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# SIMULATING THE SNOW TRANSPORTATION BY WIND ON A WIDE IRREGULAR ROOF IN TURBULENT LAYER WIND TUNNEL

BY

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**Abstract.** The research results presented in this paper was developed in the wind tunnel of the Laboratory of Buildings Aerodynamics of the Civil Engineering and Building Services Faculty from Iaşi and concerns the effects of wind on the snow layer that is deposited on a very large domed roof covering an architectural complex which is situated in an urban complex in Iaşi.

The irregular in plane shape and the small curvature of this roof are reasons for believing that snow will gather in large and heavy deposits but also make the evaluation of the wind and snow loading a very difficult task because of the lack of sufficient design data in the current codes for practice for such a particular case. In cases like theses testing in atmospheric boundary layer wind tunnel of the modelled building at reduced scale gives important information.

The model is realized at the reduced scale of 1:400, the wind local pressures on the roof were determined with the miniature pressure transducer ZOC 17 and analysed in parallel with numerical simulations with ANSYS CFX. The simulation of snow transportation uses the erosion technique and the material that replaces the snow consists in glass beads of 200...400 μmm.

The results of the study are encouraging because the analysed parameters offer sufficient accuracy of the modelled phenomenon and it may become a handy tool for both research and a safe structural design.

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**Key words:** atmospheric boundary layer wind tunnel; scale modelling; wind pressures; snow transportation.

## 1. Miscellaneous

Romania is facing, like all European countries, abrupt climatic changing and unusual strong storms with heavy snow falls more often in the last years, drawing the attention of the design engineers because of the consequences of the important deposits of drifted snow that covers the modern built environment as well as the terrestrial communications. Increasing the safety design limits not only must be a responsible act but also have in view the optimization of any design solution and, usually in this respect, the codes for practice give as much assistance as they are prepared to. Any structural designer knows that there are particular situations for which there might not be enough information for the design against the effects of unusual wind and snow actions and experimental studies are the only able to offer a clear view of their impact on the future structure.

Extensive researches on the snow combined with wind actions were developed and continue to raise the interest because of the possibilities of performing studies in atmospheric boundary layer wind tunnels, appreciated for the extensive and comprehensive data provided and the assistance given in the elaboration of the theoretical, physical and mathematical models. The close interaction between wind and snow drift make the atmospheric boundary layer tunnels very appropriate tools for study but it is a common acknowledgment that the snow transportation and deposit in snow drifts is very difficult to simulate when neither the temperature of the air, nor the material that simulates the snow are accurately reproduced. Cold boundary layer wind tunnels are able to work with the ideal material for simulation that is the snow particles, but they are rare and the costs involved in research are very high.

For the structural engineer the simulation of the snow falls on buildings and the interaction with wind is resumed to that part involved in transportation and deposit and that is why the interest lays on a thorough analysis of the phenomenon from the point of view of the particles motion in their entraining by wind and drifting apart. The studies dedicated to snow loading on structures in normal boundary layer wind tunnels may satisfy if the various and sometimes conflicting modelling parameters are harmonized.

This paper represents partially a previous research program of wind and snow loading on a particular structure having a domed roof with wide in plan dimensions and low aspect ratio, placed in a complex urban environment. Several attempts of simulation of snow drifting were done, by changing the method (simulation of snow fall entrained by wind with specific equipment followed by simulation of wind drifting the deposit on the roof) and by changing the material that simulates the snow (particles of sawdust and glass beads).

As the target of the part of the study presented herein is the approach of modelling the snow transportation on the roof, the attention was focused on the parameters involved in, their majority being the result of wind local fluctuating speed and the specific turbulence.

## 2. Simulation of Snow Transportation by Wind

### 2.1. Setup of the Experiments in Wind Tunnel

a) *Wind tunnel study of local pressure coefficients on the low rise domed roof*

The research is developed in an open circuit boundary layer wind tunnel with a transversal section of 1.4 m × 1.4 m and 8.8 m experimental length. The simulated boundary layer of the wind flow has the following characteristics: a power law variation of the wind speed specific to urban exposure with the exponent about 0.30, wind mean speed in the top part of the tunnel of maximum 7.5 m/s, turbulence intensity at reference height 22%…24% (Teleman *et al.*, 2008).

The reference speed was determined at the height of the roof, in front of the model and the geometric scale is 1:400. The modelled building is a construction with an irregular in plan shape, the vertical walls having sharp edges and a domed roof with a low aspect ratio. The dome measures a maximum span, $L$ = 160 m and maximum height, $f$ = 10.93 m, the aspect ratio being $f / L$ = 6.4%; the surface of the roof measures about 15,500 m$^2$.

Fluctuant pressure values on the roof were acquired using a pressure transducer ZOC 17, (SCANCO USA) during a 1 min. sampling with a sampling rate 10…3 s/sample and the data were processed with a standard conversion mother board and software NI-DAQ (N.I. USA).

In deciding the wind angle of attack, the dominant direction was prevailing having in view the location of the building in the urban texture. The mean and extreme values of local pressures coefficients, measured in the pressure taps positions, are presented in Figs. 1 and 2, showing the following dominant features: almost all mean local pressures on the surface of the roof are negative, with values of –0.6….–0.85 in areas of high turbulence, diminishing to –0.1…–0.2 in more sheltered areas. The negative peak values are large and generally spread all over the surface of the roof (local values –3.0 and –1.7, almost all of them being about –2.7) while positive peak pressures are situated between 0.2 and 0.7. Note the pressure coefficient in tap 1 on the in-wind face located close to the reference height, whose mean value is +0.85, rather a standard value, suggesting a good simulation of the flow over the model. In the same time, observations made by Holmes (2007) and Cook (1985) confirm the flow separation pattern for angles under 30º and the location of the positive pressure values close to windward edge of the roof, where the flow reattaches.

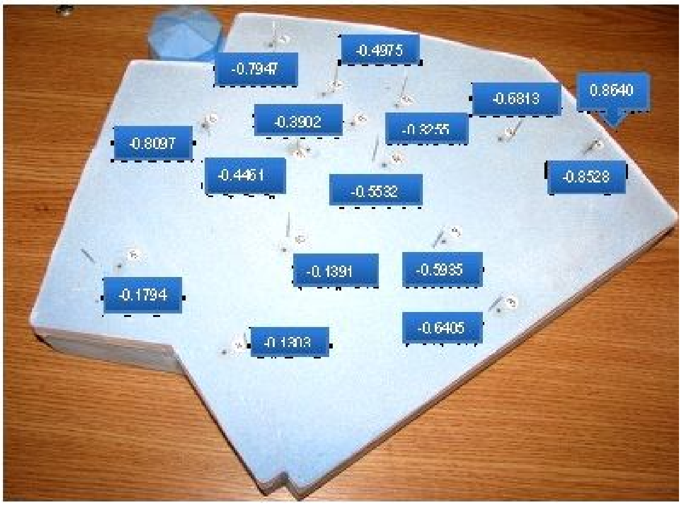
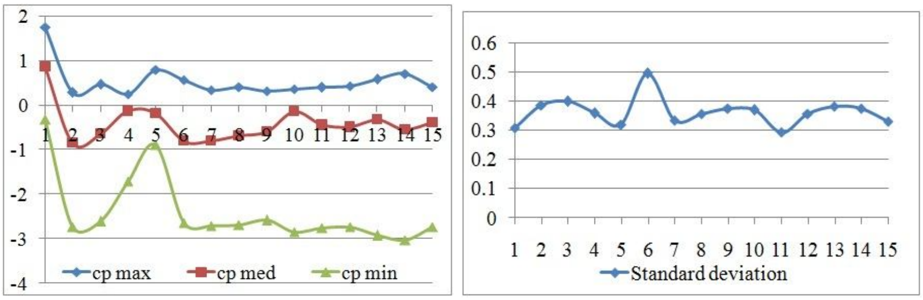



Fig. 1 – The model of the building and the positions of the pressure taps 1…15: top view with values of the local mean pressure coefficients.



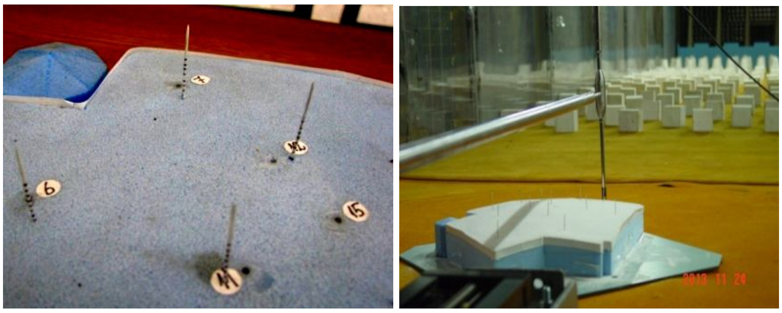

*a* *b*

Fig. 2 – Results of the wind pressure study: *a* – peak local positive, mean and negative pressure coefficients; *b* – standard deviation of the pressure coefficients.

b) *Wind tunnel study of the snow drift on the domed roof*

Snow is a granular material in suspension; once deposited on surfaces increases its density in time under temperature effect from new 0.12...0.2 g/cm$^3$ to old 0.45...0.55 g/cm$^3$. The snow particles dimensions as well as shape vary from less than 0.1 mm in case of eroded particles to more than 10 mm in case of freshly fallen snow flakes. Snow hardens with the dropping temperature but cohesion between particles increase when temperature rises under the sun exposure. On the surface of the roofs with inclinations from 00 to 500 solar radiation or other sources of heat partialy melts the snow layer covering its surface with a compact ice crust (Tabler, 1994).

Wind action has a great contribution in modeling and remodeling the snow drifted deposit on the roofs of the buildings, its speed being the major factor of starting this phenomenon. Researches demonstrate that under 12 m/s about 90% of the whole quantity of snow is found in a layer of 100 cm height above the surface covered with snow (Anno, 1984; Iversen *et al*., 1990). After the determination of instantaneous values of the wind local pressures on the surface of the roof, markers were placed close to the positions where pressure taps were situated. The markers have 10 graduations at every 2 mm (Fig. 3 *a*).



*a* *b*

Fig. 3 – *a* – View of the roof with markers placed near the pressure taps; *b* – measuring the speed with hot wire sample for the determination of $z_0^{'}$.

Two distinct spatial areas are associated with the wind drifted snow, one is generated by the transportation of the particles entrained in the wind flow and the other is the snow drift itself, where the speed of the particles is cancelled due to kynetic energy loss. Related to the study, this manifestation is particularly stimulated by the regions on the roof associated with increased turbulence where the velocity components vary, reaching 0 values or reversing the sign inside the vortices generated by turbulence.

Snow particles are transported by translation on the surface parallel to the flow within very small heights not exceeding milimeters; by saltation at heights of several centimeters and by turbulent movement and suspension in a chaotic layer of even up to 100 m above the surface (Lieberherr, 2010).

Saltation is associated with dropping temperatures and the increasing wind speed; together with suspension originate drifting and important snow agglomeration.

Wind entrains the snow from surfaces at speeds of 0.3...1 m/s at 20 cm height above the surface and the transported volume of snow increases with wind speed in cubic progression but during the snow storms with or without snowing the wind speeds vary from 6....10 m/s maybe exceeding 17 m/s (Florescu, 2001).

In Romania the maximum wind speeds during snow storms may vary, generally, between 24 m/s and 29 m/s but regularly the mean speed during a snow storm is between 11 m/s and 17 m/s, from 6 m/s up snow agglomeration on surfaces being significant (Florescu, 2001).

In nature, time interval of agglomeration is between 2...4 h and occasionally they are sufficient to develop snow deposits that may reach 1 m height and, locally, even more.

The time scaling of the event in laboratory must consider several aspects; the process associated with drifting consists in episodes of rather strong wind that may last from several hours up to a whole day but the intensity decreases as the time is longer. Strictly observing the drifting process of the existing uniform distributed snow deposit on the roof, a longer period will result in transportation of the snow from the roof in which manner this might be possible. Consequently, the interval of time that interested was the one that in laboratory allowed to observe the drawing of particles followed by the formation of deposits on the roof up to worst situations. Time scaling is derived from the general relationship of similarity between the process in nature and the one in laboratory:

$$\frac{V_{\text{model}}}{V_{\text{nature}}}=\frac{L_{\text{model}}}{L_{\text{nature}}}\cdot\frac{T_{\text{model}}}{T_{\text{nature}}}, \tag{1}$$

where: $V_{\text{model}}/V_{\text{nature}}$ is the speed scale; $L_{\text{model}}/L_{\text{nature}}$ – length scale; $T_{\text{model}}/T_{\text{nature}}$ – time scale.

The reference speed of the wind in nature, at 10 m above the ground, was determined according to the standard recommendations SR EN 1991-1-4-2005, SR EN 1991-1-4/NA-2006, CR 1-1-4-2005 (revized 2010) and the reference speed in the tunnel was considered in front of the model at the top level. Based on the mean wind speed profile, the mean wind speed at the building height in the tunnel is set and a 1:4 scale of modelling the speeds was obtained. In Table 1 the wind speeds that were used for modelling at natural scale and at reduced scale are presented.

As the length scale is 1:400, a time scale resulted of 1:100. A minute in laboratory is 100 min. in nature, which is about 2 h of drifting with constant wind speed. Following the observations of previous reference studies (Michaux, 2003) the process of acceleration of drifting was rather associated with modifications of wind speed and of the wind attack angle than of a continuous wind speed acting quasi monotonously. Drifting episodes consisted in steps of increasing the speeds continuously from 1.83 m/s up to 3.15 m/s.

**Table 1**
*Reference Speeds Used in the Experiment*

| 1:1 scale | Model in tunnel | In the numerical simulation | | |
|---|---|---|---|---|
| | | Model 1:400 scale | Model 1 at 1:1 scale | Model 2 at 1:1 scale |
| 10.58 m/s ($z_{ref}$ = 10 m); 14.39 m/s ($z_{ref}$ tunnel) | 1.83 m/s… …3.55 m/s | 2.85 m/s | 20.413 m/s | 11.37 m/s |

Derived from the motion eq. of the snow particles the similitude of transportation by saltation must be insured in the process of simulation of snow drifting. A correct simulation of the phenomena in nature to a reduced scale in laboratory, is based on several conditions:

i. The geometric scales must be respected.

ii. The model of the building must be totally imersed in the boundary layer (Da Matta Sant'Anna, 1983):

$$\frac{u_*^3}{2\mathrm{g}\,\nu} \geq 30 \tag{2}$$

where: $u_*$ is the wind velocity corresponding to the stress, [m/s], g – the gravity constant, [m/s$^2$] and $\nu$ – the kinetic viscosity of the fluid, [m$^2$/s].

iii. The model of wind must insure proper scales of the friction speed, $u_*$, threshold speed, $u_{*,t}$ and final speed, $u_f$ that define the combined regime of the snow particles, saltation and suspension. In order to simulate particles in saltation mode, the following condition must be respected (Naaim-Bouvet & Naaim, 1998):

$$\frac{u_f}{u_{*,t}} > 1. \tag{3}$$

iv. For limited wind speeds under those that determine strong storms, the mobility and suspension are controlled by the following relationship proposed by Owen (inferior limit controls the mobility and the superior the suspension) (Da Matta Sant'Anna, 1983):

$$0\ldots0.001 \leq \frac{\rho_{\mathrm{air}} u_*^2}{\rho \mathrm{g} D} \leq 0\ldots1.0\,. \tag{4}$$

v. Proportion between inertia and gravitational forces, which means the similitude between trajectories of movement of the snow particles and the model particles known as Froude's criterion expressed in the following forms (Leitl, 2006):

$$Fr = \frac{v^2}{Dg};\ C_D\frac{\rho_{\text{air}}L}{\rho_p D} \text{ and } \frac{gL^2}{u_*^2 h}. \tag{5}$$

In the relationships (4) and (5) the significance of the terms is: $C_D$ – the drag coefficient; the other terms are defined under the relationship (8).

In the laboratory of Buildings Aeodynamics of the Faculty of Civil Engineering from Iaşi the model of the snow particles with glass beads showed a good similarity with all criteria excepting Froude's criterion, this one being rather difficult to be respected. Relevant studies (Naaim-Bouvet & Naaim, 1998; Naaim-Bouvet *et al.*, 2002), show that the lack of similarity of Froude's criterion may be tolerated, still reaching the geometrical similarity of a snow drift between the model and the prototype if the surface shear stress distribution is not sensitive to the shape of the wind profiles where the flow is dominated by abrupt changes; also if trajectories are small in comparison with the dimesions of the modeled structure.

A common difficulty of the simulation is the fact that while the model of the interaction between the wind action and the building is more appopriate at smaller scales because of the necessity of immersing them properly in the boundary layer, for the study of snow agglomerations on structures, a greater scale would suit better.

This study is based on the erosion technique of an uniform layer of 2 mm of particles of glass beads with diameters of 0.2...0.4 mm distributed on the surface of the roof. The roof perimetral edge is outlined with a 2 mm vertical band that simulates the element used to prevent from sliding and dropping down the snow agglomeration.

The basic similarity criteria being the subject of numerous studies over the at least 50 years, derived similarity requirements resulted (Thiis & Gjessing, 1999; Thiis, 2003), and in the herein presented research they were analysed further from the following points of view: the roughness length $z_0^{'}$ is the parameter which defines the characteristics of the turbulent flow in the proximity of the surface, influencing directly the instantaneous speed values. The value of the roughness length was determined in the laboratory with the following relationship:

$$z_0^{'} = e^{\frac{u(z_2)\ln(z_1) - u(z_1)\ln(z_2)}{u(z_2) - u(z_1)}}, \tag{6}$$

where: $u(z_1), u(z_2)$ are the values of in-wind speed determined in two locations in the proximity of the model of the building; $z_1$ , $z_2$ – the related heights where the speed was determined, one close to the surface and the other at the reference height (usually the height of the building).

Roughness length associated with the drifting experiment was determined by choosing the height $z_1$ at 3 mm above the surface of the floor near the model of the building (about 1 m height above the ground in nature) and $z_2$ at 4.2 cm, the eave level of the model. The two values of in-wind speeds were $u(z_1) = 2.1$ m/s and $u(z_2) = 3.04$ m/s (Fig. 3 *b*).

The value of the roughness length based on the boundary layer characteristics is 0.006 m.

1. Based on the value of the modified roughness length, $z_0^{'}$, the friction velocity is evaluated with the log-law relationship:

$$u_* = \frac{u(z)k}{\ln\left(z/z_0^{'}\right)}. \tag{7}$$

2. The mechanisms that controle drawing and falling of particles in saltation are linked in through the initial eqs. of motion. The threshold velocity of the particle is determined with the following relationship:

$$u_{*_t} = A\sqrt{\frac{\rho - \rho_a}{\rho_a}\mathrm{g}D}, \tag{8}$$

where: $A$ is a parameter depending on the internal friction angle of the particle material and on the turbulence of the entraining flow, $\rho$ – the density of the particle in saltation motion, $\rho_a$ – the density of the air, g – the gravity constant and $D$ – the particle diameter.

For the Reynolds number $\Re e = u_{*_t}D/\nu > 5$, $A$ = 0.118 and $A$ = 0.1...100 for $\Re e < 5$.

3. According to Michaux, (2003), Valembois' iterative process (1983) developed on sand particles was tested on the characteristics of the glass beads in order to obtain the final speed of falling of these particles. Accordingly, a so called, „parameter of the particle" was found with the relationship:

$$G = \frac{\rho - \rho_a}{\rho_a}\mathrm{g}\frac{D^3}{\nu^2}, \tag{9}$$

where $\nu$ is the kynetic viscousity.

The values of $\Re e$ numbers depend on the values of the parameter $G$ (Table 2).

**Table 2**

*Values of $\Re e$ Number Depending on the Parameter of the Particle, G* (Michaux, 2003)

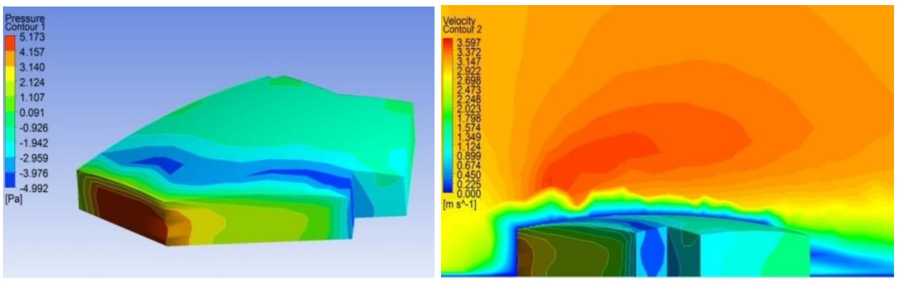
| $G$ | $\Re e = \phi(G) = \frac{U_f D}{\nu}$ |
|---|---|
| $G \le 10$ | $\Re e = 0.0556G$ |
| $10 \le G \le 300$ | $\Re e = 0.0784G^{0.85}$ |
| $300 \le G \le 67{,}000$ | $\Re e = 0.1711G^{0.713}$ |
| $67{,}000 < G$ | $\Re e = 1.826G^{0.5}$ |

4. The value $\Re e$ is used then to obtain a theoretic value of the final speed of the particle, $u_f$, with the relationship:

$$u_f = \frac{\nu \Re e}{D}. \tag{10}$$

### 2.2. Computer Aided Simulations

This study needed a stage of numerical simulations from several motivations, one being related to the flow on the curved roof, although sharp edges of the walls and the vave itself insure the self-modelling. Other reasons are related to the identification and analysis of the particular areas affected by the local turbulence manifested by the detaching layers and the vortices caused by re-attaching of the flow to the roof.




*a* *b*

Fig. 4 – Simulation of the wind flow over the model of the building (reduced scale): *a* – wind pressure capture; *b* – wind speed capture.

Three models of the wind flow on the roof without snow drift were developed in ANSYS CFX at full scale: wind speed at 20 m/s and 10 m/s respectively at the entrance of the domain, and finally, at reduced scale 1:400 of the building in the wind tunnel and consequently adopting the reference mean wind speed corresponding to the experiment (Fig. 4).

### 3. Results and Discussions

Glass beads were used in previous research experiments in our laboratory, mostly related with simulations of the snow agglomeration on communications infrastructure (Iversen, 1979). The model material was found to suit well the simulation because it contains particles with different aspects similar with the snow that presents itself flakes with various dimensions and aspect. The characteristics of the material that models the snow in laboratory and the snow itself are presented in Table 3.

**Table 3**
*Comparative Characteristics of the Model Particles and of the Snow Used in the Tests* (Florescu, 2001)

| Characteristics | Glass beads | Snow |
|---|---|---|
| Density, [g/cm$^3$] | $\rho_m = 1.308$ | $\rho_s$[1)] $= 0.3$ |
| Particle diameter, [mm] | 0.2...0.4 | 0.15...0.5 |
| Internal friction angle, $\alpha$, [º] | 19...32 | 40...45 |

[1)] Specific weight of the snow varies between 0.12...0.2 g/cm$^3$ for fresh snow to 0.45...0.55 g/cm$^3$ for old snow.

Previous researches on the simulation of the erosion and transport show that sudden increasing the wind speed in gusts favourizes the occurence of saltation and transport (Michaux, 2003). Finally, a continuous drifting experiment was run during 5 min. at continuous increasing speed 3.15 m/s (Fig. 5).

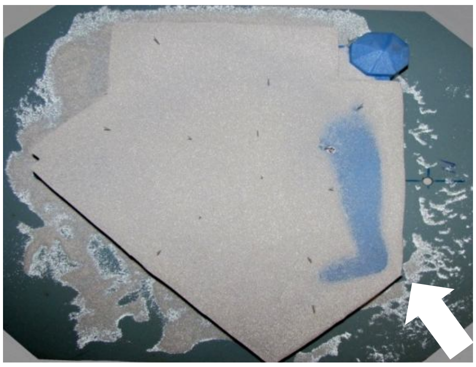


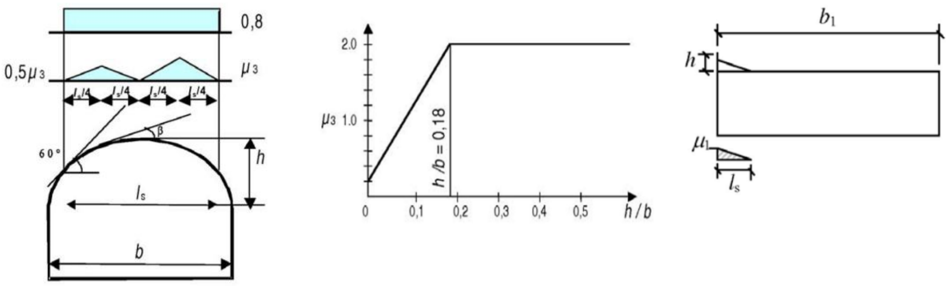
Fig. 5 – Snow drifted contours at the final experiment (wind direction is emphasized).

An uniform layer of 2 mm thickness covered the domed roof before wind action. In choosing the height of the uniform layer it was taken into account the estimated depth of the snow deposit (CR 1-1-3-2005, revized 2010), considering the specific weight of the snow after several hours or days of continuous snowing, which is 2…3 kN/m$^3$.

The rate of transportation and saturation are not in particular evidentiated in this study, but during the experiment, the ablation zones are put in evidence. Also, based on the friction velocity values, a theoretic saltation height was determined according to Pomeroy, 1988 (Michaux, 2003):

$$h_s = \frac{1.6u_*^2}{2g}. \tag{11}$$

The surface of the roof is large and quite planar, so drifting was not expected in important agglomerations, excepting the eave areas on the perimeter contour, the particles layer being not eroded, but increased. In the top area, regions with increased thickness of the particles were noticed and there is a general agreement with the shape of the snow deposits on curved roofs resulted from agglomeration presented in Eurocode 1 (Fig. 6).




*a* *b* *c*

Fig. 6 – Snow shape factors (EN 1991-1-3/NA): *a* –shape factor (uniform distribution and agglomerations) of the snow load on cylindrical roofs; *b* – values of shape factor relative to aspect ratio *h*/*b*; *c* – exceptional snow load distribution on terrace roofs in the parapet area.

In the case of uniform distributed snow layer, the shape factor is 0.8. In the case or drifted snow, the shape factor of the snow deposit on domed roofs with small slopes is $\mu_3$ , its value being diminished at half on the in-wind exposed part of the roof and is increased to its maximum value in the part affected by agglomeration (Fig. 6 *a*). Shape factor, $\mu_3$ , is determined with the relationship

$$\mu_3 = 0.2 + 10\frac{h}{b}, \tag{12}$$

and limited to 2.0, although national annex to EN 1991-1-3/NA may recommend lightly altered values.

Shape factor, $\mu_1$, of the exceptional agglomeration of snow load behind the parapet in the eave area is obtained from expression:

$$\mu_1 = \min\left(\frac{2h}{s_k};\frac{2b_1}{s_k};8\right). \tag{13}$$

The length of the agglomerated snow deposit is estimated by

$$l_s = \min(5h;b_1;15m). \tag{14}$$

Although the study refers to a building with irregular shape and large in plane dimensions, the application of these relationships gives the following results for the full scale data regarding the geometry of the building and the snow reference value with 50 years period of return: $s_k$ = 2.5 kN/m$^2$, $\mu_3$ = 0.84, $\mu_1$ = 1.0, $l_s = 5m$.

With respect to these particular determinations the following observations must be put into light:

a) in the regions on the roof where the drift is observed, the height of the agglomeration is increased at 2.5…3 mm; a validation of the results in laboratory is thus put in evidence, the shape factor, $\mu_3$, determined for full scale data showing a relative small increase from 0.8 (case of uniform distribution) to 0.84;

b) the value of the shape factor, $\mu_1$, for full scale data is such as it is obvious that the agglomeration as a rule, cannot exceed the height of the parapet, otherwise the snow will be drifted and pulled of the roof; or, the uniform layer of the particles of glass beads was at first of 2 mm and finally, agglomerated behind the eave in heights of 3...3.5 mm, showing an increase of about 50% from the initial uniform layer.

The difference between the quantity of snow involved in transportation on the ground and the snow deposit on the roof is that in the last case snow may be lost also from pulling off and dropping from the surface of the roof. As the transportation length of the glass beads particles was not previously analysed, basic information about an estimation of this quantity is even harder to endeavour but it is handy to determine the loose material in laboratory; the glass beads deposit on the roof was weighted before the experiment and after and it was found that under 5% was lost by drifting away, which having in view the important dimensions of the roof is quite realistic.

The application of relationships (2),...,(12) and comparisons between model and full scale are presented in Table 3. In spite of a wide variation of the dimensions of the snow flakes, it is quite often to observe that a diameter of 0.15 mm is preferred for simulation of drifted snow so the calculations were done with this diameter and with a snow specific weight of 300 kN/m$^3$, value recommended by CR 1-1-3-2005. The diameter of the glass beads introduced in calculation has a mean value of 0.3 mm.

The results presented show that using glass beads is a good approach of the phenomenon, although the authors did not manage the matching of Froude's number; this happened indirectly by good fitting of the threshold speed of the particle theoretically determined with the data provided in the experiment which corresponds to the values obtained by other authors in literature (Iversen, 1990). The final speed of falling of the particle also theoretically determined is in agreement with the values presented by Michaux, (2003), and Naaim, (1995).

An increased scale of the simulation might give more information about the transportation length and about the maximum possible depths of the drift. The saturation of the drift is difficult to be put in evidence because of the irregularity of the roof and because partially, the snow will be either in suspension or transported away from the surface. A separate analysis of saturation on a drift at the same modelling scale, might perhaps give thorough information, in particular linked with the ablation area observed on the roof at the end of the drifting episodes.

The numerical simulation of the turbulent flow over the domed roof was designed to assist the physical simulation in the wind tunnel by adding information about the parameters involved (Fig. 5). Indeed, the computer simulation shows the flow field around the building and puts in evidence the regions of increased turbulence and important negative values being in concordance with the results from direct measurements in the tunnel. Still, improvements must be performed in order to control the simulation because although very accurate regarding the wind flow, the combined wind and snow drift simulation should be validated with more reliable determinations on physical models.

**Table 4**

*Results of Simulating the Snow Drifting Parameters in the Wind Tunnel and at Natural Scale*

| Nr.crt. | Relationship verified | In laboratory | In nature (snow drift) |
|---|---|---|---|
| 1 | (2) | 89.58 | 30,000 |
| 2 | (3) | 1.58/0.172 = 8.8 | 0.28/0.08 = 3.5 |
| 3 | (4) | 0.023 | 1.4 |
| 4 | (6) | $6 \times 10^{-3}$mm | $10^{-3}$…..$6 \times 10^{-3}$m (Hautoy, 1973) |
| 5 | (7) | 0.26 m/s | 0.5 (0.8) m/s, (Thiis & Gjessing, 1999; Thiis, 2003) |
| 6 | (8) | 0.172 m/s | 0.07...0.25/0.25 (Iversen *et al*., 1990) |
| 7 | (9) | 2,677.3 | 76.48 |
| 8 | (10) | 47.55 | 4.85 |
| 9 | (11) | 1.58 m/s | 0.28 m/s (Michaux, 2003) |
| 10 | (12) | 0.0055 m | 0.24 m |

**Notes:** The values presented in the table are determined by the author. Values accompanied by references in brackets are cited from other authors for comparison.

## 4. Final Remarks

The paper focused on the importance of modelling the snow drifting in boundary layer wind tunnels where all the characteristics of the wind flow may be controlled. A method of simulation and analysis of the wind combined with snow drift was completely set up and performed. The basis of the simulation consists in the evaluation of the characteristics of the particles that substitute the snow and in modelling the proportions of the phenomenon in time and space.

Patterns of the deposits of the particles on the roof resulted from the experiments performed in wind tunnel were put in evidence, and the physical relevant characteristics of the drift were analysed: the area where the saltation initiated, the depth of the deposit in specific positions, the length of transportation of the particles. Some of these characteristics were determined and compared directly with similar research results.

In order to obtain more information about snow drift deposits this research in the atmospheric boundary layer will be carried on in extended directions of study.

## REFERENCES


Anno Y., *Requirements for Modelling of a Snowdrift*. Cold Reg. Sci. a. Technol., **8**, 241-252 (1984).

Cook N.J., *The Designer'Guide to Wind Loading of Building Structures*, Part 1, 2. BRE Report, Butterworths, Univ. Press, Cambridge, Great Britain, 1985.

Da Matta Sant'Anna F., *Simulation de la neige en souflerie* (edifice a toit plat). DBR Internal Report nr. *474,* NRCC, Division of Build. Res., Canada, 1983.

Da Matta Sant'Anna F., Taylor D.A., *Snow Drifts on Flat Roofs, Wind Tunnel Tests and Field Measurements*. J. of Wind Engng. & Ind. Aerodyn., **34**, 223-250 (1990).

Florescu E.C., *Modelarea parametrilor climatici în vederea optimizării elementelor geometrice ale profilului transversal al drumului în regiuni cu ierni aspre*. Ph.D. Diss., "Gheorghe Asachi" Techn. Univ., Iaşi, 2001.

Hautoy C., *La souflerie a couche limite du C.S.T.B.: Simulation des propriétés dynamique du vent*. Étude. Section Aerodynamique des Constructions, ADYM, Nantes, France, 1973.

Holmes J. D., *Wind Loading of Structures*. Sec. Ed., Taylor & Francis, London, U.K, 2007.

Iversen J.D., Wang W.-P., Rasmunssen K.R., Mikkelsen H. E., Hasiuk J. F., Leach R.N., *The Effect of a Roughness Element on Local Saltation Transport*. J. of Wind Engng. & Ind. Aerodyn., **36**, 845-854 (1990).

Leitl B., Schatzmann M., Baur T., Koenig-Laglo G., *Physical Modeling of Snow Drift and Wind Pressure Distribution at the Proposed German Antarctic Station NEUMAYER III*. 25th Internat. Conf. on Offshore Mechan. a. Arctic Engng., Hamburg, Germany, 2006.

Lieberherr G., *Modeling Snow Drift in the Turbulent Boundary Layer*. Environ. Fluid Mechan. a. Hydrol., Ecole Polyt. Fédérale de Lausanne, Labor. of Environ. Fluid Mechanics, 2010.
Michaux J. L., *Étude, compréhension et modélisation des phénoménes liés au transport de la neige par le vent*. Thèse de doctorat, Univ. Joseph Fourier, Grenoble, France, 2003.
Naaim-Bouvet F., Naaim M., Michaux J.L., *Snow Fences on Slopes at high Wind Speed: Physical Modelling in the CSTB Cold Wind Tunnel*. Natural Hazard a. Earth Syst. Sci., *3-4*, 137-145 (2002).
Naaim-Bouvet F., Naaim M., *Sowdrift Modelling in a Wind Tunnel: Vertical and Horizontal Variation of the Snow Flux*. Ann. of Glaciol., **26**, 212-216 (1998).
Tabler D.R, *Design Guidelines for the Control of Blowing and Drifting Snow*. Strategic Highway Res. Program, N.R.C. Washinton, U.S.A., 1994.
Teleman E.C., Silion R., Axinte E., Pescaru R. *Turbulence Scales Simulations in Atmospheric Boundary Layer Wind Tunnel*. Bul. Inst. Politehnic, Iaşi, s. Constr. Archit., **LIV(LVIII)**, *2*, 7-14 (2008).
Thiis T. K., *Large Scale Studies of Development of Snowdrifts around Buildings*. J. of Wind Engng. & Ind. Aerodyn., **91**, 829-839 (2003).
Thiis T.K., Gjessing Y., *Large Scale Measurements of Snow-Drifts around Flat Roofed and Single-Pitched Roofed Buildings*. Cold Reg. Sci. a. Technol., **30**, 241-252 (1999).
*** *Evaluarea acţiunii vântului asupra construcţiilor* (modified 2010). CR 1-1-4-2005, SR AC ISO 9001, UTCB, Bucureşti, 2010.
*** *Eurocod 1*: *Acţiuni asupra structurilor.* Partea 1-3: *Acţiuni generale.- Incărcări date de vânt.* SR EN 1991-1-4-2005.
*** *Eurocod 1*: *Acţiuni asupra structurilor.* Partea 1-3: *Acţiuni generale.- Incărcări date de vânt. Anexa naţională*. SR EN 1991-1-4/NA-2006.

## SIMULAREA FENOMENULUI DE VISCOLIRE A ZĂPEZII DE PE SUPRAFAŢA UNUI ACOPERIŞ CU FORMĂ NEREGULATĂ ŞI DIMENSIUNI MARI ÎN TUNEL AERODINAMIC CU STRAT LIMITĂ TURBULENT

(Rezumat)

Lucrarea constituie este parte a unei teme mai ample de cercetare, scopul acesteia fiind determinarea presiunilor din vânt şi a încărcărilor din zăpadă pe acoperişul sub formă de dom, cu o curbură foarte redusă, a unei clădiri cu formă neregulată şi dimensiuni neobisnuit de mari, aşadar aproape imposibil de încadrat în prevederile normelor de proiectare.

Modelarea la scară redusă a clădirii (1:400) şi studiul său în tunelul aerodnamic cu strat limită turbulent la acţiunea combinată a vântului cu viscolirea zăpezii a fost însoţită de o modelare numerică în programul ANSYS CFX. Prin modelarea numerică s-au evidenţiat zonele puternic afectate de acţiunea vântului, acestea constituind suprafeţe de pe care zăpada este antrenată şi transportată. S-a evidenţiat astfel formarea

unor depozite localizate în zone specifice, puternic influențate de câmpul de presiuni şi sucțiuni a vântului.

Modelarea fizică a ninsorii şi viscolirii este foarte dificilă datorită parametrilor implicați, în cadrul simularii realizate similizăpada fiind formată din bile de sticlă de dimensiuni de 200 până la 400 μmm. Rezultatele obținute au fost comparate atât cu valorile obținute în alte studii de cercetare cât şi cu valorile recomandate de normele de proiectare la acțiunea zăpezii, care pot fi parțial asimilate.