gust} - K_{gust-p}}{\sigma} = \frac{2.2 - 1.8}{0.179} = 2.24
\]

Using tables for a normal probability distribution, it can be found that,

\[
F(x) = 0.488 \times 2 = 0.976
\]

Thus, \( P(K_{gust} \geq 2.2) = 1 - 0.976 = 0.024 \). This means that about a 2.4% of probability that the maximum wind gust will exceed 22 m s\(^{-1}\) in an interval when the mean windspeed is 10 m s\(^{-1}\).

5. Conclusions

The distribution of 10-minute mean windspeed and its extreme, as well as the gust factor, are predicted reasonably well over the sand-control forest at Aoyama, Niigata prefecture by the methods developed for building design purposes. It is likely that these methods, and the measurements presented here, will be useful in predicting wind damage in the sand-control forest areas. It can be concluded that the results observed from the study are very important for the establishment and management of the sand-control forests nearby the sea because there were few long-term measurements in the strong wind areas.

Acknowledgements

We would like to acknowledge Professor Masashi Yamamoto and the graduate and undergraduate students in SABO Laboratory of Faculty of Agriculture, Niigata University for their great help in making the field in-
vestigation and constructing the observation towers. We would also like to appreciate Professor Tomohiko Kaminani for providing the stand information. Thanks are also due to the Department of Forest, Erosion Control Laboratory, Tokyo University for the loan of the sonic anemometer; and to Department of Forestry, Niigata Prefecture for providing the experimental forest.

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