DE GRUYTER OPEN

Vol. 10, Issue 1/2014, 1-9 DOI: 10.2478/cee-2014-0001

THE MULTIPURPOSE NEW WIND TUNNEL STU

Oľga HUBOVÁ[1,*], Peter LOBOTKA[1]

[1] Slovak University of Technology, Faculty of Civil Engineering, Slovak Republic.
[*] corresponding author: olga.hubova@stuba.sk.

Abstract

BLWT STU tunnel, which is currently in test mode, will in its two measuring sections allow to prepare measurements with laminar and turbulent wind flow. The front section will fulfill technical parameters of steady flow for testing sectional models and dynamically similar models. In the rear operating section it is necessary to reproduce correctly the roughness of the earth surface covering different terrain categories and to prepare boundary layer suitable for experimental testing. Article deals with the brief description of the preparation and testing laminar flow and boundary layer for the urban terrain, which was simulated with rough elements and barriers of different heights. The attention is focused in getting get at least 1 meter height of boundary layer, which allows to optimize scale similarity of model.

Keywords:

Experimental technic;
Wind engineering;
Wind flow;
Wind load;
Wind tunnel.

1. Introduction

A newly built BLWT STU wind tunnel enables primarily the experimental assessment of static and dynamic effects of wind on reduced models of buildings and structures or their parts, which are positioned in the turbulent flow, simulating the natural wind in various terrain categories. Boundary wind tunnel STU in Bratislava was designed with open circuit scheme (Fig.1) with overall length 26,3 m and the operation sector of cross-section 2,6 x 1,6 m and length 14,6 m can be divided into front and rear test sections. This device in Bratislava - Trnávka is constructed as a vacuum tunnel. This means that the pressure in the out-of-operation tunnel is equal to the outside barometric pressure. During operation, the static pressure in tunnel decreases counter to the dynamic pressure.

Fig. 1: General view of BLWT STU wind tunnel in Bratislava.

2. The front section

Test section with laminar flow will be used for measurements of aero-elastic instabilities for the slender structures with more than fundamental mode and also for the sectional models. The range of stream velocity varies from 0,2 to 32 m/s. The front section (Fig. 2) is equipped by the reference sensor – Prandtl sensor (Pitot static tube) for assessment of dynamic air pressure and measuring the overall and static pressure.

Using digital probe ALMEMO FVAD 35 TH5K2 detailed measurements of the horizontal profiles of wind speed were made in the front section. Barometric pressure: p_b = 98 770 [Pa], temperature: T = 18,3 - 18,6 [°C], air density: ρ = 1,17548 - 1,1742 [kg/m3].

Results of experimental measurements of wind flow can be seen in Table 1 and in Fig. 3, where U is mean wind speed and U_r is reference wind speed on Prandtl sensor.

Fig. 2: The view of front wind tunnel section.

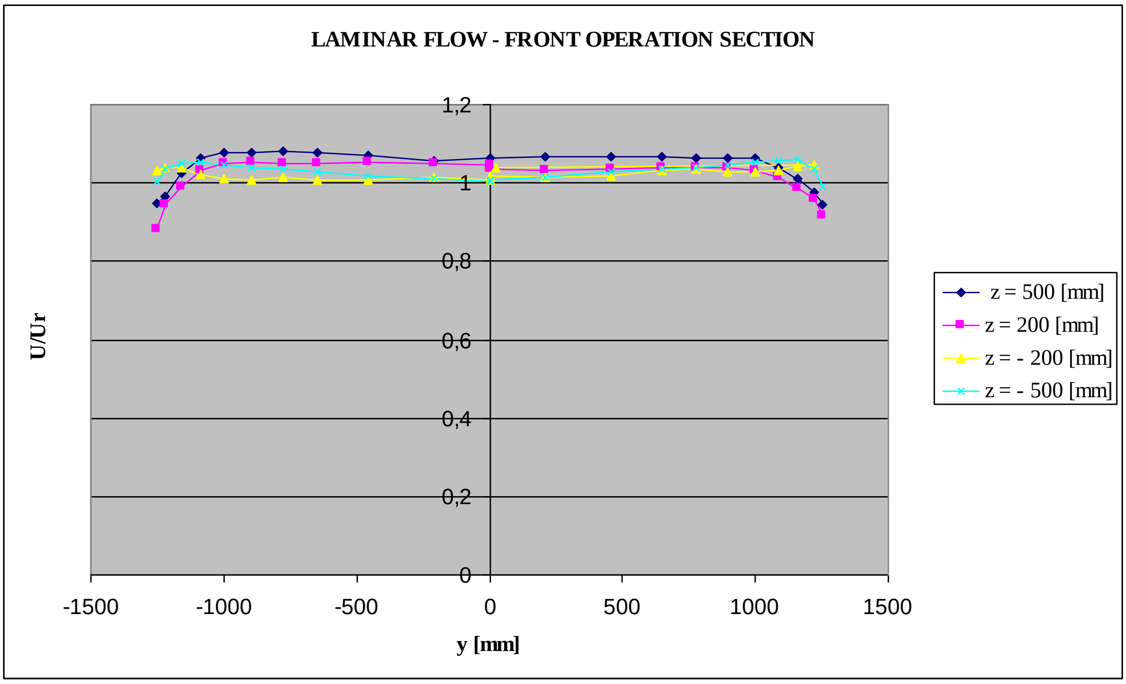

Fig. 3: Laminar flow at different heights in the cross section of front area.

Table 1: Measuring of wind speed at basic height 800 mm ± 200 mm.

	z =+200 mm				*z* = -200 mm			
***y* [mm]**	*q* [Pa]	U_r [m/s]	***U*** [m/s]	U/U_r	*q* [Pa]	U_r [m/s]	***U*** [m/s]	U/U_r
-1250	123	14,466	12,75	0,8814	123,2	14,48	14,96	1,0331
-1220	123	14,466	13,64	0,9429	123,2	14,48	15,07	1,0407
-1160	123	14,466	14,34	0,9913	123,2	14,48	15,06	1,0401
-1085	123	14,466	14,92	1,0314	123,2	14,48	14,79	1,0214
-997	123	14,466	15,16	1,0480	123,2	14,48	14,64	1,0110
-895	123	14,466	15,21	1,0514	123,2	14,48	14,59	1,0076
-778	123	14,466	15,18	1,0494	123,2	14,48	14,71	1,0159
-648	123	14,466	15,2	1,0507	123,2	14,48	14,61	1,0090
-458	123	14,466	15,22	1,0521	123,2	14,48	14,6	1,0083
-208	123	14,466	15,19	1,0500	123,2	14,48	14,69	1,0145
0	123	14,466	15,11	1,0445	123,2	14,48	14,61	1,0090
0	123,3	14,48	14,99	1,0352	123,3	14,49	14,73	1,0166
208	123,3	14,48	14,93	1,0311	123,3	14,49	14,71	1,0152
458	123,3	14,48	14,97	1,0338	123,3	14,49	14,74	1,0173
648	123,3	14,48	15,06	1,0401	123,3	14,49	14,98	1,0338
778	123,3	14,48	15,04	1,0387	123,3	14,49	15,01	1,0359
895	123,3	14,48	15,05	1,0394	123,3	14,49	14,9	1,0283
997	123,3	14,48	14,93	1,0311	123,3	14,49	14,89	1,0276
1085	123,3	14,48	14,7	1,0152	123,3	14,49	14,95	1,0317
1160	123,3	14,48	14,29	0,9869	123,3	14,49	15,11	1,0428
1220	123,3	14,48	13,87	0,9579	123,3	14,49	15,18	1,0476
1250	123,3	14,48	13,25	0,9151	123,3	14,49	15,06	1,0393

3. The rear operation section

Test section provides turbulent flow with the height – depending structure of the surface of the atmospheric boundary layer above terrain of specific roughness in the scale 1:300 – 1:400. Model tests in this part enable to detect local pressure, surface and overall wind load under various wind directions using the turn table and to determine mean and fluctuation wind load of structures having atypical special shapes for which the wind effects are not specified in standards. This sector is also proper for assessment of wind effects upon the pedestrians as well as for monitoring of wind comfort in built-up areas.

4. Simulation of the ABL

The mean velocity profile above FUR terrain (FUR - Flat Uniformly Rough) up to the geostrophic height can be formed in works by Panofsky and Dutton [7]. The thickness of the ABL is defined like height, where surface shear stresses may be neglected and wind velocity is constant. The vertical line of the mean wind velocity by the neutral air flow should be defined by logarithmic law (1).

$$v_m(z) = (u_* / \kappa) \cdot \ln(z / z_0) \tag{1}$$

where $u_* = \sqrt{\tau_0 / \rho}$ is frictional speed,
τ_0 is shear stress at the ground,
ρ is air density,
κ = 0,4 is von Kármán coefficient,

z_0 is parameter, which describes logarithmic law profile of the mean wind velocity above different roughness of the terrain (height of extrapolation to the mean wind = 0).

Aerodynamic roughness lengths according Wieringa for different types of terrain can be formed in [6].

The mean wind velocity due to EN 1994-1-4 [1] depends on terrain roughness and is defined up to 200 m by logarithmic law:

$$v_{\mathrm{m}}(z) = c_{\mathrm{r}}(z) \cdot c_{\mathrm{o}}(z) \cdot v_{\mathrm{b}} = k_{\mathrm{r}} \cdot \ln(z / z_0) \cdot 1 \cdot v_{\mathrm{ref}} \tag{2}$$

where v_{ref} is basic wind velocity at the height 10 m above terrain FUR (Flat Uniformly Rough – Terrain II).

$c_{\mathrm{r}}(z) = k_{\mathrm{r}} \ln(z / z_0)$ is the roughness factor for $z_{\min} \leq z \leq z_{\max}$ (3)

$k_{\mathrm{r}} = 0{,}19 \cdot (z_0 / z_{0,\mathrm{II}})^{0{,}07}$ is terrain factor, depends on the roughness length z_0 :

z_0 is roughness length,

$z_{\min}$ is minimum height,

$z_{\max}$ is 200 m.

$c_{\mathrm{o}}(z)$ is orography factor

$z_{0,\mathrm{II}} = 0{,}05$ m (terrain Cat. II), $z_0 = 0{,}3$ m (terrain Cat. III), $z_0 = 1$ m (terrain Cat. IV)

5. Preparation of the boundary layer

Simulated boundary layer requires the similarity criteria in four basic parameters:
1/ profile of mean value of longitudinal component of velocity vector,
2/ profile of turbulence intensity of this component,
3/ integral length scale,
4/ power spectral density of vortexes in the air flow.

Velocity profiles must be investigated for different roughness and we are able to obtain information on type and quality of boundary layer. The special devices like grids or foil and 2D barriers (Fig. 4) or Counihan vortex generators are inserted along wind tunnels (see [3], [4], [5]).

Fig. 4: Arrangement of simulation of boundary layer in BLWT STU (wall 100 – 250 mm).

For this purpose an anemometer with heated wire is a proper device, working on the principle of King's cooling law. CTA (Constant Temperature Anemometry) is used for measuring velocity in a point and continuously provides information on the velocity in time series. Presently the BLWT tunnel is equipped with Mini CTA (Fig. 5, 6), sufficient for simple experiments.

Fig. 5: View on the moveable arm with mini CTA probe.

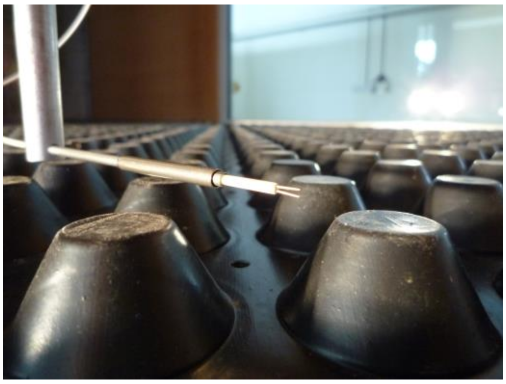

Fig. 6: View of the probe near the rough surface.

The results of the experimental measurements in the preparation of boundary layer and comparison with EN 1991-1-4 are shown in Fig. 7, 8.

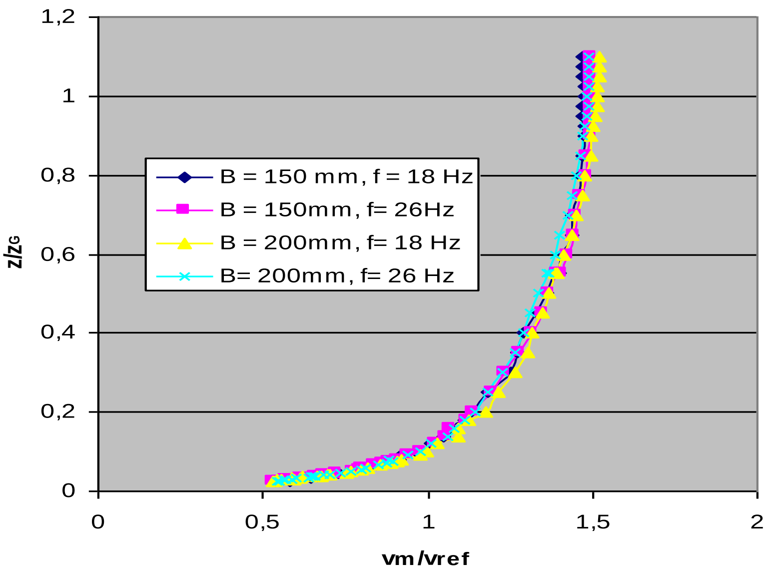

Fig. 7: Experimental measurements of the $v_{\mathrm{m}}(z)$ for different height of barriers (B) and wind velocity.

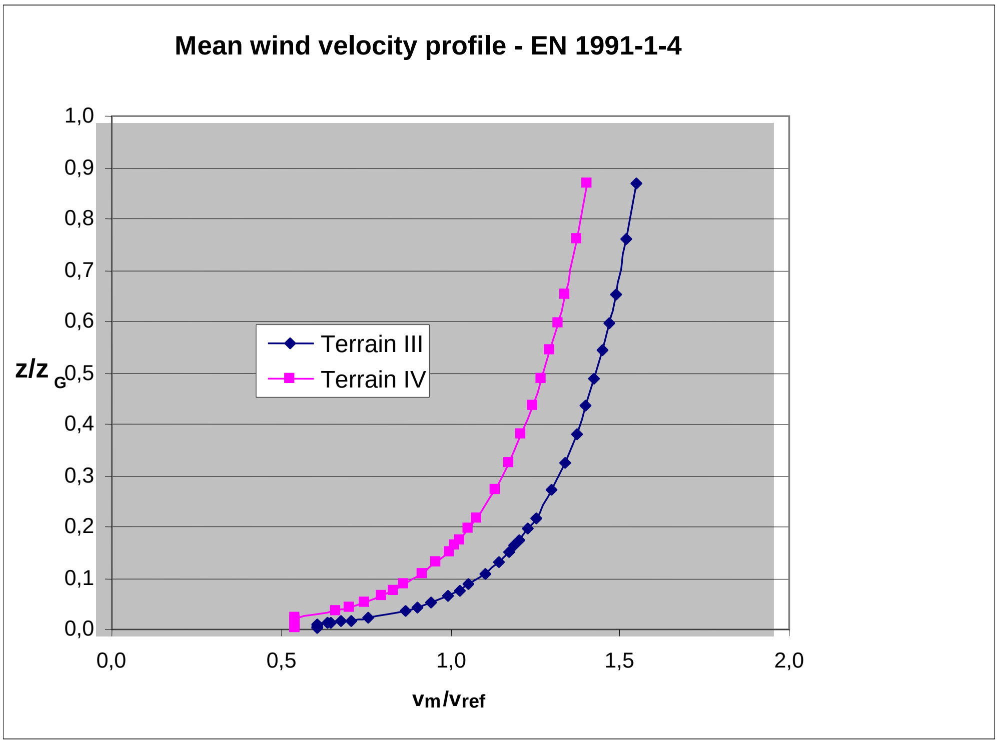

Fig. 8: Mean wind velocity as a function of height and terrain category.

By comparing Fig. 7, 8, we can see, that the prepared boundary layer is between terrain category III and IV.

6. The turbulence intensity

The turbulence intensity $I_{\mathrm{v,i}}(z)$ is defined as the standard deviation of the turbulence divided by mean wind velocity in different directions (*x*, *y* and *z*). The values of turbulence intensity were developed using micro-meteorological measurement by different researchers (Kaimal, Busch, Panofsky). The rules for determination of $I_{\mathrm{v,i}}(z)$without thermal effects are given in expression (4).

$$I_{\mathrm{v,i}}(z) = \frac{\sigma_{\mathrm{i}}(z)}{v_{\mathrm{m}}(z)} = \frac{A_{\mathrm{i}}}{\ln(z/z_0)} = \frac{\kappa \cdot (\sigma_{\mathrm{i}}/u*)}{\ln(z/z_0)} \qquad (4)$$

For along wind part A_{i} = 1, for crosswind part A_{i} = 0,8 and for vertical part A_{i} = 0,5.

In general, the longitudinal turbulent component is the most significant with respect to the response of a structure.

The similar distribution of the turbulence intensity for along wind is given in EN 1994-1-4 (5).

$$I_{\mathrm{v}}(z) = \frac{\sigma_v(z)}{v_m(z)} = \frac{k_I}{\mathrm{c_o}(\mathrm{z}) \cdot \ln(z/z_0)} = \frac{1}{\mathrm{c_o}(\mathrm{z}) \cdot \ln(z/z_0)} \qquad (5)$$

The results of the experimental measurements of boundary layer and comparison with EN 1991-1-4 are shown in Fig. 9, 10.

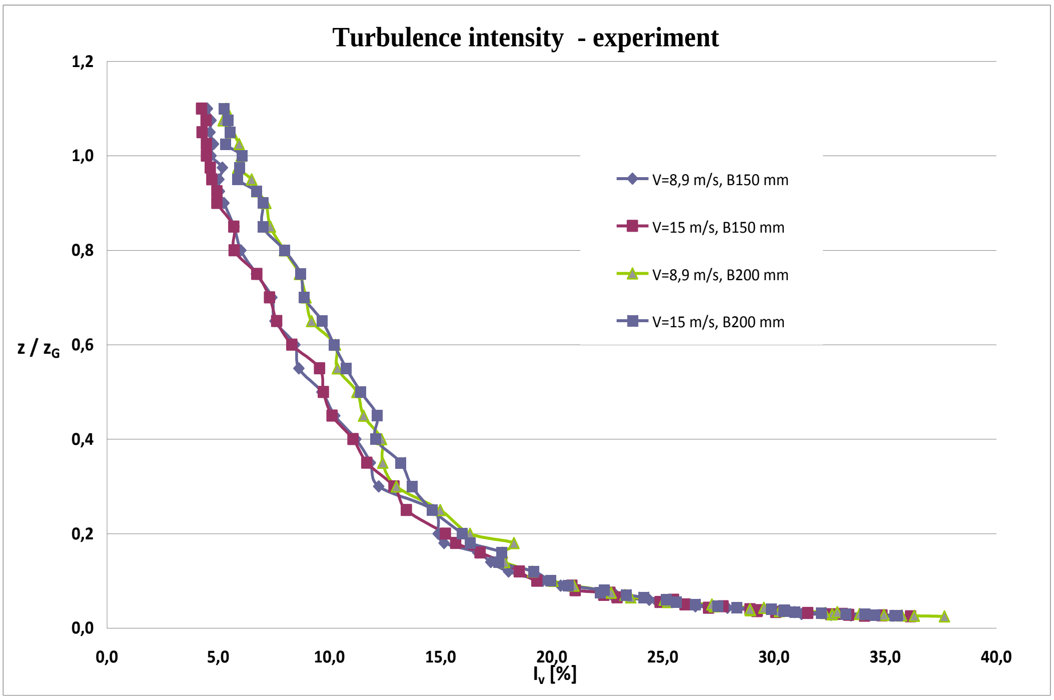

Fig. 9: Experimental measurements of the $I_v(z)$ for different height of barriers (*B*) and wind velocity.

By comparing Fig. 9, 10, we can see, that the prepared boundary layer with turbulence intensity is between terrain category III and IV.

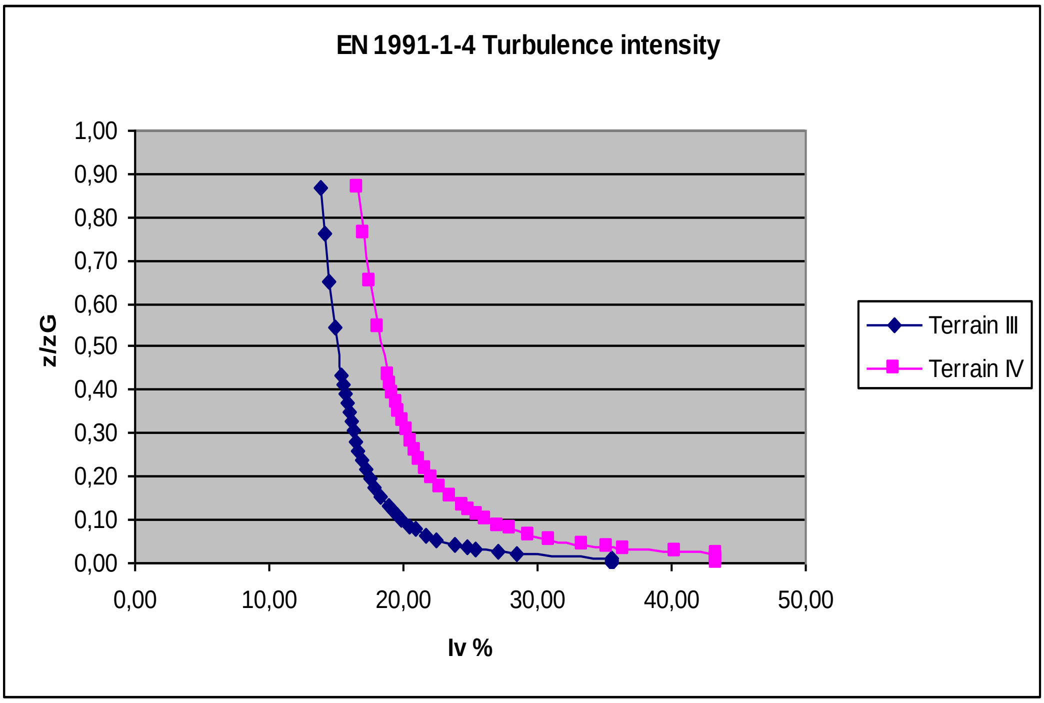

Fig. 10: The turbulence intensity as a function of height and terrain category.

7. The integral length scale

The turbulent length scale represents the average gust size for natural wind. For height *z* and for along wind part of turbulence should be determined by expression (6):

$$L_{u,x}(z) = v_m(z)\int_0^\infty \frac{R_{uu}(\tau)}{\sigma_u^2}d\tau \tag{6}$$

where $R_{uu}(\tau)$ is autocorrelation function of fluctuating part in wind direction and σ_u^2 is the variance of along wind velocity.

According to Counihan [8] integral length of turbulence can be expressed as follows:

$$L_{u,x} = 300\cdot(z/300)^{\varepsilon} \tag{7}$$

$$\varepsilon = 0{,}46 + 0{,}074\cdot\ln(z_0)$$

The modify expression for the turbulent length scale $L(z)$ can be find in Annex B EN 1991-1-4 [1] where length scale depend on roughness length z_0.

$$L(z) = 300\cdot\left(\frac{z}{200}\right)^{0{,}67+0{,}05\ln(z_0)} \tag{8}$$

Experimental measurement in BLWT STU and comparison with Counihan [8] and EN code [1] are presented in Fig. 11.

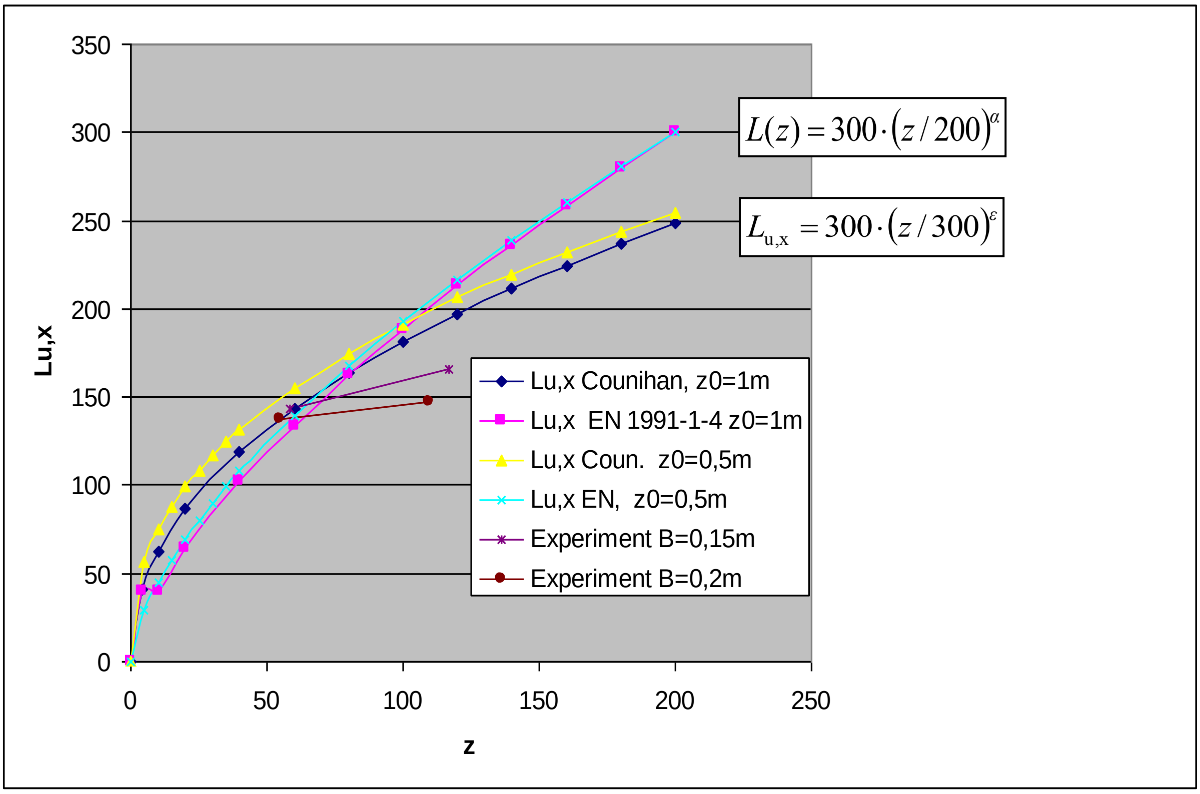

Fig. 11: The integral length scale for terrain category IV - III and experimental results in BLWT STU.

8. Conclusions

The paper shows that detailed measurements of the wind action, especially near the ground, help us to prepare boundary layer in BLWT STU according to EN 1991-1-4. It is necessary to compare various measurements with different barriers (height *B* = 0,1 – 0,25 m) and choose optimal parameters for roughness in wind tunnel. By comparing the velocity and turbulence of the surface layer we could classify terrain roughness between the III and IV according to EN 1991-1-4 standard, which corresponds to the roughness of terrain in Bratislava. The basic design characteristics of the boundary layer, i.e. components of the time and height dependent wind velocity vector, give us roughness len z_0, turbulence length scales $L_v(z)$ and power spectral density function $S_v(n)$. Experimental measurements in BLWT STU so far have ensured height of boundary layer about 1,05 m and SF 366 - 390. Due to the fact that the roughness length for area with regular cover of buildings or vegetation - terrain category III z_0 = 0,3 m, our boundary layer in wind tunnel with value z_0 = 0,7 – 0,77 m is closer to the terrain category IV (area with at least 15 % of the surface covered with buildings while their height exceeds 15 m), where z_0 = 1 m.

Acknowledgement

The presented results were achieved under sponsorship of the Grand Agency VEGA of the Slovak Republic (grant. reg. No. 1/0480/13).

References

[1] EN 1991-1-4 Eurocode 1: Actions on structures-Part 1-4: General actions-Wind actions 2005.

[2] PIRNER, M. - FISCHER, O.: Zatížení staveb větrem, vydalo ČKAIT Praha 2003, ISBN 80-86769-10-0.

[3] JIRSÁK, M. - HORA, A. - KRÁL, J.: Větrný tunel VZLÚ/KÚ ČVUT pro modelové zkoušky staveb. Letecký zpravodaj č.1, 8-15 VZLÚ 1997.

[4] ACSE Manuals and Reports on Engineering Practice, no.67. Wind Tunnel studies of buildings and structures. Aerospace Division of the American Society of Civil Engineers. Preklad Jirsák, M.: Studie budov a konstrukcí ve vetrných tunelech., ČKAIT Praha, 2009, ISBN 978-80-87093-87-0.

[5] JIRSÁK, M. – KRÁL, J.: A new wind tunnel VZLÚ/KÚ for wind engineering, EECWE' 94 paper, Warszaw 1994.

[6] WIERINGA, J.: Representative Roughness Parameters for Homogeneous Terrain. Boundary Layer Meteorology, 63, p. 323-363, 1993.

[7] PANOFSKY, D. A. – DUTTON, J. A.: Atmospheric turbulence: Models and methods for Engineering Applications, Wiley, New York, 1983.

[8] COUNIHAN, J.: An Improved Method of Simulating an Atmospheric Boundary Layer in a Wind Tunnel, Atmosf. Ennviron., 3, p. 197 – 214, 1969.

[9] HUBOVÁ, O.: The effect of the wind on the structure, Slovak Journal of Civil Engineering 2007/3, Volume XV, pp. ISSN 1210-3896, 2007.

[10] HUBOVÁ, O.: Aeroelasticata, Statické a dynamické účinky vetra na stavebné konštrukcie, vydavateľstvo STU Bratislava, ISBN 978-80-227-3886-6, 2013.