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INSPECTION OF WAR-DAMAGED BUILDINGS AND STRUCTURES BY THE EXAMPLE OF URBAN SETTLEMENT BORODIANKA

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Inthe first 100 days of the full-scale armed aggression of Russia's armed forces against Ukraine, more than 1600 rocket strikes were carried out, not including other shelling.In this regard, numerous buildings and structures suffered various damages.

Using the developed "Methodology of surveying and registration of its results", surveyors developed a procedure for surveying many buildings and structures in a short period.

KNUCA (Kyiv National University of Construction and Architecture) specialists inspected multi-apartment, communal, and administrative buildings in the Borodiankavillageinthe Kyiv region.Based on the results of the surveys, damage to buildings was systematized depending on their causes, namely explosions, and their impact on structures – explosive shock wave, fire, and bullet or shrapnel damage.

The direct damage caused by the explosive shock wave included: destruction, cracking, distortion, and declination from the axis of symmetry, damage to window glasses and frames, for brick structures: knocking out (individual bricks or sections of the wall), protrusion (indentation) and displacement of masonry elements, cracks in masonry and spilling of seams between building elements.The direct damage to structures from shrapnel and bullet injuries includes: through holes, splinters, damage to coatings and the roofing layer, jamming of structures, et cetera.The direct damage to structures caused by thermal effectsincludes fire damage, including irreversible thermal elongation of reinforcement and destruction of concrete; damage to the finishing layers; destruction of window and door frames and their filling; the collapse of the roof; destruction of wooden walls and ceilings.

KNUCA specialists established that buildings suffer significant damage and destruction when an aerial bomb hits. The most destructive effect is the damage caused by multiple launch rocket systems (MLRS), artillery weapons, and tanks. However, buildings (building structures) suffer minor damage when hit by Armory Personnel Carriers (APVs) and small arms.

Keywords: inspection; warfare; buildings; technical condition; damage; explosion; fire; explosive wave.

Problem formulation. February 24, 2022,began a full-scale invasion of Russia's armed forces on Ukraine's territory.The enemy mercilessly destroys everything in its path, from roads to people.In just 100 days of the invasion, about 1,600 missile strikes were carried out on the territory of Ukraine.Furthermore, this is not taking into account other shelling.Part of the Kyiv region was under the invaders' occupation from the beginning of the full-scale invasion until April 2, 2022 (the official date of the liberation of the Kyiv region).During the 38 days of occupation, about 1,000 buildings and structures were damaged in various and numerous ways only on the territory of Borodianka's hromada.

The structures were affected by numerous explosions and fires, which sometimes led to violation of the requirements for mechanical resistance and stability according to the SLS (serviceability limit state) and ULS (ultimate limit state).

To eliminate the consequences of warfare, the government developed and implemented order [1] and the methodology [2] for conducting inspections of buildings and structures.Such an inspection involves: establishing defects and damage to building structures by determination of their amount; making a decision on the further operation or dismantling in connection with damage to the object as a result of extra-design influences (in this case, military actions and fires caused by them); establishing the technical condition of building structures and the construction object as a whole for further implementation of project work for overhaul, reconstruction or restoration.

Specified by the inspection methodology, a preliminary or detailedsurvey, or both, is distinguished, based on which a report on the survey results with recommendations for further operation is drawn up.

The purpose of the work. Systematize the damage/destruction of buildings depending on the type of weapon that affected them. Systematization is based on the inspection results of multi-apartment and administrative buildings in the Borodianka, Kyiv region village. This region suffered damage due to the full-scale armed aggression of Russia's armed forces.

Research results. Taking into account the large amount of constructionobjectdamage as a result of military operations and the need for their rapid technical examination for further rapid processing of the received materials and decision-making, some changes regarding this type of activity were adopted at the state level. First of all, changes were made to the legislative framework [1] regarding the process of technical inspection, and the "Methodology of conducting the inspection and registration of its results" [2] was developed. According to such changes, the list of persons allowed to conduct inspections was expanded. Therefore, in addition to the certified experts in "technical inspection of buildings and structures", permission was granted to the following accredited specialists: design engineer in "engineering and construction design in terms of ensuring mechanical resistance and stability", construction expert in the specialization "expertise of project documentation in terms of ensuring mechanical resistance and sustainability" and consulting engineer (construction). It is also envisaged to inspect two

stages: preliminary and/or main (detailed) survey. This allows only a visual inspection to be performed as part of the preliminary examination to determine the presence and type of damage. The primary survey is not required in the case of damage that does not reduce the strength, stability, and rigidity of building structures and operational indicators of the elements of engineering networks and systems of the object or in the case of heavy damages that cause the necessity of demolishing the object.

Inspection of damaged objects is carried out to determine the actual condition and assess the object's compliance with the basic requirements for buildings and structures defined by legislation and to take measures to ensure reliability and safety during its operation, including:

- confirmation of the possibility of further safe operation of the object;
- establishment (substantiation) of the need to take measures to ensure reliability and safety during its operation;
- planning works on repair or overhaul of the object (parts of the object), reconstruction of the object (separated parts of the object), restoration of the damaged object;
- planning of emergency works, conservation;
- justification of decision-making regarding the termination of operation and performance of works on the dismantling of the object.

Depending on the degree of damage to the objects, according to the methodology, they can be attributed to three categories of damage, namely: Category I – there is minor damage to the load-bearing and enclosing structures, but without violation of the requirements for mechanical resistance and stability according to the SLS and ULS, which can be restored through repair and/or overhaul of the object or its parts; Category II – existing damage to load-bearing and enclosing structures (categories of responsibility for structures A and B), thatrequires to perform work on partial dismantling of the object or its individual structures, strengthening of the object or its individual load-bearing and enclosing structures, which can be carried out by overhaul of the object or its parts or reconstruction of the object; Category III – the object is unsuitable for use for its intended purpose, has completely lost its economic value, there is damage to the supporting and enclosing structures, the that indicates the danger of an collapse of the object, or the object is destroyed, then it is necessary to carry out urgent works related to the dismantling of the object [10].

Because of the extremely large volume of work presented to the surveyors, the methodology provided for the use of standard forms (questionnaires), which contained information on general information about the object (location, functional purpose, year of construction, etc.), information about the owner (manager) of the object, the main technical indicators of the object (length, width, number of floors (above-ground and underground parts), conditional height, etc.) and a brief description of the characteristics of the main building structures, engineering networks and other elements that determine the operational suitability of the building. Often, taking into account the destruction caused by military actions (fires, rubble, etc.), the customer could not provide design, technical or other documentation for the object. Therefore,

thanks to the use of such questionnaires, surveyors can quickly and efficiently survey with the clarification of the initial data, the main technical and economic indicators, and at the same time systematize the damage and not miss anything important in the difficult conditions of the work.

Thanks to the performance of a preliminary inspection using a visual inspection of the object, a preliminary assessment of its technical condition are performed, with the subsequent selection of buildings that are not subject to restoration (Category III) or those that have minor damage, such as fragmentary damage to the window or door filling or minor chips (fragmentary damage) on the facade (I category) [8, 9] and do not require an urgent need to conduct the main inspection. Thus, first of all, the primary survey was performed on objects that were classified by the preliminary survey as II and I Categories (buildings with roof damage, significant damage to window or door fillings, etc.), that is, those that require the fastest possible decisions regarding their further operation.

In the future, the initial data from the preliminary survey for each specific object will allow the surveyors to draw up a plan of the necessary instrumental studies for the qualitative conduct of the primaryinspection or, if necessary, a list of verification calculations for a comprehensive assessment of the technical condition of the building or structure and to provide conclusions regarding its further safe operation [11, 12].

If, according to the results of the preliminary or main survey, the damage is found, indicating the possibility of the sudden destruction of the building, then according to the Methodology, it is recommended to perform a calculation for progressive destruction with the help of a spatial model in a physically and geometrically non-linear formulation of the problem. The results of such calculations will make it possible to make more informed decisions regarding the further operation of such objects.

The result of both the preliminary and main surveys is the drawing up of a report on the results of the inspection with recommendations for further operation of the facility.

Thus, by following the purpose and procedure of conducting the inspection specified in the Regulation and Methodology and using standard forms (questionnaires) for reporting the results of the survey, the surveyors managed to perform the survey of a large number of damaged buildings in the shortest possible time and provide conclusions on their technical condition and recommendations on the need for conducting emergency works or object conservation; current or overhaul or reconstruction of the facility; partial or complete dismantling of the object.

At the final stage, the construction object survey report is entered by the executor into the Register of construction activities of the Unified State Electronic System in the field of construction, where all information about the life cycle of each construction object is accumulated. Entering reports into the system makes it possible to analyze them at the departmental and state levels to determine damages, make decisions about the further operation, form monetary and material support necessary for restoration, etc.

This approach to the inspection of a largeamount of construction objects can also be used when objects are damaged as a result of natural or man-made disasters.

The following are the features and analysis of destructions as a result of military actions that are not typical for civilian life, revealed as a result of technical surveys.

In the period from April to July 2022, specialists of the Kyiv National University of Construction and Architecture (KNUCA) inspected more than 50 multi-apartment (multi-story) buildings and about 50 objects of communal property (schools, kindergartens, lyceums,hospitals, administrative buildings, et cetera) and more than 300 private houses located in the villageBorodianka village, Kyiv region.

As per the data of the performed inspections, the damage to the buildings and structures due to extra-design influences on them was systematized.Identified damage to structures in one way or another affected the mechanical resistance and stability of elements of structures or structures as a whole.At the same time, explosions [3, 4], or more precisely, their impact on structures, namely: shock waves, shrapnel damage, and fires [5], were attributed to the main causes of the following damages.

The main part of residential apartment buildings in Borodianka is represented by brick and prefabricated panel buildings.Usually, these construction objects were built in the period 1970-2000.Wallfooting (often made of concrete blocks, less often of stones) uses as foundations.Even only some buildings have pile foundations.Precast reinforced concrete floor slabs are mainly used as the ceilings.

The vast majority of administrative buildings and private houses have walls that consist of bricks (ceramic or silicate).Some of the new buildings have walls from foam concrete blocks.The ceilings of most public buildings are hollow reinforced concrete slabs, and in residential buildings, they are wooden beams.

It should be noted that the amount and degree of structural damage depend on the type of explosive projectile/bomb and the place of its impact.

According to the definition [6], an *explosion* is an exceptionallyrapid transformation of matter accompanied by the immediate release of a large amount of energy in a small volume.An essential feature of a blast is a sharp increase in pressure, which causes a shock wave in the environment.The shock (explosive) wave is a zone of compressed air that spreads in all directions from the center of the explosion at speedhigher than the speed of the sound.

In the case of a direct hit of an *aerial bomb* on a building, the damage/destruction caused to it was the greatest, regardless of the type of building structures and constructive solutions.Thus, when a bomb hit a multi-story building, its part was destroyed with significant damage to the "standing" part (Fig. 1).

A shock wave from an aerial bomb hitting a building can also cause large-scale destruction to nearby construction sites.The direct damage to load-bearing building structures subjected to the action of the blast wave isdamage/destruction of enclosing load-bearing structures (Fig. 2 (a)), damage/destruction of internal non-load-bearing structures (Fig. 2 (b)), change of project position (Fig. 2 (c)), damage to window glasses and frames (Fig. 2 (d)).

(a)

(b)

Fig. 1. Destruction of multi-story buildings as a result of being hit by an aerial bomb: (a) – multi-story residential buildings made of prefabricated reinforced concrete panels; (b) – brick houses with ceilings made of prefab circular hollow reinforced concrete slabs

In addition to the damage mentioned earlier, the destructionof filling joints between the structures (floor slabs, external and internal wall panels) was often observeddue to the shock wave's impact.

It should be noted that the damage to building structures and the building as a whole decreased as the distance from the explosion's epicenter increased.

An important factor is also the presence of obstacles in the shock wave path.For example, consider the plot on Tsentralna street within Taras Shevchenko Square (Fig. 3).Behind the square in the open area is the building of the Palace of Culture at the address of 1A Parkova Street, along TsentralnaStreet, there are three residential high-rise buildings (numbers 353, 355 and 359) within the square.In the house at the address of 353 Tsentralna Street and 359Tsentralna Street was the impact of aerial bombs on the central sections of buildings, as a result of which these sections were destroyed, and the outer ones were damaged, making their further safe operation impossible.Instead, the building at the street address 355 Tsentralna street suffered minor damage, and it can be restored by repairing/overhauling.Simultaneously, the distance from the epicenters of the explosions to the damaged building was an average of 30 m.At the same time, the building located on the opposite side of the street (palace of culture), at a distance of more than 100 m, was more affected by the blast wave.As a result, there was a certain displacement (oscillation) of the building (up to 80 mm relative to the vertical) with displacements of load-bearing structures and damage/destruction of

(a)

(b)

(c)

(d)

Fig. 2. Defects of damage/destruction of structures from a shock wave

window and door fillings, internal non-load-bearing structures, and equipment.

The following in terms of the destructive effect on buildings can be attributed to damage by multiple launch rocket systems (MLRS), artillery weapons, and tanks (Fig. 4).Destruction and damage to structures from the impact of projectiles from the specified weapons are usually smaller than when an aerial bomb is hit and causes local damage to the building with the destruction of individual supporting structures.

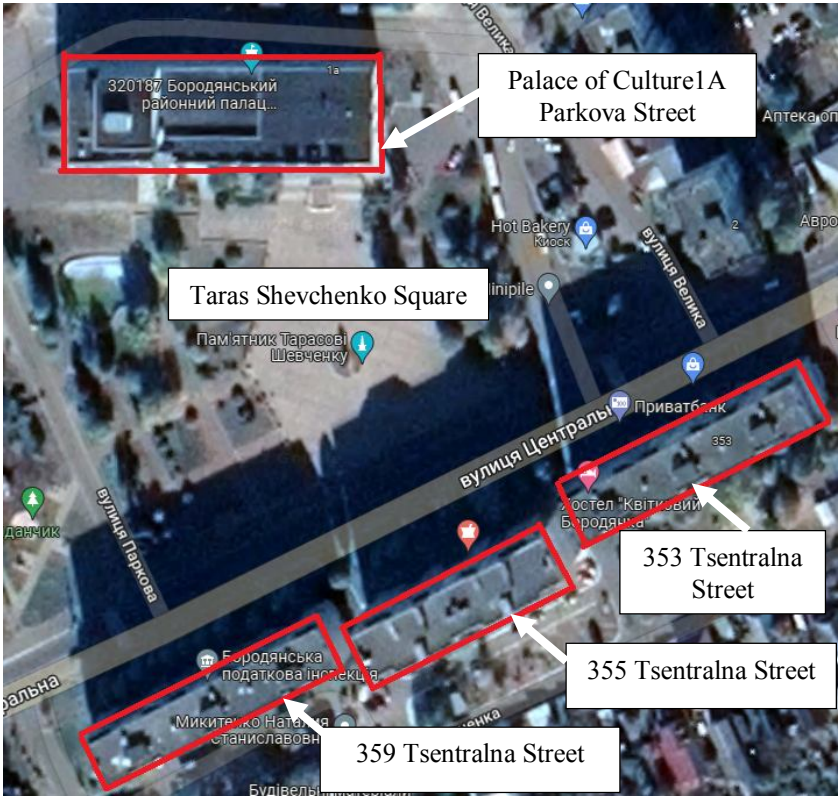

Fig. 3. Situational plan of the location of the Palace of Culture
in relation to residential buildings destroyed by an aerial bomb

Building structures suffer minor damage when they are hit by armored personnel carriers (APCs) and small arms (Fig. 5 (a)); and shrapnel (Fig. 5 (b)).

Often a fire starts as a result of an explosion.However, according to DSTU 2272:2006 [7], fire is an extra-regulatory process of destruction or fire damage to property, during which factors dangerous to living beings and the environment arise.

During active military operations, the fires that arose were not often extinguished.Therefore, the duration and intensity of the burning of buildings and structures were such that they led to significant damage to structures and

irreversible consequences.The typical primary damage to structures exposed to high temperatures (thermal impact) as a result of fires was: fire damage to structures - concrete (especially visible in the lower zone of round hollow floor slabs along voids) (Fig. 6 (a)) and bricks (Fig. 6 (b)); damage to finishing layer (Fig. 6 (c)); burning and melting of a window and door frames and their filling (Fig. 6 (d)); destruction of the roof (Fig. 6, e); the destruction of wooden walls and ceilings (Fig. 6 (f)– the wooden building, that was faced with bricks on the outside).

Fig. 4. Damage to structures due to the impact of projectiles from an MLRS, artillery, and tanks

It should be noted that as a result of damage/destruction of external enclosing structures (roof, windows, walls), precipitation enters inside the premises (Fig. 7). As a result, significant soaking of construction structures is observed.Over time, under the influence of such a negative factor, building structures' physical and mechanical properties will deteriorate, particularlywhen the temperature of the external environment changes.

Considering the data above, all damage to structures depends on the type of weapon that affected them, summarized in Table 1.

(a)

(b)

Fig. 5. Damage to structures due to hits from APCs, small arms (a), and shrapnel damage (b)

(a)

(b)

(c)

(d)

(e)

(f)

Fig. 6. Damage/destruction of structures due to fire


Fig. 7. Impact of precipitation on building structures

Table 1

Destruction/damage to structures from the type of weapon that affected them

Destruction / damage	Kind of weapons															
	Aerial bomb				Tank/Artillery				APV				Small arms			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Complete/partial destruction of the building	✓	✓	✓	✓		✓	✓	✓								
Destruction of individual elements	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓					
Displacement (declination) from the design position	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓					
Distortion/deflections	✓	✓	✓	✓		✓	✓	✓								
Cracking/cracks	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓				
Spilling of seams between building elements	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓				
Cracks in the masonry	✓	✓			✓	✓				✓	✓					
Fire/thermal damage	✓	✓	✓	✓	✓	✓	✓	✓								
Temperature elongation of reinforcement		✓	✓			✓	✓									
Buckling of elements	✓	✓	✓	✓	✓	✓	✓	✓								
Holes					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Knocking out individual masonry elements	✓	✓			✓	✓			✓	✓						
Destruction/damage to window and door frames and their filling		✓				✓				✓				✓		
Chips/damage the protective layer of concrete	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Damage to the finishing layer	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Damage to the roofing layer				✓				✓				✓				
Soaking as a result of damage to communications/roofing layer	✓	✓	✓		✓	✓	✓		✓	✓	✓					

Notes: numbers "1", "2", "3", "4" conventionally indicate the type of construction. So: "1" - foundations; "2" - walls / partitions; "3" - ceiling; "4" - covering / roof.

As a result of the performed work, it was established that all the examined buildings (about 400 pieces) suffered various damages due to the impact on them of various weapons.Based on the analysis of the obtained data, a histogram (Fig. 8) was constructed, which shows the percentage ratio of damage to construction objects by various types of weapons.

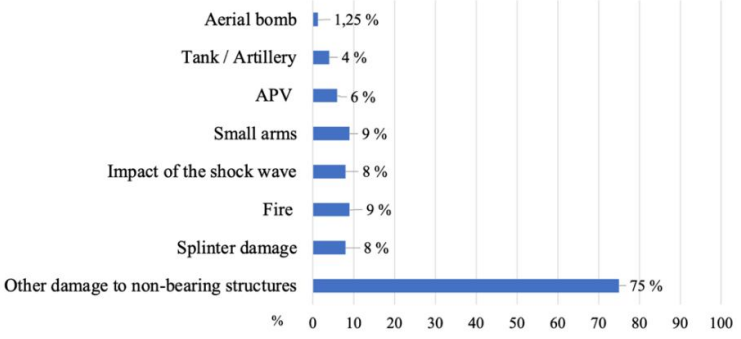

Fig. 8. Damage to construction objects by various types of weapons

So then, it can be seen from the histogram that about 1.25% of the buildings were destroyed due toaerial bombs hitting them.About 4% of the buildings suffered partial destruction and other significant damage (declination from the design position, distortion, cracks, holes, et cetera) due to being hit by shells from tanks or other artillery weapons.6% of buildings were damaged (holes, destruction of individual structures, cracks, destruction, and damage of masonry, et cetera) due to being hit by shells from APC.Moreover, another 9% of buildings were damaged (chips on the facades, damage to the filling of windows and doors, et cetera) from small arms.At the same time, about 8% of the buildings were damaged (distortion, deviation from the design position, cracking, destruction, and damage of window and door frames with filling and furnishing layer, et cetera) due to the impact of the shock wave.Another 9% of buildings were damaged due to fire (fire/thermal damage to bricks and reinforced concrete structures, thermal elongation of reinforcement, damage to the finishing layer, et cetera).About 8% of the buildings suffered various splinter damage (chips, damage to the protective layer, damage to the furnishing layer, et cetera).Nevertheless, about 75% of the buildings suffered other damage to non-bearing structures, including damage to windows and doors, as a result of illegal actions by looters.

Conclusions. With the beginning of hostilities, many buildings and structures located on the territory of Ukraine suffered numerous damages.About 1,000 buildings were damaged in the 38 days of occupation in the Borodyanka village inthe Kyiv region.

To establish the current technical condition of damaged buildings, KNUCA specialists examined them. As a result, conclusions were drawn, and recommendations were made regarding principled decisions on restoration, further operation, or the need to dismantle damaged structures or objects as a whole.

According to the analysis of the survey results, it was established that about 11% of the buildings suffered a variety of significant damage or destruction due to being hit by various types of weapons - aerial bombs, tanks, artillery weapons, andAPCs.Other buildings were damaged due to extra-design impacts, such as shockwaves, fire, and shrapnel damage.As a result, the vast majority of damaged buildings require overhaul strengthening, dismantling, or replacement of individual structures.

The experience of restoring buildings and structures after World War II and other military operations in different countries proves that this is a very long and complex process, which sometimes lasts for decades [11, 12, 13, 14].Therefore, the process of restoring damaged building structures should be started as soon as possible.At the same time, it is necessary to use both traditional and innovative methods and technologies to restore various structural damages [15, 16].

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ОБСТЕЖЕННЯ БУДІВЕЛЬ ТА СПОРУД ПОШКОДЖЕНИХ ВНАСЛІДОК ВІЙСЬКОВИХ ДІЙ НА ПРИКЛАДІ СМТ БОРОДЯНКА

Актуальність. За 38 днів окупації тільки на території Бородянської ОТГ близько 1000 будівель та споруд зазнали численних та різноманітних пошкоджень. Усі об'єкти будівництва в меншій чи більшій мірі зазнали впливу військових дій, що призвело, в окремих випадках, до порушення вимог щодо механічного опору та стійкості за граничним станом першої та другої групи. Таким чином, було важливим швидко обстежити об'єкти, що були пошкоджені внаслідок військових дій із подальшим опрацюванням отриманих матеріалів відповідними інстанціями. У результаті обстеження виокремили характерні дефекти та пошкодження різних типів будівельних конструкцій, надали їх опис та зовнішній вигляд, систематизували пошкодження / руйнування будівель залежно від виду зброї, що на них вплинула. Вид та ступінь ураження окремих будівельних конструкцій зокрема та будівель вціломузалежав від матеріалу конструкцій, конструктивних рішень будівлі та засобу, що викликав дане ураження.Окрім того,зазначеноб'єкти будівництва, що не підлягають відновленню і повинні бути ліквідовані, котрі потребують капітального ремонту та які потребують поточного ремонту. **Мета роботи.** За результатами обстеження багатоквартирних будинків та адміністративних будівель у смт. Бородянка Київської обл., що зазнали пошкоджень у наслідок дії збройної агресії зсрф систематизувати пошкодження / руйнування будівель залежно від виду зброї, що на них вплинула. **Результати.** За результатами проведеної роботи,виконано аналізнормативно-правової документації, що регламентує проведення обстежень об'єктів будівництва пошкоджених у наслідок військових дій. Виконано аналіз отриманих пошкоджень будівельних конструкцій, встановлено їх вплив на опір і стійкість об'єкту, систематизовано пошкодженняза видом засобів, що їх спричинили залежно від виду конструкцій.

Ключові слова: обстеження, військові дії, об'єкти будівництва, технічний стан, пошкодження, вибух, пожежа, вибухова хвиля.

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Молодід О.С., Ковальчук О.Ю., Скочко В.І., ПлохутаР.О., Молодід О.О., Мусіяка І.В. **Обстеження будівель та споруд пошкоджених внаслідок військових дій на прикладі смт Бородянка**/ Опір матеріалів і теорія споруд: наук.-тех. збірн. – К.: КНУБА, 2023. – Вип. 110. – С. 328-343. – Англ.

Наведено результати обстеження пошкоджених у наслідок військових дій будівель та споруд у смт Бородянка. У результаті обстеження виокремили характерні дефекти та пошкодження різних типів будівельних конструкцій, надали їх опис та зовнішній вигляд, систематизували пошкодження/руйнування будівель залежно від виду зброї, що на них вплинула.
Табл. 1. Іл. 7. Бібліогр. 12 назв.

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Molodid O.S., Kovalchuk O.Yu., Skochko V.I., Plokhuta R.O., Molodid O.O., Musiiaka I.V. **Inspection of war-damaged buildings and structures by the example of urban settlement Borodianka /** Strength of Materials and Theory of Structures: Scientific-and-technical collected articles. – K.: KNUBA, 2023. – Issue 110. – P. 328-343.
The results of the inspection of the damaged buildings and structures as a result of military actions in the city of Borodyanka are given. As a result of the inspection, characteristic defects and damage of various types of building structures were identified, their description and appearance were provided, damage / destruction of buildings was systematized depending on the type of weapon that affected them.
Tabl. 1. Fig. 7. Ref. 12.

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