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Probability of brick structures destruction

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The results of calculations of construction brick destruction probability determination at central and off-center compression are given; the determination of the brick structures destruction probability, caused by the exhaustion of the masonry strength on local compression (crushing); determination of the brick structures destruction probability associated with the exhaustion of the masonry strength on the displacement (cut); determination of the brick structures destruction probability associated with the exhaustion of the masonry strength on the fold, the stretch; determination of the brick structures destruction probability on the crack opening. The value of the security characteristic for each case has been determined and the comparison with the normative values has been made.

Keywords: limit state of the system; integral model of reliability estimation; the Monte Carlo method; refusal model; system reliability; system "building - base"; brick construction.

Ймовірність руйнування цегляних конструкцій

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У статті розроблено методологію розрахунків, яка би дозволила позволила виконати ймовірність руйнування цегляних конструкцій. Наведено результати розрахунків визначення ймовірності руйнування конструкцій з цегли при центральному та позацентровому стиску; визначення ймовірності руйнування конструкцій з цегли, пов’язаного з вичерпанням міцності кладки на місцевий стиск (зминання); визначення ймовірності руйнування цегляних конструкцій, пов’язаного з вичерпанням міцності кладки на зсув (зріз); визначення ймовірності цегляних конструкцій, пов’язаного з вичерпання міцності кладки на згин, на розтяг; визначення ймовірності руйнування цегляних конструкцій на розкриття тріщин. При розрахунках вважаються відомими закони розподілу випадкових величин навантажень і впливів – для постійного, корисного, снігового, вітрового навантажень, температурних впливів та впливів від нерівномірних осідань. Випадкові значення максимальних розрахункових напруг у перерізах цегляних конструкцій знаходять в залежності від випадкових зусиль, що виникають у конструкціях від випадкових впливів. При розв'язанні даної задачі статистичної динаміки використовується функція граничного стану, рішення якої проводиться методом статистичних випробувань (Монте-Карло). Імовірнісна оцінка міцності конструкцій з цегли здійснюється на основі виконання розрахунків по визначенню ймовірності руйнування за умови вичерпання міцності цегляної кладки. Визначено значення характеристики безпеки для кожного випадку та виконано порівняння з нормативними значеннями. Показано, що значення ймовірності руйнування цегляних конструкцій за базовий строк служби знаходиться в діапазоні 1×10^{-5}… 1×10^{-4}, що відповідає мінімальним значенням надійності, рекомендованим чинними нормами та Єврокодами. Розходження між запропонованим підходом та нормативною методикою складають не більше 8% - 10%.

Ключові слова: граничний стан системи; інтегральна модель оцінювання надійності; метод Монте-Карло; модель відмови; надійність системи; система «будівля – основа»; цегляна конструкція.

Introduction

In Ukraine, brick house construction is a significant part of the total housing fund. The number of brick buildings that are in critical condition is constantly increasing, The major repairs, reinforcement of structures are demanded. The accidents causes analysis in brick structures of the «building-base» system indicates the need to control and manage the reliability and operational suitability at all stages of the life cycle.

Review of research sources and publications

Today there is an obvious need for new science-intensive models for assessing the reliability of building structures both at the level of design and operation, and in normative regulation.

It is considered that the constructions, designed in accordance with the current rules, have sufficient level of safety, the quantitative security parameters are not set. The reliability assessment remains at the designer's level of intuition.

Only since 2009, with the introduction of DBN B.1.2-14:2009 [1], the assessment of the building elements reliability as the main criterion for the level of safety, has become obligatory in the design. However, the practical implementation of the provisions [1] is slowed down by the lack of the corresponding apparatus in the design standards – for almost 10 years of the DBN's effect, the Ukrainian norms of the construction industry did not lead (with a small exception) not only algorithms for determining reliability at the design stage, but also recommendations for the choice of materials and loads statistical models, which is fundamentally important. The security issue of the "building-base" system is also problematic. For many years, the scientific works in this direction were aimed exclusively at the development of models of load-deformed state analysis; the probability side of the problem for the most part is open.

In the Eurocodes system, a number of normative documents has been developed that regulate the probabilistic approach to building constructions and structures [2 - 3]. Problems of reliability and safety assessment of building structures are considered in the works of O. Weinberg [4], V. Rayzer [5], A. Perelmuttr [6], O. Lichov [7], A. Lantuch-Lyaschenko [8, 9], S. Pichugin [10], N.P. Hoej [11], R. Sêco e Pinto [12], A.U. Ebenuwa [13] and many other domestic and foreign scientists.

It should be noted that in the Ukrainian scientific sphere of residential and industrial construction there are currently no studies devoted to the stochastic modeling of the «building-base» system during the operation – researches that enable to determine the resource of the system at the random time of the life cycle.

Definition of unsolved aspects of the problem

The given analysis of the problem state enables to state that the research devoted to the scientific search for models of reliability and safety assessment of the "building-base" system is relevant, corresponds to the needs of the present in society, opens the way for a realistic assessment of the technical condition of residential and industrial buildings, has a significant socio-economic effect.

Problem statement

One of the parts of the research cycle is the development of a calculation methodology that enables to determine the probability of the brick structures destruction.

Basic material and results

The article is devoted to determining the probability of brick structures destruction. In accordance with the new normative documents, the author has proposed the following algorithms: determination of the brick structures destruction probability at central and off-center compression; determination of the structures made of brick destruction probability, associated with the exhaustion of the masonry strength on the local compression (crushing); determination of the brick structures destruction probability associated with the exhaustion of the masonry strength on the displacement (cut); determination of brick structures destruction probability associated with the exhaustion of the masonry strength on the fold, the stretch; calculation for opening cracks.

An algorithm for determining the brick ctructures destruction probability. Execution of the calculation is reduced to the determination of the destruction probability of the most dangerous cross section in the brick structure of those or other influences. In this case, it is necessary to determine the value of maximum tensions in the structural cross sections, which are due to the current loads, which can be represented by probabilistic and deterministic quantities.

The laws of the distribution of random quantities of loads and influences are known (Table 1) [14].

Random values of the maximum calculated tensions in cross sections of brick structures are based on random efforts that arise in designs from random influences. While solving the problem of statistical dynamics, the function of the boundary state is used, which solution is made by the method of statistical tests (Monte-Carlo).

In order to estimate the probability of the boundary state occurrence of a particular type, the problem of the reliability theory is solved with involving the apparatus of probability theory. At this case, the sequence of solving this problem is as follows:

– the condition of the brick element (construction) strength is considered;

– the parameters of the random variables distribution, which are the initial data, are determined;

– the solution to the problem of the probability assessment of the brick structures destruction is made.

Probabilistic assessment of brick structures strength is carried out on the basis of calculations that determine the probability of destruction on the condition of strength exhaustion of the brickwork. [15].

Table 1 – Existing tensions and influences, accepted in the model of brick structures failure

Type of load	The designation	Units	Average value	Variation coefficient V_x	The distribution law
Constant load	G	kN	G	0,1	Normal
Payload (50 years)	Q	kN/m^2	$0,6Q$	0,35	Gumbel
Snow load (50 years)	S	kN/m^2	$0,7S_0$	0,5	Gumbel
Wind load	W	kN/m^2	$0,75W_0$	0,35	Gumbel
Temperature impact	T	C^o	T	0,15	Normal
Uneven settlement impact (effort in the foundation)	D	kPa	P	0,59	Normal

To do this, it is necessary to determine the distribution of the tensions and the boundary resistance of the brickwork on the compression, local compression (crushing), stretching (axial and bending) and on the cut (on the bound and unbound cross sections).

An algorithm for determining the brick structures destruction probability on the compression by Monte-Carlo method is proposed as follows.

1. N statistical tests are performed.

2. Random probabilities of calculated loads are assigned: from construction own weight P_G, from snow P_S, payload P_Q and loads from uneven subsidences P_D.

3. According to the known values P_G, P_S, P_Q, P_D the quantiles of loads are determined, from own weight G, snow S, payload Q, uneven subsidences D.

4. The random value of the vertical load N_{Ed} . is determined

5. The random probabilities of the strength of the brickwork for compression P_{fd}. are determined.

6. By the value of P_{fd} the quantiles f_d and the value of the vertical strength of the wall N_{Rd} are determined.

7. The value of the boundary state function Y at the central compression can be written by the formula:

$$Y = N_{Rd}\,(f_d\,, b,\, t) - F\,(\gamma_{constr},\, q,\, S_0,\, A',\, E,\, a,\, b) - - F_1\,(\gamma_{constr},\, q) \geq 0 \quad (1)$$

with off-central compression:

$$Y = f_d{\cdot}A_c\,(b,\, t,\, e_0) - N(\gamma_{constr},\, q,\, S_0,\, F,\, F_1,\, e_0) \geq 0. \quad (2)$$

8. The condition $Y \geq 0$ is checked.

Graphs of the vertical load distribution function N_{Ed} and the vertical strength of the wall N_{Rd} and graphs of distribution probability density of vertical load N_{Ed} and vertical strength of the wall N_{Rd} are shown on the fig. 1, 2.

In equations (1) and (2) F, F_1 are the load values from the above floors of the building and the load on the current floor, respectively; b, t – geometric dimensions of the brick structure, e_0 – eccentricity, γ_{constr} – specific gravity of structures, S_0 – characteristic value of snow load, E – the absolute value of deformation; A' – cargo area, A_c – area of the compressed zone of the cross section; N – applied load.

In the general case, all input parameters of the equations (1, 2) are random variables. However, some values, such as: the geometric dimensions of the cross section, the size of the structure can be considered as deterministic quantities. In accordance with the rules of the brickwork arrangement, the allowable deviations in the thickness of building structures are: for walls ± 15 mm, for pillars ± 10 mm, for the thickness of the solder seams -2…+3 mm. Compared with the size of the construction, this is a maximum of 5% of the cross section of the construction, therefore, the variability of the structure geometric dimensions can be neglected.

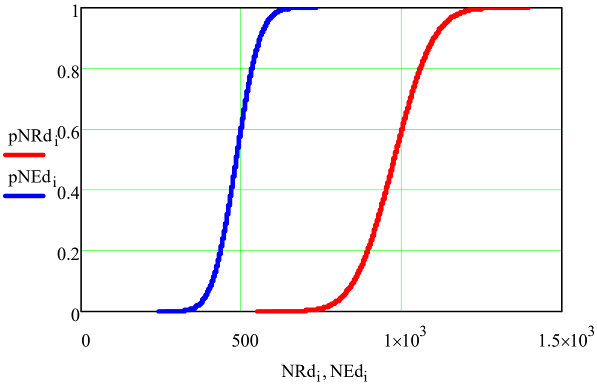

Figure 1 – Vertical load distribution N_{Ed} and vertical strength of the wall N_{Rd} functions

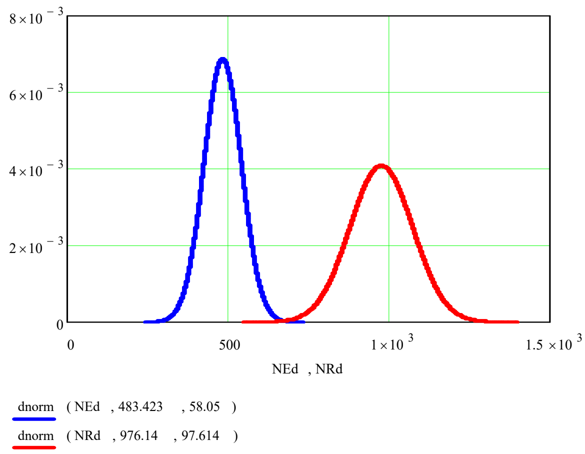

Figure 2 –Density of the probability of vertical load distribution N_{Ed} and vertical strength of the wall N_{Rd}

After performing all N tests, the probability of the brick structure element destruction during the estimated lifetime is calculated as the ratio of the number of tests n, for which $Y<0$, to all tests N. Consider that the number of tests N must be large enough to more accurately determine the value of Y, in this case, the number of tests has been taken as $N = 1\times10^5$.

Calculations have been made to determine the probability of the brickwork destruction; the following probability values for the various cases given in Table 2 are obtained.

Table 2 – Calculations results of brick structures destruction probability

Name of the quantities	Value	β	Difference, %
Probability of the brick structure destruction on the central compression	1×10^{-5}	4,27	+10%
Probability of the brick structure destruction on the off-central compression	$1,2\times10^{-4}$	3,7	-3,3
The probability of the brick structure destruction on local compression (crushing)	4×10^{-4}	3,51	-8,26
Probability of the brick structure destruction on the displacement (cut)	$1,8\times10^{-4}$	3,66	-3,825
Probability of the brick structure destruction to the fold on the bound cross section	$1,2\times10^{-4}$	3,7	-2,3
Probability of the brick structure destruction on the cracks opening	$1,4\times10^{-4}$	3,692	-2,48
Recommended minimum values by DSTU-N B V.1.2-13:2008 (EN 1990:2002, IDN) [16], **ISO 2394-1998** [17]	**1×10^{-4}**	**3,8**	

Conclusions

In the framework of reliability theory, a methodology for determining the probability of brick structures destruction as a result of achieving each of the possible boundary states has been proposed; algorithms and computer programs that are designed to solve such probabilistic problems by the Monte-Carlo method have been developed.

Calculations have been made to determine the probability of the brickwork destruction. The following probability values for different cases are obtained: Table 2.

The value of the probability of the of brick structures destruction for the base lifetime is in the range $1\times10^{-5}\ldots1\times10^{-4}$, which meets the minimum reliability values recommended by the applicable norms and Eurocodes.

The difference between the proposed approach and the normative method is no more than 8% - 10%.

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