INTERNATIONAL JOURNAL
OF
CONSERVATION SCIENCE
ISSN: 2067-533X
Volume 15, Special Issue 1, 2024: 205-220
www.ijcs.ro
DOI: 10.36868/IJCS.2024.SI.17

MODERN RESTORATION METHODS FOR DAMAGED HISTORICAL BUILDINGS AS A RESULT OF MILITARY AGGRESSION. CASE OF EDUCATIONAL INSTITUTIONS

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Abstract

As a result of the military operations taking place on the territory of Ukraine, thousands of buildings and structures have suffered significant damage and destruction. A substantial share of such buildings belongs to immovable cultural heritage sites, such as historical buildings of local and national significance; frequently, including educational institutions such as kindergartens, schools, lyceums etc. Damaged buildings are subject to restoration by repairing or strengthening their building structures, restoration, or conservation. There is a large number of repair materials and technologies for conducting restoration works, which are regulated by the requirements of DSTU B V.3.1-2:2016. However, while performing repair work on the structures of historical buildings, it is necessary to focus on the DSTU-NB B B.3.2-4 requirements. Among the most common types of damage to historical buildings caused by blast waves, splinters etc., are cracks in the masonry of wall structures and foundations; cracks in the joint of structures; knocking out fragments of masonry with damage to facing; damage to the elements of the floor and covering; systematic soaking of foundations etc. An essential aspect of restoring historical buildings is the maximum preservation of their historical and cultural significance with minimal interventions in the structure of structures and their appearance. The article considers modern methods of restoring the operational suitability of historical building elements, namely repair of cracks by injection and impregnation; strengthening the walls of buildings with the help of external reinforcement with carbon tapes and installation of high-strength rods in stone walls; restoration of stonework using special mixtures; strengthening of reinforced concrete and metal span elements with high-strength carbon fabrics, or lamellas (FRP); installation of waterproofing of walls subjected to systematic locking from the middle of the building.

Keywords: *Historical buildings; Military actions; Damage; Restoration of structures; Masonry; Reinforced concrete; Cracks; Carbon fabrics and lamellae (FRP); High-strength rods.*

Introduction

Since the beginning of the Russian full-scale invasion of Ukraine, thousands of buildings and structures of public, residential, or administrative purposes have suffered severe damage. Although Russians claim that they allegedly attack the military facilities of Ukraine only, many

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facts confirm the opposite. For example, more than 3,500 educational institutions, which are by no means military facilities, suffered various damage during the invasion.

According to the official data (from open sources of information), educational institutions that were located in active hostilities zones suffered the greatest damage and destruction. Among them are Kharkiv region, Mykolaiv region, Donetsk region, Kyiv region, Sumy region, and others. As of the writing of this article, 341 destroyed educational institutions (schools, kindergartens, universities etc.) were officially registered. However, it would be possible to give the exact figure of destruction and damage only after the war.

A significant part of the damaged and destroyed educational institutions are buildings of historical and cultural significance and architectural monuments (Figs. 1 and 2). Russia has been systematically destroying the historical and cultural monuments of Ukraine, even though it is a party to the "Hague Convention for the Protection of Cultural Property in the Event of Armed Conflict" (The Hague, 1954) [1].

Fig. 1. Examples of historical buildings of educational institutions that were destroyed as a result of the Russian aggression against Ukraine: a – The Mykola Arkas First Ukrainian Gymnasium (Mykolaiv) [https://nikvesti.com/ru/news/photoreportage/259158]; b – building of Kharkiv Petro Vasylenko National Technical University of Agriculture (Kharkov) [https://culturecrimes.mkip.gov.ua/?p=3248]

Fig. 2. Examples of historical buildings that were damaged as a result of military actions, in particular from explosive (dynamic) impacts ether from rockets or UAVs: a – Zolochiv school No. 1, Lviv Region 1; b – Onufriiv Lyceum (building No. 1), Kirovohrad Region

The issue of cultural heritage protection under conditions of military actions is extremely relevant and urgent [1, 2]. It is historical buildings and architectural monuments, among other educational institutions, that require immediate measures aimed at restoring and preserving the historical heritage for posterity.

In accordance with the Law of Ukraine "On the Protection of Cultural Heritage" [3], the following types of work are allowed on objects of cultural heritage: conservation, restoration, rehabilitation, museification, repair, and adaptation of monuments with the permission of the relevant cultural heritage body based on an agreement of scientific project documentation.

At the same time, it is desirable that the measures to strengthen or restore the enclosing structures, which can be applied during the recovery, reconstruction or restoration of buildings, do not worsen the microclimate parameters of the premises, which were typical for these buildings before the damage. For this, at the stage of development of project solutions for the restoration of building structures, it is necessary to carry out complex modeling of the thermal balance of the building [4-14], both in warm and cold seasons.

Materials and Methods

The following general scientific methods were used in the study: visual - determining the technical condition of structures based on external features; analytical - assessing the technical condition of the inspected object, instrumental - studying the physical and mechanical indicators of structures; experimental - conducting research in laboratory conditions to determine the strength indicators of restored structures.

In accordance with the purpose of the study, the following sources were used:

1) Legislation framework [1, 3, 7, 8];
2) The issue of preservation of historical and cultural heritage [1-3, 15];
3) Issues related to the technologies of restoration of operational suitability [7-14];
4) Issues related to systematization of damage [6];
5) Issues related to preservation and restoration of buildings and structures [4, 5, 15-19];

The study of the legislative framework and the state of historical and cultural buildings and structures that were damaged as a result of military aggression against Ukraine became a theoretical basis for analyzing the studied sources and providing recommendations for restoring the operational suitability of damaged educational buildings, including historical ones.

Results and Discussion

The team of authors conducted an examination of a number of buildings of educational institutions that were damaged as a result of the military aggression. It also included historical and architectural monuments, which were not directly damaged as a result of active military actions at the frontline, but were hit with missiles/UAVs from the distance. According to the results of the mentioned surveys and available information, it can be stated that, usually, damage to buildings and structures is caused by blast waves in this case. The degree of their impact on buildings often depends on the location of the building to the epicenter of the explosion [6]. In the case of close proximity to the epicenter of the explosion, the damage is characterized by visible destruction or significant damage to the structures of walls, partitions, ceilings and roofs, and numerous fragmentary damages to the facade (Fig. 3).

Visible damage to buildings located at a certain distance (approximately 300m or more) from explosion epicenters usually includes destruction and damage to window, door fillings, and frames (Fig. 4b); shrapnel damage to external and internal finishing; shrapnel damage to the roof (Fig. 4a) etc. Such damage should be repaired in initial stages, because the roof and windows are a protective barrier against the external environment impact on the building (precipitation, wind, temperature changes etc.).

Fig. 3. Damage to structures of historical buildings of educational institutions: a, b, d, f – damage to facades; c, d, f - damage to masonry walls; e, f – damage to floor slabs; f - damage to the roof structures; namely: a-b – The main building of the Taras Shevchenko National University of Kyiv; c - Borivske Church of St. Nikolas, Luhansk region; d - Kharkiv School No. 7 ; e - Vysokopil Lyceum, Kharkiv Region; f - V. N. Karazin Kharkiv National University [https://www.5.ua/kyiv/raketnyi-udar-po-kyievu-naskilky-sylno-postrazhdav-universytet-imeni-tarasa-shevchenka-290134.html; https://culturecrimes.mkip.gov]

Fig. 4. Shrapnel damage to the roof and window filling: a – Velyka Kostromka St. Oleksii Church, Dnipropetrovsk region; b – the building of the Taras Shevchenko National University of Kyiv

Justification of the relevance of the research

A lot of damage to load-bearing structures appear, as a result of explosions (dynamic effects) of buildings. However, they are often not paid enough attention to, because they can be hidden by finishing, be at a height, or due to lacks of owner's appropriate competence.

Such damage can be attributed to cracks in foundation, basement and wall structures; cracks/chips in reinforced concrete structures (beams, slabs, columns); slight tilting of structures; soaking of structures as a result of damage to the rainwater drainage system; displacement and damage to the load-bearing structures of the roof; soaking of structures due to damage to the base, waterproofing layer or paving.

Usually, after dynamic effects, this kind of damage is formed in places of stress concentration, joints of structures, in areas of structures with the lowest load-bearing capacity or in overloaded areas etc. The specified damage is extremely significant and may affect the load-bearing capacity of structures and the buildings as a whole.

It is extremely important to complete a full range of repair and restoration works on historical buildings promptly, and in cases where this is not possible, to take steps to conservate damaged structures and the buildings as a whole to protect them from possible further destruction.

It is important to understand that during the designing and execution of repair, reconstruction or restoration works, the developed measures to strengthen the enclosing structures should not impair their thermal properties. This means that during the development and implementation of such a measures for the structural elements of the external walls, windows, doors and other constructions of buildings, it is necessary to ensure that the corresponding measures do not lead to an increase in thermal bridges and heat-conducting inclusions in general, as this leads to the intensification of heat losses and increases the probability of condensation on the surface of walls and windows. And this, in its turn, is very harmful to building structures and can lead to their gradual destruction or the appearance of fungi, mold and other harmful microorganisms in the thickness of structures.

The goal of the work

Researching on modern methods of restoring the operational suitability of historical buildings, in particular, educational institutions, which were damaged by military actions.

Work results

Technologies for restoring the operational suitability of damaged buildings as a result of military actions depend on the type of structures and the type of damage that appeared as a result of extra-design influences.

Thus, damage like cracks in supporting structures, in the abutments of walls, and ceilings etc. (with opening widths that do not significantly exceed normative values), which were caused by dynamic influences, usually remain in the same state for long period of time, provided there is no additional factors or dynamic loads that could worsen conditions. There is a significant number of repair materials and technologies that will allow to provide design parameters exactly at the point of damage and in the adjacent areas. Choosing the particular tool depends on the material of the damaged structures, the type of damage and the financial capability of the customer.

However, when it comes to restoring the operational suitability of historical buildings or architectural monuments, the choice of technologies for their repair should be approached very carefully. For the repair of such objects, it is appropriate to use scientifically based and proven methods that allow to perform repair and restoration work or strengthening with minimal intervention in the structure without disturbing its appearance.

It is important to understand that any intervention in the building has to be as unintrusive as possible to preserve its historical and cultural significance. It is also important to take into account the spatial configuration of the building and structures, their appearance, and existing engineering networks.

Let's take a look at some of the most common examples of damage to historical buildings that can occur (including those, which were caused by military actions) and modern methods of restoring their operational suitability.

Carrying out repair and restoration work on historical buildings, first of all, it is necessary to focus on the standard of DSTU-NB V.3.2-4 [7], which establishes requirements for the performance of repair and restoration work on monuments of architecture and urban planning, directed to their preservation. It also includes normalization of the moisture condition of structures, repair of brick structures, repair of wooden and metal elements, furnishing of facades and interiors etc.

Appearance of cracks in structures could be often observed after blast waves (Fig. 5). Usually, cracks appear at the junctions of vertical elements, walls and ceilings, floor structures, or within window and door openings etc.

Fig. 5. Occurrence of cracks after dynamic explosion impacts: a – in the joints of floor slabs; b, c – in the walls; d - in the joints of the walls and ceiling, where: a - Onufriiv Lyceum (building No. 1), Kirovohrad region 1; b, c, d – Zolochiv school No. 1, Lviv Region

Damage like cracks can be eliminated by injecting and impregnating them with special repair solutions, replacing bricks of the masonry (in the case of significant cracks), or installing additional reinforcement elements [8].

Cracks and voids injection must be performed after completing masonry restoration work (if necessary) and fixing all existing emergency areas. Injecting the masonry of historical buildings, it is important to use particular repair solutions that poses required physical and mechanical characteristics of the masonry and do not change the original texture of brick surfaces. Here is the technology of injecting cracks with repair solutions (Fig. 6): drill holes alongside the crack for 2/3 of the wall thickness with a step of about 50 cm; clean the crack and holes from dust and dirt; stick injectors of a special solution in the holes; fill the crack lengthwise to avoid leakage of the solution; a day before injection, soak the crack with water; start injection from the lowest injector and gradually fill it with repair solution to the top; after hardening of the repair solution, remove the injectors and fill the holes; if necessary, prepare the surface.

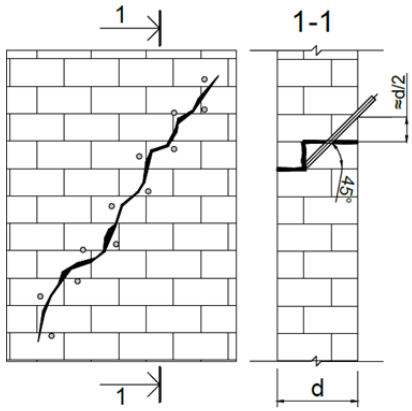

Fig. 6. Schematic diagram of injection of masonry cracks [9]

Repairing cracks in reinforced concrete structures is similar to the latter one, but in this case, it is more appropriate to use polymer [10] or cement-polymer compositions as a repair solution.

In case of restoring the stonework of the structures of historical buildings (for example, as shown in Figure 3c) caused by numerous shrapnel damage, the impact of the blast wave, fires caused by explosions etc., then the following technological operations should be followed - first, perform unloading structures to be restored; if necessary, dismantle the masonry; clean structures from fragile, restructured, contaminated outer layers; to restore the geometric section, it is necessary to use special solutions and substitutes that are similar to the original material of the structures (bricks from destroyed parts, or those that are similar in quality and dimensions to the original); if there are cracks and voids in the masonry, inject them with special repair solutions; if necessary, strengthen the masonry by inserting high-strength rods into it or arranging external reinforcement, taking into account minimal intervention in the structure; carry out further finishing (if necessary).

It is important to use special means and methods of treating the damaged surface when cleaning the surface of dirt and efflorescence.

Also, during repair and restoration work, it should be taken into account that currently, in accordance with the order of the Cabinet of Ministers of Ukraine dated 04.21.2021 No. 443-r "On the approval of the National Action Plan for Environmental Protection for the period until 2025" the issue of implementing environmental criteria for balanced resource management, reducing the negative impact on the environment is relevant; possibilities of reuse and recycling of materials etc. [11].

During visual inspections it has been claimed that often masonry structures are not destroyed due to blast waves. However, cracks and chips occur on them that exceed the limits of normative values. In this case, DSTU B V.3.1-2:2016 [8] recommends restoring or increasing the bearing capacity by introducing various reinforcement elements, such as: non-prestressed reinforced concrete or steel hanging clips for stone pillars and pilasters, and for walls with one- or two-sided extension made of reinforced concrete or reinforced mortar. However, such reinforcement options are unacceptable for historical buildings, since the main restoration requirement of this type of buildings is the principle of the minimal intervention in the materials of the building, its external and internal appearances.

The least invasive technology is the one of strengthening masonry with cracks caused by dynamic loads, including blast waves, by inserting high-strength rods. There may be design

solutions for their installation. It depends on configuration and location of the crack, the nature of the structure's destruction, and the constructive specifics of each individual object. Surface mounting of high-strength rods, mixed mounting, and base mounting are distinguished.

During the surface installation of the rods (Fig. 7a), in the seams of the masonry, grooves with a depth of at least 50mm are made, with a step of about 300mm in height and approximate lengths of about 1.0m (500mm on each side of the crack). After cleaning the strobe, an adhesive mixture is placed in it, into which a high-strength rod is immersed. After the adhesive mixture has hardened, finish the seams.

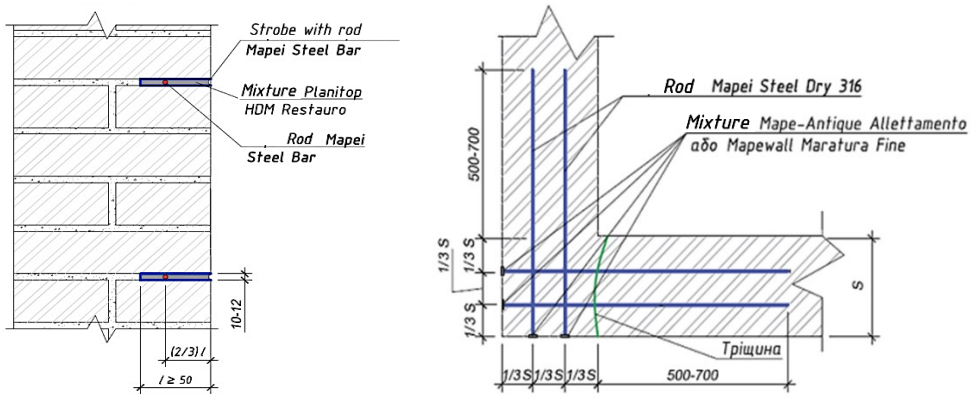

Fig. 7. Constructive solution for bridging cracks in stone masonry (according to MAPEY LLC technology [9] or analogues): a – with surface mounting of high-strength rods; b - with the installation of high-strength rods in the base

When installing the rods in the body of the structure (Fig. 7b), it is necessary to drill a hole in the indicated places to the design depth. High-strength rods are screwed into the cleaned holes. After installing the rods, the surface of the holes is covered with a special repair mixture.

There is also a distinction between mixed installation, when placing high-strength rods in the body of structures and surface installation. It is advisable to use this technology, for example, to strengthen the jack arch and masonry above the window opening (Fig. 8). In the future, the cracks are to be injected with repair solutions.

For strengthening stone walls damaged by blast waves, you can use the technology of external reinforcement, that is, gluing high-strength composite materials to the surface of the walls. At the same time, such a solution can be used both to strengthen local areas with individual cracks and throughout the outer contour of the building with a large number of cracks on the walls or violations of integrity or stability. The width and area of reinforcement should be determined by calculations.

The essence of the technology consists in cleaning the plaster layer (if available), preparing the base (leveling and, importantly, rounding the corners). On the prepared area in the technological sequence, apply a primer, an epoxy-based glue into which to sink the carbon fiber (FRP) and apply another layer of glue on top of the fiber. If necessary, perform additional fixation with point fastening (in the corners, along the length of the tape and places where the fiber direction changes).

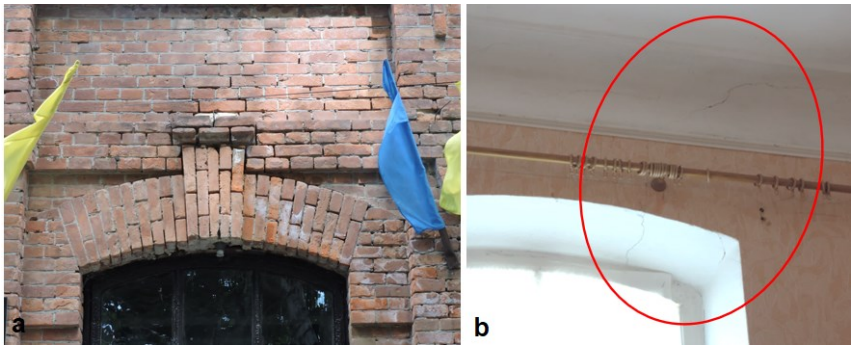

Fig. 8. Jack arch with cracks in it (Onufriiv Lyceum (building No. 1), Kirovohrad Region):
a – external appearance; b - view from the middle

There were a number of experimental studies performed to verify the effectiveness of the given method of strengthening damaged walls [12] (Fig. 9). Their main goal was to strengthen fragments of brick walls by gluing carbon fabrics (FRP) with further determination of their bearing capacity. Reinforced or unreinforced (control) fragments of wall structures were installed on two supports at the edges and a concentrated force was applied to the center of the walls until the moment of their destruction.

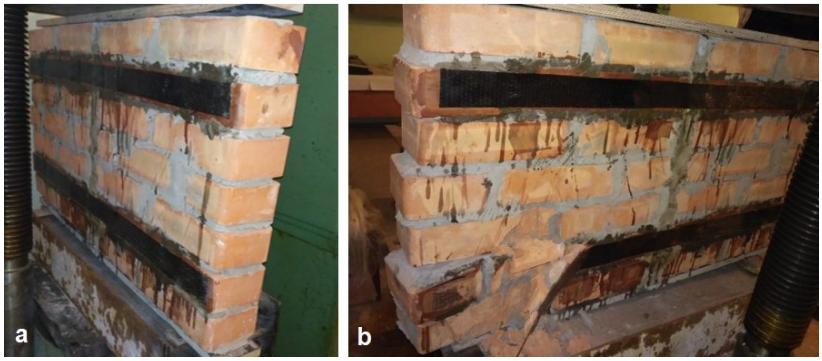

Fig. 9. Experimental studies of brickwork reinforcement with carbon fiber:
a – reinforced wall before the start of the experiment; b - the wall after the bending strength test

The obtained research results showed an increase in the bearing capacity of reinforced structures compared to unreinforced ones from 3.8 to 6 times, depending on the method of strengthening (Fig. 10). Hence, according to experimental research, the method of strengthening walls with high-strength fabrics is quite effective and can be used to strengthen historical school buildings.

The occurrence of numerous vertical cracks of the masonry wall structures or in a certain area of the building due to the impact of a blast wave may indicate a decrease in their bearing capacity. In this case, the process of strengthening damaged structures must be approached comprehensively. In particular, it is recommended to strengthen the walls along the entire perimeter of the building at the level of the floor coverings in the arrangement of special belts made of carbon fabrics (FRP) (Fig. 11). At the same time, cracks need to be injected in the future or strengthened by introducing high-strength rods.

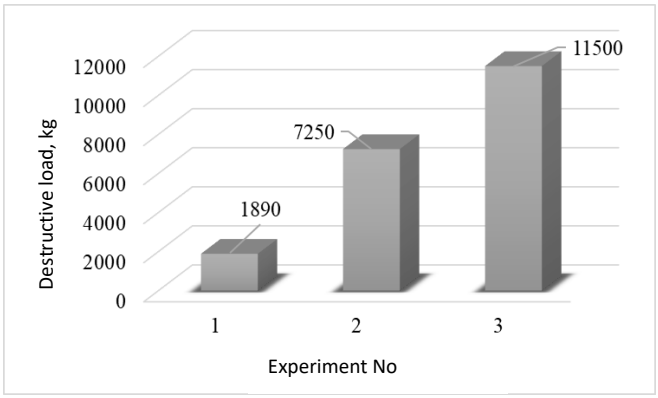

Fig. 10. Results of experimental studies to determine the bearing capacity of reinforced brick walls, where: 1 - unreinforced structure (control sample); 2 – the structure is reinforced with carbon fabrics; 3 – the structure is reinforced with carbon fabrics after impregnation of the base with a primer

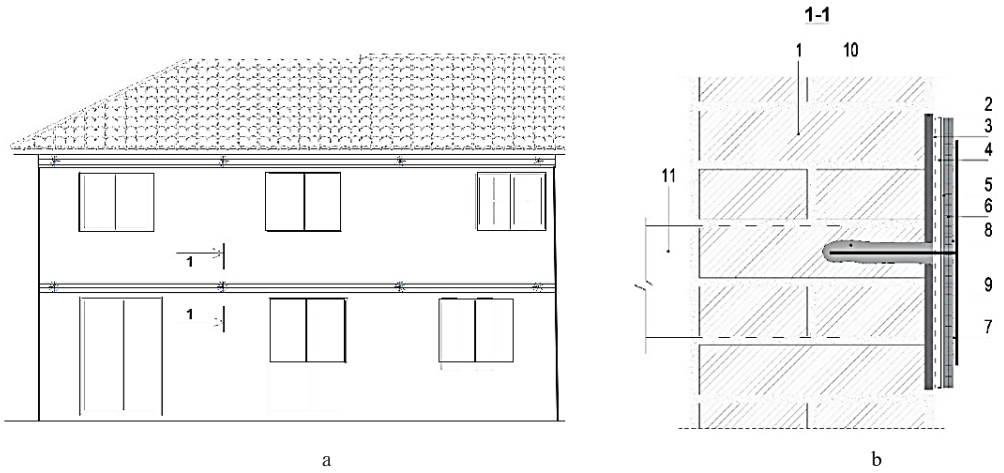

Fig. 11. Design solution for the arrangement of inter-floor belts for wall reinforcement (according to MAPEY LLC technology [9] or analogues): a – facade of the building with possible placement of belts; b – section 1-1, where: 1 – wall; 2 – repair solution; 3 – primer; 4 – epoxy-based putty; 5, 8 – solution for fabric impregnation; 6 – carbon fabric; 7 – quartz sand; 9 – anchor cord; 10 – anchoring solution; 11 - overlapping

The repairs technology will depend on the size and nature of the damage and its geometric position in the case of restoring the geometry of reinforced concrete structures. Mainly, such works are performed manually by using specifically developed system solutions, which consist in cleaning the reinforcement from corrosion and applying anti-corrosion coatings to it, applying special repair mortars to the damaged area of concrete to restore their geometric parameters. In addition, specifically developed and scientifically based methods of restoring damaged reinforced concrete structures by embedding a highly mobile repair mortar to the formwork can also be used [13].

The ceilings is one of the core elements that requires the restoration of serviceability as a result of shrapnel damage, the influence of dynamic or minor thermal loads that occur during military operations (Fig. 12). In historical buildings, wooden or metal beams, reinforced concrete slabs and beams were used as ceilings.

Fig. 12. Damage to the floor beam due to the impact of the blast wave, Zolochiv school No. 1, Lviv Region

When restoring structures of historical buildings, including span structures, it is important to choose the technology of repair and restoration works, which will not only strengthen the structure, but also will not change the stressed state and spatial planning decisions.

According to the standard DSTU B V.3.1-2:2016 [8] repair and strengthening of reinforced concrete span structures without changing the design scheme and stressed state can be performed by repairing the geometric section, chips and cavities with repair solutions; injection and impregnation of cracks; by strengthening the stretched and compressed zones by increasing the cross-section by concreting, arranging clips and shirts etc.

Since all methods of strengthening span structures proposed in the standard involve an increase in the cross-section of the structures, which is undesirable during repair and restoration works, it is recommended to use the method of strengthening with external reinforcement (gluing high-strength carbon fabric or carbon plates (lamellas)).

Numerous experimental studies of the specified method performed by the co-author of the publication [12] proved that applying external reinforcement to span structures (beams, webs, slabs) is an effective way of strengthening them, which allows to increase the bearing capacity of the structure by almost 4 times. At the same time, one of the most significant parameters of such strengthening of building structures, especially during the restoration of historical buildings, is that the geometric characteristics of the reinforced structures do not change. It is important that the mentioned experimental studies (Fig. 13a) were repeatedly tested in natural conditions during reinforcement of reinforced concrete structures and such solutions proved themselves from the positive side for a long time (Fig. 13b). That is why this method of strengthening can be recommended for use in repair and restoration works on historical buildings, in particular, and at educational institutions.

When strengthening metal structures (for example, beams of the ceiling) of historical buildings (Fig. 14), which could be damaged by dynamic influences, you can use a method of strengthening similar to the one mentioned above - gluing high-strength fabrics or lamellas.

The technological process of strengthening metal beams includes the following work operations: surface cleaning; surface dedusting; stabilization of (if necessary); strengthening of the structure; and protective and decorative finishing (if necessary), which in most respects (except reinforcement) meets the requirements of DSTU-NB B V.3.2-4 [7]. Experimental studies aimed at checking the effectiveness of reinforcement allow us to state that reinforced elements (metal beams) have significantly lower deformability, namely deflection, compared to non-reinforced elements by 39.5%. At the same time, the permissible load on the reinforced beam was 11.8% more than the load for the unreinforced structure [12].

Fig. 13. Span structures reinforced with high-strength carbon materials (FRP) : a - reinforced concrete beam in the process of experimental research (mounted on a press before testing); b – reinforcement of the beam slab of the floor at the construction site

Fig. 14. Metal beams in the ceiling in basements (Zolochiv school No. 1, Lviv Region)

The technology of strengthening load-bearing structures by applying carbon fabrics or lamellas on them is also effective when it is necessary to strengthen reinforced concrete structures, such as columns [14].

It is worth noting that in the course of the inspections it was found that in a significant part of the inspected educational institutions (including historical buildings) there is systematic soaking of plinth structures, basement structures, and foundations due to damage or lack of paving, damage to the waterproofing layer, or due to improper drainage of rainwater and melt water from the roof. In general, such a problem can led to the weakening and subsidence of the base under the foundations, the tilting of structures, the formation of cracks and the appearance of fungi, mold or leaching. Sometimes, the specified defect is the reason for the appearance of cracks on structures after exposure to dynamic loads.

In such cases, it is necessary to take a comprehensive approach to the solution of the task, to eliminate not only visible defects and damage (cracks, bends, deviations), but also the cause of their occurrence, namely strengthen the structure directly, install a drainage system and paving, arrange the plinth, drain water from the drainage system outside the building, normalize the humidity of the structures, and, if necessary, strengthen the bases or foundations.

In particular, to normalize the moisture condition of structures, namely to ensure the waterproofing of structures after removing the cause of their excessive moisture, it is recommended to use impregnation, coating (painting), pasting, injection or backfill waterproofing made of mineral, bituminous, polymer, polymer cement, plastic or metal material. However, choosing a type of waterproofing, it is recommended to give preference to methods that involve the least intervention in structures and elements of the monument [7].

An effective method of waterproofing foundation structures, which will allow to protect structures from the influence of positive water pressure, is to apply external coating waterproofing on them. For its arrangement, it is necessary to excavate trenches to the depth of the foundations along the perimeter of the building. These actions may negatively affect the stability of the building; in addition, such actions will change the external landscape of the surrounding areas. Accordingly, when choosing a specified technology, it is necessary to provide for the temporary fastening of the building structures. However, in the presence of capillary suction, external waterproofing will not be effective.

Taking into account the latter, it can be argued that injection waterproofing is the most effective and least invasive technology for installing waterproofing in stone structures of historical buildings to eliminate their high humidity, capillary absorption and the effect of hydrostatic water pressure (Fig. 15). This technology allows you to minimize mechanical interventions in the structure and at the same time arrange reliable waterproofing without changing its appearance.

The core of the technology consists in removing the plaster layer (in the places where the holes are arranged), drilling the holes and cleaning them, installing injectors in the holes, injecting special solutions, and, cutting the injectors after a technological break.

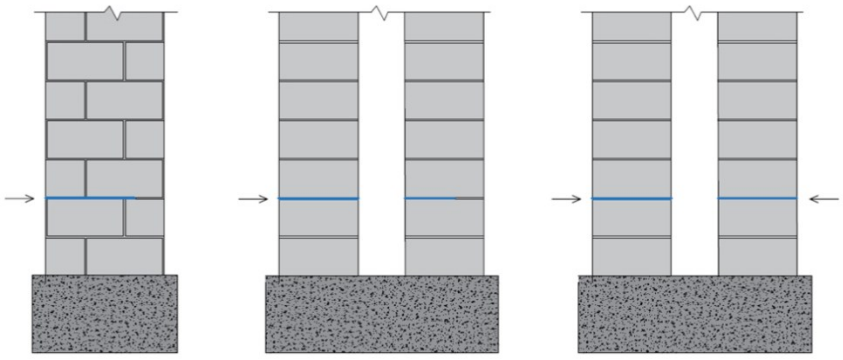

Fig. 15. Injection of masonry depending on its type (according to MAPEY LLC technology [9] or analogues): a – solid masonry; b – with voids (injection from one side); c – with voids (injection from both sides)

However, it is worth remembering that any waterproofing must be conducted in combination with other measures - the organization of the correct drainage of atmospheric precipitation from the walls, the general arrangement of the territory, and, if necessary, also the implementation of vertical waterproofing.

Of course, there is other structural damage of historical buildings and structures that require restoration, such as fragmentary damage to decorative elements and facade equipment; damage to the internal equipment of walls, floors, and ceilings etc. However, according to the authors of the publication, this damage does not have a significant impact on the load-bearing capacity of the structures and buildings in general. It can be repaired or restored later after removing damage to the load-bearing structures, or after the end of hostilities. If the second option is selected, all structures are subject to conservation.

Finally, it should be added that the above-described repair and reconstruction measures have a very minor effect on the heat-conducting properties of the enclosing structures and should not significantly lower their thermal properties. And this is very important, because buildings that represent architectural heritage, as a rule, cannot be insulated in order not to deteriorate their appearance and preserve their historical value.

Conclusions

Due to the armed aggression of Russia against Ukraine, thousands of buildings and structures, including educational institutions, have been damaged and destroyed. Among those are also buildings of historical importance account for a significant. To restore the operational suitability of historical buildings, it is necessary to use such technologies and materials that will minimize interference with the appearance of the structure or building and at the same time ensure the quality of repair and restoration works.

In accordance to the above mentioned, a study of modern technologies for restoring the strength indicators of structures and their geometric parameters was conducted, a significant part of which was scientifically substantiated by the authors and tested on construction sites.

The indicated technologies of repair and restoration work are recommended for the restoration of stone, reinforced concrete and metal structures of buildings of historical importance, which have suffered various damage from the influence of dynamic loads (explosive waves), shrapnel damage etc. during Russia's military aggression.

However, it is important to note that the selection of the technology for restoring the operational suitability of damaged building structures must be considered and verified. It also has to include a complex of visual and instrumental surveys, verification calculations, and, most importantly, take into account the historical and cultural significance of the building.

Acknowledgments

This article was prepared as part of the implementation of the Scholarship of the Supreme Council of Ukraine according to the Resolution of the Verkhovna Rada of Ukraine "On the appointment in 2023 of named scholarships of the Verkhovna Rada of Ukraine for young scientists - doctors of sciences" №. 3297-IX of August 9, 2023. The title of the scientific work is "Developing constructive and technological solutions and practical recommendations of operational suitability restoration for buildings and structures, that were damaged due to warfare". Scholar - Oleksandr Stanislavovych Molodid

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Received: November 10, 2023
Accepted: February 2, 2024