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Autor: Milcic, Vuk / Hemerich, Edo

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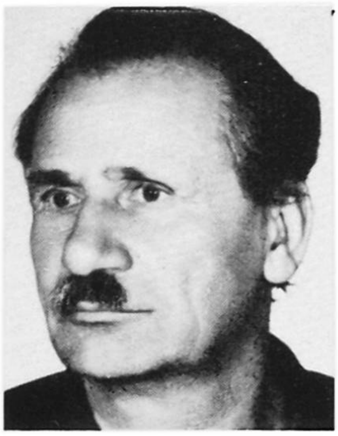
Determination of Design Snow Loads

Détermination de la charge de neige

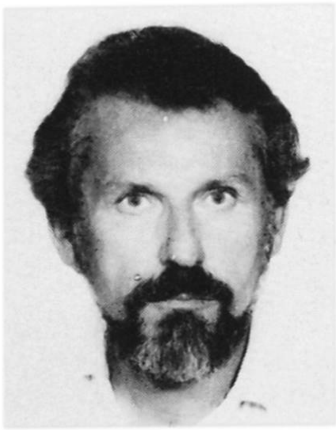
Rechnerische Bestimmung der Schneelast

Vuk MILCIC
Prof. Dr.
University of Zagreb
Zagreb, Yugoslavia



Vuk Milcic, born in 1921, graduated and received his Sc.D. from the University of Zagreb. As a chief designer, he was in charge of an office for designing metal structures. Since 1973 he has held a chair for metal structures. Now, as head of the Department of Metal and Wooden Structures at the Faculty of Civil Engineering, Univ. of Zagreb, his major concern is the safety of metal structures.

Edo HEMERICH
Senior Lecturer
University of Zagreb
Zagreb, Yugoslavia



Edo Hemerich, born in 1940, graduated at the University of Zagreb. Employed at the Faculty of Civil Engineering since 1966 in the Department of Metal and Wooden Structures, Univ. of Zagreb, as technical manager of the department.

SUMMARY
Based on probabilistic methods, level II, the reliability of steel structures under snow loading has been investigated and a simple formula developed for estimating the snow load. By this means a more uniform degree of safety can be achieved under this loading condition.

RESUME
Une formule simple est proposée pour la détermination de la charge de neige. Elle résulte de recherches sur la fiabilité des structures, au moyen de la méthode probabiliste. Un degré de sécurité suffisant et plus uniforme est ainsi obtenu pour le dimensionnement des structures.

ZUSAMMENFASSUNG
Eine vereinfachte Beziehung für die rechnerische Bestimmung der Schneelast wurde hergeleitet. Sie basiert auf Forschungsergebnissen über die Sicherheit von vorwiegend durch Schnee belasteten Stahlbauten und wurde unter Verwendung probabilistischer Methoden erhalten. Die vereinfachte Beziehung ergibt einen genügenden und einheitlicheren Sicherheitsfaktor auch bei Anwendung der üblichen Verfahren mit globalen Sicherheitskoeffizienten.

1. INTRODUCTION

The problems of non-uniform safety degree of our bearing structures become distinctly revealed where snow is a predominant load. From experience, we know that light structures (of lesser weight but also with little dead load in general) suffer damages due to snow load much more frequently than other structures under other and bigger loads. Such structures are most often steel roofs or halls but they can also be wooden or light reinforced concrete structures. Although, most often in such cases, a direct cause of a collapse or of a damage in general can be found out as a consequence of an error commited in designing or construction, yet it is significant that similar errors on other structures do not result in such drastic consequences. The safety degree of predominantly snow loaded structures is obviously too low.

The solution of the problem of making the safety degree of bearing structures uniform was embarked upon about ten years ago on a wide international scale.As a result of the work of various international associations, general principles on achieving reliability and safety respectively of all bearing structures regardless of the material, the type or the way of stressing [1] and [2] have already been set up. Therefore, in future procedures of structural design, by introducing, on the semiprobabilistic basis, partial safety coefficients, and by virtue of statistical data of characteristic values of actions, it will be possible to equalize the safety degree for all structures regardless of the predominance of the action. But, in so far applied deterministic procedure with the global safety coefficient and prescribed nominal calculation values for actions, this non-uniformity remains present almost always on the side of the lower safety in case of predominant snow load.

In the course of 1980, at the Faculty of Civil Engineering, University of Zagreb, a research project to determine the safety degree of predominantly snow loaded steel structures in SR Croatia, Yugoslavia, has been realized by establishing the reliability index by means of the level II probabilistic method in the Hasofer-Lind procedure [3]. Based on the analysis of the results, the conclusion was drawn that the safety degrees achieved at various locations were highly non-uniform, and considering ratio of the dead load to the snow load, almost always on the side of lower safety.

This statement prompted further research to find out the necessary calculation snow load by means of which even now the safety degree could be equalized in locations with regard to various statistical data about snowfall as well as with regard to different relations between the dead load and the snow load. As a result of the work and of the data obtained from the analysis of the reliability index of existing structures, a simple formula for the necessary calculation snow load has been found out in the structural designing procedure by currently standard method with the global safety coefficient.

2. BASIS FOR FORMULA DERIVATION

As a primary basis for the derivation of this formula, a linear equation of the ultimate limit state from the probabilistic procedure of the level II method was taken.

Taking into consideration only structures in which snow is a predominant load, only three basic variables as random values were chosen. These are resistance, dead load and variable live load.

Equation of ultimate limit state in the probabilistic level II is:

$$X_R^* - X_D^* - X_L^* = 0$$

Indexes: R ... structure resistance
D ... dead load
L ... variable live load (snow)

in wich

X_i ... any of the basic variables as random value (i=R,D,L) expressed as a force,

and its design value in checking point i.e. the one that, according to the Hasofer-Lind procedure, corresponds to the greatest probability of failure

$$X_i^* = m_i \cdot (1 - \alpha_i \cdot \beta \cdot V_i)$$

in which

m_i ... mean value of basic variable (i=R,D,L)

α_i ... sensitivity coefficient of basic variable (i=R,D,L)

V_i ... coefficient of variation of basic variable (i=R,D,L)

β ... reliability index, the value of which is chosen with regard to the adopted safety degree

In order to reduce this equation of ultimate limit state of the probabilistic level II to the probabilistic level I, it is necessary only to introduce

$$X_i^* = \gamma_i \cdot X_i^k \qquad \text{for } i = R,D,L$$

in which

X_i^k = ... nominal (characteristic) value of the basic variable from the deterministic procedure of design (i=R,D,L)

$$\gamma_i = \frac{m_i \cdot (1 - \alpha_i \cdot \beta \cdot V_i)}{X_i^k}$$ ... partial safety coefficient for the basic variable (i=R,D,L)

In the current deterministic procedure of the bearing capacity proof with the global safety coefficient the linear equation of ultimate limite state is as follows

$$X_R^k = \gamma_N \cdot (X_D^k + X_L^k)$$

in which

γ_N ... global safety coefficient is standardized in current deterministic design procedure

The equation of the ultimate limit state of probabilistic level I can be transformed into

$$X_R^k = \frac{\gamma_D}{\gamma_R} \cdot X_D^k + \frac{\gamma_L}{\gamma_R} \cdot X_L^k$$

if

$$\kappa = \frac{X_D^k}{X_L^k}$$

is inserted

$$X_R^k = \frac{\gamma_D}{\gamma_R} \cdot \kappa \cdot X_L^k + \frac{\gamma_L}{\gamma_R} \cdot X_L^k = X_L^k \cdot \left(\frac{\gamma_D}{\gamma_R} \cdot \kappa + \frac{\gamma_L}{\gamma_R}\right)$$

is obtained.

Formally, we reduce this equation to the form similar to the deterministic one

$$X_R^k = \gamma_N \cdot X_D^k - \gamma_N \cdot X_D^k + X_L^k \cdot \left(\frac{\gamma_D}{\gamma_R} \cdot \kappa + \frac{\gamma_L}{\gamma_R}\right)$$

$$X_R^k = \gamma_N \cdot X_D^k - \gamma_N \cdot \kappa \cdot X_L^k + X_L^k \cdot \left(\frac{\gamma_D}{\gamma_R} \cdot \kappa + \frac{\gamma_L}{\gamma_R}\right)$$

$$X_R^k = \gamma_N \cdot \left[X_D^k + X_L^k \cdot \underbrace{\left(\frac{\gamma_D}{\gamma_N \cdot \gamma_R} \cdot \kappa + \frac{\gamma_L}{\gamma_N \cdot \gamma_R} - \kappa\right)}_{\eta} \right]$$

which yields the final expression

$$X_R^k = \gamma_N \cdot (X_D^k + X_L^k \cdot \eta)$$

As is evident, if in the current equation of the ultimate limit state of the deterministic procedure only the corrected value of the predominant load (snow in our case) is introduced, the required safety degree of a structure can be obtained. This value for the correction coefficient is

$$\eta = \frac{\gamma_L}{\gamma_N \cdot \gamma_R} + \kappa \cdot \left(\frac{\gamma_D}{\gamma_N \cdot \gamma_R} - 1\right)$$

This means that the new calculation value for the predominant variable load (snow in our case) must be

$$X_o^k = \eta . X_L^k = \left[\frac{\gamma_L}{\gamma_N \cdot \gamma_R} + \kappa \cdot \left(\frac{\gamma_D}{\gamma_N \cdot \gamma_R} - 1\right)\right] \cdot X_L^k$$

By introducing the values for γ_L and for κ the general expression is obtained

$$X_o^k = \frac{m_L}{\gamma_N \cdot \gamma_R} (1 + \beta \cdot \alpha_L \cdot V_L) + X_D^k \cdot \left(\frac{\gamma_D}{\gamma_N \cdot \gamma_R} - 1\right) \quad .... \quad (1)$$

in which X_L^k value is eliminated.

3.FORMULA DERIVATION FOR SNOW

If the mentioned general expression (1) is applied to determine the necessary calculation snow load (X_o^k=S) in order to obtain a sufficient and uniform safety degree of a structure, a series of parameters must be determined in this formula. These are primarily the mean value (m_L) and the coefficient of variation (V_L) which refer to the snow load as a random variable connected to other variables through the sensitivity factor (α_L). Then the partial safety coefficient for resistance (γ_R) and for the dead load (γ_D) must be determined as well as the characteristic value for the dead load (X_D^k). It is also necessary to choose the safety degree of a structure by accepting a certain reliability index (β) and to introduce into the formula the global safety coefficient (γ_N) which is prescribed in the current deterministic procedure of structural design. This is a very large number of parameters and, generally, the determination of calculation snow load could be a very complex task. Fortunately, for most of these parameters some fixed values can be adopted. The analyses of results obtained in the research work mentioned in the introduction, showed that changes of some of the coefficients (γ_R, γ_D, α_L) run within very narrow limits: for γ_R from 1.09 to 1.14; for γ_D from 1.05 to 1.08 and for α_L from 0.805 to 0.899. Some fixed values such as the ones for γ_R=1.10; for γ_D=1.07 and for α_L=0.86 can be adopted so that this has almost not any substantial influence upon the value of the final result. For the global safety coefficient we can choose the fixed value of γ_N=1.5 which, in the current regulations, is the most frequently used safety coefficient for steel structures with which only snow can be a distinctly predominant load. The choice of reliability index, by means of which a sufficient safety degree is achieved, is a particular problem. The previously mentioned analyses of results of the research work showed that the uniformity of the safety degree for structures predominantly loaded with snow should be made on the value β =4.0, which generally meets the requirements for the ultimate limit state. As a characteristic value of the dead load there can be taken the nominal value of the covering usual with steel structures (X_D^k = G) and this possibly with two variants: as a light covering (i.e. G_1=300 N/mm^2) and as a heavy covering (i.e. G_2 = 1000 N/mm^2).

Therefore, the remaining problem is to determine, from statistical data about snowfall, the mean value of snow loads on a roof (m_L) as random values during the life period of a structure (n-years), and to find out the corresponding coefficient of variation (V_L) for this random value. This coefficient of variation is corrected, in order to use the Hasofer-Lind method, considering the reduction of the real distribution of the extreme snow load to the necessary normal distribution, according to the simplified Paloheimo-Hannus procedure (4).

If we know the maximum annual ground snow weight (Q_i) recorded for years (T=10 to 30 years), then we can calculate the mean value from

$$\overline{Q} = \frac{\sum Q_i}{T}$$

and also the standard deviation (s) from

$$s = \sqrt{\frac{\Sigma (Q_i - \overline{Q})^2}{T}}$$

We can possibly correct this standard deviation by way of one of the known procedures due to the relatively small number of members of the set Q_1.

On the usual assumption that the distribution of maximum annual snow weights follows the Type Ex-I, we can also calculate the mean value of the extreme snow weights ($\overline{Q}_n$) during the life period of a structure (n-years) from

$$\overline{Q}_n = \overline{Q} + \frac{\sqrt{6}}{\pi} .s \, . \ln (n)$$

and the coefficient of variation (V_n) from

$$V_n = \frac{s}{\bar{Q}_n} = \frac{s}{\bar{Q} + \frac{\sqrt{6}}{\pi} \cdot s \cdot \ln(n)}$$

For the snow load on a flat roof, it is necessary to reduce the ground snow weight with the empiric coefficient of 0.8 and so the mean value is obtained.

$$m_L = 0.8 \cdot \left(\bar{Q} + \frac{\sqrt{6}}{\pi} \cdot s \cdot \ln(n)\right) \quad (2)$$

The coeficient of variation (V_n), in order to reduce the distribution Type Ex-I to the normal distribution, should be reduced by means of

$$V_L = V_n \cdot \frac{\beta_{Ex-I}}{\beta_N} = \frac{s}{\bar{Q} + \frac{\sqrt{6}}{\pi} \cdot s \cdot \ln(n)} \cdot \frac{\beta_{Ex-I}}{\beta_N} \quad (3)$$

in which β_{Ex-I} is the reliability index of the Type Ex-I distribution for the same probability which corresponds to the β_N reliability index for the normal distribution.

It is also necessary to adopt a particular life period of a building, expressed in years. As warehouse and industrial halls with light steel bearing structures tend to be the most sensitive to the snow load, we can adopt their average life period which is about 30 years (n=30). To the already previously adopted reliability index $\beta = \beta_N = 4.0$, on the assumption of the same probability of failure, corresponds $\beta_{Ex-I} = 7.7$.

Therefore, determined are the values for all parameters by means of which a simple expression for calculation snow load ($X_o^k = S$) of bearing structures can be obtained from the equation (1).

4. FORMULA FOR CALCULATION SNOW LOAD

In the equation (1) it is necessary to replace m_L by the expression (2) and to introduce all the above chosen fixed values for parameters ($\gamma_N = 1.5$; $\gamma_R = 1.1$; $\gamma_D = 1.07$; $\alpha_L = 0.86$; $\beta = 4.0$; n=30) the nominal value ($X_D^k = G$) for the dead load so as to obtain a simple formula for the necessary calculation snow load ($X_o^k = S$) on a flat roof

$$S = 0.485 \cdot (\bar{Q} + 2.65 \cdot s) \cdot (1 + 3.44 \cdot V_L) - 0.35 \cdot G$$

The value for the corrected coefficient of variation (V_L) is obtained form (3) also by inserting the values for the fixed parameters (n=30; $\beta_{Ex-I} = 7.7$; $\beta_N = 4.0$)

$$V_L = \frac{1.925 \cdot s}{\bar{Q} + 2.65 \cdot s}$$

For the value of the dead load (G) it is sufficient to take only two extreme cases

$G = 300\ N/mm^2$ ..... light covering
$G = 1000\ N/mm^2$ ..... heavy covering

and in very extreme snow loads the dead load can be neglected (G=0).
From the statistical data about snowfall it is necessary to calculate.

$\overline{Q} = \frac{\sum Q_i}{T}$ ... mean value of recorded maximum (Q_i) annual ground snow loads (T is 10 to 30 years)

$s = \sqrt{\frac{\sum (Q_i - \overline{Q})^2}{T}}$ standard deviation of maximum annual ground snow loads

In the current deterministic design procedure with global coefficient of safety, most often by the allowable stress method, these values for the calculation snow load can be used not only for the predominantly snow loaded structures but for all structures, because these values are then always on the safe side and this does not have any influence upon the economy of a building.

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