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Strength and deformations of volume-blocks

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ABSTRACT: The results of experimental studies of the stress-strain state of reinforced concrete three-dimensional blocks under the action of vertical loads are presented. Information is given on the distribution of deformations, the formation and opening of cracks, horizontal displacements, strength and nature of destruction, and the influence of the type of concrete. Proposals are given for calculating the bearing capacity, taking into account damage.

Keywords: reinforced concrete volume blocks, strength, deformations, cracks and displacements, failure patterns.

1 INTRODUCTION

The ideas of volume-block construction originated in the USSR and abroad at the beginning of the 20th century. At the end of the fifties, the design of structural systems and the construction of residential buildings from reinforced concrete three-dimensional blocks began in the Soviet Union. Currently, in various cities of the CIS (Khabarovsk, Krasnodar, Gulkevichi, Volzhsk, Minsk, Voronezh, Moscow and Astana) there are factories for the manufacture of volumetric blocks and the construction of volumetric-block buildings up to 16 floors high. The most widely used volumetric blocks such as "cap" and "lying glass". In recent years, several countries have built a significant number of multi-storey buildings from reinforced concrete three-dimensional blocks (Weisman 1967, Drozdov 1969, Berezovsky 1973).

The advantages of volumetric-block construction are the transfer of the main construction processes to the factory, which makes it possible to improve the quality of construction (Toleubayeva 2020), automate production, use effective building materials, reduce the impact of seasonal work, drastically reduce construction time, and significantly reduce construction costs (Kirkorov 1975, Ilyenko 1979). The main features of a three-dimensional block building are associated with increased flexibility of wall elements, which leads to premature loss of wall stability (Zhussupbekov 2020). In addition, the extremely limited amount of experimental and theoretical studies of such constructive systems should be attributed to the disadvantages of using volume-block housing construction (Utepov 2022).

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In the city of Astana (Kazakhstan), a house-building plant "ModeX Astana" was built, which manufactures reinforced concrete volumetric blocks of the "lying glass" type of enlarged sizes. The building is mounted from pillars of volumetric modules, leaning against each other through a layer of mortar. In the process of mastering the technology at the plant, control tests were carried out on the main load-bearing structures of volume-block multi-story buildings, which made it possible to improve their manufacturing technology and design solution, taking into account the use of modern materials.

2 EXPERIMENTAL STUDIES

This article presents the results of testing full-scale volumetric blocks that differ in the type and strength of concrete, as well as reinforcement. Volumetric blocks have two side walls of a ribbed design with a wall thickness of 50 mm and ribs 100 high, as well as a flat end wall 100 mm thick. The floor slab of the volumetric unit is ribbed with a shelf 80 mm thick and ribs 170 mm high. The ceiling slab of the volumetric unit is flat with a run-out, 80-97 mm thick. Volumetric blocks are reinforced with spatial frames and reinforcing meshes made of cold-drawn wire Ø4-Ø5 mm Y500C class, combined into a single spatial block, as well as additional bar reinforcement Ø12 S500. External insert wall panels are multi-layered with a bearing layer of concrete, effective insulation and a facing layer, installed as a facade system.

Three-dimensional blocks were tested on a test bench, which is a rigid rod system of adjustable vertical and horizontal frames (Guidelines 1977, Guidlens 1983). The loading of volumetric blocks was carried out using hydraulic jacks with a capacity of 200 tf through a distribution reinforced concrete slab. During the tests, the compressive deformations of concrete were measured using vertical strain gauges with a base of 50 mm, horizontal and vertical displacements of walls and ceilings - using digital deflection gages PA0-6, and the crack opening width - using an MPB-3 microscope (CP 501.1325800.2021).

Volumetric block No. 1 is made of concrete of axial compressive strength class LC20/22 and density grade D1800 using crushed expanded clay. At a vertical load of N = 728.4 tf, cracks were observed at the corners of the volumetric block, vertical cracks in the lintel above the window in the wall panel and in the lintel above the doorway in the end wall. At the same time, the opening width of existing technological cracks increased by 0.05 mm (CP RK EN 2011).

Figure 1 shows a plot of longitudinal deformations of concrete along the perimeter of the walls of a volumetric block with a vertical load N = 829.86 tf. The value of vertical deformations along the length of the longitudinal walls was within -(26-61) 10-5 relative units and averaged -(42-53)10-5 relative units. The concrete deformations in the end wall and wall panel were almost 20% less. Under this load, the crack opening width in the lintels reached 0.05-0.10 mm, and the crack opening width in the longitudinal walls was in the range of 0.10-0.25 mm.

The destruction of the volumetric block occurred at a vertical load N = 1083.88 tf and was caused by fragmentation of the upper part of the longitudinal wall in the area of adjacency to the wall panel with the continuous growth of horizontal deformations of the walls from the plane and the formation of new cracks. The crack opening width in the lintels reached cracks of 0.15-0.2 mm, and the crack opening width in the longitudinal walls was within 0.20-0.25 mm (Figure 2).

Figure 3 shows diagrams of horizontal displacements of walls from the plane of the volumetric block. The largest movements of the top of the longitudinal walls reached 2.1-2.45 mm, the movements of the end wall were 3.08 mm, and the wall panel - 4.24 mm. The increase in displacements almost linearly depended on the vertical load, and only at the last stage of loading was a sharp increase in horizontal displacements (deplanation) of the walls observed. (Figure 5). The average compressive stresses of concrete in the longitudinal walls were equal to 8.74 MPa, that is, they amounted to 43.7% of the concrete strength. The average compressive stresses in the concrete of the longitudinal walls were equal to 8.33 MPa, that is, they amounted to 41.7% of the concrete strength. The experimental breaking load exceeds the control breaking load for 16-storey buildings in Astana by 4%.

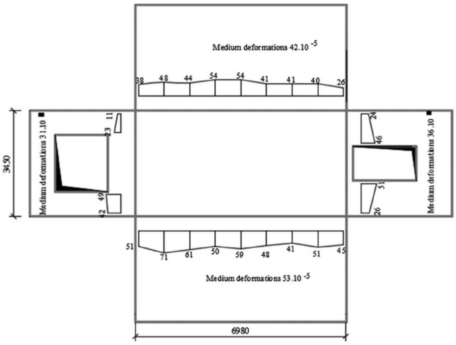

Figure 1. Distribution of concrete compression strains along the perimeter of the walls of block No. 1 at 76% of the breaking load.

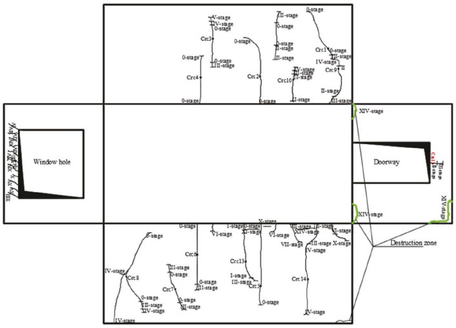

Figure 2. Scheme of the location of cracks on the development of the walls of block No. 1.

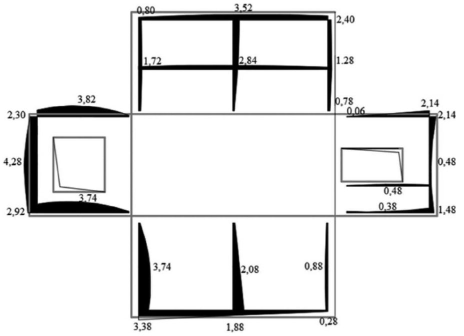

Figure 3. Horizontal displacements of walls under breaking load.

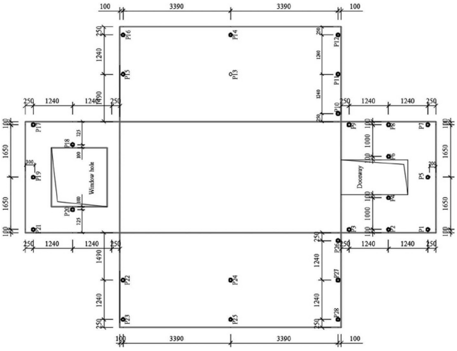

Figure 4. Scheme of the location of deflectometers.

Figure 5. Damage to the interface between walls and ceiling slabs.

Volumetric block No. 2 is similar in geometrical dimensions to block No. 1, however, it had less reinforcement of walls and floors, and was also made on crushed expanded clay from concrete of class LC16/18, density grade D1800. When loading the sample with a vertical load up to N = 652.4 tf, cracks formed at the corners of the volumetric block, vertical cracks in the lintel above the window in the wall panel and the lintel above the doorway in the end wall. With a vertical load N = 815.5 tf, the crack opening width in the lintels reached 0.05-0.10 mm, and the crack opening width in the longitudinal walls was in the range of 0.10-0.25 mm. The value of vertical deformations of concrete along the length of the longitudinal walls was within -(22 - 49) 10-5 relative units, concrete deformations in the end wall were about 72% of the average deformations of the longitudinal walls, concrete deformations in the wall panel were about 52 % of these deformations. In this case, the largest displacements of the top of the longitudinal walls were 2.63 and 2.84 mm, deformations of the end wall - 3.29 mm, and the wall panel - 2.07 mm.

The destruction of the volume block occurred at a vertical load of N = 1002.33 tf (Figure 6) and was accompanied by the destruction of the concrete of the upper part of the longitudinal walls in the area of interface with the roof slab and the outer wall panel, the splitting of the roof slab and the end wall, as well as the continuous increase in the horizontal deformations of walls from the plane. The average compressive stresses in the longitudinal walls were equal to 7.93 MPa, that is, they amounted to 49.56% of the concrete strength. The experimental breaking load exceeds the control vertical load for 13-storey buildings in Astana by 30%.

Figure 6. Splitting of the block floor slab No. 2.

Block No. 3 was similar in terms of reinforcement and geometrical dimensions to block No. 1, but was made of heavy concrete of class C20/22. The first vertical cracks appeared in the lintel of the wall panel under a vertical load of N=850 tf, then vertical cracks appeared in the lintel of the doorway and vertical cracks in the window sill of the wall panel. During the stage before the destruction of the volume block, the largest crack opening width did not exceed 0.20-0.25 mm, the horizontal displacements of the walls from the plane of the volume block did not exceed 1.2 mm, and in the middle part of the window opening of the wall panel was 5.03 mm. The compressive deformations of concrete in the longitudinal walls were in the range of -(19 - 31)10-5, and in the area of adjacency to the wall panel they increased sharply, approaching the ultimate compressibility of concrete in axial compression. The deformations of concrete in the end wall and wall panel were two times less than the deformations of concrete in the longitudinal walls.

The destruction of the volumetric block occurred at a vertical load N = 1482.21 tf and was accompanied by the destruction of the upper part of the longitudinal walls in the area of interface with the floor slab, the opening of vertical seams between the wall panels, the formation of cracks in the lintels of the wall panel and the end wall, the formation of longitudinal cracks in the ceiling slab with an opening width of 0.10-0.15 mm. The average compressive stresses in the longitudinal walls were equal to 12.03 MPa, that is, they amounted to 57.8% of the concrete strength. The experimental breaking load exceeded the control breaking load for 16-storey buildings in Astana by 4%.

3 ANALYSIS OF RESEARCH RESULTS

The performed studies of the bearing capacity of three-dimensional blocks revealed their complex stress state under vertical loads, established the sequence of formation and width of cracks in walls and ceilings, the magnitude of the ultimate deformations of walls from the plane, the distribution of longitudinal deformations of concrete in the walls and the causes of destruction of three-dimensional blocks. The main features of the behavior of volumetric blocks under vertical loads are associated with a small wall thickness compared to that required for buildings with load-bearing reinforced concrete walls, which, according to [18], should be at least 200 mm.

Increased flexibility of the walls of volumetric blocks at initial loads, an increase in the free length of walls in the process of significant damage to walls and ceilings, as well as significant displacements of walls from the plane of the building under high vertical loads, lead to premature destruction of volumetric blocks.

The destruction of the walls of expanded clay concrete volumetric blocks for the destructive stage of the work of the walls occurs at compressive stresses in the walls equal to 44.7-49.6% of the concrete strength. Thus, the strength of reinforced concrete walls should be determined by introducing the coefficient of reduction in the bearing capacity of flexible compressed elements $\varphi=0.44\text{-}0.5$. When designing the walls of the volume blocks of the lower tiers of buildings, damage to the volume blocks should be taken into account. Changes in the flexibility of walls in the calculation of serviceability limit states (SLS) can be ignored, and for critical states in terms of bearing capacity (ULS), the design length of the walls should be increased by 50-56%.

The rigidity and crack resistance of volumetric blocks made of heavy concrete is much higher than that of volumetric blocks made of expanded clay concrete. Therefore, when designing walls of bulk blocks made of heavy concrete for the action of vertical loads, taking into account damage to bulk blocks, the change in the flexibility of walls when calculating serviceability limit states (SLS) can also be ignored, and for critical states in terms of bearing capacity (ULS), the calculated length walls should be increased by 43%.

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