WIND SHEAR CHARACTERISTICS OF LOCAL WINDS

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ABSTRACT

The paper deals with the investigations of wind characteristics of local winds in the coastal area of Croatia. The measurements of wind speed and direction were carried out on an antenna column at heights of 10, 20 and 35 m. The objective of these measurements was to determine the wind characteristics for dominant winds (bura, jugo, levant) according to the wind rose defined from the measured days. The investigations showed that there are three dominant wind directions for which the relations between the wind shear factor and the wind speed and direction have been analyzed. The obtained values of the wind shear coefficient WSC are relevant considering the social and national interest since a wind-park is planned to be built on the mentioned location. These investigations were carried out in order to determine the National Annex for the norms 1991-2-4: Wind action upon the structure.

KEYWORDS: WIND SHEAR COEFFICIENT, TURBULENCE INTENSITY, WIND SPEED, WIND TURBINE

Introduction

The measured maximum speed and direction of the wind represent important data for the design, construction and exploitation of any structure with a dominant wind load. According to the recommendations of the European norms the main wind parameter used in computation of wind action upon structures is the referent wind speed Vref defined as a maximum 10-minute average speed at 10m level above the ground with a II category roughness which can be expected once in 50 years (the structure duration). Consequently, the most accurate and representative estimation of the Vref speed is of exceptional relevance for the assessment of the wind load and hence for the reliability and safety of the structure. The safety of structures such as wind turbines is significantly influenced by wind gusts of short duration (1-3 seconds), i.e. turbulent wind characteristics at a given location.

The modern wind turbines of today are efficient and capable of producing more power as the height of the turbine rotor increases. Wind speed increases with height and hence the power output from the wind turbines. Therefore, for accurate assessment of wind power potential at a site, one should have precise knowledge of wind speed at different heights. This can be achieved either by measuring wind speed at the hub height of interest or by estimating using 1/7th wind power law. The best and economical way is to make wind speed measurements at two or three heights for a period of at least one year and then calculate the
wind shear coefficient (WSC) using measured values. This WSC then can be used with confidence to estimate the wind speed at hub height. The other important parameter that directly affects the wind power estimates is the air density.

The paper presents the measurements of wind characteristics of local winds at the Bobani location in the vicinity of the city of Split. The investigations were carried out at an antenna column 40 m high, at three levels/heights – 10, 20 and 35 m above the ground during 4 months. The measurements included wind directions and speeds. The turbulent characteristics of wind were studied according to IEC 61400-1 since the mentioned location is important for the construction of a wind-park.

**Background**

The Croatian coastal region is well known for the unstable regime of air circulation with the dominant winds of Bora and Jugo so that the hourly and ten-minutes averaging of wind speed does not present a real picture of the wind regime, which is true particularly for the Bora wind. The Bora wind along the Adriatic Sea can reach velocities up to 70 m/s and depends upon the local features of the surrounding terrain; it is characteristic as a local catabatic, turbulent, strong wind. (Figure 1).

Thus, the following factors such as the position of the coastal belt, the islands, the vicinity of the coast hinterland and the orographic complexity of the Adriatic area, influence the complex thermally conditioned coastal circulation of the air not only near the soil, but also at higher heights.

![Figure 1. Time series of mean hourly wind speed (Vh in m/s), mean 10 minutes wind speed (V10min in m/s) and maximum wind gust at Maslenica Bridge on 21 – 23. December 1998.](image)

This phenomenon was also referred to as a gravity wind. An improvement in the theoretical and experimental approach was made possible due to the mentioned ALPEX-SOP experiment (observational studies based on large frequency of ratio soundings and special aerial measurement) which yielded first reliable data in the northern part of the Adriatic (Smith 1984; Baja 1984 – 1993; Juries 1982 – 1990; Keratin 1982 – 1984; Poje 1982 - 1988; Petkovšek 1976 - 1991; Peroš 1984, 1995; Vučetić 1988 – 1993; et. al.). The results of these studies, obtained by this experiment and subsequent results proved that the Bora in the Adriatic area represents one of rare phenomena, which mainly satisfies the approximations of the hydraulic theory (Smith: 1982-1989) which has significantly changed the traditional view of the Bora as a down-slope wind. Special attention should be paid to the study developed by a Japanese researcher Yoshino (1968 – 1973) entitled "Local wind Bora" and published in 1976.

The first special profile measurements (bottom layer) of the second values of the wind speed and direction were performed at the construction site of the Dubrovnik bridge (2001.).
The measurements were taken at the altitudes of 10, 52 and 140 m for one profile (cross-section) and at the height of 52 m at another profile, at a distance of ca 300 m from the first one.

It should be noted that the changes in the Bora speed considering altitude significantly differ from the wind profile recorded in literature, which is especially evident when in our case the wind speed constantly changes and in most cases the values decrease with the profile height. Investigations on wind engineering carried out during recent years in Croatia (Peroš, B., Bajić A., 2001, 2005; Peroš B. et al. 1998, 2000, 2002, 2003, 2004, 2006.) have provided databases for the development of the National Application Documents for wind action upon structures- wind load according to the Eurocode recommendations.

The investigations of the characteristics of local winds presented in this paper at a specific location in the coastal area of Croatia represent a continuation of the mentioned investigations.

Site and data description

The measurement of the wind direction and speed at the Bobani location (x = 5616682, y = 4828806) were carried out on an antenna column 40 m high at three levels: 10 m, 20 m and 35 m (a.s.l.) above the ground. The measurement data presented in the paper include for each level and for each 10-minute interval the following parameters: average wind velocities, the dominant wind direction and the highest second values of the wind speed with the respective direction and the standard deviation of the wind speed for the period from 12. 2007. – 01. 05. 2008. (Figures 2. and 3.)

For the estimation of the climatic feature of the circulation regime and the presented measured data it is important to know whether the period of the measurements is representative for a several years sequence. In order to prove that it is necessary to have measurement data on wind direction and speed during a longer period at another location in the same climatic region. Consequently, the data on wind speed obtained at the main meteorological station GMP Split Marjan (ϕ= 43o 31’, λ = 16o 26’, hp = 122 m) during a 30-year period 1978-2008 were used. The location of the meteorological station with regard to the measurement column is presented in Figure 2.

The parallel positions of the average daily wind velocities (Figure 4) prove that it is the same climatic region and the correlation 0.9556 shows that the wind velocities at those two locations display significant statistical correlation (Figure 5). This enable the use of the measurement data on the wind direction and speed obtained during a several years period at the GMP Split Marjan station for the extrapolation of a short series of measurements at the
MS Bobani to a several years period. Thus, it was possible to obtain a climatically representative picture of the circulation at the Bobani location which will make possible an evaluation of the meteorological parameters relevant for the determination of the characteristics of local winds. The several years measurements at the Marjan station have also shown that the wind speed reaches highest values during the winter months which is the consequence of very intensive Bora action. That is why the investigations in this paper were limited to the winter period in which we investigated the relation WSC for the dominant wind directions and velocities.

![Figure 4](image.png)

Figure 4. Average daily wind velocities/speeds at 10 (a.s.l.) at the MS Bobani and GMP Split Marjan during the period 20. December 2007 – 18. December 2008.

![Figure 5](image.png)

Figure 5. Relationship between the wind speed at 10 m (a.s.l-) at MS Bobani ($V_{BO}$) and GMP Split Marjan ($V_{ST}$) during the period 20. December 2007 – 18. December 2008.

**Estimation of WSCs**

Figure 6 presents the wind rose defined according to second data recorded at a 10 m height at location MS Bobani.
Three directions of dominant winds: NE (north-eastern wind-bora), E (eastern wind-levant), SE (south-eastern wind-jugo) have been defined according to the wind rose.

The number of recorded data amounts to 973584 out of the possible 11491200 data, i.e. 84.72%. According to the recorded data the wind did not blow during 1.07% of the time period analysed. The dominant winds blew during 63.62% of the considered time period.

The wind shear coefficient was defined by an expression quoted in literature (12)

\[ v(h) = v_{10} \left( \frac{h}{h_{10}} \right)^2 \]  

(1)

The wind shear coefficient was computed from the second values at three levels using the least squares method for each recording with velocities higher than zero. The relationship between the shape coefficient and the measured speed is given in Expression 2.

\[ \alpha = \frac{\sum_i \left[ \log \left( \frac{v_i}{v_{10}} \right) - \log \left( \frac{h_i}{h_{10}} \right) \right]}{\sum_i \left[ \log \left( \frac{h_i}{h_{10}} \right) \right]^2} \]  

(2)
All the recorded data of the computed values $\alpha$ are classified into groups depending upon the wind speed and direction of the measured reference speed at a 10 m height, which is presented in Table 1.

### Table 1. Number of data $\alpha$ in each class

<table>
<thead>
<tr>
<th></th>
<th>0-2 m/s</th>
<th>2-4 m/s</th>
<th>4-6 m/s</th>
<th>6-8 m/s</th>
<th>8-10 m/s</th>
<th>10-12 m/s</th>
<th>12-14 m/s</th>
<th>14-16 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bura</td>
<td>241223</td>
<td>453561</td>
<td>357961</td>
<td>167936</td>
<td>174933</td>
<td>139670</td>
<td>90575</td>
<td>65368</td>
</tr>
<tr>
<td>Levant</td>
<td>480199</td>
<td>1149855</td>
<td>5468010</td>
<td>144850</td>
<td>85301</td>
<td>36371</td>
<td>12949</td>
<td>4990</td>
</tr>
<tr>
<td>Jugo</td>
<td>245962</td>
<td>267581</td>
<td>275919</td>
<td>298560</td>
<td>373678</td>
<td>255859</td>
<td>129764</td>
<td>70708</td>
</tr>
<tr>
<td>$\Sigma$</td>
<td>967384</td>
<td>1870997</td>
<td>1180680</td>
<td>610806</td>
<td>431900</td>
<td>233288</td>
<td>141066</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>16-18 m/s</th>
<th>18-20 m/s</th>
<th>20-22 m/s</th>
<th>22-24 m/s</th>
<th>24-26 m/s</th>
<th>26-28 m/s</th>
<th>28-30 m/s</th>
<th>30-32 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bura</td>
<td>41842</td>
<td>17042</td>
<td>11361</td>
<td>3373</td>
<td>1390</td>
<td>365</td>
<td>42</td>
<td>0</td>
</tr>
<tr>
<td>Levant</td>
<td>1679</td>
<td>302</td>
<td>87</td>
<td>12</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jugo</td>
<td>3360</td>
<td>9200</td>
<td>3180</td>
<td>344</td>
<td>66</td>
<td>7</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>$\Sigma$</td>
<td>76881</td>
<td>26544</td>
<td>14628</td>
<td>3729</td>
<td>1460</td>
<td>372</td>
<td>44</td>
<td>1</td>
</tr>
</tbody>
</table>

Each class of data on values $\alpha$ was statistically processed and it was concluded that the random variable $\alpha$ acts according to the normal distribution. The distribution parameters $\mu$ and $\sigma$ were defined for each class of data and the results are presented in Table 2. The average distribution value and the average speed class for each wind direction were taken as a reliable set.

### Table 2. Statistic values for each set of data

<table>
<thead>
<tr>
<th></th>
<th>0-2 m/s</th>
<th>2-4 m/s</th>
<th>4-6 m/s</th>
<th>6-8 m/s</th>
<th>8-10 m/s</th>
<th>10-12 m/s</th>
<th>12-14 m/s</th>
<th>14-16 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bura</td>
<td>0.2216</td>
<td>0.1846</td>
<td>0.1528</td>
<td>0.1223</td>
<td>0.0982</td>
<td>0.1025</td>
<td>0.0859</td>
<td>0.0671</td>
</tr>
<tr>
<td>Levant</td>
<td>0.1238</td>
<td>0.1191</td>
<td>0.1443</td>
<td>0.1302</td>
<td>0.1027</td>
<td>0.0945</td>
<td>0.0694</td>
<td>0.0444</td>
</tr>
<tr>
<td>Jugo</td>
<td>0.3625</td>
<td>0.2</td>
<td>0.1329</td>
<td>0.1162</td>
<td>0.1025</td>
<td>0.1038</td>
<td>0.0994</td>
<td>0.0887</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>16-18 m/s</th>
<th>18-20 m/s</th>
<th>20-22 m/s</th>
<th>22-24 m/s</th>
<th>24-26 m/s</th>
<th>26-28 m/s</th>
<th>28-30 m/s</th>
<th>30-32 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bura</td>
<td>0.0703</td>
<td>0.0674</td>
<td>0.0522</td>
<td>0.0489</td>
<td>0.0248</td>
<td>0.0094</td>
<td>-0.022</td>
<td>-</td>
</tr>
<tr>
<td>Levant</td>
<td>0.0843</td>
<td>0.0763</td>
<td>0.069</td>
<td>0.0604</td>
<td>0.0528</td>
<td>0.0472</td>
<td>0.058</td>
<td>-</td>
</tr>
<tr>
<td>Jugo</td>
<td>0.0388</td>
<td>0.0285</td>
<td>0.0126</td>
<td>-0.0382</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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Figure 8. – Graphs of the density function for the bora classes

Figure 9. – Graphs for the density function for the levant classes
Each set of data was used for defining the function which best describes the relationship between the speed and wind shear coefficient for each wind direction.

For the NE direction (bora):

$$\alpha(v) = -2,815 \cdot 10^{-5} \cdot v^3 + 1.396 \cdot 10^{-3} \cdot v^2 - 2,611 \cdot 10^{-2} \cdot v + 2,486 \cdot 10^{-1}$$

(3)

For the E direction (levant):

$$\alpha(v) = -3.055 \cdot 10^{-2} \cdot v^3 - 4,236 \cdot 10^{-2} \cdot v^2 - 6,569 \cdot 10^{-2} \cdot v^3 + 5,510 \cdot 10^{-2} \cdot v^2 - 9,186 \cdot 10^{-2} \cdot v + 6,420 \cdot 10^{-2}$$

(4)

For the SE direction (jugo):

$$\alpha(v) = 5,935 \cdot 10^{-6} \cdot v^3 - 3,236 \cdot 10^{-4} \cdot v^2 - 5,571 \cdot 10^{-3} \cdot v + 1,921 \cdot 10^{-1}$$

(5)

Conclusion

The site investigations of the characteristics of local winds were carried out at the Bobani location in the coastal area of Croatia in order to analyse the wind shear coefficient and its relationship to the recommended values from literature according to Expression 1. The investigations showed that the coefficient $\alpha$ is not constant but depends on several factors, primarily upon the wind speed. The regularity of the wind shear coefficient WSC was studied according to the experimental measurements of the characteristic wind direction at a given location: it was shown that for the wind speed at an height of 10 m the wind profile can be approximated for a particular dominant direction. These results can represent a basis for further investigations of the characteristics of local winds depending upon the averaging of the wind speed; they can be subsequently correlated with the turbulent wind characteristics and the estimated wind intensity and used for the possible implementation of wind-parks.
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