Wind tunnel modelling of a residential ensemble in a high rise building urban area

Iustina Bianca Florea, Oana Alexandra Iagar, Cezar Alexandru Vladut, Costin Ioan Cosoiu, Andrei Mugur Georgescu, Liviu Valer Hasegan and Mircea Degeratu

Technical University of Civil Engineering Bucharest, Hydraulics and Environmental Protection Department, Lacul Tei 124, Bucharest, Romania

Corresponding author: iustinaflorea@gmail.com

Abstract. This paper refers to wind tunnel testing of a residential complex located in a crowded urban area in the vicinity of some tall buildings. Due to the agglomeration of certain urban areas, the erection of new tall buildings becomes increasingly challenging, both in terms of location finding and structural load assessment. For a tall building located in such an area, the complexity of the structural challenges is increased by the loads resulting from the wind action. Usually the wind velocity profile from which these loads result is influenced by the roughness height factor associated with the urban areas surrounding the building. In the vicinity of other tall buildings, the interinfluences between the buildings must also be ascertained. Following the request of the project developer, the Technical University of Civil Engineering Bucharest through the Aerodynamics and Wind Engineering Laboratory “Constantin Iamandi” performed wind tunnel static tests of the residential complex using two different roughness heights above the floor of the wind tunnel (corresponding to different terrain categories with respect to wind orientation) and adding models of the existing adjacent tall buildings for some of the wind directions. The paper presents test methodologies used, the wind tunnel set-up, the residential complex static model and obtained results.

1. Introduction
The aim of this research is to determine the building response to the wind action for the residential ensemble Up Site from Bucharest.

Due to the buildings height and surroundings it is hard to assign pressure coefficients during the design stage and the purpose of this paper was to assess those coefficients through experimental measurements.

In general, the high-rise buildings are designed with complex and unique shapes by architects. For this kind of structures, the wind load is very important in the design stage and it can be determined by using standards, experimental methods or numerical simulations. From the three the most suitable method is numerical simulation, but in order to have accurate results the method must be validated by an experiment [1–7]. Experimental measurements in wind tunnel are more expensive, but the results are accurate for different kind of problems of fluid mechanics.

The experimental tests were performed in the boundary layer wind tunnel TASL1 from the Aerodynamics and Wind Engineering Laboratory (L.A.I.V.) “Constantin Iamandi” where the wind pressure distribution was determined for the residential ensemble similar to other experimental tests performed in the same laboratory [8–10].

In order to obtain accurate results, the tested model had to be coupled in addition to the proper analyzed building model, to the surrounding buildings with significant heights.
The influence of the surroundings and the fact that they must be taken into account in addition to the roughness system of the wind tunnel have been already studied by other researchers\cite{11–14} and the results showed that in makes a big difference in terms of wind induced pressure coefficients and wind characteristics.

2. The model

The studied ensemble is composed of two-towers with different heights connected to each other by a third building at the ground and first floor. The highest tower of the two is 95.30 m high and the other is 49.15 m high.

The Up Site residential ensemble model was built at a length scale of $S_L = 1:200$, the choice of this scale being dictated on one hand by the manufacturing technology and on the other by the dimensions of the experimental vein of the boundary layer wind tunnel TASL1. A front view of the ensemble and the experimental model are presented in figure 1.

The model of the ensemble was placed in the experimental area of the boundary layer wind tunnel TASL1 on a circular turntable with a 1.6 m diameter, which provides the possibility to rotate the model for different incidence angles with the air flow.

In order to obtain the local pressures distribution on the real ensemble, the local pressures distribution on the experimental model were measured and then transposed on the real structure.

Local pressures were recorded from 266 pressure taps placed on the exterior surface of the rigid model of the Up Site ensemble by means of a pressure scanner. For the mean velocity profiles (of logarithmic type) two profiles were used in the experimental vein of the boundary layer wind tunnel corresponding to two terrain roughness types present in the surroundings of the ensemble.

Figure 1. Front view of the residential ensemble and the experimental model

3. Methodology

3.1. Wind characteristics in Bucharest

The direction of the main wind was taken to be N-E according to the measurements of the multiannual values at the Baneasa and Filaret meteorological stations. The wind rose as a function of the frequency of occurrence of the direction and as a function of the magnitude of mean wind velocity for each direction in Bucharest at Baneasa and Filaret meteorological stations are shown in figure 2.
The wind rose by the frequency of occurrence of wind by direction and magnitude of mean wind velocity by direction in Bucharest at Baneasa and Filaret meteorological stations.

3.2. The mean wind velocity profile according to EN 1991-1-1-4

The variation of the mean wind velocity with the height above the ground due to the its surface roughness can be represented by a logarithmic profile according to the EN 1991-1-1-4 [15] or by an exponential profile according to similar codes from USA and Canada.

For this experiment, the results were obtained for mean wind velocity profiles constructed with a logarithmic law with respect to the roughness of the terrain and its topography.

\[ v_m = \frac{u_*}{k} \cdot \ln \left( \frac{z}{z_0} \right) \]  

(1)

where:

- \( k \) von Karman constant, experimentally determined and its value is 0.4;
- \( u_* \) friction velocity; \( u_* = \sqrt{\tau_0/\rho_a} \) [m/s];
- \( z_0 \) integration constant, known as roughness length [m].
The values taken into account in this study were $z_0=0.3$ m (area III) for wind blowing from W, NW, N, NE and E and $z_0=0.05$ m (area II) for wind blowing from SW, S and SE. Those two mean wind profiles were assessed with different roughness’s height on the floor of the boundary layer wind tunnel (see figure. 3) as explained in the sequel.

Figure 3. Boundary layer aerodynamic wind tunnel TASL1-M

3.3. The mean velocity profile used in experimental tests

Experimental tests were performed for a length scale of 1:200 using the mean velocity profiles from natural ABL (Atmospheric Boundary Layer) corresponding to each direction. The mean wind velocity profiles used corresponds to Terrain category II area with low vegetation such as grass and isolated obstacles (tree, buildings) with separations of maximum 20 obstacle heights $z_0=0.05$ m and Terrain category III area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest) $z_0=0.3$ m.

Figure 4. Wind velocity profile for scale 1:200

Figure 5. Turbulence intensity profile for scale 1:200

The TASL 1 variable roughness wind tunnel is an open circuit wind tunnel with a long guided experimental vein. TASL 1 has a total length of 25.0 m and an experimental vein with an inner section of 1750 x 1750 mm. The length of the work area, consisting of the area where the boundary layer develops, the experimental area itself and the visiting area, is 20.85 m.
The mean wind velocity from the experimental vein can be adjusted continuously from 0.1 to 30 m/s and velocity profiles and turbulent intensity profiles comply with the Eurocode EN 1991-1-1-4[15].

The tunnel is equipped with measuring equipment to determine the velocities in the measuring vein and the values of local pressures on the side surfaces of the models: LDV (Laser Doppler Velocimetry) from Dantec Dynamics, a laser anemometer that measures both local speeds and turbulent intensity on all three components, 300 miniature pressure transducers with a measuring range between 0 and 500 Pa, 128 fast pressure transducers with an acquisition rate of 25 ks/s (kilo samples per second – defines the speed with which DAC is sampled), a complex data acquisition system (DAC – Digital to Analog Converter) based on PXI technology from National Instruments with 320 analog channels and 192 digital channels, a system of variable roughness over the length of 14 openings that allows obtaining different velocity profiles inside the tunnel [10].

![Figure 6](image1.png)  ![Figure 6](image2.png)  ![Figure 6](image3.png)

**Figure 6.** Measuring equipment TASL 1 a) LDV – 3 components, b) Pressure transducers, c) Variable roughness system

### 3.4. The experimental setup

The pressure was measured in 266 points where pressure taps were mounted and connected by hoses to the pressure transducers. The total number of 266 points were distributed 80 points on the small tower facades and roof and 176 points on the facades and roof of the taller tower.

![Figure 7](image4.png)  ![Figure 7](image5.png)  ![Figure 7](image6.png)

**Figure 7.** Pressure taps location
The model was fixed on a turntable in order to allow the change in direction for the measurements that were made for all 8 wind directions N, NW, NE, S, SW, SE, E, W at 3 different frequencies of 11 Hz, 12 Hz and 14 Hz.

The Up Site residential surroundings must be considered due to their significant height. The highest of them is also the highest building in Bucharest (SkyTower – 137 m). These surrounding buildings are found in NW, N, NE and E directions with respect to the ensemble.

Cartboard templates (constructed from google maps photos) were used for each wind direction in order to assess the exact position of the high-rise buildings in front of the studied ensemble. Models of the buildings without pressure taps (length scale 1:200) were then fixed on the tunnel floor with Velcro tape. In order to be able to use the same models for all wind directions where those high-rise buildings would influence the pressures on the ensemble, several of the models were constructed out of multiple pieces (as for a given wind direction only half of the building would fit in the wind tunnel and for others the whole building would be needed).

Figure 8. Position of the ensemble (yellow rectangle) google earth view

Figure 9. Experimental model setup in TASL1 from L.A.I.V. (for the North-East direction and the roughness length $z = 0.05$ m.)

Figure 10. Google earth view of the ensemble (yellow rectangle) for the North-East direction.
4. Results
The pressure distribution was determined by measuring pressure values $p_k (k=1..266)$ on the buildings facades. Knowing the local pressures $p_k$ the local pressures coefficients have been determined with respect to the static pressure recorded in the aerodynamic tunnel $p_\infty$ and the air velocity $U_\infty$ measured at reference height ($z=0.6$ m) as:

$$C_{pk} = \frac{p_k - p_\infty}{\rho U_\infty^2}$$

where:
$p_k$ - local pressures corresponding to the pressure taps $k=1..266$ [kPa],
$p_\infty$ - upstream local static pressure at the reference height [kPa],
$\rho$ - air density [kg/m$^3$],
$U_\infty$ - upstream air velocity at the reference height [m/s].

Figure 11. Pressure coefficients on North obtained from experimental measurements at scale 1:200
Figure 12. Pressure coefficients on North-East obtained from experimental measurements at scale 1:200

Figure 13. Pressure coefficients on South-West obtained from experimental measurements at scale 1:200
Results obtained for pressure coefficients for wind blowing from the N, NE, SW and W are presented in figures 10-13.

The surrounding high-rise buildings are shielding the ensemble for wind direction from the N, and the NE, figures 11 and 12. The pressures are smaller for those two orientations as compared to the SW and W directions, from figures 13 and 14, where the roughness length changes, and no buildings are shielding the ensemble.

5. Conclusion

The distribution of static pressure coefficients on a residential building ensemble was investigated in this study using an experimental approach. Due to the surrounding conditions (high-rise buildings in the vicinity) the variable roughness system of the boundary layer wind tunnel had to be coupled for some wind directions to a mock model of the high buildings shielding the studied ensemble.

The obtained results look realistic and permitted the structural engineers in the design stage of the building to assess the correct wind loads on the two towers that form the ensemble.

References

[1] Lamberti G, Amerio L, Pomaranzi G, Zasso A, Gorlé C 2020 Comparison of high resolution pressure measurements on a high-rise building in a closed and open-section wind tunnel J Wind Eng Ind Aerodyn. 204

[2] Gomes M G, Moret Rodrigues A, Mendes P 2005 Experimental and numerical study of wind pressures on irregular-plan shapes. J Wind Eng Ind Aerodyn 93(10):741–56

[3] Wang M, Tian Y, Yu L, Wang X, Zhang Z, Yan G. 2019 Research on the wind pressure coefficient in natural wind calculations for extra-long highway tunnels with shafts. J Wind Eng Ind Aerodyn. 195

[4] Zhang J W, Li Q S 2018 Field measurements of wind pressures on a 600 m high skyscraper during alandfall typhoon and comparison with wind tunnel test. J Wind Eng Ind Aerodyn. 175:391–407
[5] Kwon K seok, Kim D woo, Kim R woo, Ha T, Lee I bok. 2016 Evaluation of wind pressure coefficients of single-span greenhouses built on reclaimed coastal land using a large-sized wind tunnel. *Biosyst Eng* **141**:58–81

[6] Lou W, Huang M, Zhang M, Lin N 2012 Experimental and zonal modeling for wind pressures on double-skin facades of a tall building *Energy Build* **54**:179–91

[7] Kim Y, Kanda J 2010 Characteristics of aerodynamic forces and pressures on square plan buildings with height variations *J Wind Eng Ind Aerodyn* **98**(8–9):449–65

[8] Coşoiu C I, Damian A, Damian R, Degeratu M 2008 Numerical and experimental investigation of wind induced pressures on a photovoltaic solar panel. *Int Conf ENERGY, Environ Ecosyst Sustain Dev* **74**–80

[9] Vlăduţ C A, Coşoiu C I, Georgescu A M, Degeratu M, Haşegan L V, Chiulan A E, et al 2019 Experimental Study of the Wind Loading on a Multifunctional Sports Hall Model *International Conference on ENERGY and ENVIRONMENT CIEM*

[10] Haşegan L V, Degeratu M, Sandu L, Georgescu A M, Coşoiu C I 2008 *Experimental and Numerical Modeling in Wind Engineering (Modelare Experimentală și Numerică în Ingineria Vântului)*

[11] Liu S, Pan W, Zhao X, Zhang H, Cheng X, Long Z, et al 2018 Influence of surrounding buildings on wind flow around a building predicted by CFD simulations *Build Environ* **140**:1–10

[12] Lee D S H 2017 Impacts of surrounding building layers in CFD wind simulations *Energy Procedia* **122**:50–5

[13] Gough H, King M F, Nathan P, Grimmond C S B, Robins A, Noakes C J, et al 2019 Influence of neighbouring structures on building façade pressures: Comparison between full-scale, wind-tunnel, CFD and practitioner guidelines *J Wind Eng Ind Aerodyn* **189**:22–33

[14] Macháček M, Urushadze S, Pospišil S, Trush A, Pirner M 2020 Aerodynamic interference of wind flow around three cylindrical bodies with surface roughness *MATEC Web Conf* **313**:00051

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