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Brickwork structure influence on reliability of structures being constructed

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Abstract. The modern brickwork development is related to the material quality improvement and reliability level enhancement for structures. To solve the above problem, this work substantiates moving to the probabilistic standardization of structural behavior of brickwork units taking into account the multi-level hierarchical structure. The complexity of brickwork structure is assessed experimentally on the basis of deformations of structural elements along and across the load direction. The work considers the substantiated reliability level and assurance coefficient, settable during a brickwork test in standard samples. This approach allows the considerable increase of the quality of material, reliability and failure safety of brick structures being constructed.

1. Introduction

The modern development of the building industry has led to a gradual substitution of brick structures by more effective and cheaper options. The existing approaches during designing and evaluation of the technical condition of operable masonry and reinforced masonry structures do not allow ensuring the optimal regulation level of its reliability. When analyzing the statistic data, illustrated at figure 1, one can make the conclusion that the accidents of masonry structures in some years are more than 50% of the total quantity of accidents. It should be noted that about 4% of all accidents are related to the imperfection of regulatory documents: designed structural loads were exceeded during operation [1, 10]. Today, brick and masonry structures require an additional study because their efficiency from the point of view of the usage of structural behaviors of elements (brick, stone and mortar) does not correspond to the modern vision [7].

The brickwork development and improvement shows that up to the 50s, the average concrete strength was equal to 20 MPa, and now it is 40–60 MPa. Today, it is possible to apply concretes with the strength of 100–200 MPa. For this time, the brickwork strength has not practically changed and is equal to 3.9 MPa, and, if different methods of its reinforcement are used, it is equal to 7.8 MPa [2].

2. Materials and Methods

The reasons of detected insufficient development of design theories of brickwork structures can be as follows:

1) The complexity of brickwork structure is related to the multi-level hierarchy of a system of joint-operating elements, different genesis and morphology, different geometrical sizes, etc. [8] The
brickwork structure is formed at 6 hierarchical levels from the most large-size to having a less size ones (mega-, macro-, meso-, micro-, submicro-, nano-level).

Figure 1. Accidents of buildings and structures in different structural solutions occurred during 1999-2003 [1]

2) The national standard, including the brickwork test requirements in standard samples, recently came into effect. The modified formula of Ohischik L.I. is the basis for the strength calculations. The European standards provide the possibility to use tests in standard samples [3, 5]. The calculations consider the brick strength during compression and bending, mortar strength during compression, brickwork type, while the coefficients reducing the brickwork strength depending on the mortar and brick type are used.

3) There are many brickwork types with different bonds, construction technologies, structural behaviors (chain, row, light, multi-layer, etc.).

4) There is a large quantity of brick and masonry types, including the ones appeared last time. The variety is also inherent to brick mortars (e.g., heat-protective, self-recovering, with elevated adhesion, etc.).

5) The material test methods and quality control methods are low-perfected [9].

6) The variety of reinforcement types and complex sections to improve the brickwork features.

7) Differences in staff qualification and construction conditions.

3. Results

The main structural brickwork behavior is designed at the macro-level, what is stipulated by the interface of structural elements of this level: brick, mortar of vertical and horizontal seams. The difference of element behavior of this level is well-demonstrated by the figure of separate elements deformations. Short-time and long-time deformations of elements should be considered, what causes the impairment of operation conditions for some structural elements and the improvement of others.

It shall be considered that brickwork deformations do not correspond to a simple total of brick and seam mortar deformations even with the account of proportions of the total thickness of mortar and brick
seams by height. The total brickwork deformations occurred to be considerably higher than the brick and mortar deformations, being separately tested. In order to assess the effect of stress and deformation field irregularity, an analysis of deformations was made on brickwork samples made of brick (M150) with cement-sand mortar (M150), deformations were measured by tensometers installed as shown at figure 2. In order to assess the stress-deformed condition of elements, deformations of brick, mortar of horizontal and vertical seams along and across the line of compressive force application were measured. Relative deformations of elements on the basis of experimental data are specified at figure 3.

![Figure 2](image_url)

**Figure 2.** View of installed tensometers at brickwork sample

The essential distinctions of element deformations are clearly seen, despite the apparent brickwork uniformity during mechanical loading, this is one of reasons of ineffective brickwork application.

![Figure 3](image_url)

**Figure 3.** Scheme of deformations of structural brickwork elements relative to corresponding brickwork deformations along load application line
4. Discussion
That is why, with the further development of brickwork calculation and design principles, it is required to rely on the reliability theory, based on probabilistic methods, what allows giving a more objective evaluation of carrying capacity of brick structures with the account of above mentioned problems. It will allow calculating the features of intricately structured brickwork material and random character of the inter-relation between the carrying capacity and external factors and loads. The reliability level is realized by the object capacity to execute the preset function during the designed service life with the account of structure failure risk and consequences.

The brickwork strength is about 20 – 30% of brick strength.

When designing masonry structures, some detected problems shall be solved after the implementation of GOST 32047-2012 Masonry. Method of compressive test [4]. While it is required to evaluate the assurance coefficients, ensuring the required reliability level and fail-safe structure operation probability [6].

\[
K_{saf} = \frac{R}{Q},
\]

(1)

where \(R\) and \(Q\) are allowable and normalized strength value correspondingly.

Besides, the safety characteristic or reliability index gains in especial value:

\[
\beta = \frac{K_{saf} - 1}{\sqrt{(V_R^2 K_{saf} + V_Q^2)}},
\]

(2)

\[
V_Q = \frac{S_Q}{Q}; V_R = \frac{S_R}{R}
\]

where \(V\) and \(V_Q\) are the strength and load variation coefficients.

The failure probability is determined by the formula:

\[
P_f = \frac{1}{2} - \Phi(\beta) = \frac{1}{2} - \frac{1}{\sqrt{2\pi}} \int_0^\beta \exp\left(-\frac{x^2}{2}\right)dx.
\]

(3)

An experimental test is made on samples of two types:
- of silicate modular brick M125 on cement-sand mortar M150 (composition 1: 2.92 W/C=0.65 CS=8-10 cm), sample sizes: 250×250, height of 5 rows;
- ceramic blocks with slot-like hollows of 14.3 NF M150 (h=400 mm) on cement-sand mortar M150, sizes of 60×40 cm, height of 3 rows.

By experimental data, the fail-safe operation parameters are calculated as per Russian and European regulatory documents; the results are specified in table 1.

Table 1. Fail-safe operation probability for experimental brickworks

| \(R_{mas}, \text{MPa} \) | Design Crack form. | Real | \(K_{saf} \) | \(B \) | \(P_f \) |
|---|---|---|---|---|---|
| SP | EN | | SP | EN | SP | EN | SP | EN |
| 2.0 | 2.02 | 2.4 | 4.84 | | 2.42 | 2.40 | 1.81 | 2.90 | 0.029937 | 0.001809 |
| 1.8 | 2.29 | 5.81 | | | | | | | 0.005939 | 0.00086 |
Taking into the consideration of variation of features of material $\nu_R$ and load $\nu_Q$.

| Standard | $\nu_R$ | $\nu_Q$ |
|----------|---------|---------|
| SP       | 0.47    | 0.288   |
| EN       | 0.25    | 0.288   |

5. Conclusions

The specified experimental data confirm that brickwork is an intricately structured material, which properties depend on the morphology and genesis of structured elements, level of their interaction and technology. That is why it is required to change approaches to designing and quality control of brick structures with the account of real structures and required reliability level of structures.

The adoption of probabilistic methods is curbed by insufficient knowledge of structure and properties; that is why, despite large assurance coefficients, acceptable as per the standards of the Russian Federation, safety index and fail-safe operation probability in the above rates stipulated in the European standards.

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