
Vít KRIVÝ¹, Martin STRÍŽ²**DIGITAL GROUND SNOW LOAD MAP FOR THE AREA OF THE CZECH REPUBLIC****DIGITÁLNÍ MAPA ZATÍŽENÍ SNĚHEM NA ZEMI PRO ÚZEMÍ ČESKÉ REPUBLIKY****Abstract**

The paper deals with the problems of design and reliability assessment of roof structural elements exposed to the effects of snow load. A new digital ground snow load map of the Czech Republic is introduced in this paper. This digital map provides to structural designers detailed information about the characteristics of snow load on the ground for arbitrary selected locality in the Czech Republic.

Abstrakt

Článek se zabývá problematikou návrhu a posudku spolehlivosti nosných prvků střešních konstrukcí vystavených účinkům zatížení sněhem. V příspěvku je představena nová digitální mapa zatížení sněhem na zemi pro území České republiky. Nová sněhová mapa poskytuje projektantům detailní informace o charakteristikách zatížení sněhem na zemi v libovolné lokalitě na území České republiky.

Klíčová slova

Zatížení sněhem, MWLR, mapa, konstrukce, posudek únosnosti, posudek použitelnosti.

Keywords

Snow load, MWLR, map, steel structure, safety assessment, serviceability assessment.

1 INTRODUCTION

Transition from national to European standards for reliability assessment of structures (so called Eurocodes) 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 loads may affect the economics of roof structural elements design. Lightweight steel and timber roofs are mostly influenced. The assessment of existing structures designed in agreement with national standards could be also complicated due to higher design values of snow loads according to Eurocodes.

Non-negligible economic savings could be achieved by applying some improvements to the reliability assessment procedures proposed in the European standards. The first possibility is improvement (refinement) of European ground snow load maps given in EN 1991-1-3, the second one is the application of more appropriate probabilistic-based design methods if compared to the traditional partial factors method proposed in Eurocodes.

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A new-designed digital ground snow load map of 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) or on probabilistic reliability assessment methods. 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 MULTIPLE WEIGHTED LINEAR REGRESSION 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 hydrometeorological data (temperature, rainfall, snow height, snow water equivalent ...) and the altitude of the hydrometeorological 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 hydrometeorological 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. 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 hydrometeorological 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 hydrometeorological stations should be selected (similar ground characteristics, close distance to investigated point) that are qualified by the weight of the station.

(a) Weight of the station

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

$$W = w_h \cdot W_h + w_v \cdot W_v + w_s \cdot W_a + w_c \cdot W_c \quad (1)$$

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_s, w_c are selectable coefficients ($w_h + w_v + w_s + w_c = 1,0$).

(b) 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:

$$W_h = \frac{C1}{(C1 + h^{C2})} \quad (2)$$

where:

h is horizontal distance between the station and grid point under investigation [km],

$C1$ and $C2$ are selectable constants.

(c) 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:

$$W_v = \frac{C3}{(C3 + v^{C4})} \quad (3)$$

where:

v is vertical distance between the station and grid point under investigation [m],

$C3$ and $C4$ are selectable constants.

(d) 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:

$$W_A = \left[1 - \frac{\sqrt{(F_1)^2 + (F_2)^2}}{2} \right]^{C5} \quad (4)$$

$$F_1 = (\sin \alpha_1 \cdot \cos \beta_1) - (\sin \alpha_2 \cdot \cos \beta_2)$$

$$F_2 = (\sin \alpha_1 \cdot \sin \beta_1) - (\sin \alpha_2 \cdot \sin \beta_2)$$

where:

α_1 is slope gradient of the grid point under investigation [deg],

α_2 is slope gradient of the station [deg],

β_1 is geographical azimuth of the grid point under investigation [deg],

β_2 is geographical azimuth of the station [deg],

$C5$ is selectable constant.

Slope gradient α 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:

$$\alpha = \arctan \left[\sqrt{\left(\frac{dz}{dx} \right)^2 + \left(\frac{dz}{dy} \right)^2} \right] \cdot 57,3 \quad (5)$$

$$\frac{dz}{dx} = \frac{(C + 2 \cdot F + I) - (A + 2 \cdot D + G)}{8 \cdot Cx}; \quad \frac{dz}{dy} = \frac{(G + 2 \cdot H + I) - (A + 2 \cdot B + C)}{8 \cdot Cy}$$

where:

α is slope gradient [deg],

$A, B, C, D, E, F, G, H, I$ are altitudes of surrounding grid areas [m],

C_x is size of grid area in x-direction [m],

C_y is size of grid area in y-direction [m].

Geographical azimuth β in point (E) is also calculated from 8 surrounding grid areas in digital ground model, see Figure 1. The following equations are used:

$$\beta^* = 2 \cdot \arctan \left[\frac{\frac{dz}{dy}}{\sqrt{\left(\frac{dz}{dx}\right)^2 + \left(\frac{dz}{dy}\right)^2} + \frac{dz}{dx}} \right] \cdot 57,3 \quad (6)$$

$$\frac{dz}{dx} = -\frac{(C + 2 \cdot F + I) - (A + 2 \cdot D + G)}{8}; \quad \frac{dz}{dy} = \frac{(G + 2 \cdot H + I) - (A + 2 \cdot B + C)}{8}$$

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

$$\begin{array}{lll} \text{if} & \beta^* < 0 & \beta = 90 - \beta^* \\ \text{else if} & \beta^* > 90 & \beta = 360 - \beta^* + 90 \\ \text{else} & & \beta = 90 - \beta^* \end{array} \quad (7)$$

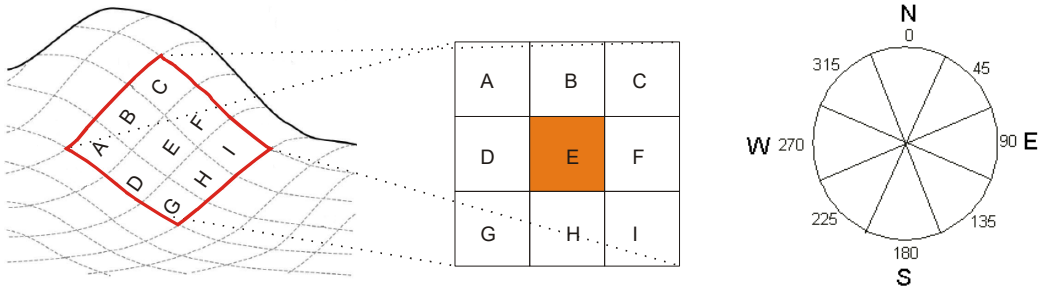


Figure 1: Calculation of slope gradient (left) and slope orientation (right)

(e) 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:

$$W_c = \left(\frac{1}{1 + |\kappa_1 - \kappa_2|} \right)^{C_6} \quad (8)$$

where:

κ_1 is ground curvature of the grid point under investigation,

κ_2 is ground curvature of the station,

C_6 is selectable constant.

(f) Determination of best stations

For every grid point under investigation, it is necessary to calculate resulting weights W of all hydrometeorological stations, though only the best n stations with highest resulting weights W enter the regression analysis (10 selected stations were used in calculations for 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.

(g) Grid layers used in new digital ground snow load map of the Czech Republic

Grid layers with step 100 m were calculated for the new digital ground snow load map of the Czech Republic, whereas weekly measurements (interval 1962 - 2009) of water snow equivalent from approximately 800 stations are used as input data. Because the sets of measured water snow equivalent are often incomplete and influenced by measurements 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. The application of this equation allows using the daily data (necessary mainly in lower altitudes where the weakly measurements do not need to identify maximum of water snow equivalent).

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

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

3 DIGITAL GROUND SNOW LOAD MAP FOR THE AREA OF THE CZECH REPUBLIC

3.1 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 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. 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. 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 μ , standard deviation σ , variation coefficient V and skewness α) 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 1900 and JCSS documents [1]. The suitable probabilistic distributions are the three-parametric lognormal distribution or Gumbel distribution. The Figure 2 shows distribution of annual maximum ground snow load using three-parametric lognormal distribution in locality Frýdek-Místek (GPS: 49°41'39.109"N, 18°21'53.888"E).

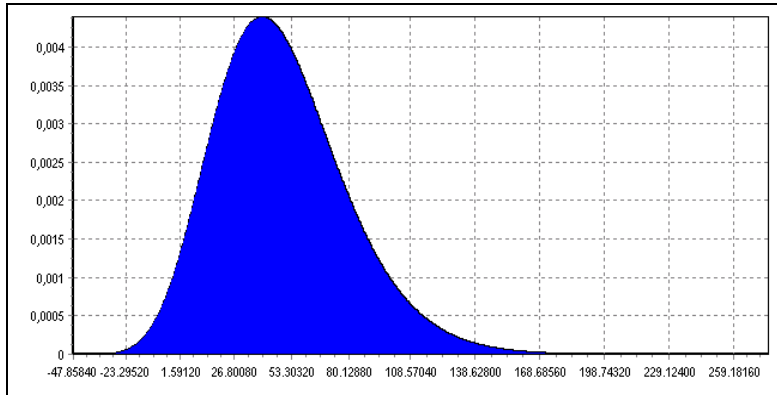


Figure 2: Annual maximum distribution for the locality Frýdek-Místek [2]

- (c) The sorted ground snow load history, so called load duration curves [3], 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 3. 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.

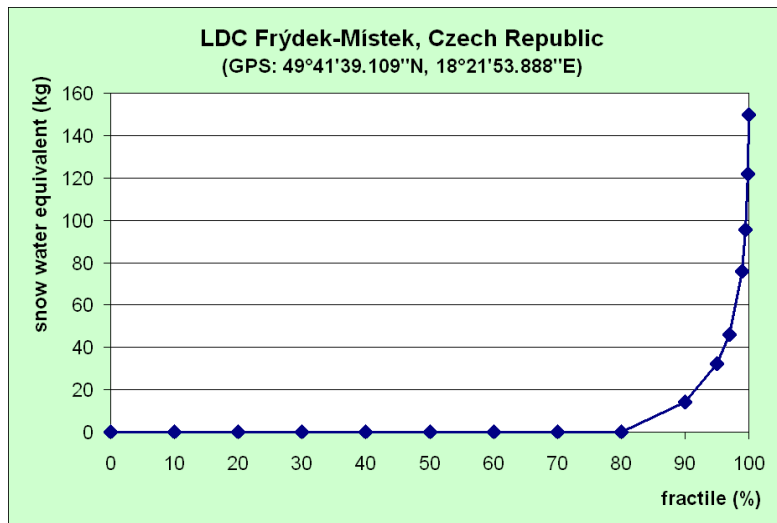


Figure 3: Load duration curve for the locality Frýdek-Místek

3.2 Characteristic values comparison of snow load on the ground (s_k) for selected localities

The characteristic values of ground snow load (s_k) are mostly applicable in practical design based on partial factor method. Table 1 compares the characteristic values (s_k) taken from the current ground snow load map of the Czech Republic given in ČSN EN 1991-1-3 and the characteristic values calculated for new digital map. The comparison is carried out for 28 selected locations in the area of the Czech Republic. GPS coordinates of the localities are given in [4].

Tab.1: Snow load on the ground according to the ČSN EN 1991-1-3 and new digital map

Locality	ČSN EN 1991-1-3 s_k (kg/m ²)	digital map s_k (kg/m ²)	difference (%)	difference (kg/m ²)
Praha (Prosek)	70	57.3	-18.2	-12.7
Plzeň (Bolevec)	70	64.4	-8.0	-5.6
Pardubice (Pardubičky)	70	50.6	-27.7	-19.4
Brno (Modřice)	70	62.4	-10.9	-7.6
Brno (Žabovřesky)	100	63.8	-36.2	-36.2
Ostrava (Hrabůvka)	100	92.7	-7.3	-7.3
Opava (Femont Opava)	100	83.4	-16.6	-16.6
Znojmo (Přímětice)	100	93.0	-7.0	-7.0
Havířov (Šumbark)	150	100.2	-33.2	-49.8
Valašské Meziříčí	150	144.0	-4.0	-6.0
FM (Místek)	150	107.7	-28.2	-42.3
FM (Frýdek)	150	129.1	-13.9	-20.9
Vsetín	200	158.6	-20.7	-41.4
Rožnov pod Radhoštěm	200	143.2	-28.4	-56.8
Jeseník	200	172.4	-13.8	-27.6
Frýdlant N/O (sever)	200	138.7	-30.6	-61.3
Frýdlant N/O (jih)	250	153.8	-38.5	-96.2
Jablunkov (Návsí)	250	167.4	-33.0	-82.6
Frenštát p/R (Trojanovice)	250	253.0	1.2	3.0
Nové Město na M. (jih)	250	210.1	-16.0	-39.9
Nové Město na M. (sever)	300	232.6	-22.5	-67.4
Rýmařov	300	301.2	0.4	1.2
Moravský Beroun	300	237.1	-21.0	-62.9
Vrbno p/P (západ)	300	222.6	-25.8	-77.4
Staré Město	400	312.2	-21.9	-87.8
Hanušovice	400	227.5	-43.1	-172.5
Ostravice (jih)	400	284.5	-28.9	-115.5
Mosty u Jablunkova	400	266.6	-33.4	-133.4

Table 1 shows significant differences between the characteristic values. Lower values taken from the digital map are more numerous. The comparison results shows that mainly the localities with higher snow load are often classed to higher snow region than necessary. The maximum difference is at the locality Hanušovice (-43 %; -172 kg/m²). The reasons leading to such differences between the both characteristic values are following:

- (a) The new digital snow map does not work with eight discrete snow regions as defined in the current ground snow load map of the Czech Republic given in ČSN EN 1991-1-3. The net with basic size 100 x 100 m covers the area of the Czech Republic so closely, that we can speak about continuous distribution of the ground snow load. The term “snow region” is irrelevant. The largest differences are at the localities lying closely behind the boundary of snow regions defined in the map given in ČSN EN 1991-1-3.
- (b) It is important to keep in mind that every snow region covers specific range of values, e.g. the third snow region covers the range 100 till 150 kg/m².
- (c) The local ground characteristics (valleys, solitary hills etc.) are not often taken into account in the printed map in ČSN EN 1991-1-3 because of its resolution limits.
- (d) More sophisticated model for calculating snow characteristics was applied to the digital map by comparing it with the map given in ČSN EN 1991-1-3. The influence of slope gradient, orientation and convexity were not considered when processing the map of snow regions for ČSN EN 1991-1-3. Suitable hydrometeorological stations for regression analysis were selected only upon their horizontal distance from investigated grid point.
- (e) Statistical data from the period 1962 – 2009 were used for the new digital map, data from the period 1962 – 2006 were used for the map in ČSN EN 1991-1-3.

4 CONCLUSIONS

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 28 selected locations (see Table 1) 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 steel and timber roof structures that could be favorably influenced by lower values of snow load. Assessment of existing structures designed according to the former national standards (already invalid) 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. The goal for authors of this paper is to add the digital map as National Annex to ČSN EN 1991-1-3. The digital map can serve as a more accurate alternative to the current printed map.

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