INTRODUCTION

During the operation of buildings and structures, under the influence of external and internal factors, building structures wear out. That is, their physical and mechanical parameters deteriorate. Usually, such a deterioration in the performance of load-bearing building structures is unacceptable, as it can lead to loss of stability and emergency situations.

Due to non-design impacts on buildings or structures that occur in peacetime (gas or explosive explosions, earthquakes, floods, etc.), building structures are damaged and require comprehensive repair or replacement. In the case of comprehensive repair, it is necessary to restore both the physical and mechanical indicators and the geometric parameters of the structures with their subsequent reinforcement.

During hostilities, tens of thousands of buildings and structures are subjected to non-design impacts [20]. These impacts include, but are not limited to, blast waves, high-velocity weapon fragments (shrapnel), thermal effects, and ground vibrations. Critically, structural damage occurs not only on the front line but also deep within the rear areas. It is essential to distinguish between direct damage from ammunition impact (such as rockets, shells, mortar rounds, and large-caliber bullets) and secondary damage resulting from the action of the explosive air wave. Destruction is often large-scale and systemic, manifesting in diverse ways. For instance, fire and temperature deformations can induce cracking in walls in areas distant from the initial impact. Furthermore, structures frequently suffer from hidden defects, such as the internal delamination of brickwork caused by severe impacts. The consequences of these events are often aggravated in settlements that have been under occupation. The operational failure of state institutions and emergency services (e.g., the State Emergency Service) meant that fires were not promptly extinguished, leading to a much greater escalation of their destructive effects.

Certain types of buildings or parts thereof may be less resistant to off-design impacts. In addition, different types of buildings may experience specific effects of such impacts. This may affect subsequent actions regarding the renovation or construction of new buildings, for example:

– deciding on the construction of new, more resistant to off-design impacts buildings and considering their organizational and technological features of construction;

– considering the nature of damage and the features of organizational and technological solutions in the complex process of restoration of buildings and structures.

It is quite clear that the reconstruction of buildings and structures destroyed by the enemy or the creation of new ones must be carried out in parallel with the restoration and modernization of the logistics infrastructure. Road and railway infrastructure provide opportunities for the evacuation and movement of the population, the delivery of military equipment and humanitarian cargo. The most dependent on the transport sector are agriculture, metallurgy, coal industry, mining and metallurgy and defense complexes. All these factors have a greater or lesser impact on the implementation of restoration and repair construction works. The war not only was forced to put on hold all large-scale infrastructure construction plans of the country but also set the priority accents for restoration. Despite the significant destruction of Ukraine's transport infrastructure during the war, work continues its restoration, opening new routes and logistics hubs, and attracting foreign funds, since the restoration/development of the economy is impossible without the full functioning of its logistics component.

Thus, during the war in Ukraine, a large percentage of buildings and structures were damaged. Even before the end of hostilities, the issue of quickly restoring damaged residential buildings arises, and this becomes one of the most important tasks for our country. Inspection and assessment of the technical condition of construction sites, carried out in accordance with [23; 24; 64], should assess the possibilities of restoring buildings and structures, the extent of their damage, determine the list of works for repair, restoration or reinforcement of structures, and, if necessary, dismantling. Therefore, an urgent inspection of damaged buildings and structures is critical for making informed decisions and initiating restoration work.

Based on the completed surveys of such buildings and structures damaged because of off-design impacts, technical reports are prepared with specific recommendations for their restoration, which are in most cases individual in nature. There are publications in open sources that summarize

and typify the information collected in technical reports to simplify further surveys of damaged buildings and structures.

In particular, [73] presents the results of the first studies of damage to buildings and structures as a result of hostilities in the territory of the Kyiv region within the settlements and surrounding areas of Borodyanka, Makariv, Gostomel, Irpin, Bucha, Vorzel, etc. It is noted that in the first months after de-occupation, when conducting surveys by leading organizations, including state research institutes, conclusions were made about the partial dismantling of buildings and structures, which, when conducting alternative surveys, turned out to be hasty and erroneous. Therefore, the quality of the assessment largely depends on the experience of experts and design engineers conducting the survey.

The city of Chernihiv suffered significant damage in the spring of 2022, when it was massively shelled with missiles and other weapons of mass destruction. As a result, many buildings and structures in the city were damaged and destroyed. [91] presents the results with demonstration photographs of the significant work carried out to restore damaged residential buildings, which was carried out on the basis of reports prepared with the involvement of specialists from the State Enterprise "State Research Institute of Building Structures" in the survey and development of design documentation.

The achievement of the article [10] is that, based on the results of a field survey of multi-storey buildings floor panels in the Pivnichna Saltivka 3 microdistrict in the city of Kharkiv, the main destructions are analyzed, on the basis of which a gradation of the damage degrees is provided. The categories of damage are distinguished, in which it is advisable to carry out reinforcement work. The article also considers the most common methods of strengthening destructed reinforced concrete floors and provides a prototype of the design for developing a constructive solution for the restoration of damaged floor panels.

Article [83] analyzes information sources to document concrete examples of damage to brick buildings near the contact line in the Luhansk and Donetsk regions. The study found the most common damage includes the destruction of ceilings, walls, roofs, and door/window openings, as well as the formation of extensive networks of cracks and potholes. Future research will employ numerical modeling to identify the most effective

restoration technologies for these complex brick structures. This will be complemented by mathematical modeling to select optimal solutions by quantifying the impact of various factors on key performance indicators.

A certain generalization of damage to buildings of all structural schemes was made in [63; 70]. Article [63], examples of damaged and destroyed brick, large-block, panel, frame buildings and other objects (which are either unique, or their type could not be established by structural features) were considered. According to the study results, it was established that the most resistant to the effects of military operations are frame-monolithic buildings; the least resistant are panel buildings. It has been established that the general nature of the damage does not depend on the type of building and whether there is a direct hit or not. However, each type of building may have specific defects or damage (for example, large cracks in brick buildings).

Monograph [70] employs a systematic approach to address a pressing issue in contemporary construction: the restoration of building structures damaged by non-design impacts. It analyzes the topic of restoring the operational suitability of damaged buildings and systematically categorizes the damage sustained during both typical operation and off-design events, particularly hostilities. The work synthesizes known restoration methods, presents modern approaches to building examination, and details both classical and contemporary repair techniques for structures affected by non-design impacts, including those from military operations. Finally, it presents practical experience in implementing the studied restoration methods.

There are also separate publications related to the restoration of transport infrastructure. In [12], in addition to defining the basic principles of restoration, measures for reforming the transport infrastructure network in the post-war period are highlighted. [48] highlights the experience of conducting surveys of destroyed and damaged bridges, as well as changes in legislation after the introduction of martial law, which are aimed at regulating the processes of recording, surveying and restoring damage and destroyed transport structures on public highways, streets and roads of cities and other settlements. The article [74] presents the results of the assessment of the technical condition of the pedestrian bridge across the Desna River in the city of Chernihiv, which was damaged because of military operations.

Given the significant number of these publications, there is an urgent need to develop new methods for repairing objects damaged by off-design impacts. It is worth considering that the developed or researched technologies must, firstly, be economically justified, and secondly, they must allow for the rapid restoration of buildings and structures with minimal loss of time.

In addition, it is important to apply solutions that will ensure the necessary strength and stability of restored building structures. In the work [40], an analysis and improvement of organizational and technological solutions for temporary reinforcement of structures and sections of emergency buildings during emergency rescue operations were performed and recommendations were given for choosing the optimal option for such solutions. In the article [79], the prospects of prefabricated monolithic construction for the restoration of facilities in Ukraine were substantiated.

The scientific analysis of the impact of military actions on buildings and structures must directly inform and enable further research into restoration. Specifically, the findings should guide the selection of organizational and technological solutions by accurately accounting for the nature of the damage and the peculiarities of the restoration process.

Thus, the search, research, and development of methods for restoring the operational suitability of damaged building structures are extremely urgent tasks. These efforts require a comprehensive approach that addresses a multitude of issues and guides the formation of specific solutions. Crucially, these solutions must prioritize not only the effectiveness of the restoration but also the safety of personnel working at or living in the restored facilities. The development of such effective restoration methods is only possible by conducting a detailed study of the condition of damaged and destroyed buildings using specific case examples, which unequivocally establishes the relevance of this monograph.

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