MASONRY RELIABILITY UNDER DIAGONAL SPLITTING

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Abstract. In this work, the issue of reliability assessment of masonry of existing building structures is covered. Attention is paid to the specificity of diagnostics and calculation of the reliability of these types of objects. Methods of determining the compressive strength of masonry in existing building structures are presented, taking into account the theory of reliability. Practical solutions are provided for determining the design strength of the masonry, which can be used in assessing the safety of massive brick walls and pillars, which are important structural elements of the existing brickwork. Stone houses have been the main building type in cities for centuries and many of them have survived to the present day. However, during the reconstruction and repair of such buildings, it is necessary to carry out calculations and tests to ensure their safe operation. The safety and reliability of a structure depends on many factors, such as the load applied to it and its bearing capacity. Given an acceptable probability of failure, reliability theory takes into account probabilistic approaches and methods for assessing and managing structural failure risks. Building codes and regulations provide requirements for load-bearing capacity, deformation and fire resistance of the structure, taking into account the social, economic and environmental consequences of failure. Characteristic damages of stone walls under the combined action of vertical and horizontal loads are analyzed. Considered possible patterns of masonry destruction. Diagonal shift is singled out as a typical case of wall failure under seismic effects. Emphasis is placed on the closeness of the loading conditions of load-bearing walls under the action of seismic force to those that occur in the frame when it is skewed. The results of experimental studies of stone samples on skew

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as models of the work of walls under seismic influences are considered. The nature of destruction, the determining factors affecting the load-bearing capacity of stone walls are analyzed: masonry material, strength of stone and mortar, internal and external reinforcement of masonry. On the basis of the analysis of experiments, suggestions are provided regarding kinematically possible schemes for the destruction of stone blocks, which are proposed as the basis for calculation. The problem of wall strength was solved by the variational method in the theory of plasticity, developed at the National University "Yuri Kondratyuk Poltava Polytechnic". The influence on the strength of the dimensions of the element and the platform of load application is considered.

1. Introduction

The safety and reliability of building structures depend on many factors, primarily on the type and magnitude of loads and the bearing capacity of their elements. The adequacy of the state of safety depends on compliance with the relevant construction standards and regulations [25, p. 41–50]. The standards provide requirements for the load-bearing capacity of cross sections, deformations, displacement of the structure or its fire resistance. These requirements take into account the consequences of failure, such as loss of life, as well as the social, economic and environmental consequences.

An acceptable level of probability of failure is most often measured in terms of the probability of its occurrence. One of the basic concepts of reliability theory is the axiom of inadmissibility of zero probability of failure. It states that it is impossible to design or create a structure that has absolutely zero probability of failure.

Ensuring earthquake resistance is always one of the main tasks in the design and construction of buildings and structures in earthquake-prone areas. Recently, the relevance of this problem for Ukraine has significantly increased due to frequent occurrences of earthquakes in Europe, including a large number of human victims and significant material losses [25, p. 91–99].

New seismic zoning maps of the ZSR-2004, put into effect in the norms [1, p. 180] since 2006, foresee an increase in the share of territories that may be under the influence of seismic influences with a high probability. Currently, approximately 15% of the territory of Ukraine is seismically dangerous with an estimated seismicity of more than 7 points.

The number of economic losses from earthquakes established as a result of the analysis for buildings with different structural schemes (with the same seismicity of the site) [2, p. 18–24] shows that the buildings with brick walls, widespread in Ukraine, are the most vulnerable to seismic influences and belong to the least earthquake-resistant type. This is caused, in particular, by the increased mass of structures and the presence of a large number of joints and seams, which leads to significant damage to building elements.

The results of recent studies show that houses with load-bearing stone walls receive the following characteristic damages from the action of seismic loads [3, p. 760–765]: inclined and cross-shaped cracks in walls and blind walls; vertical cracks at the joints of longitudinal and transverse walls with possible falling of wall fragments to the outside; horizontal cracks in the walls, more often at the level of the bottom of the window openings, lintels or at the level of the ceiling abutment; cracks in places where reinforced concrete bridges are laid; cracks of chaotic direction in the walls, which are a combination of the above [4, p. 851–856].

The analysis of the mentioned damages made it possible to identify their main schemes depending on the direction of load application (Table 1).

The calculation of stone masonry under the action of horizontal force according to national standards is carried out on a section (shear) (using calculated shear resistance of the masonry f_{vd}) and bending in the corresponding direction (taking into account the characteristics of tensile resistance during bending in unbonded cross-section f_{xk1} – with the fracture plane parallel to the horizontal seams, and the bending tensile strength of the bonded cross-section f_{xk2} – with the fracture plane perpendicular to the horizontal seams).

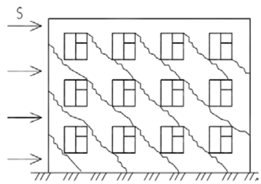
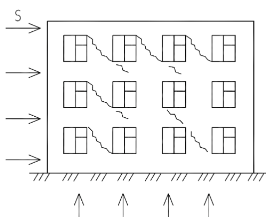
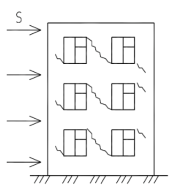
The combined, vertical and horizontal load is allowed to be taken into account by using the main eccentricities due to horizontal loads e_{hi} or e_{hm} when calculating the strength reduction factor Φ or by using the increased calculated tensile resistance of the stone masonry when bending in a plane parallel to the horizontal seam (unless cut section).

Currently, there is no reliable method for calculating stone structures under the combined action of vertical and horizontal forces, which would be based on a general theoretical basis.

In order to create such a technique and to make a justified decision regarding the effective strengthening of stone walls, it is necessary to

Table 1

The main schemes of damage to stone walls of buildings depending on the direction of load application

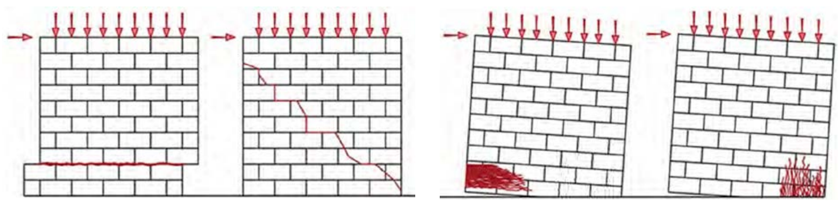
Direction of force, places of damage	Damage patterns	Characteristics of damage
Parallel to the longitudinal walls, the outer longitudinal walls.		At *slight vertical accelerations*, oblique cracks in the blocks and in the areas under the slots, horizontal cracks in the blocks near the top and bottom of the openings.
Parallel to the longitudinal walls; external and internal longitudinal walls.		At *large vertical accelerations*, oblique cracks in wide pylons with horizontal sections in the masonry between slots, destruction of bridges.
Perpendicular to the longitudinal walls; external and internal transverse walls.		With *slight vertical accelerations* in walls with slots: oblique cracks in the jambs and window belts, horizontal cracks in the jambs near the top and bottom of the openings. Damage is most developed in the lower floors.

analyze the nature of their destruction and the results of physical modeling in the experiment. The obtained data serve as a basis for creating calculation schemes of elements when assessing their strength.

2. The main types of destruction of brickwork under the combined action of vertical and horizontal forces

In scientific literature [5, p. 180] based on the results of experimental studies, a classification of cracks observed in stone walls under the joint action of vertical and horizontal forces is proposed. The main types include: trunk vertical cracks that divide the wall surface into separate vertical blocks; main inclined diagonal cracks located within inclined compressed bands; inclined cracks, which delineate the boundaries of an inclined compressed band (area of destruction); microcracks, the accumulation of which causes fragmentation of stonework; cracks in the stretched zone; cracks that characterize the section of compressed masonry in inclined compressed strips.

The proposed classification can be considered as a criterion for the implementation of separate masonry failure schemes: shear in the horizontal plane, diagonal shear, fracture along the stretched zone, and fragmentation (Figure 1).



a b c d

Figure 1 – The nature of the destruction of brickwork under the combined action of vertical and horizontal loads:
a – displacement in the horizontal plane; b – diagonal shift;
c – destruction behind the stretched zone; d – fragmentation

One of the most vulnerable structures of brick buildings from the point of view of earthquake resistance are window partitions, cases of destruction of which are shown in Figure 2 [6, pp. 1–3].

The width of the wall to some extent affects the arrangement of cracks. The most characteristic damage to the walls is the formation of oblique and X-shaped cracks, which spread mainly along the seams of the masonry, starting in the corners of the holes and other places of weakening (changes in stiffness).

According to [7, p. 36–42] under the action of seismic force, the walls of the load-bearing walls are under loading conditions that are close to those that occur in the frame when it is skewed.

In the first stage of brickwork deformation (Figure 3), when the seismic forces are small, the walls work together with the window belt over the

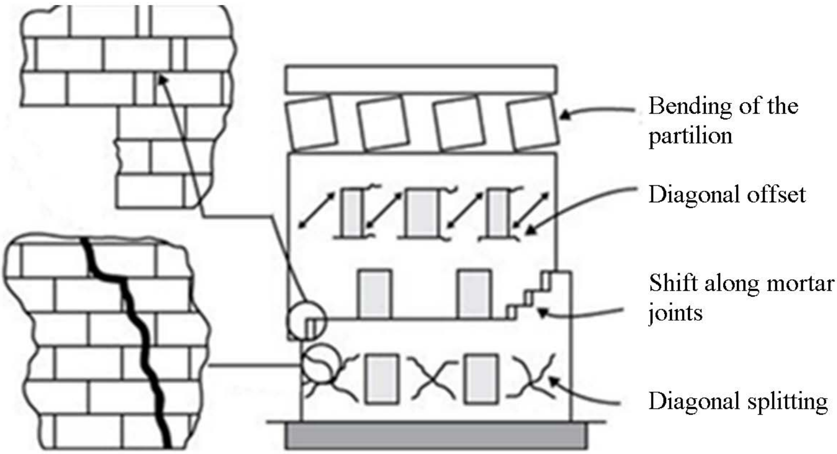


Figure 2. Cases of the destruction of window partitions under seismic effects

entire contact area. The vertical load is transferred from the upper wall to the lower one at all levels along the entire horizontal section.

In the second stage, cracks are formed in the stretched zones of the horizontal section of the blocks at the levels of the upper and lower parts of the slots adjacent to them, and the contact between the masonry is broken. At this stage, the load transfer in the mentioned sections is carried out only along the length $a_c < 2a$ (where a is half the width of the wall). When horizontal load changes in sign, the bond in the masonry is broken at the contact of the top of the wall and the bottom of the belt due to the formation of cracks.

The third stage is characterized by the further reduction of the length of the compressed zone and the formation of a diagonal crack in the wall. Partitions on different floors of the building may be at different stages of deformation, which is associated with a change in the magnitude and ratio of vertical and horizontal forces, as well as with possible differences in the strength and stiffness of the partitions.

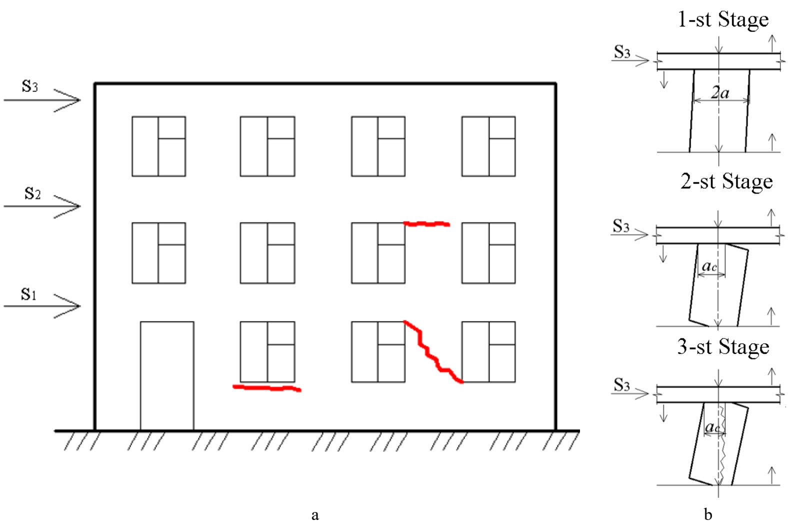


Figure 3. Operation of load-bearing wall blocks under the action of a horizontal seismic force:
a – typical damage; b – stages of deformation of the wall

3. Experimental studies of brickwork under the simultaneous action of vertical and horizontal loads

An experimental study of the work of window partitions on the combined effect of vertical and horizontal load can be carried out by testing fragments of vibro brick walls for shift [8, p. 60]. Peculiarities of filling work in frame and stone buildings were studied [9, p. 188]. A large volume of experimental studies of the strength and deformability of fragments of masonry made of various types of bricks, limestone and other materials during skewing without frame has been accumulated. In most cases, the samples were tested with a concentrated load applied along one of its diagonals (Figure 4). To prevent buckling of the loaded masonry corners, the latter were reinforced with steel or reinforced concrete shoes. With such a test scheme, the strength indicators of the samples are affected by the length of the support platforms (l_{loc}), through which the load is transferred to the sample.

Various methods of increasing the load-bearing capacity of elements with the simultaneous action of vertical and horizontal forces were investigated.

Known experiments with vibro brick panels with side dimensions of 1060×1060 mm, 1120×1120 mm, 800×800 mm, 800×1200 mm and 800×1600 mm [10, p. 76–82]: without reinforcement and with reinforcement with vertical rods and wire meshes through three rows of masonry, which did not increase the strength of the samples. The desired result was achieved with external reinforcement, and here the distance between the moment of formation of a diagonal crack and the destruction of the element increased significantly.

In work [11, pp. 26–31], test samples with dimensions of 1060×1060×250 mm made of solid brick with a strength of f_b = 10 MPa were tested on a cement-sand mortar strength f_m =7.5 MPa: control samples without reinforcement and reinforced on one or both sides with carbon fiber FibARM Tape 230 and FibARM Tape 240 and binding FibARM Resin 230+ and FibARM Resin 530+. The application of the external reinforcement system made it possible to increase the load-bearing capacity of stone masonry by 30– 100%, depending on the strength of carbon fiber, area, thickness and number of reinforcement layers. The destruction of these samples, unlike those reinforced with reinforced concrete and concrete applications, which are applied by conventional technology and the shotcrete method, occurred along the diagonal crack on the outside, fragile, almost instantly after reaching the limit loads.

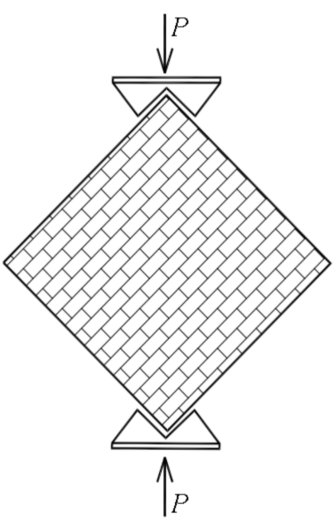


Figure 4. Scheme of testing brick blocks with a concentrated load applied along one of their diagonals

During the tests [12, p. 259–265] of unreinforced samples with dimensions of 500×500×140 mm made of bricks with strength f_b = 15 MPa, the moment of formation of diagonal cracks coincided with the moment of destruction. At the same time, depending on the strength of the solution, the following mechanisms of destruction were observed: splitting along the diagonal, in which the crack trajectory passes both behind the stones and along individual vertical and horizontal seams of the masonry (for a solution with compressive strength f_m = 7.9 – 10.9 MPa); diagonal splitting, in which the critical crack has a stepped trajectory and passes only along the horizontal and vertical seams of the masonry; shift along the horizontal mortar joint (the last two types of failure were observed when using mortar with a strength of fm = 3.1 MPa).

Experiments were conducted [13, p. 183–205] on masonry samples with dimensions of 500×500×65 mm, for the manufacture of which solid and hollow bricks were used in standard mortars with compressive strength f_m = 3.1, 7.9 and 10.9 MPa. The obtained results indicate a decrease in the strength of the masonry at the shear f_{vv} at the strength of the solution f_m = 3.1 MPa.

Samples with dimensions of 1030×965×250 mm were tested using bricks of medium strength f_b = 12.5 MPa on mortar with strength f_m = 7.5 MPa: control samples and reinforced with MBRACE FIB CF230 / 4900.200g / 5.100m carbon fiber fabric from one and two sides of the sample along its stretched diagonal [14, p. 36–42]. The carrying capacity in the first case of external reinforcement increases by approximately 1.5 times, and in the second case by 2 times.

At work [15, p. 303–317] the results of experimental studies of the strength of four series of samples under the action of static and pulsating loads directed along the diagonal are given. Both traditional masonry and vibro brick elements were used. Reinforcement was carried out by applying a plaster layer of high-strength solution on the side surfaces or reinforcing the latter with metal meshes. Vibration and the presence of plaster layers on the side surfaces of the samples increases the strength of the masonry up to 2 times; reinforcement moves the destruction away from the moment of crack formation, creating conditions for the development of plastic deformations. The destruction of brick elements took place along a diagonal crack that spread along the seams, vibrating brick samples were destroyed along a tied section; and reinforced vibro brick samples – along an inclined compressed strip. The effect of reinforcement with steel diagonal ties or pre-compression on the masonry resistance was also analyzed.

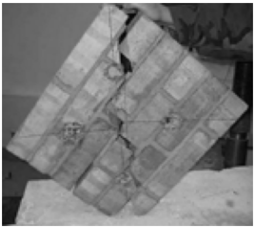
Experimental studies were conducted [16, p. 397–412] test samples with strength characteristics of brick f_b = 21.06 MPa and mortar f_m = 3.72 MPa. The first two series had three non-reinforced brick blocks with dimensions of 700×700×115 mm (single-layer) and 700×700×230 mm (double-layer). Samples 3-6 series were reinforced externally (in one and two planes) with welded wire mesh placed in a layer of concrete. The failure of the unreinforced specimens occurred along a jagged diagonal crack and was sudden and outwardly brittle. The authors propose to consider such destruction as a combination of diagonal shear and horizontal sliding. The behavior of reinforced samples depended on their thickness, intensity and method of reinforcement. The destruction began with the formation of a diagonal crack, the development of which was restrained for some time by the reinforcement, which contributed to a more plastic failure compared to samples without reinforcement. For samples reinforced in one direction, the failure was accompanied by cracks localized at the edges of the sample. With large displacements, significant local fragmentation of the concrete adjacent to the welded mesh was observed, which was torn in some places. For samples reinforced in two directions, the failure occurred along a crack that spread along the length of the compressed diagonal of the samples. At the last stage of loading, local fragmentation of the masonry near the loading shoes was observed. The increase in shear strength of reinforced samples compared to reference ones was in the range of 0.57–1.48 MPa.

In experiments [17, p. 48–66] for the manufacture of samples with dimensions of 2100×1560×240 mm and 1560×1560×240 mm, solid bricks and ordinary mortar were used. Three samples without reinforcement acted as reference, the other 8 were reinforced with reinforced cross and horizontal strips of mortar 250 mm wide. In the experiment, the strength of the masonry solution and reinforcement strips, their thickness, the intensity of reinforcement of the strips, the location of the reinforcement (on one or both sides), and the amount of vertical load were varied. Bricks with dimensions of 240×115×53 mm with f_b = 10 MPa and mortar with f_m = 1 MPa, 2.5 MPa and 10 MPa for non-reinforced elements were used to make the samples. For reinforcement strips with a thickness of 40 mm and 60 mm, a solution with f_m = 2.5 MPa, 5 MPa and 10 MPa was used, respectively. The tapes were reinforced with steel rods with a diameter of 6-12 mm. In the reference samples, the first diagonal crack appeared in the center of the wall. It spread mainly along the horizontal and vertical layers of the mortar, while also crossing the bricks. Sometimes a second diagonal crack perpendicular to the first one could appear. Reinforced samples collapsed from shear-compression along diagonal and vertical cracks, the latter appeared in unreinforced areas of the wall. Provided that the maximum load-bearing capacity was reached, the tapes maintained their integrity and prevented the collapse of the test samples during destruction. The cracking load for reinforced elements increased by 20-40%, and the destructive load by 40-65%. An increase in the reinforcement ratio of the strips, the level of vertical stresses, and the strength of the solution increased the shear resistance, while an increase in the ratio of the thickness to the width of the element, on the contrary, decreased it. Reinforcement increased the plastic properties of masonry by 1.6 times with one-sided reinforcement, and 2.8 times with bilateral reinforcement.

In experiments [18, p. 330–336] samples with dimensions of 1200×1200×250 mm was used with the average compressive strength of brick f_b = 24.03 MPa and mortar f_m = 5.68 MPa. The samples were reinforced with a fiberglass mesh on both sides of the wall, followed by the application of a solution layer.

In the control unreinforced samples, the destruction occurred according to compressed diagonally, mainly along soluble seams. However, in some cases, a combination of sliding along the mortar horizontal joints over a length of approximately 500 mm with a diagonal crack that propagated exclusively through the mortar joints was observed. Fiberglass-reinforced samples were destroyed along the compressed diagonal, their strength increased by an average of 1.3 times, while the plastic characteristics of the masonry increased.

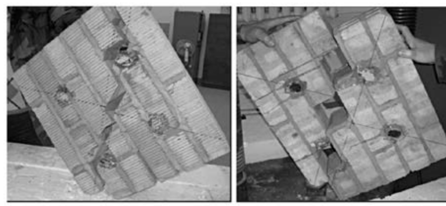
Therefore, analyzing the experimental studies of brickwork on skew, which can be considered as a simulation of the work of brick blocks under the combined action of vertical and horizontal seismic forces, it should be noted that the most characteristic variant of destruction (Figure 5) is a diagonal shift according to the classification (a crack can be stepped – extends only along vertical and horizontal soluble seams or straight – crosses both seams and stone). Local fragmentation of the masonry near the cargo shoes is also observed.



I.E. Demchuk's experiments

M. Enea's experiments

S. Kadam's experiments



V.N. Derkach's experiments

Figure 5. Diagonal section of masonry in experimental studies on skew

Undoubtedly, the most complete data on the nature of deformation and destruction of masonry during shearing can be obtained experimentally. However, experiments require significant costs, and most importantly, they are parametrically limited, so numerical calculation is an effective addition to them. A correct mathematical model is a tool for analyzing the influence of selected parameters and their combination on the stress-strain state of masonry.

4. The proposed methodology for calculating strength in diagonal splitting

As a calculation model, it is proposed to use the variational method in the theory of plasticity [19, p. 76–82], which is widely used in the calculations of concrete and reinforced concrete structures with a sectional failure scheme [20, p. 19–26]. The analysis of the considered experimental material made it possible to propose a substantiated kinematically possible scheme for the destruction of stone elements during skewing, which serves as the basis for the application of the method of calculating the strength of such structures by the variational method in the theory of plasticity.

In the theoretical model (Figure 6), in the stage of destruction, the wall is divided into four hard disks: two wedges under the loading platform (in general, the wedges can be non-equilateral) and two hard disks delineated by the sliding sections of the wedges and the cleavage plane that connects the vertices wedges

The frontal projection of the sample has the shape of a rectangle, i.e. $L \neq H$, the sizes of the load areas on the vertical and horizontal faces of the element differ from each other $a_1 \neq a_2$. Accordingly, the angles of the sealing wedge $\gamma_1 \neq \gamma_2$.

The element strength problem is solved in the following sequence [28, p. 41–63]:

1) initially there are speed jumps on the sections of the fracture surface AC, BC, CC1 (Figure 7), as well as the sizes of these sections:

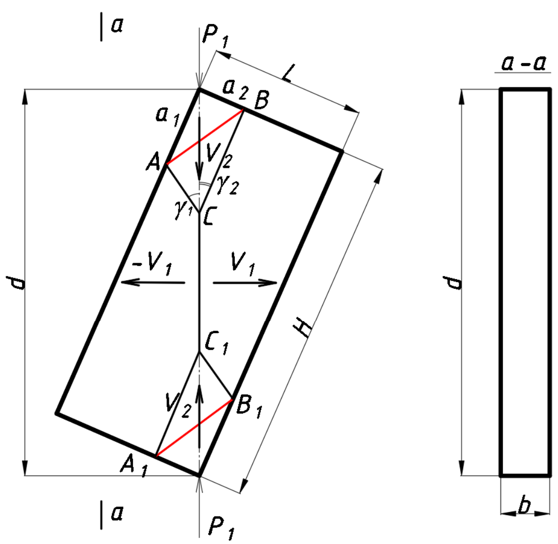


Figure 6. Kinematic diagram of the destruction of a brick wall during diagonal splitting

$$\left.\begin{aligned}\Delta V_{n1} &= V_1\cos\gamma_1 - V_2\sin\gamma_1\\ \Delta V_{t1} &= V_1\sin\gamma_1 + V_2\cos\gamma_1\\ \Delta V_{n2} &= V_1\cos\gamma_2 - V_2\sin\gamma_2\\ \Delta V_{t2} &= V_1\sin\gamma_2 + V_2\cos\gamma_2\end{aligned}\right\}, \tag{1}$$

here γ_1 and γ_2 – the angles of inclination of the AS and VS destruction areas to the vertical plane (unknown parameters);

– surface areas, respectively:

$$S_{AC} = \frac{a_1\sin\alpha_1}{\sin\gamma_1}b,\ S_{BC} = \frac{a_2\sin\alpha_2}{\sin\gamma_2}b. \tag{2}$$

where b is the thickness of the sample; $\sin\alpha_1 = \frac{tg\alpha_1}{\sqrt{1+tg^2\alpha_1}}$; $\sin\alpha_2 = \frac{tg\alpha_2}{\sqrt{1+tg^2\alpha_2}}$; $tg\alpha_1 = L/H$; $tg\alpha_2 = H/L$.

– for the CC_1 section speed gaps:

$$\left.\begin{aligned}\Delta V_n &= 2V_1\\ \Delta V_t &= 0\end{aligned}\right\}, \tag{3}$$

and the surface area of the site CC_1:

$$S_{CC_1} = \frac{H}{\cos\alpha_1} - 2a_1\left(\cos\alpha_1 + \frac{\sin\alpha_1}{tg\gamma_1}\right); \tag{4}$$

2) write down the functional of the variation method, which includes three components:

– power of plastic deformation of brickwork on the area AC

$$m\left[2B\sqrt{1+0,25\left(\frac{\Delta V_{t1}}{\Delta V_{n1}}\right)^2} - 1\right]\Delta V_{n1}S_{AC}, \tag{5}$$

– power of plastic deformation of brickwork on the area BC

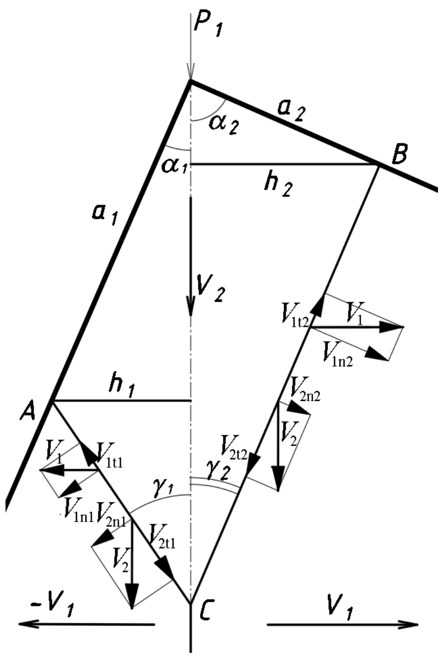


Figure 7. To determine the parameters at the destruction sites

$$m\left[2B\sqrt{1+0,25\left(\frac{\Delta V_{t2}}{\Delta V_{n2}}\right)^2}-1\right]\Delta V_{n2}S_{BC} \tag{6}$$

– the power of external forces at given speeds on sites CC_1 and AB (section CC_1 is taken as the main one, on which the ultimate tensile stresses act, the last component describes the action of external forces on section AB)

$$f_{xd2}V_1S_{CC_1}-f_{loc}V_2S_{AB}\,. \tag{7}$$

After substituting the components in the functional of the method, certain mathematical transformations and taking into account its equality to zero, a formula is obtained for determining the limit load in the function from unknown parameters

$$\frac{P_{1u}}{mb}=R_1+R_2+\frac{f_{xd2}}{m}\left(\frac{H}{\cos\alpha_1}-2a_1\left(\cos\alpha_1+\frac{\sin\alpha_1}{tg\gamma_1}\right)\right), \tag{8}$$

here $R_1=\left[2B\sqrt{(k-tg\gamma_1)^2+0,25(k-tg\gamma_1+1)^2}-(k-tg\gamma_1)\right]\dfrac{a_1\sin\alpha_1}{tg\gamma_1}$,

$$R_2=\left[2B\sqrt{(k-tg\gamma_2)^2+0,25(k-tg\gamma_2+1)^2}-(k-tg\gamma_2)\right]\frac{a_2\sin\alpha_2}{tg\gamma_2},$$

where $m=f_d-f_{xd2}$; $B^2=\left(1+\chi/(1-\chi)^2\right)/3$; $\chi=f_{xd2}/f_d$; $k=V_1/V_2$.

The angles of inclination of the faces of the sealing wedge are interdependent

$$tg\gamma_1=\frac{tg\alpha_1tg\gamma_2}{k_1tg\alpha_1tg\gamma_2-tg\gamma_2+k_1}, \tag{9}$$

here $k_1=a_2/a_1$.

In the case of symmetrical application of the load for a square sample, we use kinematically possible scheme (Figure 8).

Formula (8) for determining the limit load takes the form

$$\frac{P_{1u}}{mb}=\left[\frac{2B\sqrt{(k-tg\gamma)^2+0,25(ktg\gamma+1)^2}-(k-tg\gamma)}{(k-tg\gamma)}\right]\left(\frac{k-tg\gamma}{tg\gamma}\right)+$$
$$+\frac{f_{xd2}k(atg\gamma-1)}{tg\gamma m}, \tag{10}$$

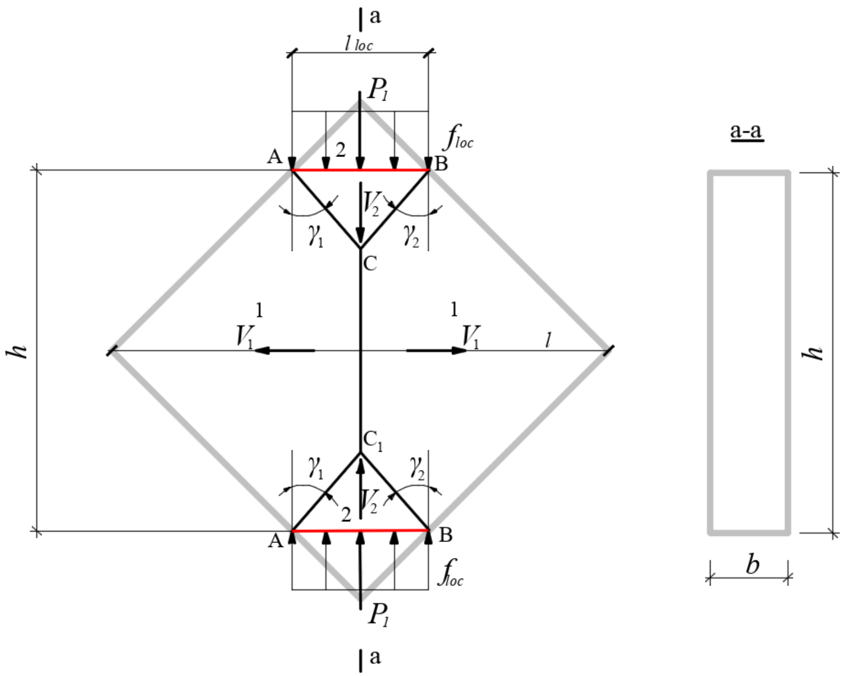


Figure 8. Kinematically possible failure scheme of a square brick sample under diagonal loading

here $\alpha = h / l_{loc}$.

When solving the strength problem, the MS Excel spreadsheet and its "Solution Search" add-in are used: the objective function (10) is optimized according to unknown parameters $tg\gamma$ and k.

5. Assessment of the reliability of stone structures

It is impossible to achieve absolutely zero probability of structural failure. Reliability theory takes into account these uncertainties and sets itself the task of assessing and managing the risks of structural failure, taking into account probabilistic approaches and methods. This involves taking into account an acceptable probability of failure. The probability of failure (P_f) is determined by the following formula:

$$P_f = P\left[g\left(X\right) \le 0\right] \int\limits_{g(X) \le 0} f\left(x\right) dx \tag{11}$$

g (X) is a quality function,

X is a vector of basic random variables,

f_X () is a multidimensional function of variables x.

EN-1990 standards [25, p. 87–88] indicate the permissible probability of failure depending on the classes of failure consequences (CC3, CC2, CC1) and reliability classes (RC3, RC2, RC1). An important safety parameter is the reliability index (β), which is related to the probability of failure by the ratio:

$$\beta = \ln\left(\frac{1}{P_f}\right) \tag{12}$$

β – reliability indicator (relative reliability coefficient)

P_f – failure probability

This ratio makes it possible to estimate the reliability index (β) based on the given probability of failure (P_f). When designing and evaluating structures in accordance with European standards, the reliability index (β) and the probability of failure (P_f) play an important role in determining the required level of safety and reliability of the structure. The reliability estimation method associated with the reliability index (β) is often called the second-level probabilistic method.

The vector F of random events of structural failure is defined as a function:

$$F = \left\{g\left(x\right) \le 0\right\} \tag{13}$$

g (x) is a quality function:

$$g\left(x\right) = R\left(x\right) + E\left(x\right) \tag{14}$$

R (x) is resistance,

E (x) is the effect of actions,

R (x), E (x) are random variables.

A building is considered to have survived if:

$$g = R - E \ge 0 \tag{15}$$

The criterion of the reliability of the structure in the probabilistic method of level II can be written by comparing the calculated resistance (R_d) and the calculated value of the influence of the influence (E_d):

$$R_d \ge E_d \tag{16}$$

Taking into account the reliability index (β), formula (17) can be presented in the form:

$$R_d = \mu_R - \beta_R \sigma_R \geq \mu_E + \beta_E \sigma_E \tag{17}$$

$$\beta_R = \beta |\alpha_R|, \beta_E = \beta |\alpha_E|$$

α_R, α_E – values of sensitivity coefficients to the effects of resistance and action, respectively.

The calculated resistance R_d can be expressed in the following form:

$$R_d = \frac{1}{\gamma_{Rd}} R(X_d; a_d) = \frac{1}{\gamma_{Rd}} R\left(\eta \frac{X_k}{\gamma_m}; a_d\right) \tag{18}$$

X_d – estimated value of material property,
X_k – characteristic value of material property,
γ_{Rd} – partial coefficient covering the uncertainty in the resistance model,
η – conversion factor,
γ_m – partial coefficient for material property,
a_d – calculated value of geometric data.
Provided that:

$$\gamma_{Rd} \gamma_m = \gamma_M \tag{19}$$

the calculated resistance R_d can be obtained as follows:

$$R_d = R\left(\eta \frac{X_k}{\gamma_M}; a_d\right) \tag{20}$$

The main task in the calculation of stone structures is to determine the load-bearing capacity of walls and columns subjected to loads compression Thus, in equation (20), the material parameter that determines the resistance of the wall or column is the compressive strength of the masonry ($X_k = f_k$; $X_d = f_d$). The calculated value of the compressive strength of masonry (f_d) is:

$$f_d = \eta \frac{f_k}{\gamma_M} \tag{20}$$

The methods of determining the standard compressive strength of masonry (f_k) and the value of the partial margin of strength (γ_M) are given in the standard EN 1996-1-1 [26, p. 89]. However, these norms apply only to recently erected stone structures. At present, there are no norms by which it is possible to determine the masonry strength of existing structures, which makes it very difficult to analyze such types of structures.

In the standard EN 1996-1 [26, p. 90] it is recommended that the values of the partial coefficient of strength margin (γ_M) are determined on the basis of classes related to performance control, the type of solution provided for in the project, and the brand of brick that will be used in masonry. Thus, this factor primarily captures the difference between the masonry strength selected in the design and the masonry that can be found in the structure. For the analysis of existing structures, the situation is completely different. The safety factor should be determined on the basis of the test results and take into account the uncertainty arising from the limitations of the research methods used.

In the calculation schemes presented in this work, it is possible to take into account the destruction behind the stone and mortar (along the diagonal plane) or only under the mortar (broken, which passes along the vertical and horizontal seams) by using different characteristics of the tensile masonry resistance.

In addition, the ratio between the vertical and horizontal components of the load significantly affects the dimensions of the loading platform: when the magnitude of the horizontal force increases, its dimensions decrease. At small values of the horizontal force, on the contrary, the dimensions of the sealing wedges increase and the length of the separation section decreases, which usually leads to an increase in the destructive load.

6. Conclusions

1. One of the most vulnerable constructions of a building with load-bearing brick walls in terms of seismic resistance are partitions. According to the results of the research, the walls under the action of seismic force are under load conditions that are close to those that occur in the frame when it is skewed. The third stage of wall deformation is characterized by a significant reduction in the length of the compressed zone due to the spread of contour horizontal cracks at the level of the bridge and is accompanied by the formation of diagonal cracks.

2. Research results show that buildings with load-bearing brick walls receive the following typical damages from the action of seismic influences: inclined and cross-shaped cracks in blocks and solid walls; vertical cracks at the intersection of longitudinal and transverse walls; horizontal cracks in the walls, mostly at the level of the bottom of window sections, lintels; cracks of chaotic direction, which are a combination of the above.

3. Experimental studies of the operation of brick blocks under the combined effect of vertical and horizontal loads were carried out when testing masonry samples for skew. In most cases, the samples were tested for a concentrated load applied along their diagonals.

4. The nature of the destruction, the determining factors of influence were analyzed: masonry material, strength of stone and mortar, internal and external reinforcement of masonry, reinforcement with mortar and concrete applications, cross and horizontal reinforced concrete strips, carbon fiber, diagonal metal ties and others.

5. Based on the results of the analysis of the nature of the destruction of the test samples, kinematic schemes of destruction are proposed, which are the basis for calculating the strength of masonry.

6. To determine the load-bearing capacity of the walls of stone buildings, the variational method of the theory of plasticity is promising, which can be used to calculate structures whose materials' resistance to compression and tension is significantly different. Dependencies for determining the strength of masonry specify the existing regulatory methodology for calculating the bearing capacity of the walls of the building.

7. One of the basic concepts of reliability theory is the axiom of inadmissibility of zero probability of failure, which means the impossibility of creating a structure with absolutely zero probability of failure. Reliability theory therefore takes into account probabilistic approaches and methods for assessing and managing structural failure risks with an acceptable probability of failure.

8. The probability of failure (P_f) is an important parameter for assessing the reliability of the structure. Taking into account the probability of failure allows for a rational approach to planned repair and reconstruction of buildings, ensuring their normal operation.

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