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Prevention of uncontrolled progressive collapse of a high-rise brick building

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Abstract. In recent years, there is a trend towards increasing the failure rate of buildings and structures as a result of unforeseen situations. This study is aimed at assessing the operational reliability of the structure to prevent emergencies and progressive collapse. The behavior of structures affected by various factors was analyzed. The operational condition of a building with stone walls and a rigid structural frame constructed in the middle of the 20th century was considered. By means of a detailed instrumental examination, effects of long-term operation, climatic factors and violations during construction on the serviceability of the building were analyzed. Geotechnical conditions of the site were investigated. Necessary re-calculations for load-bearing structural elements and foundations were carried out. An expected failure diagram for vertical load-bearing structures of the building is presented. Proposals for preventing progressive collapse were developed on the basis of the author's technique.

Introduction

Due to various factors, the operational condition of buildings aged 50 years old or above does not always meet the regulatory requirements. These factors include climatic and industrial factors, period of operation, violations of operating rules, as well as deviations from the design and building regulations. This is especially true for buildings from such building materials as brick, mortar and wood.

Operational reliability assessment of buildings and their structural elements are addressed by a number of scientists and specialists such as V.S. Abrashitov, M.D. Boyko, A.N. Dobromyslov, O.V. Kabantsev, V.G., Kazachek, M. Kusainov, A.I. Malganov, V.S. Plevkov, G.P. Tonkikh, M. Rimshin, A.G. Roytman, I.A. Fizdel, and others. [1-13].

The subject of this study is an instrumental examination of actual physical and mechanical parameters of load-bearing structural elements to prevent uncontrolled progressive collapse of the building in case of failure of its load-bearing structures. For this purpose, author's design solutions were used in the form of crib piers installed in the area of potential collapse.

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Research Methodology and Results

As a typical example for solving this problem, we will consider a high-rise building with reinforced concrete foundations, brick bearing walls, reinforced concrete and wooden ceilings, and a wooden rafter system.

The building under consideration is located in Tomsk (Russia). It is a five-storey building with a U-shaped plan constructed in the 1950s (Fig. 1). The overall dimensions of the building in plan view along layout axes are 73.618 × 32.600 m. The building was designed and erected on the basis of a rigid structural diagram with an incomplete load-bearing frame. Vertical bearing structures along the internal axes are represented by brick piers with a cross section of 640×510 mm, and brick walls with a thickness of 380 mm. There are longitudinal load-bearing walls along the outer axes. The walls are made of ordinary clay brick on cement-sand mortar. The thickness of the external walls is 640 mm. The thickness of the basement walls is 770 mm. The external walls are made of clay bricks on a cement-sand mortar.

The building is corridor-type. Rigidity and stability of the structure is ensured by a system of longitudinal and transverse walls monolithically connected with each other, rigidity of the incomplete load-bearing frame and floor disks that are rigid in their plane. Frame girders are made of reinforced concrete. They are laid in the longitudinal direction. Metal beams made of rolled section No. 25 are laid in the transverse direction of the building.

a) *b*)

Fig. 1. General view of the building: northern (*a*), central and southern blocks (*b*).

The building has a hip roof designed according to the general building plan. The main load-bearing structures are represented by jack rafters with substructures of two types: posts and purlins. The rafter system is made of wood. Intermediate and attic floors are made of wood according to the beam pattern. The main load-bearing elements of the attic floor include metal, reinforced concrete and wooden beams laid in the longitudinal and transverse directions of the building.

According to the results of the examination performed in accordance with [14, 15], the current condition of foundations, vertical load-bearing structures, floors and roof was determined. Geometric parameters were measured with laser and metal measuring tapes. Strength parameters of reinforced concrete structures were estimated by the shock-pulse method using an ONIKS 2.5 electronic strength tester for non-destructive strength testing. A destructive test was performed with press equipment for testing the strength of materials (brick and mortar) extracted from the load-bearing walls of the building. Moisture content of wooden structures was measured with a Delta 200L moisture meter. All facilities that were necessary to assess the operational reliability of the building were constructed in compliance with the applicable regulatory requirements.

Hydrogeological conditions of the site were studied. The results show that the soils under the foundations of the building are moistened and functional only to a limited extent. Load-bearing stone structures of the external walls were analyzed. The results show that they are water saturated at the level of the ground floor and the plinth almost along the entire perimeter, both outside and inside the building. Due to high hygroscopic properties of bricks, moisture in load-bearing walls rises to a height of two–three meters. The masonry of the walls is watered not only from below, through the plinth, but also from above, due to damaged integrity of interfacing between the roofing and cornice sections of the walls. It should be noted that the bricks and mortar in the masonry of the plinth part of the walls are under destruction.

Due to saturation of the masonry with ground water, atmospheric precipitation and household water accompanied with cyclic exposure to negative temperatures, the strength of the masonry has significantly deteriorated. Crushing and disintegration of bricks are observed in exposed sections of the masonry of the ground floor walls (Fig. 2).

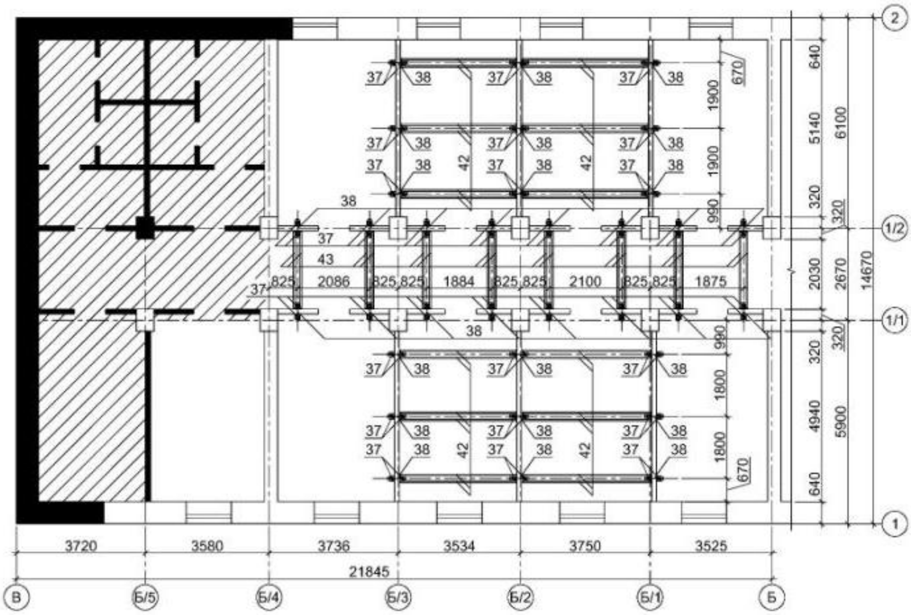
a) *b*)

Fig. 2. Destruction pattern of the masonry of ground-floor wall partitions.

Samples of bricks and mortar taken from the walls of the building were tested. The results show that the strength of the ground-floor and basement walls changes from “zero” to M 10. According to the compression test, the strength of bricks corresponds to grade M 25 ... M 50.

Re-calculations for the masonry of the building walls at actual strength characteristics of their materials and operating permanent and temporary loads [16] established by building codes and regulations [17] showed that the load-bearing capacity of the masonry in the external basement walls, the ground and first floors does not meet the regulatory requirements [18]. The masonry of the walls and piers in the areas where concentrated loads are transferred from reinforced concrete and metal beams does not meet the requirements for crushing strength of walls and masonry piers of the basement, ground, first, second and third floors of the building.

The condition of the end wall in the northern block is of particular concern. The load-bearing walls are seen to be outside the plane and buckled. At the same time, the masonry is segregated into separate vertical columns along the thickness due to loss of frost resistance and deteriorated strength parameters of bricks and mortar. Cracks in the walls result from out-of-tolerance deformations of soils under the foundations due to watering, as well as from the compliance of the masonry in the plinth part of the wall due to loss of compressive strength and frost resistance. Due to the combined effect of these factors, the end wall and adjacent sections of the longitudinal external walls do not meet the regulatory requirements [18], are in a state of disrepair [13, 14], and may result in collapse (Fig. 3) [19, 20].



Legends:

- Floor sections to be dismantled;

- Brick piers, partitions and sections of walls to be dismantled.

Fig. 3. Expected collapse diagram for the northern block of the building and proposals for prevention of uncontrolled progressive collapse.

Developed deformations and movements are so significant that these areas cannot be restored or strengthened and should be dismantled. The end wall of the building should be dismantled. To prevent uncontrolled collapse along the end wall of the building, relieving crib piers [21] along the entire height of the building are proposed to be installed.

The basic idea behind installing crib piers in the expected collapse area is that loads from the floors will be transferred to these piers during collapse of the load-bearing walls in the end part of the building. The overall dimensions of the piers and the number of beams in the lower row were selected so that the stresses in soils under them did not exceed the calculated resistance of watered foundation soils. The number of piers along the load-bearing wall and the distance between them were calculated in such a way that they took active loads from the floors and all overlying structures. Cross sections of individual beams for the crib were selected so that their bending and shearing strength was ensured. Frame piers were used as emergency prevention measures for the rest of the building.

It should be noted that the end wall collapsed as expected, in full accordance with the prediction (Fig. 4).

Fig. 4. The real collapse of the northern block of the building.

Conclusion

The operational reliability of a building should be assessed on the basis of an integrated approach, including diagnostics of its foundation and load-bearing frame, the strength and deformability of intermediate floors and a roof. The proposed measures to prevent uncontrolled progressive collapse of a building in a state of disrepair proved to be effective and prevented the uncontrolled progressive collapse of the building.

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