New Digital Snow Load Map for the Area of the Czech Republic

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Abstract: - Transition from national to European standards for reliability assessment of structures is connected with many problems in the Czech Republic. One of them is an expressive increase in design values of climatic actions, mainly of snow and wind loads. Higher design values of snow and wind loads increase the price of the structure. In this paper, special attention is focused on the new digital ground snow load map of the Czech Republic that was developed in cooperation between VSB-Technical University Ostrava and Czech Hydrometeorological Institute.

Key-Words: - snow, reliability of structures, snow load, map, MWLR, probabilistic methods

1 Introduction
Snow is one of the most important natural hazards that may affect the reliability of building structures [1, 2, 3]. When calculating the snow load on the roof, it is necessary to have the basic information about the value of snow load on the ground in the building locality. For this reason, special maps given in relevant codes are used [4]. A new-designed digital ground snow load map of the Czech Republic is introduced in this paper. The database for the map was created in cooperation with the Czech Hydrometeorological Institute. Total area of the Czech Republic is divided in the sections of size 100 x 100 m. The database is prepared for practical design of structures based either on partial factors method (traditional design) [5] or on probabilistic reliability assessment methods [6]. Several data are given for each section 100 x 100 m: (a) characteristic value of the ground snow load $s_k$ with a return period of 50 years, (b) statistical parameters of annual maximum ground snow load – mean value, standard deviation and skewness, (c) sorted ground snow load history – so called load duration curves.

2 MWLR Method
The following part of the paper briefly describes main principles of Multiple Weighted Linear Regression method (MWLR) that is used for calculation of snow characteristics in arbitrary place of the Czech Republic.

2.1 Interpolation methods
Different interpolation methods are used for surface processing of data in Geographical Information System (GIS). These interpolation methods can be generally divided in simple methods (IDW, Spline, Kriging) and in methods based on linear regression between the measured climatological data (temperature, rainfall, snow height, snow water equivalent ...) and the altitude of the climatological station. These methods based on local linear regression are mainly applied at Czech Hydrometeorological Institute (CHMI).

The methods based on linear regression calculate for every nodal point (grid point) regression parameters from climatological stations lying in the defined surroundings of the nodal point. The calculation of regression parameters is based on the least-squares method. Grid layers are created from the calculated regression parameters according to the selected interpolation method (IDW, Kriging) and finally the overall distribution of searched quantity (snow water equivalent) is calculated using selected mathematical equation and map algebra.

Multiple Weighted Linear Regression method (MWLR) is used for development of the new digital ground snow load map of Czech Republic [7]. The MWLR specifies the characteristics of snow water equivalent in arbitrary point of investigated area (Czech Republic) depending on the altitude, slope gradient, slope orientation and convexity whereas digital ground model of the Czech Republic and data from 800 climatological stations and 100
locations of fieldwork measurement are used for the calculations.

2.2 Weight of the station
For every grid point of digital ground model most suitable climatological stations should be selected (similar ground characteristics, close distance to investigated point) that are qualified by the weight of the station.

2.2.1 Resulting weight of the station
Resulting weight of every climatological station (related to the investigated grid point) is calculated using the following equation:

$$\text{W} = w_h \cdot W_h + w_v \cdot W_v + w_a \cdot W_a + w_c \cdot W_c ,$$

where:
- $W_h$ is the weight of horizontal distance between the grid point and given station;
- $W_v$ is the weight of vertical distance between the grid point and given station;
- $W_a$ is the weight of slope gradient and orientation between the grid point and given station;
- $W_c$ is the weight of slope convexity between the grid point and given station;
- $w_h$, $w_v$, $w_a$, $w_c$ are selectable coefficients ($w_h + w_v + w_a + w_c = 1.0$).

2.2.2 Weight of horizontal distance
Generally, the station that is more close to the grid point under investigation has a higher weight $W_h$. The following equation is applied:

$$W_h = \frac{C1}{(C1+h^{C2})} ,$$  \hspace{1cm} (2)

where:
- $h$ (km) is horizontal distance between the station and grid point under investigation;
- $C1$ and $C2$ are selectable constants.

2.2.3 Weight of vertical distance
Generally, the station that has less difference in the altitude from the grid point under investigation will have higher weight $W_v$, defined by the equation:

$$W_v = \frac{C3}{(C3+v^{C4})} ,$$  \hspace{1cm} (3)

where
- $v$ (m) is vertical distance between the station and grid point under investigation;
- $C3$ and $C4$ are selectable constants.

2.2.4 Weight of slope gradient and orientation
Generally, the station that has similar orientation and slope gradient as the investigated grid point will have higher weight $W_a$. Similarity between the grid point and the station under investigation is expressed using the following equation:

$$W_a = \left[ 1 - \frac{\sqrt{(F_1)^2 + (F_2)^2}}{2} \right]^{-C5} ,$$  \hspace{1cm} (4)

where:
- $\alpha_1$ (deg) is slope gradient of the grid point under investigation;
- $\alpha_2$ (deg) is slope gradient of the station;
- $\beta_1$ (deg) is geographical azimuth of the grid point under investigation;
- $\beta_2$ (deg) is geographical azimuth of the station;
- $C5$ is selectable constant.

Slope gradient $\alpha$ in point (E) is calculated from the altitudes of 8 surrounding grid areas, see Figure 1. The value of slope gradient in point (E) is calculated using the following equations:

$$\alpha = \arctan \left[ \sqrt{\left( \frac{dz}{dx} \right)^2 + \left( \frac{dz}{dy} \right)^2} \right] \cdot 57,3$$

$$\frac{dz}{dx} = \frac{(C + 2 \cdot F + I) - (A + 2 \cdot D + G)}{8 \cdot Cx} ,$$ \hspace{1cm} (5)

$$\frac{dz}{dy} = \frac{(G + 2 \cdot H + I) - (A + 2 \cdot B + C)}{8 \cdot Cy}$$

where
- $\alpha$ (deg) is slope gradient;
- $A$, $B$, $C$, $D$, $E$, $F$, $G$, $H$, $I$ (m) are altitudes of surrounding grid areas;
- $Cx$ (m) is size of grid area in x-direction;
- $Cy$ (m) is size of grid area in y-direction.
Geographical azimuth $\beta$ in point (E) is also calculated from 8 surrounding grid areas in digital ground model, see Figure 1. The following equations are used:

$$\beta^* = 2 \cdot \arctan \left( \frac{dz}{dy} \right) \cdot \frac{\sqrt{(\frac{dz}{dx})^2 + (\frac{dz}{dy})^2 + (\frac{dz}{dx})}}{8},$$

which is defined by the following relation:

$$\frac{dz}{dx} = \frac{(C+2 \cdot F+1)-(A+2 \cdot D+G)}{8},$$

$$\frac{dz}{dy} = \frac{(G+2 \cdot H+I)-(A+2 \cdot B+C)}{8},$$

Modification of calculated $\beta^*$ to the azimuth direction (0 – 360 deg) is defined using the following relation:

If $\beta^* < 0$  
$$\beta = 90 - \beta^*$$

Else if $\beta^* > 90$  
$$\beta = 360 - \beta^* + 90,$$  (7)

Else  
$$\beta = 90 - \beta^*$$

For every grid point under investigation, it is necessary to calculate the weights $W$ of all climatological stations, though only the best $n$ stations with the highest resulting weights enter the regression analysis (10 selected stations were used in calculations for the digital ground snow load map of the Czech Republic). Regression coefficients related to the investigated grid point are calculated from the selected stations using the least-squares method. Finally, the searched quantity (snow water equivalent) of grid point under investigation is calculated upon its altitude from digital ground model.

Grid layers with step 100 m were calculated for the new digital ground snow load map of the Czech Republic, whereas weekly measurements of water snow equivalent are often incomplete and influenced by measurement errors, an equation was derived that could estimate the water snow equivalent from measured total snow cover height, new snow cover height, daily sum of precipitations and average relative air humidity [8].

The following values are considered for the selectable coefficients and constants in MWLR (the values were calibrated depending on fieldwork measurements):

- $C1 = 100$
- $C2 = 2$
- $C3 = 100$
- $C4 = 5$
- $C5 = 1$
- $C6 = 100$
- $w_h = 0,50$
- $w_v = 0,00$
- $w_A = 0,25$
- $w_e = 0,25$

2.2.6 Determination of best stations

2.2.5 Weight of slope convexity

Generally, the station that has similar ground curvature as the grid point under investigation will have a higher weight $W_c$ defined by the following equation:

$$W_c = \left( \frac{1}{1 + |\kappa_1 - \kappa_2|} \right)^{C6},$$

where

- $\kappa_1$ is ground curvature of the grid point under investigation;
- $\kappa_2$ is ground curvature of the station;
- $C6$ is selectable constant.
3 Conception of the digital map

The new digital ground snow load map covers the area of the Czech Republic by the net 100 x 100 m. Needed snow characteristics were calculated for every square of the net using the MWLR method. Statistical data from the period 1962 – 2009 were used for filling the database. The map is available at www.snehovamapa.cz (see Figure 2).

Fig. 2 View on the map (www.snehovamapa.cz)

The map conception is such as to be user friendly. Snow characteristic of the selected location are obtained either by clicking on a virtual map or directly by entering the GPS coordinates. The digital map is applicable not only for the traditional analysis using partial factor method but also for the direct probabilistic assessment of structures [9]. The following data are given to every square 100 x 100 m:

(a) The first data is the characteristic value of snow load on the ground ($s_k$). The characteristic value is based upon the probability of 0.02 of its time-varying part being exceeded for a reference period of one year, see EN 1990 [5]. This is equivalent to a mean return period of 50 years for the time-varying part. The characteristic value ($s_k$) is applicable for common analysis using partial factor method given in Eurocodes.

(b) Statistical characteristics of annual maximum ground snow load (mean value $\mu$, standard deviation $\sigma$, variation coefficient $V$ and skewness $\alpha$) constitute the second group of data provided by the digital map. Arbitrary fractile can be derived from these statistical characteristics (including the characteristic value ($s_k$) defined in point (a)). The statistical characteristics can be used also for the direct probabilistic analysis according to EN 1990[5] and JCSS documents [6]. The suitable probabilistic distribution is the three-parametric lognormal distribution. Figure 3 shows distribution of annual maximum ground snow load in locality Frýdek-Místek.

(c) The sorted ground snow load history, so called load duration curves [1], is the next characteristic that is given to each section 100x100 m. The load duration curves are derived from data being measured during the whole year, i.e. including periods when the snow does not occur. The load duration curve is obtained by the ascending sort of the measured data. The most lasting value of ground snow load is $s = 0$. For example, the zero value of snow load is expected during 80% of structural service life considering the locality Frýdek-Místek, see Figure 4. Distribution function and corresponding histogram is very easy to derive from the load duration curve – the distribution function is an inverse function to the load duration curve.

3 Usage limitation of the map

The characteristic values of ground snow load ($s_k$) are mostly applicable in practical design based on partial factor method [5]. The ($s_k$) value listed in the output form of the digital map is derived from the statistical characteristics of annual maximum snow
load on condition of the three parametric lognormal probability distribution.

Statistical results of a processing of annual maximum water equivalents of snow peaks obtained for each climatological station show that mainly stations with little snow load occasionally experience the situation when one value of the annual peak significantly exceeds another values from the set of statistics. As an example can be used the climatological station of Horšovský Týn, where one value measured in 1970 significantly exceeds the other readings which, as per [10], has the character of extraordinary load - see Figure 5. In accordance with the ČSN EN 1991-1-3 standard it refers to, so called, exceptional conditions, namely an exceptional snowfall [4].

When designing building structures, special attention should be paid to possible exceptional situations, e.g. floods, snow, fire or undermining [11-14]. According to the National Annex to the ČSN EN 1991-1-3 standard [4], however, an exceptional snow load for the Czech Republic has not been considered. This discrepancy is partially offset by a minimum characteristic value of the snow load on the ground, which is under consideration for permanent and temporary proposal situations, which is for the first snow field equal to: 

\[ s_k = 0.7 \text{ kN/m}^2 \]

The digital map of the ground snow load for areas with a minor snow load often shows the characteristic value of the snow load \( (s_k) \), which is lower than 0.7 kN/m\(^2\) (the value for Horšovský Týn: \( s_k = 0.54 \text{ kN/m}^2 \)) – see Figure 5, and thus increases the risk that in the event of an exceptional snow fall the construction designed for a low snow load value will not be sufficiently reliable. It is therefore recommended to consider the minimum characteristic value of the snow load on the ground \( s_k = 0.7 \text{ kN/m}^2 \).

### 4 Conclusion

The new digital ground snow load map for the area of the Czech Republic was introduced in this paper. The digital map provides detailed snow characteristics for arbitrary locality in the Czech Republic.

For practical design of structures, the characteristic value of snow load on the ground \( (s_k) \) is the most important data provided by the map. It results from the comparison of selected locations in the Czech Republic, see [15], that the values of \( (s_k) \) determined from the new digital map often differ from the values determined from the printed map given in ČSN EN 1991-1-3, whereas the values provided by the digital map are in most cases lower.

It is, in particular, the price of new designed lightweight roof structures that could be favorably influenced by lower values of snow load [16]. Assessment of existing structures designed according to the former national standards (not in force anymore) could be complicated by higher values of snow load required by Eurocodes. The differences are significant mainly in the middle and higher snow regions. Lower values of snow load determined from the digital map could help to solve this problem. It is important to emphasize that the characteristic value of snow load on the ground \( (s_k) \) provided by the new digital map is fully in agreement with the definition of characteristic value given in EN 1990.

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