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Research on Wind Structure in the Wind Tunnel of Wind Engineering Laboratory of Cracow University of Technology

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Abstract. The paper is devoted to the research of the wind structure in a wind tunnel. The work consists of the measurements of flow velocities with use of the X hot-wire anemometers at different sets of turbulizers, as well as the statistical analysis of the measured signals. Power spectral density functions have been obtained for 45 sets of turbulizers placed at the inflow, then 6 sets related to PSD functions representing real wind characteristics have been selected for further analysis.

1. Introduction

Measurements in a wind tunnel are a basic method of research on wind loads. The wind structure has a great impact on the pressure distribution on buildings (comp. Noda *et al.* (1995)) and the wind field around it. Therefore it is important to determine with experiment what kind of wind structure, is generated by the turbulizing elements in the wind tunnel. Such wind structure parameters as vertical wind speed profile, turbulence intensity profile and wind spectrum are very influential on pressure distributions on stiff models, as well as on the response of aeroelastic ones. Additionally, if the results are to be related to real structures, the models must be kept in appropriate geometrical scale and the flows - in the respective frequency scale. Methods of analysis of the wind structure and the results for the wind tunnel of the Wind Engineering Laboratory of the Cracow University of Technology have been presented here in this paper.

2. Description of wind speed measurements

2.1. Wind tunnel

The wind tunnel where the measurements have been provided has a mixed circulation, open or closed. The measurements have been made with the closed circulation. The basic dimensions of the wind tunnel are: width – 2.20 m, height – from 1.40 m at inflow to 1.60 m at the end of measurement space, length – 10 m. Formation of the the wind structure takes place in the first part of the measurement space at the distance of 6 m. The turbulizing nets, barriers, spires and blocks of the adequate geometry, deployment and with mechanically adjusted heights are used. The maximum mean flow speed in the measurement space is 40 m/s. More detailed description of the wind tunnel can be found in Flaga *et al.* (2004) and Flaga (2008).

The following elements have been used to form wind flow:



Figure 1. Turbulizers and the wind tunnel view.

- triangular cross-section spires of heights: 80, 100 and 120 cm set at inflow, (referred later in the profile symbols as Iv with numbers describing heights);
- T-shape cross-section spires of heights: 80, 100 and 120 cm set at inflow, (it);
- zig-zag barriers with heights: 20, 30 and 40 cm set at inflow, (bz);
- even barriers with heights: 20, 30 and 40 cm set at inflow, (br);
- blocks adjusted to heights of 5, 10 or 20 cm, on the floor between inflow and the measurement space, (kl).

The elements used to generate wind structure are presented in figure 1.

2.2. Measurements

Three sets of anemometers have been used to provide measurements. Anemometer probes, measurement system ATU2001 and the acquisition software has been produced in the Strata Mechanics Research Institute of the Polish Academy of Sciences in Cracow (see Ligęza (2007) and Jamróz & Socha (2007)). The measurements have been made with use of two single wire probes and seven X probes (two wires). The data obtained from single wire anemometers has been used to estimate mean inflow speed, so these probes have been placed aside in front of the model. These values have been verified with use of data obtained from pressure taps placed in the undisturbed flow. Uncertainty of the measurement is 3% and not less than 0.1 m/s. Error analysis for this type of equipment has been presented by Ligęza (2007). The mean wind speed has been set to about 10 m/s during the experiments. The main measurements have been made with use of X hot-wire anemometers placed 1 m in front of the future location of models. The wind speeds have been measured at 28 heights from 6 cm above floor, every 5 cm and with 45 different sets of turbulizers. Three measurements have been made at each height of the probes with sampling frequency 500 Hz and the number of samples is equal to 3000, therefore single measurement time is 6 s. The time series of two, perpendicular to the wires, wind speed components have been measured. Then on this basis, horizontal along wind speed component and vertical one, the resultant vector of wind speed and the standard deviations of turbulent wind speeds have been calculated. Exemplary time series of wind speed components at the height of 76 cm have been presented in figure 2. Data analysis has been performed following recommendations by Elsner (1987), Evans (1974), Hinze (1975) and Shabbir *et al.* (1996).

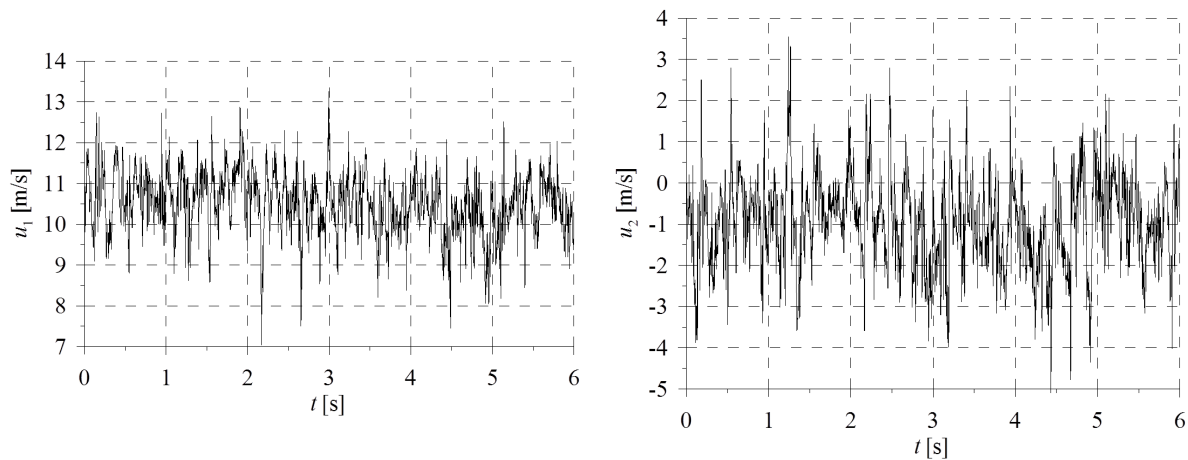


Figure 2. Time series of along wind (left) and vertical (right) wind speed components at 76 cm.

3. Analysis of the flow structure

Mean values, standard deviations, turbulence intensities and FFTs have been calculated for these series of wind speeds in each measurement points. Distribution of the wind parameters along the wind tunnel height or in frequency range for each case of flow has been approximated with the least square method. These approximations for one of the cases have been presented as continuous lines in figure 3.

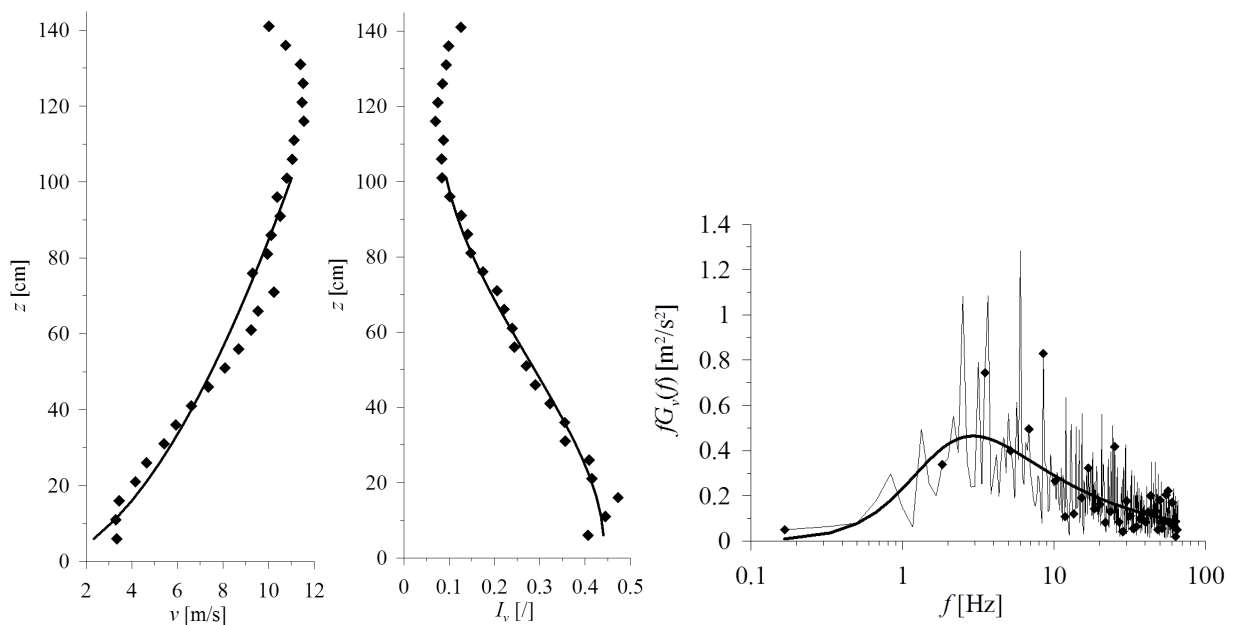


Figure 3. Results of statistical analysis of measurements for the wind profile No.6 (Iv10bz4okl20): wind speed and turbulence intensity profiles, power spectral density function; ♦ measured values, — approximation obtained with least square method.

It has been assumed that the wind profiles may be represented by the power law formulas:

$$v(z) = k \cdot z^\alpha \quad (1)$$

Table 1. Wind profiles parameters.

No.	Symbol	k	α	z_{min} [cm]
1	bz2kl0	4.26	0.20	1.7
2	Iv10bz4okl0	2.42	0.32	0.55
3	it10bz3kl0	3.06	0.28	0.85
4	Iv10bz2okl10	1.77	0.42	0.25
5	it10bz3kl20	1.13	0.52	0.1
6	Iv10bz4okl20	0.87	0.55	0.07

Table 2. Turbulence intensity functions.

No.	$I_v[-]$
1	$I_v(z) = 4.341 \cdot 10^{-9}z^4 - 1.097 \cdot 10^{-6}z^3 + 9.685 \cdot 10^{-5}z^2 - 4.605 \cdot 10^{-3}z + 0.231$
2	$I_v(z) = 7.102 \cdot 10^{-9}z^4 - 1.879 \cdot 10^{-6}z^3 + 1.627 \cdot 10^{-4}z^2 - 6.971 \cdot 10^{-3}z + 0.367$
3	$I_v(z) = 5.190 \cdot 10^{-9}z^4 - 1.292 \cdot 10^{-6}z^3 + 1.096 \cdot 10^{-4}z^2 - 5.291 \cdot 10^{-3}z + 0.293$
4	$I_v(z) = -1.001 \cdot 10^{-9}z^4 + 4.271 \cdot 10^{-7}z^3 - 2.684 \cdot 10^{-5}z^2 - 3.460 \cdot 10^{-3}z + 0.334$
5	$I_v(z) = -1.179 \cdot 10^{-9}z^4 + 5.534 \cdot 10^{-7}z^3 - 4.163 \cdot 10^{-5}z^2 - 4.070 \cdot 10^{-3}z + 0.447$
6	$I_v(z) = -1.907 \cdot 10^{-9}z^4 + 9.583 \cdot 10^{-7}z^3 - 1.187 \cdot 10^{-4}z^2 + 7.448 \cdot 10^{-4}z + 0.440$

where: k and α are the values estimated with the least square method and z [cm] is the height. The resultant wind speed is expressed in m/s. These estimated values for six selected wind profiles (sets of turbulizers) have been presented in table 1.

Turbulence intensity has been calculated according to the formula:

$$I_v(z) = \frac{\sigma(z)}{\bar{v}(z)} \quad (2)$$

where $\bar{v}(z)$ is mean wind speed and $\sigma(z)$ is standard deviation of wind speed. The turbulence intensity profiles have been approximated with 4th order polynomials and presented in table 2.

The wind spectra have been described with the following formula:

$$fG_v(f) = \frac{bf^2}{(1 + cf^2)^d} \quad (3)$$

where b , c and d are the coefficients with values obtained with the least square method, f is frequency in Hz, and the result ($fG_v(f)$) is expressed in m^2/s^2 . The spectra parameters at three heights for the selected sets of turbulizers have been presented in table 3.

Among the 45 wind profiles obtained with respective sets of turbulizers, there are profiles with exponents α from 0.19 to 0.69 and with factors k varying from 0.57 to 5.09. Further analyses have been provided for the 6 selected wind profiles giving most varied parameters. Such selection of the profiles enables analysis of the parameters of wind structure influence on static and dynamic wind action on structures.

The results of the statistic analysis as wind profiles and turbulence intensity profiles for six selected cases are presented additionally in figure 4. Respective graphs of the power spectral density functions measured at three heights are presented in figure 5.

Table 3. Spectra parameters.

-	h=31 cm			h=51 cm			h=71 cm		
No.	b	c	d	b	c	d	b	c	d
1	0.109	0.375	1.293	0.079	0.187	1.396	0.104	0.338	1.329
2	0.233	0.443	1.292	0.407	0.437	1.352	0.549	0.490	1.348
3	0.346	0.774	1.282	0.283	0.474	1.332	0.307	0.777	1.254
4	0.133	0.271	1.354	0.112	0.320	1.322	0.079	0.542	1.230
5	0.388	0.440	1.341	0.171	0.244	1.346	0.104	0.330	1.238
6	0.373	0.520	1.291	0.324	0.288	1.371	0.348	0.356	1.329

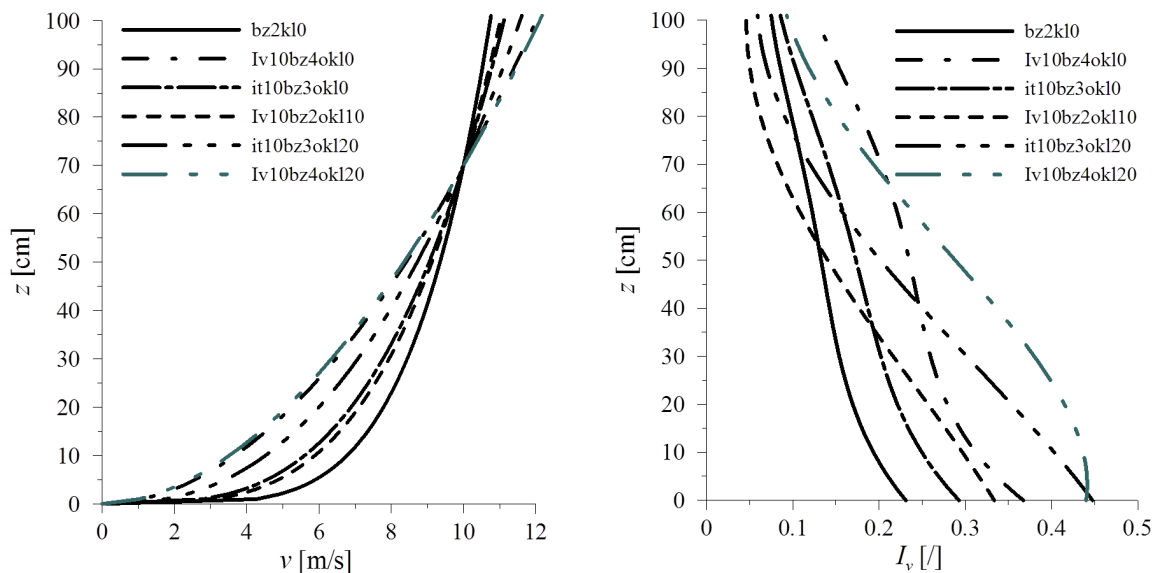


Figure 4. Vertical profiles of wind speed and turbulence intensity.

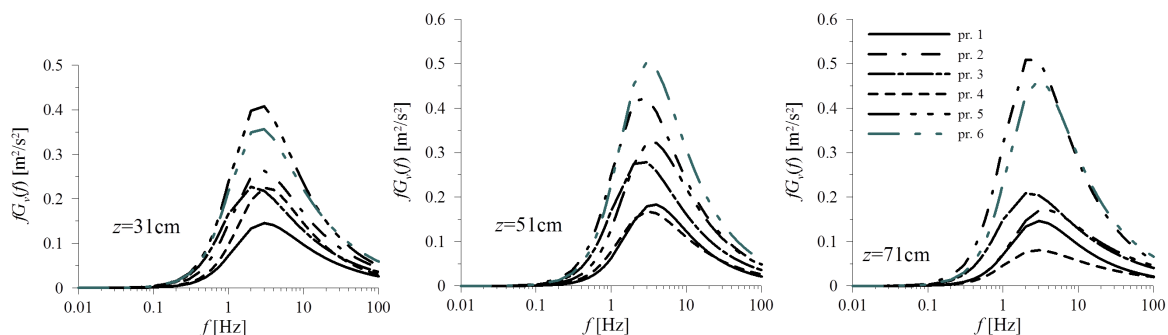


Figure 5. Power spectral density functions for six selected wind profiles at three heights.

4. Conclusions

The presented analysis shows that the wind structure in the Wind Engineering Laboratory of Cracow University of Technology is similar to the real wind structure. With the respective sets of

turbulizers the flows with the wind profiles of the exponents from 0.19 to 0.69 may be obtained. The graphs of the calculated power spectral density functions are of the similar shape as the wind spectrum according to Davenport's formula (Flaga *et al.*, 2004).

The higher turbulizing elements, result in higher values of the wind profile exponent α . The biggest influence on the parameters of the wind structure is produced by the height of the spires. The blocks do not introduce too much turbulence. Their height is most influential when they are applied together with barriers of the 40 cm heights. The higher barriers result in the larger extremes of PSDs. This effect stays in force in case of both, even and zig-zag barriers.

The wind profile in the wind tunnel refers to the real wind profile to the height of 100 cm. Because of this fact, and taking into account the scale of turbulence, which is probably equal to the wind tunnel height, we assume that the geometrical scale should be kept as 1:100. The second scale to be kept is related to frequencies. Comparison of PSDs obtained in wind tunnel and the ones for the real wind, we conclude that this scale should be taken as 1:150.

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