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THE FEATURES OF SNOW LOADS ON BUILDING ROOFS

WŁAŚCIWOŚCI OBCIĄŻENIA ŚNIEGIEM DACHÓW BUDYNKÓW

A b s t r a c t

In this paper the probabilistic model of the snow accumulation on the roofs with height discontinuity was worked out, the decreasing coefficient for the snow load weight was received and the ways of their application in the designing were elaborated. The probabilistic model for impulse stochastic process of snowfall sequence was developed. Data from meteorological stations in Ukraine allow determination of statistical characteristics: average annual snowfall amount and exponential distribution of values of one snowfall. The law of intensity distribution of snow melting has been determined experimentally. The territorial zoning map of Ukraine by characteristic values of the snow load on the roofs that emanate heat was developed.

Keywords: building roofs snow load, snow accumulation, snowfall, safety

S t r e s z c z e n i e

W pracy opracowano probablilistyczny model akumulacji śniegu przy zmianie wysokości dachu, otrzymano współczynnik zmniejszający dla obciążenia śniegiem oraz wypracowano sposoby jego wykorzystania w projektowaniu. Rozwinięto model probablistyczny dla impulsowego procesu stochastycznego dotyczącego opadu śniegu. Dane ze stacji meteorologicznych na Ukrainie pozwoliły określić charakterystyki statystyczne: średni roczny opad śniegu i wykładniczy rozkład wielkości w pojedynczym opadzie śniegu. Prawo rozkładu intensywności topnienia śniegu zostało określone eksperymentalnie. Rozwinięto mapę stref terytorialnych Ukrainy za pomocą charakterystycznych wielkości obciążenia śniegiem dachów wydzielających ciepło.

Słowa kluczowe: dachy budynków, obciążenie śniegiem, akumulacja śniegu, opad śniegu, bezpieczeństwo

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1. Introduction

The Ukraine has practically adapted its atmospheric load codes to European ones with the help of new state Codes DBN B.1.2.-2:2006 'Loads and loading' [4]. It should be mentioned that there are still lots of issues concerning matching national Ukrainian codes with European ones. This problem is being complicated by the position of the state in the process of gradual transition to European codes as the national searching results should be taken into account. Modern probabilistic and numerical methods can help in solving the structure snow load comprehensive research. Climatic changes should be taken into consideration. The results of the scientific work have to be embodied into the national application of European Codes. These fully meet Ukraine climatic requirements and can be realized. These methods might be applied to the recommendation development for designers.

2. Review of the latest pieces of research and publications

Numerous scientific works of specialists of different countries were devoted to the description of snow falls as a natural phenomenon and a source of loading on buildings [1, 8, 11, 13]. Certain attention is spared to the questions of snow accumulation at points of different heights on buildings [9, 17, 18]. Advanced approaches to the study of snow loads are developed using methods of computational fluid dynamics which have been in applies in Japan, USA and Poland for some time. Verification of the obtained results is performed by comparing them with snow survey data and snow modelling in a wind tunnel [6, 7].

3. Separation of not solving parts of general problem

Significant drawbacks in the application of numerical methods and aerodynamic modelling are their high cost, the need for highly capable PC hardware and the considerable complexity of modelling such heterogeneous subject-matter as snow. Thus, until recently, the most informative way to obtain snow parameters (height, density, thawing and accumulation) was through snow surveys and natural snow investigation. Such approach allows solving the tasks such not decided fully, as a snow loading at points of different heights on buildings and code setting of the snow loading on cold roofs and roofs of heated buildings.

4. Target statement

The aim of the article is the development of engineering methods that allow taking into account an increased snow load on the covering of buildings of variable heights; this is in

order to estimate the processes of snow thawing on roofs of heated buildings and snow laying on cold roofs.

5. Principal material and results

In the limits of complex mode to the study of snow load, the snow crystals physical characteristics were analyzed, evolution of the national designing standards of snow loads was tracked, and factors that have an influence on the increased snow accumulation at points of different heights on buildings were determined (Fig. 1) [12, 15].
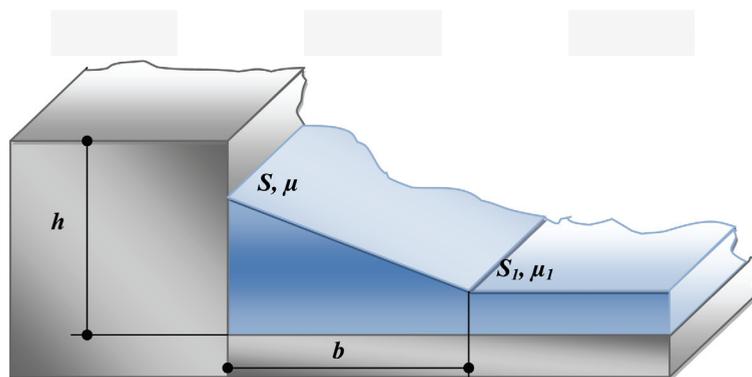

Fig. 1. Drifted snow load zone in the places of height discontinuity (according to codes of structural design)

Analysis of the results of the carried out investigations has shown that such variable factors as the physical characteristics of snow crystals, the solid atmospheric precipitation quantity, local wind patterns, thaw and pouring have a considerable influence on the formation of excess snow laying at points of different heights on buildings. However, this is not represented in the national and foreign design standards.

The snow cover experimental investigations (snow surveys) were the next stage in the studying of snow loads. They carried out in 2008–2010 with parallel information acquisition about physical and meteorological factors (wind speed and direction, external air temperature) that influence on the drifted snow load forming at points of different heights on buildings [12]. The statistical processing of the results was effectuated. It was ascertained that wind plays a main part in the increased snow accumulation at points of different heights on buildings. The comparison of the measurements on the ground surface and on the building roofs confirms this fact. It was proven that 20–25 % of snow from lower and upper roofs are blown away to the drifted snow load zone. The actual geometric parameters of the drifted snow load zone are in near total compliance with recommendations of DBN [4]. The main difference lies in the fact that current standards over-estimate the value of the increased snow accumulation at points of different heights and at the same time, clearly under-estimate (by 10–40%) the snow load in zone outside drifted snow load.

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Special attention was paid to the comparative analysis of national standards [4] with Soviet standard, SNiP [16] and foreign analogues – American codes, ASCE [2] and European codes, Eurocode-1 [5]. It was established that there is no clear relationship between the drifted snow load calculated by SNiP and DBN for the same roofs. The drifted snow load may go up by 27–81% and decrease by 19% in the case of snow filling of the entire height difference with the increasing of the snow load on the ground at 48%. It was found that the drifted snow load calculated according to the DBN and Eurocode-1 standards varies by 15–30% on both smaller and larger sides, and European codes are distinguished by a too simplistic and generalized approach and a small amount of design schemes. Norms of the USA [2], in comparison with national standards, may significantly over-estimate (to 55%) the weight of excess snow laying at points of different heights in conditions up to 3m and under-estimate (to 58%) it for differences from 3m to 8m. The final stage of research was the creation of the probabilistic model of snow accumulation at points of different heights on buildings. Such important factors of drifted snow load forming as snow load on the ground, wind speed and direction, ambient air temperature and snow thawing were considered and evaluated. As a result of careful analysis of these influential factors, the most important of them, such as snow load on the ground and wind speed, were taken into consideration in an explicit probabilistic form. In addition, the frequency of winds with a speed greater than 4m/s was considered as a deterministic value. Other factors were not taken into account because they could lead to significant model complications, contributing only to the reduction of the snow quantity at points of different heights.

The obtained probability model of the snow accumulation at points of different heights on buildings allowed estimating the drifted snow load defined by the DBN [4]. The snow load combination coefficients for a number of roofs with lifetimes of 50 and 100 years [12] based on the developed method was determined. These coefficients allow the optimization of the drifted snow load at points of different heights. In order to implement them, engineering practice offers a special approach to adjusting design values of drifted snow loads, based on field studies (Fig. 2). This supposes redistributing the snow by moving some of it to the 'non-snow bag area'. This becomes possible when proportionally reducing the maximal value of coefficient μ to value μ_{sb}, along with the reduction of snowdrift run value from b to b_{sb}. Simultaneously, the coefficient μ_1 should be raised to μ_{1sb} value.
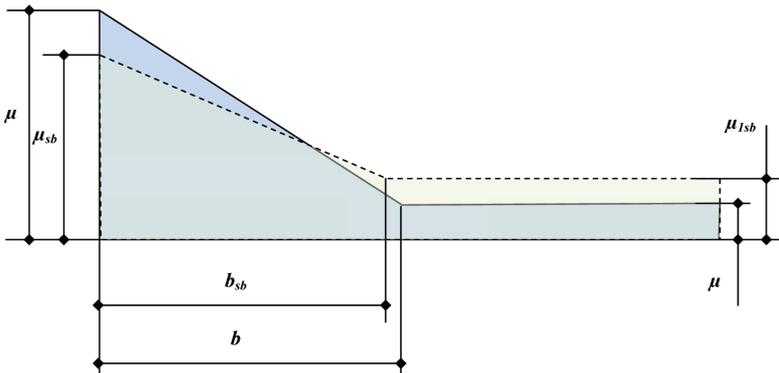

Fig. 2. Correction algorithm of design values of drifted snow load

According to the given rule, approximate correction relations have been found:

$$\mu_{sb} = \mu(\gamma_{sb} + 0.05)$$

$$\mu_{1sb} = \frac{\mu_1}{(\gamma_{sb} + 0.05)}$$

$$b_{sb} = b(0.2\gamma_{sb} + 0.77) \tag{1}$$

Standard deviation between theoretical values of reduced drifted snow load and those being calculated according to the above-given formulae (1) fluctuates in the range of 0.7 to about 8% adding to safety margin. That is, these formulae (1) can be successfully applied in engineering design.

These coefficients allow optimising the weight of snow deposits at points of different heights on buildings. The approach to the correction of the design parameters of drifted snow loads based on the field observations was proposed for use in engineering practice. Its essence lies in the redistribution of the part of snow from the drifted snow load area to other areas.

Thus, the probabilistic model of drifted snow load made it possible to get reasonable coefficients of the snow load at points of different heights on buildings. Their values for the Ukraine territory can be taken at first approximation on a level 0.8. This decision allows reducing the efforts in the truss elements by 6–16% and reducing the estimated load on structures.

At the same time with character of the snow distribution, snow blowing and snow moving on the roofs surfaces of various forms create the snow thawing on the roofs that also affects on the value of snow load. Moreover, thawing can have different intensities because of the different amounts of heat which depends on the thermal resistance of the roof surface. This process has not been studied enough, the existing standards DBN and SNiP [4, 16] take it into account through the use of reducing (thermal) coefficients of exploitation conditions $C_e = 0.8$ for the snow load value on non-insulated roof surfaces with increased heat loss while the roof slope is equal to more than 3% and proper drainage of meltwater is ensured. It is quite approximate that leads to the excessive materials consumption for some structures and the insufficient reliability of others. It remains unclear what roofs should be considered as non-insulated. Besides that, looking on the variety of using building materials and the wide limits of the possible thermal resistance structures, it would be reasonable to introduce a differentiated coefficient depending on the roof thermal resistance and climatic characteristics of the locality. All of these factors bring a necessity for studies of the process of snow thawing on roofs, the influence of thermal characteristics of the snow cover on the snow load size, and refinement coefficient of exploitation conditions of the roofs.

A number of field observations showed that some roofs have sufficient insulating properties and do not allow practically any heat loss and other roofs let pass significant heat flows, this can lead not only to the snow load decreasing, but full snow thawing. The decrease in the snow load on the roof was fixed at 30%.

The mathematical model and the calculation program of snow thawing on the roof on account of the heat proceed from the room [10] was developed on the basis of the information about the features of formation and physical properties of snow cover received from field

observations and analysis of the literature, as well as basic heat transfer laws. This program made it possible to predict the height and weight of the snow on the surface at any time from the beginning of melting. The comparison of calculation results with experimental data received in Poltava National Technical Yuri Kondratyuk University on real and simulated buildings showed good congruence of the total thawing time which affirms the adequacy of the proposed model.

The program of statistical snow load modelling based on the developed method of calculation of melting snow on roads was compiled. The snow-measuring data was collected over years 1980-2000 for 16 meteorological stations from different regions of the Ukraine and the processes of snow loads on the ground and on the roofs with different thermal resistances were modeled [10].

Coefficients of the roof exploitation conditions obtained for non-insulated roofs with low thermal resistance were found to be much lower than the current standards determine at a value of 0.8. With increasing of the roof thermal resistance, the thawing coefficient increases. At the same time, the return period of the designed snow load has virtually no influence on the result, it is therefore possible to be guided by $T = 100$ years in all cases, taking factor C_e in the range 0.6–1.0 in depend of the roof thermal resistance.

The selected meteostation network allowed covering all typical regions of the Ukraine. The territorial variability analysis of the obtained coefficients with their dependence on thermal resistance allows obtaining the analytical expression for the calculating of the coefficient of roof exploitation conditions

$$C_e = 1 - 0.00022 S_0 \cdot \exp(-0.6R)$$ (2)

where S_0 – characteristic snow load corresponding to DBN (Pa) [4], R– thermal resistance of roof (m²·°C/Wt).

As the coefficient of roof exploitation conditions decreases with increases in the snow load characteristic value, it can substantially reduce the snow load in areas with significant snow deposits that are accumulated during the winter. In areas where snow accumulation is practically unobserved, the snow thawing effect is minimal.

In order to estimate the economic effect of C_e coefficient using the calculation of real roof structures with consideration of suggested propositions and by the current DBN [4] was done. The maximum effect of using the specified coefficient of roof exploitation conditions was obtained in the conditions of snow region with the largest characteristic value of snow load. For heavy roofs, the snow load does not play a significant role thereafter the effect of its reduction was small. When calculating light roofs, the influence of the coefficient of roof exploitation conditions is the largest and using the specified C_e value saves the steel consumption by 5–30%.

Particular attention was paid to the investigation of the formation processes of snow load on the non-insulated (cold) roofs of industrial buildings with excessive heat emission [3] and to the development of scientifically based proposals for the snow load rationing on the roofs of metallurgical plants and agricultural industrial buildings (greenhouses and hotbeds) [3]. Thus, experimental studies of the formation process of snow cover on the roofs that emanate heat were conducted on a model that provided stable internal air temperature below

the glass roof and the ability to periodically determine the height and the average density of snow on the roof similar to the method of the snow survey. Observations after snow cover on the roof were carried out during the snowfall process and by the artificial creation of snow cover in order to determine its melting laws. Observations during two winters gave the possibility to find out the statistical characteristics of the random value of the snow melting speed on the roofs that emanate heat and also its dependence on a number of influencing factors. The theoretical model that allows determining the speed of snow melting on the emanating heat roofs was developed in consideration of the thermal snow properties, heat transfer from premise to the snow cover on the roof and heat consumption for the heating and melting of snow. Comparison of calculated data with experimental results has shown satisfactory coincidence. This fact allows using the developed theoretical model for the snow loads determining in consideration of snow melting on the non-insulated roofs of premise with heat excess emanating.

The calculated values of snow load on non-insulated roofs of buildings with excess heat emanating were determined on the basis of the developed probabilistic model of snowfall sequence after the results of snow surveys carried out over 20 years at 183 meteorological stations in the Ukraine. A relatively dense network of meteorological stations allowed obtaining representative statistical characteristics of snowfall sequences regarding average annual snowfall and the expectation value of single snowfall occurrences. Maps of the Ukraine showing territorial zoning that reflect the regularities of territorial variability of these characteristics were developed [14]. In consideration of the influence of the snowfall sequence random parameters, snowfall duration and snowmelt speed on the value of the snow load on the roof, the statistical modelling procedure by a specially developed program was used to calculate the design values. It was established that the value of snow load on the roof could be described by discrete-continuous exponential distribution – this takes into account both the value of snow load, and the possibility of its complete absence. Absence of enough closely relation with the characteristic value of full snow load on ordinary roofs given in the standards [4], stipulate the need of separate rate setting of the snow load on the roofs that emanate heat. For this purpose, through the generalization of the results of 132 plain meteorological stations, the map of the territorial districting of the Ukraine is worked out in correspondence with the characteristic values of the snow loading from one snow-fall S_0 that answer a return period of 10 years (Fig. 3).

The map identified 3 territorial regions with regional values of snow load equal to 250, 300 and 350 Pa. The averaged dependence of reliability coefficient is also determined for the snow loading from the return period of T (in years) :

$$\gamma_f^* = 0.1 + 0.9 \log T \tag{3}$$

The character of territorial variability of snow load on the roofs that emanate heat is significantly different from full snow load prescribed by standards [4]. Comparison of calculated values obtained by the developed recommendations with appropriate data of standards [4] showed an increase in the design values for the whole territory of the Ukraine. This fact will lead to increase of the materials consumption for roof framing, but provide social effect by increasing their reliability.

Fig. 3. The Ukraine territorial districting of the snow loading on cold roofs

6. Conclusions

The probabilistic model of the snow accumulation on the roofs with height discontinuity was worked out, the decreasing coefficient for the snow load weight was received and the methods of their application in the designing were elaborated. The proposed approach allows differentiating the coefficient of roof exploitation conditions C_e depending on the roof thermal resistance, and in some cases, significantly to reduce the design snow load values and to give a substantial saving of steel. The probabilistic model for impulse stochastic process of snowfall sequence has been developed. According to the data from 132 meteorological stations in the Ukraine, its statistical characteristics have been found – average annual snowfall amount and exponential distribution of values of one snowfall. The law of intensity distribution of snow melting has been determined experimentally. The territorial zoning map of the Ukraine by characteristic values of snow loads on roofs that emanate heat was developed.

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