# Transition to the Assessment of the Brickwork Quality in Terms of Compressive Strength Class

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**Abstract.** One of the widely used materials in the construction industry is brickwork, while it should be noted that its mechanical properties significantly lag behind other structural materials. According to the results of the analysis of emergency situations, brick structures are among the most dangerous from the point of view of accidents. The main causes of accidents are related to the violation of the construction and operation technology, but about 4% of all accidents relate to the imperfection of regulatory documents. An adequate determination of the actual strength is the key to high-quality and efficient operation of materials in the structures of buildings and structures, as reliability is laid down in the design. Based on the analysis of data obtained by various authors over the past 70 years, the search for the limiting coefficient of variation was carried out. For different groups of brickwork, its value was from 2 to 58%, so the average value of 38% was taken as the maximum allowable value for in-series tests. Taking into account the required value of the reserve coefficient, possible classes of brickwork strength were calculated. Switching to strength classes for brickwork will allow: controlling effectively the mechanical strength indicators in standard samples; simplifying the marking of brickwork and reducing the range of design resistances of brickwork.

**Keywords:** Brickwork · Effective masonry mortars · Assessment of strength indicators · Strength class · Coefficient of variation · Safety factor

## 1 Introduction

The development of the construction industry leads to the emergence of new materials and requires continuous improvement of traditional ones. One of the widely used materials is brickwork, while it should be noted that its mechanical properties significantly lag behind other structural materials. According to the results of the analysis of emergency situations, brick structures are among the most dangerous from the point of view of accidents (Fig. 1) [1].


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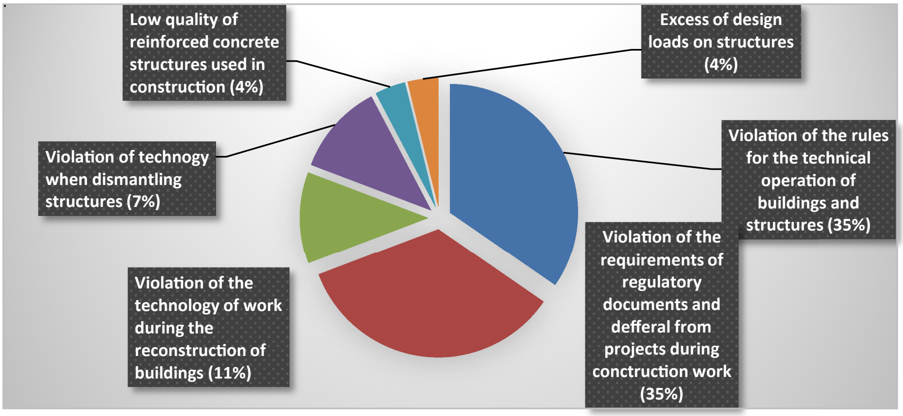


**Fig. 1.** Distribution of accidents that occurred in 2003 by the main reasons for their origin [1].

As it can be seen, the main causes of accidents are related to the violation of the construction and operation technology, but about 4% of all accidents relate to the imperfection of regulatory documents that define the methods for determining the actual structural properties of brickwork.

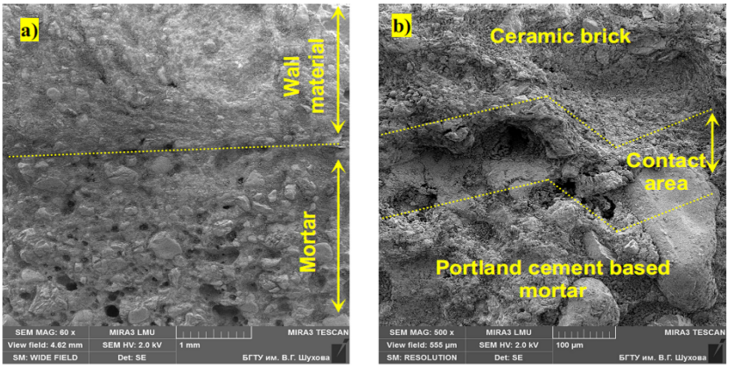


**Fig. 2.** Micrograph of the brick-mortar contact zone: a) modified; b) traditional.

It is necessary to note the scientific and technical features of the development of brickwork, which continues, although noticeably slower than other wall construction materials. New types of brickwork appear, with noticeably changed physical and mechanical properties, for example, with increased adhesion in the contact zone of bricks and mortar (Fig. 2) due to the use of the “theory of affinity of structures”, which allows to increase the strength and other mechanical physical and mechanical properties [2, 3]. Methods of calculation and construction are being improved [4], the brickwork structure is being improved [5], and the testing and quality control methods are being improved [6–9].

Quality control of brick structures is one of the components of the reliability triad. An adequate determination of the actual strength is the key to high-quality and efficient operation of materials in the structures of buildings and constructions, as reliability is laid down during design, evaluated and provided during construction, and maintained during operation. Quality control based on imperfect methods does not always provide a high level of accuracy and reliability of measurement and control operations [10].

In this regard, this paper offers a method for correct assessment of brickwork indicators based on the use of the concept of "class".

## 2 Methods

To determine the limit coefficient of variation, data obtained by various authors over the past 70 years were analyzed. A statistical sample of 73 series of brickwork was evaluated. The coefficient of variation of a series of brickwork samples made of bricks M100, 150, 200 and mortar M100, 75, 50, 25, 4 was analyzed. Series of samples were made at different times, by different groups of authors, from different bricks and mortar. Using this approach allows getting objective information without reference to certain manufacturers of materials, regions and construction sites, which is necessary to establish a representative value of the coefficient of variation.

The collection of information on the performance characteristics of various types of brickwork was carried out by processing, analyzing and communicating data from open primary sources presented on the portal of the Scientific electronic library eLIBRARY. RU; collections of classic full-text journals published by Elsevier on the ScienceDirect platform; Google Scholar search engine.

## 3 Results and Discussion

Analysis of the data array for a series of samples revealed that in 13% of cases, the calculated strength is higher than the actual one, which means that the brickwork has a high risk of destruction. At the same time, the average coefficient of excess of the actual strength over the calculated one is 1.7 times. For standard test methods, the pattern of event probability distribution is assumed to be normal with confidence P = 0.95. The margin factor is calculated based on the required uptime probability and reliability index. The coefficient of variation for different groups is from 2 to 58%, the average value of the coefficient of variation for all non-vibrated samples was 38%, so they can take this value as the maximum allowable for in-series tests.

The maximum permissible coefficient of variation will be significantly higher than for concrete, due to the variety of types of bricks and stone, mortars, construction technology, etc. Regulatory documents assume the design of structures based on the calculated strength according to an empirical formula based on the brand of bricks and mortar for compression [17].

The concept of strength class is defined in the A.V. Rzhanitsyn's works and later [11, 12]. At the same time, the concept of class is "truncated" in comparison with the initial theoretical justification in the works on ensuring reliability using the indicator of the probability of failure-free operation. As the literature evaluates the load-bearing capacity, when moving to a class, this concept is narrowed to the strength of the material. It is necessary to take into account the random nature of the values of the load-bearing capacity and the load effect.

The concept of strength class forms the basis of probabilistic calculation methods and allows moving on to determining the reliability of materials in structures through the relationship of indicators "design strength – class – average strength according to test results", taking into account the variability of the strength properties of the material. The main concept is that the destruction of the material occurs when the equality of the load-bearing capacity and the operating loads is achieved. This means that the actual strength of the test results should be equal to $\bar{R} = \bar{Q}$ (Fig. 3).

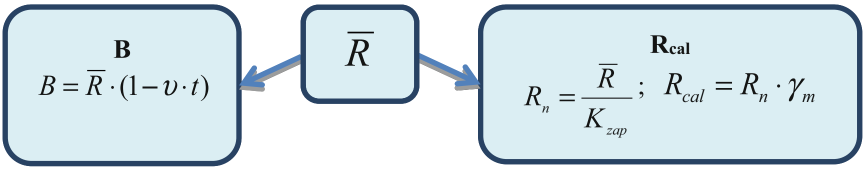


**Fig. 3.** Interrelation of strength indicators.

In earlier N.S. Streletsky's works, to ensure the required level of reliability, the indestructibility guarantee indicator was used, which is determined by the area of the probability distribution curves, as shown in Fig. 4. The indestructibility guarantee indicator has not found practical application, as it cannot clearly determine the probability of destruction.

$$G = 1 - \omega_1 \omega_2 \quad (1)$$

Taking into account probabilistic characteristics of bearing capacity and load effect based on the characteristic of the probability of failure-free operation or probability of failure, which is regulated with the help of index of reliability and is controlled via the coefficient of reserve that is the relation between the failure-free operation generalized strength and the load effect.

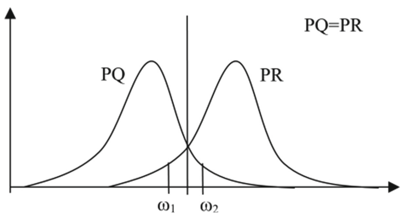


**Fig. 4.** Graphical representation of the indicator of the guarantee of indestructibility (G) according to N.S. Streletsky [13].

The main task of ensuring the indestructibility and reliability of structures is to provide conditions.

$$\bar{R} - \bar{Q} \geq 0 \tag{2}$$

where, $\bar{R}$ - generalized structural strength; $\bar{Q}$ - generalized load.

The security characteristic or reliability index is provided by the dependency:

$$\beta = \frac{\bar{R} - \bar{Q}}{\sqrt{S_R^2 + S_Q^2}} \tag{3}$$

where, $S_R$ and $S_Q$ - standard deviation of the strength properties of the material and loads. $\upsilon_R = \frac{S_R}{R}$; $v_Q = \frac{S_Q}{Q}$ are coefficients of variation.

Then the probability of failure:

$$P_f = \frac{1}{\sqrt{2\pi}} \frac{\beta^2 - 1}{\beta^3} \exp(\frac{-\beta^2}{2}) \tag{4}$$

The probability of failure has an inverse relationship with the variability of the strength reserve. The smaller the strength reserve, the lower the reliability index β, and the higher the probability of failure. The density of the failure probability distribution is related to both the reliability index and the coefficient of reserve.

$$\beta = \frac{K_{zap} - 1}{\sqrt{(v_Q^2 K_{zap} + v_R^2)}} \tag{5}$$

$$K_{zap} = \frac{\left(2 + \beta^2 v_R^2\right) + \sqrt{\left(2 + \beta^2 v_R^2\right)^2 - 4\left(1 - \beta^2 v_Q^2\right)}}{\sqrt{(v_Q^2 K_{zap} + v_R^2)}} \tag{6}$$

where, $R_N = \frac{\overline{R}}{K_{zap}}$; $R_{cal} = R_N \cdot \gamma_m$ .

GOST 32047-2012 “Stonework. Compression test method” and GOST R 57290-2016/EN 1052-1: 1998 “Stonework. Method for determining compressive strength” allows determining the value of the average strength of brickwork based on the test results, but do not allow avoiding using empirical formulas. It is necessary to introduce a safety factor that provides the required level of reliability according to the indicator “probability of failure-free operation taking into account the coefficient of variation”. In European norms, the coefficient of reserve is from 1.7 to 3.3 [16, 20]. As the Russian standards have lower indicators of operating conditions coefficients, it is advisable to apply this range only for structures with a reduced level of reliability for a normal level of reliability, the coefficient should be $К_{зап}$ = 3.9 [18].

When switching to the brickwork class, when calculating brick structures with the required level of reliability with a confidence of 0.95, it is necessary to take into account that the calculated strength index, without additional methods of increasing strength (such as reinforcement or vibration), can reach 3.9 MPa. The strength of brickwork with a maximum coefficient of reinforcement will reach 7.8 MPa [17], vibrated to 5.6 MPa. As it is possible to switch to the production of high-strength brickwork, so the classes of brickwork strength will be determined by the following relation.

$$R_{расч} = 3.0 \text{ MPa};$$

$$\overline{R} = R_{расч}\, К_{зап} = 3 \times 3.9 = 11.7 \text{ MPa};$$

$$B = \overline{R}(1 - \nu t) = 11.7(1 - 0.38 \times 1.64) = 4.4 \text{ MPa}.$$

We approximate the brickwork class to B4 (at $n = \infty$ and $P = 0.95$). Based on the above, classes of brickwork for compressive strength, taking into account the principles of standardization, can be assigned: B 0.25; 0.5; 1; 2; 3; 4; 5; 6; 7; 8; 9; 10; 12.5; 15; 20; 25. The maximum involved class value should be B10 for modern brickwork.

## 4 Conclusion

The introduction of the concept of brickwork class together with a new standard for its testing will significantly improve the quality of brick construction, reduce the likelihood of accidents in buildings under construction and in operation, and make more efficient use of material resources. It allows regulating the coefficient of reserve and the variability of strength properties, achieving a high probability of failure-free operation $P_f = 10^{-3}$.

Switching to strength classes for brickwork will allow:

– controlling effectively the mechanical strength indicators in standard samples, which will increase the reliability, durability and safety of the structures being built. Control of masonry in structures using brickwork strength tests in standard samples will reduce the number of dangerous accidents due to an insufficient level of reliability due to exceeding the calculated brickwork strength over the actual one obtained experimentally;
– simplifying the marking of brickwork to reduce the range of design resistances of brickwork. At the moment according to the characteristics of the calculated strength in the standards there are more than 90 different groups of brickwork strength depending on the strength of bricks and mortar;
– simplifying the work of designers and builders when coordinating the work performed, increasing the possibility of interchangeability when creating a structure by selecting various more effective ratios of brick and mortar strength.

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