INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 16, Issue 3, 2025: 1347-1362 www.ijcs.ro

DOI: 10. 36868/IJCS.2025.03.08

RESTORATION OF CEILINGS IN BUILDINGS DAMAGED AS A RESULT OF OVER-DESIGN IMPACTS, WHILE PRESERVING THE ESTABLISHED URBAN ENVIRONMENT

Oleksandr MOLODID[1*], Ivan MUSIIAKA[1], Sergey BOGDAN[2], Yehor YASHCHENKO[3], Małgorzata HRYNIEWICZ[4], Bartosz MATLAK[4], RuslanaPLOKHUTA[1],Yevheniia NOVAK[5]

[1] Kyiv National University of Construction and Architecture, 31 Povitroflotskyi Avenue, Kyiv, 03037, Ukraine
[2] LLC "Mapei Ukraine," 13 Yevhena Sverstiuka Street, 5th floor, Kyiv, 02002, Ukraine
[3] National Transport University, 1 M. Omelianovycha-Pavlenka Street, Kyiv, 01010, Ukraine
[4] Cracow University of Technology, 24 Warszawska Street, 31–155 Cracow, Poland
[5] Yuriy Fedkovych Chernivtsi National University, 2 Kotsiubynskoho Street, Chernivtsi, 58012, Ukraine

Abstract

This article deals with the issue of restoration and modernization of buildings that have been damaged, inter alia, as a result of warfare. These facilities largely have cultural values, and the need to revitalize them is a priority for society. Consequently, it is important to conduct research into the methods of repairing built structures and the results of their implementation. The article considers the issues of restoring inter-floor ceilings damaged due to off-design impacts. These ceilings are most often made of reinforced concrete hollow-core slabs. Existing repair methods do not solve the issue of restoring the structural integrity and geometric parameters of these slabs while at the same time leading to undesirable changes in the spatial and geometric parameters of the building interior. Therefore, finding a way to restore the operational suitability of damaged reinforced concrete hollow-core slabs is an urgent task. The hypothesis of solving the restoring problem of damaged hollow core reinforced concrete slabs by installing reinforcing cages inside the slab voids with the formwork installation inside the voids (damaged areas) and filling the voids with high-fluidity concrete was tested. Experimental studies were conducted to substantiate the possibility of using this method. Based on the data obtained during the experiments, a damaged floor slab was brought into operational condition at one of the construction sites.
After operability restoration, this slab has been successfully operated for more than two years, which indicates the correctness of the selected design and technological solutions and the possibility of using this technology to restore the operability of damaged reinforced concrete slabs.

Keywords: *Off-design impact; Restoration technology; Operational suitability; Hollow-core slabs; Historic heritage*

Introduction

The war in Ukraine has caused destruction and damage to many buildings and areas in large cities but also in suburban areas. These buildings and building complexes are partly of historical value. Many of them are also located in conservation areas.

This has led to intensive scientific research into the strengthening, repair, and monitoring of built structures. This research is sometimes all the more difficult because it concerns historical structures whose preservation, rescue, and conservation should be a priority due to

* Corresponding author: malgorzata.hryniewicz@pk.edu.pl

their cultural value. In this regard, Ukrainian researchers often benefit from international experience and consultations, including with researchers from Poland (Fig. 1), with whom they work together for the reconstruction of Ukraine [1-4].

Fig. 1. Polish experience in the repair and structural reinforcement of historical buildings. Renovation of the manor complex in Wrocanka and the wooden church of St. Mary Magdalene in Rabka-Zdroj

It is known that as a result of the hostilities in the Ukraine territory, the established settlements' environment where military operations took place has changed. According to the Kyiv School of Economics report [5], 88.9 million m² of construction objects were damaged or destroyed, which is about 8.6% of the total housing stock of Ukraine. In total, the direct losses incurred by the state due to the destruction of buildings and structures amounted to $131.5 billion (as of April 2024) and continue to grow.

Some affected facilities have significant damage (more than 80%) and cannot be restored and must be liquidated following current regulations [6, 7]. The other part of the buildings, which has a lower degree of damage (up to 80%), is subject to reconstruction or overhaul/minor repairs, depending on the degree of damage.

In the process of urban development, an established environment emerges, which is manifested in the overall architectural ensemble, territory planning, availability of key commercial, educational, and public institutions, and recreational and leisure areas within walking distance. In the event of damage to buildings that can be repaired through major repairs or reconstruction that make up the existing built environment, it is possible to rebuild them; however, due to dense development and the need to involve heavy construction equipment in such work, this may be difficult and inappropriate. It should be understood that the built environment of cities founded more than 30 years ago, in most cases, does not meet modern planning requirements, and the buildings located there have a high degree of both moral and physical deterioration and do not meet modern requirements for energy efficiency, inclusion, utilities, etc. Therefore, in the event of significant destruction of such buildings as a result of the war, it may be economically feasible to completely dismantle them and provide for both the redevelopment of the territory of the settlement and the construction of new buildings that meet the requirements of today.

Instead, in towns that are suburbs of large cities, including regional centers, new residential areas (neighborhoods) have been actively built up over the past decade (Fig. 2). Therefore, such established neighborhoods currently have modern infrastructure, and the buildings meet the latest trends. In the case of individual buildings or their parts, restoring them to the same form as before is appropriate. Of course, improving the parameters of individual building elements, such as replacing windows or insulating facades with more energy-efficient ones, is possible.

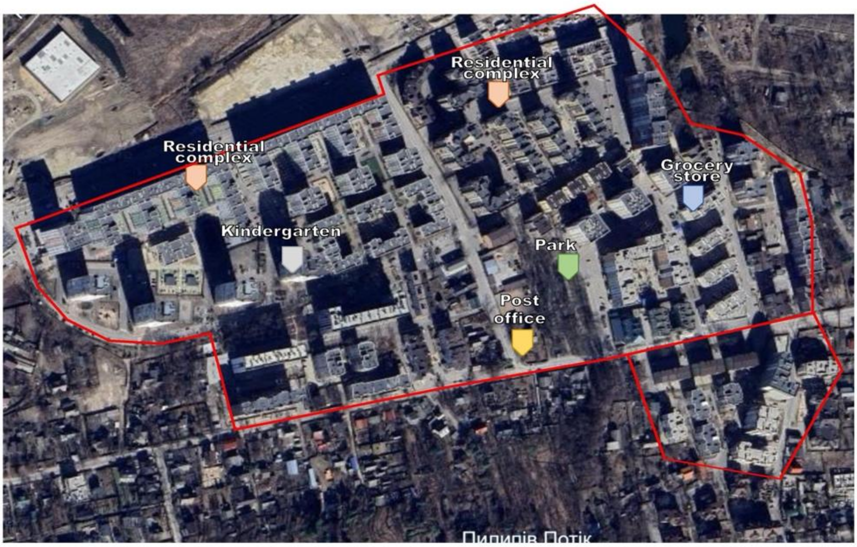

Fig. 2. A new neighborhood in the city of Irpin (circled), located 5km from Kyiv

During military operations, most buildings' damages occur due to ammunition hitting one of the rooms, followed by a fire. The fire then spreads throughout the building within ventilation shafts, communication niches, or along the facades if they have combustible insulation. As a result of this fire spread, individual premises of the building or building structures in the burning areas are damaged.

Vertical load-bearing elements (walls, columns) are easily restored, provided that there are no deformations and shifts of structures resting on them. Most often, sloped roof structures are subject to destruction because they are made of wood. Even if the explosion occurs on the low floors of the building, the flames can easily and quickly reach the roof structures through ventilation or chimney shafts. However, easy access to roof structures makes it relatively easy to replace or repair them. At the same time, in case of significant damage to the ceilings, their replacement is difficult due to the presence of overlying structures. It is impractical to carry out a set of replacement works due to the considerable duration and labor intensity of such works.

Hundreds of high-rise and low-rise residential buildings in Irpin, Bucha, Borodianka, Kharkiv, Mykolaiv, and other cities are examples of the above damage (Fig. 3).

Given many buildings need restoration to operational suitability and the need to spend significant funds on this, finding the most effective technologies for repairing building structures is an extremely important task.

An analysis of the hostilities-caused building structures' damages [8] found that the enclosing structures are the most damaged. This is due to the perception of the explosive element primarily by the building envelope. Damage to such structures includes holes, cracks, and localized delamination/peeling.

Fig. 3. A multi-story residential building in Irpin damaged by the shelling: left—exterior; right—interior

The second most damaged structures are ceilings (reinforced concrete, metal, and wooden beams), most of which are made of precast concrete hollow core slabs. This percentage applies to towns with a predominantly old housing stock. At the same time, in towns near large cities, where new houses were actively built, the share of hollow core slabs is approximately 35%.

Damage to reinforced concrete floor slabs caused by hostilities includes deterioration of the physical and mechanical characteristics of the materials from which the slabs are made due to high temperature or fire; formation of holes; breakage of reinforcing elements; and falling out/destruction of the body of the elements. The general view of damaged hollow-core slab floor structures is shown in Figure 4.

Fig. 4. General view of ceiling damaged by thermal impact: left – slab body falling out; right – lower zone cracking

Repairing such structures is more complicated and requires more careful consideration of design and technological solutions due to their location inside the existing facility and the difficulty of accessing them. Installation of lifting mechanisms is particularly difficult. Dismantling the part of the building above the damaged structure is usually impractical. This increases labor intensity and duration, and as a result, the cost of such work increases significantly, which is undesirable.

Repair of wooden floors usually involves replacing the beams with new ones of similar cross-section. Repair of monolithic floors in case of damage is usually carried out by shotcreting the damaged area with the preliminary installation of additional reinforcing bars or with the installation of external reinforcement. Ceilings made of prefabricated hollow core slabs are repaired or reinforced, for example, by bringing in steel beams, installing additional supports, installing tie-downs, etc. [9]. However, such methods do not solve the issue of restoring the integrity and geometric parameters of hollow core slabs at all and lead to changes in the spatial and geometric parameters of the building's interior, which is undesirable, especially in residential areas where the floor-to-ceiling height is already small [10]. Therefore, such works should be carried out using methods that allow for restoring operational suitability without changing the established external environment and internal space. That is, the following task is to restore the serviceability of floors made of hollow core slabs without dismantling the upper floors of the building, without rebuilding it, and without changing the rooms' interior space.

If the slabs are not mechanically damaged but still need to be reinforced, this can be done by gluing high-strength carbon lamellas or fabrics to the stretched area of the floor structures [10, 11]. However, if the physical and mechanical performance of the structure decreases, for example, due to a fire, the glued lamellas will be torn out along with part of the body of the floor slab after it is loaded. Therefore, this method, like other methods, is aimed at repairing damage or strengthening defect-free structures, and, as a result, cannot be widely used in modern realities.

In the course of the research, a hypothesis emerged that a possible way to solve the problem of restoring damaged hollow-core reinforced concrete slabs is to install reinforcing cages inside the slab voids with the installation of formwork within the cavities (damaged areas) and fill the voids with high-flow concrete mortar. However, there is no scientific research on this method of slab restoration, and it is not known whether it will be effective and produce the desired results.

This technology can reduce labor costs and be economically feasible, which is achieved by inserting the concrete mixture through slots or holes that are arranged along the cavities in the upper or lower plane of the slab. Slots are made only for a part of the length of the slab voids. The continuous filling of the cavities along the length of the slab is achieved by using a high-flow concrete solution.

Certain components of this method are subject to calculation, including the diameter and strength class of the reinforcement and the strength class of the concrete. The initial data for the calculation is an instrumental technical inspection, which establishes the geometric parameters of the existing structure, quantitative and qualitative characteristics of defects, concrete strength, diameters, and number and parameters of reinforcing bars, etc.

However, several factors require scientific substantiation. For their comprehensive analysis, the following sources were studied:

– regulatory documents [6, 7, 9, 12, 13];

– issues related to the preservation and restoration of buildings, including historical and cultural heritage [11, 14-22];

– issues related to the technology of restoration and repair of building structures [21-23];

– other issues [5, 9].

Such studies are also relevant for buildings of architectural or historical value, including architectural monuments.

An example of a historic building that has suffered damage to its structures, including ceilings, is the regional youth library in Chernihiv. The library building is an architectural monument of the late nineteenth century. It was damaged as a result of full-scale military aggression on March 11, 2022. Due to the blast wave, the supporting and enclosing structures were damaged (walls, roof, windows, ceilings), as well as interior and exterior finishes (Fig. 5).

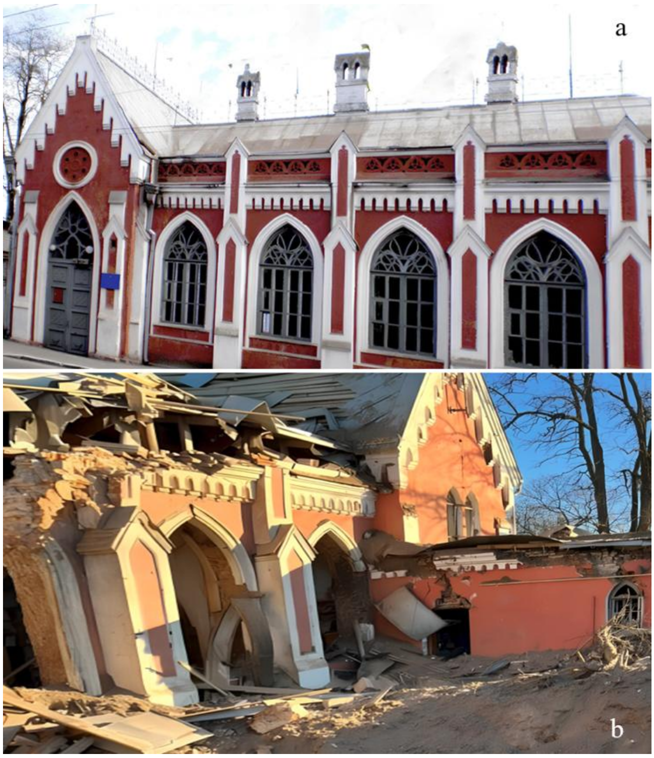

Fig. 5. Exterior of the regional youth library in Chernihiv:
above – view as of the 2010s; below – view after damage

Experimental part

Methods

In real conditions, the restoration of the serviceability of hollow core slabs can be performed in two ways, as follows:

– access to the surface of the slabs from above;

– access to the slab surface from below;

In this article, we will consider studies aimed at restoring the serviceability of slabs with access to the upper surface. Research on the restoration of hollow-core slabs with access from below will be covered in further work.

To test the feasibility of the proposed method and prove its effectiveness, a series of experimental studies was planned, aimed at:

– studying the possibility of filling the cavities with concrete grout (1);

– establishing the possibility of ensuring the joint operation of the concrete mixture and the existing concrete of the slab (2);

– concrete grout distribution in the void (3);

– preparation of the void surface to ensure sufficient contact between the slab and the concrete grout (4).

First of all, theoretical studies to determine the required length of filling the slab voids. For this purpose, a calculation of the reinforcement of a damaged hollow core slab with a length of 6 meters (the most common length) was performed.

From a structural point of view, the reinforced slab must meet the requirements of the applicable regulations, in particular, the requirements of ULS (ultimate limit state) and SLS (serviceability limit state). This means that the slab must not collapse and/or have deflections that do not exceed the values established by the standards and a crack opening width that does not exceed the permitted values when the slab is subjected to a load.

From the technological point of view, the process of strengthening damaged slabs should be of low duration, labor intensity, and cost while meeting the design requirements. This necessitates the use of commonly used and cheap materials, classical technological techniques, and widespread equipment.

Given the technological requirements, it is most optimal to reinforce each void of such a slab using three reinforcement cages (to avoid combining cages in the area of the highest bending moments and to combine them within one-third of the slab length, where relatively small bending moments and shear force act). When reinforcing with a diameter of 12mm, according to [8], the length of the overlap should be at least 400mm. Based on these conditions, a slab reinforcement scheme was developed (Fig. 6). Based on these conditions, the length of the required strobe at the top of the slab will be 2.5 meters, through which the edge frames will be lowered into the strobe and pushed into the design position. To install the frames, it is possible to make a stroboscope for the entire length of the slab, but this will increase the labor intensity and duration of the work. According to the scheme (Fig. 6), the length of the void filling should be about 1750mm. Based on this requirement, experimental studies on cavity filling will be carried out for a length of about 2000mm.

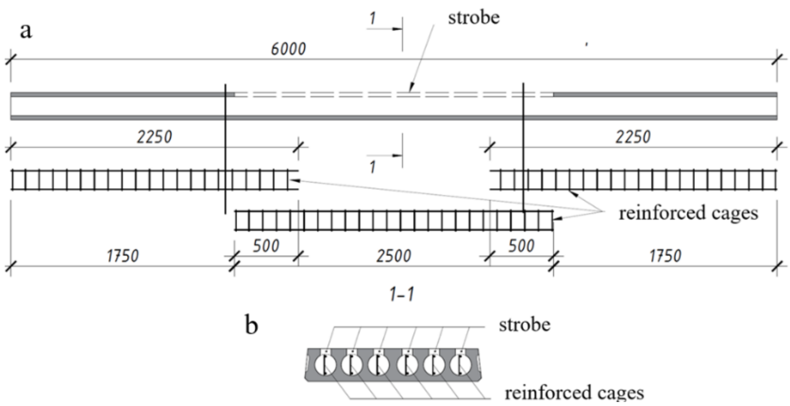

Fig. 6. Scheme of slab reinforcement: above – longitudinal section; below – transverse section

Research

Experimental studies were carried out using plastic pipes with an internal diameter of 200mm, simulating the voids of hollow-core reinforced concrete slabs (190mm). To simulate the irregularities and roughness of the slab's inner surface, the surface of the pipes was sandpapered. Additionally, the inner surface was graduated with length marks to facilitate data evaluation. To facilitate the dismantling of the pipe after the experiment and evaluation of its results, the pipe was cut longitudinally. A hole was made in the upper part of the pipe on one side for pouring concrete mortar, and a hole was made on the other side to control the filling of the pipe during the experiment. A reinforcing cage was also installed in the pipe to simulate the actual process of reinforcement. The general view of the pipe is shown in figure 7.

Within the framework of the study of void filling, 3 different types of concrete mixtures were used in terms of flowability (the grade of the mixture by cone slump and spread was determined following [13]:

a) mixture No. 1 (conventional concrete mixture with a cone slump of 45mm (concrete mixture grade by cone slump S1));

b) mixture No. 2 (concrete mixture with plasticizers with a cone slump of 325mm (concrete mixture grade by cone slump F1));

c) mixture No. 3 (concrete mixture with superplasticizers with a cone spread of 810mm (concrete mixture grade by cone spread F6)).

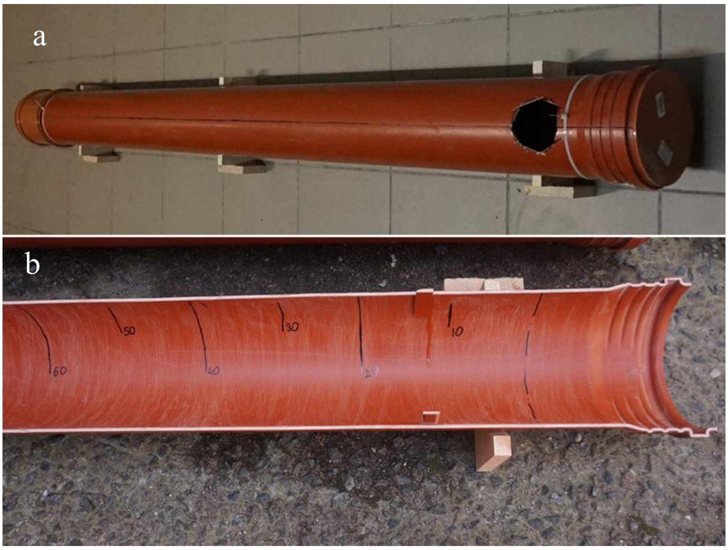

Fig. 7. General view of the pipes for a series of experiments No. 1: above – external view; below – internal view

The concrete mixture was placed through a hole in the upper part of the pipe. After the concrete mixture was placed, a technological break was maintained for its hardening, after which the pipe was disassembled and the results were evaluated. The appearance of the concrete obtained from each of the experiments is shown in Figure 8.

The data obtained from the experimental studies are summarized in Table 1.

Table 1. Results of experiments on filling pipes with concrete mixtures

Sample	**0**	**20**	**40**	**60**	**80**	**100**	**120**	**140**	**160**	**180**	**200**
	Filling, %										
Mixture No. 1	100	100	0	–	–	–	–	–	–	–	–
Mixture No. 2	100	100	99	0	–	–	–	–	–	–	–
Mixture No. 3	100	100	90	80	70	60	50	40	30	20	10

For a more visual representation of the research results, a graph of the percentage of cavity filling along the length of the pipe was constructed (Fig. 9), as well as the dependence of the concrete mixture distribution length in the pipe on the cone spread (Fig. 10).

Following the experiment results, it was found that for the void filling to the furthest possible distance, it is necessary to use a concrete grout with the largest cone spread. However, the concrete grout alone does not allow for achieving a sufficient percentage of the void cross-section filling; in the most distant zone, the filling is only about 10%.

This is not enough to allow the void-fill concrete to work together with the existing slab concrete to restore the slab's serviceability and load-bearing capacity.

To ensure the necessary distribution of the mixture through the pipe, it was decided to apply technological methods, namely different methods of distributing the mixture. To determine the most effective method, a series of experimental studies were conducted.

Fig. 8. Results of filling the pipes with concrete mixtures:
from top to bottom – mixture No. 1; mixture No. 2, and mixture No. 3

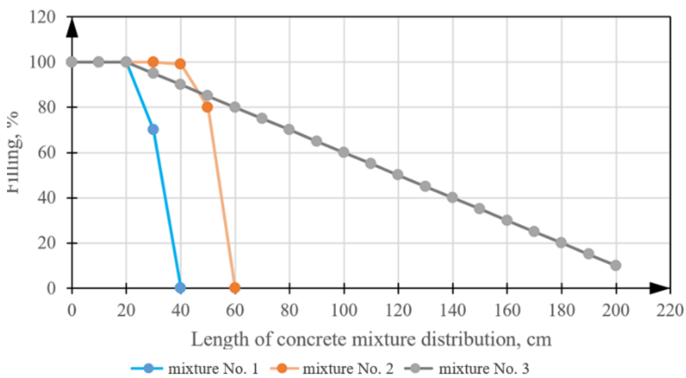

Fig. 8. Graph of the percentage of void filling along the pipe length

For the experiments, concrete mixture No. 3 was selected with the use of a superplasticizer, which was distributed along the entire length of the pipe. Within the framework of this study, three experiments were conducted, two of which involved the use of different methods of distributing the concrete mixture (vibration and pushing), and one was a control (without distribution).

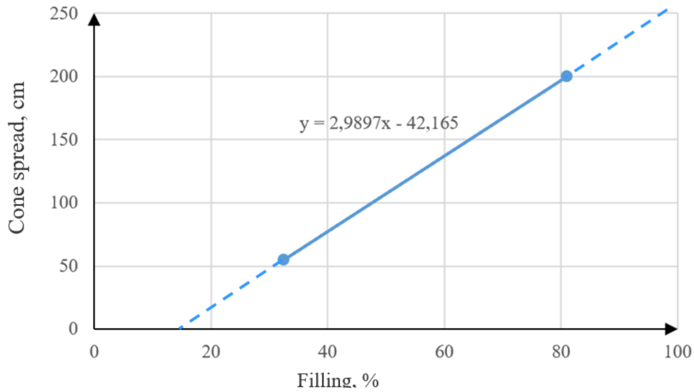

Fig. 10. Dependence of the concrete mixture distribution length in the pipe on the cone spread

The purpose of the experiment was to achieve the greatest possible filling of the void cross-section along its entire length. Plastic pipes were also used to simulate the void of a reinforced concrete round hollow core slab, but with a diameter of 110mm to reduce the material consumption of the study.

A vibration grinder was used as a source of vibrations. Pushing was performed using a composite reinforcement rod. Photos of the results of these studies are shown in Figure 11.

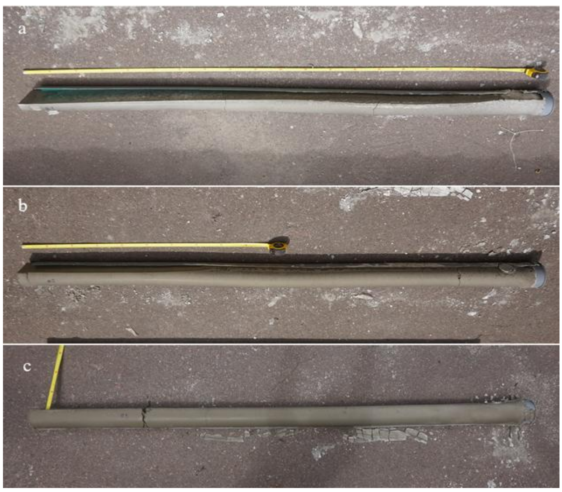

Fig. 11. Results of experimental studies on pipe filling with additional measures of mixture distribution—from top to bottom: control experiment; distribution using pushing; distribution using vibration

Results and Discussion

The experiment results are listed in Table 2. Based on these data, the dependence of the filling of the pipe cross-section with concrete mixture on the method of its distribution was constructed (Fig. 12).

Table 2. Results of experimental studies on pipe filling at different methods of concrete mixture distribution

Method of mixture distributing	Length of concrete mixture distribution, cm										
	0	20	40	60	80	100	120	140	160	180	200
	Filling, %										
Without distributing	100	97	95	92	90	88	85	80	75	72	70
Pushing	100	100	100	100	100	100	98	96	95	92	90
Vibration	100	100	100	100	100	100	100	98	96	93	91

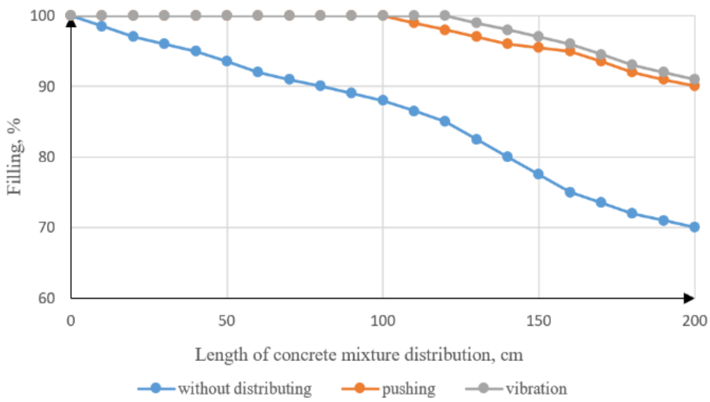

Fig. 12. Dependence of pipe section filling on the method of mixture distribution

According to the experiment results, the use of additional technological methods made it possible to significantly increase the filling of the pipe section along its length. The greatest filling of the pipe cross-section was achieved by vibrating the concrete mixture, although the difference, compared to pushing, is insignificant (less than 5%).

During the compaction process, concrete shrinks, which can lead to delamination between layers that are placed at different times, which can lead to a lack of joint performance. To establish the possibility of ensuring the joint operation of cavity fill concrete and slab concrete after hardening, an experiment was conducted to determine the shrinkage for mixture No. 3. For this purpose, two rectangles were made from it, the initial length of which was 256mm. After gaining initial strength, they were stored for 28 days in a moisture-saturated environment for hydration. After that, the total length of the beams was measured, which was 255mm. The process of manufacturing and measuring the beams is shown in figure 13.

Thus, the shrinkage of the concrete mixture is:

$$\left(1 - \frac{255}{256}\right) \times 100\% = 0.39\%$$

In conventional construction practice, concrete mixture shrinkage should not exceed 3%. Taking into account the results obtained, this composition of concrete mixture with superplasticizer can be considered non-shrinkage. The use of such a concrete mixture will ensure the joint operation of the restoration elements with the existing concrete of the slab due to the property of the mixture to maintain its geometric dimensions without detachment from the existing concrete when gaining strength.

Based on the results of preliminary studies, the technology of filling the cavities was finalized to ensure that the cross-section is close to 100% full. To do this, it is proposed to make small holes with a diameter of about 50–80mm at the ends of the slab, through which a small volume of the mixture is fed to completely fill the void. This will create a homogeneous monolithic structure by combining two materials (the placed concrete mixture and the existing concrete of the slab), which will work together during the life of the restored structure.

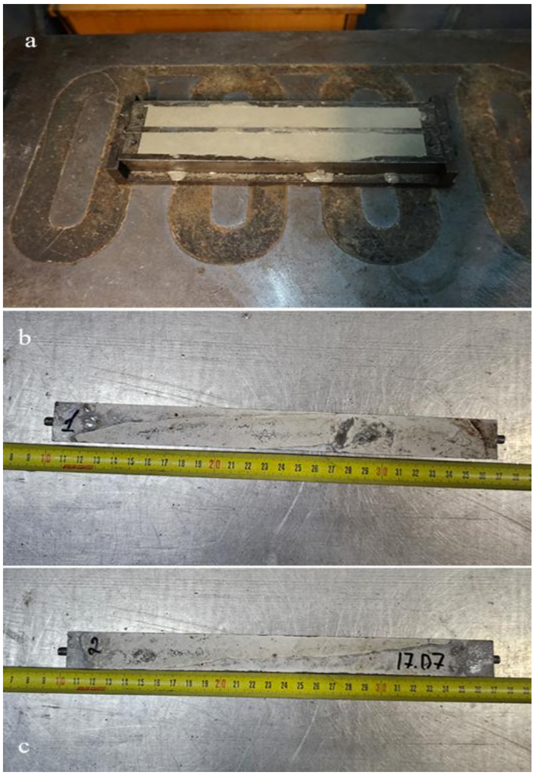

Fig. 13. Manufacturing process and measurement of beams after their hydration– from top to bobottom: beams in the manufacturing process; determination of the beams' length after their hydration

The experimental studies' results were tested at one of the construction sites damaged by off-design impacts. The damaged floor slabs were restored to serviceability. The slabs to be restored had damage to the lower surface, in particular, destruction of the lower zone body, cracking of the slab body, loss of structural integrity, loss of individual reinforcement (individual ropes), pretension, etc. (Fig. 14). It was decided to use this method for the restoration of the damaged slabs' serviceability. This involves installing reinforcing cages in the voids and then filling them with concrete. Before the work, the slabs were calculated to determine the need for additional reinforcement.

Fig. 14. Appearance of the damaged floor slab: left – bottom surface; right – interior space

The initial data for the calculation were slab width b = 1200mm; slab thickness h = 400mm; slab span (between supports) L = 11,800mm; protective concrete layer a = 40mm.

Based on the calculation results, it was decided to install reinforcing cages inside the slab cavities, followed by pouring the concrete mixture into the slab voids. Before that, the parts of the slab body that had lost their structural integrity were dismantled, and the internal space of the cavities was cleaned.

The drawings for restoring the slab's serviceability are shown in figure 15.

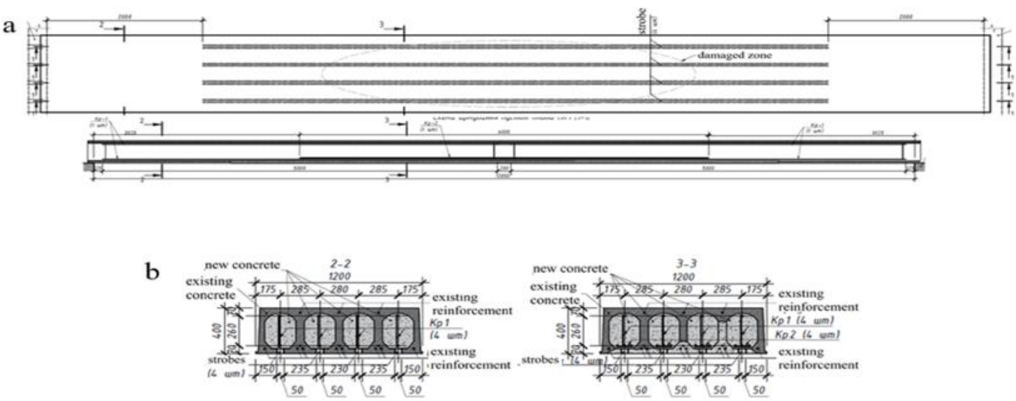

Fig. 15. Drawings for restoring the operational suitability of the hollow-core slab:
a – slab plan; b – longitudinal section; c – cross-sections

In the process of restoring the slabs' serviceability, the following was performed: installation of unloading racks; dismantling of the damaged part of the slab body; preparation of the inner surface of the slabs before concreting; installation of reinforcing cages; installation of formwork; filling the slab voids with concrete mortar, maintaining a technological break to gain concrete strength; dismantling of formwork and racks. The process of restoring operational suitability is shown in Figure 16.

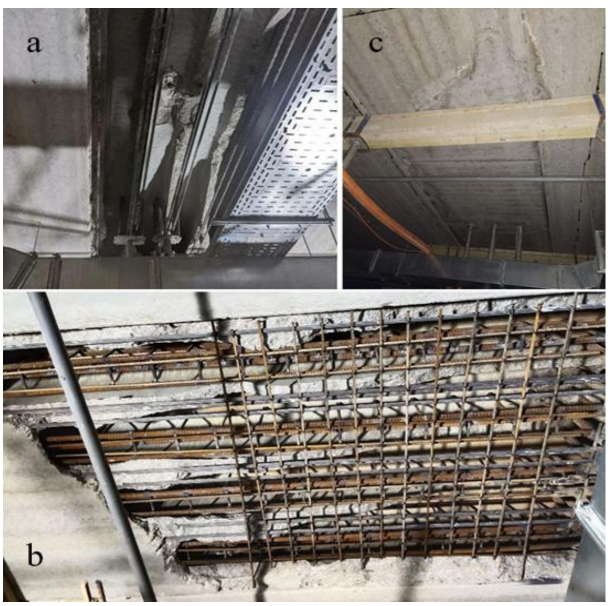

Fig. 16. The process of restoring the serviceability of a hollow-core slab: a – slab after cleaning from damaged concrete; b – slab with reinforcement installed; c – appearance of the slab before dismantling the posts

After the work to restore their operational capability, these plates have been in successful operation for more than two years, proving the correctness of the design and technological solutions choice.

Conclusions

In conclusion, it should be stated that research on the reinforcement, renovation, or reconstruction of the structures of buildings, both historical and contemporary, is extremely necessary, especially now that many valuable buildings in Ukraine are being destroyed as a result of the war. Cooperation in this field between scientists and engineers from Ukraine, Poland, and other countries, working in interdisciplinary teams, brings results in the form of new methods and procedures for the reconstruction and revalorization of buildings.

It should be noted that as a result of the hostilities in Ukraine, the built environment (including historical development) of the settlements where the hostilities took place has changed. Some buildings with significant damage to building structures (total percentage of damage over 80%) are subject to liquidation (dismantling), while other buildings with lesser damage (total percentage of damage up to 80%) are subject to restoration through reconstruction or major/recurrent repairs. In the case of restoring buildings or parts of buildings, it is appropriate to carry out repairs to restore the original appearance, i.e., to preserve the existing environment.

According to the available data, all building structures were damaged during the hostilities. Some of them are not difficult to repair (replace), while repairing other structures (such as floors) is a difficult task due to their spatial position within the building.

There is a hypothesis that a possible way to solve the problem of restoring damaged hollow-core reinforced concrete slabs is to install reinforcing cages inside the slab voids with the installation of formwork within the cavities (damaged areas) and fill the voids with high-flow concrete grout. However, there are no scientific studies of this method of slab restoration. At the same time, some structural and technological factors require scientific research to establish the possibility of using the technology in the restoration of damaged building structures.

For this purpose, experimental studies were conducted to determine the possibility of filling the cavities of hollow core slabs with concrete grout, checking the selected concrete for the possibility of ensuring joint operation with the existing concrete of the slab, and choosing a method of distributing the concrete grout in the slab void.

Based on the experimental studies' results, it was possible to confirm the hypothesis that it is possible to restore the serviceability of hollow core slabs by installing reinforcing cages inside the slab voids, followed by installing formwork within the cavities (damaged areas) and filling the voids with high-flow concrete grout.

This approach reduces the duration of the work and its labor intensity, which in turn reduces the cost. In total, the restoration of serviceability using this method allows the restoration of the serviceability of floor structures made of precast concrete hollow core slabs without changing the established external and internal environments and is suitable for the restoration of various buildings, including historical ones.

This method was tested to restore the serviceability of damaged reinforced concrete hollow core slabs at one of the facilities.

It should be noted that the research conducted and the method presented are one of the stages of research work concerning the reconstruction and revalorization of objects that have suffered as a result of warfare. Further research is in progress and will be discussed and verified with interdisciplinary teams from Ukraine, Poland, and other European countries.

References

[1] O. Molodid, O. Kovalchuk, Y. Ivashko, D. Kusnierz-Krupa, P. Tisliar, A. Dmytrenko, Ł. Bednarz, Research for Banksy mural 'Judoki' in Borodyanka, **International Journal of Conservation Science**, **14**(4), 2023, pp. 1381-1390. DOI: 10.36868/IJCS.2023.04.08.

[2] G. Wojciechowska, Ł.J. Bednarz, N. Dolińska, P. Opałka, M. Krupa, N. Imnadze, *Intelligent monitoring system for integrated management of historical buildings*, **Buildings**, **(14)**, 2024, pp.1-30. DOI: 10.3390/buildings14072108.

[3] W. Putra, Ł. Bednarz, D. Bajno, P. Opałka, M. Krupa, A. Mamedov, *Diagnosis, repair, strengthening and monitoring of a postindustrial heritage site: flyover of the Odra Cement Factory*, **Wiadomości Konserwatorskie – Journal of Heritage Conservation**, **(75)**, 2023, pp. 144-152. DOI: 10.48234/WK75ODRA.

[4] D. Kuśnierz-Krupa, Ł.J. Bednarz, O. Ivashko, M. Hryniewicz, *Original research procedure as an important stage of heritage site investigation: the case of the manor and garden complex in Wrocanka*, **Muzeologia a Kulturne Dedicstvo**, **(12)**, 2024, pp. 109-132. DOI:10.46284/mkd.2024.12.4.6.

[5] * * *, https://kse.ua/wp-content/uploads/2024/05/Eng_01.01.24_Damages_Report.pdf

[6] * * *, **Methodology for Inspection of Buildings and Structures Damaged as a Result of Emergencies, Hostilities and Terrorist Acts.** Approved by the Order of the Ministry of Communities and Territories Development of Ukraine on April 28, 2022, No. 65. (Original language: **Методика обстеження будівель та споруд, пошкоджених внаслідок надзвичайних ситуацій, бойових дій та терористичних актів.** Затверджено наказом Міністерства розвитку громад та територій України від 28 квітня 2022 року № 65).

[7] * * *, **DSTU 9273:2024. Guidelines for buildings and structures inspection to determine and assess their technical condition. Mechanical resistance and stability,** SE "UkrNDNC", Kyiv, 2024. (Original language: **ДСТУ 9273:2024. Методичні вказівки щодо обстеження будівель і споруд з метою визначення та оцінювання їх технічного стану. Механічна стійкість і стабільність,** ДП «УкрНДНЦ», Київ, 2024).

[8] O. Molodid, O. Kovalchuk, V. Skochko, R. Plokhuta, O. Molodid, I. Musiiaka, *Inspection of war-damaged buildings and structures by the example of urban settlement Borodianka,* **Опір матеріалів і теорія споруд/Strength of Materials and Theory of Structures**, **10**, 2023, pp. 328-343. DOI: 10.32347/2410-2547.2023.110.328-343.

[9] * * *, **DSTU B V.3.1-2:2016. Repair and reinforcement of load-bearing and enclosing building structures and foundations of buildings and structures,** Kyiv: Minregion, 2016. (Original language: **ДСТУ Б В.3.1-2:2016. Ремонт і підсилення несучих і огороджувальних будівельних конструкцій та основ,** ДП «УкрНДНЦ», Київ, 2016).

[10] O.S. Molodid, *System of Formation of Constructive and Technological Solutions for the Restoration of the Operational Suitability of Building Structures*, **PhD. Thesis,** Kyiv National University of Construction and Architecture, Kyiv, 2021. (Original language: О.С. Молодід, *Система формування конструктивно-технологічних рішень відновлення експлуатаційної придатності будівельних конструкцій*. **Докторська дисертація**, Київський національний університет будівництва і архітектури, Київ, 2021).

[11] O. Molodid, V. Skochko, R. Plokhuta, O. Molodid, I. Musiiaka, S. Benderskyi, S. Bogdan, *Modern Restoration Methods for Damaged Historical Buildings as a Result of Military Aggression. Case of Educational Institutions,* **International Journal of Conservation Science**, **15**(SI), 2024, pp. 205-220. DOI: 10.36868/IJCS.2024.SI.17.

[12] * * *, **DSTU B V.2.6-156:2010. Structures of buildings and structures. Concrete and reinforced concrete structures of heavy concrete. Design rules,** Ministry of Regional Development, Construction, Housing and Communal Services of Ukraine, Kyiv, 2011. (Original language: **ДСТУ Б В.2.6-156:2010 Конструкції будинків і споруд. Бетонні та залізобетонні конструкції з важкого бетону. Правила проектування,** Мінрегіонбуд України, 2011).

[13] * * *, **DSTU B V.2.7-176:2008 (EN 206-1:2000, NEQ). Construction materials. Concrete mixtures and concrete. General technical conditions,** Ministry of Regional Development and Construction of Ukraine, Kyiv, 2010. (Original language: **ДСТУ Б В.2.7-176:2008 (EN 206-1:2000, NEQ) Будівельні матеріали. Суміші бетонні та бетон. Загальні технічні умови,** Мінрегіон України, Київ, 2010).

[14] A. Pawłowska, A. Gralińska-Toborek, P. Gryglewski, O. Sleptsov, O. Molodid, O. Ivashko. M. Początko, *Problems of Expositions and Protection of Banksy's Murals in Ukraine*, **International Journal of Conservation Science**, **14**(1), 2023, pp. 99-114. DOI: 10.36868/IJCS.2023.01.08.

[15] O. Molodid, R. Plokhuta, O. Molodid, M. Początko, K. Janicka-Świergula, V. Skochko, Y. Novak, *Research of the Component Composition of Drying Renovation Brick Crumb Plaster for Restoration of Architectural Monuments*, **International Journal of Conservation Science**, **15**(1), 2024, pp. 89-102. DOI: 10.36868/IJCS.2024.si.08.

[16] O. Molodid, V. Skochko, R. Plokhuta, O. Molodid, I. Musiiaka, S. Benderskyi, S. Bogdan, *Modern Restoration Methods for Damaged Historical Buildings as a Result of Military Aggression. Case of Educational Institutions,* **International Journal of Conservation Science**, **15**(1), 2024, pp. 205-220. DOI: 10.36868/IJCS.2024.si.17.

[17] Y. Ivashko, A. Dmytrenko, O. Molodid, O. Ivashko, V. Molochko, S. Belinskyi, P. Bigaj, *The Destruction of the Established Urban Environment of Borodianka and Irpen as a Result of the Russian-Ukrainian War,* **International Journal of Conservation Science**, **15**(2), 2024, pp. 785-800. DOI: 10.36868/IJCS.2024.02.03.

[18] T. Kozłowski, Y. Ivashko, S. Belinskyi, A. Dmytrenko, O. Ivashko*, Theoretical and Legal Rules for the Reconstruction of Architectural Monuments in Ukraine that Suffered During the Russian Military Aggression – Teoretyczne i prawne zasady odbudowy zabytków architektonicznych w Ukrainie, ktore ucierpały w trakcie agresji rosyjskiej,* **Teka Komisji Urbanistyki i Architektury Oddziału Polskiej Akademii Nauk w Krakowie**, **L**, 2022, pp. 391-408. DOI: 10.24425/tkuia.2022.144859.

[19] Y. Ivashko, A. Dmytrenko, A. Pawłowska, M. Lisińska-Kuśnierz, M. Krupa, P. Tišliar, A. Hlushchenko, A. Serafin, A. Shpakov, *Destruction of the architectural heritage as a result of war: the experience of reconstruction (conservation and logistical aspects),* **International Journal of Conservation Science, 15**(S.I.), 2024, pp. 17-30, DOI: 10.36868/IJCS.2024.SI.02.

[20] Y. Ivashko, V. Tovbych, A. Hlushchenko, S. Belinskyi, J. Kobylarczyk, D. Kuśnierz-Krupa, A. Dmytrenko, *Preparing for the post-war reconstruction of historical monuments in Ukraine: Considerations in regard of the ongoing Polish post-WWII experience and international law on the protection and conservation of historical monuments,* **Muzeológia a kultúrne dedičstvo**, **11**(1), 2023, pp. 53-71. DOI: 10.46284/mkd.2023.11.1.4.

[21] R. Plokhuta, H. Tonkacheiev, O. Molodid, O. Galinskyi, I. Rudnieva, I. Priadko, *The technology of crack repair by polymer composition,* **Опір матеріалів і теорія споруд/Strength of Materials and Theory of Structures**, **108**, 2022, pp. 203-216. DOI: 10.32347/2410-2547.2022.108.203-216.

[18] O.M. Galinsky, O.S. Molodid, N.V. Sharikina, R.O. Plokhuta, *Research of technologies for restoration of the concrete protective layer of reinforced concrete constructions during the reconstruction of the buildings and structures,* **IOP Conference Series: Materials Science and Engineering**, **907**, 2020, Article Number: 012056. DOI: 10.1088/1757-899X/907/1/012056.

[22] O. Molodid, R. Plokhuta, I. Musiiaka, I. Reznichenko, *Sealing joints between concrete elements with polyurethane material,* **AIP Conference Proceedings**, **31 May 2023**, **2684**(1), 2023, Article Number: 040017. DOI: 10.1063/5.0120368.

Received: January 25, 2025
Accepted: August 10, 2025