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Wind tunnel model tests of snow precipitation and redistribution on rooftops, terraces and in the vicinity of high-rise buildings

A. Flaga [a], G. Bosak [a], A. Pistol [a,*], L. Flaga [b]

[a] Institute of Structural Mechanics, Cracow University of Technology, ul. Warszawska 24, 31-155 Krakow, Poland
[b] Wind Engineering Laboratory, Cracow University of Technology, Al. Jana Pawla II 37/3a, 31-864 Krakow, Poland

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ABSTRACT

This paper describes the model tests conducted in the Wind Engineering Laboratory of the Cracow University of Technology aimed at determining the shape coefficients of snow load on high-rise buildings of *The Warsaw Hub*. The shape coefficient was measured at two different situations: snow precipitation and its subsequent redistribution. The model tests were conducted independently for rooftops and terraces in the scale of 1:120 and for the neighbouring area of the buildings in the scale of 1:300. The results allowed for creation of snow shape coefficient maps on the investigated areas both for snow precipitation and redistribution for the use of designers, constructors and architects.

1. Introduction

Accurate prediction of snow distribution on rooftops of buildings is important both for structural engineers and architects. Most building codes and standards provide only very basic guidelines which can be utilized in the cases of simple roof shapes and without the wind interference of additional buildings located in the neighbouring area. Wind tunnel tests are one way of more precise determination of the phenomena of snow drifting on more complex area.

Methods of studies in this area vary in the approach. Wind tunnel tests may use different particles that simulate snow, which determines different methods and similarity criteria. Bran was used [1] to model particles of the snow in wind tunnel tests and simulate the drifting on the lower level of large area two-level roof under different wind speeds and in different surroundings. The authors stated that not every similarity criterion can be fulfilled at the same time in model studies of snow drifting and accumulation at a reduced geometric scale. In the work [2], authors have used crushed walnut shells in flume tests to analyse the snow drift formation process,

* Corresponding author.
E-mail addresses: liwpk@windlab.pl (A. Flaga), gbosak@pk.edu.pl (G. Bosak), aleksander.pistol@gmail.com (A. Pistol), flagarch@gmail.com L. Flaga).
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focusing mostly on particles transport rates and trapping efficiency of geometric irregularities. Their tests results have shown decent similarity with full scale transport rates of snow particles, providing the method to be useful in practice. Another method, presented in Ref. [3], employs high-density silica sand for wind tunnel tests of snow redistribution on flat roofs. They have analysed in detail the influence of wind velocity, wind duration and roof span on transport rates, snow accumulation and the location of peak points of snow drifts. Another material used for simulating snow is grinded Styrofoam [4], where the authors develop similarity criteria for snow precipitation and redistribution basing on multiphase flows theory, where the snow is depicted as a homogenous dispersion described by concentration field k and mass flux field **Q**. This method is used by the same authors in Ref. [5] to perform practical model tests of snow loads on large span roof shaped as two flattened domes. The performed tests allowed to find shape factors μ for different areas of the roof, which diverge significantly from the value extrapolated from Eurocode, but are reasonable. Most of the mentioned works notice the fact that design codes and standards provide no appropriate snow load schemes for atypical roof shapes.

A thorough comparison of different materials with different densities (low-density wood ash, medium-density polyfoam and high-density silica sand) in snow redistribution tests on a flat roof have been provided in Ref. [6], where nearly identical conditions have been taken into account in each test to allow a reasonable comparison. The results were also compared with those from field observations of prototypes, taking different characteristics and parameters into account. It is worth mentioning that most of the materials used for snow simulation (silica sand, crushed walnut shells, bran, but also activated clay, glass dust, baking soda or powdered potatoes) have higher density than snow, which implies higher wind speeds need to be used in the tests. Grinded Styrofoam has a lower density, which is closer to freshly precipitated snow.

Analytical methods may be used to take other parameters into account, for example heat transfer [7]. The authors have studied the influence of heat loss through large sized roofs for four different cases using FEM, which resulted in proposing revised snow formulae for large size roofs. A more convenient way of evaluating snowdrifts than model test was established in Ref. [8], which can be particularly useful for less complex rooftops. This procedure is based on physics of drift formation and consists of two main parameters: transport rate of snow particles and trapping efficiency, described as percentage of snow transported from the source area which is captured in the drift.

The subject of this studies is a complex of three high-rise buildings located in Warsaw. Building A is designed to be 86,5 m tall, whilst buildings B and C are intended to be 130,5 m tall. Between buildings A & B and B & C there are lower buildings that are 26,5 m high. The part between buildings A & B contains a small passage at the ground level, allowing for communication. The subject buildings – as modelled for the tests in the scale of 1:300 – and their surroundings are shown in Fig. 1.

The entire set of environmental tests conducted in the Wind Engineering Laboratory of the Cracow University of Technology (WEL CUT) concerning these buildings included also investigations of wind action on the buildings, wind comfort on pedestrian level, sunlight reflection analysis and vibration comfort analysis of the subject buildings. However, this paper only covers the snow load tests.

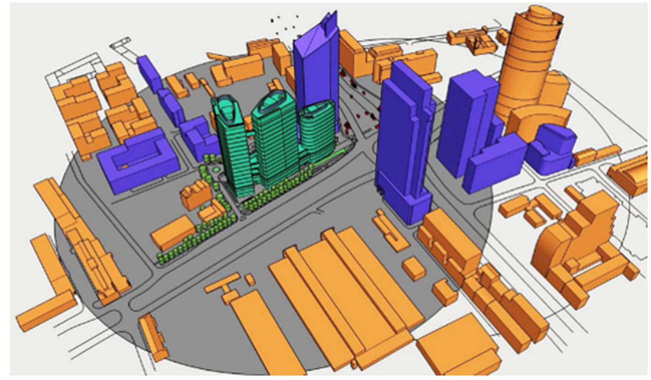

Fig. 1 – Buildings of *The Warsaw Hub* (central) and their surroundings as modelled for the tests.

The main scientific aim of the research was to determine the snow load on rooftops, terraces and elevation details of the subject buildings. The results were also intended for use in predicting possible pollution accretion in parts designated for penthouse cafes and restaurants located on the rooftops. The investigation of snow distribution on ground level around the buildings was aimed at identifying possible critical zones of accumulation and erosion and possible dangerous spots where large chunks of snow could be dropped from the rooftops. Patterns of snow cover after the redistribution tests were conducted could also be used for indicating the air turbulization and stagnation zones in the vicinity of the buildings.

The modelling scale was chosen respectively to dimensions of the wind tunnel working section. Together with the tower complex, the surroundings within the radius of 300 m with respect to existing buildings and future planned buildings were modelled in the scale of 1:300. For the snow load tests, only the situation with already existing buildings was taken into consideration.

2. Research method

For the tests, artificial snow was created with Styrofoam grinded on sandpaper until fine, loose consistence was achieved (Fig. 2). Prepared like this, the material shows some cohesion, perhaps resulting from electrostatic loads generated in the grinding process, effectively simulating the structure of snow and its behaviour. The particle diameter d resulted from the thickness of sandpaper. Such material has been successfully utilized in Wind Engineering Laboratory of Cracow University of Technology in former studies [4,5]. Basic parameters of grinded Styrofoam are listed below [9]:

- ρ_c – particle cover (layer) density: ~10 kg/m^3
- d – mean particle diameter: 0.43 mm
- v_t – terminal speed: 0.3 m/s