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On the assignment of dependability level

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Abstract. *The problem of assignment of optimum level of dependability is not new and has not yet been solved. The requirement of complete dependability is noted to be erroneous. However, insufficient dependability of buildings is fraught with significant social and economic losses. Hence is the problem of definition of the required, optimal level of dependability. In Russia, there are no quantitative guidelines for the dependability of buildings and structures. At the same time, the strengths of the materials of ferroconcrete structures are regulated by GOST 34028-2016 for rod reinforcement and GOST 18105-2010 for concrete, as well as by building regulations SP 63.13330-2012 Concrete and ferroconcrete structures. In this paper, the dependability of the "Loads – design" construction system is suggested to be defined using the total probability formula. We assume that the mechanical characteristics of a structure's materials and the loads are independent and joint random values: the emergence of one random value does not depend on the emergence of another one; change of load changes the stresses in the structural section. Probabilistic calculations showed that over the period of 10 years facilities designed in accordance with SP 38.13330.2012 for operation in the Gulf of Finland, will be destroyed almost with the 100% probability. For normal consequence class facilities (KS-2) the required dependability must tend to 3σ (0.99865). In order to ensure the required dependability of construction system of about 3σ, the probability of loads of 0.99865 should be attempted to be ensured. The application of SP does not always guarantee the required dependability of construction facilities. The application of probabilistic approaches in solving engineering problems can prevent emergency situations.*

Keywords: *probability, building, materials, loads, dependability, destruction, construction, building regulations, characteristics.*

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The problem of assignment of optimum level of dependability is not new and has not yet been solved [1]. The Russian version of the Hütte reference book [2] with a developed system of dependability coefficients was published in 1890. In 1926, professor M. Maier published the paper [3], in which he criticized the calculation on allowed voltage and proposed calculating structures assuming an disadvantageous combinations of loads and material resistances. In 1929, N.F. Khotsialov [4] elaborated upon M. Meyer's ideas. Noting the stochastic variability of mechanical and geometric parameters of structures, he proposed a new formula – "Building with a viable number of destructions" – instead of "Building without destructions, by all means". According to N.F. Khotsialov, engineering should take into account capital costs as well as possible "defects" and amount of losses that an accident brings to the state.

In 1945, in connection with the development of new forms of calculation and engineering standards, the Commission for calculation methods unification organized by Narkomtiazhprom (People's Commissariat of Construction of Heavy Industry), adopted a conventional scheme of estimated coefficients proposed by I.I. Goldenberg, M.G. Kostyukovsky and A.M. Popov. According to this scheme, the overall safety coefficient depended on uniformity, overload coefficients and operating conditions of the structure. In the future the proposed scheme was included in the calculation method for limit states. It was assumed that structures were to meet the relevant requirements with a reasonable level of risk.

The development of the dependability theory of engineering structures is related to a number of socio-economic issues. A.V. Gemmerling [5] noted the invalidity of the requirements of absolute dependability. He supposed that no matter which calculation methods were used, the real loads and strength characteristics always remain random values or functions. Therefore, there is a problem of determining the required dependability level.

A.R. Rzhanitsyn in [6] took into account the economic aspects of safety calculation. He determined a minimum of the mathematical expectation of costs related to building a structure and its possible damage over the life cycle, i.e. defined the minimum of function:

$$R = C + V \times D, \tag{1}$$

where C is the initial cost of the engineering structure; V is the probability of its damage; D are the losses caused by the damage, including renewal costs and loss caused by disturbed operation.

A.P. Sinitsin in his works noted the nonlinear relationship between the risk value and expected value and provided statistical data on the risk value for various industries. According to A.P. Sinitsin [7], the risk, characterized by the number of accidents 10^{-3} per person per year, is completely unacceptable. The risk level of 10^{-4} requires some measures and can be accepted only if there is no other solution.

For American conditions, the risk of car accidents can be as high as $2{,}8\times10^{-4}$. The risk level 10^{-5} corresponds to natural accident events, for example, accidents during swimming in the sea, for which the risk is estimated as $3{,}7\times10^{-5}$. Accidents with the risk of 10^{-6} belong to a low risk level as it is possible to avoid this risk by observing basic precautions.

Outside of Russia [8], the following formula for failure probability $Q(t)$ regulation became widespread:

$$Q(t) = 10^{-5}\, \xi_S\, T / L, \qquad (2)$$

where ξ_S is the coefficient of social significance (Table 1); T is the estimated lifecycle in years; L is the average number of people inside or around the building during the period for which the risk is assessed.

Table 1. Coefficient of social significance, ξ_S

Structure type	ξ_S
Public places, dam	0.005
Apartments, office and commercial buildings, industrial buildings	0.05
Bridges	0.5
Towers, pillars, offshore buildings	5

The required dependability on (2) for buildings with normal level of criticality is the following:

$1 - Q(t) = 10^{-5} \times 0.5\times 50 / 50 = 0.999995$ or $0.9^5 5$.

Professor Ryush (Table 2) proposed to standardize structures dependability $P(t)$ based on their failure probability $Q(t)$, where $Q(t) = 1 - P(t)$.

Table 2. Standardization of ferroconcrete structures dependability

Failure type and characteristic	$Q(t)$
Failure without warning sign (brittle failure, buckling etc.)	10^{-7} ... 10^{-5}
Loss of carrying capacity with warning sign	10^{-4}
Inoperability with no loss of carrying capacity (similar to the 2-nd group of limit states)	10^{-3} ... 10^{-2}

In the Russian Federation, the significance of buildings and structures dependability is not quantified [9]. At the same time, the strengths of the materials of ferroconcrete structures are regulated by GOST 34028–2016 for rod reinforcement and GOST 18105-2010 for concrete, as well as by building regulations SP 63.13330-2012 Concrete and ferroconcrete structures. According to these documents, the dependability (reliability) of characteristic strength of materials is 0.95 (1.64σ), and the probability of calculated strength of materials is near 0.99865 (3σ): standard strengths are divided into dependability coefficients on materials that are above 1. Therefore, the dependability value is $P(A\times B) = 0.99865$ (A, B are random events; A is the structural carrying capacity and B is the loads) should be assigned to engineering structures with normal level of criticality.

The dependability of the "Loads – design" construction system is suggested to be defined using total probability formula (3). We assume that the mechanical characteristics of structure's materials and loads are independent and joint random values: the emergence of one random value does not depend on the emergence of another one; change of load changes the stresses in the structural section.

$$P(A\times B) = 1 - [P(A') + P(B') - P(A')P(B')], \qquad (3)$$

where $P(A')$ and $P(B')$ are the probabilities of opposite events of A and B: $P(A') = 1 - P(A) = 1 - 0.99865 = 0.00135$, $P(B') = 1 - P(B) = 1 - 0.95 = 0.05$.

Let us substitute the known values to formula (3) and define $P(A\times B)$:

$P(A\times B) = 1 - (0.00135 + 0.05 - 0.00135 \times 0.05) = 0.94872$.

To increase the system dependability to about 3σ, it is required to increase the non-exceedance probability of loads, for example, up to 0.99865. Then the system dependability will be as follows:

$P(A\times B) = 1 - (0.00135 + 0.00135 - 0.00135 \times 0.00135) = 0.9973$ or 2.78σ.

The low exceedance probability of loads for the Gulf of Finland is defined, for example, by SP 38.13330.2012 [11]:

$$F_{c,p} = 1.26\cdot10^3\, V\, h_d (m\, A\, k_b k_v R_c\, \rho\, \mathrm{tg}\gamma_{)})^{1/2} = 1.26\cdot10^3 \times 0.87 \times 1.002 \times (0.83 \times 330.75 \times 4.529 \times 3.18 \times 0.3 \times 1000 \times 2.7475)^{1/2} = 1.505\ MH, \qquad (4)$$

where V is the movement speed of the ice field; $V = 3\% \times 29$ *m/s* = 0.87 *m/s*; m is the shape factor of the supporting structure in plan view, $m = 0.83$; A is the maximum area of the ice field, m^2 that can affect the calculated structural element, identified through field observations or adopted depending on the lateral dimensions of the span as $A = 3l^2 = 3\times10.5^2 = 330.75$ (where l is the span); k_b and k_v are the factors 18 and 19 [11], respectively (according to tables): $k_b = 3.18$, $k_v = 0.3$; $R_c = 4.529$ *MPa*; ρ is the water density, $\rho = 1000$ kg/m^3; tg(70°) = 2.7475.

According to [11] the load $F_{c,p}$, determined by formula (4), cannot be greater than the load $F_{b,p}$ *MH*, determined by formula (5):

$$F_{b,p} = m\, k_b k_v R_c\, b h_d = 0.83 \times 3.18 \times 0.3 \times 4.529 \times 1.22 \times 1.002 = 4.386\ MH, \qquad (5)$$

where b is the lateral dimension of the supporting structure at the ice level, $b = 1.22$ *m*.

According to [11], a lower value of the ice load should be adopted in calculations, 1.505 *MH*.

The wind speed for the entire observation period at the Saint Petersburg weather station is taken into consideration in formula (4). According to the Saint Petersburg weather station, the wind distribution is approximated by the Pearson curve type I [12]:

$$y = 1{,}13\left(1 + \frac{x}{-13{,}834}\right)^{-0{,}37}\left(1 - \frac{x}{37{,}466}\right). \qquad (6)$$

The value of the wind speed with the probability of 0.99 is 29 m/s. The average long-term value of the sum of the frost degree-day according to the Saint Petersburg weather station for the period between 1881 and 1980 is 775ºC.

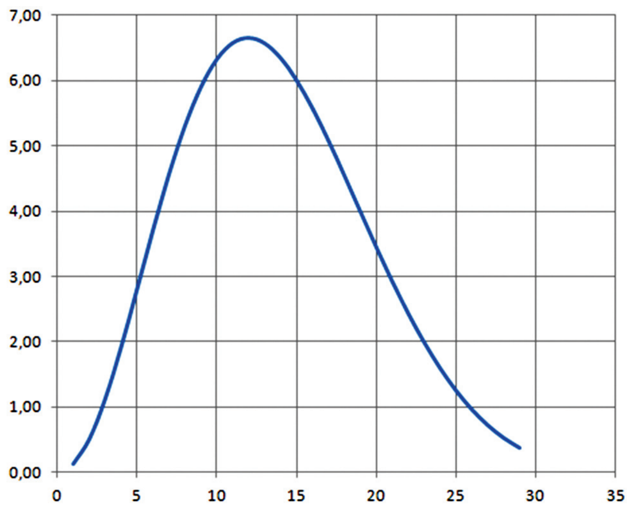

Figure 1. Freezing index distribution

Figure 1 shows the freezing index distribution for the Gulf of Finland. The freezing index distribution is also approximated by the Pearson curve type I. With the probability of 90% the freezing index is 983.9. Freezing indexes with the probability of 99% and 99.9% are 1274.2 and 1358.2 respectively.

The ice thickness is calculated using formula (7) after substitution of known values with the freezing index, R = 1358.2, with the probability of 99.9%:

$$h_d = 0.034nR^{1/2} = 1.002\ m, \quad (7)$$

where n is the coefficient of the local conditions; we take the larger value: $n = 0.8$.

The ice strength under compression, R_c, is calculated using formula (48) from [11]:

$$R_c = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(C_i + \Delta_i)^2} = 4.529\ MPa. \quad (8)$$

The ice load 1.505 MH calculated by the formula (5) causes the shearing load of the one pile relative to the foundation frame of the conventional leading mark 1.172 MH.

In 2013, several leading beacons, designed for the load of 1.505 MH, were destroyed as a result of shearing of 80% of piles relative to the foundation frames. Piles were reinforced 16∅25A500. The pile load capacity by the shearing, N_{sh}, with an average (not with calculated) resistance of steel was 2.104 MH. Let us assume that this is a shearing with an average value of the ice load.

The average value of the ice load is calculated using formula (9):

$$F_{c.pm} = N_{sh} / (1 – 3.25/14.7) =$$
$$=2.104 / (1 – 3.25/14.7) = 2.701\ MH. \quad (9)$$

where 3.25 and 14.7 are the dimensions of the pile in m above the water surface and under water.

With the variation coefficient of 0.15 of the ice load the mean-square deviation will be as follows:

$$\sigma_{ice} = F_{c.pm} \times v = 2.701 \times 0.15 = 0.405\ MH. \quad (10)$$

As 80% of the pile was destroyed, the specified average value and the mean-square deviation of the ice load will be respectively: 2.701 + 0.405 = 3.106 MH and 3.106 × 0.15 = 0.466 MH.

Then the ice load with the probability of 0.99865 will be:

$$F_{c.p3\sigma}=F_{c.pm}+3\sigma_{ice}=3.106+3 \times 0.466=4.504\ MH. \quad (11)$$

Thus, the probability of the ice load calculated by [11] in the Gulf of Finland is:

$$t = [(1.505 – 4.504) / 0.466] = -6.44. \quad (12)$$

That means, that the facilities designed per [11] for the Gulf of Finland will be destroyed with the 100% probability within 10 years.

In our opinion, in [11] formula (50): $F_{c,p}=1.26{\cdot}10^{-3}\ V\ h_d\ (m\ A\ k_b k_v R_c\ \rho\ \text{tg}\gamma)^{1/2}$, should be modified.

Experience shows that the force, $F_{c,p}$, increases in direct proportion to the growth of the ice strength, R_c. Therefore, the variable R_c should be taken outside the radical sign.

The ice thickness is not homogeneous, therefore, $F_{c,p}$ has a hyperbolic dependence on variable h_d. Therefore, the variable h_d should be taken inside the radical sign.

The wind influence on the hydraulic structure should be taken into account with the ice massifs which in form of variable A and coefficient k_v are inside the radical sign in the formula (50) [11]. Therefore, the wind speed also should be taken inside the radical sign.

The variable of the water density (ρ = 1000 kg/m^3) practically doesn't change, so it should be removed from the formula (50). Then, the coefficient $1.26{\cdot}10^{-3}$ will change to 0.04: $1.26{\cdot}10^{-3} \times (1000)^{1/2} = 0.04$. This coefficient was used to determine $F_{c,p}$ in SNiP 2.06.04-82*.

After the transformations formula (50) in [11] will be as follows:

$$F_{c,p} = 0.04\,R_c\,(m\ k_b\ k_v\ A\ V\ h_d\ \text{tg}\gamma)^{1/2}. \quad (13)$$

Then the force from the ice load, $F_{c,p}$, will more accurately correspond to the physical meaning, and its dimension $F_{c,p}$ will be: $ms/m^2 \times (m^2 \times m/s \times s \times m)^{1/2} = ms/m^2 \times m^2 = ms$. Using formula (50) [11] it is possible to obtain "at the output" the following dimension: $m/s \times s \times m \times (m^2 \times ms/m^2 \times ms/m^3)^{1/2} = ms \times (m)^{1/2}$.

The new value of the ice load $F_{c,p}$, determined by (13), will be:

$F_{c,p}$ = 0.04×4.529×(0.83× 3.18× 0.3× 300× 0.87× 1.02× 2.75)$^{1/2}$ = 4.538 MH.

The value $F_{b,p}$, determined by (5), is 4.386 MH. Thus, we obtain the comparable values of the ice load. For further calculations we will use not a lower ice load value, as recommended in [11], but a higher one, 4.538 MH.

The probability of the ice load will be:

$$P[(4.538 – 3.106) / 0.466 = 3.073] = 0.99894. \quad (14)$$

Conclusions. The problem of assignment of optimum level of dependability is not has not yet been solved. In order to ensure the dependability of construction system of about 3σ, the probability of loads of 0.99865 (3σ) should be attempted to be ensured.

The application of SP does not always guarantee the required dependability of construction facilities. The application of probabilistic approaches in solving engineering problems can prevent emergency situations.

References

[1]. Dolganov AI. Nadezhnost sterzhnevykh zhelezobetonnykh konstruktsiy [Dependability of framed ferroconcrete structures]. Magadan: OAO MAOBTI; 2001 [in Russian].

[2]. Hütte. Reference book for engineers, architects, mechanics and students. Ninth edition. Moscow: T-vo skoropechati A.A. Levensona; 1916.

[3]. Maier M. Die Sicherheit der Bauwerke und ihre Berechnung nach Grenzkräften anstatt nach zulässigen Spannungen. Berlin: Springer; 1926.

[4]. Khotsialov NF. Zapasy prochnosti [Strength margin]. Stroitelnaya promyshlennost 1929;10:840 [in Russian].

[5]. Gemmerling AV. O nadezhnosti massovykh konstruktsiy [On the dependability of mass buildings]. Stroitelnaya mekhanika i raschet sooruzheniy 1974;5:69-73 [in Russian].

[6]. Rzhanitsyn A.R. Ekonomicheskiy printsip rascheta na bezopasnost [Economic principle of safety calculation]. Stroitelnaya mekhanika i raschet sooruzheniy 1973;3:3-5 [in Russian].

[7]. Sinitsin AP. Metod konechnykh elementov v dinamike sooruzheniy [Finite elements method in structural dynamics]. Moscow: Stroyizdat; 1978 [in Russian].

[8]. Augusti G, Baratta A, Casciati F. Probabilistic methods in structural engineering. Moscow: Stroyizdat; 1988.

[9]. GOST 27751–2014. Reliability for constructions and foundations. Brought into force by order of the Federal Agency for Technical Regulation and Metrology no. 1974-st. dated December 11, 2014. Moscow: Standartinform; 2015 [in Russian].

[10]. GOST 34028–2016. Reinforcing rolled products for reinforced concrete constructions. Specifications. Brought into force by order of the Federal Agency for Technical Regulation and Metrology no. 232-st. dated March 31, 2017. Moscow: Standartinform; 2016 [in Russian].

[11]. SP 38.13330.2012. Loads and impacts on Hydraulic structures (from wave, ice and ships). Updated version of SNiP 2.06.04-82 by JSC B.E. Vedeneev VNIIG. Moscow: FGUP TsPP; 2012 [in Russian].

[12]. Mitropolsky AK. Tekhnika statisticheskikh vychisleniy [Method of statistical calculations]. Moscow: Nauka; 1971 [in Russian].

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