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Key words: *milling and rotary snow blower, throw-off distance, snow mass, throwing machine*

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EXPERIMENTAL INVESTIGATIONS OF SNOW BANK FORMATION DURING MILLING AND ROTARY SNOW BLOWER OPERATION

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The main purpose of this paper is to identify basic regularities of snow bank formation when using milling and rotary snow blowers. The study of the mechanism of snow bank formation was based on experimental investigations of the throwing machine rotor of the low-powered milling and rotary snow blower. Moistened sawdust was used as artificial snow. As the result of the conducted investigations, the nature of the snow bank formation has been determined and the regression equations for the distribution of the number of particles, total mass and average mass of individual particles of the material simulating one specific type of snow along the length of the snow bank have been obtained. The relative amount of the material transported by the rotor in relation to the total amount of material loaded into the rotor for the specified geometric and kinematic parameters of the rotor of the throwing machine has been found. The dependencies obtained make it possible to carry out simulation and visualization of snow bank formation during snow clearing operations, to choose the most rational parameters of the throwing machine of the milling and rotary snow blower, as well as to specify the strategy of snow clearing operations with the application of milling and rotary snow blowers.

Key words: milling and rotary snow blower, throw-off distance, snow mass, throwing machine

INTRODUCTION

Winter maintenance of transport network and territories for industrial and social needs is of great practical importance, both from the security point of view, as has been demonstrated in papers [1, 2] and from the economic point of view, as is proven in papers [3, 4]. Efficient removal of snow cover from hard surfaces comprises several problems, which should include issues related to the operational efficiency of area clearing and how to do it, because there are hidden costs (sedimentation, subsequent spring clearing and disposal), according to paper [3]. One of the most common types of snow clearing equipment used for snow clearing operations is milling and rotary snow blowers.

The issue of the selection of the type of snow plow equipment used was reflected in papers [5-7]. In the survey [7] the mechanism of intensification of the clearing process at the expense of optimization of traffic route of snow clearing equipment is investigated. The choice of optimum quantity of equipment, in particular for operations of spreading and plowing is investigated in the paper [8].

Several works [9-11] have been devoted to the investigation of the mechanism of snow drift formation and the factors influencing its formation, as well as the paper [12] has been devoted to the possibility of applying the Computational Fluid Dynamics (CFD) method and numerical solutions to the Navier-Stokes equations for these investigations. The earlier studies [13] have been devoted to the assessment of such parameters as the computational grid resolution, snowfall velocity, turbulent Schmidt number, threshold snow friction velocity and impact of CFD turbulence models on the computational accuracy. Further investigations have been carried out to assess the impact of a uniformly rough surface, according to paper [14] as well as various structural elements, such as snow barriers, which are usually installed on or outside the excess right-of-way in order to exclude blowing and snow drifting onto roads and thus improve road traffic safety, as described in the paper [15]. Some investigations have been carried out to assess the influence of forms that simulate a simple cab structure described in the paper [16], stepped flat roofs demonstrated in the paper [17] on snow transportation and the formation of snow drifts. At the same time, investigations aimed at complicating the mathematical model by taking into account the accumulation and erosion of snow, as well as time variations of the snow surface were conducted according to paper

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[18]. As for computer modeling of the snow particle structure, the work [19] has attracted the interest. In this work, the frequency function of particles collision was defined through the connection of discrete element method with computational hydrodynamics for investigation of granule growth and destruction mechanisms during granulation in the air-fluidized bed, while the function of one particle collision frequency was defined with the Froude number application. In order to simplify the dispersed phase, snow particles were considered in the work [20] as spheres with the identical diameter of 0.15 mm and density of 250 kg/m3, according to paper [21]. The improvement of the 3D DEM-FEM contact detection algorithm for the simulation of the interaction between particles and structures is presented in the paper [22]. The paper [23] demonstrates an algorithm for modeling an arbitrary particle. However, there are no both theoretical and experimental data on the geometric dimensions of the particles at the outlet of the working bodies of snow blowers.

To ensure the adequacy and accuracy of mathematical models of such complex phenomena as snow, along with computer modeling, extensive experimental investigations to determine its physical and mechanical properties are conducted, as can be seen from the paper [24]. In order to compile a physically-based model and predict the amount of snow run into the air intake opening of a car, measurements of snow particle sizes in a climatic wind tunnel were carried out, as demonstrated in the paper [25]. Works [26, 27] describe the phenomenon of snow clustering and point to its degree distribution in size, fractal shape, vertical elongation and high fall velocity, which increases with the cluster size. In the paper [27], the dependencies of the size distribution on the masses in the snow drift are presented. Experiments have been carried out in a wind tunnel for the investigation of snow mass flow and snow transport rate as a function of friction and particle diameter presented in papers [28, 29].

The influence of the morphology of snow on such characteristics as the angle of rest has been studied experimentally in the work [30]. In papers [31, 32] the process of snow drift formation on roofs of buildings for various functional purposes has been investigated experimentally. Of practical interest is the study [33] which demonstrates, that when the number of particles in agglomerate increases, the velocity increases and the agglomerate is more likely to adhere to the surface. It should be noted that in the paper [32] investigations on sedimentation and redistribution of snow were conducted using powder polystyrene foam in the function of artificial snow. The structure of snow in studying the mechanism of origin of avalanches is especially intensively considered. In the paper [34] a model of snow based on its microstructure has been developed and used to study the destruction of snow under combined load conditions. Also in the paper [35], the authors determined the critical length of the crack required for rapid propagation of shear fracture in the snow, which was considered as a quasi-brittle material.

As can be seen from the above, a number of papers [10, 12, 16, 17] are devoted to the investigation of formation of snow banks and change in time of their main parameters in different conditions. However, they investigate the behavior of snow banks of natural origin. Also, it is a matter of fact that there is a need to clear snow masses and increase the efficiency of this process, which is the subject of the large number of investigations [3, 4, 7, 8] but they emphasize on the optimization of the clearing process algorithm. However, the application of snow blowers usually results in the formation of snow banks with characteristics different from those produced by natural processes. The authors of the paper [36] solve the problem of finding the shortest path of a snow blower in the process of clearing the territory covered with snow of the identical thickness while limiting the height of the snow bank.

The work [37] describes the approach to determining the parameters of snow banks during the milling and rotary snow blower operation depending on its structural and technological parameters. However, the works [36] and [37] do not take into account the features of the formed structure, which does not make it possible to judge about their further impact on the cleared areas. As for experimental investigations of the system "snow blower – snow mass", in this case, the main emphasis is placed on the investigation of characteristics of the structural components of the milling and rotary snow blowers. Accordingly, in the investigation [38] the loads that the feeder of the small-sized rotary-auger snowplow experiences are studied experimentally, and in the investigation [39] aerodynamic characteristics of air flow formed by the feeder of the milling and rotary snow blower are investigated.

It is important to know the regularities of snow bank formation produced in the result of the operation of snow blowers because this will make the techniques more advanced and will develop the most effective ways to minimize the negative impact of snow banks on the transport infrastructure, industrial zones and residential areas. The main purpose of this work is to determine the main characteristics of the snow banks formed during operation of the throwing machine of the milling and rotary snow blower. The following tasks were solved in order to achieve this objective:

- Obtaining experimental values of the basic parameters of the snow banks during operation of the throwing machine of the milling and rotary snow blower;
- Recording and describing the results of the experiment.

MATERIALS AND METHODS

The experimental plant represents an assemblable platform on which a physical model of the throwing machine is installed, which is geometrically similar to the throwing machines of low-powered milling and rotary snow blowers, and video recording system of the throwing machine rotor operation process. The design parameters of the

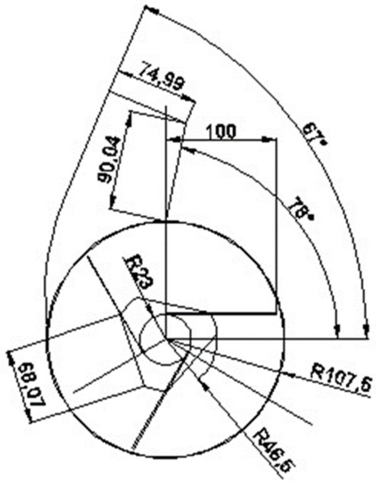

Figure 1: Geometric parameters of the throwing machine rotor (all measurements are in mm)

rotor of the throwing machine are presented in the figure (Figure 1). The video registration system represents video cameras with the possibility of obtaining photographs with 96 dpi resolution, which are installed in two mutually perpendicular planes. Figure 2 represents a general view of the plant for experimental investigations of snow bank formation during operation of the throwing machine of the milling and rotary snow blower.

An active single-factor experiment was carried out, in which the variable parameter was the angle of inclination of the guide spray nozzle relative to the horizontal surface. The angle of inclination varied from 200 to 600. The angular position was measured using a protractor with a measuring error of ±0.50.

The material to be transported represented compressed sawdust, which was moistened with water just before the experimental investigations (Figure 3). A part of the moistened sawdust was marked out in black color.

To register the mass of material loaded into the rotor and separate pieces of the mass, we used a scale with a relative measurement error of ± 0.01 gr. and a measuring range from 0 to 500 gr.

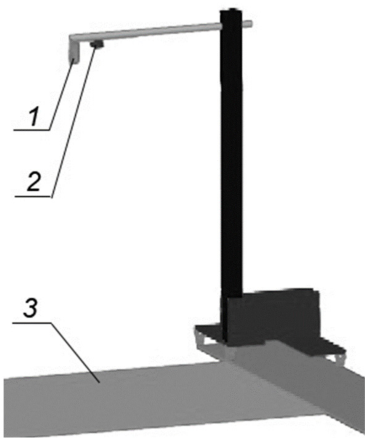

Figure 2: General view of the plant for experimental investigations of snow bank formation during the operation of the throwing machine of the milling and rotary snow blower: 1 is the laser rangefinder, 2 is the video camera, 3 is the assemblable platform

a) b)

Figure 3: Fragment of the material to be transposed: (a)initial view (before moistening); (b)prepared (after moistening)

The order of the experiment was as follows: a portion of material was loaded into the rotor of the throwing machine, where it was randomly distributed in the interlobe space (Figure 4).

As the result of the rotor's operation, it was unloaded. The specified amount of material was thrown off towards the side. At the same time, the angular speed of the rotor of the throwing machine was recorded, and the video recording of the material flow was performed. To determine the angular rotor speed of the throwing machine, the SS49E analogue Hall sensor and Arduino hardware-in-the-loop platform were used. The angular rotor speed of the throwing machine was 77.6 rad/s during experimental investigations. This value is average of values range of the angular speeds of the rotation of the rotor of the throwing machine real models, presented in the market of snow plows. The dispersion spot was then photographed using the camera mounted in the horizontal plane at a height of 0.916 m from the platform (Figure 5).

Figure 4: Filling of the interlobe rotor space of the milling and rotor snow blower with the transported material

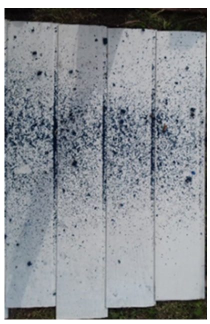

Figure 5: Fragment of the dispersion spot on the assemblable platform

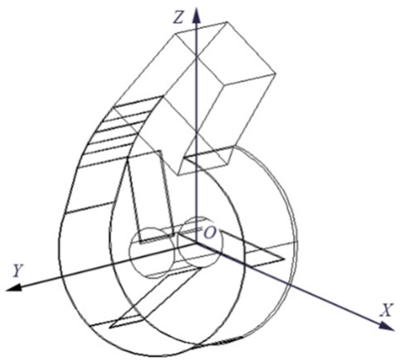

Figure 6: Coordinate system associated with the rotor of the throwing machine

Photographic materials of the dispersion spot were subjected to computer processing. As the result of this processing, the coordinates of the particle's positions in the adopted coordinate system were determined (Figure 6), and point-to-point calculation of their number in the dispersion spot was carried out.

A special image processing program was created to process the results. The image processing consisted of the calculation of particles and their position determination in the adopted coordinate system. The identification of the particles was based on the colour contrast between the background (the assemblable platform of the experimental plant) and the particles simulating the snow. C# programming language and VisualStudio development environment were used. Figure 7 illustrates a fragment of the running of the program.

After automated calculation of the number of particles N_i and determination of their total masses M_i, the average mass of one particle in the group was determined by the formula:

$$M_{0i} = \frac{N_i}{M_i} \quad (1)$$

RESULTS

All results obtained were statistically estimated and their statistical characteristics were determined. The basic statistical characteristics are presented in Table 1.

The most preferable option for describing the density of the particle number distribution over the width of the snow bank N_i was the gamma distribution function (Figure 8). Distribution of the total masses over the collection areas is also satisfactory; it is described by the gamma distribution (Figure 9).

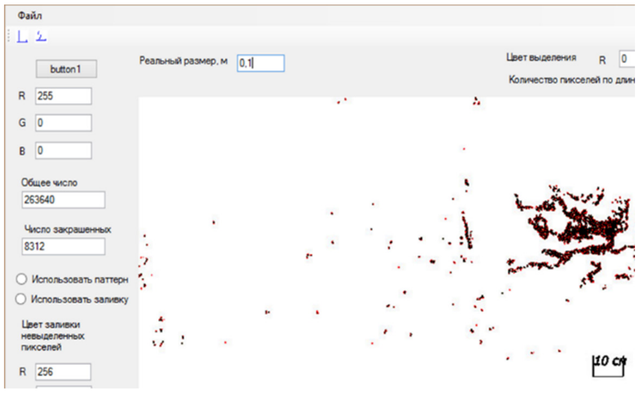

Figure 7: Fragment of the program for the quantitative treatment of the dispersion spot

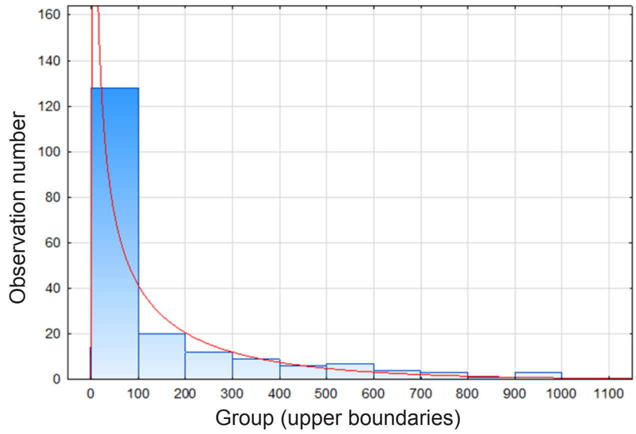

Figure 8: Histogram of particle number distribution on selected sections of the assemblable platform, N_i

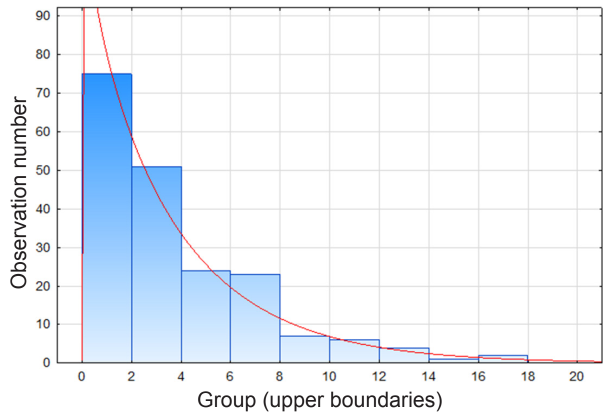

Figure 9: Distribution histogram of the total masses of particles on separate sections of the assemblable platform, M_i

Table 1: Basic characteristics of the number of particles and their masses distribution over selected sections of the dispersion spot length

Characteristics	Observation number	Average	Minimum	Maximum	Statistical deviation
Number of particles at angular rotor speed 77.6 rad/s	193	142.135	1.00	974.00	214.79
Total masses of particles at angular rotor speed 77.6 rad/s	193	3.646	0.01	17.68	3.43
Average mass of one particle in a group M_{0i} at angular rotor speed 77.6 rad/s	193	0.195	0.0016	2.76	0.38

Distribution of average masses of one particle in the group M_{0i} over the collection areas is described by the χ^2 distribution (Figure 10).

The values of the validation criteria of the accepted hypotheses are presented in Table 2.

Table 3 presents the statistical characteristics of the relative amount of material thrown off in relation to the total mass of the initially loaded material.

The next stage was the determination of regression equations to describe the process of snow bank formation.

Figures 11 and 12 represent the observed experimental distribution of the number of particles N_i, total masses M_i, and average masses of individual particles M_{0i} along the length of the dispersion spot L_i and diagrams of the fitted functions.

The regression equation describing the dependence of the number of particles N_i on distance L_i has the following form:

$$N_i = \frac{e^{-L_i/0{,}25}}{0{,}0033 \cdot 0{,}25^{2{,}52}} L_i^{-0{,}75} \quad (2)$$

This function is presented in Figure 11. The value of determination coefficient was R=0.883.

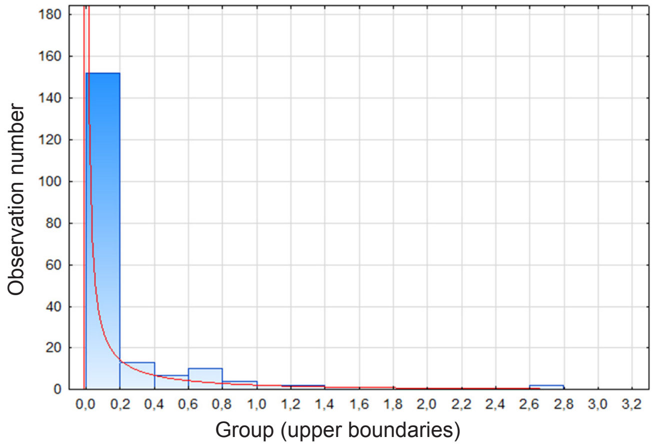

Figure 10: Distribution histogram of average masses of one particle in the group over the collection areas

The regression equation describing the dependence of the total masses M_i on distance has a similar form:

$$M_i = \frac{e^{-L_i/0{,}69}}{0{,}078 \cdot 0{,}69^{1{,}52}} L_i^{-0{,}31} \quad (3)$$

The value of determination coefficient was R=0.747. The graph of the regression equation is presented in Figure 12.

Table 2: Values of the validation criteria of the accepted hypotheses

Characteristics	Distribution law	Chi-square	df	p
Number of particles on separate sections of the assemblable platform, N_i	Gamma	7.15374	4	0.12798
Total masses of particles on separate sections of the assemblable platform, M_i	Gamma	6.6054	4	0.15827
The average mass of one particle in the group over the collection areas, M_{0i}	χ^2	13.79380	4	0.00798

Table 3: Statistical characteristics of the relative amount of material thrown off in relation to the loaded material

Characteristic	Observation number	Average	Minimum	Maximum	Statistical deviation
Relative amount of material thrown off	9	0.361709	0.161135	0.539278	0.123899

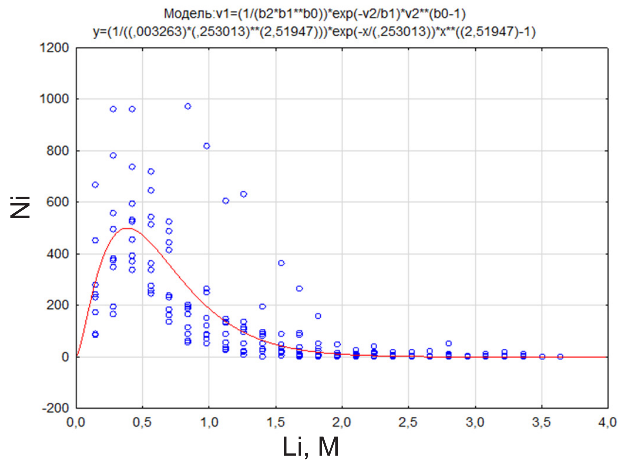

Figure 11: Dependence of the number of particles on distance obtained as the result of the experiments, as well as the graph of the estimated regression equation

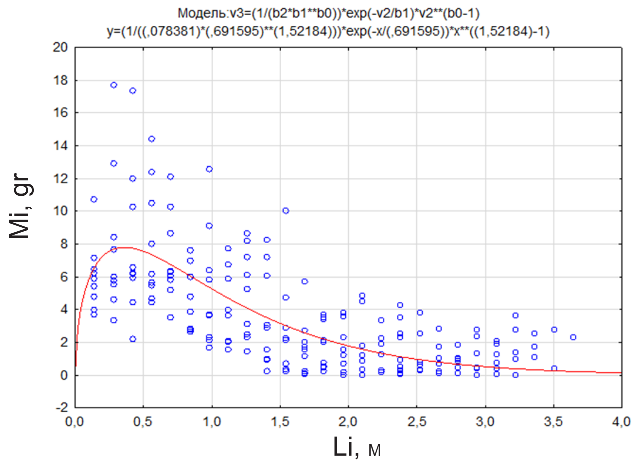

Figure 12: Dependence of total masses M_i along the length of the dispersion spot L_i, as well as the graph of the estimated regression equation

Table 4: Parameters of piecewise linear regression with a discontinuity point of average masses of separate particles M_{0i} along the length of the dispersion spot L_i

	Coefficient of the first straight line	Li	Coefficient of the second straight line	Li	Discontinuity point
Estimation	0.017109	0.022265	-0.072845	0.314241	0.195052

To describe the dependence of average masses of individual particles M_{0i} along the length of the dispersion spot L_i, a piecewise linear regression with a discontinuity point was applied. The model parameters are presented in Table 4.

DISCUSSION

It has been found that the formation of the snow bank during snow removal has certain regularities that differ significantly from those that underlie naturally formed snow drifts. Accordingly, it is necessary to take this aspect into account when assessing changes in the characteristics of snow formations in time and the degree of sedimentation of cleared out areas in the future.

The nature of particle distribution over the width of the snow bank has the following character: the larger the particle, the farther it from the place of the throw-off. This may be explained by the fact that they acquire more kinetic energy in the process of unloading the rotor of the throwing machine, and in the process of free-flying operation, they experience less aerodynamic resistance forces. This phenomenon is consistent with the natural behavior of snow particles according to papers [26, 27]. The described tendency of particle distribution remains at different values of the angle of inclination guide spray nozzle relative to the horizontal surface.

Thus, with the application of the obtained regression equations, it is possible to perform simulation of the snow bank formation during operation of the milling and rotor snow blower, as well as its visualization. However, these dependencies do not cover the whole variety of possible snow structures and can be applied to one specific type of snow.

Besides, additional information may be achieved about the process of unloading snow mass from the rotor blade of the throwing machine. For this purpose, it is necessary to consider the inverse problem of mechanics of particle movement in the air environment.

Conducted experimental investigations have made it possible to get an insight about the nature of the distribution of the main characteristics of snow banks: the number of particles and their distribution over the width of the snow bank, the total mass of particles over the width of the bank, and the distribution of masses of individual particles over the width of the bank.

Regression equations based on the results of experimental investigations have been obtained.

REFERENCES

1. Ayon, B. D., Ofori-Amoah, B., Meng, L., Oh, J.-S., Baker, K. (2020). Modeling the effects of lake-effect snow related weather conditions on daily traffic crashes: A time series count data approach. Accident Analysis & Prevention, 144, 105510. doi: 10.1016/j.aap.2020.105510
2. Qin, Y., Zhu, L., Zhang, Z., Kou, L., Cheng, X. (2015). Railway Disaster Prevention and Snow Survey Design Optimization Technology. The Open Automation and Control Systems Journal, 7, 1895–1902. doi: 10.2174/1874444301507011895
3. Muthumani, A. (2014). Strategies for Snow and Ice Control at Extreme Temperatures: Review of Current Practice. Transportation Research Board 93rd Annual Meeting, 14 – 4014.
4. Labelle, A., Langevin, A., Campbell, J.F. (2002). Sector design for snow removal and disposal in urban areas. Socio-Economic Planning Sciences, 36, 183–202. doi: 10.1016/S0038- 0121(01)00024-6
5. Tverdokhlebov, V. A. (2016). Determination of the rational structure of the transport and technological complex involved in the snow-clearing. Intellect. Innovations. Investments, 6, 120–124.
6. Trofimova, I. F. (2011). Determination of the optimal number of snowplows for the mechanized cleaning of the city highways and airfields from the new-fallen snow. Bulletin of Moscow Automobile and Road Construction University (MADI), 1, 91–94.
7. Perrier, N., Langevin, A., Campbell, J. F. (2006). A survey of models and algorithms for winter road maintenance. Part II: System design for snow disposal. Computers & Operations Research, 33(1), 239–262. doi: 10.1016/j.cor.2004.07.007
8. Campbell, J. F., Langevin, A. (1995). The Snow Disposal Assignment Problem. Journal of the Operational Research Society, 46, 919–929. doi: 10.1057/jors.1995.131
9. Dunin, A. K. (1963). Mechanics of snow-storms. Publishing House of the Siberian Branch of the USSR Academy of Sciences, Novosibirsk.
10. Sundsbo, P. A., Hansen, E. W. N. (1996). Numerical modeling and simulation of snow-drift around fences. Proceedings of the 3rd International Conference on Snow Engineering. Sendai.

11. Bang, B., Nielsen, A., Sundsbo, P. A., Wiik, T. (1994). Computer Simulation of Wind Speed, Wind Pressure and Snow Accumulation around Buildings (SNOW-SIM). Energy and Buildings, 21, 235–243. doi: 10.1016/0378-7788(94)90039-6
12. Du, S., Petrie, J., Shi, X. (2017). Use of Snow Fences to Reduce the Impacts of Snowdrifts on Highways: Renewed Perspective. Transportation Research Record: Journal of the Transportation Research Board, 2613, 45–51. doi: 10.3141/2613-06
13. Sato, M., Hansen, J. E., McCormick, M. P., Pollack, J. B. (1993). Stratospheric aerosol optical depths, 1850-1990. Journal of Geophysical Research, 98, 22987–22994. doi: 10.1029/93JD02553
14. Kang, L., Zhou, X., Hooff, T., Blocken, B., Gu, M. (2018). CFD simulation of snow transport over flat, uniformly rough, open terrain: Impact of physical and computational parameters. Journal of Wind Engineering and Industrial Aerodynamics, 177, 213–226. doi: 10.1016/j.jweia.2018.04.014
15. Du, S., Petrie, J., Shi, X. (2017). Use of Snow Fences to Reduce the Impacts of Snowdrifts on Highways: Renewed Perspective. Transportation Research Record: Journal of the Transportation Research Board, 2613, 45–51. doi: 10.3141/2613-06
16. Beyers, M., Sundsbo, P. A., Harms, T. (2004). Numerical simulation of three-dimensional, transient snow drifting around a cube. Journal of Wind Engineering and Industrial Aerodynamics, 92, 725–747. doi: 10.1016/j.jweia.2004.03.011
17. Yu, Z.-X., Zhu, F., Cao, R. Z., Xiaoxiao, C., Zhao, L., Zhao, S. (2019). Wind tunnel tests and CFD simulations for snow redistribution on roofs 3D stepped flat roofs. Wind and Structures, 28, 31–47. doi: 10.12989/was.2019.28.1.031
18. Beyers, M., Sundsbø, P. A., Harms, T. (2004). Numerical simulation of three-dimensional, transient snow drifting around a cube. Journal of Wind Engineering and Industrial Aerodynamics, 92, 725–747. doi: 10.1016/j.jweia.2004.03.011
19. Hayashi, K., Nakamura, H., Watano, S. (2020). Numerical study on granule aggregation and breakage in fluidized bed granulation by a novel PBM with DEM-CFD coupling approach. Powder Technology, 360, 1321–1336. doi: 10.1016/j.powtec.2019.11.027
20. Boutanios, Z. (2018). Two-way Coupled Eulerian-Eulerian Finite Volume Simulation of Drifting Snow. PhD thesis.
21. Zhao, L., Yu, Z., Zhu, F., Qi, X., Zhao, S. (2016). CFD-DEM modeling of snowdrifts on stepped flat roofs. Wind and Structures, 23(6), 523–542. doi: 10.12989/was.2016.23.6.523
22. Zheng, Z., Zang, M., Chen, S., Zhao, C. (2016). An improved 3D DEM-FEM contact detection algorithm for the interaction simulations between particles and structures. Powder Technology, 305, 308–322. doi: 10.1016/j.powtec.2016.09.076
23. Zhang, Q., Xu, W.-ya & Liu, Q.-Y., Meng, Q. (2017). A novel non-overlapping approach to accurately represent 2D arbitrary particles for DEM modelling. Journal of Central South University, 24, 190–202. doi: 10.1007/s11771-017-3420-1
24. Tominaga, Y. (2018). Computational fluid dynamics simulation of snowdrift around buildings: Past achievements and future perspectives. Cold Regions Science and Technology, 150, 2–1410. doi: 1016/j.coldregions.2017.05.004
25. Huber, C., Weigand, B., Reister, H., Binner, T. (2015). Modeling and Numerical Calculation of Snow Particles Entering the Air Intake of an Automobile. SAE International Journal of Passenger Cars - Mechanical Systems, 8(2), 538–545. doi: 10.4271/2015-01-1342.10.4271/2015-01-1342
26. Li, C., Lim, K., Berk, T., Abraham, A., Heisel, M., Guala, M., Coletti, F., Hong, J. (2020). Settling and Clustering of Snow Particles in Atmospheric Turbulence. https://arxiv.org/pdf/2006.09502.pdf
27. Guala, M., Manes, C., Clifton, A., Lehning, M. (2008). On the saltation of fresh snow in a wind tunnel: Profile characterization and single particle statistics. Journal of Geophysical Research, 113(F3). doi: 10.1029/2007JF000975
28. Sugiura, K., Nishimura, K., Maeno, N., Kimura, T. (1998). Measurements of snow mass flux and transport rate at different particle diameters in drifting snow. Cold Regions Science and Technology, 27(2), 83–89. doi: 10.1016/S0165-232X(98)00002-0
29. Qiang, S., Zhou, X., Kosugi, K., Gu, M. (2019). A study of snow drifting on a flat roof during snowfall based on simulations in a cryogenic wind tunnel. Journal of Wind Engineering and Industrial Aerodynamics, 188, 269–279. doi: 10.1016/j.jweia.2019.02.022
30. Willibald, C., Lowe, H., Theile, T., Dual, J., Schneebeli, M. (2020). Angle of repose experiments with snow: role of grain shape and cohesion. Journal of Glaciology. doi: 10.1017/jog.2020.36
31. Flaga, A., Bosak, G., Pistol, A., Flaga, L. (2019). Wind tunnel model tests of snow precipitation and redistribution on rooftops, terraces and in the vicinity of high-rise buildings. Archives of Civil and Mechanical Engineering, 19(4), 1295–1303. doi: 10.1016/j.acme.2019.07.007
32. Flaga, A., Flaga, L. (2019). Wind tunnel tests and analysis of snow load distribution on three different large size stadium roofs. Cold Regions Science and Technology, 160, 163–175. doi: 10.1016/j.coldregions.2019.02.002

33. Eidevag, T., Abrahamsson, P., Eng, M., Rasmuson, A. (2020). Modeling of dry snow adhesion during normal impact with surfaces. Powder Technology, 361, 1081–1092. doi: 10.1016/j.powtec.2019.10.085
34. Mede, T., Chambon, G., Nicot, F., Hagenmuller, P. (2020). Micromechanical investigation of snow failure under mixed-mode loading. International Journal of Solids and Structures, 199, 95–108. doi: 10.1016/j.ijsolstr.2020.04.020
35. Mcclung, D., Borstad, C. (2019). Probabilistic size effect law for mode II fracture from critical lengths in snow slab avalanche weak layers. Journal of Glaciology, 65(249), 157–167. doi: 10.1017/jog.2018.88
36. Chernak, R., Kustiner, L. E., Phillips, L. (1990). The snowplow problem. The UMAP Journal, 11, 241–250.
37. Aleshkov, D. S., Sukovin, M. V. (2018). The model of the formation of snow piles at work milling and rotary snowblower. The Eurasian Scientific Journal, 10(6), 58–70. https://esj.today/PDF/13SAVN618.pdf
38. Zakirov, M. (2020). The research of resistance to snow cutting and moving with an auger of a small-sized rotary-auger snowplow. IOP Conference Series: Materials Science and Engineering, 786, 012043. doi: 10.1088/1757-899X/786/1/012043
39. Aleshkov, D., Sukovin, M. (2017). Aerodynamic characteristics of the milling and rotary snowblower feeder in the loading gate area. International Review of Mechanical Engineering, 11(9), 701-708. doi: 10.15866/ireme.v11i9.13832

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