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MODELING OF SNOW LOAD ON ROOFS OF UNIQUE BUILDINGS

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Abstract

Introduction: The purpose of the work is to study the processes of snow transfer and snow deposition on the roofing of a unique building. Currently, the problem of assigning snow loads to the roofs of buildings and structures remains relevant, since cases of roof collapses in winter are still recorded annually, including those in the Russian Federation. A circus building with the roof in the form of a suspended reinforced concrete shell was chosen as the object of study. **Methods:** The design diagram for this type of roof is contained in SP 20.13330.2016; the snow load distribution diagrams for this roof were adopted according to Appendix B to SP 20.13330.2016. The author considered several options of snow load distribution and chose the most unfavorable one, when an increased value of the snow load is observed on one half of the roofing. During one winter period, field measurements of the thickness of the snow cover were carried out at the site. **Results:** It was established that in general, with the exception of local zones, the actual distribution of snow cover coincides with the adopted design solution, while the actual value of the weight of the snow cover for the current winter season was significantly lower than the calculated one. **Discussion:** The obtained result demonstrates that when developing design solutions for certain types of suspended roofing, it is permissible, without conducting specialized experimental studies, to use the data given in the scientific and technical literature, based on the results of monitoring the thickness of the snow cover on the roofing of the building.

Keywords: snow load, validation, snow deposits, snow transfer.

Introduction

The main task of designing building structures is to ensure their safety. In recent years, the Russian Federation has seen an increase in technogenic emergency failures of buildings and structures (Gar'kin and Gar'kina, 2014). Snow loads are the most common cause of roofing collapses (Lobkina, 2012). Roof collapses of buildings and structures are recorded annually in the territory of the Russian Federation. In the vast majority of cases, underestimation of the snow load at the design stage is what causes such accidents (Lobkina, 2012).

A number of works are devoted to the issues of modeling snow impacts and taking into account snow loads on the roofing of buildings and structures (Bang et al., 1994; Belostotsky et al., 2021; Delpech et al., 1997; Ellingwood and O'Rourke, 1985; Giever and Sack, 1990; Meløysund et al., 2007; O'Rourke and Wrenn, 2004; Poddaeva, 2021; Popov et al., 2001; Scarascia-Mugnozza et al., 2000). Domestic regulatory document SP 20.13330.2016 contains diagrams of snow deposits for typical roof shapes.

In this paper, snow load distribution diagrams are adopted on the basis of the regulatory document SP 20.13330.2016, which is currently in force. The purpose of this work is to assess the possibility of using the specified snow cover distribution diagrams when designing a circus building with a unique roof shape without conducting specialized experimental studies.

Methods

The method for determining snow load is based on the assumption that snow deposits form on the roofing as a result of precipitation and further wind transfer of snow. Fallen snow covers the roof with a uniform layer with a thickness equivalent to the layer on a flatland. During a snowfall, snow may slide off the inclined surfaces of the roof forming snow bags in the proximity of these roof design features. Due to the influence of wind, snow deposits are redistributed, thus forming a general pattern.

Wind transfers the snow particles. The uneven structure of the wind flow over the roofing determines the pattern of snow deposits. The design features of the roofing shape lead to the formation of the zones of low wind speed and the zones of strong wind, which blows snow particles off the surface of the snow cover, and carries them along or off the roof. There are studies that determine the wind speed at which snow is blown off the surface of the snow cover and carried by the wind flow. It is known that when the wind speed decreases, the raised snow falls again on the roof forming an uneven layer of snow deposits. For a given wind direction, a certain vortex structure is formed above the roof, which uniquely determines the redistribution pattern of snow deposits. A change in wind direction changes the pattern of wind flows over the roof and leads to the formation of new zones with increased snow deposits. During the cold period of the year, when precipitation in the form of snow falls in a given area, the intensity of the snowfall changes randomly, the direction of the wind changes and, as a result, it is impossible to predict what form of snow deposits is expected in the coming winter. The random nature of the atmospheric influence on a building structure requires assigning the load value with a certain margin. At the same time, the roof structure may contain elements of such wind characteristics that the snow cover does not linger there, which allows assigning snow load with a reduction factor. To model snow transfer, different authors use different materials. A common property of the model material is the ability to move it along the roofing under the influence of wind flow. Modeling of snow deposits requires choosing such a flow velocity at which the particles rise from the layer of the fallen model powder and are further transferred along the roofing.

When choosing a model powder, the desire to simulate the microstructure of individual snowflakes is justified. The retention of the model powder on the roofing under study should be identical to natural conditions. At the same time, the range of changes in the physical parameters of natural snow is so wide that the main property of the model powder is the ability to move it with the wind flows. Thus, for identical roof structures, identical snow deposit patterns should be expected for a given wind direction. This criterion can be considered as a parameter for comparing the results of a model experiment performed in different wind tunnels. Based on the results of circular blowing with a certain step along the angle of attack, the snow load on the roof is modeled. When assigning a snow load, the prevailing wind direction, determined in accordance with the methodology outlined above, is taken into account. There may be structural elements on the roofing that can be interpreted as standard shapes reflected in building regulations. When assigning a snow load, "standard" elements are identified and the results of the assigned load are checked with the recommendations of the standard. Wood flour manufactured in accordance with GOST 16361-87 is used as a model material. The moisture content of wood flour in the experiment was no more than 8%, particle size was 0.2 mm.

The process of the experimental research on snow transfer was carried out in three stages:

• Applying a uniform thin layer of wood flour to the roof of the facility.

• Blowing the model with a wind flow at a speed when powder particles begin to fall off the roofing. The typical speed was 2–5 m/s. Exposure for sufficient time until significant transfer of model powder ceased.

• Increasing the flow speed by 2–3 m/s for a few seconds and stopping the blowing.

At the end of the blowing, photographic recording of the results of model snow transfer was carried out. The surface of the model was cleared and the model was rotated to a different angle of attack. The experiment repeated. The number of angles at which blowing was performed was regulated by the technical specifications. In some cases, blowing was carried out in detailed steps in case other structures could interfere with the flow.

Based on the results of the experiment, as well as engineering analysis of regulatory diagrams for snow load distribution, which represent a more conservative approach based on field observations, the snow load was assigned taking into account the prevailing wind directions in the construction area. For buildings and structures, the shape of which differs significantly from the primitives considered in the regulatory documents, developing of recommendations should include the use of the data on similar facilities obtained as a result of monitoring or from published scientific and technical sources.

A circus building with a suspended reinforced concrete shell as its roofing was chosen as the object of study (Fig. 1).

According to clause 10.1 of SP 20.13330.2016 "Loads and actions", the standard value of the snow load on the horizontal plan of the roofing is determined by the following equation:

$$S_0 = c_e\, c_t\, \mu\, S_g, \quad (1)$$

where c_e is the coefficient that takes into account the removal of snow from building roofing under the influence of wind or other factors, taken equal to one for a given roofing; c_t is the thermal coefficient taken equal to one; m is the coefficient of transition from the weight of snow cover of the ground to the snow load on the roofing, taken in accordance with the SP 20.13330.2016 diagrams; S_g is the weight of snow cover per 1 m^2 of horizontal ground surface. According to clause 10.2 of SP 20.13330.2016, the calculated value of the weight of snow cover per 1 m^2 of horizontal ground surface should be taken as S_g = 245 kgf/m^2.

As a rule, the snow load on the roofs of single-span buildings is distributed unevenly, since the snow deposits on double-slope roofs are blown off the roofing. This phenomenon is reflected in the standards of most countries by means of special coefficients m depending mainly on the roofing incline and elevation differences.

The structural elements located on the roof of the facility under study, as well as the shape of the roofing correspond to the diagrams given in Appendix

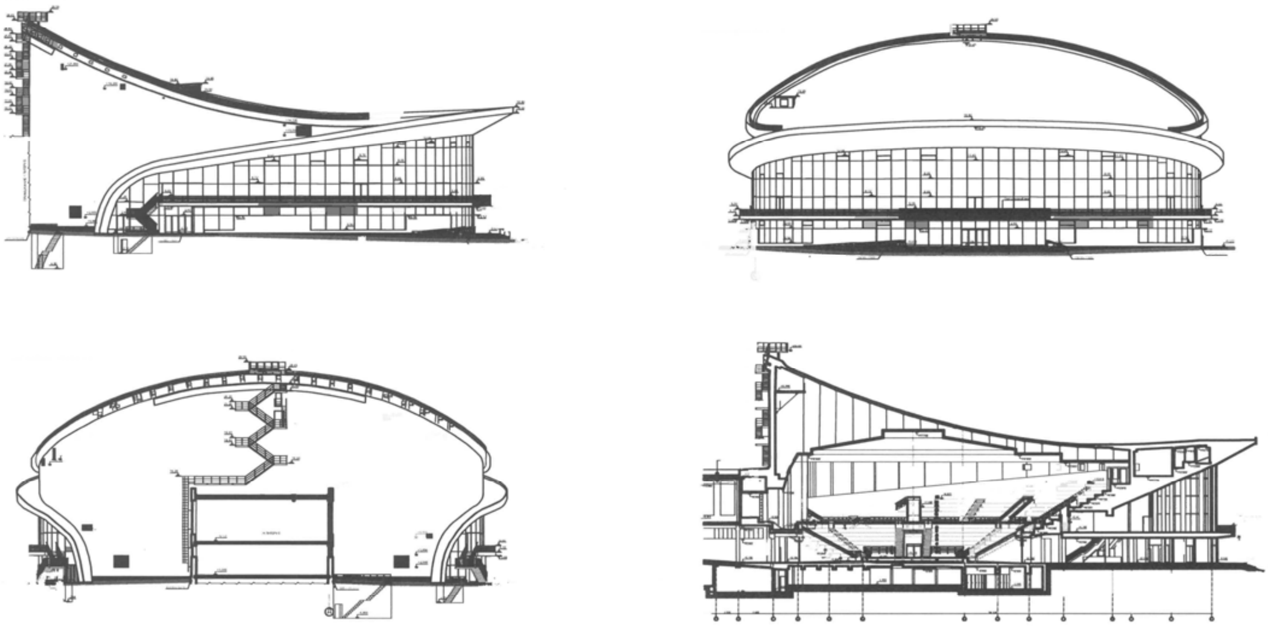

Fig. 1. Facility under study

B to SP 20.13330.2016 “Loads and actions". Updated edition of SNiP 2.01.07-85* permits using the diagrams given in the scientific and technical literature without conducting additional specialized experimental studies when assigning the transition coefficient μ and calculating the snow load.

The distribution of snow load in a section perpendicular to the longitudinal one is assumed to be the same as for a flat surface. Additionally, it is necessary to take into account the diagrams with partial loading of the roofing in both longitudinal and transverse directions. It is precisely these snow load diagrams that make it possible to take into account the most unfavorable operating conditions of the sagging shell.

Diagram B.10 is the closest shape in the longitudinal direction to the considered version of the suspended roof according to SP 20.13330. The standard view of this diagram is shown in Fig. 2.

This diagram takes into account the uniform loading of the roofing over the entire area of the horizontal plan, as well as uneven loading while

$\mu_1 = 1{,}0;\ \mu_2 = \frac{l}{b}.$

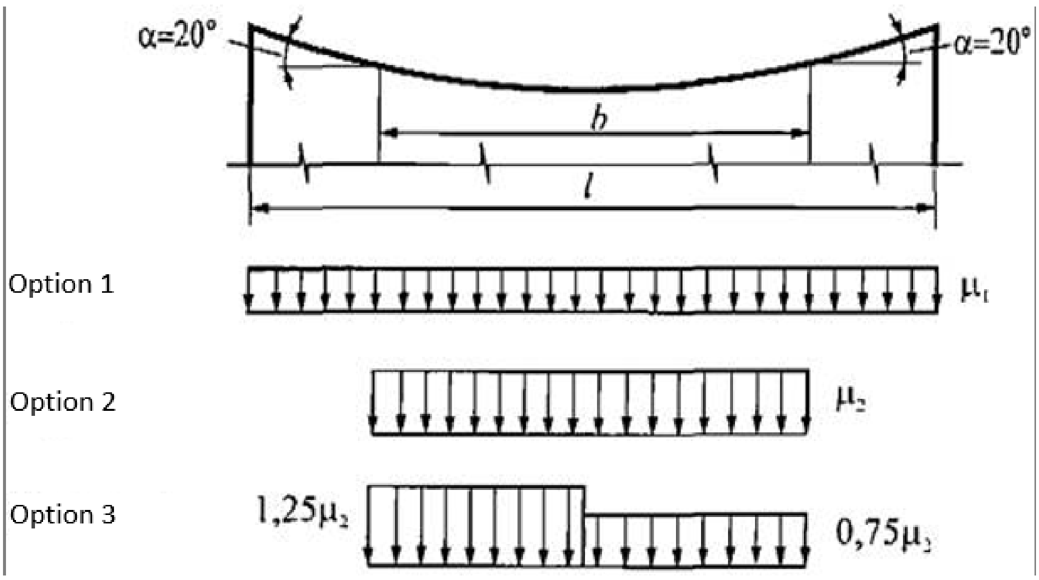

Fig. 2. Diagrams for snow load distribution on suspended cylindrical roofs

considering the possible accumulation of snow in the lower (sagging) part of the roofing and partial snow transfer with a stable wind direction.

Based on the SP Appendix, various options of snow load distribution on the roof of the facility were obtained. The most unfavorable loading option that must be taken into account during design is the diagram shown in Fig. 3. The diagrams show an increased value of the snow load on one half of the roofing as a result of transfer under a stable wind direction.

Results and Discussion

To compare the obtained data, photographic recording (Fig. 4) and field measurements of the thickness of the snow cover on this roof in the winter were carried out.

The measurements were carried out five times during the winter period. The snow load values obtained by taking a snow core were: 12/02/2022 – 16.8 kgf/m^2; 12/09/2022 – 54.3 kgf/m^2; 12/16/2022 – 49.7 kgf/m^2; 12/29/2022 – 76.7 kgf/m^2; 01/13/2023 – 113.8 kgf/m^2.

Snow thickness was measured at various points located according to the diagram in Fig. 5a, and the results of field measurements of the layer thickness at the indicated points are in Fig. 5b.

In general, the results of the field measurements indicate significant uneven distribution of snow cover on the roofing under study. It is not possible to directly compare field measurements and results obtained through analytical calculations even at a qualitative level, primarily due to the fact that the regulatory documents consider an idealized situation when the wind flow is directed strictly along the main coordinate axes of the roof. In our case, the most common direction of wind flow recorded on the dates of field measurements is at an angle to the coordinate axes. This condition explains the difference between the analytical diagrams and monitoring data; quantitative comparison requires a significantly longer observation time. However, the local nature of snow deposits corresponds to the analytical diagrams; zones with snow removal on the leeward part of the roofing (points 15, 17, 19, 25) and a fairly uniform distribution of snow cover in its central part are observed.

In general, the obtained results indicate that when developing design solutions for certain types of suspended roofing, it is permissible to use the data given in the scientific and technical literature, as well as the results of field observations without conducting additional specialized experimental studies. If necessary, one can adjust the snow load distribution diagrams based on the quantitative data from ongoing monitoring.

Conclusions

Comparing the diagrams obtained from the SP with the data of field measurements, it is clear that as a whole, the facility roofing under study corresponds to the diagram of uneven snow cover close to option 1 taking into account the direction of the wind flow (Fig. 3). Obviously, the data from five measurements of snow cover during one season are not enough to draw final conclusions. However, comparison of computational research data (as well as the results of numerical and experimental research) with field observation data is an important direction for ensuring the safety of buildings and structures, especially in matters of assigning snow loads, which have a significant impact on the stress-strain state of building structures.

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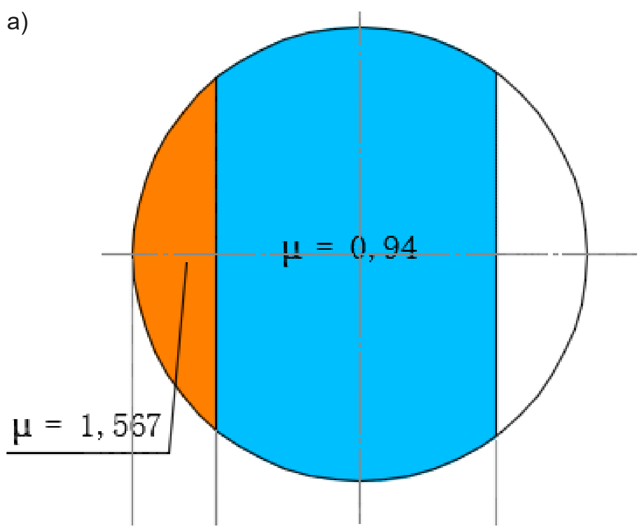

Fig. 3. Options of snow load distribution: a) option 1; b) option 2

Fig. 4. Photo recording of snow transfer on a full-scale facility

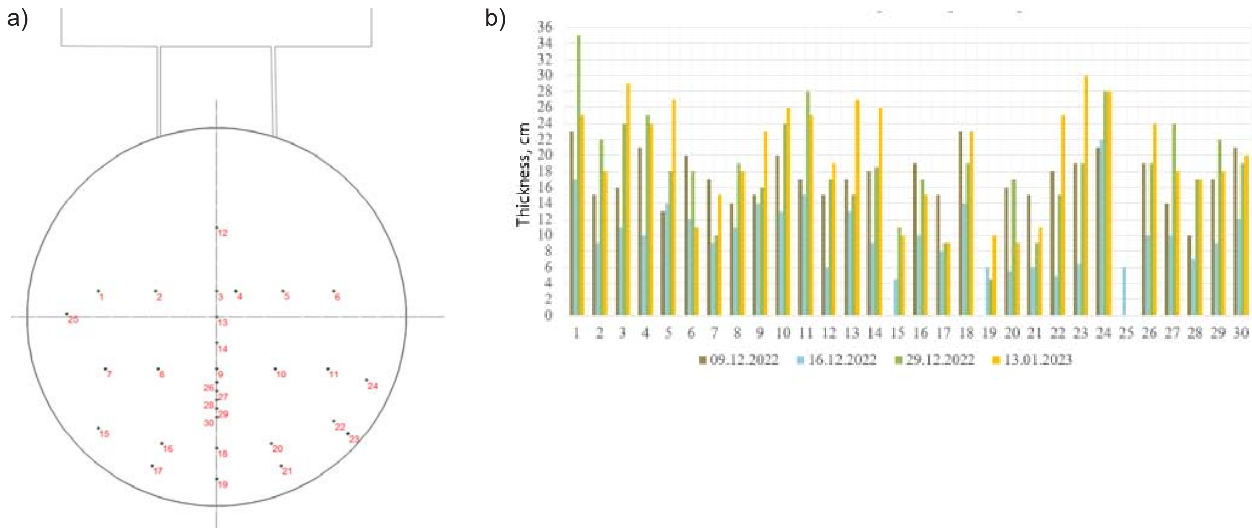

Fig. 5. Diagram of the points located on the roof of the facility (a) and the thickness of the snow cover on the facility roof at the points (b)

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МОДЕЛИРОВАНИЕ СНЕГОВОЙ НАГРУЗКИ НА ПОКРЫТИЯХ УНИКАЛЬНЫХ ЗДАНИЙ

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Аннотация
Введение: Целью работы является исследование процессов снегопереноса и снегоотложений на кровельном покрытии уникального здания. В настоящее время проблема назначения снеговой нагрузки на покрытия зданий и сооружений остается актуальной, поскольку случаи обрушения кровель в зимний период по-прежнему ежегодно фиксируются, в том числе на территории РФ. В качестве объекта исследования было выбрано здание цирка с покрытием в виде висячей железобетонной оболочки. **Методы:** Расчетная схема для данного типа кровли содержится в СП 20.13330.2016, схемы распределения снеговой нагрузки для данной кровли были приняты по приложению Б СП 20.13330.2016. Рассмотрены несколько вариантов распределения снеговой нагрузки, выбран самый неблагоприятный, когда наблюдается повышенное значение снеговой нагрузки на одной половине покрытия. В течение одного зимнего периода были проведены натурные замеры толщины снежного покрова на данном объекте. **Результаты:** Установлено, что в целом, за исключением локальных зон, реальное распределение снежного покрова совпадает с принятым проектным решением, при этом реальное значение веса снежного покрова для текущего зимнего сезона существенно ниже расчетного. **Обсуждения:** Полученный результат демонстрирует, что при разработке проектных решений для отдельных типов висячих кровельных покрытий допустимо без проведения специализированных экспериментальных исследований использовать данные, приведенные в научно-технической литературе, базирующиеся на результатах мониторинга толщины снежного покрова на поверхности покрытия здания.

Ключевые слова: снеговая нагрузка, валидация, снегоотложение, снегоперенос.