Research on the Strength of Compressed Masonry Elements from Cellular Concrete Blocks with Transverse Reinforcement

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Abstract. The work is devoted to the study of the possibility of using transverse reinforcement to increase the bearing capacity of masonry from aerated concrete blocks and the development of a calculation method that allows to quantify the proposed reinforcement. The need for the formulation of such studies was due to the lack of regulatory data regarding the reinforcement of the masonry concrete blocks, as well as an increase in production volumes and demand for cellular concrete. The results of experimental studies of masonry of aerated concrete blocks, reinforced by welded meshes under the short-term action of axial compressive loads are presented. The effect of increasing the carrying capacity due to the constraint of deformation of the masonry due to transverse reinforcement is revealed. The reinforcement rods of welded meshes, located in horizontal mortar joints, possessing a much greater modulus of elasticity than the masonry, prevent the development of masonry deformations in the transverse direction and, thereby, create lateral compression stresses. The proposed and experimentally confirmed by the authors method of increasing the carrying capacity of compressed elements, based on the principle of transverse (indirect) reinforcement of stone materials, can be applied to the laying of concrete blocks.

1. Introduction
The use of various types of concrete and masonry for the erection of bearing and enclosing structures of buildings retains a dominant position for the furthest perspective. A significant role in the further improvement of structures made of concrete should play a decrease in their mass. In this regard, over the past decades, the role of cellular and porous concretes has significantly increased, which are finding more and more widespread and complex application, not only as heat insulating, but also as an effective structural material for bearing wall structures of buildings [1, 5, 9, 19, 23]. The problem is becoming relevant especially now, as there is a tendency for a wider use of such types of concrete in construction due to a change in thermal requirements not only for enclosing buildings, but also for the supporting structures of buildings and the constant increase in energy prices for heating buildings [2, 4, 11, 12, 17, 20]. New plants and lines for the production of small-piece wall products, mainly blocks of cellular foam and gas concrete, were commissioned. This phenomenon is dictated by economic factors that determine the need to use the most efficient products, based on its cost, thermal conductivity and environmental friendliness.
The use of cellular concrete opens up broad possibilities for creating fundamentally new and efficient bearing and enclosing structures, makes it possible not only to reduce the size and weight of structures, but also at the same time reduce the weight of the building, which will significantly reduce the load on the foundation and reduce the size of foundations.

2. Statement of the problem
In the current regulatory documents due to the lack of knowledge of the properties of cellular concrete structures there is no number of provisions for their design. In particular, this applies to the elements of the laying of small cellular concrete blocks with transverse reinforcement, which prevents their practical use. The experience of using masonry structures has shown that transverse (indirect) reinforcement is an effective means to increase strength, crack resistance and reduce the material intensity of compressed elements [3, 6-8, 21-22]. Laying rebar in horizontal mortar joints of masonry in the process of erection design allows you to increase its carrying capacity and reduces deformation. In addition, this method of reinforcement, from a production point of view, does not cause difficulties, since it fully meets the requirements of the modern construction industry. The implementation of similar tasks aimed at filling the existing gap in relation to masonry of small cellular concrete blocks with transverse reinforcement will allow the use of transverse reinforcement in the design of heavily loaded wall elements of buildings, increase the number of floors of buildings and reduce their overall weight.

The aim of the work is to study the possibility of using transverse reinforcement to increase the strength of masonry from cellular concrete blocks and to develop a calculation method that allows us to quantify the proposed reinforcement. The content of the work is considered as an integral part of the task of a comprehensive study of the construction and technical properties of combined structures of cellular and porous concrete, recommended for use in modern construction [10, 13-16, 18].

3. Methodical provisions of experimental studies
According to the plan of the experiment, 12 experimental elements reinforced with welded meshes and 3 unreinforced experimental elements of the same size were manufactured and tested to study the effect of the grids on the parameters studied and the strength of the experimental elements (figure 1). Experimental elements are made in the form of a masonry fragment of 300x300x1100 mm in size from wall gas silicate blocks of class B2 compressive strength, average density marks D600 and cold resistance mark F25 on cement-sand mortar, model 50. Welded grids for transverse reinforcement are made of wire, diameter of 3 mm, class B500. The percentage of masonry reinforcement \( \mu_{xy} \) in volume by transverse meshes was determined by the formula (1) and was 0.06; 0.12; 0.19 \( \pi \) 0.27.

\[
\mu_{xy} = \frac{200 \cdot A_s}{c \cdot s}
\]  

(1)

where \( A_s \) - cross-sectional area of mesh reinforcement; \( c \) – mesh size; \( s \) – grid spacing.

The control of the physico- mechanical properties of cellular concrete was carried out according to the results of tests of cubes with a rib size of 150 mm and prisms of 100x100x400 mm cut from an array of blocks used for the laying of experimental elements. The grade of the masonry mortar according to compressive strength and its deformation properties were determined on sample cubes with a fin size of 70.7 mm and prisms of 40x40x160 mm made from the solution used for the laying of experimental elements. In total, 6 samples of cubes, prisms and reinforcing wire were tested for each series of experimental elements.

Testing of control samples for axial compression and tension was carried out taking into account the requirements of COST 12852.1-77, COST 10180-2012, COST 24452-80, COST 5802-86, COST 10446-80, COST 12004-81 on specialized equipment of the center for collective use named after Prof. Yu.M. Borisov, created on the basis of the Voronezh SUACE.

The test results of control samples of cellular concrete, masonry mortar and reinforcing wire are presented in table 1.
The test of experimental elements for axial compression was carried out in a hydraulic press with hinged end support and preliminary centering along the physical axis. Measurement of the deformations of the reinforcement was carried out by the electric strain method. The measurement of the longitudinal and transverse deformations of the experimental elements was carried out with the help of hour-type indicators with a division value of 0.001 mm, installed on the base of 200 mm in both the longitudinal and transverse directions on all its four edges. The age of the experimental elements at the time of testing was 28 days. The loading of the test specimens was carried out in steps until their destruction, as a result of which experimental data were obtained on the magnitude of the increase in the strength of the experimental elements depending on the percentage of indirect reinforcement.

### Table 1. The results of testing samples of gas silicate, masonry mortar and wire.

| Mechanical properties | Gas silicate | Masonry mortar | Wire Ø3 B500 |
|-----------------------|-------------|----------------|-------------|
| Cubic strength R (MPa) | 3.4         | 5.8            | -           |
| Prismatic strength Rb (MPa) | 3.0        | 4.4            | -           |
| Elastic modulus E_b/E_s (MPa) | 2080      | 2400           | 208800      |
| Poisson's ratio ν | 0.165       | 0.21           | -           |
| Relative longitudinal strain ε_z,u | 183·10^{-5} | -             | -           |
| Relative lateral deformations ε_xy,u | 45·10^{-5} | -             | -           |
| Turnover limit σ_y (MPa) | -          | -             | 389.0       |
| Temporary tear resistance σ_u (MPa) | -         | -             | 671.9       |
| Deformation at break, % | -          | -             | 18.2        |

4. Results of experimental and theoretical studies

As a result of tests of compressed masonry elements from cellular concrete, it has been established that with an increase in the percentage of transverse reinforcement μ_xy, an increase in strength occurs (table 2). The effect of lateral pressure created by transverse meshes on a loaded experimental element changes the conditions for the occurrence and development of cracks. The reinforcing wire of welded meshes located in the horizontal mortar joints of the experimental element, having a much greater modulus of elasticity than masonry, prevents the development of deformations of the experimental elements.
element in the transverse direction and, thereby, creates stress lateral reduction. The restraining influence of the transverse deformations of the experimental element with grids can be traced by the nature of the change in the transverse strain coefficient. (figure 2).

Table 2. Experimental and calculated characteristics of experimental elements.

| Mark experienced item | % reinforcement μxy | breaking load N_u (kN) | Strength of masonry R_u (MPa) | Estimated masonry resistance R (MPa) | Strain in transverse reinforcement σ_u (MPa) | Efficiency ratio k |
|-----------------------|---------------------|------------------------|-------------------------------|-------------------------------------|------------------------------------------|-------------------|
| KC-1                  | 0                   | 221                    | 2.46                          | 1.09                                | -                                        | -                 |
| KC-2                  | 0.06                | 238                    | 2.64                          | 1.18                                | 72.7                                    | 2.27              |
| KC-3                  | 0.12                | 251                    | 2.79                          | 1.24                                | 71.2                                    | 1.97              |
| KC-4                  | 0.19                | 264                    | 2.93                          | 1.30                                | 66.3                                    | 1.78              |
| KC-5                  | 0.27                | 273                    | 3.03                          | 1.35                                | 63.0                                    | 1.52              |

With an increase in the percentage of shear reinforcement, the efficiency coefficient and the magnitude of the elastic characteristic decrease, and the strain modulus increases, i.e. constraining transverse deformations due to reinforcement increases the stiffness of the experimental elements already in the initial stages of their work under load. Both relationships between the change in the efficiency ratio of the reinforcement and aerated concrete masonry with k nets and the elastic characteristic α of the masonry as a percentage of the transverse reinforcement μxy are non-linear.

\[ k = \frac{2.62}{2.62 + \mu_{xy}} \]  

(2)

Figure 2. The influence of the percentage of reinforcement μxy on the coefficient of transverse deformation of experimental elements.
The inclusion of rebar grids in the work of experienced elements occurred at a load of 0.15-0.20 from the breaking. Up to this level, the work of the reinforced test elements did not practically differ from the work of the test elements without valves. The appearance of the first cracks corresponded to a load equal to 0.72-0.88 of the breaking load. Cracks in cellular concrete occurred both under vertical mortar joints and along the edges of the element, splitting, thereby, the outer corners of the blocks. The destruction of reinforced experimental elements occurred mainly from the crushing of individual blocks in the rows between the grids, which indicates a more complete use of the strength and deformation characteristics of cellular concrete. The presence of grids in horizontal joints prevents the development of small cracks, their unification into large vertical cracks dividing the masonry into separate columns, which is the ultimate cause of masonry destruction.

Thus, the experimental elements were under conditions of uneven all-round compression, which is characterized by less brittle and more ductile fracture, increased limiting deformability and an increase in the carrying capacity compared to unreinforced experimental elements that were in uniaxial compression.

When building a design formula for the strength of reinforced masonry, the main factors affecting its growth were the percentage of transverse reinforcement in terms of $\mu_{xy}$ and stresses in the reinforcement of meshes $\sigma_s$ at the time of destruction. Taking into account the results of statistical processing of experimental data and the established coefficient of efficiency $k$, the formula for determining the design resistance of reinforced cellular concrete masonry $R_{sk}$ is as follows:

$$R_{sk} = R + \frac{1,66 \cdot R_s \cdot \mu_{xy}}{100} \leq 1,24 \cdot R$$

where $R$ – design resistance of unreinforced masonry; $R_s$ – design mesh reinforcement resistance; $\mu_{xy}$ – mesh reinforcement percentage.

The calculated resistance of steel reinforcement in (4) should be accepted taking into account the coefficient of its working conditions $\gamma_{s8}$, taking into account the strength properties and features of the cellular concrete. In view of the fact that the reinforcing bars of the grids in the experiments did not reach the value of the yield strength, it is recommended to take it equal to $\gamma_{s8}=0,21$.

5. Conclusion
It has been established experimentally that the use of transverse reinforcement of a cellular concrete masonry is an effective means of increasing its bearing capacity. The magnitude of the increase in strength of the experimental elements, due to the introduction of transverse reinforcement in horizontal mortar joints of the masonry, is from 7 to 24%, depending on the percentage of reinforcement. The effect of transverse reinforcement primarily depends on the degree of lateral compression, i.e. from the percentage of transverse reinforcement and stress in the reinforcing bars of the grid at the time of destruction of the experimental element.

The transverse reinforcement of welded meshes increases the rigidity of the masonry of concrete blocks, the greater the percentage of transverse reinforcement. The linear dependence of the increase in the calculated resistance of the aerated concrete masonry on the percentage of transverse reinforcement and nonlinear analytical relationships for the efficiency coefficient and the magnitude of the elastic characteristics of the masonry are proposed. As a result of the analysis of strain gauge data, according to which the strain on the reinforcement of the grids did not reach the value of the yield strength, the coefficient of the working conditions of the reinforcement $\gamma_{s8} = 0.21$ was determined, taking into account the strength properties and features of the cellular concrete.

The results of the experimental data presented in this article are included in the STO NAAG 3.1-2013 “Structures using autoclaved aerated concrete in the construction of buildings and structures. Rules of design and construction "p. P. 9.11, 9.12 in terms of the maximum percentage of

$$\alpha_s = \frac{\alpha}{1 + 0.17 \mu_{xy}}.$$
reinforcement, design resistance of shear reinforcement and determination of the bearing capacity of masonry.

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