PRESSURE COEFFICIENTS ON THE MODEL OF SILSOE CUBE DETERMINED BY TESTS IN BLWT TUNNELS

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1. Introduction

Paper deals with determination of wind pressure coefficients on the model of SILSOE cube by experimental measurements done in two different BLWT tunnels. First set of measurements was done in VZLU tunnel (Výzkumný a zkušební letecký ústav, a.s.) in Prague. After that, the same measurements were repeated in new BLWT tunnel, which belongs to The Slovak University of Technology in Bratislava (STUBA). Obtained results were compared with literature.

The main purpose was verification of simulated boundary layer in STUBA BLWT tunnel, which was put into the test operation at the end of 2013. This universal wind tunnel contains two operating spaces, which are suitable for analyses of laminar wind flow (front operating space) and turbulent wind flow (rear operating space). Total length of tunnel is 26.35 m. Dimensions of cross-section of tunnel are 2.6 m x 1.6 m (w x h).

This type of analysis is ideal for the solution of the given task, because the same model of SILSOE cube was used in two BLWT tunnels with different parameters and dimensions.

2. The real SILSOE cube and in-situ measurements

The real cube with length of edge equalled to 6 m was built in Silsoe Research Institute (England) in 2000, Fig.1a. Pressure coefficients were determined by set of experimental measurements directly in-situ. Wind parameters and obtained results from measurements of turbulent spectra of natural wind layer are mentioned in [1]. Cube was situated in the open terrain with few trees (terrain category II according to [2]). It is not possible to consider typical parameters for terrain category II in this case, because effective roughness length of terrain z_0 was in range from 0.006 to 0.01 m. This fact was caused by relatively flat terrain with periodic skiving. Parameters of roughness length were constant during all measurements, [3]. Jensen number of this cube h/z_0 was in range from 600 to 1 000. Intensity of turbulence was (19 – 20) % on the top of cube. Walls of the cube had smooth surface with small holes, where the pressure sensors were located. Six pressure sensors were put in the middle of wall in horizontal and vertical directions. Roof was divided into 4

quadrants. Thirty pressure sensors (5 in one direction and 6 in perpendicular direction) were arranged in each quadrant. The cube was rotated every 15° clockwise [4].
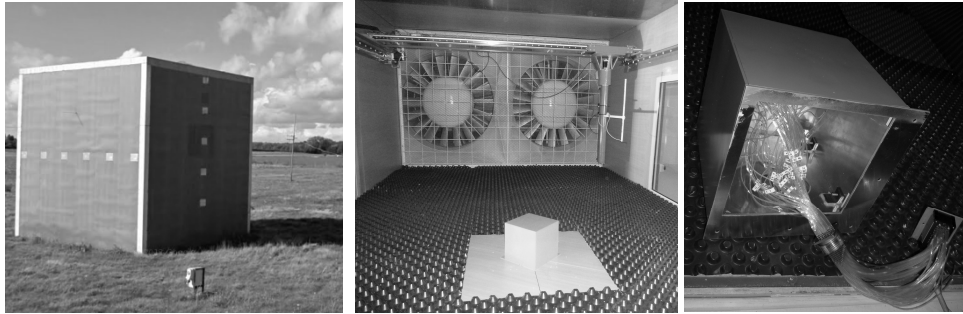

Fig. 1. a) SILSOE cube in-situ [5], b) Model of cube in scale 1:30 during the tests in STUBA BLWT tunnel, c) Detail of model – connection of pressure sensors.

3.   Measuring devices used during the tests in both BLWT tunnels

Pressure scanner ESP - 64HD Miniature Electronic Pressure (Pressure systems) – 64 measuring channels with measuring range ±2.5 kPa. It was used for measurements of pressure coefficients on the walls and roof of the model (Fig. 1b). Scanner was connected with pressure sensors by silicone tubes and by pneumatic connector, Fig. 1c. Electronic signal from scanner was filtered by lowpass analogue filter up to 300 Hz and then it was converted to digital signal by 16-bit convertor card NI PCIe-6259.

Hot-wire anemometer miniCTA 54T42 – is using a method of constant temperature (CTA – Constant Temperature Anemometry) for determination of value of wind velocity. It was used for measurement of reference pressure at the top of the model. This device was fixed on the cantilever beam of the adjustable system, which can move in 3D space (x, y, z).

Prandtl tube – was used as reference probe during the tests. It was located in front of the rear operating space. The main advantage is that the calibration of this device is not needed before the test. It determines the value of wind velocity by the method of difference between the pressures in two sensors placed on the cover of the steel tube. This probe was used also for calibration of Hot-wire anemometer mini CTA. During the measurements of pressure coefficients, it was used also as back pressure; hence, it was connected to pressure scanner interim. Portable Prandtl probe was used for measurement of reference wind velocity on the top of the model in VZLU tunnel.

4.   Description of the model of SILSOE cube

Optimal scale of model, in regards to the parameters of boundary layer in both BLWT tunnels and procedures according to [4, 6, 7], was determined 1:30 in our case. Consequently, length of the edge of the model was equalled to 200 mm (6 m in real model in-situ). Material of the model was chosen with respect to the basic criterions: permanency of form, evenness, resistance during the transport of the model, hardness, easy workability (creation of the holes with diameter of 1.3 mm, because of the pressure sensors).

Consequently, scale model of SILSOE cube was made from duralumin plate with thickness 3 mm. It is necessary to note, that the longitudinal axis of the pressure sensors

have to be perpendicular to the surface of the cube! Therefore, the edges of the drilled holes must not skewed, but they have to be perpendicular. When the holes were prepared, brass tubes (external diameter of tubes was 1.2 mm, internal diameter was 0.6 mm, and total length of tubes was 30 mm) were put into them. It was needed to pay attention also to the putting of the ends of the tubes to the holes (the edge of the tube and edge of the hole have to be in the same layer). Tubes were fixed to the holes by special methacrylate glue, which is ideal for gluing of metals. The same glue was used for fixing of duralumin walls of cube, except one. This was fixed by four screws (because of the maintenance and revision).

After that, vinyl tubes with external diameter of 1.68 mm and internal diameter of 0.86 mm were put on the brass tubes. Length of these vinyl tubes was 300 mm. Ends of vinyl tubes were put on the pneumatic connector (it consists of two parts – one from the side of the model, second from the side of the pressure scanner). The main advantage is that the tubes are permanently joined to the one part of the connector; hence, it is not necessary to disconnected them during the preparation of the model before the measurements or during the transport of the model and pressure scanner.

5. Simulated boundary layer and experimental measurements

Simulated boundary layer is made by combination of rectangular barrier with plastic film. Both tunnels are different, mainly in total dimensions and dimensions of cross-section of tunnel. Therefore, also the simulating system is conformed to given specifications and parameters of simulated boundary layer are not the same. All measurements were done for 3rd category of terrain according to [2] (areas uniformly covered by vegetation, buildings or stand-alone barriers with maximum distance equalled to 20-times of height of barrier, e.g. suburban housing, forest, and village). Reference velocity considered during the measurements, was determined by unified procedure usually used for experimental measurements of wind pressures on the SILSOE cube as mean value of wind velocity in the height of top edge of cube ($z = 6$ m in real model, $z_M = 200$ mm in scale model).

In both cases, pressure coefficients were measured for three various values of wind velocity: 5, 10 and 15 m/s. Reference velocity was measured by reference Prandtl probe (because of verification of obtained results). Model was rotating in the following angles: 0°, 15°, 22.5°, 30°, 45° and 67.5°. Sampling frequency was 100 Hz, total time of measurement was 30 s, number of samples during the each measurement was 3 000. From the evaluation of measured data (60 pressure sensors x 6 positions of rotation x 4 positions of cube in each measured angle x 3 values of wind velocity = 4 320 values obtained from whole test). After that, the mean values of pressure coefficients were statistically evaluated from all data. Other properties of turbulent wind flow were measured by Hot-wire anemometry miniCTA 54T42. Vertical profile of mean value of longitudinal component of velocity vector and profile of turbulence intensity of this component were measured during 30 s (sampling frequency 3 000 Hz, number of samples was 90 000). Spectral density of turbulence energy in boundary layer in height of 200 mm above the floor of tunnel was measured for 180 s (sampling frequency was 25 000 Hz, number of samples was 450 000).

VZLU tunnel - the terrain was created by roughness field made by plastic film with height 7 mm in combination with rectangular barrier with height equalled to 120 mm. Reference velocity on the top of the model ($z_M = 200$ mm) was measured by portable Prandtl probe connected to pressure scanner ESP - 64HD. Back pressure was measured by

static reference Prandtl probe placed on the wall of tunnel. Average temperature during the measurements was 18.1°C, barometric pressure 98 909 Pa and air density was 1.187 kg/m^3, (see Table 1).

STUBA tunnel - the terrain was created by plastic film FASTRADE 20 (height is 20 mm) and rectangular barrier with height equalled to 150 mm. Reference wind velocity was measured by Hot-wire anemometer miniCTA 54T42. Average temperature was 16.8 °C, barometric pressure 99160 Pa, and air density 1.195 kg/m^3 (see Table1).

Table 1 Parameters during the measurements in both tunnels

Velocity on the reference Prandtl probe	VZLU BLWT tunnel, T =18.1°C, b_p = 98909 Pa			STUBA BLWT tunnel, T = 16.8°C, b_p = 99160 Pa	
	Reference dynamic pressure from mobile Prandtl probe	Reference velocity	Reynolds number of model for angle of rotation 0°	Reference velocity	Reynolds number of model for angle of rotation 0°
	p_{ref} [Pa]	U [m/s]	Re [-]	U [m/s]	Re [-]
5 m/s	11,8014	4,459	5,85E+03	4,1	5,44E+03
10 m/s	43,7488	8,585	1,13E+04	7,558	1,01E+04
15 m/s	89,2911	12,265	1,61E+04	11,519	1,53E+04

6. Comparison of results

Values of pressure coefficients on the walls and on the roof of the model, obtained from measurements, were analysed by self-developed program created in software Matlab R2011 and Microsoft Excel 2010. This evaluation was done for all angles of rotation of the model (totally 6 angles). In this paper, only results for angle of rotation of the model equalled to 45 º and reference velocity 15 m/s are shown - graph of vertical profiles (Fig. 2), graph of horizontal profiles (Fig. 3) and graph of pressure coefficients on the top of the model (Fig. 4). Values of pressure coefficients on the walls of the model were compared with [7]. Values of the pressure coefficients on the top of the model were compared with [3].

Good coincidence is evident from the comparison of resultant values in all three graphs. Also these results confirmed that the newly built modern STUBA BLWT tunnel is set correctly and it provides good results with required (high) accuracy.
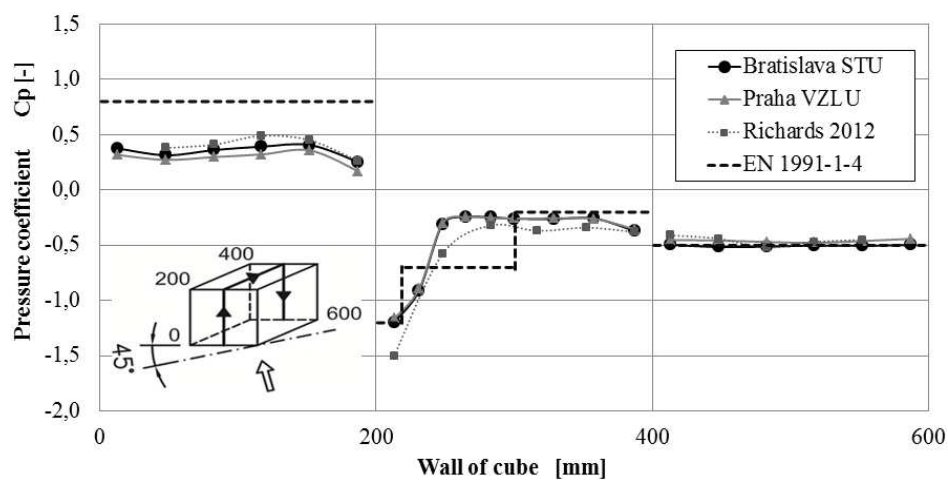
Fig. 2. Vertical profile – angle of rotation of model 45º, reference wind velocity 15 m/s.
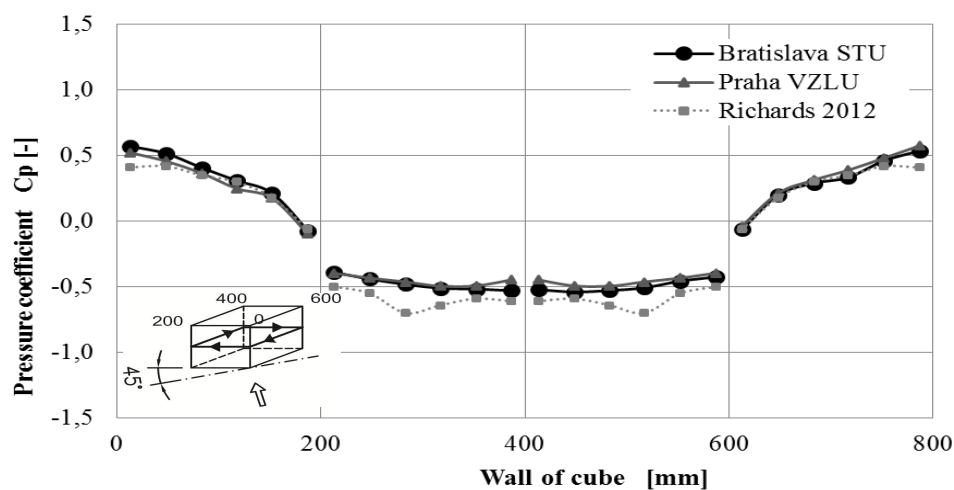

Fig. 3. Horizontal profile – angle of rotation of model 45º, reference wind velocity 15 m/s.
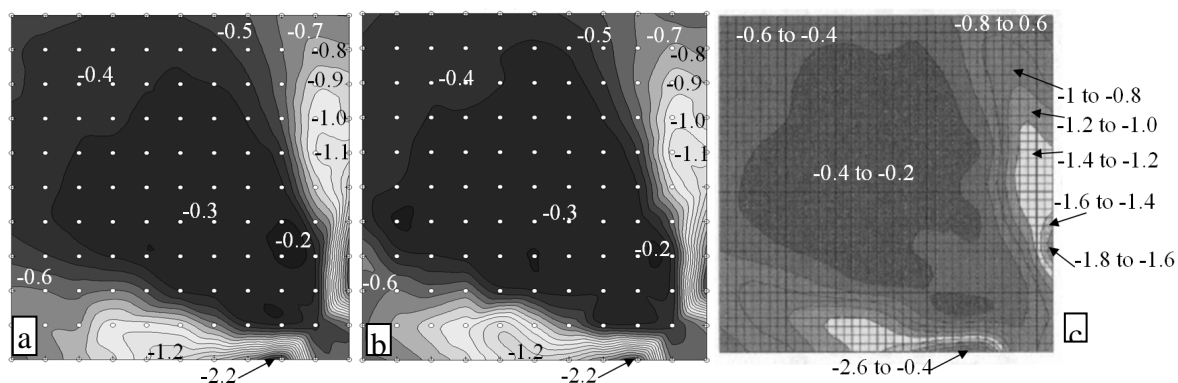

Fig. 4. Pressure coefficients on the roof of the SILSOE cube – angle of rotation of model 45º, reference wind velocity 15 m/s, a) STUBA, b) VZLU, c) [3].

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Acknowledgement

SÚČINITELE TLAKU VETRA NA KOCKE SILSOE STANOVENÉ POMOCU TESTOV V BLWT TUNELOCH

Zhrnutie

Článok sa zaoberá stanovením tlakových koeficientov na modeli kocky v mierke 1:30 pomocou experimentov v dvoch odlišných tuneloch s medznou vrstvou (STUBA, VZLU). Výsledky meraní boli porovnané s literatúrou, ktorá uvádza hodnoty tlakových koeficientov meraných priamo na reálnej kocke s hranou 6 m, v Inštitúte SILSOE v Anglicku. Z porovnania získaných výsledkov bola zistená veľmi dobrá zhoda. Cieľom tejto série meraní bolo zistiť parametre medznej vrstvy a presnosť získaných výsledkov v novom veternom tuneli, uvedenom do skúšobnej prevádzky Slovenskou technickou univerzitou v Bratislave. Merania potvrdili, že tento univerzálny tunel dáva výsledky porovnateľné so zabehnutými svetovými veternými tunelmi a že parametre medznej vrstvy sú nastavené správne. Teda výsledky zodpovedajú realite (meraniam urobených in-situ).