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EVALUATION AND MAPPING OF SNOW LOAD ON THE GROUND

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The analysis of the current state of the regulatory framework used in the evaluation of the snow load at the stages of design and construction has been fulfilled. The observed method of calculating the amount of snow load on the ground for the poorly studied areas has been considered. The method is based on the value of the maximum water equivalence of snow cover and vertical gradient increment of the weight of the snow cover. The algorithm of zoning by the snow load has been carried out. The map "Snow Load Zoning of the Territory of Sakhalin" has been created using this algorithm.

Snow load, snow accumulation, construction regulations, depth of snow cover

INTRODUCTION

Over a long period of development (since 1933), regulations in the area of snow load evaluation have been significantly changed. Currently the standards of snow load in Russia are determined in the map of snow load per 1 m^2 of horizontal surface, calculated by the average annual values of maximum snow cover thickness and by the average snow density values, provided in the Code of Regulations (hereinafter referred to as CR) [*CR 20.13330.2011..., 2011*] .

In 1976, M.V. Zavarina carried out zoning of the territory of the former USSR by the weight of snow cover recurring once every five years. Each region has a corresponding average value of snow load, given 20 % recurrence rate. In the larger part of the territory, the values of snow load used in CR and in the indicated zoning map comply; i.e., the standard values calculated by the snow cover thickness and its density comply with the standard values calculated by the amount of 20 % water content.

The snow cover weight zoning map provided in CR has a scale of 1:17 000 000, which is insufficient for determining the concrete values of snow load in the settlements of RF subjects.

In the new version, CR is a set of Construction Norms and Regulations as of 2003 and Amendments for them. CR retains division of the territory into eight snow regions and the corresponding values of snow load in them. With small exceptions, the borders of snow regions in the CR maps comply with the regions indicated in the Construction Norms and Regulations of 2.01.07-85*.

Although the snow load values in CR (and accordingly, their values in the Construction Norms and Regulations of 2.01.07-85*) are higher than those indicated in the preceding documents, they are still insufficient, as the strength factors calculated for the building design have essentially decreased and are not compensated by the increased values of the snow load. Fig. 1 shows the subjects of RF, in the territories of which accidents with building structures have taken place, caused by snow loads.

The larger part of the structures in the urban territory of Russia is not designed for actual snow load. Over the recent five years, 129 cases of roof destruction have been reported, including those involving incidents with 45 roofs of residential buildings [*Lobkina, 2012*]. 43 persons suffered from the damage, and 10 persons were killed.

The desire to simplify the regulatory parameters resulted in the fact that, as the snow loads were estimated, one region covered areas with a wide scatter of values, which may be justified only in the case of using standardized construction designs. However, in individual construction, which has become quite popular lately, it seems more reasonable to choose a customized approach to determining the snow load, which considers the specific conditions of the region, and to develop local standards.

To make corrections and amendments for the Construction Norms and Regulations, in some regions of RF works were started to develop and introduce territorial construction norms (TCN) relating to snow load. Such TCN were developed for Sakha Republic (Yakutia) in 1998, for Krasnoyarsk kray in 2002, for Moscow in 2005, for Udmurt Republic in 2006, and for Sakhalin region in 2009.

Special attention in TCN is paid not only to snow load mapping in the territory but also to composing regulatory documents with tables containing snow load estimates for settlements forming parts of the indicated republics and regions, which reflects the trends of the world practice. The recurrence rate of snow load is taken on average to be one every 25 years.

As the network of hydrometeorological stations and posts in Russia has reduced, introduction into regulatory documents of specific snow load values, characteristic of certain settlements where regular

Fig. 1. RF subjects in the territories of which there were breakdowns of structures caused by snow loads, for the period from 2009 to 2013.

snow measurements take place, helps avoiding possible underestimation of snow load in designing buildings and structures.

The goal of the study is to propose a methodology of calculating snow load on the ground and to develop an algorithm for zoning a territory based on the snow cover thickness.

THE WORLD EXPERIENCE OF REULATING SNOW LOAD

Development of the system of rating snow load in the world, just as in Russia, has taken place based on the results of field studies, meteorological data, analysis of breakdowns of buildings and structures caused by heavy snowfalls, and on the achievements in the study and development of the methods of calculating the norms for buildings and structures in construction [*Filippov et al., 2000*].

The issue of estimating the snow load has been studied in Canada most fully. Currently regulating possible snow load takes place in accordance with NBCC-2005 [*National building..., 2008*], and the values of regulated maximum weights of snow cover of the ground are taken to be the snow load standards, with the recurrence period equal to once every 50 years. Recalculation of the snow load on the ground on the basis of maximum thickness of the snow cover is conducted using the concept of equal snow density on the ground being 12 lb/ft^3 (≈200 kg/m^3), irrespective of the conditions of snow cover development. The final value of snow load is obtained by multiplying the snow load by the factors determining the transfer to snow load on roofing, the roof slope and the wind impact. Multiplication by these factors results in reduction of the snow load; however, if the cases of roof breakdowns caused by snow accumulation have been recorded in the construction area, snow load reduction is not allowed.

The full value of the snow load on roofing is calculated by multiplying the water content coefficient for snow moisture (the table value varying from 1.0 to 1.25, depending on the category) by the sum of the final snow load value and the rain load values, estimated for a period of 50 years. According to NBCC, the rain load value should not exceed the snow load value.

The standard of the American Society of Construction Engineers ASCE 7-10 [*Minimum..., 2010*] for regulating snow has been developed on the basis of the results of studies conducted in eight universities, Corps of Engineers, U.S. Army Corps of Engineers, Cold Regions Research, Engineering Laboratory, and the Alaska Corps. The main provisions of the Canadian standards were used.

Statistical analyses considered maximum annual values of snow cover weight per ground area. To establish the law of annual maximum load distribution, detailed analysis of information provided by 204 stations of the national weather service was conducted, which had data on the snow cover depth. Information on the snow depth from 3,300 additional weather posts was also analyzed [*O'Rourke, 2007*]. To obtain the value of snow load on the ground, snow depth was multiplied by the coefficient of 0.279, which is in fact equivalent to snow density. The probability of snow load recurrence was taken to be once in 50 years. Division into snow regions on the map presented in the ASCE 7-10 standard was performed with the image gradation of 5 lb/ft^2 (0.24 kPa).

The methodology of determining snow load on roofing used in these standards is generally not different from the Russian one. The formula of calculating the full value of snow load on roofing in the Russian CR agrees with that presented in ASCE 7-10.

In 1995, for the first time for some European countries (France, Germany, Italy, etc.), Eurocode 1 was developed to determine snow actions on structures [*EN 1991-1-3..., 2003*].

The weight of the snow cover of the Earth is determined by the annual values of maximum snow depth and density, with the probability of exceeding the average value once in fifty years. For mountainous areas, special corrections are introduced for the altitude above sea level. In order to enhance precision of estimates, especially for the rare recurrence values, the number of observation years is suggested to be taken to be at least 20. The Eurocode provides for each European country the values of the weight of snow cover on the ground. Currently studies are being conducted in these countries to develop integrated zoning of the territory based on the weight of snow cover. For some countries, it is necessary to consider dependence of snow load on the altitude above sea level. In determining the weight of the snow cover on the round surface, most European countries take the snow density to be constant for the entire territory. There are cases (France) when the borders of the snow regions are determined based on the borders of administrative districts. The level of snow load has a wide range from 0.45 kPa in France to 14.2 kPa in Germany.

Calculation of the snow load in the construction standards of Japan (http://www.aij.or/jp) differs little from that described above. The value of the depth of snow on the ground is taken to be equal to maximum from those recorded over 100 years, evaluated by the meteorological data.

The general principles of determining the value of snow load on the ground used in the world coincide with the principles employed in Russia. The major difference consists in the volume of data analyzed in the period of recurrence of maximum values of snow load. The method of calculating the snow load on roofing has more essential differences, especially in the area of calculating the coefficient of transition from the load on the ground to the load on the horizontal surface of roofing.

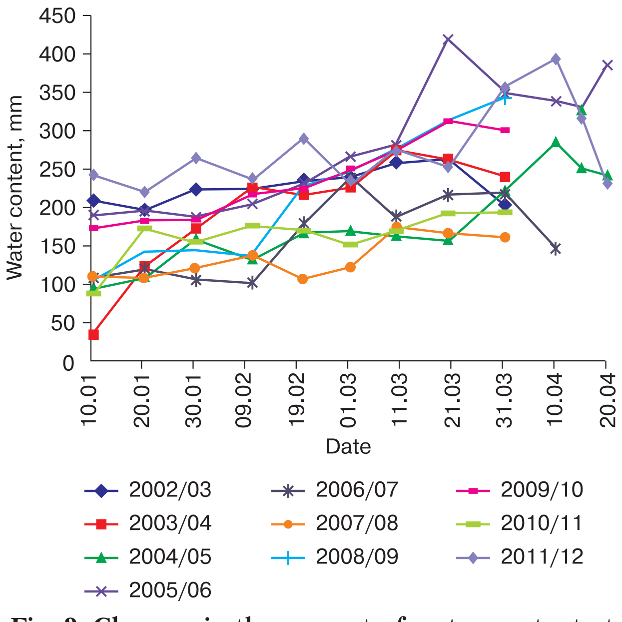


Fig. 2. Changes in the amount of water content at the control site according to the observations of the Sakhalin branch of the Far East Geological Institute, FEB RAS.

METHODS AND RESULTS

Calculation of snow load on the ground. Analysis of the data for snow measuring works conducted at the stationary observation sites for long periods of time allows tracing down both spatial and temporal changes in the values of snow load.

Shown in Fig. 2 are many years' curves of snow accumulation at a stationary observation site located in the surroundings of Yuzhno-Sakhalinsk in the bajada of the western slope of the Susunai ridge [*Lobkina, 2013*]. Built on the results of snow-measuring works, the curves of changes in the water content of the snow demonstrate the process of gradual accumulation of snow during the winter season and the process of its thawing in spring.

The process of snow cover weight change on the ground surface during the winter season is visualized as non-symmetric convex curves close to each other. Fig. 2 shows changes in the weight of snow on the site, which occurs due to the fact that snow may fall and thaw several times during the winter season.

Although the snow accumulation process is random and snow weight varies throughout winter and from winter to winter, depending on a series of climatic factors, one can identify the main features in the process of changing the value of the water content and determine the period of the largest values of snow load.

As an example, we will calculate the value of snow load at the site in question.

Based on the annual actual data of the water content (Fig. 2) and using the hypothesis of equal adequacy or independence of test data, one can calculate the maximum value of the snow load on the ground [*Grudev et al., 2007*]. For this purpose, we will increasingly place the maximum annual snow load values within integral probability ($0 \le P \le 1$), and we will obtain the probability distribution of the snow load based on actual data, where each test point ΔP will correspond to a band, and the test value will correspond to the middle part of this band (Fig. 3).

The period of observations in a certain location for which calculations are required should be at least 20–25 years. In calculating snow load, two main principles should be considered: the finitude of the snow load and the fact that the regulatory value should not depend on the statistics of snow-poor winters [*Filippov et al., 2000; Grudev et al., 2007*]. Therefore, to extrapolate, it is necessary to consider only the last (maximum) points, not more than 10 of them. In most cases, the result sought may be obtained by two last points. Ass the interpolation range is small, one can use linear extrapolation.

At the site, calculation of the amount of snow load will be made (S) by the last four points, as the observation period is only 10 years ($K = 4$).

Out of several linear extrapolation methods, the one proposed by *Grudnev et al.* [*2007*] was used.

We draw a line from each pair of selected points (ij) as far as intersection with $P = 1$, the intersection point yields the value

$$S_{ij} = \frac{(j+0.5)S_{N-i} - (i+0.5)S_{N-j}}{j-i}$$

$$(j > i;\ i = 0, ..., K-1;\ j = 1, ..., K).$$

Out of the values obtained, we select the greatest one, as this is the value of the snow load S (Table 1). This method of linear extrapolation is reliable enough, as it provides a certain reserve. It is necessary to make a correction for the obtained value of the snow load, which depends on the degree of reliability of the original data obtained.

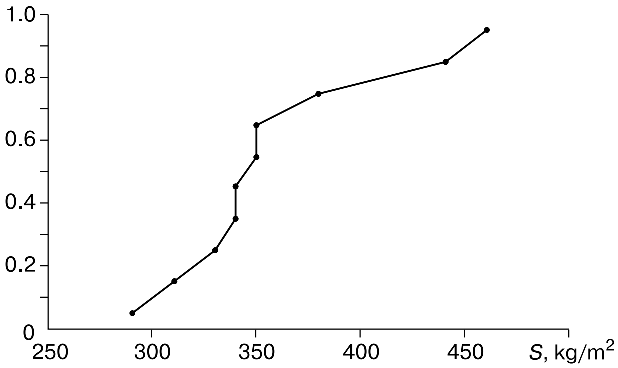


Fig. 3. Probability distribution of snow load (S) according to the observations conducted on the site for 10 years.

The methods of calculating short-term and long-term snow loads differ little. In calculating short-term load, maximum increase in the amount of water content during a snowfall is taken, not the maximum water content during the winter season.

CR 20.13330.2011 do not provide for separation of the snow load into two components: long-term and short-term. Separation of the temporal loads into long-term and short-term loads is characterized, in accordance with Clause 5.1 of CR only by their duration. According to Clause 4.1 of CR, for snow loads two standards are established: a reduced value, determined by Clause 5.4 (h), and a complete value, determined by Clause 5.5 (f). As the strength calculation is conducted considering short-term loads, in accordance with Clause 6.2 CR 20.13330.2011, the snow load should be included into the main combination with a complete standard value.

It is stated in the *Glaciological Dictionary* [*1984*] that snow load may be long-term (during the entire winter) and short-term (after long blizzards and severe snowfalls). However, the area of use for this separation of snow load is not indicated.

In the author's opinion, separation of the snow load into two components is of great practical value, especially for distribution of snow load on the roof.

In a long-term snow load situation, snow gradually gets accumulated on the roof. External factors essentially affect the amount of snow accumulated on the building roof [*Gordeyev et al., 2007*], which are not related to the snow load on the ground surface, such as: snow movement from sloping surfaces, snow thawing on the heat radiating surfaces of heated buildings; transfer and distribution of snow on the roof with snow canopies formed (the breakdown of which is dangerous for the people, transport, and the adjacent buildings with a smaller number of floors); mechanical clearing of the roof. These factors contribute to reduction of the snow weight on the roof. The amount of long-term snow load accumulated over the winter season may exceed the amount of snow load on the roof several times.

In short-term snow loads, the snow weight on the roof sharply increases over a short period of time,

Table 1. **Design snow load values (S) for the site in question, kPa (kg/m^2)**

i	j			
	$N-1$	$N-2$	$N-3$	$N-4$
N	4.70 (470)	4.65 (465)	4.62 (462)	4.59 (459)
$N-1$	–	4.40 (440)	4.33 (433)	4.25 (425)
$N-2$	–	–	4.15 (415)	4.03 (403)
$N-3$	–	–	–	3.80 (380)

Note. j, i – the point number given $j > i$; N – the actual snow load value taken for calculation.

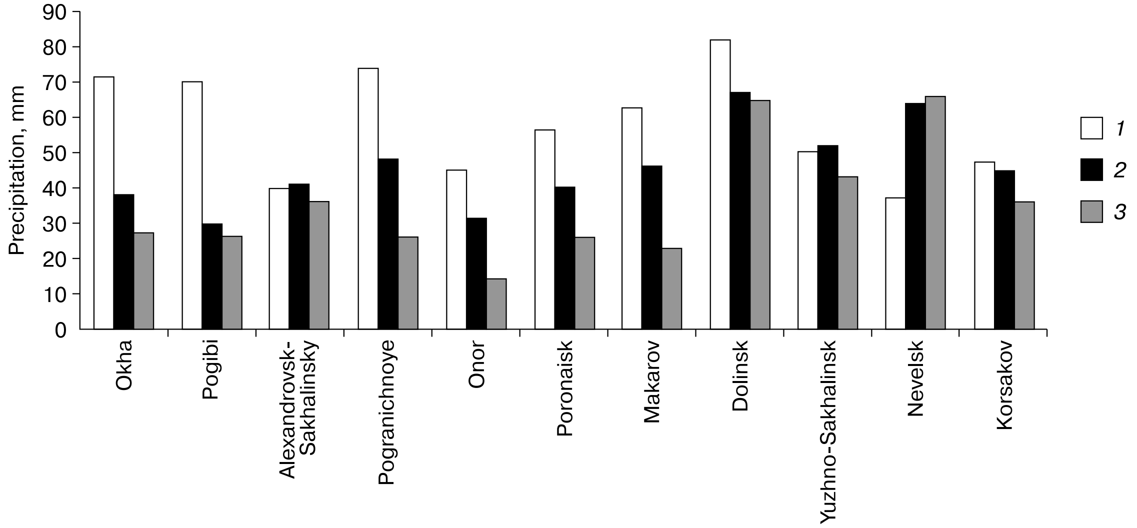


Fig. 4. The amount of precipitation, breakdown of the weather stations of Sakhalin Island:

1 – maximum precipitation (snowfall) during 12 hours and less; *2* – average precipitation for the winter; *3* – average precipitation for January.

with the impact of external factors on the amount of the snow load being insignificant or just absent.

In addition, in short-term loads, snow may get accumulated on the heat-radiating coverages of buildings and structures, where during the entire winter snow accumulation does not seem possible, as the thermal characteristics of such coverage result in thawing and rolling of snow from the roof. Accumulation of snow on such roofs occurs only when snowfall intensity exceeds the snow thawing rate.

The Sakhalin climatic conditions are characterized by the periods when blizzards accompanied by heavy snowfalls follow each other with an interval of several days. In such a situation, a monthly norm or several monthly norms of solid precipitation may fall (Fig. 4).

In the case of short-term snow loads, intense loading of the roof takes place, which may cause its breakdown. For example, maximum increase of the amount of snow load during one snowfall for the cen-

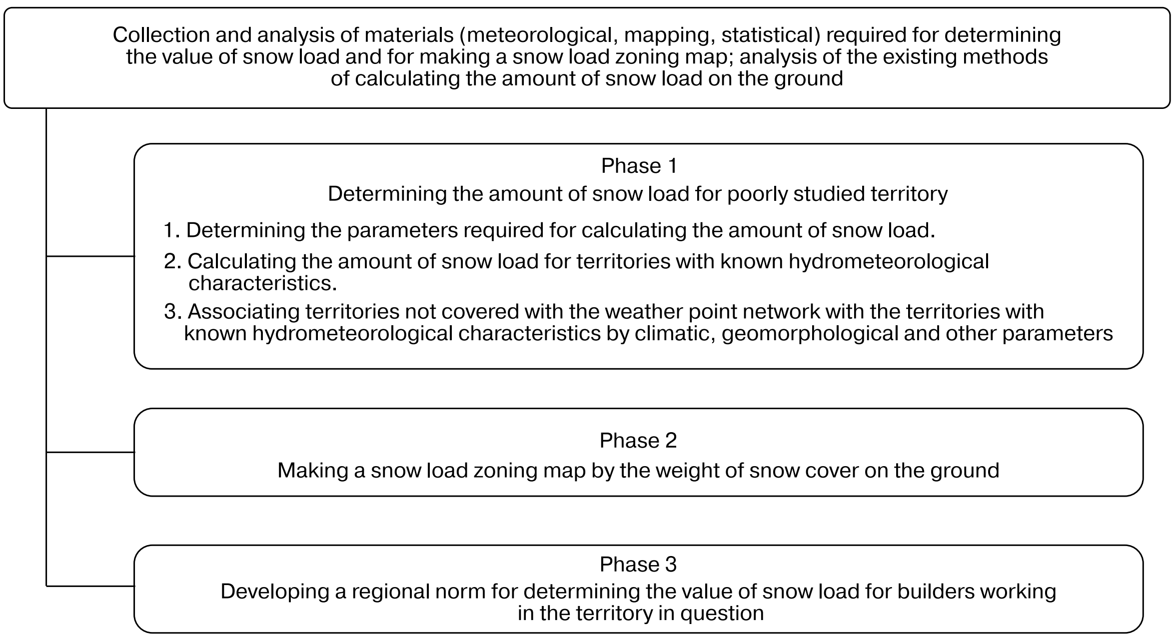
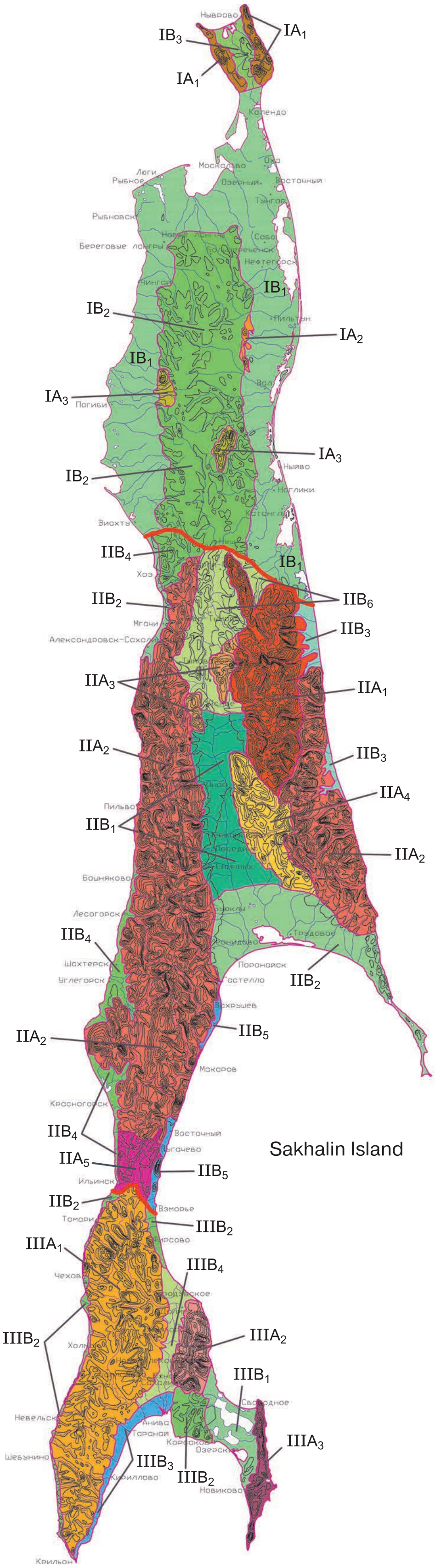


Fig. 5. The zoning algorithm.



Calculated value of the snow load weight (S_g) for Sakhalin Island

Snow region	Snow district	Subdistrict index	Absolute height, m	S_g on the border of an mountainous district, kPa (kgs/m^2)
I – northern region	A – mountainous district	IA$_1$	200–600	6.5 (650)
		IA$_2$	200–400	4.5 (450)
		IA$_3$	200–600	4.5 (450)
	B – flat and maritime district	IB$_1$	0–200	4.0 (400)
		IB$_2$	50–200	4.5 (450)
		IB$_3$	0–100	6.5 (650)
II – central region	A – mountainous district*	IIA$_1$	300–1500	5.5 (550)
		IIA$_2$	200–1300	4.5 (450)
		IIA$_3$	200–800	5.5 (550)
		IIA$_4$	200–900	3.2 (320)
		IIA$_5$	100–300	5.0 (500)
	B – flat and maritime district	IIB$_1$	50–200	3.2 (320)
		IIB$_2$	0–200	4.0 (400)
		IIB$_3$	0–200	4.3 (430)
		IIB$_4$	0–300	4.5 (450)
		IIB$_5$	0–200	4.8 (480)
		IIB$_6$	50–200	5.5 (550)
III – southern region	A – mountainous district*	IIIA$_1$	200–1000	4.5 (450)
		IIIA$_2$	200–1000	6.0 (600)
		IIIA$_3$	100–600	4.3 (430)
	B – flat and maritime district	IIIB$_1$	0–200	4.0 (400)
		IIIB$_2$	0–300	4.5 (450)
		IIIB$_3$	0–200	4.8 (480)
		IIIB$_4$	0–200	6.0 (600)

*The value of S_g for mountainous districts should be recalculated considering the snow cover weight increment gradient with altitude rise.

The value of the snow cover weight increment gradient (ΔS_g) for the mountainous snow districts of Sakhalin Island

Subdistrict index	S_g per 100 m of increment kPa (kgs/m^2)
IA$_1$	1.0 (100)
IA$_2$	0.5 (50)
IA$_3$	0.7 (70)
IIA$_1$	1.0 (100)
IIA$_2$	
IIA$_3$	
IIA$_4$	
IIA$_5$	0.5 (50)
IIIA$_1$	1.0 (100)
IIIA$_2$	
IIIA$_3$	0.5 (50)

The borderline of the snow regions
The borderline of the snow subdistricts
II Snow region
IA Snow district
IIIB$_3$ Snow subdistrict

Fig. 6. A map of snow load zoning of the territory of Sakhalin Island for the estimated snow cover value (1:1 000 000).

ters of municipalities in the Sakhalin region varies from 1.0 kPa (the settlement of Smirnykh, the towns of Korsakov and Aniva) to 2.5 kPa (the towns of Tomari and Dolinsk, the city of Yuzhno-Sakhalinsk).

Hence, in the author's opinion, in developing regional norms of snow loads, it is necessary to indicate not only the amount of long-term snow load in the settlements for which is arailable a long series of observations but also maximum increase of the snow cover during one snowfall, which has been done in the recommendations for the Sakhalin region regarding calculation of snow loads on buildings and structures.

Zoning a territory by the amount of snow load: in making territorial zoning maps in relation to some hazardous process, different concepts are used. The concept shown below was applied in making the map "A map of snow load zoning of the territory of Sakhalin Island for the estimated snow cover value" [*Gensiorovsky et al., 2011*], and may be suggested for making such maps in the other subjects of RF. The algorithm of this concept is shown in Fig. 5.

To estimate the amount of snow load for plain and maritime snow areas, the main characteristics of snow were obtained from the data provided by a network of weather stations; for the mountainous snow districts, materials of field studies were used, with extrapolation in those areas where field studies were not conducted. In calculating the amount of solid precipitation and of snow cover in the mountains, the snow load values were used, calculated on the basis of the materials of the studies conducted in the mountains of Sakhalin Island in 1961–2012.

A characteristic feature which distinguishes the proposed concept for making a snow cover weight-based zoning map from the maps of similar subject matter is separation of the mountainous sub-districts from the plain and maritime sub-districts in the snow regions.

Altogether, three snow regions are identified in the territory of Sakhalin; within the snow regions, 3 mountainous and 3 flat and maritime snow districts are identified, which are subdivided into snow sub-districts (Fig. 6). 24 snow sub-districts are identified – 13 flat and maritime snow sub-districts and 11 mountainous snow sub-districts. The amount of snow load for Sakhalin varies in the range of 3.2–6.5 kPa, without considering the vertical weight increase gradient in the mountainous snow sub-districts (Fig. 6).

The zoning conducted essentially differs from that shown on the map of CR 20.13330.2011 "Loads and Impacts" for the Sakhalin region. In SR, 4 snow districts are identified IN Sakhalin Island, which are represented by 9 areas, the values of the snow load vary from 2.4 to 4.8 kPa. These values of snow loads are severely underreported, which in many ways is related to the fact that, in accordance with CR, the data on the density and depth of the snow mass should be obtained from the nearest weather stations, which have long series of observations. However, 99 % of all the weather stations of the island are located in flat and maritime areas at absolute altitudes below 200 m, whereas the greater part of the territory of Sakhalin Island is lowland.

In accordance with CR, the maximum snow load in the island territory is observed in the north of the Tym-Poronaisk lowland, in the area of the settlement of Tymovskoye, and is equal to 4.8 kPa, while, according to empirical data, the value of the snow load in this territory may reach 6.0 kPa.

Moreover, the mountainous areas of Sakhalin Island in the CR map are referred to districts with maximum snow loads. In particular, the area of the Eastern Sakhalin mountains is referred to the 6th snow district with the snow load value equal to 4.0 kPa; however, it is in the mountains of this district that the maximum amount of solid precipitation may exceed 1,300 mm (13.0 kPa) with the average value of 800 mm (8.0 kPa), which doubles the value of the snow load designed for this district in the CR. The same can be said about the other snow regions of Sakhalin Island indicated in the CR.

Thus, the use of snow district maps developed only on the basis of snow cover and solid precipitation data, obtained at maritime and plain weather stations, results in essential underestimation of the actual values of snow loads, which does not allow, in the long-term perspective, to ensure safe and favorable conditions for people's life.

CONCLUSIONS

Evaluation of the amount of snow load according to the plan proposed in the study, based on the maximum values of the water content, allows the risk of underestimating the actual snow load related to the use of the average value of the sample deviation to be minimized.

The proposed method may be applied not only to calculation of long-term snow load but also to short-term snow load.

In calculating the values of snow loads on the territory of Sakhalin island, not only data from the weather stations located on flat territories were used but also the many years' data on the amount of precipitation in the mountainous areas, obtained from the results of many years' field trip and airborne observations. To determine the design snow load in the mountainous areas, the snow cover weight increment gradients are introduced.

The map of zoning the territory of the Sakhalin region allows the values of snow load to be determined, necessary in design and construction of buildings and structures. The map is complementary to

Code of Regulations 20.13330.2011 “Loads & Impacts” and is recommended by the Ministry of Construction of the Sakhalin region as a regional standard.

The algorithm of zoning the poorly studied territory based on the weight of snow cover may be used for making snow load maps for other subjects of the Russian Federation, as well.

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