Wind tunnel tests of snow load distribution on the roof of the New Krakow Arena
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Abstract
Authors performed a wind tunnel tests on the New Krakow Arena sports hall roof model to predict the snow cover distribution on which the construction will be exposed. The building shape consists of two flattened domes. Snow precipitation and redistribution tests were performed with the use of powdered polystyrene foam. The results were transformed into load schemes applicable in the design process of the structure.

1 Experimental setup
Test were performed in a wind tunnel with boundary layer modelling, which allowed proper recreation of natural wind speed and turbulence profile. The flow structure inside working section of the tunnel was established with 2cm floor blocks and a 20cm fence (Figure 1). Wind speed was measured in four vertically aligned points with the use of hotwire thermo-anemometers. From the regression of the mean speed measurement, exponent of the power-law wind speed profile in model situation was obtained for both precipitation and redistribution experiments as $\alpha_m \approx 0.22$. Study of wind conditions in the localisation of the building in question showed that according to European Codes (EN 1991) the value of the $\alpha$ coefficient should range from 0.19 to 0.24.

![Figure 1: Working section of the wind tunnel of Wind Engineering Laboratory of Cracow University of Technology.](image)

In the working section of the wind tunnel a 1:150 model of the building was positioned. The prototype building domes dimensions (diameter/overall height/arch height) are 186/40.8/20 m for the large one and 60/14/8 m for the smaller. Distance between domes centres is 97 m. The reference height for the model situation $z_{ref,m} = 272$ mm was chosen, which corresponds with the prototype height $z_{ref,p} = 40.8$ m.
2 Precipitation simulation

The reference length $L$ was chosen to be 1 m for the model and 150 m for the prototype. The reference flow speed (mean wind velocity at height $z_{ref}$) was obtained from the wind profile as $v_{ref,m} = 0.914 \text{ m s}^{-1}$. The main similarity criterion number (Kimbar & Flaga 2008) for the model situation was obtained:

$$\Pi_{t,m} = \frac{v_{ref}}{v_t} = 3.05$$

where $m$ and $p$ are subscripts denoting variable in model or prototype situation, $v_t$ is the terminal velocity of the dispersed phase. The $v_{t,m} = 0.3 \text{ m s}^{-1}$ (terminal velocity of the powdered polystyrene foam), and $v_{t,p} = 1.5 \text{ m s}^{-1}$ (Mellor 1965), hence the model situation corresponds with prototypical reference wind speed $v_{ref,p} = 4.6 \text{ m s}^{-1}$, which gives mean wind speed of $3.38 \text{ m s}^{-1}$ at the height of 10 m for the $\alpha = 0.22$, which is reasonable wind speed during snowfall according to local wind conditions.

The turbulence intensity at reference height was measured to be $I_{v,m} = 14.0\%$. The turbulence intensity in model conditions are considered to be satisfactory for precipitation simulation.

Eight precipitation test were conducted for different wind angle in $45^\circ$ interval. For each test after establishing steady flow, 60 litres of powdered polystyrene foam was poured into the working section of the wind tunnel from a sieve-like feeder during 5 minutes. The particle cover reference height samples were collected from the wind tunnel floor and the height of the particle cover on the model roof was measured with laser-scanner device. The particle cover shape factor $\mu_{pre}$ was determined as dimensionless height of the cover.

3 Redistribution simulation

For each wind direction redistribution test of particle cover was performed. The reference flow velocity was increased in regard to precipitation simulation up to $v_{ref,m} = 1.70 \text{ m s}^{-1}$. Tests at this velocity were performed until equilibrium state was obtained after about 20 minutes. Assuming the air density $\rho_f = 1.23 \text{ kg m}^{-3}$ following similarity numbers (Kimbar & Flaga 2008) were obtained:

$$\Pi_{t,m} = \frac{v_{ref}}{v_t} = 5.67; \quad \Pi_{g,m} = \left(\frac{\rho_c - \rho_f}{\rho_f\rho_g}\right) = 0.0104$$

where $\rho_c$ is particle cover density, $d$ is mean particle diameter, $g$ is acceleration due to gravity. It is assumed $\rho_{c,p} = 250 \text{ kg m}^{-3}$ and $d_p = 500 \mu m$ (Mellor, 1965). Condition of exact equality of the $\Pi_g$ number in model and prototype gives $v_{ref,p} = 9.8 \text{ m s}^{-1}$ (that is $7.2 \text{ m s}^{-1}$ at the height of 10 m) and $\Pi_{t,p} = 6.53$, which stays in good accordance with $\Pi_{t,m}$. As before, shape of the cover was scanned and the shape factor $\mu_{red}$ was determined.

4 Snow load distribution formulation

Procedure of assembling results from wind-tunnel experiments into recommended load distributions took into account different wind directions. So called “base scheme” (Figure 2) was obtained by determining the weighted mean from precipitation simulation results for different wind directions:

$$\mu_{base} = \sum \mu_{i,pre} p_i$$

where $\mu_{base}$ is shape factor for base scheme, $p_i$ is probability of the wind from $i^{th}$ direction (obtained from local wind rose), $\mu_{pre}$ is shape coefficient obtained from single precipitation simulation. Resultant redistribution patterns were calculated for each direction from the formula:
\[ \mu_{i,\text{drift}} = \mu_{\text{base}} + \Delta \mu_{i,\text{drift}} = \mu_{\text{base}} + (\mu_{i,\text{red}} - \mu_{i,0}) \]

where \( \mu_{i,\text{drift}} \) is a drift scheme shape factor for \( i^{th} \) wind direction, \( \mu_{\text{red}} \) is shape coefficient obtained from single redistribution simulation, \( \mu_{i,0} \) is initial shape factor for redistribution test.

### 5 Examples of results

Figure 2 to Figure 4 present example final \( \mu \) shape factors.

**Figure 2:** Basic scheme of the snow distribution (dimensionless \( \mu \) factor).

**Figure 3:** Redistribution pattern for 0° wind angle (dimensionless \( \mu \) factor).
6 Conclusions

Shape factor distribution results are reasonable. These distributions diverge substantially from results which could be obtained by extrapolation of rough shape factor distribution in Eurocode for cylindrical and abutting roofs. Peak values of obtained shape factors are lower than ones that could be derived from abovementioned code schemes. Extreme values of shape factor are (large dome/small dome) for basic scheme: 1.18/1.1, for redistribution schemes: 2.19/1.75. Non-prismatic, curved buildings such as domes are always problematic in regard of wind and snow actions. The variety and incongruity of NDPs approaches speak for itself. Hence, authors believe the results are rather specific for the construction in question.

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References


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