Practical Application of the New Digital Snow Load Map

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Abstract: -This paper turns attention to the collapse analysis of roof steel platform structure. Collapse occurred in the process of extreme winter conditions. Influence of snow conditions as well as subsequent effects are discussed in this paper. The application of a new digital ground snow load map for the area of the Czech Republic is introduced.

Key-Words: - snow, snow load, map, collapse analysis, Eurocodes

1 Introduction

Extreme weather events, particularly a longer winter with high snow cover, which in recent years we are gradually getting used to, can appropriately test the reliability of exposed structures and reveal their possible shortcomings. On many occasions, however, subsequent accidents and defects are only attributed to extreme climatic conditions.

The paper describes and discusses the factors that must be considered when investigating the causes of the accident associated with the building at the time of extreme climatic conditions. Increased attention is paid to the precise determination of snow load. The problem is explained using the example of an accident on the stands roof of the football stadium (see Figure 1) [1].

Fig. 1 View of the collapsed roof of the football stadium

2 Collapsed stands

2.1 Description of collapse

The stands supporting steel structure of the roof of the football stadium collapsed in March 2005, when the weight of snow caused a deformation of the supporting structure of the stand roof lined with consoles so that the roof fell onto the stands' seating (see Figure 2).

A forensic examination of the collapse site was carried out during the gradual dismantling of the structure. The trapezoidal sheets of the roof structure have already been dismantled, and disassembled trapezoidal sheets were placed on temporary landfill while the gradual burning of distorted consoles of the supporting structure took place as well as their removal.

Fig. 2 View of the collapsed structure after dismantling of the coverings

Authors’ visit to the accident site showed that the collapse was caused by swelling and subsequent plastic deformation of steel uprights of the welded I-girder at the connection of the stands’ girders lined with consoles [2, 3] – see Figure 3 and 4.

Fig. 3 Detail of the damaged joint in the part of structure with covering

Fig. 4 Detail of the damaged joint in the part of structure without covering

2.2 Structural design of stands

Steel structure of roofed stand is based on the original documentation from the manufacturer created in a longitudinal direction by a number of welded transverse T-frames anchored to the foundations at a longitudinal spacing of 6.75 m. An eccentric longitudinal continuous bracing is performed with vertical steel elements in the "A" shape on the ends of the shorter consoles of the welded frames. In the transverse direction, these vertical elements subsequently complete the transverse I-frames and co-create the transverse three-joint bond. At the roof level, the frames are connected by steel purlins and completed by the steel roofing (trapezoidal sheets). In the fourth field in the roof plane there is transversal bracing, which builds on the vertical longitudinal bracing. Anchoring of the T-frame design is done in the plane of T-frames as joint and in the longitudinal direction as restrained (Figure 5). This restraint, however, is located in the area of the lowest stiffness of a graded profile of T-frame column, so from the static point of view it is a flexible restraint.

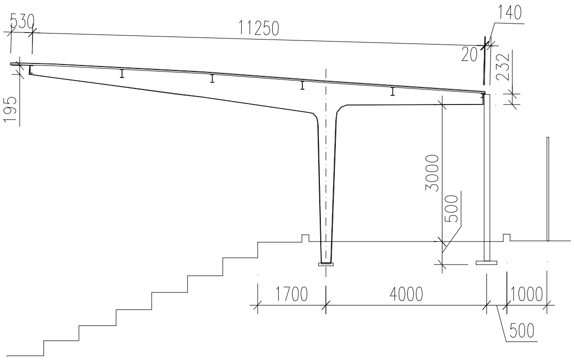

Fig. 5 Diagram of the stands’ supporting frame

2.3 Snow load at the time of the collapse

There is a climatological station of the Czech Hydrometeorological Institute (CHMI) near the collapsed structure. Based on CHMI data (Figure 6) it can be stated that at the time of the accident snow water equivalent in the structure area was approximately 135 mm, which corresponds to a snow load on the ground of 1.35 kNm^{-2}. The height of snow cover was approximately 60 to 70 cm. The data provided by CHMI were confirmed by simplified measurement on a site of the accident.

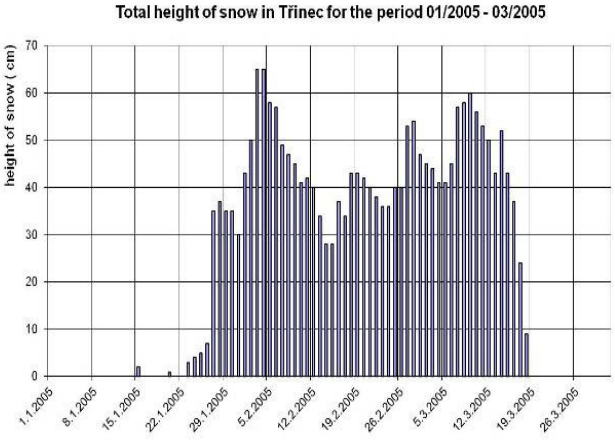

Fig. 6 History of snow height in the assessed locality

3 Determination of snow load according to standards

3.1 Comparison of national and European standards

Construction of the stands was designed in 1989. At that time European standards for the design and evaluation of structures, the so-called Eurocodes, were not yet available. The supporting structures were designed according to national standards CSN. Specifically, the snow load was determined in accordance with the national standard CSN 73 0035 [4]. Snow load for a location under consideration is determined by the relevant map of snow areas. The site assessed is in accordance with the map provided in the national standard CSN 73 0035 located in the second snow area (marked in blue – see Figure 7), for which the characteristic value of snow load on the ground $s_k = 0.7$ kNm^{-2} is defined. This value was proposed for the structure of the stands. It is important to note the characteristic value (s_k) is approximately equivalent to a median return of $T = 10$ years. The coefficient of reliability according to ČSN 73 0035 $\gamma_F = 1.4$, design value of load is equal to $s_d = 1.4 \times 0.7 = 0.98$ kNm^{-2}. A calculation shows that the current load value measured by CHMI $s = 1.35$ kNm^{-2} significantly exceeds the design value $s_d = 0.98$ kNm^{-2}, for which the construction was proposed. This fact together with the errors in the design solution of the structure caused the accident. Details of the errors in the design solutions are given in [1].

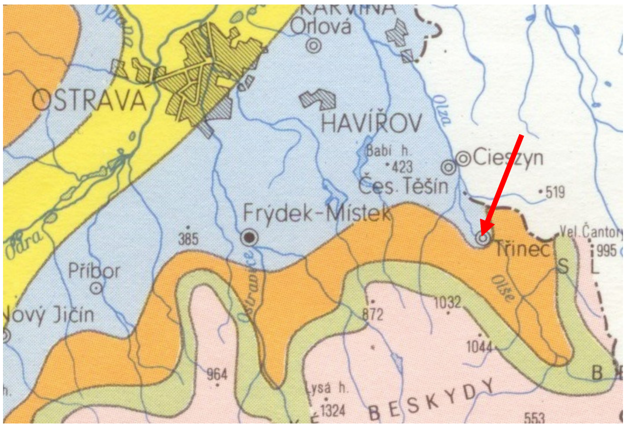

Fig. 7 Segment of the map of snow areas according to [4]

Since 2010, the supporting structure design is governed by European standards (Eurocodes). The definition of characteristic values of snow load in comparison with the national standard [4] is different. Characteristic value of (s_k) corresponds to a median return of T=50 years. There is a significant increase in the characteristic value which is in the assessed site equal to $s_k = 1.5$ kNm^{-2} (third snow area marked in yellow – see Figure 8). Also, the reliability coefficient, according to European standard [6] is considered higher, specifically $\gamma_F = 1.5$. Design value of snow load on the ground, according to European standard is $s_d = 1.5 \times 1.5 = 2{,}25$ kNm^{-2}. That means the design value (s_d) significantly exceeds the measured value of $s = 1.35$ kNm^{-2}.

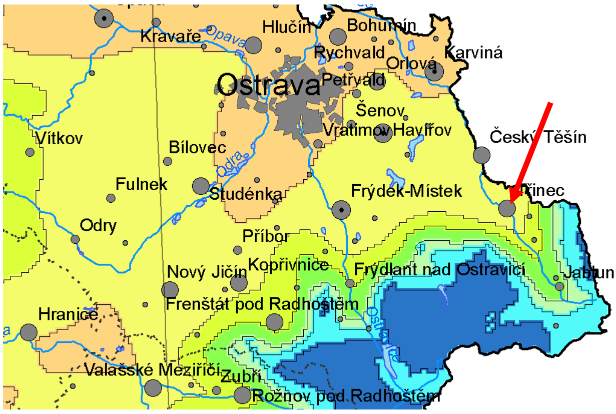

Fig. 8 Segment of the map of snow areas according to [6]

Note: National standards and European standards do not use the same terminology. In order to maintain clarity, terminology currently valid in European standards [5, 6] is simultaneously used for the original national standard CSN 73 0035 [4] in the presented paper.

3.2 Digital map of snow load

Since 2012, designers can, as an alternative to paper maps, use a new digital map of snow load on the ground (Figure 9) [7], which became part of the national annex to CSN EN 1991-1-3. The map is freely available on the www.snehovamapa.cz.

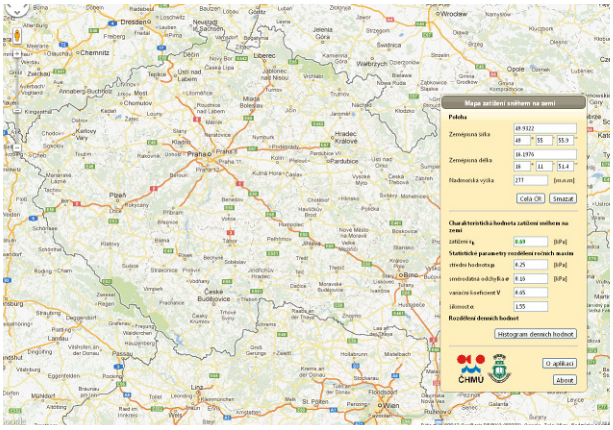

Fig. 9 View of the digital map (www.snehovamapa.cz)

A digital map was created based primarily on the desire of designers who wanted precise information on snow characteristics related to a location under consideration. One of the main complaints was the issue of precise determination of snow load in the foothill areas, for which the resolution is insufficient in existing printed map - see the Beskydy area shown in Figure 8.

A digital map of the snow load on the ground covers the Czech Republic by the ground plan network of basic size 100 x 100 m, while for each square of the network of 100 x 100 m the characteristics of snow were determined using the MWLR method [8]. To calculate the database of statistical data from the Czech Hydrometeorological Institute on the measured or derived water value of snow from the years 1961-2009 was used.

The concept map is chosen so that it is user-friendly. Snow characteristics for a given location can be obtained either by clicking on a virtual map, or by directly entering the GPS coordinates. The digital map can be used not only for traditional analysis of structures using the partial factor method [6], but also for direct probabilistic assessments of structures [9, 10, and 11].

When comparing the characteristic values of snow load on the ground s_k taken from a printed map of snow areas in the Czech Republic territory [7] with the values provided by the new digital map, significant differences can be seen at many sites. For most of the Czech Republic a digital map shows lower s_k values compared with a printed map. Causes leading to frequent differences between the maps are as follows:

a) The new digital map is not working with eight discrete areas of snow as does a printed map. The ground plan network of the basic size of 100 x 100 m covers the territory of the Czech Republic so densely that we can speak of nearly a continuous distribution of an assessed value. The biggest differences are at the sites located just beyond the snow areas defined in the printed map, where there is a sudden increase in the determination of snow load.

b) It should be noted that the third area of snow according to [5] covers the range of values from $s_k = 1.0$ to 1.5 kNm^{-2}. In the areas where the real value s_k is just above $s_k = 1.0$ kNm^{-2}, and thus the value $s_k = 1.5$ kNm^{-2} according to the printed map must be considered [5].

c) Resolution of the printed maps listed in [5] cannot be such that it captured the local characteristics of the assessed area more in detail (valleys, single hills, convexity or concavity of the ground etc.), which may significantly affect the characteristics of the snow.

d) Compared with the printed map referred to in [5] the digital map was designed using a more sophisticated computer model to compile data. Site terrain characteristics (slope, orientation, convexity) were not considered when creating the printed map, as it is using the method MWLR [8]. When designing the printed map, suitable climatological stations for regression analysis were selected only to meet the criterion of the shortest horizontal distance from the point under consideration.

Almost identical data from climatological stations have been used for processing of both maps. For the new digital map data from 1961 to 2009 was used, and for the printed map [5] data from the years 1961 to 2006.

The characteristic value of snow load on the ground is for the assessed location equal to $s_k = 1.44$ kNm^{-2} according to the digital map. It is worth noting that in the cadastral area of Trinec, in which the assessed location lies, the characteristic values of snow load on the ground move between $s_k = 1.20 – 1.60$ kNm^{-2}. Such detailed information cannot be obtained from printed maps.

4 Conclusion

Snow load is one of the major natural factors affecting the supporting structures [12, 13]. In this paper the example of construction of a collapsed roof of a football stadium stands demonstrated the importance of concise determination of snow load for the site under consideration.

The example of the accident shows the influence of the statistical definition to determine the snow load on the ground. A less strict definition of (s_k), according to a national standard [4] no longer valid, may in some cases lead to a significant underestimation of the structural design. This deficiency was removed by the introduction of new European standards for structural design, which compared with the national standard [4] introduced much stricter definition of characteristic values of snow load on the ground.

Currently, designers have available not only a printed map of snow areas in the Czech Republic, but also a new digital map of snow load. A map allows precise determination of characteristic values of snow load on the ground for a specific location under consideration. That means that the designer can design the structures based on the real values of snow load.

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