Determination of the snow cover weight and altitude coefficient values in mountainous and poorly studied areas for assessing loads on buildings and structures

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Abstract. The materials use in structures and calculations for buildings and structures in Russia is determined, inter alia, by the normative loads of snow cover on the construction site. An urgent task is to determine its significance for the unexplored areas. The results of determining the normative value of the snow cover weight and changes with the height of the snow weight terrain for the designed objects of the “Udokan” Mining and Metallurgical Combine at the altitudes from 600 to 2000 m are presented. To determine the estimated snow load on buildings and structures in the territory of the facility creation, we used the series of the water supply annual maximums in the snow cover obtained as a result of the snow-measuring route observations at high-altitude weather stations located close to the designed objects. Based on the data of weather stations, a regression linear model of the water supply dependence in the snow cover on the height above the sea level was built. The main calculation method for finding the coefficients of a linear equation is the least squares method. It was revealed that with an increase in the height above the sea level by 1 m, the water supply in the snow cover increases by about 0.1 mm.

Introduction

When designing various objects, the estimated snow load is calculated from the normative by multiplying the normative load by the transition coefficient from the ground snow cover weight to the snow load on the coating (μ), which changes in accordance with the Appendix B BC 20.13330.2016. In this regard, it is important to correctly determine the normative weight of the snow cover on 1 m² horizontal ground surface.

According to BC 20.13330.2016, the normative value of snow cover weight Sg to 1 m² the horizontal ground surface is taken depending on the snow area for the territory of the Russian Federation. However, the values obtained in this case are significantly overstated and underestimated in the poor studied territories.

According to the part 10.2 of BC 20.13330.2011, which is included in the List of the national standards and rules codes (parts of such standards and rules codes), the application of which on a mandatory basis ensures compliance with the requirements of the Federal Law of the Russian Federation “Technical Regulation on the Safety of Buildings and Structures” of 30.12 .2009 № 384-FL, in mountainous and poorly studied areas indicated on the map 1 of Appendix G, in the points with a height above the sea level of more than 1500 m, in places with a difficult topography and in other cases, the snow cover weight can be determined in the established manner based on the data from the
nearest weather stations of the Federal Hydrometeorology and Environment Monitoring Service. In this case, the value of the snow cover weight should be taken as the annual maximum snow cover weight exceeded on average once every 25 years, determined on the route snow surveys basis on water reserves in the areas protected from direct wind (in the forest under tree crowns or in the forest glades) for a period of at least 20 years.

In the materials of the technical report, engineering and hydrometeorological surveys “Udokan” Mining and Metallurgical Enterprises Group, the construction phase with the productivity of 12.0 million tons of ore per year, the zoning and altitude coefficient are determined from the snow observations at the meteorological stations of the Highlands [1]. The designed facilities of MMEG “Udokan” are located on the border of the zones II and IV on the zoning map of the Russian Federation for the snow load (BC 20.13330.2016). Snow measurements were not carried out at the construction site and nearby territories.

According to the authors [1], the use of the altitude coefficient recommended by the BC 20.13330.2016 for the altitudes of 1000 m and more for the territory under consideration can lead to significant errors. In addition, this coefficient, as shown in [1, 2], will vary with height.

**Materials and methods**

In [1], the distribution of precipitation was obtained depending on the height for the territory under consideration. Based on them, it is proposed to use the equation in the calculations of the snow cover weight on 1 m$^2$ horizontal ground surface (1 time in 25 years):

$$ S = 81 \ln(H) - 457, $$

where $S$ kg/m$^2$, $H$ – defines height, m. abs. The results of calculating snow load using this expression are shown in Table 1.

In accordance with the Appendix E of BC 20.13330.2016, the facilities design territory belongs to the II district (mountainous poorly studied region). For the mountain regions, the snow load expression (BC 20.13330.2016, Appendix E) depends on the height in the form:

$$ S_g(h) = S_g + k_h(h - 500), $$

where $k_h$ by the Table E, is equal to 0.002, $S_g = 1.0$ kPa.

Table 1 shows the values of the snow cover weight on 1 m$^2$ the ground surface according to the equation (1) adopted in [1] and the normative snow cover weight on 1 m$^2$ the horizontal ground surface $S_g$, kPa according to BC 20.13330.2016.

As it can be seen from Table 1 in the values of the snow cover weight on 1 m$^2$ according to the data of [1] and the values calculated by BC 20.13330.2016, there are significant discrepancies from 200% at the altitudes of 600 m and up to 250% at the altitudes of 2000 m above the sea level. Such a discrepancy in the values of the snow cover weight according to the weather stations obtained in [1] and according to the BC is due to an incorrect value in the BC coefficient $k_h$ for this territory. The difference in the snow cover weight by 1 m$^2$ according to [1] and calculated according to BC 20.13330.2016 is also possibly caused by the high-altitude location of the weather stations used in [1].

According to BC 20.13330.2016, the average of the water supply’s annual maximums (snow load) is used as a normative parameter of the snow loads on structures – $S$ mm (kg/m$^2$). According to this indicator, the territory flat part zoning of the former USSR (the snow regions map M 1:15 000 000) was carried out with the allocation of mountain areas as unexplored, which include the territory of the creation of the “Udokan” mining and metallurgical complex.

**Table 1.** The value of the snow cover weight on 1 m$^2$ ground surface [1], kPa and the snow cover standard weight on 1 m$^2$ the horizontal ground surface $S_g$, kPa, according to BC 20.13330.2016.

| Height, [m] | Snow cover weights on 1 m$^2$, [kPa] according to the expression (1) | $S_g$, [kPa] (BC 20.13330.2016) |
|------------|-------------------------------------------------|---------------------------|
|            |                                                 |                           |
It is necessary to take into account the fact that for the calculations according to the formula (2), the author of BC 20.13330.2016 proposed a linear dependence, in the calculations the snow load standard value depending on the regions is used.

The values $K_h$ significantly differ both for the adjacent territories, for example, 7.5 times between the territories of the Stavropol Territory and Adygea, and in the snow regions. Evenki Autonomous Okrug and Kemerovo Region in VI snow region, difference in ratios $K_h$ is 6.8 times.

In this work, to analyze the dependence of the change in the estimated water supply in the snow cover with height, we used the series of the annual maximums of the water supply in the snow cover obtained as a result of the snow-measuring route observations at the weather stations Chara, Kalakan, Sredniy Kalar, Bolshaya Leprinda, Katugino, Moklakan (see. Table 2).

**Table 2.** The observations series at the weather stations.

| Weather stations       | Length of used row, [year] | The height of the weather station above the sea level, [m] |
|------------------------|----------------------------|----------------------------------------------------------|
| Chara                  | 51                         | 709                                                      |
| Kalakan                | 47                         | 612                                                      |
| Sredniy Kalar          | 49                         | 748                                                      |
| Bolshaya Leprinda      | 38                         | 998                                                      |
| Katugino               | 23                         | 990                                                      |
| Moclacan               | 17                         | 708                                                      |
| Naminga                | 11                         | 1400                                                     |
| Udokan                 | 12                         | 1600                                                     |

The data of 4% and 2% coverage at the weather stations Chara, Kalakan, Sredniy Kalar, Bolshaya Leprinda, Katugino, Moklakan was received from NPK Atmosphere (see Table 3). Based on these data, the values of the water reserve of the snow cover at altitudes of 1400 and 1600 m, 4% and 2% of the supply were calculated.

**Table 3.** The water supply estimated values, possible once every 25 years at the weather stations.

| Weather stations       | The estimated water supply in the snow cover, possible once every 25 years, [mm] | The height of the weather station above the sea level, [m] |
|------------------------|---------------------------------------------------------------------------------|----------------------------------------------------------|
| Chara                  | 71.6                                                                            | 709                                                      |
| Kalakan                | 73.9                                                                            | 612                                                      |
| Sredniy Kalar          | 60.0                                                                            | 748                                                      |
| Bolshaya Leprinda      | 116.2                                                                           | 998                                                      |
| Katugino               | 99.0                                                                            | 990                                                      |
| Moclacan               | 85.8                                                                            | 708                                                      |
| Naminga                | 174.0                                                                           | 1400                                                     |
| Udokan                 | 213.0                                                                           | 1600                                                     |
Discussions and Results

As a result of the initial data processing, the snow cover water reserve values were obtained with a number of standard supplies at the Naming and Udokan weather stations.

According to the Naming meteorological station, the calculated values of the snow cover water reserve of 2% of the supply is 178 mm, the value of the snow cover water supply of 4% of the supply is 174 mm.

According to the Udokan meteorological station, the estimated values of the snow cover water reserve of 2% of the coverage are 225 mm, the value of the snow cover water reserve of 4% of the coverage is 213 mm.

Depending on the slopes’ exposure, the snow thickness (snow reserve) with a height of up to 3,000 m above the sea level increases linearly [3, 4].

Based on this, extrapolation upwards with data on precipitation in the altitude range 612–1600 m to unexplored 2,000 m based on the long-term observations at the weather stations provided by SPC Atmosfera [5] and the Trans-Baikal Central Office for Hydrometeorology and Environmental Monitoring, in the form of the snow cover weight linear approximation was performed.

Taking the increase in snow thickness with height in the mountains into consideration, a linear relationship \( S \) is used with a height in the form:

\[
S = \frac{S_2 - S_1}{H_2 - H_1} H + \frac{S_1 H_2 - S_2 H_1}{H_2 - H_1},
\]

(3)

where \( S_1 \) and \( S_2 \) are the values of the snow cover normative weight on 1 m\(^2\) ground’s surface at the heights \( H_1 \) and \( H_2 \) above the sea level; \( S \) is the snow cover normative weight value on 1 m\(^2\) ground surface at the height \( H \) above the sea level. Therefore, the aforementioned high-altitude interpolation of the snow cover weight on the territory of the “Udokan” MMEG is quite justified.

According to the weather stations located at different altitudes above the sea level (see. Table 3) Chara, Kalakan, Sredniy Kalar, Bolshaya Leprinda, Katugino, Moklakan, Naminga, Udokan, a regression linear model of the water supply dependence in the snow cover (mm) on the height above the sea level (m) is constructed:

\[
Y = a x + b,
\]

(4)

where \( a \) and \( b \) are the equation coefficients (4).

We have chosen the above-mentioned weather stations as the most representative for the territory under consideration.

The main calculation method for finding the equation coefficients (4) is the least squares method (LSM). The equation coefficients (4) are determined using the built-in function of the Excel LINEYN worksheet, which calculates not only the coefficients’ values, but also determines the errors of their calculation, Fisher statistics and the determination coefficient of the model \( R^2 \), etc. The statistical significance of the model \( R^2 \) determination coefficient, therefore, the reliability of determining the coefficients (F\( \text{fact} - \text{test} \)).

In our calculations, Fisher’s statistics were 38.9. Based on the calculations and analysis, the expression (4) takes the form:

\[
Y = 0,1508 x - 34,096
\]

(5)

From the equation (5) it follows that with an increase in height above the sea level by 1 m, the water supply in the snow cover increases by about 0.1 mm (see Figure 1). The trend is statistically significant, the coefficient of determination is: \( R^2 = 94,45\% \).
From the equation (5) it follows that:
\[
S = 0.0015H - 0.34, \quad \text{(6)}
\]
where \(H\) denotes height, m.

The calculation results according to the formulas (1) and (6) are shown in Table 4.

Table 4. The estimated snow cover weight on 1 m² ground, [kPa].

| Heights (m) | Calculation according to the formula (1) [1], [kPa] | Calculation according to the formula (6), [kPa], once in 25 years | Calculation by the formula (8), [kPa], once in 50 years |
|------------|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 600        | 0.60                                          | 0.56                                            | 0.658                                           |
| 800        | 0.86                                          | 0.86                                            | 0.95                                            |
| 1000       | 1.02                                          | 1.16                                            | 1.24                                            |
| 1200       | 1.18                                          | 1.46                                            | 1.53                                            |
| 1400       | 1.26                                          | 1.76                                            | 1.826                                           |
| 1600       | 1.42                                          | 2.06                                            | 2.118                                           |
| 1800       | 1.50                                          | 2.36                                            | 2.81                                            |
| 2000       | 1.59                                          | 2.66                                            | 2.7                                             |

As it can be seen from Table 4, the snow cover weight ground value on 1 m² according to the formulas (1) and (6) up to the heights of 1200 m practically coincide. From 1400 m to 2000 m, the difference between the snow cover weight values per 1 m² according to the formulas (1) and (6) increases to 1 kPa. At an altitude of 1600 m, the difference is 0.64 kPa.

Table 5 presents the water reserves’ estimated values in the snow cover possible once every 50 years at selected the weather stations of the Trans-Baikal Territory, the Republic of Buryatia and the Amur Region.

Table 5. The estimated values of the water supply in the snow cover, possible once every 50 years at the weather stations
According to the weather stations located at different altitudes above the sea level (see Table 6) Chara, Kalakan, Sredniy Kalar, Bolshaya Leprinda, Katugino, Moklakan, Naminga, Udokan a regression linear model of the dependence of the water supply in the snow cover (mm) on the height above the sea level (m), possible once every 50 years is built (see Fig. 2):

\[
Y = 0.1464x - 21,859
\]  

(7)

From the equation (7) it follows that the snow cover weight of 2% coverage is:

\[
S = 0.00146H - 0.218
\]  

(8)

where \(H\) denotes height, m. The calculation results according to the formula (8) are shown in Figure 2.

![Figure 2. The estimated dependence of the water supply in the snow cover on the altitude (possible once every 50 years)](image_url)

For the design decisions on the territory of the “Udokan” Mining and Metallurgical Enterprises Group, the snow cover weight is 1 m² the ground surface is determined according to the snow measurements at the nearest weather stations. Its values depending on height and supply are presented in Table 6.

**Table 6.** The snow cover weight value per 1 m² ground (kPa) at various heights N (m) and supply

| Heights, [m] | 1 time in 25 years, [kPa] | 1 time in 50 years, [kPa] |
|--------------|---------------------------|---------------------------|
| 600          | 0.56                      | 0.658                     |
| 800          | 0.86                      | 0.95                      |
Summary
A regression linear model of the water supply dependence in the snow cover (mm) on the height above the sea level (m) is constructed in the form of a linear relationship.

From the obtained equation it follows that with an increase in height above the sea level by 1 m, the water supply in the snow cover increases by 0.1 mm. The trend is statistically significant, the coefficient of determination is: \( R^2 = 94.45\% \).

The calculated values of the snow cover weight per 1 m² of the various coverage ground surface are obtained. Its value at an altitude of 1600 m above the sea level is 2.06 kPa at 4% supply and 2.12 kPa at 2% supply.

References
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