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TECHNOLOGY FOR RESTORING STRUCTURES OF MULTI-APARTMENT PANEL BUILDINGS DAMAGED BY MILITARY ACTIONS

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Abstract. This paper addresses the problem of restoring the load-bearing structures of multi-apartment large-panel residential buildings damaged as a result of military actions, based on a real case study. The nature of structural damage caused by blast effects is analyzed, including the displacement and destruction of wall panels, loss of stiffness in structural joints, damage to floor slabs, and disruption of the building's spatial behavior. It is shown that the main hazard is associated not only with local structural failures, but also with the loss of composite action between the elements of the structural system.

A phased technology for emergency stabilization and restoration works under conditions of partial building operation is proposed. The technology includes structural stabilization using temporary shoring systems, local strengthening of floor slabs, alignment of deformed elements, dismantling of emergency-damaged structures, and the introduction of new structural solutions using steel framing systems and cast-in-place reinforced concrete elements. Particular attention is given to the implementation of a "safety frame" as a structural measure for redistributing internal forces and restoring the spatial stiffness of the damaged building section.

It has been established that the effectiveness of restoration is determined not only by the adopted structural solutions, but also by the organizational and technological conditions under which the works are performed, in particular the need to ensure the safety of both residents and construction personnel while carrying out the works without taking the building out of service. The expediency of applying BIM technologies for modeling damaged structures, coordinating engineering decisions, and promptly introducing changes into the design documentation is substantiated.

The obtained results may be used for developing methodological approaches to the restoration of damaged housing stock and for improving the regulatory framework under current challenges.

Keywords: building restoration; reconstruction; structural strengthening; panel buildings; reinforced concrete structures.

INTRODUCTION

The purpose of this study is to develop and substantiate an effective technology for restoring the load-bearing structures of a multi-apartment panel residential building damaged as a result of military actions, taking into account the building's operating conditions during the execution of the restoration works.

To achieve this goal, the following objectives were defined:

- to analyze the nature of structural damage;
- to assess the impact of the damage on the spatial behavior of the building;
- to develop a sequence for carrying out emergency stabilization works;
- to substantiate the use of steel strengthening elements;
- to evaluate the effectiveness of BIM technologies.

The scientific novelty of the study lies in:

- proposing a phased technology for the restoration of panel buildings under conditions of partial operation;
- adapting traditional strengthening approaches to blast-induced damage conditions;
- integrating BIM modeling into the process of structural decision-making during the reconstruction of emergency-damaged buildings.

PROBLEM OVERVIEW

The housing stock is an important component of the infrastructure of populated areas, and its technical condition directly affects the safety and living conditions of the population [4, 9, 12].

One of the factors contributing to urban development is the construction of new buildings and the reconstruction of existing ones. The need to strengthen building structures may be caused by a change in functional purpose, modernization, physical deterioration, corrosion processes, violation of operating conditions, or the action of accidental and emergency loads [1, 14, 15, 18].

As a result of the armed aggression against Ukraine, the number of damaged and destroyed buildings has increased significantly, which has led to the need to develop effective approaches to their inspection, strengthening, and restoration [2, 4, 7, 9, 12].

At the first stage, it is necessary to determine whether the building should be considered completely destroyed or partially damaged and therefore suitable for restoration [9, 10, 12]. An important element of the inspection is to determine whether people can safely return to those parts of the building that have not suffered direct damage, and whether these facilities can be operated safely at all [10, 12, 19].

In a number of cases, the feasibility of restoring damaged buildings should be assessed in comparison with the option of new construction, taking into account technical, economic, and social factors [4, 12].

Naturally, the reconstruction of partially damaged buildings will require significantly fewer resources and less time.

The first stage of assessment includes a visual inspection of the building. At this stage, the damage is documented and the percentage of damaged structural components is calculated in relation to the total area of the building. According to the methodology for inspecting buildings and structures damaged as a result of emergencies, military actions, and terrorist acts, three categories of damage are identified, based on which a decision is made regarding the further fate of buildings and structures [10, 22].

At the second stage, the impact of the damage on the stability and safety of the building is determined. After that, experts decide whether the restoration of the building is possible and what resources are required for its

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implementation. This stage is crucial for assessing the economic costs of carrying out the building restoration works.

The 10-storey panel residential building consists of a single section (single-entrance building) (Fig. 1) and was constructed according to Series No. 96. The floor height is 2.7 m.

Fig. 1 Panel residential building damaged during military actions. Photo by Dmytro Levkivskyi
Рис.1 Панельний будинок пошкоджений під час бойових дій. Автор фото Дмитро Левківський

BUILDING DATA

At the end of the 1970s, standard designs of large-panel residential buildings of Series 96 with a frequent spacing of transverse walls were developed. The project range of this series includes the necessary set of 9-storey block sections and sectional residential buildings of complete structural configuration with various apartment layouts. A distinctive feature of Series 96 is that its primary design units are block sections, which makes it possible to form buildings of various configurations, lengths, and numbers of storeys, thereby ensuring high urban planning quality of the development.

Taking into account new requirements and the experience gained from the construction of 16-storey buildings of the KT and BPS series, Series 96 was provided with an internal frame composed of reinforced concrete panels with transverse and longitudinal orientation. The thickness of the load-bearing walls is 350 mm. The external walls are made of expanded clay concrete.

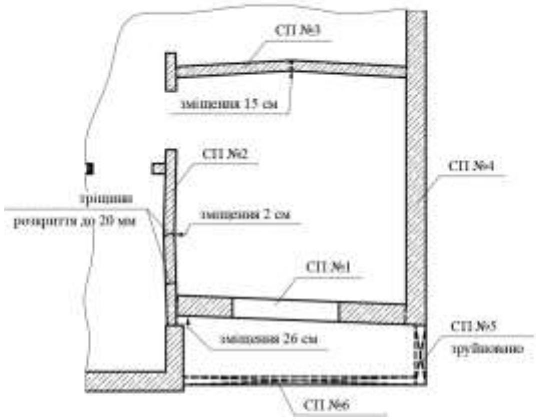

Fig. 2 Plan of the damaged room, Apartment No. 40, 10th floor
Рис.2 План пошкодженої кімнати, квартира №40. 10 поверх

DESCRIPTION OF THE DAMAGED ROOM

As a result of military actions, an enemy shell struck the apartment located on the tenth floor, destroying the external balcony walls and damaging the internal walls of Apartment No. 40, as well as the floor slab between the apartment and the technical floor (Figs. 1, 2). In addition, the joints between slabs were destroyed in several locations [9, 11, 12, 17]. The nature of the identified damage indicates not only local failure of individual elements, but also a disturbance of the spatial behavior of the entire structural system of the room [11, 17, 20, 23, 25]. Under such conditions, even partially preserved elements cannot be considered reliable without additional analysis of their interaction with adjacent structures [11, 20, 23].

1. The shell damaged wall panel No. 1 (Fig. 2) and displaced it by 26 cm (Fig. 3) into the room, causing the floor slab and wall panel No. 2 to lose their structural restraint.
2. Wall panel No. 2 was displaced by 2 cm, resulting in the formation of two vertical cracks with an opening width of up to 20 mm (Fig. 2).
3. Wall panel No. 3 fractured in the middle under the effect of the blast wave and was displaced by 15 cm (Fig. 4). The panel contains weakened zones in the form of channels for electrical networks located in the middle of the slab, which contributed to the development of failure in this area.
4. Balcony wall panel No. 5 and enclosing panel No. 6 were destroyed (Fig. 5).

Fig. 3 Damaged wall panel No. 1, displacement of 26 cm (view from the balcony side).
Photo by Dmytro Levkivskyi

Рис. 3 Зруйнована стінова панель СП№1, переміщення 26 см (фото зі сторони балкона).
Автор фото Дмитро Левківський

Fig. 4 Damaged wall panel No. 3. Vertical through-cracks (view from the room side).
Photo by Dmytro Levkivskyi

Рис. 4 Пошкоджена панель СП№3. Вертикальні наскрізні тріщини. (фото з кімнати).
Автор фото Дмитро Левківський

Fig. 5 Destroyed wall panels No. 5 and No. 6 on the balcony. Photo by Andrii Zabrodskyi

Рис. 5 Зруйновані панелі СП№5 та СП№6 на балконі.
Автор фото Андрій Забродський

5. The cantilever floor slab above the balcony experienced significant deflection, and an 8 cm gap formed between it and the façade wall, creating an emergency condition (Fig. 5).
6. The blast wave lifted the floor slab of the technical floor, tore out the embedded connections, and caused diagonal cracks to form throughout the slab, making its normal operation impossible (Fig. 6).
7. The floor slab between the 9th and 10th floors sustained similar damage.

The analysis of the damage showed that the most critical issues are not only the destroyed or displaced wall panels, but also the failure of connections between floor slabs and vertical load-bearing elements. It is precisely the loss of composite structural action that creates the risk of progressive deformations and local loss of stability of individual parts of the building [11, 17, 20].

Fig. 6 Diagonal cracks in the floor slab. Photo by Andrii Zabrodskyi
Рис.6 Діагональні тріщини в плиті перекриття. Автор фото Андрій Забродський

DESCRIPTIOM OF THE RESTRATION TECHNOLOGY

In the room on the 10th floor, a situation arose in which five out of the six load-bearing panels of the room (three wall panels and two floor slabs) were in an emergency condition. Wall panel No. 1 was displaced into the room and became wedged between the floor slabs, which temporarily limited further displacement of the elements, but did not ensure their code-compliant structural reliability.

The most hazardous area was the open balcony with the cantilever slab, where there was a risk of slab collapse during vibrations and construction works.

The restoration measures included the replacement or restoration of certain destroyed building elements (the balcony walls), as well as the strengthening of the walls and floor slab of the panel building using steel and reinforced concrete structures.

Under such conditions, the key task was not only the restoration of individual damaged elements, but also ensuring the temporary and subsequent stable spatial behavior of the entire structural system of the room. For this reason, the restoration technology was developed according to the principle of phased reduction of the emergency condition, with a transition from temporary stabilizing measures to final structural solutions.

The first stage of restoration consisted of stabilizing the damaged structures and carrying out emergency works.

The sequence of operations was determined taking into account the geometric variability of the structures, technological constraints, and occupational safety requirements.

Therefore, a system of shoring props was first installed according to the scheme (Fig. 7) on the 10th, 9th, and 8th floors in order to stabilize the floor slabs and ensure the safety of the construction workers.

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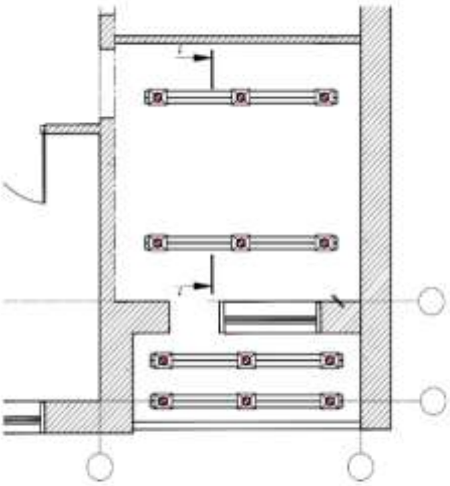


Fig. 7 Layout of the shoring prop system
Рис.7 Схема влаштування системи опалубочних стійок

This solution made it possible to reduce the risk of sudden escalation of the emergency situation during dismantling and installation operations, and also created controlled conditions for further intervention in the damaged structural system.

At the next stage, a scheme was developed for lifting and leveling the cantilever balcony floor slab (Fig. 8), which had tilted by 8 cm. For this purpose, a steel beam made of paired 125×8 angles was installed on the technical floor using an M16 threaded rod system, as shown in Fig. 9.

The proposed solution made it possible to locally compensate for the loss of geometric stability of the cantilever section and to avoid dismantling a larger number of adjacent structures. This is important from the point of view of minimizing intervention in the existing structural system of the building.

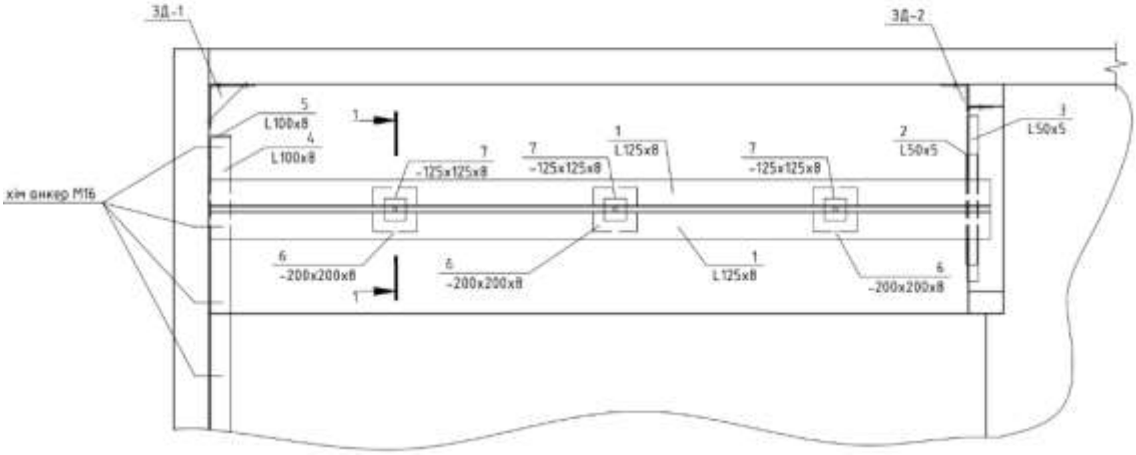


Fig. 8 Scheme for lifting and leveling the balcony slab
Рис.8 Схема виважування плити балкону

Fig. 9 Scheme for lifting and leveling the balcony slab: steel beam made ofpaired 125×8 mm angles. Photo by Andrii Zabrodsky i
Рис.9 Схема виважування плити балкону, сталева балка з спарених кутиків 125х8 мм. Автор фото Андрій Забродський

To ensure safe occupancy of the room during the dismantling of the destroyed walls, the floor slab between the 10th floor and the technical floor was preliminarily strengthened by introducing a system of steel beams, which were engaged structurally by means of M16 threaded rods and steel plates (Figs. 10, 11).

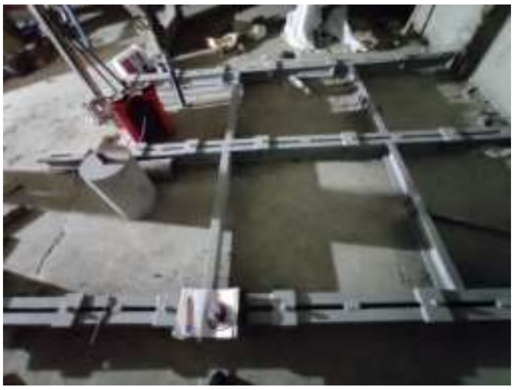


Fig. 10 Scheme for strengthening the floor slab between the 10th floor and the technical floor. Photo by Andrii Zabrodskyi
Рис.10 Схема підсилення плити перекриття між 10-м та технічним поверхом Автор фото Андрій Забродський

The preliminary strengthening of the floor slab is a fundamentally important stage, as it makes it possible not only to ensure the safe execution of the works, but also to prevent the redistribution of internal forces in the already damaged elements during the dismantling of emergency structures.

Fig. 11 Scheme for strengthening the floor slab between the 10th floor and the technical floor.
Photo by Andrii Zabrodskyi
Рис.11 Схема підсилення плити перекриття між 10-м та технічним поверхом. Автор фото Андрій Забродський

After strengthening the floor slab, the destroyed balcony panels No. 5 and No. 6 were replaced by installing a steel frame made of angle sections beneath the slab and reconstructing a brick wall in place of the destroyed reinforced concrete panel (Figs. 12, 13).

Fig. 12 Steel frame for the restoration of the balcony structures. Photo by Dmytro Levkivskyi
Рис.12 Сталевий каркас відновлення конструкцій балкону. Автор фото Дмитро Левківський

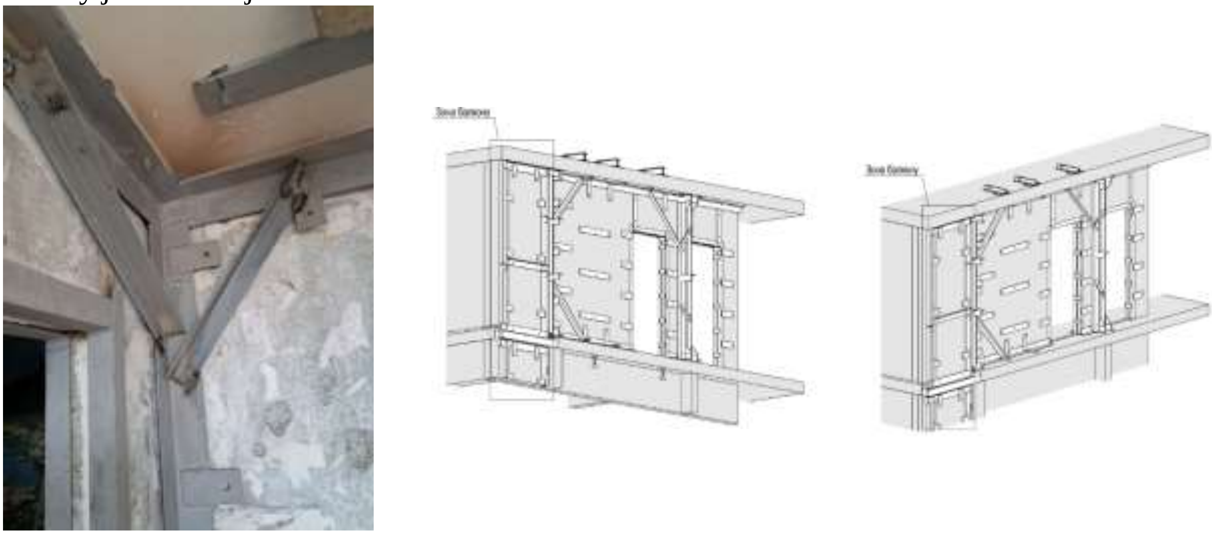
Fig. 13 Steel frame for the restoration of the balcony structures. Photo by Dmytro Levkivskyi
Рис. 13 Сталевий каркас відновлення конструкцій балкону. Автор фото Дмитро Левківський

This made it possible to create a safe space for the subsequent dismantling of wall panel No. 1

and to protect the apartment from atmospheric exposure.

Thus, the restoration of the balcony performed not only an enclosing function, but also played an important role in ensuring the technological sequence of the subsequent restoration works.

At the next stage, a “safety frame” was introduced in the room in order to restore the assembly joints of adjacent floor slabs and wall panels and to redistribute internal forces. Along the perimeter of the room, a framing system made of 125×8 and 100×8 angle sections was installed. These elements were anchored to the reinforced concrete components using M16 chemical anchors, while some of the elements were temporary due to the distorted geometry of the room walls (Fig. 14).



a *b*

Fig. 14 Installation of the safety frame in the room: a - actual view (photo of implementation); b - schematic diagram of the structure.
Photo by Dmytro Levkivskyi

Рис.14 Введення каркасу безпеки в кімнаті: *a* - фактичний вигляд (фотографія завершеного монтажу); *b* - схематичне зображення конструкції.
Автор фото Дмитро Левківський

The introduction of temporary and partially permanent steel framing made it possible to redistribute local internal forces within the damaged room and to stabilize the geometry of the joints between structural elements.

At the next stage, wall panel No. 1 was dismantled (Fig. 15), and a steel frame made of Channel No. 16 and 125×8 and 100×8 angle sections was installed. The space between the steel elements was filled with 300 mm thick aerated concrete blocks (Fig. 16).

The adopted solution combines the structural efficiency of the steel frame with the technological feasibility of using a lightweight infill material, which makes it possible to reduce the additional load on the existing structures.

Fig. 15 Dismantled wall panel No. 1.
Photo by Dmytro Levkivskyi

Рис.15 Демонтована стіна СП№1.
Автор фото Дмитро Левківський

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Fig. 16 Restoration of wall panel No. 1.
Photo by Dmytro Levkivskyi
Рис.16 Відновлення стіни СП№1.
Автор фото Дмитро Левківський

After the restoration of wall panel No. 1, works were carried out to restore wall panel No. 3. In the preliminary design, it had been planned to cut out a portion of the wall around the cracks, lift and level the floor slab, and pull the parts of the wall panel back into their design position using threaded rods. However, this concept proved technologically unfeasible and was not implemented. As a result, a decision was made to dismantle the wall and introduce a steel frame similar to that used for wall panel No. 1 (Fig. 17).

The revision of the initial technical solution during the execution of the works confirmed the need for a flexible approach to the restoration of damaged buildings, where the actual technical condition of the structures may require prompt adjustment of the design solutions.

The introduction of monolithic elements into the damaged floor system makes it possible to increase the stiffness of the section affected by the blast and to partially compensate for the loss of load-bearing capacity of the existing slabs.

The restoration of the wall panels of the room and balcony, as well as the floor slab between the 10th floor and the technical floor, has been completed.

Fig. 17 Dismantling of wall panel No. 3.
Photo by Dmytro Levkivskyi
Рис.17 Демонтаж стіни СП№3.
Автор фото Дмитро Левківський

The remaining task is to strengthen the floor slab between the 9th and 10th floors, which was affected by the explosion and exhibits significant cracks and deflections. A decision was made to introduce a system of cast-in-place reinforced concrete beams (Figs. 18, 19, 20).

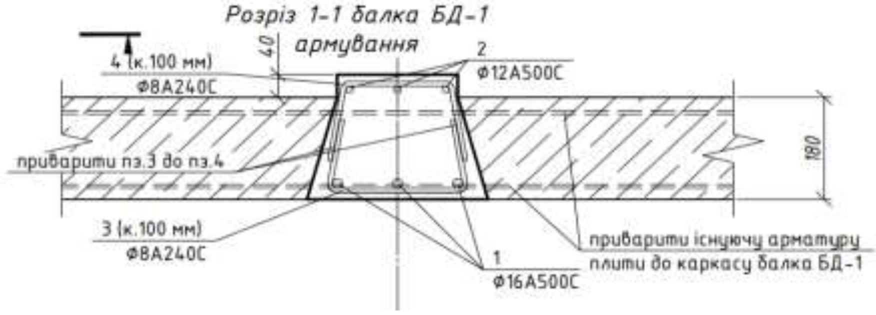

Fig. 18 Introduction of cast-in-place reinforced concrete beams into the floor slab
Рис.18 Введення монолітних балок в перекриття

Fig. 19 Reinforcement of the cast-in-place beam. Photo by Dmytro Levkivskyi
Рис.19 Армування монолітної балки. Автор фото Дмитро Левківський

Fig. 20 Reinforcement of the cast-in-place beam. Photo by Dmytro Levkivskyi
Рис.20 Армування монолітної балки. Автор фото Дмитро Левківський

INTEGRATED APPROACH AND ADVANTAGES OF BIM DESIGN IN THE DEVELOPMENT OF WORKING DOCUMENTATION FOR THE RECONSTRUCTION OF DAMAGED BUILDINGS AND STRUCTURES

The use of a BIM model makes it possible to quickly prepare all the necessary information and drawings by creating a three-dimensional digital model of the facility that contains all the required information about the object. With the help of this technology, the number of errors and miscalculations can be significantly reduced, making it possible to identify potential inconsistencies and adjust design solutions at early stages.

It is possible to manage work phases in real time and monitor parameters directly within the project, as well as to automatically update drawings when changes need to be made to the model. This is especially relevant for the reconstruction of damaged buildings, since the structural systems of such projects contain a large number of defects and damages that must be accurately incorporated into the project in order to create an up-to-date digital model of the technical condition of the structural system.

This helps to position new structural elements more accurately exactly where they are required (Figs. 21, 22).

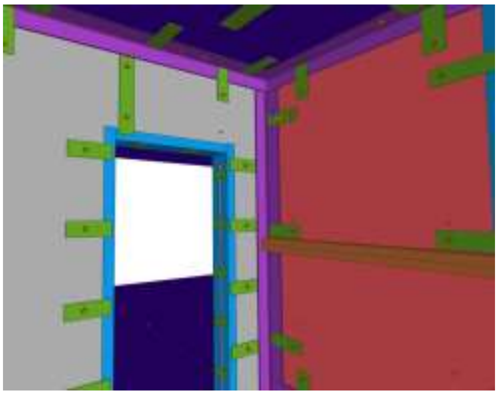

Fig. 21 Three-dimensional model of the structural strengthening of Apartment No. 40
Рис.21 Тривимірна модель підсилення конструкцій квартири №40

In the case of restoring damaged buildings, the BIM model performs not only a graphical but also an analytical function, as it allows for the systematization of information about defects, tracking the spatial relationship between new and existing elements, and prompt adjustment of design solutions during implementation.

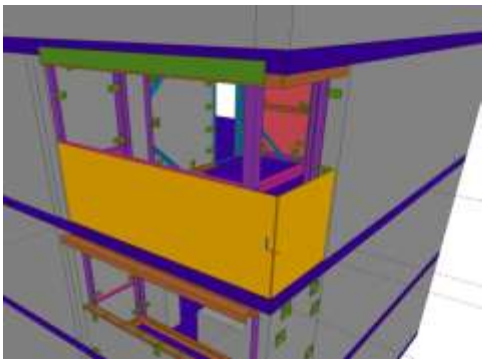

Fig. 22 Three-dimensional model of the structural strengthening of the balconies
Рис.22 Тривимірна модель підсилення конструкцій балконів

REGARDING THE DIRECT EXECUTION OF THE WORKS

Under conditions where a significant number of facilities have been damaged as a result of military actions, practical experience in carrying out emergency stabilization and restoration works becomes especially valuable for the development of effective organizational and technological approaches.

Based on the direct experience of implementing the above-mentioned design solutions for emergency stabilization works at the facility located at 162 Severynivska Street, Irpin**,** it is advisable to highlight a number of organizational and technological features related to the execution of emergency works at this site.

The analysis of the practical experience of implementing the design solutions showed that the effectiveness of restoring damaged buildings is determined not only by the correctness of the structural solutions, but also by the organizational and technological conditions of their execution. In many cases, these factors are decisive for the safety, duration, and quality of the restoration works.

1. The contractor bears increased responsibility for the safety of personnel, building residents, and adjacent facilities and surrounding areas. This concerns not only the confined working conditions and the unstable technical condition of the preserved structures — in many cases, including this specific one, it was not possible to fully evacuate the residents or remove them entirely from the emergency work zone.

The works were carried out without taking the building out of operation, and without disconnecting the existing utility networks or elevators. This created additional risks associated with the technological processes involved in dismantling damaged fragments, removing dismantled elements and debris from the site, installing steel structures, performing concrete works, and other related activities.

Working under such conditions requires increased attention and responsibility, as well as a high level of competence and discipline from both engineering and technical personnel and construction workers. Enhanced supervision is required with regard to the implementation of safety measures, occupational health and safety, and waste handling.

Before commencing this type of work under such conditions, it is necessary to elaborate all technological processes in as much detail as possible, to develop the relevant method statements, work execution plans, and safety instructions. It should also be taken into account that standard solutions may not meet the requirements of specific situations at different sites, and that each such facility may in fact be unique and atypical, requiring site-specific approaches and solutions.

An appropriate communication and public information algorithm should also be developed, and the work schedule and operating regime should be carefully coordinated on an hourly basis with the residents in order to minimize risks to occupants during the execution of the works.

In many cases, there will also be a need for additional safety measures, such as the installation of temporary support systems directly inside occupied and operational residential premises, in common-use areas, as well as the closure of window and door openings, stair flights, elevator zones, and similar elements.

These factors require additional organizational measures and close coordination with local residents, including proper communication of the risks involved, regular resident safety briefings, and continuous monitoring of compliance with safety instructions, as well as preventing unauthorized persons from entering the work zones, in order to avoid additional risks to the life and health of both residents and personnel.

2. When carrying out works at damaged facilities that remain in operation, particular attention must be paid to the technical condition of existing utility systems. Thorough and detailed inspections of these systems are required, including integrity checks and testing, in order to assess their condition and level of hazard, especially in areas of concealed routing. It is also necessary to eliminate the consequences of damage to the networks caused by external impacts or technical deterioration.

   Prior marking and tracing of all existing active utility systems within the work zones is mandatory. These systems must be protected by safety frames and protective screens to prevent damage during the dismantling of destroyed structures and the subsequent installation of new ones. Where necessary, the complete removal of utility systems from the work zones should be carried out by switching them to temporary schemes.

   All of this requires additional coordination and communication with representatives of operating organizations and asset owners responsible for the networks and equipment. In the areas where emergency works are being carried out, all utility systems must be disconnected and removed from the zones of dismantling and installation.

   After the completion of emergency works, all utility systems passing through both the damaged premises and the adjacent areas must be properly restored and tested.

3. Particular attention must be paid to the equipment, tools, and methods selected for the execution of the works. All possible impacts associated with equipment and tools must be taken into account and controlled, including noise, impact and vibration effects, dust generation, and the use of process water for cooling equipment and removing slurry during diamond cutting operations, as well as electrical load during simultaneous operation, sparks, flames, and light flashes during welding and hot works.

   It is essential to develop and strictly follow measures aimed at minimizing these technological impacts, since neglecting this principle may lead to negative consequences, including additional damage to the building structures and frame elements, both damaged and intact adjacent ones; damage to or flooding of existing utility systems and neighboring premises; deterioration of the contractor's and residents' property; excessive dust load on ventilation systems; and similar effects.

   The selection and methods of using light construction equipment and tools must be carefully calculated already at the stage of preparation and development of method statements and work execution plans. Personnel involved in the operation of such equipment must be properly trained and qualified, while the equipment itself must be intact, serviceable, and compliant with the manufacturer's technical specifications, with regular inspections of its condition, conductor insulation resistance, and routine maintenance.

   The use of outdated, worn-out, defective, technically unfit, or otherwise unsuitable equipment at such facilities is unacceptable.

4. At the beginning and during the execution of emergency stabilization works at facilities damaged as a result of military actions, it is always necessary to take into account situations such as the following:
   - identification of additional hidden defects and structural damage that were not detected during the preliminary inspection of the facility;
   - identification and elimination of defects and damage caused by the technical deterioration of the building structures, which are not related to external impact but are purely the result of long-term operation;

- detection of unauthorized alterations and modifications to load-bearing and enclosing structures caused by unapproved redevelopment or repair interventions by residents;
- unauthorized changes made by residents to utility system layouts, as well as the installation of additional equipment such as underfloor heating systems, heaters, air conditioners, satellite antennas, radiators, and similar devices.

All of this requires a highly flexible and prompt approach, including on the part of the designer. It may necessitate numerous revisions and adjustments to the design solutions. Additional structures and load-bearing frame elements may need to be introduced. Repeated inspections and recalculations are often required. The scope of work may also increase. In some cases, even radical changes to technical solutions, structural types, materials, and equipment may be needed during the execution of emergency stabilization works.

CONCLUSIONS

The presented case of restoring a damaged apartment in a panel residential building demonstrates that the reconstruction of facilities damaged by military actions requires the simultaneous consideration of structural, technological, organizational, and safety-related aspects. It is precisely this integrated approach that constitutes the key condition for the successful implementation of such projects.

This study investigated the specific features of restoring the load-bearing structures of a multi-apartment panel residential building damaged as a result of military actions, based on a real-life case study.

It was established that the nature of damage to panel buildings after blast effects has a complex spatial character and is accompanied by the disruption of connections between structural elements, which requires an individual approach to the development of restoration solutions.

A phased technology for carrying out emergency stabilization and restoration works was proposed. It includes structural stabilization, local strengthening of floor slabs, dismantling of damaged elements, and the introduction of new structural systems. This approach ensures the restoration of the building's load-bearing capacity and spatial stiffness without complete withdrawal from operation.

It was demonstrated that the use of steel strengthening elements in combination with reinforced concrete structures is an effective solution for localized damage in panel buildings.

The feasibility of applying BIM technologies for modeling damaged structures and optimizing design solutions was substantiated, making it possible to improve the accuracy, efficiency, and coordination of the restoration works.

The obtained results may be used in the development of methodological recommendations for the restoration of damaged housing stock and for improving the regulatory framework under current challenges.

As a result of applying an integrated approach, ensuring clear coordination between construction teams, using BIM technologies, and continuously monitoring the situation, effective structural and technological solutions were developed and implemented, making it possible to restore the damaged structures and ensure the further safe operation of the building.

The results of the conducted study indicate that the future implementation of numerous similar projects will require changes in a number of approaches and methods, both in design practice and in the methodology of carrying out restoration works for damaged facilities. Current conditions of restoring damaged housing stock require the adaptation of existing design and construction approaches, as well as the development of new technological solutions.

ETHICAL DECLARATIONS

The authors have no relevant financial or non-financial interests to report.

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ТЕХНОЛОГІЯ ВІДНОВЛЕННЯ КОНСТРУКЦІЙ БАГАТОКВАРТИРНОГО ПАНЕЛЬНОГО ЖИТЛОВОГО БУДИНКУ, ПОШКОДЖЕНОГО ВНАСЛІДОК БОЙОВИХ ДІЙ

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Анотація. У статті розглянуто проблему відновлення несучих конструкцій багатоквартирних панельних житлових будівель, пошкоджених внаслідок бойових дій, на прикладі реального об'єкта. Проаналізовано характер пошкоджень конструктивних елементів, спричинених вибуховим впливом, зокрема зміщення та руйнування стінових панелей, втрату жорсткості стиків, пошкодження плит перекриття та порушення просторової роботи будівлі. Показано, що основною небезпекою є не лише локальні руйнування, а й втрата сумісної роботи елементів конструктивної системи.

Запропоновано поетапну технологію виконання протиаварійних та відновлювальних робіт в умовах часткової експлуатації будівлі, яка включає стабілізацію конструкцій за допомогою тимчасових підпірних систем, локальне підсилення плит перекриття, вирівнювання деформованих елементів, демонтаж аварійних конструкцій та впровадження нових конструктивних рішень із використанням сталевих каркасів і монолітних залізобетонних елементів. Особливу увагу приділено введенню «каркасу безпеки» як інструменту перерозподілу внутрішніх зусиль та відновлення просторової жорсткості пошкодженого об'єкта.

Встановлено, що ефективність відновлення визначається не лише прийнятими конструктивними рішеннями, але й організаційно-технологічними умовами виконання робіт, зокрема необхідністю забезпечення безпеки мешканців та персоналу при виконанні робіт без виведення будівлі з експлуатації. Обґрунтовано доцільність застосування BIM-технологій для моделювання пошкоджених конструкцій, координації рішень та оперативного внесення змін у проєктну документацію.

Отримані результати можуть бути використані для розроблення методичних підходів до відновлення пошкодженого житлового фонду та вдосконалення нормативної бази в умовах сучасних викликів.

Ключові слова: відновлення будівель; реконструкція; підсилення конструкцій; панельні будинки; залізобетонні конструкції

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