DOI: 10.23968/2500-0055-2023-8-2-49-57

INFLUENCE OF THE PROBABILISTIC METHOD TO SUMMARIZE LOADS ON THE RELIABILITY AND MATERIAL CONSUMPTION OF BUILDING STRUCTURES

Dmitrii Kuligin*, Filipp Shkoliar

Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russia

*Corresponding author's e-mail: dmitrykul17@gmail.com

Abstract

Introduction. Load rates are one of the main factors affecting the assessment of the reliability of building structures. All loads are probabilistic in nature, but short-term loads are the most representative in terms of this study since they have the most stochastic nature compared to other types of loads. According to regulatory documents, the short-term loads on a building should be summarized based on their base return period — 50 years. Due to variety of design situations, it is impossible to optimally standardize calculation methods for all types of buildings, therefore, the return period of 50 years is taken for all types of buildings regardless of their required useful life, which in some cases may lead to an excessive safety margin. **Methods.** To summarize loads on the structural schemes of buildings, two methods are used: deterministic, which is based only on data from regulatory documents, and probabilistic, which takes into account the probabilistic nature of the origin of loads. Reliability is assessed by the limit state method and Rzhanitsyn method. **Results.** In a number of cases, the use of the probabilistic method when summarizing loads makes it possible to reduce the stiffness properties of sections by equating the period of return of probabilistic loads to the required useful life of the building. Thus, reliability is guaranteed not for 50 years (as in the deterministic method) but for the useful life of a building, and, as a result, the reliability of building structures is not reduced during the entire set period of their operation. This method made it possible to reduce the total weight of the frame of an industrial building by 3 %, and that of a small-sized building — by 27 %, which indicates a more rational application of the proposed method to small-sized building schemes, since in large schemes the gains from the reduced material consumption in structures will be neutralized by the consequences of their failure and the cost of equipment inside the building.

Keywords: reliability of building structures, safety characteristics, return period, limit state method

Introduction

In the design of buildings and structures, the reliability of building structures is one of the most important factors. On the one hand, it is necessary to ensure reliability, and on the other, not to neglect the economic component of construction. Factors affecting the reliability assessment include the types of buildings, the load rates, and the calculation methods. Yet, due to variety of design situations, it is impossible to optimally standardize calculation methods for building structures, which makes this research topic extremely relevant. There have been many studies applying mathematical modeling methods to reliability assessment problems (Perelmuter and Pichugin, 2014). However, one of the related issues is the low effectiveness of those methods resulting from insufficient input data, i.e., statistical information. This may cause erroneous results and lead to even higher margin than when using regulatory methods (Kurguzov et al., 2020). Therefore, if there is not enough statistical data for a comprehensive analysis of the structural schemes of buildings by probabilistic methods of calculation, it may make sense to apply probabilistic methods locally. Load rates have a key impact on the reliability of building structures, and their representation in the form of probabilistic models is one of the fundamental principles of the reliability theory (Spaethe, 1994). Thus, within this research, we will assess the application of the probabilistic method to summarize loads with regard to the reliability of building structures. For this purpose, we will consider snow and wind loads as the most variable types of loads. Based on comparative calculations for two structural schemes, we will assess the reliability of building structures with the application of the probabilistic and deterministic methods of calculation by the limit state method and Rzhanitsyn method.

Methods

For the analysis, we chose two structural schemes of buildings with different parameters to be used as examples to make comparative calculations of the reliability of building structures depending on the influence of various factors. The first structural scheme is large-sized, with an expected useful life of 20 years. An industrial building may serve as an example of its use. The second structural scheme is small-sized, with an expected useful life of 5 years. It can be used for construction trailers and various mobile buildings. Both frames are made of metal structures. The large-sized building is represented by a single-span building with a span of 30 m. The general view of its design model is given in Fig. 1a. All elements of the small-sized frame are made of metal profiles of square section (Fig. 1b). The height and width of the building — 3 m, the length of the building — 9 m (Fig. 1).

Load rates represent the main comparative factor in the calculations. During the research, we will use two methods to summarize those loads. The first one is the deterministic method based exclusively on Regulations SP 20.13330 “Loads and actions”. The second one is the probabilistic method, which takes into account the probabilistic nature of the loads. Let us consider in detail the probabilistic method of calculation for each type of load.

Snow load. According to Regulations SP 20.131330.2016, the regulatory value of the snow load on the horizontal surface of roofing shall be determined by the following equation:

$$S_0 = c_w \cdot c_t \cdot \mu \cdot S_g, \tag{1}$$

where: c_w — the coefficient that takes into account snow drifting from the roofing and depends on the type of terrain, the shape of the roofing, and the availability of protection from the direct effects of wind;

c_t — the thermal coefficient, which takes into account snow melting on cold roofs with high heat emissions;

μ — the roofing shape coefficient;

S_g — the regulatory value of the weight of the snow cover per 1 m^2 of the horizontal ground surface.

The S_g value is of the greatest interest for the research since it represents the maximum weight of the snow cover, being exceeded on average once every 50 years, which indicates the stochastic nature of this value. However, for buildings with a short required useful life, the 50-year return period suggested in the regulatory document may lead to an excessive safety margin. Therefore, it makes sense to take the S_g value for a period of time equal to the required useful life of buildings. This approach can have a significant impact on the material consumption of structures and, therefore, reduce the cost of construction (Bulanchik and Lalin, 2021).

For further calculations, we will use the analytical method of determining S_g. First of all, it is necessary to choose a distribution function for random variables. For snow and other weather loads, it is the Gumbel distribution that is used most often (Benjamin and Cornell, 2014; Nadolsky and Veryovka, 2018):

$$S_g = u - \frac{1}{a} \cdot \ln\left\{-\ln \Phi\left(S_g\right)\right\}, \tag{2}$$

where: $u = \mu - \frac{0.577}{a}$; $a = \frac{\pi}{\sigma \cdot \sqrt{6}}$;

μ — the mathematical expectation of the annual maxima;

σ — the standard deviation of the variable;

$\Phi\left(S_g\right)$ — the maxima distribution function.

$$\Phi\left(S_g\right) = 1 - \frac{1}{\mu_T}, \tag{3}$$

where: μ_T — the mathematical expectation of the probability period (the number of years under consideration).

Let us find the values of the snow cover weight for the application of loads to the considered building frames. For the industrial building, we adopt the design period of load return equal to 20 years, and for the small-sized building — equal to 5 years.

To determine the missing statistical values, we will use the equation to determine the reliability index, which is a characteristic representing a measure of reliability in Eurocodes (CEN, 2001):

$$\beta = \frac{S_g - \mu}{\sigma}. \tag{4}$$

Using Eq. (2), we obtain the weight of the snow cover:

$$S_g = u - \frac{1}{a} \cdot \ln\left\{-\ln\left(0.98\right)\right\} = u + \frac{3.9}{a}, \tag{5}$$

a) b)

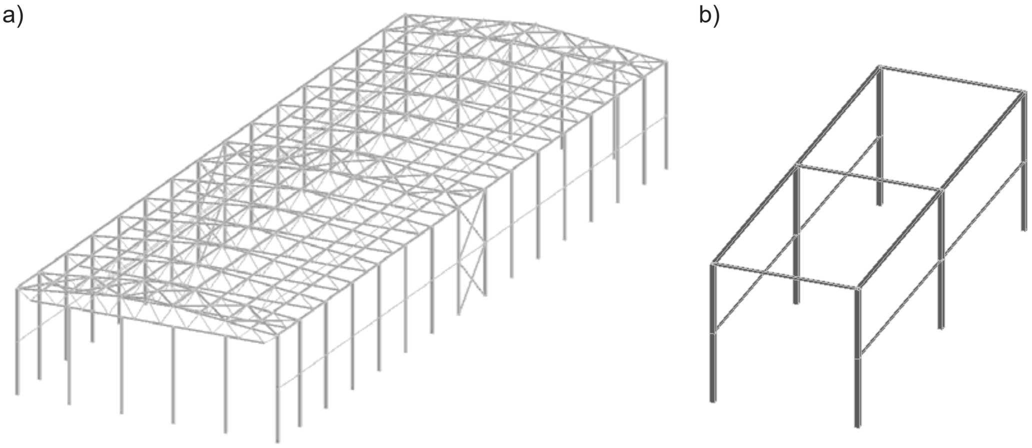

Fig. 1. Structural schemes of the buildings

Mathematical expectation and standard deviation:

$$\mu = u + \frac{0.577}{a}; \tag{6}$$

$$\sigma = \frac{\pi}{a \cdot \sqrt{6}} = \frac{1.282}{a}. \tag{7}$$

Then:

$$\beta = \frac{u + \frac{3.9}{a} - u + \frac{0.577}{a}}{\frac{1.282}{a}} = 2.59. \tag{8}$$

Let us express the standard deviation through the mathematical expectation and variation coefficient (which is approximately equal to 0.4 for show load):

$$\beta = \frac{S_g - \mu}{\mu \cdot f} = 2.59. \tag{9}$$

Thus:

$$S_g = \mu \cdot (1 + 2.59 \cdot f) = \mu \cdot (1 + 2.59 \cdot 0.4) = 2.036 \cdot \mu. \tag{10}$$

As a result, we obtain an expression where we can apply the weight of the snow cover from the regulatory documents and then find the mathematical expectation, and after that, the standard deviation of the value. For snow zone III (Saint Petersburg):

$$\mu = \frac{S_g}{2.036} = \frac{1.5}{2.036} = 0.74 \text{ kN/m}^2; \tag{11}$$

$$\sigma = \mu \cdot f = 0.74 \cdot 0.4 = 0.296 \text{ kN/m}^2. \tag{12}$$

Thus, we obtain all the parameters necessary to determine the values of the snow cover weight for different return periods. Let us substitute the obtained values in Eq. (2) for the 20-year and 5-year return periods, respectively:

$$S_{g20} = u - \frac{1}{a} \cdot \ln\{-\ln(0.95)\} = u + \frac{2.97}{a} = \\ = \mu + \frac{2.393 \cdot \sigma}{1.282} = 1.29 \text{ kN/m}^2; \tag{13}$$

$$S_{g5} = u - \frac{1}{a} \cdot \ln\{-\ln(0.8)\} = u + \frac{2.97}{a} = \\ = \mu + \frac{2.077 \cdot \sigma}{1.282} = 1.21 \text{ kN/m}^2. \tag{14}$$

Thus, when going from the 50-year return period to the 20-year return period, the weight of the snow cover decreased by 14 %, and when going from the 50-year return period to the 5-year return period, the weight of the snow cover decreased by 19 %.

Wind load. Wind load is also probabilistic. Numerous studies mathematically modeling wind effects have been conducted on this topic (Krasnoschekov and Zapoleva, 2015a; Makhinko and Makhinko, 2015; Pshenichkina et al., 2019). In addition to wind speed, which is more variable than the weight of the snow cover, wind direction should be also taken into account in the calculations. This provides more complex combinations of possible wind effects for calculation and analysis.

Wind pressure at height *z* is proportional to half the square of wind speed and air density (Vrouwenvelder, 1997):

$$w(z) = \frac{1}{2} \cdot \rho \cdot v(z)^2, \tag{15}$$

where: ρ — standard air density equal to 1.25 kg/m^3 according to the JCSS;

$v(z)$ — wind speed at height *z*, m/s.

In the out-of-use Construction Rules and Regulations SNiP 2.01.07-85, wind speed and standard wind pressure were traditionally linked by the following expression:

$$w(z) = 0.61 \cdot v_5^2, \tag{16}$$

where: v_5 — wind speed at a height of 10 meters, corresponding to the 10-minute averaging period, being exceeded on average once every 5 years, m/s.

In the latest regulatory documents, this expression was revised and modified according to Regulations SP 20.13330:

$$w(z) = 0.43 \cdot v_{50}^2. \tag{17}$$

In this expression, v_{50} is a value similar to wind speed v_5 in Eq. (16) but for a period not exceeding 50 years.

To estimate the stochastic component of wind load and determine the value of wind pressure relative to the return period equal to the useful life of a building, we will also use the Gumbel distribution as a function of probability distribution of random variables, but in a different form:

$$F(v) = \ln\{-\ln[-a(v-u)]\}. \tag{18}$$

In cases where there is insufficient data to determine the mathematical expectation of the values and their standard deviations, those can be expressed based on Eqs. (16) and (17).

For example, the regulatory value of wind pressure for wind zone II (Saint Petersburg) is 300 Pa. Thence, we can express v_5 and v_{50}:

$$v_5 = \sqrt{\frac{w}{0.61}} = \sqrt{\frac{300}{0.61}} = 22.18 \text{ m/s}; \tag{19}$$

$$v_{50} = \sqrt{\frac{w}{0.43}} = \sqrt{\frac{300}{0.43}} = 26.41 \text{ m/s}. \tag{20}$$

Let us compose a system of equations to determine the unknown statistical values. For this purpose, we will use the equation by Dubrovin and Semenov (2018) as the basis:

$$-\left[\frac{1.282 \cdot (v - \mu)}{\sigma(v)} + 0.577\right] = \ln\left[-\ln\left(\frac{T}{T+1}\right)\right], \tag{21}$$

where: T — the period of time under consideration, years.

Thus:

$$\begin{cases} -\left[\frac{1.282 \cdot (22.18 - \mu)}{\sigma(v)} + 0.577\right] = \ln\left[-\ln\left(\frac{5}{5+1}\right)\right] \\ -\left[\frac{1.282 \cdot (26.41 - \mu)}{\sigma(v)} + 0.577\right] = \ln\left[-\ln\left(\frac{50}{50+1}\right)\right] \end{cases}. \tag{22}$$

Thence, we can find the following:

$$\sigma = 2.443 \text{ m/s } \mu = 20.037 \text{ m/s}. \quad (23)$$

We will use these statistical values to find the values of wind speed for other return periods using Eq. (21). Let us find the values of wind speed and the regulatory value of wind pressure for return periods of 20 and 5 years:

$$v_{20} = \frac{\left(\begin{array}{c} -\ln\left[-\ln\left(\frac{T}{T+1}\right)\right]\cdot\sigma + \\ +1.282\cdot\mu - 0.577\cdot\sigma \end{array} \right)}{1.282} = 24.69 \text{ m/s}; \quad (24)$$

$$v_{5} = \frac{\left(\begin{array}{c} -\ln\left[-\ln\left(\frac{T}{T+1}\right)\right]\cdot\sigma + \\ +1.282\cdot\mu - 0.577\cdot\sigma \end{array} \right)}{1.282} = 22.18 \text{ m/s}. \quad (25)$$

Then we will find the regulatory values of wind pressure by Eq. (17):

$$w_{20} = 0.43\cdot 24.69 = 262 \text{ Pa}; \quad (26)$$

$$w_{5} = 0.43\cdot 22.18 = 212 \text{ Pa}. \quad (27)$$

Thus, when going from the 50-year return period to the 20-year return period, the regulatory value of wind pressure decreased by 13%, and when going from the 50-year return period to the 5-year return period — by 29 %.

We will perform all further calculations related to the summary of loads according to Regulations SP 20.13330.2016, substituting (when applying the probabilistic method to summarize loads) the values of wind pressure and the weight of the snow cover, obtained earlier, in the equations where they are present. As a result, two combinations of loads are applied to each of the design models: loads summarized by the deterministic method and loads summarized by the probabilistic method.

After applying loads to the design models of buildings, we will analyze the design models by the limit state method in SCAD. First, we will choose arbitrary sections for the structural elements and conduct primary calculations. To analyze the schemes for the first group of limit states, let us move on to the static calculation of the schemes. It is based on the determination of the utilization rates for various factors. In case of compressed elements, they are determined for strength, stability and flexibility. In case of tensile elements, they are determined only for strength and flexibility. The utilization rates obtained based on the calculations according to Regulations SP 16.13330.2017 “Steel structures” must be less than one but close to it. If the utilization rate is more than one, it is necessary to increase the section of the structural element or use steel with a higher design structural strength. The schemes must also meet the requirements of the second group of limit states. According to clause 15.1.1 of Regulations SP 20.133.2016 “Loads and actions”, structural deflection must not exceed the limit value determined by Table E.1 depending on the span of the structure.

We can consider economic gains from reducing material consumption in building structures as the practical application of the obtained research results. Let us summarize the dimensions of the sections of the structural elements, meeting the limit state criteria for the probabilistic and deterministic methods to summarize loads, in a table, calculate the total weight of the frames of the buildings, and compare their values depending on the influence of different calculation methods.

Next, we will consider the designed models in terms of the reliability theory. There are numerous methods to assess the reliability of building structures, e.g., the method of two moments (Gordeeva, 2012; Krasnoshchekov and Zapoleva, 2015b), the Streletsky method, etc. One of such methods is the Rzhanitsyn method based mainly on the fact that the forces taken up by building structures must not exceed their load-bearing capacity (Rzhanitsyn, 1982).

Let us assume that the load forces are described by a function for random distribution of values with distribution density $f_F(F)$. The strength of a structural element is described by the deterministic value Φ_{det}, and the strength, in turn, also has its own distribution density.

It is believed that structural failure will occur when the design state represented by the shaded area w in Fig. 2 occurs. This state corresponds to the moment when the force from the applied load exceeds the load-bearing capacity of the structure. The probability of failure in such a case will be equal to the following:

$$Q = \int_{\Phi_{det}}^{F_{max}} f_F(F)\,dF. \quad (28)$$

Hence, the probability of failure-free operation can be found as follows:

$$P = 1 - Q. \quad (29)$$

In cases when the probability of failure is not zero, it is logical to assume that there is a safety margin, which can be denoted as ψ. This means that failure occurs when the safety margin is less than zero and

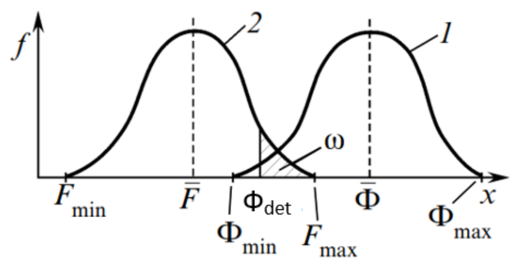

Fig. 2. Density of the load-bearing capacity and load distribution

represents the difference between the load-bearing capacity of the structure and the load applied to it (Fig. 3).

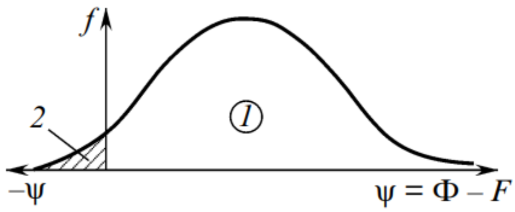

Fig. 3. Strength margin distribution density

Given that the values are distributed according to the normal law, the probability of failure can be calculated by the following equation:

$$Q = 0.5 - \Phi(\gamma), \quad (30)$$

where: γ — the safety characteristic similar to the reliability index β, which was discussed earlier.

$$\gamma = \frac{\bar{\psi}}{\hat{\psi}}, \quad (31)$$

$$\bar{\psi} = \bar{\Phi} - \bar{F}, \text{ and } \hat{\psi} = \sqrt{\hat{\Phi}^2 + \hat{F}^2}.$$

$\Phi(\gamma)$ — the probability integral:

$$\Phi(\gamma) = \frac{1}{\sqrt{2\pi}} \int_0^{\gamma} \exp\left(-0.5 \cdot x^2\right) dx. \quad (32)$$

Thus, the γ value is the number of standards falling within the range from $\psi = 0$ to $\psi = \bar{\psi}$. By converting the equation, we obtain:

$$\gamma = \frac{\bar{\Phi} - \bar{F}}{\sqrt{\hat{\Phi}^2 + \hat{F}^2}}, \quad (33)$$

where: $\bar{\Phi}$ — the mathematic expectation of the load-bearing capacity of an element;

$\bar{F}$ — the mathematic expectation of the bending moment from the load;

$\hat{\Phi}$ — the standard of distribution of the load-bearing capacity;

$\hat{F}$ — the standard of distribution of the bending moment from the load.

To determine the mathematical expectation of the load-bearing capacity of an element, it is necessary to multiply the modulus of its section by the limit of proportionality of steel of which the element under consideration is made:

$$\bar{\Phi} = \sigma_{0.2} \cdot W_y. \quad (34)$$

We will determine the mathematical expectation of the bending moment from the load by the design model of the buildings in SCAD. The standards of distributions can be found by multiplying the mathematical expectations by the variation coefficients. They are determined based on the reference data. The variation coefficient of the load-bearing capacity of steel is 0.01, and that of the bending moment from the load is 0.15.

We will compare the obtained values of the safety characteristics of the structures with their regulatory values according to Table F.2 of GOST R ISO 2394-2016.

The frame of the industrial building can be attributed to the major consequences of failure since the building can contain a large amount of expensive equipment. The cost of safety measures can be classified as moderate. Because of the small number of the frame structures in the small-sized building, additional safety measures (in percentage terms) can significantly increase the total weight of the frame, therefore, the relative cost of safety measures can be classified as high. The consequences of failure, in turn, can be classified as minor since structural failure will not lead to any significant consequences. Thus, the resulting values of the safety characteristics are compared with their regulatory values from Table 1 and a conclusion can be made about the compliance or non-compliance of the frame structures with the reliability requirements when applying the probabilistic method to summarize loads.

Results and discussion

Based on the calculation results for the considered frames in SCAD, sections of structural elements were selected for the deterministic and probabilistic calculation methods. In the case of the industrial building, the section dimensions decreased only at the top and bottom chords of the truss. Below you can find a table with the calculation of the total weight of the frames with initial (deterministic method) (Table 2) and adjusted (probabilistic method) (Table 3) sections.

Thus, the gains from the reduced material consumption in the building structures from the use of the probabilistic method to summarize loads amounted to 3.2 tons, which is 3.4 % of the total weight of the frame when applying the deterministic method.

Let us compile a similar table for the frame of the small-sized building. In this case, the use of the probabilistic method made it possible to reduce the sections for columns and longitudinal beams (Table 3).

The total weight of the frame with the adjusted sections decreased by 0.156 tons, which is 27% of the initial frame weight.

Table 1. **Target values of the safety characteristics**

Relative cost of safety measures	**Consequences of failure**			
	Minor	**Notable**	**Moderate**	**Major**
High	0	1.5	2.3	3.1
Moderate	1.3	2.3	3.1	3.8
Low	2.3	3.1	3.8	4.3

Table 2. **Weight of the structural elements of the frame in the industrial building**

Structural element	Section	Weight, r. m	Length, quantity	Total weight, kg
Top chord	180x100x6	24.52	30.14·16	739.03
	160x100x6	22.63		682.07
Bottom chord	180x100x7	27.91	27·16	753.57
	160x100x6	22.63		611.01
Diagonal members R1, R6	50x4	5.45	8.56·16	46.65
Diagonal member R2	70x4	7.97	4.02·16	32.04
Diagonal members R3, R5, R7, R8, R9, R10	40x4	4.2	30.06·16	126.25
Diagonal member R4	60x4	6.71	4.44·16	29.79
Columns	30K1	87	9·32	25,056
Framework	25K1	80.2	9·8	5774.4
Purlins	24P	24	88·11	23,232
Struts	50x4	5.45	88·11	5275.6
Upper cross braces	140x4	16.76	234.9	3936.9
Crane girders	50x4	5.45	410	2234.5
V-shaped members	40x4	4.2	41.04	172.4
Side cross braces	120x4	14.25	67.12	956.5
		Per building	Initial	93,852.2
			Adjusted	90,659.8

Thus, comparing the obtained gains from the reduced material consumption in the structures of the two frames, we can conclude that it is most rational to use the probabilistic method to summarize loads for the frame of a small-sized building, since the gains for the frame of an industrial building will be neutralized by the possible consequences of structural failure or the cost of equipment inside the building.

Let us move on to the calculation of the reliability of the building structures by the Rzhanitsyn method in order to justify that it is safe to reduce the size of the structural elements and use the probabilistic method to summarize loads. Let us summarize the calculation results for the safety characteristics for the deterministic and probabilistic methods, obtained in the calculations according to Eq. (33), in a table.

Reliability characteristics of the initial sections of the industrial building:

Reliability characteristics of the adjusted sections of the industrial building:

It makes sense to compare the safety characteristics by their minimum values. In both cases, the purlin turned out to be a critical element of the scheme. For the deterministic method, the value of the safety characteristic of the purlin amounted to 4.29, and for the probabilistic method, it increased to 5.65 (Tables 4 and 5). This is due to the fact that for the deterministic method these values are guaranteed by the 50-year useful life of the building, and for the probabilistic method — by the 20-year period. In turn, both of these values meet the limit value, which is 3.8 for this type of building.

Let us move on to assessing the reliability of the small-sized building. For the initial sections, the safety characteristics turned out to be as follows:

For the adjusted sections:

The longitudinal beam with a safety characteristic of 0.45 for the deterministic method with a 50-year period and 0.59 for the probabilistic method with a 5-year period (Tables 6 and 7) turned out to be a critical structural element of the small-sized building. These values correspond to the regulatory values, therefore, the application of the probabilistic method to summarize loads can be considered reasonable.

Table 3. **Weight of the structural elements of the frame in the small-sized building**

Structural element	Section	Weight, r. m	Length, quantity	Total weight, kg
Columns	100x6	16.98	3·6	305.64
	100x3.5	10.36		186.48
Longitudinal beams	80x5	7.97	9·2	202.86
	80x4	6.71		165.96
Cross beams	50x2	2.93	3·3	26.37
Beams in the middle of the columns	40x2	2.31	9·2	41.58
			Initial	576.45
			Adjusted	420.39

Table 4. **Calculation results for the safety characteristics**

Structural element	$\bar{F}$	$\hat{F}$	$\bar{\Phi}$	$\hat{\Phi}$	γ
Column	111.28	16.692	309.95	3.1	11.70
Top chord	4.51	0.6765	42.19	0.42	47.26
Bottom chord	5.57	0.8355	42.19	0.42	39.13
Purlin	36.15	5.4225	59.54	0.59	4.29
Cross braces over the truss	6.95	1.0425	23.73	0.24	15.69
Diagonal member R1	0.02	0.003	3.27	0.03	98.97
Diagonal member R2	0.03	0.01	7.1	0.07	99.38
Diagonal member R3	0.02	0.003	1.41	0.01	96.42

Table 5. **Calculation results for the safety characteristics**

Structural element	$\bar{F}$	$\hat{F}$	$\bar{\Phi}$	$\hat{\Phi}$	γ
Column	97.38	14.61	309.95	3.1	14.23
Top chord	3.36	0.50	42.19	0.42	59.08
Bottom chord	3.78	0.57	42.19	0.42	54.35
Purlin	32.12	4.82	59.54	0.59	5.65
Cross braces over the truss	4.55	0.68	23.73	0.24	26.54
Diagonal member R1	0.02	0.003	3.27	0.03	98.97
Diagonal member R2	0.03	0.01	7.1	0.07	99.38
Diagonal member R3	0.02	0.003	1.41	0.01	96.42

Table 6. **Calculation results for the safety characteristics**

Structural element	$\bar{F}$	$\hat{F}$	$\bar{\Phi}$	$\hat{\Phi}$	γ
Columns	3.93	0.58	18.67	0.19	23.84
Beams in the middle of the columns	0.06	0.01	1.04	0.01	71.29
Longitudinal beams	9.22	1.14	9.85	0.10	0.45
Cross beams	0.03	0.00	1.70	0.02	94.96

Table 7. **Calculation results for the safety characteristics**

Structural element	$\bar{F}$	$\hat{F}$	$\bar{\Phi}$	$\hat{\Phi}$	γ
Columns	2.74	0.4	12.13	0.12	21.92
Beams in the middle of the columns	0.06	0.01	1.041	0.01	71.29
Longitudinal beams	7.64	1.15	8.32	0.08	0.59
Cross beams	0.03	0.01	1.698	0.02	94.96

Thus, comparing the safety characteristics obtained in the calculations by the Rzhanitsyn method of reliability assessment, we can conclude that the use of the probabilistic method to summarize loads is reasonable in terms of reliability for both frames of the buildings under consideration.

Conclusions

In a number of design situations, the use of the probabilistic method to summarize loads reduces the loads applied to the frame of the industrial building by 13 % for wind loads and by 14% for snow loads when going from the 50-year return period to the 20-year return period. The loads applied to the frame of the small-sized building, with the use of the probabilistic calculation method when going from the 50-year return period to the 5-year return period, decreased by 29 % for wind loads and by 19 % for snow loads. The reduced loads make it possible to reduce the stiffness properties of the sections. As a result, the total weight of the frame of the industrial building decreased by 3 %, and the that of the small-sized building — by 27 %. Hence, it is more rational to apply the method proposed in this work for small-sized buildings since in large buildings the economic gains will be neutralized by the consequences of structural failure and the cost of equipment inside the building. In turn, the Rzhanitsyn method showed that despite the reduction in the geometric parameters of the sections of the structural elements, their reliability does not decrease during the entire useful life of the elements.

References

Benjamin, J. R. and Cornell, C. A. (2014). *Probability, statistics, and decision for civil engineers*. Mineola, New York: Dover Publications, Inc., 685 p.

Bulanchik, D. Yu. and Lalin V. V. (2021). Determining loads with account for the useful life of a construction facility as a factor of reducing material consumption in load-bearing structures. In: *Week of Science at the Institute of Civil Engineering: Proceedings of the All-Russian Conference*. In 3 parts. Part 2. Saint Petersburg: Peter the Great St. Petersburg Polytechnic University, pp. 431–433.

CEN (2001). *EN 1990:2002. Eurocode - Basis of structural design*. Brussels: CEN, 116 p.

Dubrovin, V. M. and Semenov, K. S. (2018). Modelling of quasi-static reliability of technical system design. *Mathematical Modeling and Computational Methods*, No. 3 (19), pp. 38–48. DOI: 10.18698/2309-3684-2018-3-3848.

Gordeeva, T. E. (2012). Application of the method two moments to determine structural reliability. News of Higher Educational Institutions. *Construction*, No. 10, pp. 88–91.

Krasnoschekov, Y. V. and Zapoleva, M. Y. (2015a). The calculated values of wind load with a given probability. *The Russian Automobile and Highway Industry Journal*, No. 2 (42), pp. 64–67. DOI: 10.26518/2071-7296-2015-2(42)-81-89.

Krasnoshchekov, Y. V. and Zapoleva, M. Yu. (2015b). Probabilistic design of a structure by the given level of reliability. *The Russian Automobile and Highway Industry Journal*, No. 1 (41), pp. 68–73.

Kurguzov, K. V., Fomenko, I. K., and Shubina, D. D. (2020). Probabilistic and statistical modeling of loads and forces. *Vestnik MGSU (Monthly Journal on Construction and Architecture)*, Vol. 15, Issue 9, pp. 1249–1261. DOI: 10.22227/1997-0935.2020.9.1249-1261.

Makhinko, A. V. and Makhinko, N. A. (2015). The calibration rationale for combination factors dead load, snow and wind loads in design of steel structures with DSTU-N B EN 1990. *Metal Constructions*, Vol. 21, No. 2, pp. 81–98.

Nadolsky, V. V. and Veryovka, F. A. (2018). Specifics of determining the reliability index for different frequency periods. In: *Perspective Directions of Innovative Development of Construction Industry and Engineering Training: Proceedings of the 21st International Research and Methodological Workshop*. In 2 parts. Part 1. Brest: Brest State Technical University, pp. 205–212.

Perelmuter, A. V. and Pichugin, S. F. (2014). Issues on estimation of building structure vulnerability. *Magazine of Civil Engineering*, Issue 5 (49), pp. 5–14. DOI: 10.5862/MCE.49.1.

Pshenichkina, V. A., Glukhov, A. V., and Glukhova, S. G. (2019). Probabilistic load parameter modeling in resolving the safety and lifetime assessment problems for buildings and constructions. *The Donbas Constructor*, Issue 2 (7), pp. 58–63.

Rzhanitsyn, A. R. (1982). *Construction mechanics*. Moscow: Vysshaya Shkola, 400 p.

Spaethe, G. (1994). *Reliability of load-bearing building structures*. Moscow: Stroyizdat, 288 p.

Vrouwenvelder, T. (1997). The JCSS probabilistic model code. *Structural Safety*, Vol. 19, Issue 3, pp. 245–251. DOI: 10.1016/S0167-4730(97)00008-8.

ВЛИЯНИЕ ВЕРОЯТНОСТНОГО МЕТОДА СБОРА НАГРУЗОК НА НАДЕЖНОСТЬ И МАТЕРИАЛОЕМКОСТЬ СТРОИТЕЛЬНЫХ КОНСТРУКЦИЙ

Кулигин Дмитрий Дмитриевич*, Школяр Филипп Сергеевич

Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия

*E-mail: dmitrykul17@gmail.com

Аннотация
Введение. Величины нагрузок являются одними из основных факторов, влияющих на оценку надежности строительных конструкций. Все нагрузки по природе имеют вероятностное происхождение, однако наиболее показательными для данного исследования являются кратковременные нагрузки, так как их характер является наиболее стохастическим по сравнению с другими видами нагрузок. Согласно нормативным документам, сбор кратковременных нагрузок на здание необходимо осуществлять, основываясь на базовый период их повторяемости — 50 лет. Из-за многообразия расчетных ситуаций невозможно оптимально унифицировать методы расчета для всех видов зданий, поэтому период повторяемости 50 лет берется для всех видов зданий вне зависимости от их необходимого срока службы, что в некоторых случаях может приводить к закладыванию излишнего запаса надежности. **Методы.** Для сбора нагрузок на конструктивные схемы зданий используются два метода: детерминистский, основанный только на данных из нормативных документов, и вероятностный, принимающий во внимание вероятностную сущность происхождения нагрузок. Оценка надежности проводится по методу предельных состояний и методу А.Р. Ржаницына. **Результаты.** Применение вероятностного метода сбора нагрузок в ряде случаев позволяет снизить жесткостные характеристики сечений, за счет приравнивания периода повторяемости вероятностных нагрузок к необходимому сроку службы здания. Таким образом, гарантия надежности дается не на 50 лет, как при детерминистском методе, а на срок эксплуатации здания, вследствие чего надежность строительных конструкций не снижается на всем закладываемом в них периоде эксплуатации. Данный метод позволил снизить общую массу каркаса производственного здания на 3 %, а малогабаритного — на 27 %, что свидетельствует о более рациональном применении предложенного метода для малых по габаритам схем зданий, так как в крупных схемах выгода в материалоемкости конструкций будет нивелироваться последствиями их отказа и стоимостью оборудования внутри здания.

Ключевые слова: надежность строительных конструкций, характеристики безопасности, период повторяемости, метод предельных состояний