National Conference with International Participation

ENGINEERING MECHANICS 2008

Svratka, Czech Republic, May 12 – 15, 2008

EXPERIMENTAL STUDY OF PEDESTRIAN WIND COMFORT OVER RAILWAY-STATION PLATFORMS

M. Jirsák*, D. Zachoval**

Summary: *Case-study of wind action in space of innovated Salzburg railway-station was performed using VZLÚ boundary layer wind tunnel. Investigation of pedestrian wind conditions over platforms was realized by multiply Irwin probes measurement. Their pressure signals were processed to mean values of velocities, standard deviations and peaks for wind comfort evaluation.*

1. Introduction

Pedestrian level comfort represents object of progressively accented experiments in wind tunnels. Importance of the case studies increases typically when new, tall buildings are designed to occupy a vacant space in lower, sooner originated estate.

Risk of adverse effects acting on pedestrians near the high objects at strong winds will not be missing even after complete transformation such areas to modern urban parts with groups of large buildings accompanied by shopping centers with opened parking, spacious parks, or sport centers. This was the reason why tests of pedestrian wind conditions were required by American cities at new projects related to urban transformation since nineties.

Methodology of so aimed wind tunnel experiments has been surveyed in VZLÚ under promotion of GA project, Jirsák, M. (2007). Then the first Irwin probes were manufactured, calibrated and tested. On spring 2007 the VZLÚ won the competition for the modeling of wind situation over the Salzburg Main Railway Station after its reconstruction, including the investigation of pedestrian wind conditions on platforms.

2. Irwin probe technique and its signal processing (general)

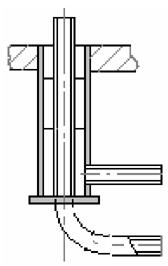
Irwin probe shows important advantages compared with other techniques that one could exploit at pedestrian level wind investigation. They are well known erosion technique, hot wire anemometer, thermistors, eventually monitoring of surface temperature over uniformly heated base under disposed building models.

* Ing. Milan Jirsák, CSc. The Aeronautical Research and Test Institute (VZLÚ), Beranových 130, 195 00 Prague, CR, tel.+420 225 115 530, e-mail: jirsak@vzlu.cz,

** Mgr. David Zachoval (VZLÚ, the same address), tel. +420 225 115 513, e-mail zachoval@vzlu.cz

The Irwin probe is omni-directional. Having small dimensions and sufficiently low flow interference, it can be used on many positions in the same time. With proper arrangement of measuring line (probe - connecting tube - pressure transducer and analog filter) its signal follows instant wind velocities on pedestrian height in model scale, with acceptable frequency response. The probe consists of two concentric tubes of small diameters, where only tip of the inner tube juts out the circumstantial surface (Fig.1). Differential pressure Δp between the outer and central tube is converted to electrical voltage, filtered and digitally recorded. Irwin (1981), analyzed conditions of similarity and described processing of the pressure record to mean velocity and to its standard deviation in details. The low pass filtering is required as it is supposed that wind gusts shorter than T= 2 s should have no effect on human stability. Besides, high frequency fluctuations occurring in a boundary layer very close the surface have to be filtered out (value of 25 Hz filtering is recommended). Irwin probe has been tested also by Durgin (1992), with result of at least 5% accuracy in typical experimental situations.

Irwin (1981), considered the dependence of instantaneous flow velocity on differential pressure of the probe is considered according in the form



$V = \alpha + \beta\sqrt{\Delta p}$, (1) where $\alpha,\ \beta$ are coefficients

which depend on probe geometry and response properties of measurement lines (piping, transducer, and analog filter). But they change slightly also with turbulent features of flow in particular positions. Calibration of the complete measuring line is based on parallel use of hot wire anemometer. It is realized for confined number or IP only situated on important positions.

Fig. 1 . Irwin probe design for mount inside turntable (VZLÚ design).

Hot wire signal has to be filtered with the same frequency as the signal from Irwin probe at the calibration. Constants α, β are processed comparing results of mean velocity (V) and its rms value (v) from signals of both means on each position of calibration.. Averaged values of α and β (checked by their standard deviations) are used finally for the complete evaluation of all pressure records of IP at all wind azimuths.

Application of the relation (1) for conversion of many pressure-time records to velocity time-dependencies before their processing to mean values and standard deviations represents vast amount of operations (about 50 millions in our case). Therefore Irwin (1981) introduces expressions for re-calculation of statistical characteristics evaluated for pressure record ($\overline{\Delta p}$ and $\overline{\Delta p'^2}$) to the mean velocity and velocity standard deviation in pedestrian level:

$$\overline{V} = \alpha + \beta\sqrt{\overline{\Delta p} - 1/4\left(\overline{\Delta p'^2}/\overline{\Delta p}\right)} \quad \text{and} \quad v = (\beta/2)\sqrt{\left(\overline{\Delta p'}/\overline{\Delta p}\right)} \quad (2), (3) .$$

3. Positions of Irwin probes, their installation and calibration

There were 35 positions for Irwin probes disposed over platforms, occupied consequently by 20 Irwin probes. They were connected by with pressure sensors Honeywell DC001NDC4 with working range of 250 Pa by polyethylene hoses of 2 mm inner diameter and 800 mm length.

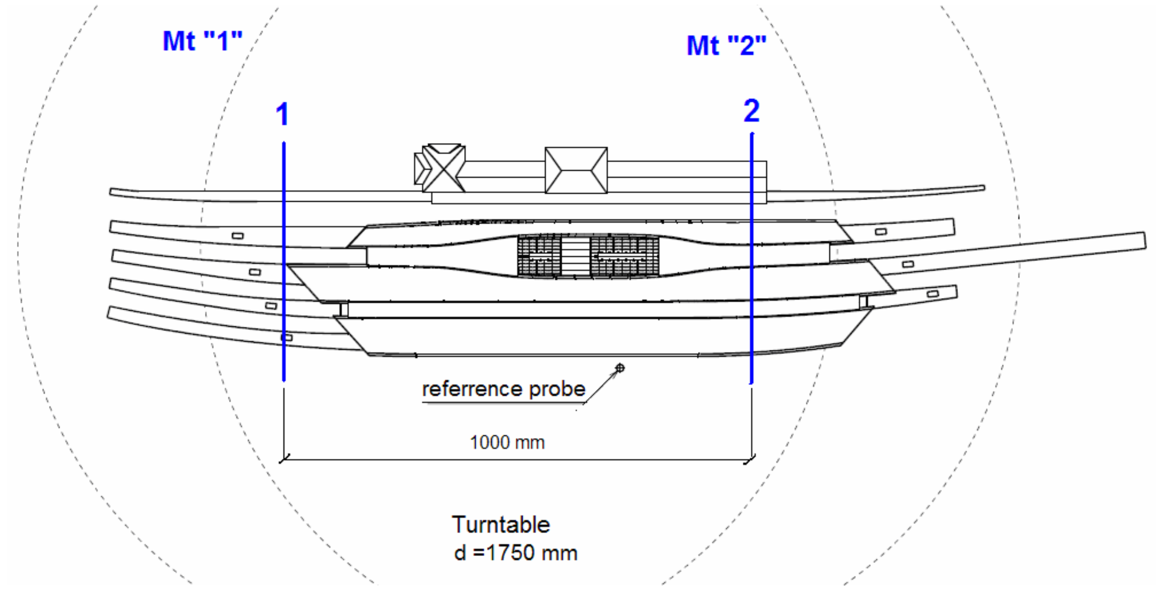


Fig. 2 Two model positions on the turntable (1750 mm diameter) are shown here. Model parts found outside sections 1 or 2 on Fig. 2 were removed for winds coming from angle sectors centered by the opposite direction parallel to R.S. axis.

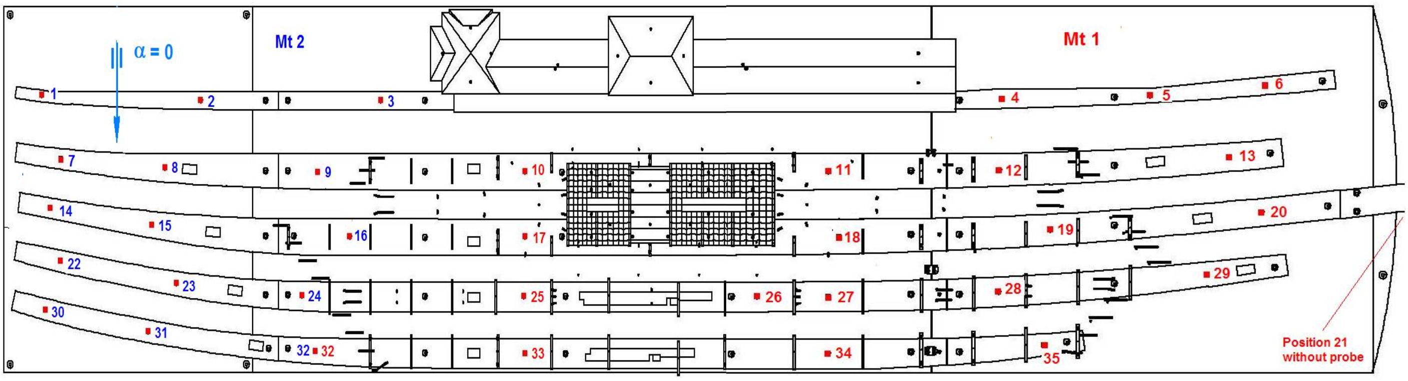


Fig. 3. Dispose of 34 positions of Irwin probes over railway-station platforms.

Fig. 3 shows the positions active at the test with mount "Mt 1" (red figures) and those active at mount "Mt 2" test (blue figures). The only position 32 was active at both mounts and angle sectors to check the influence of the model configuration. Calibration was performed in positions no.5, 6, 13, 20 and 29 at α= 270° for Mt "1" and in positions 3, 7, 14, 24 and 32 at α= 90° for Mt "2" configuration.

Hot wire sensor of 55P13 HWA Dantec probe (connected with vertical support) was oriented vertically with its centre in height of 6 mm above the surface. Record of both probes was processed onto mean values and standard deviations (resp. $\overline{\Delta p'^2}$ for pressure record) and then to

$$\beta = \frac{2u_{SD}}{\sqrt{\psi}} \quad , \quad \alpha = U_{mean} - \beta\sqrt{\overline{\Delta p} - \psi / 4} \ , \quad \text{where} \quad \psi = \frac{\overline{\Delta p'^2}}{\overline{\Delta p}} \ . \qquad (4), (5), (6) \ .$$

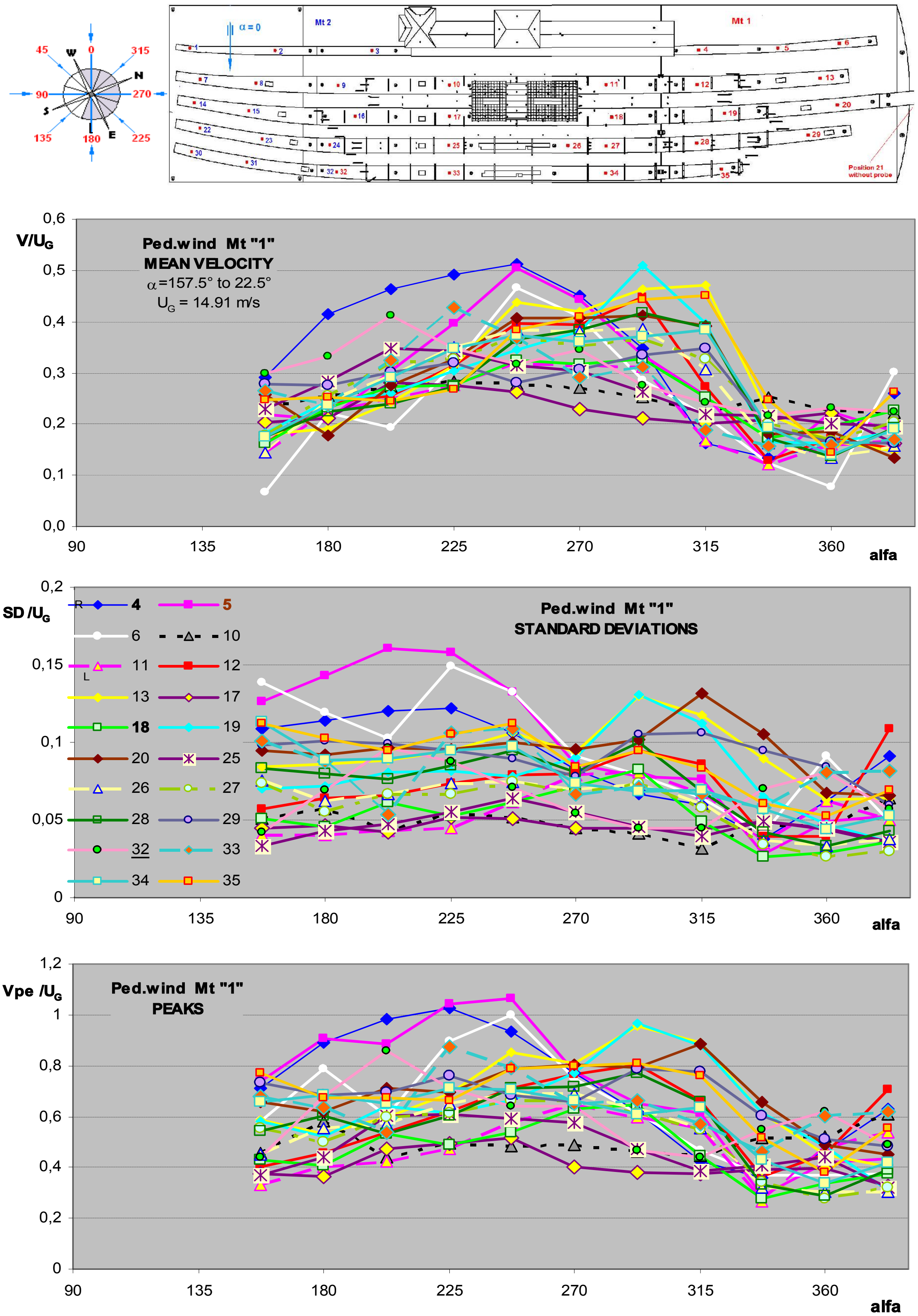


Fig. 4 Mean velocities, fluctuations and peaks for„Mt 1“ (wind angles 157,5° to 22,5°)

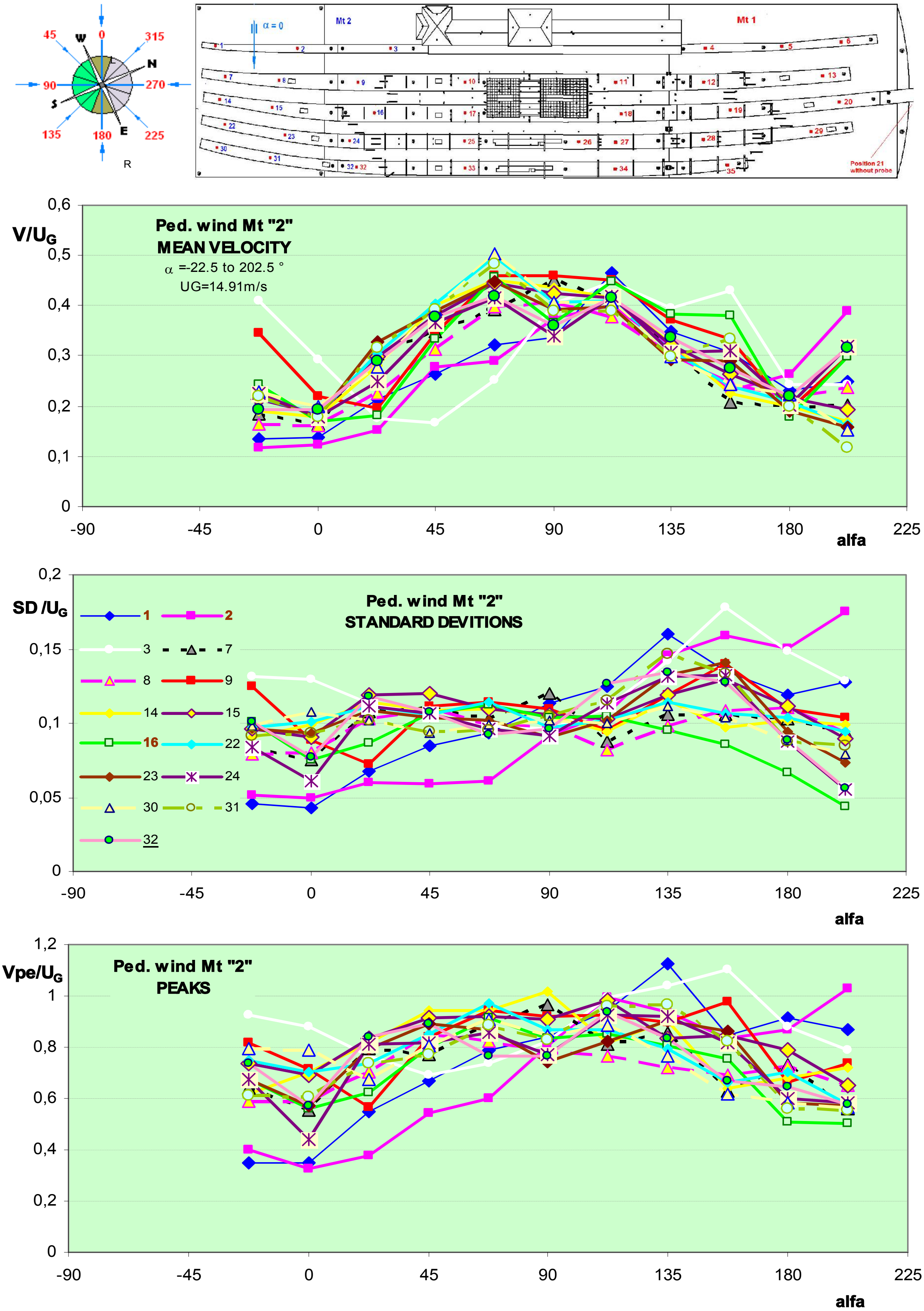


Fig. 5 Mean velocities, fluctuations and peaks for “Mt 2” (wind angles 22,5 to 202,5°)

Averaged calibration coefficients as they were used at systematic data processing are shown in the following table:

Mount	θ [°]	α [m/s]	β	Ψ
Mt "1"	270	-0.074 ±0.611	1.734 ±0.199	2.364
Mt "2"	90	0.706 ± 0.484	1.533 ± 0.078	3.867

Tab 1. The coefficients α and β developed from Irwin probes calibration

4. Measurements

The test of pedestrian level wind (so as the measurement of roofs loading) was also realized at two model positions on turntable. Wind angle was changed with 22,5° step within the sectors 270°±112,5° for Mt "1" and within 90°±112,5° for Mt "2"mount (wind angles were measured with counter clock orientation from origin of α =0° corresponding to wind coming from main R.S. building perpendicularly to rails). Ranges of the sectors are marked on wind roses in the plots (Fig. 4, Fig. 5).

The measurements were performed at 14,9 m/s mean velocity on the level of z= 900 mm in wind tunnel that is supposed be roughly approaching the gradient velocity. Output voltage from pressure transducer was low pass filtered by 300 Hz and digitized by 3 kHz sampling frequency during total sampling time T=30 s. The record was then digitally filtered with 50 Hz frequency. As 1 hour sampling time determining a peak in full scale answered to 14,4 s in the model scale (1:250), 2 peaks were found on each record and averaged to obtain nominal values of the maximal peak for the records. Resulting values of the mean velocity and standard deviations as well as the peaks related to gradient wind velocity in the wind tunnel are plotted on Fig. 4 and Fig. 5 (the predominant wind directions on the site are W and NW).

5. Final form of the results

A question has to be solve what kind of reference velocity to use for dimensionless form of the results, considering highly turbulent flow coming from fully irregular surrounding estate, violently changing with wind azimuths. Similar problem was bounded with terrain topography of the city, with complex and unknown correlation between local wind and that as measured on meteo- station of Salzburg airport (causing statistical evaluation). Therefore correlation measurement on R.S. was initialized. However, differences between the present and modeled situation, the last after reconstruction, could infract the correlation and so the main expression of PLW results remain be the dimensionless mean velocity, standard deviations and peaks related to gradient velocity, as they are shown on Fig. 4 and Fig. 5.

The data were plotted also as absolute V [m/s] mean velocities pertaining to fixed values of gradient velocities 5, 10, 15, 20 and 25 m/s after the request of designer. Fig. 6 shows the example for the pos. 32 where any exceeding of the threshold mean velocity 5 m/s according DMI criteria is easy to find. Differences between Mt „1"and Mt"2"results at α= 180° for the checked 32 position are possible to judge also in the Fig. 6.

Maximal mean values over all wind angles were graphically presented for each position, too (not shown here).

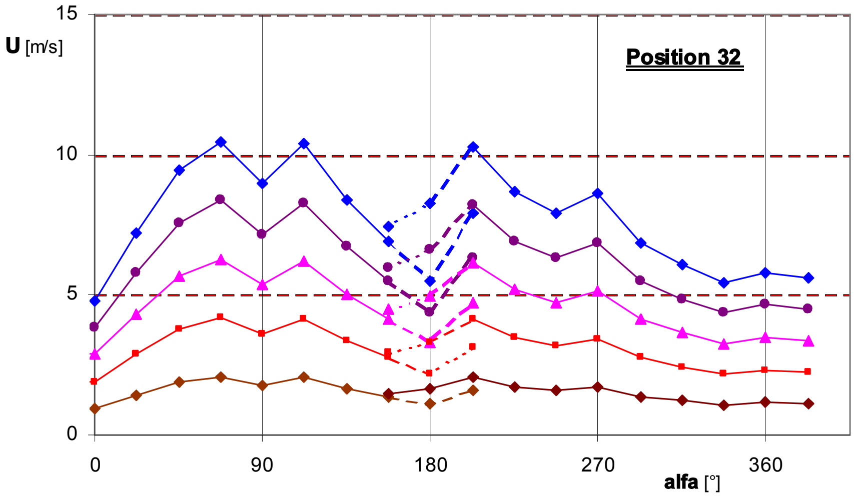


Fig. 6. Values of the mean velocity at gradient velocity 5, 10 , 15, 20, and 25 m/s for pos. 32

6. Conclusion

Mean values of velocity in pedestrian level reach maximal values (about 0,5 gradient velocity) at wind angles 90° and between 225° and 270°, when wind come from relatively free terrain. Maximal values of standard deviations reach 0,15 of gradient velocity and they show slight troughs in wind directions pertain to maxima of mean value, where minimal level of turbulence could be supposed. Maximal peaks keep mostly under the level of gradient velocity (they overcome it quite exclusively). Details of the curves of mean velocity are mostly easy explained (e.g. elevated values for definite position and angles are found close building corners, etc.).

An explaining of relatively high values of local velocities in pedestrian level one could find in gradual flow contraction occurring several times before the flow reaches the platforms. The platforms surmounting railway level of about 1 m cause the last contraction which could dominate about 1.5 m above them, i.e. just on the level of PLW measurement (6 mm height of Irwin probes at scale 1:250).

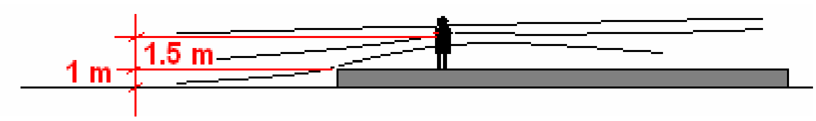


Fig. 7

After all inspection of the results as they were performed we really appreciate benefit of Irwin probe, taking it as very practical and no doubt reliable tool. However, thorough investigation of probe response, especially the filtration effect on scatter of calibration coefficients, mutual interference of probes and others are very important for following improvement of the probe performance.

<u>Standard evaluation of pedestrian comfort (appendix):</u>

Full evaluation of pedestrian wind comfort comprises currently three steps:

1) Modeling of velocity field around buildings in pedestrian level with special experimental equipment (tenths of localities are usually investigated at 16 or 24 wind azimuths).

2) Resulting mean velocities and velocity standard deviations are pre-processed on effective gust velocities. They are processed in combination with meteorological statistics to probable exceeding of defined threshold effective velocity over all wind directions. Here correlation is need between wind data on the site and on the nearest meteorological station.

3) Comparison of last results with comfort categories for selected system of *pedestrian wind comfort criteria.* This last step answers a question if particular locality of investigation complies a requirement of actual category of human activity by its probability of threshold exceeding of effective velocity.

Survey of selected European criteria for experimental evaluation of pedestrian wind comfort is available in Delpech P., et al. (2005) with a comparative study performed in frame of the EU COST 14 project. Next experiment was carried out in the VZLÚ recently (ordered by CEC Architects and AED design office) with the evaluation the pedestrian wind situation in projected area according DMI and CSTB criteria and meteorological data.

References

Jirsák, M. (2007) Větrné podmínky chodců v okolí rozměrných staveb, VZLÚ R-3927/07, Rep. on the project GACR 103/06/1522 (in Czech).

ASCE Manuals & Reports on Eng. Practice, No.67 (1999) Wind Tunnel Studies of Buildings, American Society of Civil Engineers, Reston, Virginia.

Richtlinie VDI 3783/Blatt12 (1999) Umweltmeteorologie. Physikalische Modelierung von Stromungs- und Ausbreitungsvorgangen in der atmospherischen Grenzschicht.

Irwin, H.P.A.H. (1981) A simple omnidirectional sensor for wind-tunel studies of pedestrian-level winds JWIA, 7, pp. 219-239.

Durgin, F.H (1992) Pedestrian level wind studies at the Wright brothers facility, in Progress in wind engineering, Proc.8th Int.Conf. on Wind Eng., Elsevier, JWIA 412-44, pp. 2253-2264

Delpech P., et al. (2005) Pedestrian wind comfort assessment criteria. A comparative case study. 4 EACWE Prague, pp. 82-83. Paper #217

Roztočil F. (2008) Možnosti posuzování pohody chodců při větru, CEC Praha.

Willemsen, E; Wisse, J.A. (2005) Design for wind comfort in The Netherlands: procedures, criteria and open research issues. 4 EACWE Prague , pp. 338-339. Paper #311.

Jirsák, M., Zachoval D. (2007) Experimental study on innovation project of Salzburg railway station, VZLÚ rep. R 4152/07.

Jirsák, M.(2008) Větrné tunely pro dnešní stavebnictví, Stavebnictví 04, s.57-60.

Acknowledgement

Authors are indebted to Grand Agency of Czech Republic for promotion of study of the pedestrian level wind methodology in frame of the Project No.103/06/1522.

1. Irwin probe with adjustable height of the central tube
2. Pressure transducer Honeywell DC 001NDC4 (250 N/m^2 meas. range)
3. Irwin probes connection with Honeywell transducers
4. Early calibration of Irwin probe with hot-wire anemometer (55 P01 Dantec probe)
5. Model of the full roofs length at mount Mt “1” (NNE wind)
6. Mt “2” (shortened roofs). Measurement on south platform tips (SEE wind). 7. The same in detail