THE STRENGTH OF WALLS MADE OF CELLULAR CONCRETE BLOCKS REINFORCED WITH COMPOSITE MESH UNDER THE ACTION OF STATIC AND DYNAMIC LOADS

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Abstract

The results of experimental studies of the strength of masonry walls made of cellular concrete blocks under various force influences are presented. It is noted that the use of walls made of cellular concrete blocks with a density of D400-D600 in seismic areas can significantly reduce the magnitude of the seismic load on the structure. According to the results of the research, the behavior of the masonry under the action of loads modeling seismic impacts, considering its reinforcement with composite materials based on carbon fiber reinforced polymer (CFRP) and bazalt fiber reinforced polymer (BFRP). Data on tests on the vibration platform of full-size wall samples, considering external reinforcement with CFRP tapes, are presented. An increase in the seismic resistance of reinforced structures due to the use of composite materials has been revealed. The nature of the destruction of wall panels reinforced and non-reinforced with composite canvases is shown. According to the results of tests of fragments of walls made of cellular concrete blocks using reinforcement composite mesh based on basalt fiber, the effect of its use in axial stretching of masonry was noted. The use of a composite mesh with a 25×25 mm cell based on basalt fiber made it possible to increase the tensile strength of the masonry across the cross section by 28%.

Keywords: cellular concrete blocks, composite materials, seismic resistance, tests for skewing and stretching of masonry.

I. Introduction

The problem of ensuring a comfortable level of work and human habitation in industrial and residential premises of buildings is associated with a significant expenditure of energy resources, the consumption of which does not directly depend on their extraction and reproduction.

According to the EU, if appropriate measures are not taken, Europe's dependence on external energy supplies, and Russia's dependence on energy production, will increase by 65-70% by 2030 relative to the beginning of the XXI century. In this regard, the EU – Klimatschutzpaket 20-20-20 document was adopted for the possibility of reducing energy costs in the EU, which set a goal of reducing energy consumption by 20% compared to 1990. According to Russian and European sources, 40% of the total primary energy consumption goes to the maintenance of buildings, of which 75-80% is for heating in winter and cooling in summer of residential and administrative buildings.

To improve the energy efficiency of buildings in Europe, a document was developed – the European Directive on Building Energy Efficiency "EPBD" (Energy Performance of Buildings

Directive). In the period from 06.07.2010 to 31.12.2020, the EU member states must ensure that all new buildings under construction must generate as much energy as they consume. The purpose of this step is to develop houses with zero energy consumption. A similar task is facing the Russian construction industry.

One of the main ways to reduce heat loss through enclosing structures is the use of modern cellular concrete and taumalite wall materials with reduced thermal conductivity characteristics. According to the company "YTONG" for the period from 1950 to 2015, the coefficient of thermal conductivity of autoclaved aerated concrete blocks decreased from 0.21 W/m ×°C to 0.07 W/m × °C.

Despite the advantages of cellular concrete block walls over brick walls, the disadvantage of this type of material is their low compressive strength and the effect of shear forces. This factor hinders the use of cellular concrete blocks in earthquake-prone regions. In this regard, the University's Research Center conducted comprehensive studies of the strength of masonry walls made of cellular concrete blocks under the action of seismic loads using special adhesive solutions and composite materials. This should have made it possible to increase the adhesion of the blocks to each other and the strength of the masonry under the action of compressive and tensile loads on the walls during an earthquake.

As foreign studies have shown, when meeting the requirements of Standards for masonry walls of buildings erected in earthquake-prone regions and performing special seismic protection measures, the seismic resistance of walls made of cellular concrete blocks may be quite sufficient for different earthquake intensities. According to [1,2], more than 15,300 low-rise residential buildings made of cellular concrete blocks were built in Japan from 1970 to 1979. Surveys of these buildings carried out in 1980 confirmed their higher reliability in case of earthquakes compared to houses made of other stone materials.

Surveys of buildings made of small–piece brick and stone materials [3-7] have shown that typical damages of brick buildings during earthquakes are:

- diagonal and cross cracks in piers, lintels, as well as on solid sections of walls;
- separation of longitudinal and transverse walls and the occurrence of vertical cracks in the places where they adjoin;
- horizontal cracks in the piers at the level of the lintels and window sills.

II. Experimental setup and realization of the test

The experimental studies consisted of three stages. At the first stage, the fragments of the walls were examined for deformations (Fig. 1) with various reinforcement options using carbon fiber fabrics of the brand MBrace FIB 230/4900.200 g / 5,100m, glued to the masonry fragments of the walls with special adhesives. At the second stage, seismic tests of life-size cellular aerated concrete block wall panels were carried out. The tests were carried out on a seismic platform. At the second stage, seismic studies of life-size cellular aerated concrete block wall panels were carried out. The tests were carried out on a seismic platform.

At the first stage, 4 series of wall samples were tested with CFRP reinforcement and without reinforcement (concrete class – B3.5 and density – D500):

- **I series** – reference samples of masonry wall fragments without CFRP sticker (Figure 2);
- **II series** – fragments of walls made of cellular concrete blocks with one-sided reinforcement with three CFRP canvases (Figure 3a);
- **III series** – fragments of walls made of cellular concrete blocks with double-sided reinforcement with three CFRP canvases (Figure 3b);
- **IV series** – fragments of walls made of cellular concrete blocks with double-sided

reinforcement with one CFRP canvas (Figure 4).

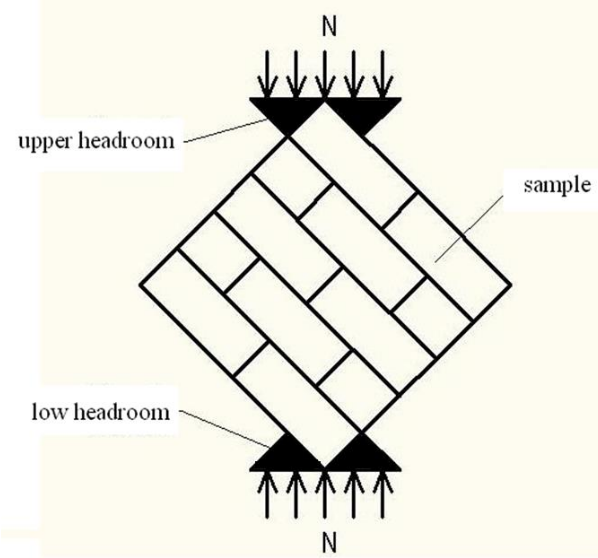

Fig. 1: *Test diagram*

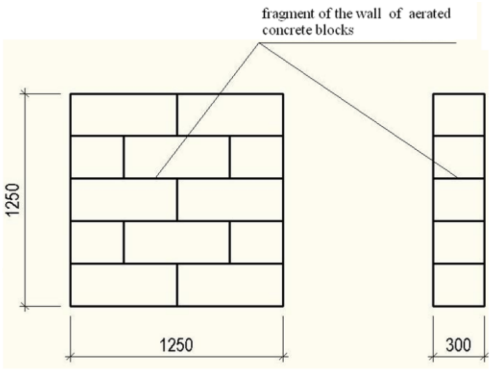

Fig. 2: *Reference samples*

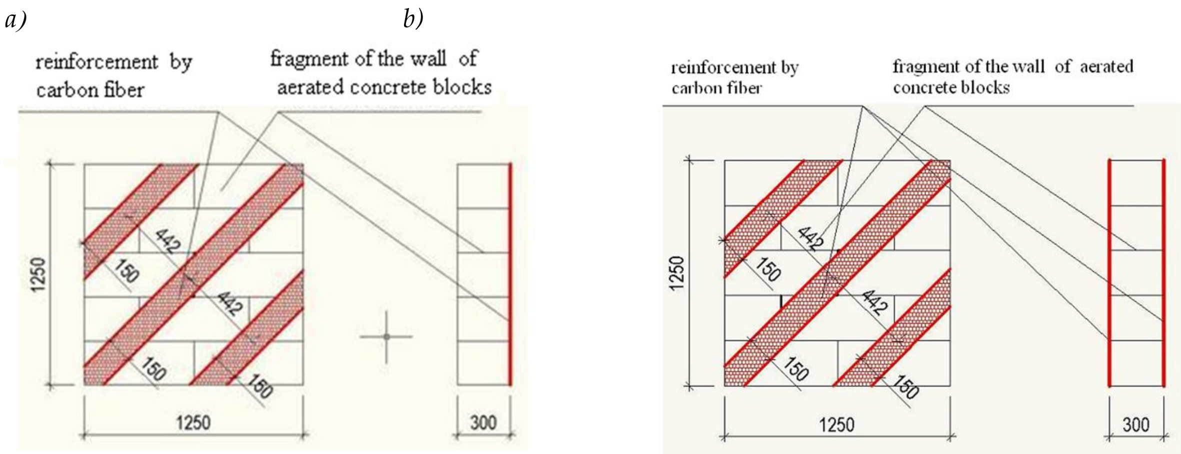

Fig. 3: *Samples of the II (a) and III (b) series*

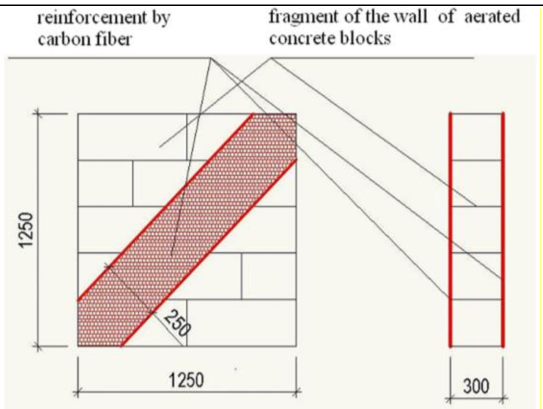

Fig. 4: *Samples of fourth series*

At the second stage, two series of life-size aerated concrete block panels were tested for the effect of seismic loading. The sample of the I series is a panel made of aerated concrete blocks without CFRP reinforcement (Figure 5a). The sample of the II series is a panel made of aerated concrete blocks with double–sided reinforcement with CFRP tapes (Figure 5b). The width of the tapes was 300 mm.

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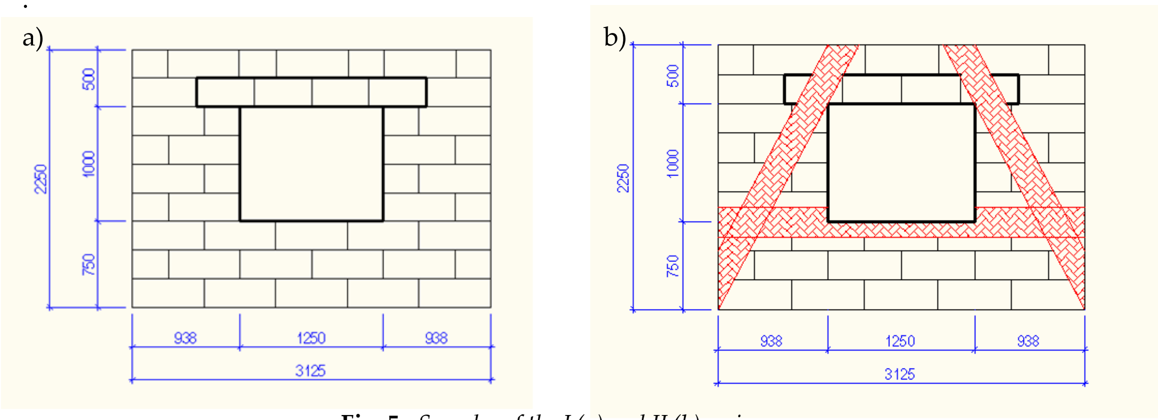

Fig. 5: *Samples of the I (a) and II (b) series*

With the help of special jacks with a capacity of 100 kN and vertical strands, the compression load of the sample was created at all stages of the tests (Figure 6). At the initial stage of dynamic tests, the static vertical load on the sample was q = 1.2 MPa. Due to the inertial force developed by the vibrating machine (Figure 7), a given frequency spectrum of impacts and a certain level of the amplitude of the platform vibrations were provided. The maximum amplitude of the platform oscillation was 43.8 mm. Figure 8 shows a vibration platform with an installed sample of the I series.

In the process of dynamic tests, after passing the loading cycle corresponding to accelerations of 1, 2 and 4 m/s^2, samples were unloaded by an amount of qi = 0.4 MPa. During the tests, 3 loading modes of the prototypes were performed.

The loading mode under dynamic action was selected based on the following basic conditions:

- the period of vibrations of the ground base, depending on the distance to the epicenter of the earthquake, varies from 0,1 to 1.5 s [8], with the duration of the oscillatory process – 10-50 s. During the tests, the duration of the dynamic impact on the structure at each stage of loading was 40-50 s;
- the frequency range of vibrations most dangerous for existing buildings is in the

range from 3 to 10 Hz. The frequency range of the platform oscillation varied from 1 to 9.9 Hz, the number of oscillation cycles was 200-500 cycles.

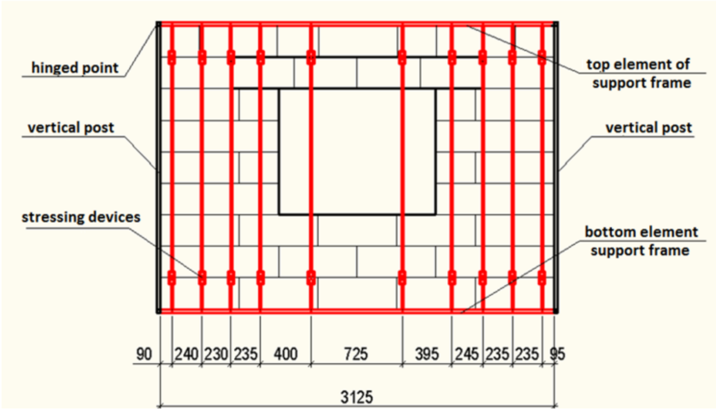

Fig. 6: *Device for creating a vertical load*

Fig. 7: *Pendulum platform*

Fig. 8: *Samples I series on the vibration platform*

At the third stage of the research, tests were carried out on the effect of a load simulating temperature effects. The experimental sample of cellular concrete blocks with and without reinforcement with a composite mesh based on basalt fiber had dimensions of 1815×1220×250 mm. Figure 9 shows the test scheme and the general view of the sample during the tests. The thickness of the mortar seam of the masonry was 3 mm.

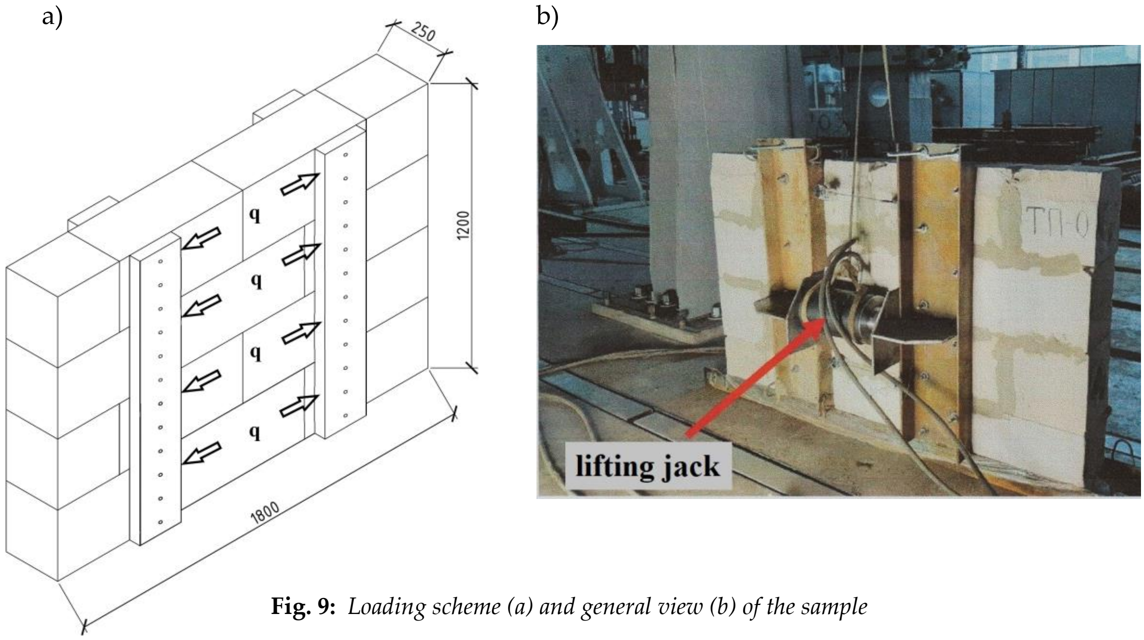

Fig. 9: *Loading scheme (a) and general view (b) of the sample*

Two samples were tested:

- reference sample without reinforcement with composite mesh;
- a sample reinforced with a basalt mesh with a 25×25 mm cell in each row.

The wall fragments were tested using a power plant that includes two jacks with a capacity of 1000 KN each. The load from the lifting jacks was transferred to the distribution beams from two channels No. 27 (Figure 9b). Masonry deformations were measured using electronic clock-type indicators with an accuracy of 0.001 mm.

III. Analysis of test results

1st stage. Analysis of the results of tests for skewing of samples of fragments of masonry walls made of cellular concrete blocks reinforced with CFRP tapes (Table 1) allows us to note the following.

1. The values of transverse tensile deformations in the samples of the II series are 1.3-1.5 times less than in the non-reinforced samples of the I series.
2. In the samples reinforced on both sides (III series), the transverse deformations are 1.6-1.7 times less than in the samples of the I series.
3. When the samples were reinforced with CFRP tapes on one side of the sample, the transverse tensile deformations decreased by 1.3 times compared to non-reinforced samples.
4. The destruction of the test sample (Figure 10) was of a fragile nature. The moment of appearance of the 1st crack corresponded to a load equal to $0.9 \times N_{des}$.
5. The use of reinforcement with CFRP allowed to increase the load-bearing capacity of samples when skewed compared to non-reinforced samples by:

- 11% - when reinforced with three CFRP tapes on one side of the sample;
- 85% - when reinforced with three CFRP tapes on both sides of the sample;
- 34% - when reinforced with one CFRP tape on both sides of the sample.

Table 1: *Results of tests of samples for skew*

Series No.	Sample No.	Sample amplification scheme	N_{des}, (KN)	R_{sl}, (MПa)	R_{sl}, (MПa)	Relative strength (%)
I	1	Not reinforced	200	0.76	0.59	100%
	2		132	0.50		
	3		157.1	0.60		
	4		133	0.51		
II	1	Reinforced with 3 canvases on one side	171.4	0.65	0.66	111%
	2		173.0	0.66		
	3		174.0	0.66		
III	1	Reinforced with 3 canvases on both sides	285.7	1.09	1.09	185%
	2		285.7	1.09		
	3		283.4	1.08		
	2		143.8	0.55		
	3		152.6	0.58		
IV	1	Reinforced with 1 canvas on both sides	200	0.76	0.79	134%
	2		214.3	0.82		
	3		204.7	0.78		
	2		242.8	0.77		
	3		230.1	0.73		

a) b)

Fig. 10: *General view of the III series samples before (a) and after (b) tests*

2nd stage. In the process of dynamic testing of a non-reinforced sample of a wall panel with an opening, the frequency spectrum of dynamic effects varied in the range from 1.4 to 6.2 Hz. The amplitude of the platform vibrations in the horizontal plane varied from 1.0 to 13.8 mm, in the vertical plane – from 0.1 to 9.5 mm. The magnitude of horizontal acceleration varied from 0.08 to 6.5 m/s^2, in the vertical plane – from 0.04 to 3.19 m/s^2. The resulting acceleration spectrum corresponded to earthquakes from 4 to 9.8 points on the MSK-64 scale. With the compression load of the sample equal to $0.8 \times R_b$, no damage was found in the masonry. After reducing the compression level of the sample to 0.4×Rb, vertical cracks appeared with the opening of horizontal seams (Figure 11).

Fig. 11: *The nature of the destruction of a non-reinforced panel made of cellular concrete blocks during dynamic tests*

During dynamic tests of the CFRP-reinforced sample, no cracks were found in the blocks and seams at compression stresses of $0.4 \times R_b$. After reducing the compression load to 0.2×Rb, the appearance of cracks in the blocks above the bridge was recorded. After reducing the compression load to 0.2×Rb, the appearance of cracks in the blocks above the bridge was recorded. Some of the CFRP tapes peeled off from the concrete, but the wall did not collapse. The magnitude of the horizontal acceleration of the vibration platform varied from 1.0 to 15.5 m/s^2, in the vertical plane – from 0.2 to 4.1 m/s^2. At a frequency of 7.6 Hz and an amplitude of 2.1 mm, a resonance occurred. However, no cracks or damage were found in the masonry (Figure 12).

Fig. 12: *General view reinforced with CFRP tapes after testing*

Stage 3. Comparison of the test results of non-reinforced and reinforced polymer reinforced with basalt fiber (BFRP) tensile samples along the cross-section of the wall (the tests simulated temperature effects) allows us to note the following.

1. The destruction of the non-reinforced sample during stretching occurred at a load from the jacks equal to 35 kN. The reinforced sample collapsed at a load of 45 kN.
2. During the destruction, a vertical crack was formed along the entire height of the prototype (Figure 13a). During tests in a reinforced sample, the composite mesh ruptured along the entire height of the sample (Figure 13b).
3. Compare of the tensile test results of the non-reinforced and reinforced samples showed that the destruction of the reinforced sample occurred at a load 28% higher than that of the non-reinforced sample.

a)

b)

Fig. 13: *The nature of the destruction of the reinforced sample during stretching*

Conclusions

1. The use of composite materials (CFRP) to strengthen load-bearing wall structures made of cellular concrete blocks allows them to be used in earthquake-prone regions with earthquakes from 7 to 9 points on the MSK-64 scale.
2. The strength of masonry reinforced with CFRP composite tapes under the action of shifting seismic loads allows to increase its strength, depending on the structural solution of reinforcement by 10-85% compared with non-reinforced samples.
3. The use of CFRP composite mesh for reinforcing masonry walls made of cellular concrete blocks increases its strength under the action of tensile forces (modeling of temperature effects) by more than 25% compared to non-reinforced masonry.

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