DOI:10.22337/2587-9618-2021-17-3-39-47

COMPARISON OF DETERMINATION OF SNOW LOADS FOR ROOFS IN BUILDING CODES OF VARIOUS COUNTRIES

***Alexander M. Belostotsky* [1,2,3], *Nikita A. Britikov* [2,3], *Oleg S. Goryachevsky* [1,2]**

[1] Scientific Research Center StaDyO, Moscow, RUSSIA
[2] National Research Moscow State University of Civil Engineering, Moscow, RUSSIA
[3] Russian University of Transport (RUT - MIIT), Moscow, RUSSIA

Abstract: The article compares the requirements for calculating the snow load on the coatings of buildings and structures in accordance with the regulations of technically developed countries and associations – Russia, the European Union, Canada and the United States. It was revealed that in these norms the general approaches, the subtleties of calculating the coefficients, the set of standard coatings and the schemes of the form coefficient proposed for them differ significantly. This situation reflects the general problem of determining snow loads – at the moment there is no recognized unified scientifically grounded approach to determining snow loads on coatings of even the simplest form. The difference in the normative schemes of snow loads is clearly demonstrated by the example of a three-level roof.

Keywords: snow loads, regulatory documents, physical modeling, mathematical modeling

СРАВНЕНИЕ НОРМАТИВНЫХ ДОКУМЕНТОВ РАЗЛИЧНЫХ СТРАН В ЧАСТИ НАЗНАЧЕНИЯ СНЕГОВЫХ НАГРУЗОК

***А.М. Белостоцкий* [1,2,3], *Н.А. Бритиков* [2,3], *О.С. Горячевский* [1,2]**

[1] Научно-исследовательский центр СтаДиО, г. Москва, РОССИЯ
[2] Национальный исследовательский Московский государственный строительный университет, г. Москва, РОССИЯ
[3] Российский университет транспорта (МИИТ), г. Москва, РОССИЯ

Аннотация: В статье сравниваются требования к расчёту снеговой нагрузки на покрытия зданий и сооружений в соответствии с нормативными документами технически развитых стран и объединений – России, Евросоюза, Канады и США. Выявлено, что в этих нормах значительно отличаются общие подходы, тонкости вычисления коэффициентов, набор стандартных покрытий и предлагаемые для них схемы коэффициента формы. Такая ситуация отражает общую проблему определения снеговых нагрузок – на данный момент отсутствует признанный единый научно обоснованный подход к определению снеговых нагрузок на покрытия даже простейшей формы. Различие в нормативных схемах снеговых нагрузок наглядно продемонстрировано на примере трехуровневой кровли.

Ключевые слова: снеговые нагрузки, нормативные документы, физическое моделирование, математическое моделирование

INTRODUCTION

The problem of determining the distribution of snow loads on roofs of various shapes does not lose its relevance to the present day. Very few full-scale tests are carried out all over the world, which does not allow obtaining new load arrangements or clarifying old ones. The physical modeling in wind tunnel or water flumes, regulated by the normative documents of all technically developed countries, makes it possible to simulate only single snow storms, and the problem of simulating the natural phenomenon of snow accumulation and scale models remains unsolvable. Progress in the direction of determining the snow loads on the roofs of structures is currently observed only in the field of mathematical (numerical) modeling [7].

Despite the development of a large number of mathematical models, their algorithmic and software implementations, the normative documents regarding the determination of snow loads remain conservative and for the most part do not allow the possibility of mathematical modeling.

The conservatism of the norms often causes designers, constructors and other participants in the construction process to misunderstand that all the problems have already been solved, and the provisions set out in the norms are unshakable. The purpose of this article is to show that the regulations in different countries and schemes for the distribution of snow loads, even for the simplest roofs, differ qualitatively and quantitatively.

COMPARISON OF BASIC PROVISIONS

This section compares the main provisions of regulatory documents in terms of determining snow loads according to the standards of Russia (SP 20.13330.2016 [1]), the European Union (EN 1991-1-3 [2]), Canada (National Building Code of Canada [3]) and USA (ASCE / SEI 7-16: Snow Loads [4]).

Similar provisions of the norms:

1) the calculation of the load is carried out according to the same principle - multiplying the characteristic value of snow load on the ground by various coefficients (drift, thermal, etc.), including the snow load shape coefficientof the snow cover of the earth to the snow load on the cover (or several such coefficients).

2) there are maps of snow zoning of varying degrees of detail to determine the characteristic value of snow load on the ground.

3) to determine the coefficient (or coefficients) of the shape, there are load arrangements for the following roofs:

- monopitch and pitched;
- dome and cylindrical;
- multi-level;
- multi-span (sawtooth, etc.)

4) To determine snow loads on other types of roofs that are not regulated by standards, it is recommended to carry out research in satisfying the requirements of wind tunnels [5].

Miscellaneous provisions of the norms:

Each regulatory document has its own set of calculated values, and not all of them can be found analogous; the detailing of zoning maps varies greatly; some norms allow the use of numerical modeling for calculating snow loads, others do not stipulate or directly prohibit due to some circumstances. Also, in some standards there are load arrangements for the transfer coefficients in addition to the above. Let's consider in more detail each of these provisions for each of the mentioned documents.

1) *Bulding Code of Russia SP 20.13330.2016 "Loads and actions" (with amendment 3)* [1] give the following formula for calculating the standard value of the snow load:

$$S = \mu c_e c_t S_g, \quad (1)$$

where μ is the shape coefficient, which takes into account the transition from the weight of the snow cover of the earth to the snow load on the roof, c_e is the exposure coefficient, c_t is the thermal coefficient, S_g is nominal weight of snow cover per square meter of surface. In order to obtain the design load, this expression is multiplied by the load safety factor γ_f, usually equal to 1.4. Amendment 3 in some cases allowed a decrease in the value of the c_e coefficient based on climatic data for the construction site.

Differences from other documents:

In Russian standards, an increase in snow load for roofs abutting and close to taller construction works is considered separately for the windward and leeward sides, while the concept of wind direction itself is absent. There are also load arrangements for specific roofs, which, from the point of view of other documents, are even redundant. Much attention has been paid to roof lanterns, as there are separate load arrangements presented for longitudal and transversal lanterns in the norms. Also, a special load arrangement for a roof abutting two taller construction works is shown, as well as for arched roofs and vaulted roofs.

Numerical Simulation:
In contrast to wind loads [6], the Russian standards do not say anything about the numerical modeling of snow loads.

2) Eurocode [2] identifies three types of snow load: for persistent / transient design situations (s_1), for the accidental design situations, where exceptional snow load is the accidental action (s_2), and for the accidental design situations, where exceptional snow drift is the accidental action (s_3), and gives the following formulas for calculating the values of each of them:

$$s_1 = \mu C_e C_t s_k, s_2 = \mu C_e C_t s_{ad}, s_3 = \mu s_k, \quad (2)$$

where μ is the snow load shape coefficient, C_e is the exposure coefficient, C_t is the thermal coefficient, s_k is the characteristic value of snow load on the ground, s_{ad}=2s_k.

Differences from other documents:
Similar to Russian standards, an increase in snow load for roofs abutting and close to taller construction works is considered separately for the windward and leeward sides, while the concept of wind direction itself is absent.

Numerical Simulation:
Unlike Russian and Canadian standards, Eurocode allows the use of numerical modeling to refine the shape coefficient along with physical modeling, however, it does not contain any specific requirements for the methods that should be used.

3) *National Building Code of Canada* [3] gives the following formula for calculating the standard value of the snow load:

$$S = I_s S_s (C_b C_w C_s C_a), \quad (3)$$

where I_s is importance factor for snow load, S_s is 1-in-50-year ground snow load, C_b is the basic roof snow load factor, C_w is the wind exposure factor, C_s is the slope factor, C_a is the accumulation factor. Togethers C_b, C_s and C_a are analogous to μ from the Building Code of Russia and the Eurocode.

Differences from other documents:
In the Canadian standards, wind directions are clearly distinguished, and the load is calculated for each of the sides separately, but then the largest of the obtained values is taken and assigned to both sides in reserve.

Numerical Simulation:
Construction Canada explicitly prohibits the use of numerical simulations of snow accumulation due to insufficient data on the legality of its use and the physicality of the results obtained with its help.

4) *ASCE standard* [4] gives the following formula for calculating the standard value of the snow load:

$$p_f = 0.7 C_e C_t I_s p_g, \quad (4)$$

where C_e is the exposure factor, C_t is the thermal factor, I_s is the importance factor, p_g is the ground snow load. Also, a minimum roof snow load for low-slope roofs, p_m, shall be obtained using the following formula:

$$p_m = I_s p_g, \quad (5)$$

For unbalanced load, the following formula is used:

$$p_s = C_s p_f, \quad (6)$$

where C_s is the roof shape factor.

Differences from other documents:
Similar to the Canadian standards, wind directions are clearly highlighted, and the load is cal-

culated for each of the sides separately, but then the largest of the obtained values is taken and assigned to both sides as a margin. The values of the shape factor depend, as can be seen from formula (4), on the thermal factor.

Numerical Simulation:

American regulations explicitly state that physical modeling results should only be used in conjunction with numerical simulations, that shape factors or load values cannot be generated based on the experiment alone. The Appendix to the ASCE standard [5] contains a classification of numerical methods for modeling snow accumulation. Also, American norms are distinguished by the most detailed map of snow zoning, it contains data for all more or less large settlements in the United States due to the arrangement of meteorological stations near airports.

In general, the differences between different norms are more likely due to the engineering tradition of countries that serve as prerequisites for the compilation of norms, and in all respects: even the standard weight of the snow cover is taken somewhere strongly in reserve, somewhere it is specified as much as possible to prevent unnecessary large loads. A significant drawback of all regulatory documents is observed in terms of legitimization and regulation of mathematical (numerical) modeling of snow loads. This circumstance for all documents is undoubtedly an inhibiting factor in the introduction of mathematical modeling into construction practice, especially considering the increasing need for its use and the increasing pace of scientific research in this direction in other countries, such as China, where in the last 7 years, several dozen articles on research (for example [18-19]), carried out with the support of government grants, were published.

EXAMPLE

In order to demonstrate the differences in the definition of snow loads according to the regulatory documents of Russia [1], the European Union [2], Canada [3] and the USA [4-5], an example of a three-level roof is considered (Fig. 1). Calculation formulas and values of the corresponding parameters and coefficients are presented in table. 1. Figures 2-5 show calculation results.

Table. 1. Calculation formulas for various regulatory documents

Regulatory documents	*Formula for snow load*	*Accepted values in the formula*
Building Code of Russia SP 20.13330.2016 (with amendment 3)	$S = \mu c_e c_t S_g$	$c_e = 0.7$ for the central level, $c_e = 1.0$ for side levels, $c_t = 1.0$, $S_g = 1.5$ kPa
EN 1991-1-3 (2003)	$s = \mu C_e C_t s_k$ (persistent); $s = \mu C_e C_t s_{ad}$ (exceptional snow load) $s = \mu s_{ad}$ (exceptional snow drift)	$C_e = 0.8$, $C_t = 1.0$, $s_k = 1.5$ kPa, $s_{ad} = 2s_k = 3$ kPa
National Building Code of Canada 2015	$S = I_s S_s (C_b C_w C_s C_a)$	$I_s = 1.0$, $C_w = 1.0$, $C_s = 1.0$, $S_s = 1.5$ kPa
ASCE/SEI 7-16: Snow Loads	$p_f = 0.7 C_e C_t I_s p_g$ $p_m = I_s p_g$ (minimum load for low-slope roofs) $p_s = C_s p_f$ (unbalanced load)	$C_e = 0.9, C_t = 1.0, I_s = 1.1$ $p_g = 0.96$ kPa (analogue of S_g)

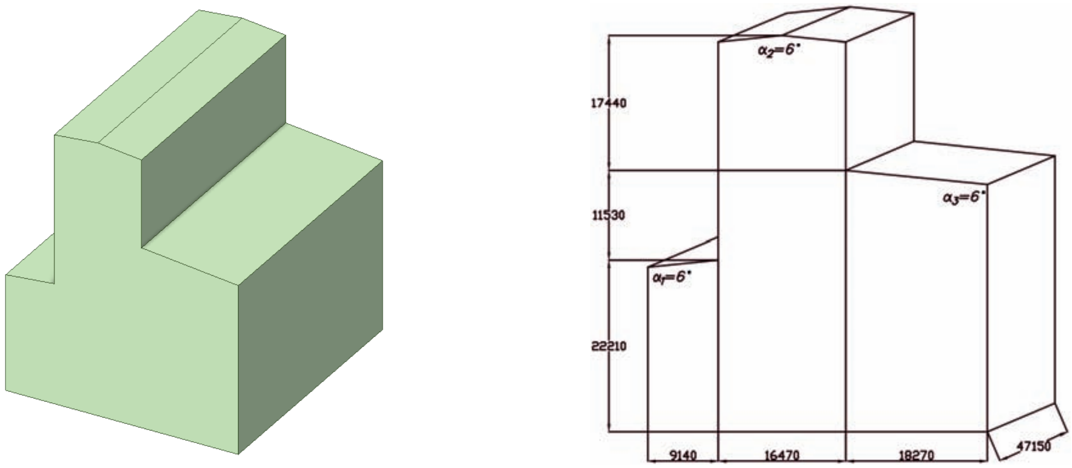

Figure 1. General view and dimensions of the structure

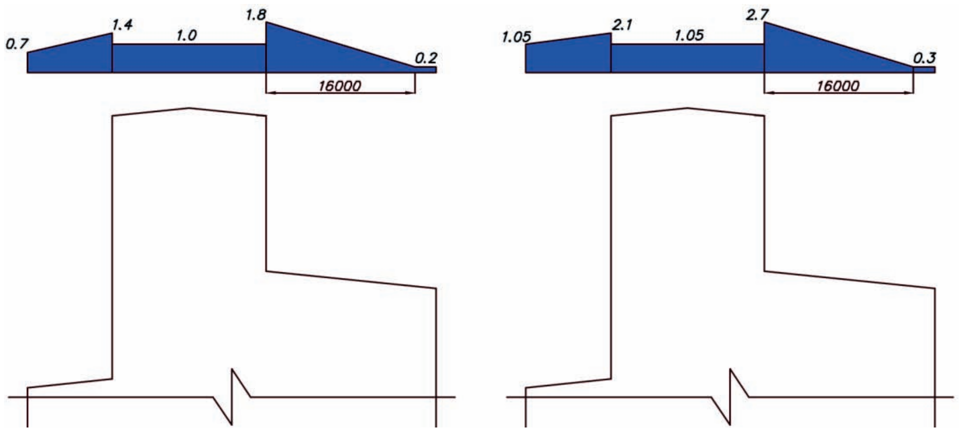

Figure 2. Load arrangement according to the Building Code of Russia SP 20.13330.2016 (with amendment No 3)

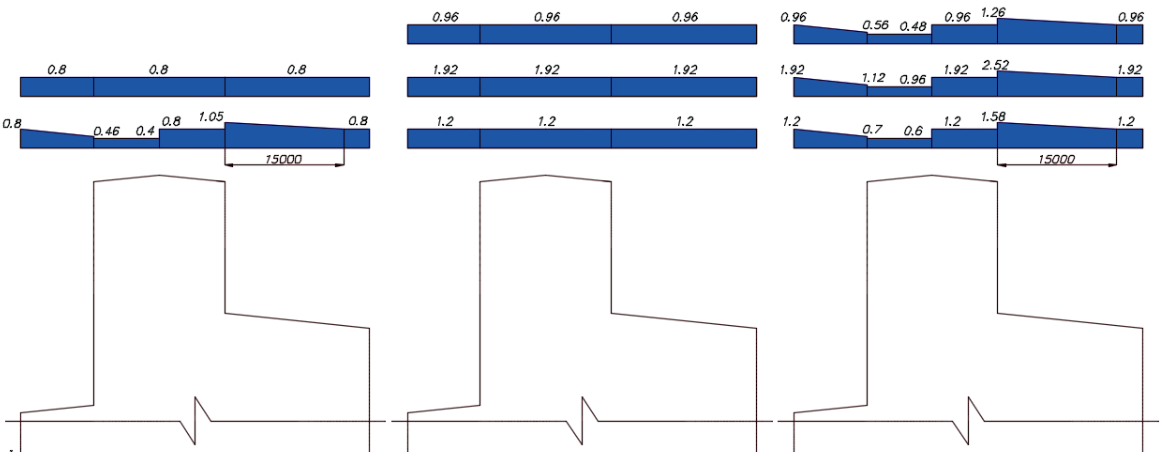

Figure 3. Load arrangement according to EN 1991-1-3 (2003)

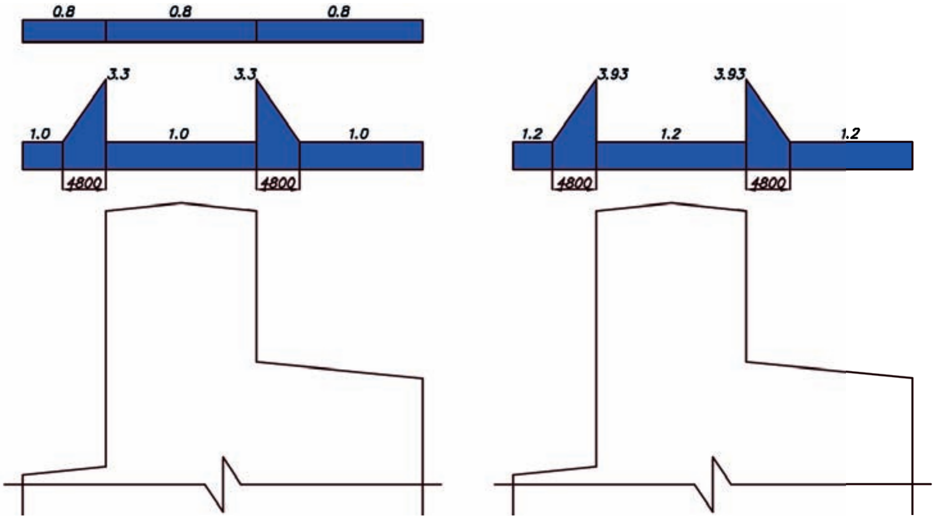

Figure 4. Load arrangement according to the National Building Code of Canada 2015

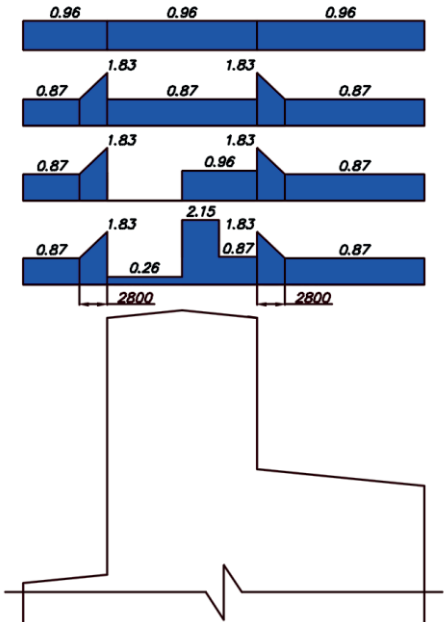

Figure 5. Load arrangement according to ASCE/SEI 7-16: Snow Loads

CONCLUSIONS

Based on the results of the analysis and comparison of the regulatory documents of Russia, the European Union, Canada and the United States in terms of determining snow loads on the roofs of structures, as well as comparing load arrangements using the example of a three-level roof, determined according to the relevant documents, the following conclusions can be drawn:

1. Normative documents of technically advanced countries / associations have their own general approach to determining snow loads, which differ significantly from other countries.

2. All normative documents contain recommendations for carrying out physical modeling of snow loads, but recommendations for mathematical (numerical) modeling are contained only in the norms of the European Union and the United States.
3. Load arrangements, even for the simplest roofs, differ in different documents both qualitatively and quantitatively.
4. This reveals the general problem of the lack of progress in a common understanding of how to determine the snow loads on roofs. We can say that in this matter there is no reliable support even in the norms.

Improvement of Russian normative documents in terms of physical modeling (regulation of requirements and procedure for conducting experiments) and mathematical (numerical) modeling (legitimization and regulation) will help to partially solve the problem of uncertainty in the assignment of snow loads to complex surfaces. Such measures, in particular, will increase the mechanical safety of large-span structures, for which the snow load is one of the determining factors.
The improvement of Russian normative documents in terms of assigning snow loads to simple typical roofs can also be helped by studies based on physical (experimental in wind tunnel) and mathematical (numerical) modeling. This alternative approach seems to be more effective than field experiments and observations, which are very time-consuming, labor-intensive, and financially expensive.

ACKNOWLEDGMENTS

This work was financially supported by the Ministry of Science and Higher Education of the Russian Federation (Project: Theoretical and experimental design of new composite materials to ensure safety during the operation of buildings and structures under conditions of technogenic and biogenic threats #FSWG-2020-0007)

REFERENCES

1. Building Code of RF 20.13330.2016 (with amendments No 1, 2, 3) Load and actions. Moscow: Ministry of Regional Development of Russia, 2021
2. Eurocode 1: Actions on structures – Part 1-3: General actions – Snow loads, CEN, 2003.
3. National Research Council of Canada. National building code of Canada 2015. – National Research Council Canada, 2015.
4. ASCE/SEI 7-16 Minimum Design Loads and Associated Criteria for Building and other Structures. USA: ASCE, 2017
5. ASCE. Wind tunnel testing for buildings and other structures. – American Society of Civil Engineers, 2012.
6. Methodical manual "Mathematical (numerical) modeling of wind loads and impacts" (to SP 20.13330.2016), M., FAU FTSS of the Ministry of Construction of Russia, 2020
7. **Belostotskiy A.M., Akimov P.A., Afanas'yeva I.N.** Vychislitel'naya aerodinamika v zadachakh stroitel'stva [Computational aerodynamics in construction problems]. Moscow: Publishing ASV, 2017, 720 p.
8. **Zhou X., Hu J., Gu M.** Wind tunnel test of snow loads on a stepped flat roof using different granular materials //Natural hazards. – 2014. – T. 74. – №. 3. – C. 1629-1648
9. **Zhou X.** et al. Wind tunnel test on responses of a lightweight roof structure under joint action of wind and snow loads //Cold Regions Science and Technology. – 2016. – T. 132. – C. 19-32.
10. **Kang, L., Zhou, X., Gu, M.,** 2016. A new method for predicting snowdrift on flat roofs. In: Proceedings of the 8th International Conference on Snow Engineering, Nantes, France, C. 137–141 (June 14–17).
11. **Zhou, X., Kang, L., Gu, M., Qiu, L., Hu, J.**, 2016a. Numerical simulation and wind tunnel test for redistribution of snow on a flat roof. J. Wind Eng. Ind. Aerodyn. T. 153, C. 92–105
12. **Sun X., He R., Wu Y.** Numerical simulation of snowdrift on a membrane roof and the mechanical performance under snow loads

//Cold Regions Science and Technology. – 2018. – T. 150. – C. 15-24
13. **Zhou X., Zhang Y., Gu M.** Coupling a snowmelt model with a snowdrift model for the study of snow distribution on roofs // Journal of Wind Engineering and Industrial Aerodynamics. – 2018. – T. 182. – C. 235-251
14. **Wang J.** et al. Modeling snowdrift on roofs using Immersed Boundary Method and wind tunnel test //Building and environment. – 2019. – T. 160. – C. 106208.
15. **Wang J.** et al. Wind tunnel test of wind-induced snowdrift on stepped flat roofs during snowfall //Natural Hazards. – 2020. – T. 104. – №. 1. – C. 731-752.
16. **Zhou X.** et al. RANS CFD simulations can be successfully used for simulating snowdrift on roofs in a long period of snowstorm //Building simulation. – Tsinghua University Press, 2020. – T. 13. – C. 1157-1163.
17. **Qiang S.** et al. A novel snow transport model for analytically investigating effects of wind exposure on flat roof snow load due to saltation //Journal of Wind Engineering and Industrial Aerodynamics. – 2021. – T. 210. – C. 104505
18. **Ma W., Li F., Zhou X.** An empirical model of snowdrift based on field measurements: Profiles of the snow particle size and mass flux //Cold Regions Science and Technology. – 2021. – C. 103312. Ma W. et al. Field measurement and numerical simulation of snow deposition on an embankment in snowdrift //Wind and Structures. – 2021. – T. 32. – №. 5. – C. 453-469.
19. **Zhang G.** et al. Numerical simulations of snowdrift characteristics on multi-span arch roofs //Journal of Wind Engineering and Industrial Aerodynamics. – 2021. – T. 212. – C. 104593.

СПИСОК ЛИТЕРАТУРЫ

1. СП 20.13330.2016 (с изменениями N 1, 2, 3) Нагрузки и воздействия. М.: Минрегион России, 2021
2. Eurocode 1: Actions on structures – Part 1-3: General actions – Snow loads, CEN, 2003.
3. National Research Council of Canada. National building code of Canada 2015. – National Research Council Canada, 2015.
4. ASCE/SEI 7-16 Minimum Design Loads and Associated Criteria for Building and other Structures. USA: ASCE, 2017
5. ASCE. Wind tunnel testing for buildings and other structures. – American Society of Civil Engineers, 2012.
6. Методическое пособие «Математическое (численное) моделирование ветровых нагрузок и воздействий» (к СП 20.13330.2016), М., ФАУ ФЦС Минстроя России, 2020
7. **Белостоцкий А.М., Акимов П.А., Афанасьева И.Н.** Вычислительная аэродинамика в задачах строительства. М., Издательство АСВ, 2017, 720 с.
8. **Zhou X., Hu J., Gu M.** Wind tunnel test of snow loads on a stepped flat roof using different granular materials //Natural hazards. – 2014. – T. 74. – №. 3. – C. 1629-1648
9. **Zhou X.** et al. Wind tunnel test on responses of a lightweight roof structure under joint action of wind and snow loads //Cold Regions Science and Technology. – 2016. – T. 132. – C. 19-32.
10. **Kang, L., Zhou, X., Gu, M.,** 2016. A new method for predicting snowdrift on flat roofs. In: Proceedings of the 8th International Conference on Snow Engineering, Nantes, France, C. 137–141 (June 14–17).
11. **Zhou, X., Kang, L., Gu, M., Qiu, L., Hu, J.**, 2016a. Numerical simulation and wind tunnel test for redistribution of snow on a flat roof. J. Wind Eng. Ind. Aerodyn. T. 153, C. 92–105
12. **Sun X., He R., Wu Y.** Numerical simulation of snowdrift on a membrane roof and the mechanical performance under snow loads //Cold Regions Science and Technology. – 2018. – T. 150. – C. 15-24
13. **Zhou X., Zhang Y., Gu M.** Coupling a snowmelt model with a snowdrift model for the study of snow distribution on roofs //

Journal of Wind Engineering and Industrial Aerodynamics. – 2018. – Т. 182. – С. 235-251
14. **Wang J.** et al. Modeling snowdrift on roofs using Immersed Boundary Method and wind tunnel test //Building and environment. – 2019. – Т. 160. – С. 106208.
15. **Wang J.** et al. Wind tunnel test of wind-induced snowdrift on stepped flat roofs during snowfall //Natural Hazards. – 2020. – Т. 104. – №. 1. – С. 731-752.
16. **Zhou X.** et al. RANS CFD simulations can be successfully used for simulating snowdrift on roofs in a long period of snowstorm //Building simulation. – Tsinghua University Press, 2020. – Т. 13. – С. 1157-1163.
17. **Qiang S.** et al. A novel snow transport model for analytically investigating effects of wind exposure on flat roof snow load due to saltation //Journal of Wind Engineering and Industrial Aerodynamics. – 2021. – Т. 210. – С. 104505
18. **Ma W., Li F., Zhou X.** An empirical model of snowdrift based on field measurements: Profiles of the snow particle size and mass flux //Cold Regions Science and Technology. – 2021. – С. 103312. Ma W. et al. Field measurement and numerical simulation of snow deposition on an embankment in snowdrift //Wind and Structures. – 2021. – Т. 32. – №. 5. – С. 453-469.
19. **Zhang G.** et al. Numerical simulations of snowdrift characteristics on multi-span arch roofs //Journal of Wind Engineering and Industrial Aerodynamics. – 2021. – Т. 212. – С. 104593.

Alexander M. Belostotsky, corresponding member of RAACS, professor, doctor of technical sciences; General Director of CJSC Scientific Research Center StaDiO; Professor of the Department of Informatics and Applied Mathematics of the National Research Center, scientific director of the REC KM named after A.B. Zolotov Moscow State University of Civil Engineering; Professor of the Department of Building Structures, Buildings and Structures of the Russian University of Transport (MIIT); 125040, Russia, Moscow, st. 3rd Yamskogo Fields, 18, office 810; Tel. +7 (499) 706-88-10. E-mail: amb@stadyo.ru

Nikita A. Britikov, engineer of the REC KM them. A.B. Zolotov of the National Research Moscow State University of Civil Engineering; postgraduate student of the Russian University of Transport (MIIT); 129337, Russia, Moscow, Yaroslavskoe shosse, 26. E-mail: n.a.britikov@gmail.com

Oleg S. Goryachevsky, Lead Structurel Engineer, CJSC Research Center StaDiO; Deputy Director of REC KM named after A.B. Zolotov of the National Research Moscow State Construction University; 129337, Russia, Moscow, Yaroslavskoe shosse, 26. E-mail: osgoryachevskij@mail.ru

Белостоцкий Александр Михайлович, член-корреспондент РААСН, профессор, доктор технических наук; генеральный директор ЗАО Научно-исследовательский центр СтаДиО; профессор кафедры Информатики и прикладной математики Национального исследовательского, научный руководитель НОЦ КМ им. А.Б. Золотова Московского государственного строительного университета; профессор кафедры «Строительные конструкции, здания и сооружения» Российского университета транспорта (МИИТ); 125040, Россия, Москва, ул. 3-я Ямского Поля, д.18, офис 810; тел. +7 (499) 706-88-10 E-mail: amb@stadyo.ru

Бритиков Никита Александрович, инженер НОЦ КМ им. А.Б. Золотова Национального исследовательского Московского государственного строительного университета; аспирант Российского университета транспорта (МИИТ); 129337, Россия, г. Москва, Ярославское шоссе, д. 26. E-mail: n.a.britikov@gmail.com

Горячевский Олег Сергеевич, ведущий инженер-расчетчик ЗАО Научно-исследовательский центр СтаДиО; заместитель директора НОЦ КМ им. А.Б. Золотова Национального исследовательского Московского государственного строительного университета; 129337, Россия, г. Москва, Ярославское шоссе, д. 26. E-mail: osgoryachevskij@mail.ru