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Changes in the Stress-Strain State of Precast Reinforced Concrete Floor Systems in Masonry Multi-Storey Buildings after Non-Design Impacts

Abstract. The article is devoted to investigating non-design impacts on precast reinforced concrete floor systems of multistorey brick buildings that arise during military actions. The study examines the influence of both external and internal factors on these structural systems and their deterioration. Using the materials of the "Report on the Detailed Survey of the Residential Building in Chernihiv, damaged as a Result of Military Actions", prepared by the State Research Institute of Building Structures (NDIBK) in 2022, the paper analyses the nature of the effects of military actions on the building as a whole and on its individual structural components, with particular attention to precast reinforced concrete floor systems. The case considered involves multiple direct artillery strikes on the building, which resulted in partial destruction of load-bearing structures and damage (or failure) of the associated floor elements. The findings of the analysis of this specific case provide a basis for further search, investigation, and development of new, more effective methods for restoring the serviceability of damaged precast reinforced concrete floor systems. This task remains highly relevant today and must consider not only the efficiency of restoration but also the safety of personnel working or residents living in buildings undergoing repair.

Keywords: residential buildings, impact of military actions, damage, restoration, reinforced concrete floor, serviceability

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Introduction.

During the operation of buildings and structures, construction elements deteriorate under the influence of external and internal factors, resulting in the degradation of their physical and mechanical properties. Such deterioration of the performance characteristics of load-bearing structures is generally unacceptable, as it may lead to loss of stability and emergency conditions.

As a result of non-design impacts on buildings and structures occurring in peacetime – such as gas explosions, explosive devices, earthquakes, floods, and other events – construction elements may be damaged and require comprehensive repair or replacement. In cases of comprehensive repair, both the physical and mechanical properties and the geometric parameters of the structures must be restored, followed by appropriate strengthening.

During military actions, tens of thousands of buildings and structures are also subjected to non-design impacts [1, 10]. These may include blast-wave

effects, direct strikes by damaging agents (e.g., high-velocity fragments), thermal impacts, vibrations, and other destructive influences. It is also necessary to distinguish between direct structural damage caused by the impact of munitions (missiles, shells, mortar rounds, large-calibre bullets, etc.) and secondary damage resulting from blast-induced air pressure waves. In some cases, the destruction is extensive and systemic—for instance, when fires and temperature-induced deformations lead to crack formation in floor systems located in other parts of the building. Hidden defects may also occur, such as cracks developing in load-bearing floor elements concealed beneath the floor assembly as a result of impact forces. Prolonged exposure to fire and temperature-induced deformations aggravates these effects and further degrades the service performance of building floor systems.

During the ongoing war in Ukraine, a significant proportion of buildings and structures have been damaged. Even before the end of hostilities, the need for rapid restoration of damaged residential buildings

arises, becoming one of the country's most critical tasks. Inspections and assessments of the technical condition of building structures carried out in accordance with [2; 3; 4] are intended to evaluate the feasibility of restoring buildings and structures, determine the extent of damage, define the scope of repair, restoration, or strengthening works, and, where necessary, recommend demolition. Therefore, the prompt inspection of damaged buildings and structures enables informed decision-making, facilitating the timely commencement of restoration efforts.

Review of the research sources and publications

Based on inspections of buildings and structures damaged as a result of non-design impacts, technical reports are prepared containing specific recommendations for their restoration, which in most cases are highly individualized. Open-source publications summarize and systematize the information collected in such technical reports in order to facilitate subsequent inspections of damaged buildings and structures.

The city of Chernihiv suffered extensive destruction in the spring of 2022, when it was subjected to intense attacks by missiles and other weapons of mass destruction. As a result, a large number of the city's buildings and structures were damaged or destroyed. Reference [5] presents the results, accompanied by demonstrative photographs, of extensive restoration work carried out on damaged residential buildings, based on reports prepared with the involvement of specialists from the State Research Institute of Building Structures (NDIBK) responsible for both inspections, development of design documentation.

The monograph [6] employs a systematic approach to addressing one of the most pressing contemporary challenges in construction practice—the restoration of structural elements damaged by non-design impacts. It analyses issues related to restoring the serviceability of damaged buildings, systematizes the types of damage sustained by structural elements both during normal operation and as a result of extraordinary impacts, including military actions, and reviews existing restoration methods. The work presents modern approaches to building inspections as well as current classical and innovative methods for restoring structural components damaged by non-design impacts, including combat-related effects. Practical experience in implementing the investigated restoration methods is also summarized.

In study [7], an analysis and improvement of organizational and technological solutions for temporary strengthening of structures and critical zones of damaged buildings during emergency rescue operations is presented, along with recommendations for selecting optimal solutions. Article [8] substantiates the prospects of precast–monolithic construction as a viable approach for the reconstruction of buildings and structures in Ukraine.

Definition of unsolved aspects of the problem

Given the substantial number of thematic publications, there is an urgent need to develop new methods for repairing structures damaged by non-design impacts. It is essential to emphasize that the technologies developed or analyzed must, first, be economically justified, and second, enable rapid restoration of buildings and structures with minimal time losses. Moreover, it is important to apply solutions that ensure the required strength and stability of restored structural components, including precast reinforced concrete floor systems.

It should be noted that, although a considerable number of publications address the repair of structures damaged by non-design impacts in general, insufficient attention has been devoted specifically to precast reinforced concrete floor systems, despite their importance and high responsibility class. There is a lack of comprehensive works dedicated exclusively to this type of construction, which significantly complicates the development of effective methods for restoring their serviceability after non-design impacts.

Problem statement

The aim of this study is to identify, based on a specific case, the level of damaged precast reinforced concrete floor system, taking into account the current technical condition of the structure and the conclusions regarding its serviceability.

Basic material and results

The object of the study is the precast reinforced concrete floor system of the residential building located in Chernihiv, which was damaged as a result of shelling during military actions. Information regarding the technical condition of the building and its structural elements, its general characteristics, and the results of the inspection were taken from the “Report on the Detailed Survey of the Residential Building in Chernihiv, damaged as a Result of Military Actions,” prepared by the State Research Institute of Building Structures (NDIBK) in 2022.

The general view of the building façade is presented in Fig. 1. In terms of its volumetric and planning configuration, the building consists of 14 storeys, with a basement and a technical floor. It has a square plan with approximate dimensions of 26×26 m. The storey height is 3 m. A schematic plan of a typical floor is shown in Fig. 2.

According to available data, the residential building was constructed in 1996 and contains a total of 65 apartments; all structural elements have been preserved since construction. It has been established that no significant changes were introduced to the structural system during its service life.

The building belongs to the category of non-frame structures and features longitudinal and transverse load-bearing brick walls. Geometric stability and spatial rigidity are ensured by the combined action of the load-bearing walls and the horizontal diaphragms formed by the reinforced concrete floor systems.



Figure 1 – General view of the building facade

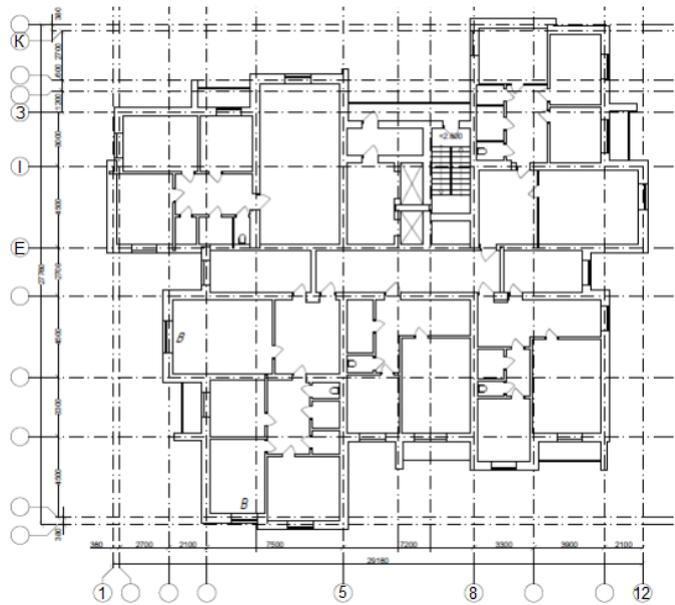


Figure 2 – Schematic plan of a typical floor of the building



Figure 3 (a-d) – Identified damages of the precast reinforced concrete floor systems

The foundations consist of precast reinforced concrete blocks. The interstorey floor slabs are factory-made precast hollow-core reinforced concrete panels supported on longitudinal and transverse load-bearing brick walls. The exterior walls are built of silicate brick laid on a cement-sand mortar. The thickness of the external load-bearing walls is 640 mm, while the internal load-bearing walls are 510 mm thick. Partitions are brick, 65 mm thick (silicate brick laid on edge).

Entrances to the residential areas are located at ground-floor level on the courtyard façades, equipped with door openings and entrance assemblies leading to the stairwells. The building is equipped with elevator shafts and is connected to centralized water, electricity, gas, and heat supply networks.

The inspection of the building was carried out in August 2022. During the examination of the external façade walls and interior spaces, a number of characteristic defects and structural damages were

identified, which resulted from shelling during military actions.

Numerous damages to the precast reinforced concrete floor systems were observed. These damages occurred due to mechanical non-design impacts caused either by direct artillery shell hits on the floor slabs or on the load-bearing wall structures, with the impact energy subsequently transmitted from the wall to the floor system. The observed damages include complete destruction of hollow-core floor panels, cracks at the

joints between floor slabs, cracking of the finishing layer, through-holes in the hollow-core panels, spalling of the concrete cover with exposure and corrosion of reinforcement, cracks and deflections at panel connections, and cracks in the joints between floor slabs (see Fig. 3).

Some floor slabs experienced thermal deformations resulting from fires caused by artillery shell impacts. Cracking of the finishing layer and soot deposits were observed (see Fig. 4).



Figure 4 (a-b) – Cracking of the finishing layer and soot on the floor slab structure

As part of the inspection of the residential building, engineering and geodetic measurements of the deformed state of the floor slabs were performed using the leveling method relative to a reference horizontal plane. This method is based on the assumption that at the time of construction, the floor slabs were positioned in the design horizontal plane, with deviations not exceeding allowable installation tolerances. The distance of the structure from the reference horizontal plane passing through the highest identical point of the element can be considered as a measure of deformation. To determine vertical displacements of the floor slabs, deformation markers were directly installed on the slabs.

In total, 100 deformation markers and 3 benchmarks for monitoring deflections were installed on the floor slabs of the building (floors 7–8 and 10–14). The results of deviations from the reference horizontal plane of the floor slabs are shown in Fig. 5.

According to the geometric leveling results, an excessive deviation of -49 mm was recorded in the slab at axes K-I/8-12 on the 7th floor. In this area, damages and destructions of interior partitions, collapse of brick masonry at the junction of load-bearing walls, a through-hole in a load-bearing wall caused by a direct artillery shell impact, and other damage to interior partitions with vertical displacements were observed. No direct artillery hits on the floor slab or fire-related effects were detected in this location.

The remaining measured slabs were within permissible deviations. During two observation cycles (August–September), vertical displacements up to -1 mm were recorded, which did not exceed the measurement accuracy. In one section, a minor upward movement of +2 mm was observed, likely due to the unloading of the floor slabs.

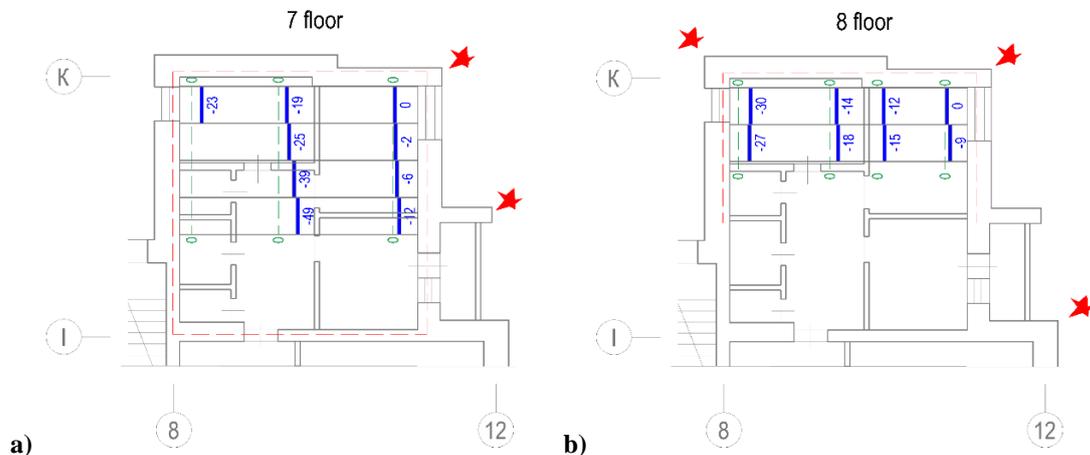


Figure 5 (a-b) – Results of deviations from reference horizontal plane of the floor slabs (beginning)

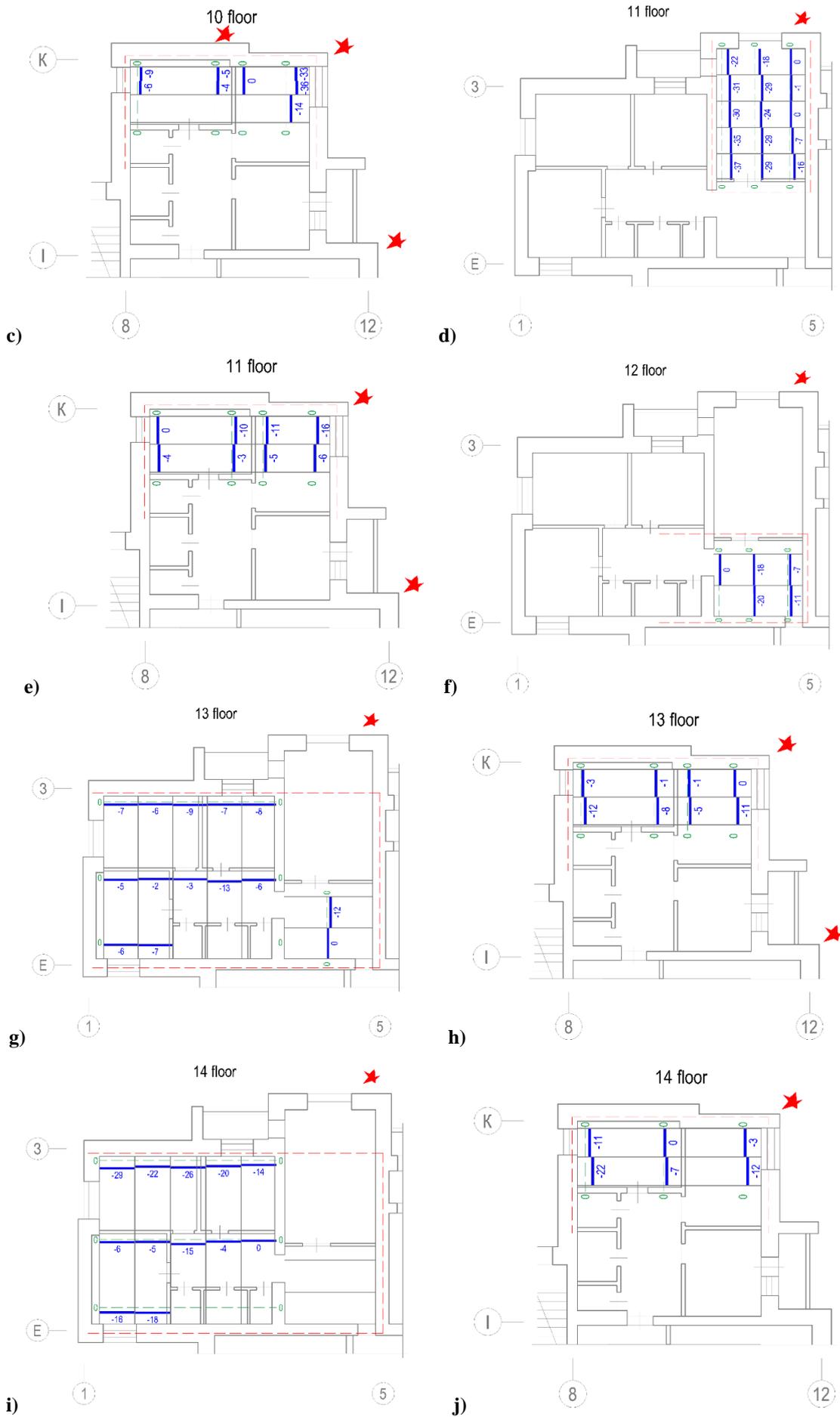


Figure 5 (c-j) – Results of deviations from reference horizontal plane of the floor slabs (completion)

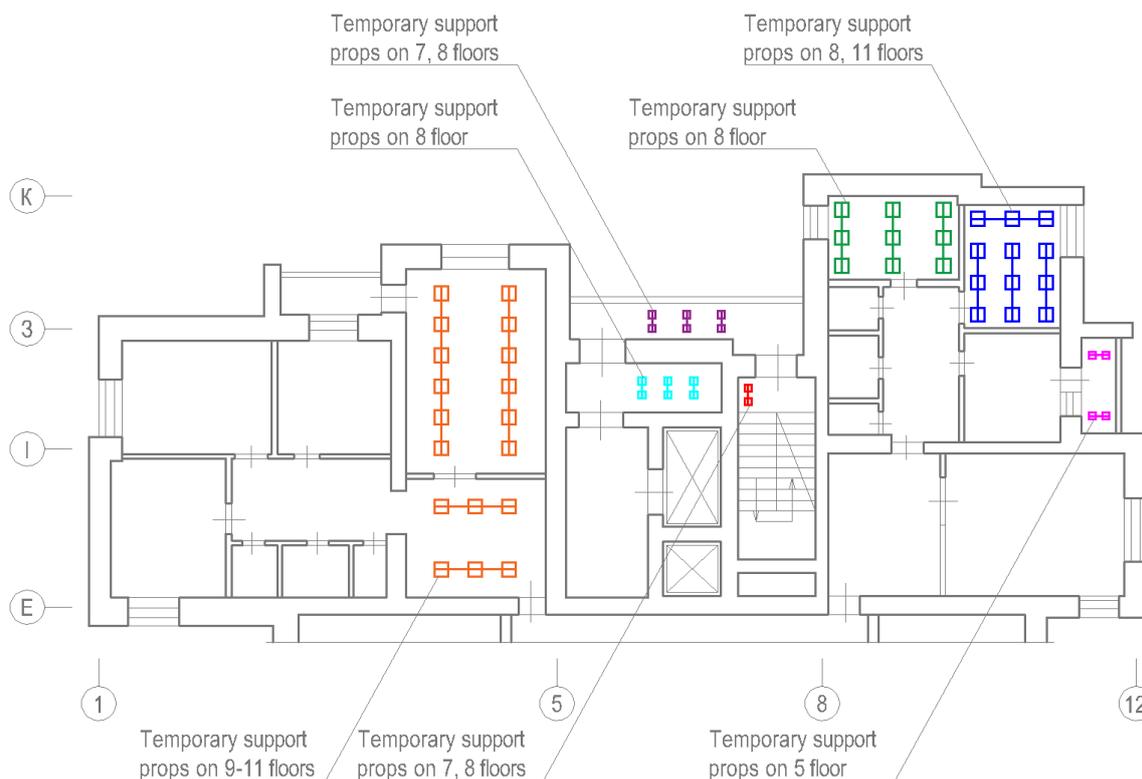


Figure 6 – Layout of temporary support props

Based on the results of the inspection, the overall technical condition of the building should also be classified as emergency (category 4), as it contains structural elements belonging to the fourth category of technical condition. It should be noted, however, that the strength and stability of the building as a whole, excluding the damaged areas, is maintained.

Conclusions

The restoration of residential buildings damaged as a result of military actions is a complex, multi-stage process that includes inspection of the buildings, assessment of their technical condition, determination of the extent and nature of the damage, preparation of design documentation, and subsequent execution of restorative construction and installation works.

In the case of the residential building in Chernihiv, which was damaged due to military actions, it is recommended that, in order to restore the serviceability and ensure reliable and safe future operation of the floor systems, the following measures be carried out: temporary strengthening of the emergency sections of the floor slabs and lintels by installing temporary props with wedging to engage them according to the scheme shown in Fig. 6; safe dismantling of completely destroyed elements; repair works to restore the brick masonry of damaged wall sections and strengthen the lintels; and restoration of the damaged floor slab sections by concrete casting, ensuring composite action of the reinforcement

All works should be carried out in accordance with current construction regulations, following the developed project, and in compliance with occupational safety and health requirements.

This specific case illustrates the behavior of precast reinforced concrete floor systems after non-design impacts and the resulting changes in their stress-strain state. In the event of a direct hit, precast reinforced concrete floor slabs are subject to significant damage and may exceed the first-group limit states, thereby being classified as emergency. When hits occur to load-bearing walls or partitions located in close proximity to the floor slabs or supporting them, the floor systems may exceed the second-group limit states, also being classified as emergency or unsuitable for normal operation.

Each building type may exhibit defects or damages that are unique to its design. The results of such studies can inform decisions on the construction of new floor systems that are more resistant to non-design impacts or the reconstruction of existing ones, taking into account the organizational and technological features of their construction.

The most resistant to non-design impacts are continuous multi-span structures, which can be implemented both in new construction and in the reconstruction of buildings or facilities. For example, multi-span reinforced steel-concrete structures using a monolithic reinforced concrete slab as the compressed planar part of the cross-section and a steel profiled section as the tensile bar component have proven highly effective due to their technological efficiency and significant load-bearing capacity, both in civil and industrial construction. Their high load-bearing capacity and ease of installation also make them suitable for floor systems in civil protection shelters.

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Зміна напружено-деформованого стану збірних залізобетонних перекриттів цегляних багатоповерхових будівель після позапроектних впливів

Анотація. Стаття присвячена дослідженню позапроектних впливів на збірні залізобетонні перекриття цегляних багатоповерхових будівель, що виникають під час воєнних дій. Розглядається вплив зовнішніх і внутрішніх чинників на дані конструкції та їх зношування. Використовуючи матеріали «Звіту про виконання детального обстеження житлового будинку у м. Чернігів, який пошкоджено внаслідок військових дій», який був виконаний ДП Державний науково-дослідний інститут будівельних конструкцій ДП «НДІБК» у 2022 році, аналізується характер впливу воєнних дій на будівлю в цілому та її окремі конструктивні елементи, особливо на збірні залізобетонні перекриття. В об'ємно-планувальному рішенні будинок 14 поверховий з підвалом і технічним поверхом, квадратної форми в плані, з орієнтовними габаритними розмірами 26×26 м. Висота приміщень становить 3 м. Будинок побудований у 1996 році та має в загальній кількості 65 квартир. Принципових змін в конструктивну схему будівлі за час її експлуатації не було внесено. Розглядається випадок прямого багаторазового влучання артилерійських снарядів в будівлю, при якому відбувається часткове руйнування несучих конструкцій і пошкодження (або руйнування) пов'язаних з ними елементів перекриття. У рамках обстеження житлового будинку були виконані інженерно-геодезичні вимірювання деформованого стану перекриттів за методом нівелювання по умовній горизонтальній площині. Встановлено 100 деформаційних марок та 3 репери для спостережень за прогинами. За результатами геометричних нівелювань в плиті на 7 поверсі зафіксоване недопустиме відхилення -49 мм. На даній ділянці були зафіксовані пошкодження та руйнування міжкімнатних перегородок і зовнішніх цегляних стін внаслідок прямого влучання артилерійського снаряду. Прямого влучання артилерійських снарядів в перекриття або наслідків пожежі зафіксовано не було. Решта плит, які вимірювалися, знаходяться в межах допустимих відхилень.

Ключові слова: житлові будинки, вплив воєнних дій, пошкодження, відновлення, залізобетонне перекриття, експлуатаційна придатність

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