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Article

Assessment of mechanical properties of elements modular block

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Abstract. This study presents the control test process to assess the bearing capacity, crack resistance, and crack opening width of the volume block ceiling slabs and the floor slab of the inter-block corridor. These parameters play an important role in ensuring the reliability and durability of buildings, especially when volumetric blocks are used in construction. The study's first phase focuses on the methodology of load-carrying capacity testing of ceiling slabs. The study's second phase focuses on the materials' crack resistance. The analysis of cracks in the material structure is a key aspect since cracks can lead to deterioration of its mechanical properties and reduced durability. The third stage of the study focuses on the crack opening width. This parameter is important in determining the criticality of cracks and their effect on structural integrity. The fourth stage of the study covers the analysis of the floor slabs of the interlocking corridor. Considering the peculiarities of loads and operating conditions in this context, tests analyzing the bearing capacity and stability of the slabs are carried out. The crack opening width reached 0.9 mm and the vertical deflections exceeded 50 mm, the deflection in the inter-block corridor floor slab before failure was about 11 mm. The test results indicate its sufficient strength, stiffness, and crack resistance. The study provides a deeper understanding of the properties and characteristics of materials used in construction and optimizes their use to improve the strength and durability of buildings.

Keywords: volume blocks, crack resistance, stiffness, strength, load, assessment.

1. Introduction

The current stage of development of large cities is marked by a significant change in the structure towards the introduction of innovative structural solutions based on the use of multi-story buildings made of prefabricated reinforced concrete structures. This is explained by the desire for modern and efficient construction methods necessary to meet the growing needs of urbanization [1]. The resurgence of high-rise residential building construction using volumetric blocks represents a significant transition in the construction industry. This approach involves the assembly of pre-designed and prefabricated modules directly at the construction site, which provides a more systematic and efficient construction process. The modular construction method offers several advantages such as shorter project time, reduced construction cost, and increased flexibility in design [2]. In addition, it complies with the principles of sustainable construction by minimizing waste and optimizing the use of resources.

Prefabricated modules provide more precise control over the materials used, which contributes to more efficient use of resources. In addition, the controlled environment in which these modules are manufactured reduces the overall environmental footprint of the construction work. With a growing population and increasing environmental concerns, modular construction acts as a sustainable solution to address these issues. The materials used in modern modular construction also contribute to the structural integrity and sustainability of buildings [3].

One of the key areas of technical advancement in the use of volumetric blocks also lies in design methodology [4]. Traditional construction often adheres to linear and sequential design processes, whereas modular construction allows for a more integrated and parallel approach. Studies have noted a shift towards the use of modern computer-aided design (CAD) software and building information modeling (BIM) tools to facilitate the design of modular components [5]. The ability to visualize and model modular structures in a digital environment allows architects and engineers to optimize designs in terms of efficiency, aesthetics, and functionality.

In practice, the system of construction with the use of volume blocks is extensive. Thus, in the construction of residential and civil buildings "Variel" (Elkon, Switzerland) uses volume blocks of open type, assembled from two load-bearing end panels or portal reinforced concrete frames, prestressed ribbed floor panels, and ceiling slab [6]. The average factory availability of volumetric blocks is 70-80%.

In Sweden, the firm "Boštodsbolaget" (Gothenburg) builds houses with 10 floors of the height of panel-block system from blocks of "glass" type of various typo-sizes [7]. The bearing walls of the blocks are 7-16 cm thick and made of concrete of 250 grade. I

n Finland, the system of volume-block housebuilding "Ausa" is developed, in which ribbed volume blocks of the "pipe" type are made in the size for the width of the building with the linear transmission of vertical loads on the long sides.

In Brasov (Romania) the experimental construction of about 200 buildings up to 5 stories high from volume blocks of the "cap" type has been carried out. From the international experience of construction of buildings from volumetric blocks, we can note the construction of low-rise buildings in Belgium, Sweden, Peru, and Dubai, as well as high-rise buildings in New York and Singapore.

From the modern European experience, it should be noted the construction of low-rise buildings with full factory finishing in Germany [8]. The modern stage of development of large cities of the Republic of Kazakhstan also applies structural solutions of multi-story buildings from prefabricated reinforced concrete structures [9]. In this regard, this study is related to the study of the operation of volumetric blocks at all stages of loading by vertical load, control tests.

2. Methods

The paper considers the control tests to check the bearing capacity, crack resistance, and crack opening width in the ceiling slabs of the volume blocks; and in the floor slab of the inter-unit corridor [10]. The strength, stiffness, and crack resistance of the floor and ceiling slabs of the volume blocks, as well as the floor slab of the inter-unit corridor, are evaluated by testing these elements under the action of uniformly distributed vertical load [11].

Claydite concrete blocks are made of the "lying glass" type with dimensions of 3480x6980x2980 mm, consisting of three walls, ceiling, and floor slabs. The volumetric modules are completed with prefabricated load-bearing exterior wall panels. According to the structural solution of buildings from volume, modules are volume-block buildings with internal single-layer walls and inserted external walls of both single-layer and three-layer execution [12].

The building is made of volume blocks supported on each other, with linear support on four sides through a layer of mortar. The volume blocks are connected horizontally by welding plates located on the ceiling.

Horizontal loads are taken by connecting elements located on three sides of the volume block. Volumetric blocks have two side walls of ribbed design with a wall thickness of 50 mm and rib height of 100 mm, as well as an end flat wall thickness of 100 mm.

The floor slab of the volume block is ribbed with a shelf 80 mm thick and ribs 170 mm high. The ceiling slab of the volume block is flat with a runaway 80-97 mm thick. Volumetric blocks are reinforced with spatial frames and reinforcement meshes united in a single spatial block (Figure 1).

The externally inserted wall panels with a total thickness of 120 mm are single-layer with a load-bearing layer of expanded clay, effective insulation, and a cladding layer in the form of a curtain wall system. The ceiling slab also integrates the walls of the volume block into a single system and is loaded vertically only by the slab's mass.

Figure 1 – Test bench with volumetric block

The volume block used for these tests with dimensions 6980x3480x2980 mm is made of expanded clay concrete of strength class LC 20/22 (B20) density class ρ = 800 kg/m3. The ceiling slab is a flat reinforced concrete slab of variable thickness with a slope from 97 mm to 80 mm. The ceiling slab is reinforced with a lower mesh of Ø4 S400C (Vr400) reinforcing wire with 200x200 mm mesh and upper supporting meshes of Ø4 S400C (Vr400) with 100x150 mm mesh. In addition, the lower grid in the area of reduced thickness is reinforced with individual Ø8 S500 (A-500C) with a spacing of 400 mm, as well as in the slab installed vertical V-shaped meshes with longitudinal reinforcement of 3Ø5 S200C (Vr200) and transverse bars 3Ø4 S200C (Vr200) with a spacing of 200 mm, installed with a spacing of 1.0-1.05 meters. The ceiling slab was loaded with small piece weights (bricks), the columns of which with dimensions of 500x500 mm were placed on a layer of sand in such a way as to exclude their mutual touching and formation of vaults (Figure 2).

Figure 2 – Loading the ceiling slab with brick columns

In the process of loading, vertical displacements were measured using PAO-6 deflection meters with a division value of 0.01 mm in the middle part of the span and at the supports (Figures 3 and 4), and the crack development pattern was recorded with crack opening width measurement using MPB-3 microscope with a division value of 0.02 mm [12].

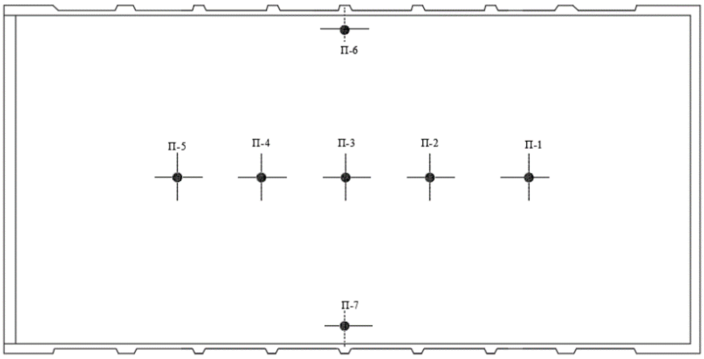

Figure 3 – Sheme of vertical deflection gauges on the ceiling slab

Figure 4 – Deflection gauges and safety supports under the ceiling slab

The reinforced concrete slabs under consideration are placed between two rows of volume blocks, forming an inter-block corridor in the building. The slabs have cantilevered overhangs, by which they rest on the projecting consoles of the volume blocks (Figure 5). Interblock floor slab is a flat reinforced concrete slab 140 mm thick, dimensions in plan 3480x2360 mm, made of heavy concrete class C20/25 (B25). The slab is reinforced with a bottom mesh of periodic profile reinforcement Ø8 S500 (A500C) and Ø6 S500 (B500C) with 200x200 mm cells and vertical frames with longitudinal reinforcement Ø8 S500 (A-500C) and transverse bars Ø4 B500 (B500C) located at the cantilever overhangs of the slab.

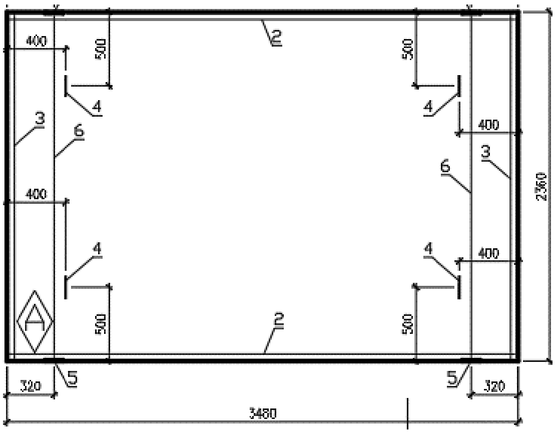

Figure 5 – Reinforcement of inter-corridor floor slab

Loading of the interblock ceiling slab with small piece weights (bricks), the columns of which with dimensions of 500x500 mm were placed on a layer of sand in such a way as to exclude their mutual touching and formation of vaults (Figures 6 and 7).   In the process of loading of the interlocking slab, vertical displacements were measured with the help of PAO-6 deflection gauges with a division value of 0.01 mm in the middle part of the span and on the supports (Figure 8).

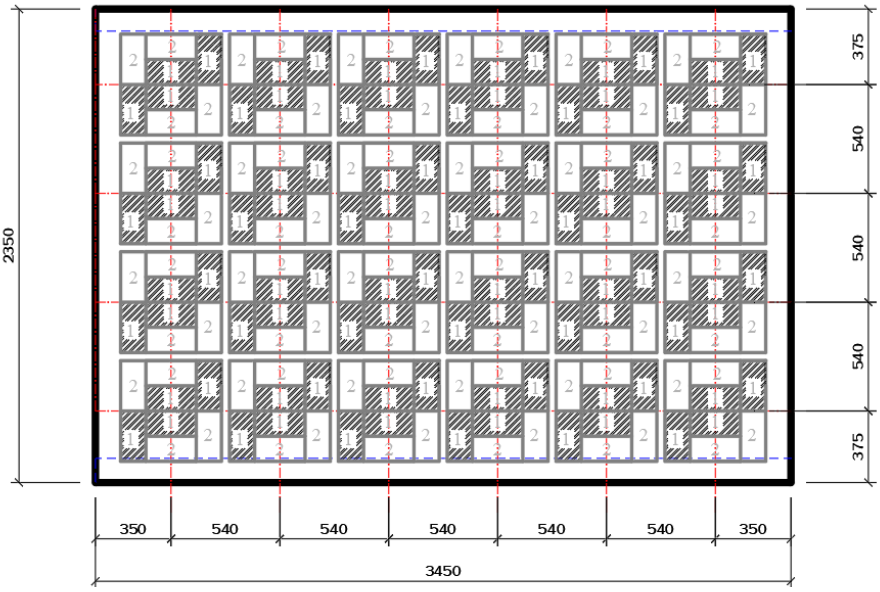

Figure 6 – Sheme of brick columns on the interlocking slab

Figure 7 – View of interlocking floor slab loaded with brick

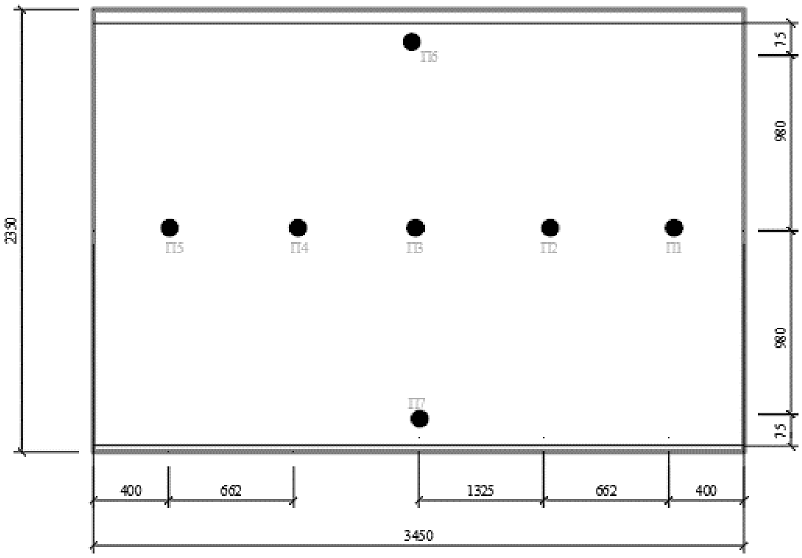

Figure 8 – Scheme of vertical deflection gauges on the interblock slab

The picture of crack development was recorded by measuring the crack opening width using a microscope MPB-3 with a division value of 0.02 mm (Figure 9). The MPB-3 microscope provides an opportunity to enlarge the observation area and allows to study of the material structure at the micro level with a high degree of resolution. Measurement of crack opening width allows not only to monitor the development of cracks but also to assess the degree of their danger to the material. The greater the crack opening width, the more likely it is that the crack may lead to failure or fracture of the material.

Figure 9 – View of safety supports under the interblock corridor slab

3. Results and Discussion

Figure 10 shows the deflection pattern of the middle part of the ceiling slab, which shows a shift of the maximum deflections to the thinner part of the ceiling slab. The deflection at the variable load q_k = 70 kgf/m^2 was about 1.5 mm, which is significantly less than the allowable deflection (at f/l=1/200 the allowable deflection is 15.6 mm), q_k = 582.3 kgf/m^2 the ceiling slab rested on the safety support, with a maximum deflection of 52.3 mm. Cracks in the ceiling slab appeared at a vertical load of 240 kgf/m^2, and before the ceiling slab failed, their opening width reached 0.9 mm (Figures 11 - 12). In general, the ceiling slab has sufficient stiffness, crack resistance, and strength.

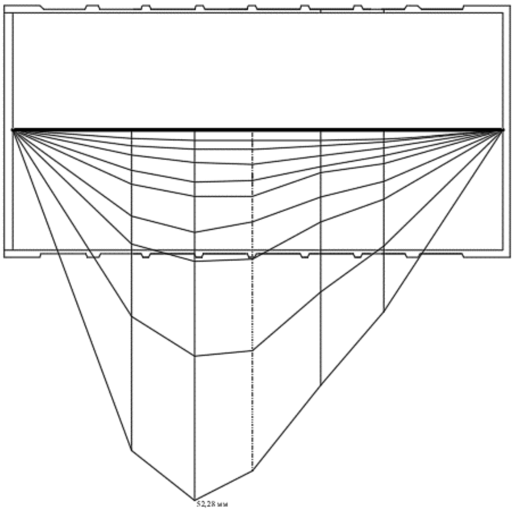

Figure 10 – Graph of vertical displacements of the middle part of the ceiling slab

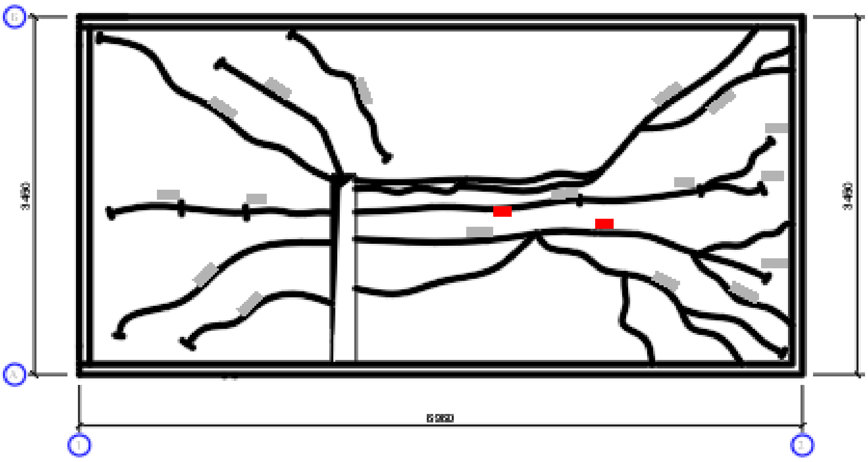

Figure 11 – Cracking pattern on the underside of the ceiling slab

Figure 12 – Cracks in the ceiling slab

The deflection at a variable load $q_k = 3.0$ kgf/m^2 was about 1.3 mm, which is significantly less than the allowable deflection (at f/l=1/200 the allowable deflection is 11.4 mm). Cracks in the interlocking slab appeared at a vertical load of 550 kg/m^2, and before the failure of the interlocking slab, the width of their opening reached 1.7 mm (Figures 13 - 14).

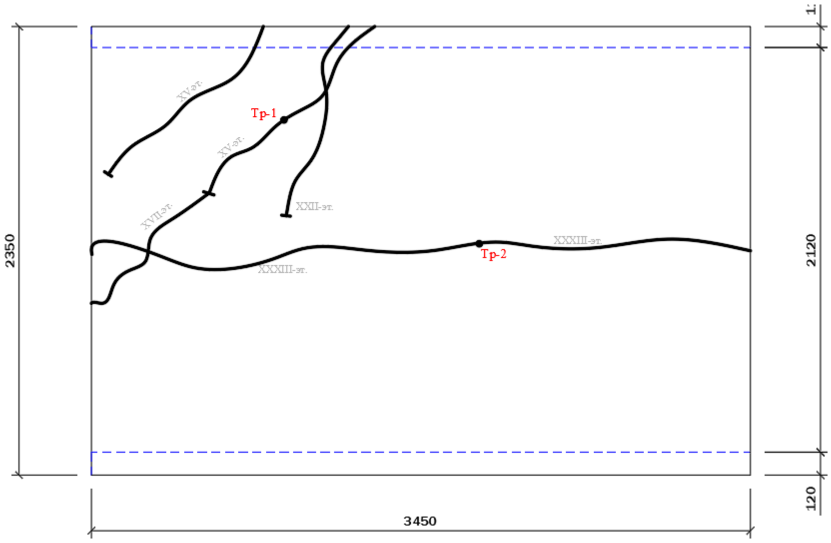

Figure 13 – Diagram of cracks in the interlocking floor slab

Figure 14 – Cracks in the interlocking floor slab

The failure of the inter-unit floor slab occurred at a vertical load qk = 1510.5 kg/m^2, which exceeds the control failure load according to [11] by almost two times. The largest deflection of the corridor slab before failure was 11 mm, indicating the high stiffness of the floor slab. In general, the interlocking floor slab has sufficient stiffness, crack resistance, and strength.

4. Conclusions

The performed control tests of elements and assemblies of volumetric blocks allow us to draw the following conclusions:

1. The ceiling slabs unite the walls of the volume block as a single system and take vertical loads only from their weight.

–Damage to the expanded clay concrete ceiling slab under vertical loading is accompanied by the formation of envelope-shaped cracks on the bottom surface of the slab. The cracks in the slab appeared at loads exceeding the alternating load. The deflections under alternating load were about 1.5 m, which is significantly less than the allowable deflection.

–Damage to the expanded clay concrete ceiling slab under vertical loading is accompanied by the formation of envelope-shaped cracks on the bottom surface of the slab. The cracks in the slab appeared at loads exceeding the alternating load. The deflections under alternating load were about 1.5 m, which is significantly less than the allowable deflection.

–The failure of the ceiling slab was accompanied by a significant crack opening, with the value of the experimental failure load exceeding the control failure load. The crack opening width reached 0.9 mm, and the vertical deflections exceeded 50 mm.

–The test results of the ceiling slab indicate that it is sufficiently strong, stiff, and crack-resistant.

2. The floor slab of the inter-unit corridor is designed to accept variable vertical loads and to unite parallel rows of modular units into a single system.

–The reinforced concrete slab of the inter-block corridor under vertical loading acts as a single-span spherically supported slab, in which the main crack runs in the middle part of the span and reaches 1.7 mm before failure. The deflections of the slab under alternating load were less than the allowable deflections and the first cracks were formed by the vertical load exceeding the alternating loads.

–The failure load in the inter-unit corridor floor slab was almost twice the control failure load, and the pre-failure deflection was about 11 mm.

–In general, the floor slab of the inter-unit corridor meets the requirements of the standards for strength, stiffness, and crack resistance.

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