

Assessing the Technical Condition of a War-Damaged Residential Building in Ukraine Based on Integrated Geodetic and Photogrammetric Surveys

Bewertung des technischen Zustands eines kriegsbeschädigten Wohngebäudes in der Ukraine auf der Grundlage integrierter geodätischer und photogrammetrischer Vermessungen

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Due to shelling, residential buildings and social infrastructure facilities are being destroyed almost daily in Ukraine. Various methods are used to diagnose the technical condition, including visual inspections and defect detection of damages. To determine changes in geometric shapes, detecting tilts or deviations on verticality, and deflections of coverings, panel misalignments in external walls, the geodetic methods such as surveying, laser scanning, and photogrammetry are appropriate. This research is dedicated to the technology of integrated diagnostics of the technical condition of an example residential building damaged due to combat operations in Ukraine. The integrated diagnostic process includes the following steps: 1) studying the structural features of the building (reviewing design data and existing technical documentation); 2) visual inspection (identifying defects and damages caused by the impact of combat UAVs, studying the consequences of fires, and the propagation zones of shock waves); 3) ultrasonic testing (non-destructive methods to diagnose the strength of construction materials and the depth of surface cracks in structures); 4) geodetic research (determining the spatial position of external wall panels near the area impacted by the combat UAV) and photogrammetric survey (spatial modeling from images by UAVs, which allows diagnosing the degree of damage and the zones of deformation and shock wave propagation caused by the combat UAV impact, as well as examining inaccessible damaged areas). Based on this approach, detailed results of the technical condition of the residential building have been obtained, allowing the evaluation of damages, taking measures for recovery, and developing technical solutions for rebuilding the destroyed areas.

Keywords: Monitoring, survey of damage, damage assessment, spatial modeling, evaluation of deformation, shock wave propagation

Aufgrund ständiger Angriffe werden in der Ukraine fast täglich Wohngebäude und soziale Infrastruktureinrichtungen zerstört. Zur Diagnose des technischen Zustands werden verschiedene Methoden eingesetzt,

darunter Sichtprüfungen und die Erkennung von Schäden. Um Veränderungen der geometrischen Formen, Neigungen oder Abweichungen von der Lotrechten sowie Durchbiegungen von Verkleidungen und Fehlausrichtungen von Paneelen in Außenwänden festzustellen, eignen sich geodätische Methoden wie Vermessung, Laserscanning und Photogrammetrie. Dieser Beitrag widmet sich der Methodik der integrierten Diagnose des technischen Zustands eines beispielhaften Wohngebäudes, das durch Kampfhandlungen in der Ukraine beschädigt wurde. Der integrierte Diagnoseprozess umfasst die folgenden Schritte: 1) Untersuchung der strukturellen Merkmale des Gebäudes (Überprüfung der Konstruktionsdaten und der vorhandenen technischen Dokumentation); 2) Sichtprüfung (Identifizierung von Mängeln und Schäden, die durch den Einsatz von Kampfdrohnen verursacht wurden, Untersuchung der Folgen von Bränden und der Ausbreitungszonen von Schockwellen); 3) Ultraschallprüfung (zerstörungsfreie Methoden zur Diagnose der Festigkeit von Baumaterialien und der Tiefe von Oberflächenrissen in Strukturen); 4) geodätische Untersuchungen (Bestimmung der räumlichen Lage der Außenwandpaneele in der Nähe des von der Kampfdrohne betroffenen Bereichs) und photogrammetrische Vermessung (räumliche Modellierung anhand von Bildern von UAVs, die eine Diagnose des Ausmaßes der Schäden und der Zonen der Verformung und Schockwellenausbreitung durch den Aufprall der Kampfdrohne sowie die Untersuchung unzugänglicher beschädigter Bereiche ermöglicht). Auf der Grundlage dieses Ansatzes wurden detaillierte Ergebnisse zum technischen Zustand des Wohngebäudes gewonnen, die eine Bewertung der Schäden, die Ergreifung von Maßnahmen zur Wiederherstellung und die Entwicklung technischer Lösungen für den Wiederaufbau der zerstörten Bereiche ermöglichen.

Schlüsselwörter: Überwachung, Schadensaufnahme, Schadensbewertung, räumliche Modellierung, Bewertung von Verformungen, Ausbreitung von Stoßwellen

1 INTRODUCTION

Armed conflicts usually cause extensive damage to residential buildings and critical infrastructure. Reliable inspection and documentation of such damages are necessary not only to ensure immediate safety but also for planning repair, reconstruction, and long-term resilience. Traditional inspection methods remain valuable, but they are often limited in hazardous or inaccessible environments. Modern geodetic and photogrammetric technologies provide new opportunities for comprehensive and accurate assessment of structural conditions, allowing experts to detect deformations, classify damages, and document changes over time.

In the Ukrainian context, where a large number of buildings have been destroyed or severely damaged as a result of ongoing military actions, systematic approaches to building inspection and damage documentation are urgently needed. Classical approaches may not provide the required accuracy to detect minor deformations or spatial displacements that could indicate the risk of progressive collapse. Therefore, there is an urgent need to integrate modern geodetic and photogrammetric instruments and methods into the system of damage diagnostics. At the same time, an important task is the approbation and practical testing of these methods on real objects affected by hostilities. Only experimental validation of their effectiveness makes it possible to adapt the methodologies to wartime conditions, improve the tools, and develop standardized approaches that can be scaled for use in different regions of Ukraine. Such an integrated approach ensures not only a reliable assessment of the current technical condition but also establishes a basis for long-term monitoring, risk reduction, and scientifically grounded recovery planning.

1.1 State-of-the-art of Survey the Damaged Objects in Ukraine

Due to the military actions in Ukraine, the issue of assessing the technical condition and determining the restoration approaches for damaged buildings and civil infrastructure facilities has become particularly relevant. Many Ukrainian researchers are actively studying this problem and offering practical approaches and their own experience to contribute to its comprehensive resolution. The topic of assessing war-damaged buildings in Ukraine using modern geodetic and photogrammetric methods has been the focus of numerous recent studies. A comprehensive methodological basis for such assessments is outlined in several publications authored by Ukrainian specialists.

Initial methodological and practical aspects of post-war building surveys are considered by /Lisenyi et al. 2023/ and /Yakovenko 2023/, where damage documentation, classification, and decision-making regarding reconstruction are discussed. Practical experience in geodetic monitoring during recovery works is presented by /Zorin et al. 2023/, emphasizing the role of repeated measurements in deformation tracking.

Modern photogrammetric and remote sensing techniques have already proven to be effective for inspecting structures, see for example /Benz et al. 2023/ or /Vierhub-Lorenz et al. 2023/. Applied these methods to war-damaged infrastructure are highlighted by /Lobanov et al. 2023, 2024/, who demonstrate UAV-based approaches for the assessment of damage severity and localization.

Similar methodologies were implemented in the survey of the Kyiv TV tower and other facilities.

Numerical modeling of structural damage caused by explosions is addressed in the work of /Barabash & Donets 2023/, while the integration of risk theory into the assessment of structural resource depletion is presented in /Kaliukh et al. 2023/. Earlier studies by /Kaliukh et al. 2018/ investigated the effect of repeated explosion loads on building lifespan.

Special attention is also given to methodological aspects of inspecting residential buildings for further exploitation after damage, as discussed in /Tabarkevych et al. 2023/ and /Melashenko et al. 2023/.

An important contribution to the development of damage classification and geodetic support systems is made by /Serhiichuk et al. 2024/, who investigated multi-story buildings in Kyiv, while the criteria for permissible geometric deformations of silos are detailed in /Zelenko et al. 2025/, showing a direct analogy to tolerance limits for residential structures.

Economic and restoration aspects of recovery projects in war-affected cities like Chernihiv are presented in /Kyrusha 2024/, focusing on cost documentation and budgeting under emergency reconstruction conditions.

Seismic protection and vibrational analysis in the context of potential secondary hazards are also covered. /Marienkov et al. 2024/ propose solutions for enhancing seismic resilience of modular and panel housing, and vibrational diagnostics for damage assessment is introduced in /Farenjuk et al. 2022/.

International research provides a strong theoretical and methodological foundation for assessing structural damage using geodetic and photogrammetric techniques. /Kraus 2007/ and /Luhmann et al. 2014/ systematize the geometric principles, data acquisition strategies, and processing workflows for close-range photogrammetry, laser scanning, and 3D imaging, which are directly applicable to documenting and analyzing war-related building damage. These works emphasize accuracy control, calibration, and integration of multi-sensor datasets – aspects essential for reliable condition assessment. In the field of structural engineering, numerical simulation of extreme loads, including blast effects, is well established; international practices align with methods discussed in Ukrainian studies, notably through the application of finite element analysis platforms such as ANSYS Mechanical for predicting deformation and failure mechanisms.

Collectively, these studies form a coherent foundation for developing an integrated methodology that combines geodetic, photogrammetric, and numerical tools to assess and monitor the technical condition of buildings damaged during hostilities.

1.2 Relevance of the Study

Given the constantly increasing demands for the safety and durability of buildings and structures, the relevance of this study on assessing the technical condition is driven by the need to develop effective integrated methods for monitoring and diagnosing the condition of buildings. In particular, studying the nature of deformations and damages to structures in real time, the zones of deformation propagation from blast waves and fires, is a critical aspect for ensuring

their stability and implementing technologies for the effective restoration of damaged buildings and structures.

1.3 Research Objectives

The aim of this study is to develop an integrated methodology for monitoring the technical condition of buildings through the combination of field, instrumental, geodetic, and photogrammetric technologies. The integrated diagnostic process comprises the following stages:

- Visual inspection, aimed at identifying defects and damage resulting from the impact of combat UAVs, including the consequences of fires and the propagation zones of shock waves.
- Ultrasonic testing, employing non-destructive methods to assess the strength characteristics of construction materials and to determine the depth of surface cracks in structural elements.
- Geodetic surveying, which involves determining the spatial position of external wall panels in the vicinity of the UAV impact zone.
- Photogrammetric research, based on spatial modeling from UAV-acquired images, enabling the diagnosis of damage extent, deformation zones, and shock wave propagation patterns, as well as facilitating the inspection of inaccessible or hazardous areas.

2 MAIN CHARACTERISTICS OF THE RESEARCH OBJECT

A multi-apartment residential building in the Kirovohrad region was struck by a military UAV. It is a nine-story large-panel structure divided into three entrances, featuring the basement (technical underground level) and a technical floor. The building consists of two temperature-shrinkage blocks (sections 1-2 and section 3) arranged in an L-shape, as shown in *Fig. 1*. The building was commissioned in 1995.



Fig. 1 | Plan of the residential building's relative positioning



Fig. 2 | Part of the building's facades

The building's structural system is a rigid large-panel, frameless design with transverse load-bearing walls (featuring a uniform longitudinal spacing of 3.3 m) and longitudinal load-bearing walls of the adapted series 94 (Ukrmiskbudproekt, Kharkiv). The primary load-bearing elements of the building are reinforced concrete wall panels, which support the reinforced concrete floor slabs. Fragments of the building's facades are shown in Fig. 2.

The building's foundations are pile-type, composed of precast reinforced concrete elements and monolithic areas. The external load-bearing walls are three-layer precast wall panels with a thick-

ness of 350 mm. The internal load-bearing walls are precast wall panels 160 mm thick. The floor slabs are precast reinforced concrete solid panels, 160 mm thick, supported along the perimeter. These slabs form rigid floor diaphragms. The roof structure consists of precast reinforced concrete ribbed slabs. Partitions are made of brick and gypsum block materials. The staircases are constructed by precast reinforced concrete flights and ribbed stair landings. The balcony slabs are precast reinforced concrete with a thickness of 100 mm. The roof is flat and covered with multiple layers of roofing felt, featuring an internal organized drainage system. The perimeter pavement around the building is concrete. The building is equipped with water supply, heating, electrical power, gas supply, and sewage systems. The engineering networks are centralized and connected to external municipal utilities. Fig. 3 presents the facade drawings of sections 1-2 of the residential building, with axis markings.

2.1 Visual Inspection of the Object

The visual inspection process represents the initial stage in the comprehensive assessment of the technical condition of buildings. This section describes the methodology for conducting the visual inspection of structural elements and the interpretation of the obtained results for preliminary damage evaluation.

The visual survey of the technical condition of the multi-apartment residential building in the Kirovohrad region was carried out in March –April 2025 with the purpose of recording defects and damages. The inspection covered the external facades of the building, stairwells, and all accessible interior rooms.

The inspection was performed in accordance with DSTU 9273, the Procedure for the Examination of Commissioned Construction Objects, and the Methodology for Surveying Buildings and Structures Damaged as a Result of Emergencies, Military Actions, and Terrorist Acts.

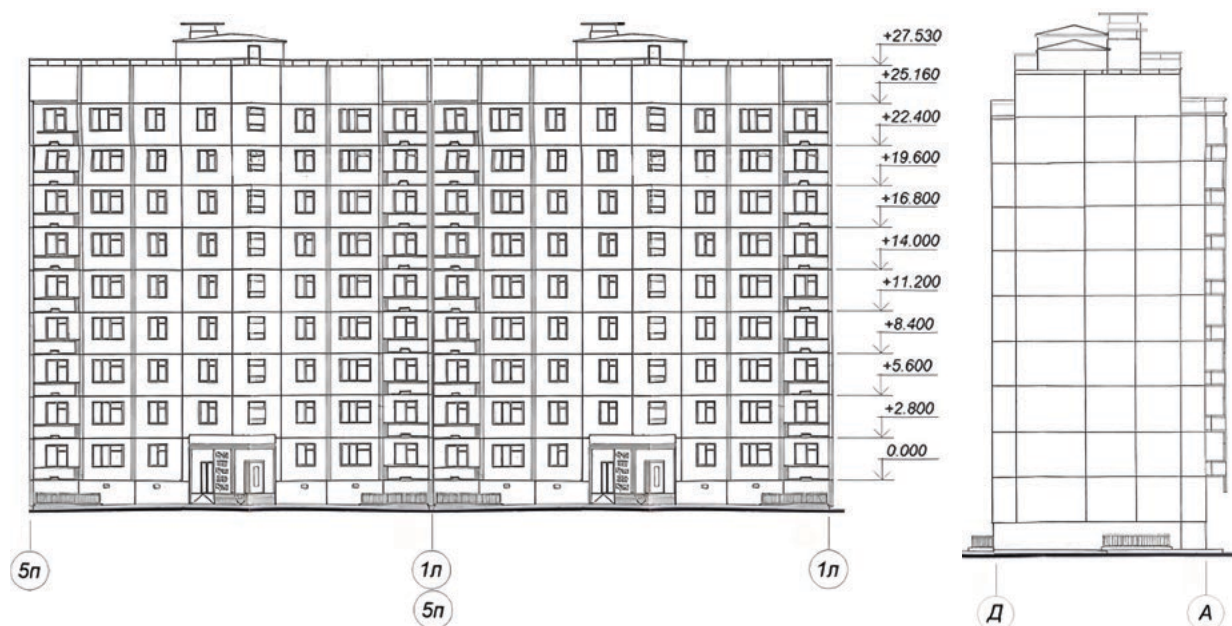


Fig. 3 | View of the courtyard and end facades of the residential building



Fig. 4 | The image of opening in the wall panel of the 8th floor at the UAV impact place

A direct hit by a combat UAV on the side facade of section 1-2 at grid axes 1L/V on the level of the 8th floor caused the following damages:

- mechanical damage to external and internal walls caused by the UAV warhead explosion and the subsequent fire;
- damage to wall panels and floor slabs of apartments due to the fire;
- initiation and propagation of existing cracks in wall panels and floor slabs as a result of the intense impact from the explosion;
- damage to the building's structural connection nodes due to the dynamic explosion effect;
- displacement of wall panels relative to their design positions due to the explosion;
- damage to finishing layers of external and internal walls, floors, and ceilings;
- full or partial destruction of glazing in windows and balconies caused by the blast wave and debris;
- damage to doors and interior property resulting from the explosion and fire;
- partial damage to water supply, sewage, and ventilation systems in some apartments of section 1-2.

The point of impact of the combat UAV was on the end wall of the eighth floor of section 1-2, creating a through opening in the external wall and causing a fire (see Fig. 4).

2.2 Results of the Analysis of Structural Features and Visual Inspection of the Object

A direct hit by a UAV on the side facade of section 1-2 at grid axes 1/V at the level of the 8th floor caused damage to the external and internal structures of the adjacent sections of the building within floors 3–9 and the technical floor, namely:

- through holes in wall panels up to 1.5 m × 2.5 m in size;
- damage to the vertical and horizontal joints between the external wall panels and floor slabs along the entire perimeter;

- horizontal panel offsets up to 40 mm;
- diagonal and horizontal cracks in individual panels with a opening width of up to 0.4 mm;
- cracks in the joints between wall panels and the monolithic concrete infill with an opening width of up to 3 mm;
- cracks in the joints between wall panels and plumbing cabins with a width of opening up to 5 mm;
- destruction and damage to window frames, window panes and fencing of apartment balconies up to 15.3 % of the total in the building;
- damage to window panes of stairwells by 19.4 % of the total in the building;
- damage to frames, window panes of balcony and interior doors with a total area of up to 21,6 m²;
- damage to water, sewerage, heating and electricity networks in two apartments located closest to the site of the hit.

3 INSTRUMENTAL STUDIES OF THE STRENGTH OF BUILDING STRUCTURES

The objectives of the instrumental inspections are to use non-destructive testing of the residential building's structures to determine the following parameters:

- concrete strength in the wall panels and floor slabs within the residential units located between the 7th and 9th floors and on the building's technical floor;
- depth of surface cracks in the concrete of the wall panels and floor slabs within the residential units between the 7th and 9th floors and on the technical floor.

3.1 Brief Description of Testing Methods and Tools

Concrete strength was determined using the ultrasonic method according to DSTU B V.2.7-226. The principle of the ultrasonic method is based on the correlation between concrete compressive strength

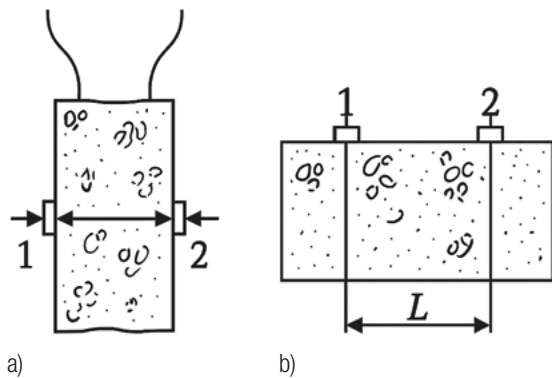


Fig. 5 | Determination of ultrasonic pulse velocity in concrete by (a) direct and (b) surface transmission methods (1, 2: transducer positions; L : measurement base (pulse path length))

and the velocity (or time) of ultrasonic wave propagation through the concrete. Concrete strength is established using a calibrated relationship between these parameters.

The pulse velocity $V = L/t$ (where L is the propagation path length and t is the travel time) reflects the material's density, homogeneity, and elastic modulus. A higher velocity indicates a denser, stronger, and more uniform structure.

Fig. 5 explains the determination of ultrasonic pulse velocity in concrete by direct and surface transmission methods. Direct transmission transducers are placed on opposite sides of the specimen along the same axis, allowing the pulse to travel through the entire thickness of the concrete. Surface (indirect) transmission – both transducers are located on the same surface; the pulse travels along the surface layer of the concrete.

To convert measured velocities into compressive strength values, a calibration relationship $R = f(V)$ is established for the specific concrete mix and curing conditions. Calibration is performed by correlating ultrasonic method results with destructive strength tests on cores or control specimens. The obtained regression curve – typically linear or exponential – is then used to estimate the in-situ compressive strength f_{cm} for structural elements.

Crack depth was measured using the ultrasonic method according to BS 1881: Part 203. The crack depth determination relies on the ultrasonic shadow method, where acoustic waves are considered as straight rays traveling from the source to the receiver by the shortest path. When these rays bypass defects (cracks, voids, etc.), the path

length increases and signal attenuation intensifies. These indicators are used to detect defects and measure crack depth in reinforced concrete structures.

Ultrasonic measurements in the structures were performed:

- with the Pundit PL-200 device equipped with a surface sounding attachment. The absolute error of ultrasonic propagation time measurements T is $\pm(0.01 T + 0.1)$ microseconds;
- with the UK-14PM device equipped with a surface sounding attachment. The absolute error of ultrasonic propagation time measurements T is $\pm(0.01 T + 0.1)$ microseconds.

The measured velocity is affected by several factors, including aggregate type, moisture content, temperature, age of concrete, and presence of reinforcement. To minimize their influence, measurements were performed on cleaned, saturated-surface-dry areas, avoiding reinforcement lines. Temperature and surface humidity were recorded during each test.

3.2 Results of Ultrasonic Testing for Concrete Strength Determination

The strength of concrete was determined in wall panels and floor slabs in residential premises located within the seventh – ninth floors (apartments No. 64, 68, 72, 97, 101, 105) and on the technical floor of the building.

The measurement of ultrasonic pulse velocity in concrete was carried out using the surface transmission method (six measurements were taken in different points of each test area). The conversion from surface transmission velocity to direct (through-transmission) velocity was performed using the conversion coefficient K_p ; for the instrument used, the value of K_p was 1.74.

Concrete strength at the test locations was determined based on a standard calibration curve correlating ultrasonic velocity to compressive strength, established from comparative ultrasonic and mechanical testing of concrete samples of various classes.

For each control zone, at least six individual measurements were taken and averaged. Outliers exceeding $\pm 10\%$ deviation from the mean were discarded in accordance with DSTU B V.2.7-224. The resulting mean velocity values were converted to compressive strength using the established calibration curve $R = f(V)$, and average strengths f_{cm} were computed for each group of elements. The basic calibration relationship between ultrasonic pulse velocity and

Type of structures, test Locations	Average compressive strength of concrete f_{cm}	Corresponding concrete strength class
<i>Section 1-2</i>		
Wall panels on the 7th, 8th, 9th, and technical floors	34.0 MPa	C20/25
Wall panels in fire-damaged areas (8th floor)	<13.0 MPa	–
Floor slabs of the 7th and 8th floors	29.4 MPa	C16/20
Monolithic joints of wall panels on the 7th and 8th floors	30.7 MPa	C16/20
<i>Section 3</i>		
Wall panels on the 7th, 8th, 9th, and technical floors	32.9 MPa	C20/25
Monolithic connection joints of wall panels on the 7th and 9th floors	28.8 MPa	C16/20

Tab. 1 | Results of concrete strength assessment in structural elements

compressive strength was established based on the results of comparative ultrasonic and mechanical tests of concrete specimens of different strength classes.

The corresponding concrete class was determined based on the obtained average strength values f_{cm} according to Table 3.1 of DBN V.2.6-98. The results of the concrete strength assessment are presented in *Tab. 1*.

As shown in *Tab. 1*, based on the average compressive strength, the concrete in the examined reinforced concrete structures corresponds to the following classes:

- C20/25 in the wall panels on the 1st, 7th, 8th, 9th, and technical floors of section 1-2, as well as in the wall panels on the 7th, 8th, 9th, and technical floors of section 3;
- C16/20 in the floor slabs of the 7th and 8th floors of section 1-2, as well as in the monolithic joints of wall panels on the 7th and 8th floors of section 1-2 and on the 7th and 9th floors of section 3.

In the wall panels affected by the fire (8th floor), the concrete strength is less than 13 MPa, which is below the minimum allowable strength for heavy concrete.

3.3 Results of Surface Crack Depth Determination in Structures by Ultrasonic Method

The depth of cracks was determined in the wall panels and floor slabs within the residential areas located between the seventh and ninth floors, as well as on the technical floor of the building.

According to the methodology, ultrasonic measurements were carried out uniformly along the length of the crack in defect-free concrete and when sounding through the crack (*Fig. 6*). The depth h of the surface crack in the concrete was calculated using Eq. (1).

$$h = \frac{L}{2} \sqrt{\frac{t_{ND}^2}{t_n^2} - 1}, \quad (1)$$

where $L = 120$ mm is the distance between the ultrasonic sensors; t_{ND} , t_n are the average ultrasonic propagation times when sounding through the crack and through defect-free areas, respectively.

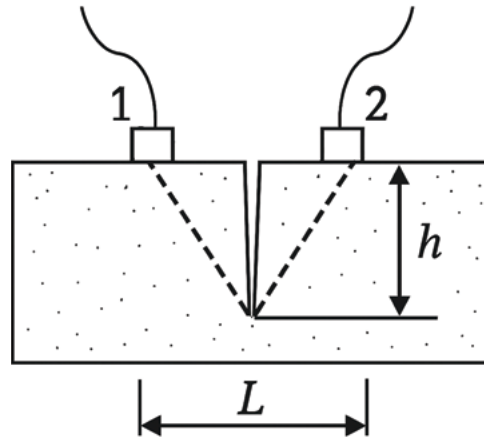


Fig. 6 | Schematic representation of ultrasonic crack depth measurement

According to the data presented in *Tab. 2*, the average crack depths range as follows:

- from 68 mm to 121 mm in the wall panels of section 1-2;
- from 70 mm to 106 mm in the floor slabs of section 1-2;
- from 94 mm to 127 mm in the wall panels of section 3.

The average crack depth at the joints between wall panels is 130 mm.

3.4 Conclusions from Non-Destructive Testing Results

The results of the non-destructive tests revealed several problematic areas within the building that require attention and possible intervention. Analysis revealed:

- extensive facade damage: the total damaged surface area reached 27.8 % of the external wall area, including spalling of concrete, loss of protective layers, and exposure of reinforcement;
- burnt and thermally degraded areas: significant surface carbonization and delamination were mapped, correlating with the

Control Locations	Type of Structures	Crack Depth	Average crack depth in structures
<i>Section 1-2</i>			
Technical floor	wall panel	from 105 mm to 137 mm	121 mm
8th floor	wall panel	from 95 mm to 128 mm	112 mm
7th floor	wall panel	from 36 mm to 94 mm	68 mm
	floor slab	from 70 mm to 106 mm	77 mm
<i>Section 3</i>			
Technical floor	wall panel	from 89 mm to 99 mm	94 mm
9th floor	wall panel	from 94 mm to 149 mm	127 mm
8th floor	wall panel	from 92 mm to 102 mm	95 mm
7th floor	wall panel	from 90 mm to 125 mm	108 mm
<i>Section 1-2, 3</i>			
	Joints between wall panels	from 90 mm to >150 mm	130 mm

Tab. 2 | Results of surface crack depth determination in concrete structures

observed reduction of concrete strength in fire-affected panels (< 13 MPa);

- dimensional documentation: precise measurement of defect geometry (e. g., through-openings up to 1.5 m × 2.5 m) supports accurate repair design and cost estimation.

The use of non-invasive methods allowed for the collection of essential data without compromising the structural integrity.

4 GEODETIC STUDIES OF THE SPATIAL POSITION AND VERTICALITY OF EXTERNAL WALLS

4.1 Research Methodology

To determine the verticality of walls, specialized measurement techniques are employed that can detect even minor deviations from the design standards. The objective of the survey is to assess the deviation of wall planes from the vertical, which may have occurred due to the intense blast wave and damage to embedded components, without causing overall structural failure and while preserving the building's geometric form. For this purpose, an electronic total station NTS-382RL10 manufactured by South Survey was used, with the following technical specifications:

- Root mean square error for measuring horizontal and/or vertical angles $\pm 2''$;



Fig. 7 | Scheme of the horizontal and vertical reference framework

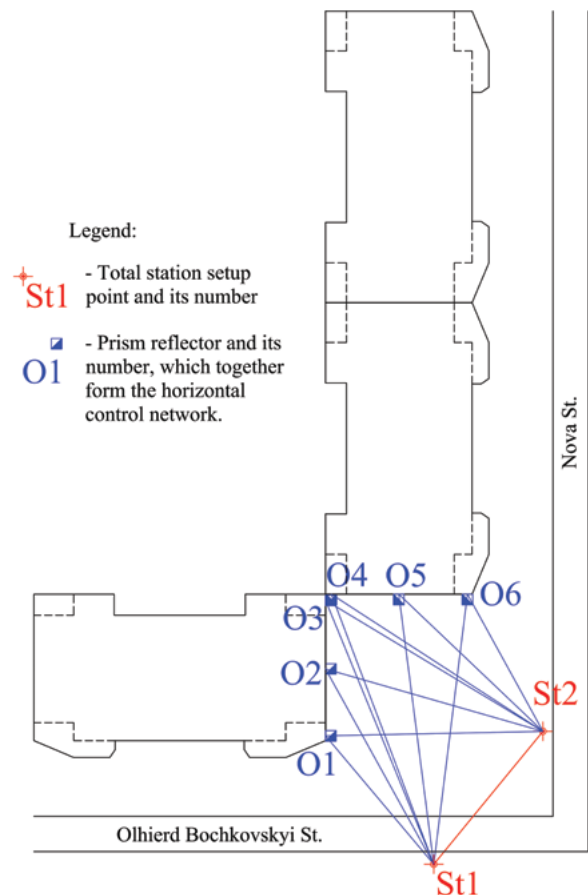
- Root mean square error for measuring slope distances ± 2 mm, and ± 5 mm in reflectorless mode.

The tilt measurement was performed indirectly based on point measurements. This approach involves determining the rectangular coordinates of points located at the bottom and top edges of the building's corners and walls (Fig. 7). The difference between the coordinates at the top and bottom of a given wall or corner edge reflects the magnitude and direction of deviation (deviation from vertical alignment) within the chosen local coordinate system. For ease of calculation, the orthogonal axes of this local coordinate system were aligned parallel to the main axes of the building. The instrumental accuracy of tilt determination by this method is approximately 5 mm.

The work was carried out in two main stages:

- establishment, fixation, and survey of control points for the horizontal and vertical reference network, which included two sighting stations and six base points (see Fig. 7);
- surveying the damaged sections by taking measurements of uniform points on each wall panel, with at least five points measured per panel. The density of points was justified by the structural features of the building.

The determination of the deviation from the verticality of the wall planes was carried out in accordance with the requirements of current regulatory documents. Fig. 8 shows the results of measuring the deviation values of points on the wall panels relative to the "conditional zero", which is taken as the farthest point from the surveying station that protrudes beyond the ideal plane of the wall.



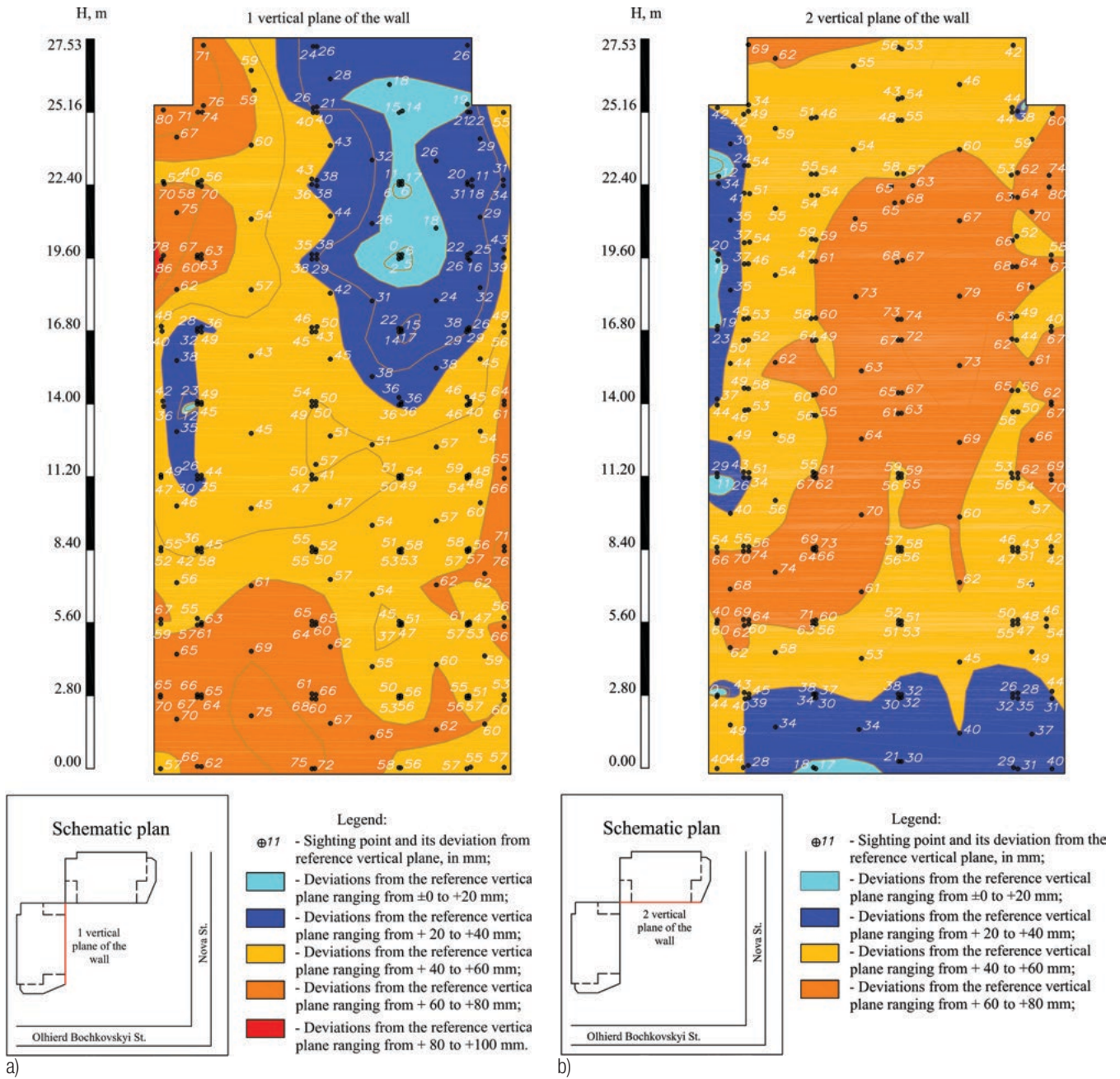


Fig. 8 | Results of determining vertical deviations of the a) wall in section 3 and b) wall in section 1-2

All presented values have a positive sign (“+”), indicating that the direction of deviation is towards the surveying station. The geodetic survey was conducted on March 27, 2025, so the indicated deviation values reflect the actual condition of the structures at that time.

4.2 Research Results

According to the conducted geodetic measurements, minor deviations from verticality were detected in some areas of the building, which may indicate the onset of settlement or deformations requiring further monitoring.

The determination of vertical deviations of the building’s walls was performed on March 27, 2025. The survey results recorded the following:

- The maximum deviation from verticality of the wall in section 3 along the entire building height reaches 86 mm at elevation +19.60 m, with deviations along the entire height reaching 51 mm. The greatest deformations were recorded within the elevation range +14.00 m to +27.53 m, with deviation directions outward.
- The tilt of the wall along the entire height of section 3 is 1.8 ‰, which does not exceed the limit value of 2.0 ‰ according to Table 4 of DSTU B V.1.2-3 (is defined in ‰ as the ratio of the deviation in mm to the height in m).

- The maximum deviation from verticality of the wall in section 1-2 along the entire building height reaches 80 mm at elevation +22.40 m, with deviations along the entire height reaching 62 mm. The largest deformations are concentrated within the elevation range +5.60 m to +25.16 m, with deviation directions inward from the building center.
- The tilt of the wall along the entire height of section 1-2 is 1.9 ‰, which does not exceed the limit value of 2.0 ‰ according to Table 4 of DSTU B V.1.2-3.

Based on the measurement results, we can conclude that the recorded deviations are minor and do not exceed the permissible limits according to the relevant regulatory documents.

5 PHOTOGRAMMETRIC MODEL AND DEFECT STUDY USING PHOTOGRAMMETRIC DATA

There are two main types of photogrammetry: aerial (with a camera in the air) /Kraus 2007/ and terrestrial (with a camera handheld or mounted on a tripod) /Luhmann et al. 2023/. Terrestrial photogrammetry typically involves distances to objects of up to about 200 meters and is also known as close-range photogrammetry. Small-format aerial photogrammetry in some way combines the features of both types, integrating an aerial viewpoint with close distances to objects and high image detail. Nowadays it is known as UAV photogrammetry.

The photogrammetric method is based on a geometric-mathematical reconstruction of the light paths from the object to the sensor of a digital camera at the moment of exposure. This enables remote detection of defective areas, precise measurement of the geometric dimensions of damage, and accurate determination of their location on the structure. However, at least one absolute scale has to be introduced into the analysis.



Fig. 9 | The DJI Mavic 3 Enterprise UAV during the survey

5.1 Data Collection Technology

For data collection, a DJI Mavic 3 Enterprise with RTK unmanned aerial vehicle equipped with a built-in camera capable of up to 4K Ultra HD resolution was used (Fig. 9). The device captured high-precision images of the building from various angles, enabling the detection and identification of wall damages caused by the impact of a combat UAV. This approach allows obtaining detailed images used for defect analysis.

A flight route was developed for data collection, taking into account the required image overlap, the level of detail, and coverage of the damaged areas. For spatial referencing, an RTK module was used, which improves accuracy and optimizes the photogrammetric processing.

To further control the positioning and georeferencing of the 3D model to the terrain, a geodetic control network was established using six retroreflective targets, which served as ground control points during model construction (Fig. 10). The use of these targets enables not only photogrammetric processing of the 3D model but also its conversion and analysis in other fields such as geodesy, architecture, construction, as well as in design and cadastral work.

To obtain the final result, continuous operation of a graphics workstation was required for approximately 8 hours. The processing was performed on a workstation with the following technical specifications: Intel Core i7-13700K 3.4 GHz processor, 64 GB of

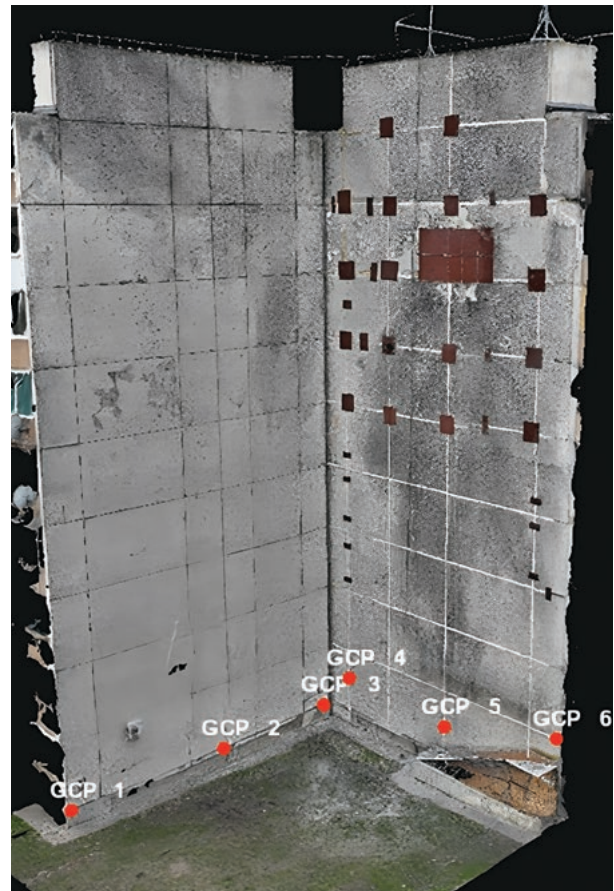


Fig. 10 | Georeferencing of the photogrammetric model using a geodetic control network

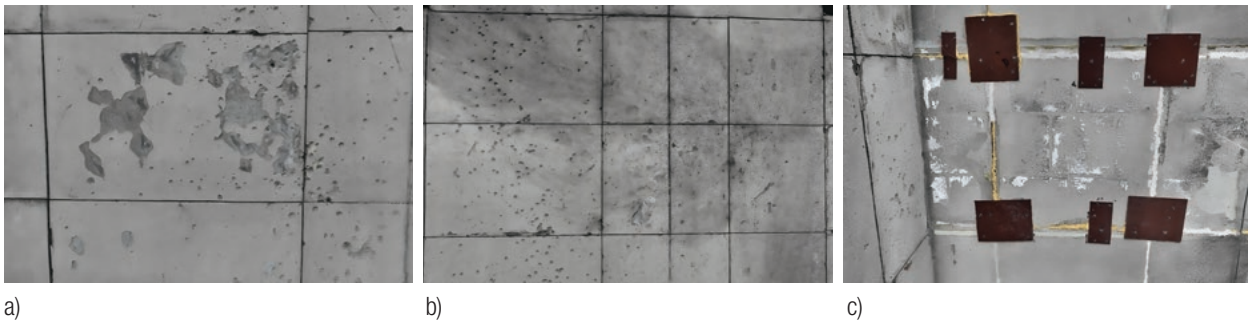


Fig. 11 | Defects and damages identified based on photogrammetric model data: a) spalling of concrete on exterior walls caused by explosion debris, b) propagation of the blast wave, c) damage to embedded parts and opening of interpanel joints

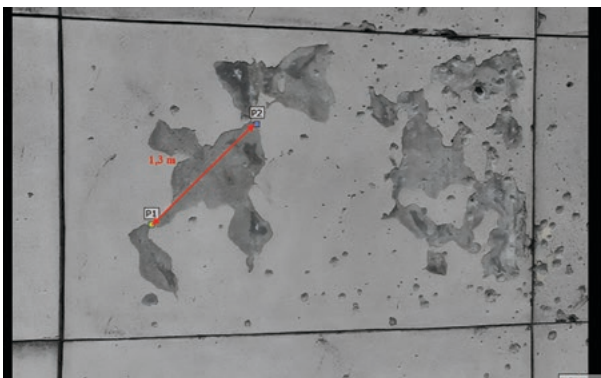


Fig. 12 | Determination of a characteristic facade defect dimension using photogrammetry

RAM, 2 TB SSD storage, and an NVIDIA Quadro RTX A4000 graphics card.

Fig. 11 shows the defects caused by the explosion and fire of a combat UAV. The remote inspection carried out enabled the assessment of the damage, measurement of its dimensions (Fig. 12), and detailed classification of the defects, which served as a basis for developing recommendations for further restoration.

5.2 Results

Analysis the data from the photogrammetric models revealed visible defects: spalling of the concrete on the exterior walls, the spread of the explosion wave and fire, burnt areas of the building, damage to embedded parts, and the opening of inter-panel joints. The area of surface damage of various types reached 27.8 % of the total external wall surface area of sections 1-2 and 3.

These defects may affect the structural integrity of the building. The results enable timely safety measures to be taken and allow for the rational use of the acquired data to make informed decisions regarding the restoration of the residential building.

6 CONCLUSION

The object of the study is a 9-story multi-section residential building in the Kirovohrad region, damaged as a result of a direct strike by a combat UAV (unmanned aerial vehicle) that occurred on the night of

February 18, 2025. Based on the results of visual and instrumental inspections using non-destructive, geodetic, and photogrammetric methods, information was obtained regarding the current technical condition, material characteristics of the structures, existing defects, and damages in a volume sufficient for assessing the technical condition and forming conclusions about the possibility of ensuring the further safe operation of the building as intended. Key results include:

- **Structural performance:** Despite localized severe damage to load-bearing elements, including loss of material strength in fire-affected panels (<13 MPa) and horizontal displacement of wall panels up to 40 mm, the overall stability of the building remains within permissible deformation limits according to current Ukrainian standards (DSTU B V.1.2-3).
- **Damage characterization:** The total surface area of various facade defects reached 27.8 % of the external walls of sections 1-2 and 3, with documented cases of through-openings up to 1.5 m × 2.5 m, joint failures, and thermal degradation of concrete.
- **Deformation assessment:** Geodetic surveys confirmed that recorded tilts (1.8 ‰ – 1.9 ‰) did not exceed normative thresholds, although concentration of deviations in certain elevation ranges indicates the need for continued monitoring to detect possible post-impact settlement or progressive displacement.
- **Integrated data utility:** Photogrammetric 3D models provided high-resolution spatial data for defect mapping, quantitative measurement, and remote access to hazardous zones, complementing geodetic and ultrasonic findings and enabling precise repair planning.

This study confirms that integrated geodetic-photogrammetric diagnostics significantly enhance the reliability and completeness of post-damage technical assessments compared to single-method inspections. The obtained results can inform both immediate safety decisions and the long-term restoration strategy for war-affected residential infrastructure. Furthermore, the methodological framework can be generalized for application to other civilian structures impacted by military actions, ensuring data consistency, safety of inspection teams, and compliance with international best practices in structural damage assessment.

Impact. This study provides a scientifically validated methodology for rapid and reliable assessment of war-damaged residential buildings, enabling informed decisions on safety and restoration priorities. The integrated geodetic-photogrammetric approach can be adapted

for broader post-disaster infrastructure monitoring, supporting both national recovery efforts and international reconstruction projects.

Excellence. The research advances the state of the art by combining visual, ultrasonic, geodetic, and UAV-based photogrammetric methods into a single, coherent diagnostic framework. This multidisciplinary integration ensures high-accuracy structural evaluation while minimizing inspection risks in hazardous environments.

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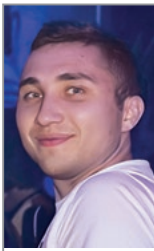


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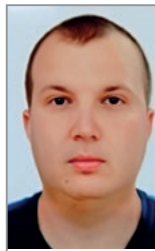


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