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INVESTIGATION OF THE STRESS-STRAIN STATE OF BUILDING STRUCTURES DAMAGED BY EMERGENCY SITUATION

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Abstract. The article investigates the stress-strain state of building structures damaged due to an emergency situation resulting from a missile strike on a building in Odesa. The study aimed to comprehensively analyze the technical condition of the damaged structure, evaluate the impact of the missile strike on bearing capacity and deformation behavior, and provide recommendations for restoration. The authors conducted detailed instrumental inspections utilizing non-destructive testing techniques, performed topographic and geodetic surveys to determine structural verticality, and carried out verification analyses using the "LIRA-SAPR" software. Significant damages to columns, floor slabs, and external walls were identified, creating a risk of progressive structural collapse. The structures were classified as being in an emergency state, with damage levels reaching up to 80%. The proposed restoration measures involve dismantling and reconstruction of damaged elements, reinforcement of load-bearing structures using metallic components, installation of temporary support systems, and ongoing structural health monitoring. Particular attention was paid to determining the actual concrete strength, corresponding to the concrete class C20/25 (B25). Reinforcement parameters, such as the diameter and concrete cover thickness of the working reinforcement in columns and floor slabs, were also investigated. It was found that the actual concrete cover thickness significantly deviated from standard values, which must be considered when planning restoration and reinforcement measures. The research underscores the importance of adopting a comprehensive approach to analyzing damaged buildings, incorporating modern techniques such as 3D scanning for accurate spatial modeling and minimizing design and restoration errors. The obtained results can improve the effectiveness of design solutions for the reconstruction of buildings damaged by emergency situations and contribute to developing advanced methodologies for assessing structural integrity and operational reliability in comparable scenarios.

Keywords: examination, defects, destruction, restoration, non-destructive methods.

Introduction. In many fields, such as biology, technology, or management, it is crucial to understand how an object ages over time. Forecasting the degradation process throughout the life cycle of an object allows for efficient planning of repair works. Maintaining residential buildings in good technical condition requires optimal planning of repair activities. For this, it is necessary to accurately determine the scope and program of reconstruction, which involves diagnosing the technical condition.

Accurately determining the state of the building, identifying the causes of damage, and forecasting adverse changes enable proper planning of repair works. Diagnosis is the foundation for organizing repair works of any technical object correctly. It encompasses the assessment of the technical condition, the causes of its deterioration, and the prediction of the degradation process.

Analysis of recent research and publications. The diagnosis of the technical condition of buildings can be carried out by two methods. The first method includes the assessment of adverse changes in objects based on on-site inspections, non-destructive testing, measurements, and calculations. The second method is a predictive approach, which relies on forecasting the building's degradation process in the program complex.

We know that under normal operation, using ISO 7162:1992 [1], we can evaluate the performance characteristics of a building. Additionally, by using the predicted service life distribution curve (PSLDC), it becomes possible to consider changes in these characteristics. The ISO standards [2, 3] provide general guidelines on the issues related to the prediction of building service life.

Several normative documents and standards are used in the US and Europe to guide building condition assessments so that structures are made safe, durable and functional.

European nations have their national standards for building condition assessments which are underpinned by EU-wide rules. To ensure that structures are safe and serviceable, the European Standard EN 1990 (Eurocode: Basis of Structural Design) gives general principles. Besides this, different countries have their own codes; for example, the UK uses RICS Building Surveys and Technical Due Diligence of Commercial Property standard.

In the US, ASTM International and the American Society of Civil Engineers (ASCE) are some of the organizations that came up with standards for building condition assessments. ASTM E2018-15, "Standard Guide for Property Condition Assessments: Baseline Property Condition Assessment Process" is commonly used. It explains how to do visual inspections and prepare reports on the state of the property.

Both areas also stress on the need for carrying out frequent evaluations so as to discover risks brought about by weaknesses in construction. Life cycle analysis together with detailed engineering appraisal form part of methods used to carry out comprehensive building inspection [4, 5]. Such appraisals touch on various parts like structural soundness, mechanical plant installations, electrical wiring systems as well as conformity with safety regulations.

In Ukraine, there were documents regulating the assessment of the technical condition of buildings, but in this case, the article focuses on new recommendations resulting from military actions. Additionally, several laws have been enacted [6-9] regarding the procedures for interacting with objects damaged due to military actions.

The study of the stress-strain state of structures damaged by missile attacks is highly relevant. After conducting field experiments, it is necessary to perform simulations in specialized software using the finite element method. Simulations of damaged reinforced concrete structures have been carried out, for example, beams [10-16], columns [17], floor slabs [18], including combined work of slabs and columns [19], masonry walls [20], and the combined work of walls and slabs [21]. Researchers are also interested in simulating entire buildings for reconstruction or other impacts, such as an industrial building [22], a church under seismic impact, and a multi-story residential building subjected to vibrations. These examples show significant interest in modeling both individual structures and entire buildings. However, in our opinion, simulations conducted due to military attacks are still insufficient.

Research Aim and Objectives. The study aimed to comprehensively analyze the technical condition of the damaged structure, evaluate the impact of the missile strike on bearing capacity and deformation behavior, and provide recommendations for restoration.

Research objectives:

1. Assess the general technical state of the building and the condition of its primary load-bearing and enclosing structures.
2. Identify defects and damages affecting the load-bearing capacity of the main structures and provide recommendations for their remediation.
3. Determine the main actual operational loads and impacts on the structures.
4. Investigate the causes of defects and damages that altered the primary design and calculated geometric parameters and physical characteristics of the building structures due to non-design impacts (fires, military actions, and terrorist acts), as well as during the building's operational period.
5. Verify the verticality of the building through topographic and geodetic surveys.
6. Examine the strength of the concrete and the actual reinforcement of columns and floor slabs by conducting instrumental tests using non-destructive testing methods.
7. Perform verification calculations of the building's load-bearing structures using the software complex PC "LIRA-SAPR".
8. Determine the feasibility and provide recommendations for the building's continued safe operation and major repairs.

Research materials and methodology. The object of study is a non-residential building of a shopping center with integrated and attached office premises (Fig. 1). Year of construction – 2007. Building classification – 1220 "Office Buildings", according to NK 018:2023 "Classifier of Buildings and Structures". Consequence (responsibility) class of the building – CC3, in accordance with Article 32 of the Law of Ukraine No. 1817-VIII dated January 17, 2017 "On Amendments to Certain Legislative Acts of Ukraine Concerning the Improvement of Urban Development Activities", DSTU 8855:2019 "Determination of the Consequence (Responsibility)".

Class of Buildings and Structures. "Fire resistance class of the building – II, according to DBN V.1.1.7-2016 "Fire Safety of Construction Sites".

The building is 11 stories high in axes "A-H, 1-9" and 3 stories high with a basement floor and a complex plan shape, standing independently. The entire building has a basement floor used as a parking area. There is a deformation joint in axes "B-G, 9-10" that separates the 11-story and 3-story sections into distinct parts. Another deformation joint divides the 3-story section into two separate parts. The total height of the building is 38.1 m. The conditional height of the building is 35.1 m. Floor heights: basement (parking) – 2.75 m; 1st floor – 3.75 m; 2nd to 11th floors – 3.0 m.

The building is equipped with two passenger elevators of the OTIS type with a load capacity of 400 kg and one freight elevator. The three-story part of the building contains two escalators.

Fig. 1. General appearance of the facade of the building

Structural solutions of the building. Structural scheme: frame, frameless with load-bearing reinforced concrete monolithic columns, slabs, diaphragms, and stiffness cores. Foundations: pile foundations with monolithic reinforced concrete grillage. Columns: monolithic, reinforced concrete with a constant square cross-section of 400×400 mm, 500×500 mm, and 500×700 mm. Stiffness diaphragms: monolithic reinforced concrete, 250 mm thick. Stiffness cores: monolithic reinforced concrete, 150 mm and 200 mm thick. Internal stairs: prefabricated reinforced concrete flights and landings made of large-sized elements of industrial production. Floor slabs: monolithic reinforced concrete, beamless, 200 mm thick. Roof structure: flat combined, with a brick parapet around the perimeter. Roof covering: flexible roll roofing, roofing felt.

The results of the research. The epicenter of the explosion was located at the level of the 8th-9th floors of the building in axes "A-B, 6-7", which led to various types of damage. The explosion significantly damaged and partially destroyed the load-bearing and enclosing structural elements of the building. There are emergency damages to the building's structures in the form of holes, shrapnel damage, deformations, ruptures, fire damage, geometry violations, and connection damages to structures and systems. The nature of the damage to the object under investigation is associated with the impact of explosive elements, the fall of rocket fragments, and the significant force of the explosive wave inertia.

During the investigation of the stress-strain state of the building, it was established:

1. Significant defects and damages in the load-bearing structures of columns, floor slabs, and enclosing walls of the building, disrupting and limiting normal operation.

2. Spatial rigidity and geometric invariability of the load-bearing and enclosing structures in axes "A-B, 5-9" are not ensured. Significant damages present may lead to further brittle failure of structures.

3. The external self-supporting walls in axes "A-B, 5-7" at the level of the 8th and 9th floors are destroyed (Fig. 2-5), the degree and nature of existing damages in the adjacent walls indicate the danger of emergency collapse.

4. Conservation of the load-bearing and enclosing structures at the time of inspection is absent. Temporary reinforcement structures of floor slabs above the 9th-10th floors are present.

5. The foundations, blind area, porches, stairs are in satisfactory "2" technical condition.

6. The floor structures, roof, and engineering networks are in unfit for normal operation "3" technical condition.

7. Damaged structures of columns, external walls, parapet walls, lintels, floor slabs, partitions, drainage, window and door blocks, internal and external finishes are in emergency technical condition "4".

8. According to the presented inspection results and considering the requirements of DSTU-N B V.1.2-18:2016 "Guidelines for the inspection of buildings and structures to determine and assess their technical condition", the overall technical condition of the object under investigation is assessed as – "4" emergency.

9. The general category of damage to the object under investigation is II. The overall degree of damage to the object under investigation is 57%, and the coefficient of functional suitability for operation is 43%.

10. Individual structures of the building, namely columns, floor slabs, walls, partitions, and filling of openings have a significant degree of damage from 55% to 80%.

11. According to the results of topographic and geodetic works on the verification of the verticality of the building's structures, it was established that the external walls partially have a tilt from 2 mm to 48 mm in the direction away from the building. Monolithic reinforced concrete columns have deviations from the vertical from 8 mm to 33 mm.

12. As a result of the verification calculations, it was established that the building has a practically uniform distributed settlement under all the foundations, which has formed over a long period of building operation.

13. According to the calculation results, it is recommended to frame the damaged columns with metal corners – 100×7 and metal plates – 6×50×100 mm and reinforce the floor slabs at the places of cracks, damages, and deformations.

14. A comprehensive analysis of the structural solutions of the object under investigation, the assessment of its stress-strain state, the analysis of identified defects and damages, the overall technical condition, categories, and degree of damage indicate the possibility and necessity of major repairs of the object, with partial dismantling, reinforcement, and restoration of load-bearing and enclosing structures.

Conventional designations of defects and damages:

1. Significant damage to columns. Perform dismantling and restoration.
2. Damage to columns. Perform reinforcement.
3. Significant damage to floor structures. Perform partial dismantling and restoration.
4. Technological damages (equipment passage holes, exposure, and damage of working reinforcement), cracks.
5. Perform reinforcement of columns, diaphragms, and floor slabs at locations of holes and reinforcement damage.
6. Significant damage to external walls. Perform dismantling and restoration.
7. Significant damage to partitions. Perform dismantling and restoration.
8. Significant damage to ceiling finishes. Perform dismantling and restoration.
9. Significant damage to openings infill (windows, doors). Perform dismantling and restoration.
10. Damage to brick parapet structures and ventilation channels. Perform partial dismantling and restoration.
11. Roof damage. Perform dismantling and restoration.
12. Roof damage. Perform restoration.
13. Damage to external finishes (brickwork, insulation of floor slabs). Perform dismantling and

restoration.

14. Damage to internal finishes. Perform dismantling and restoration.
15. Damage to floor structures. Perform dismantling and restoration.

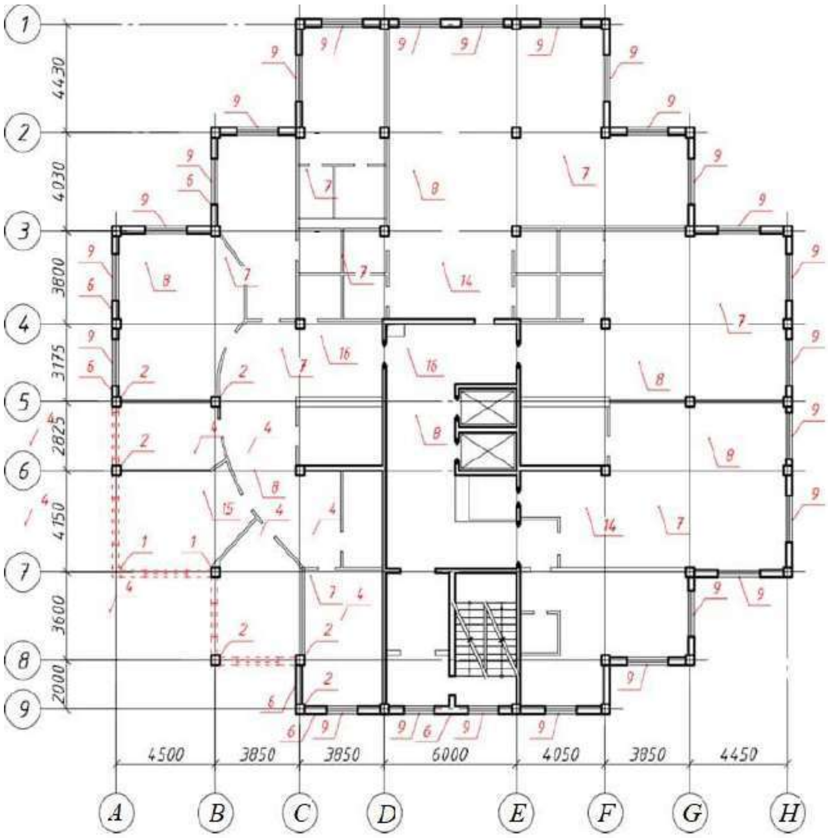

Fig. 2. Diagram of damage location. 8th floor

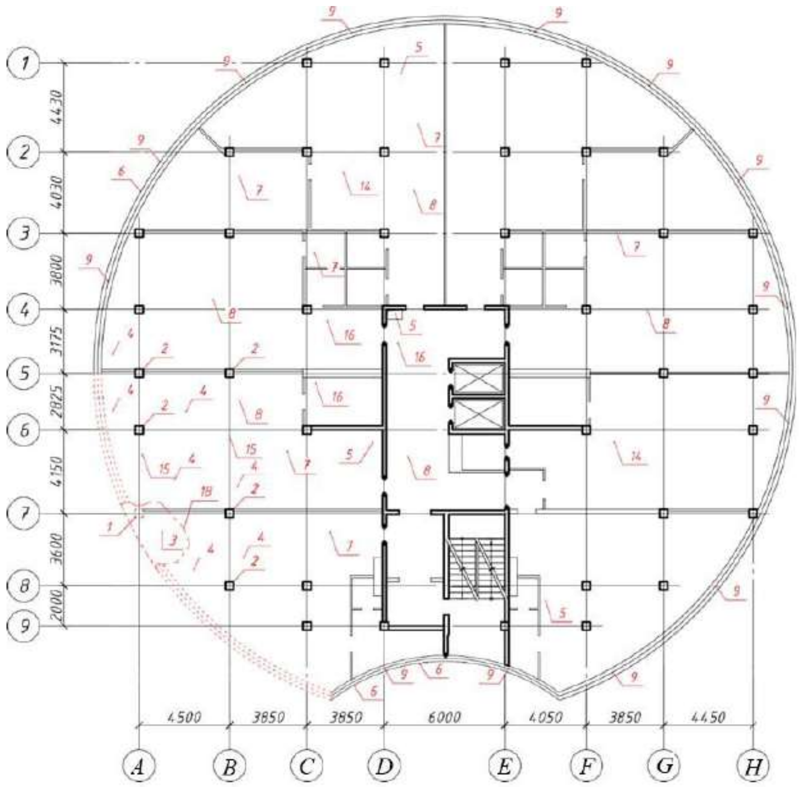

Fig. 3. Diagram of damage location. 9th floor

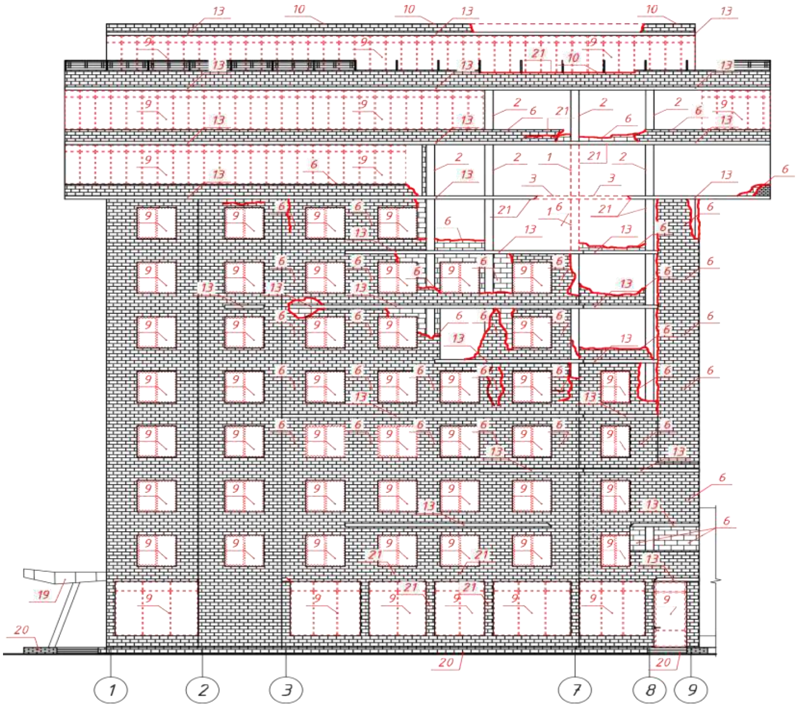

Fig. 4. Damage location scheme. Facade 1-9

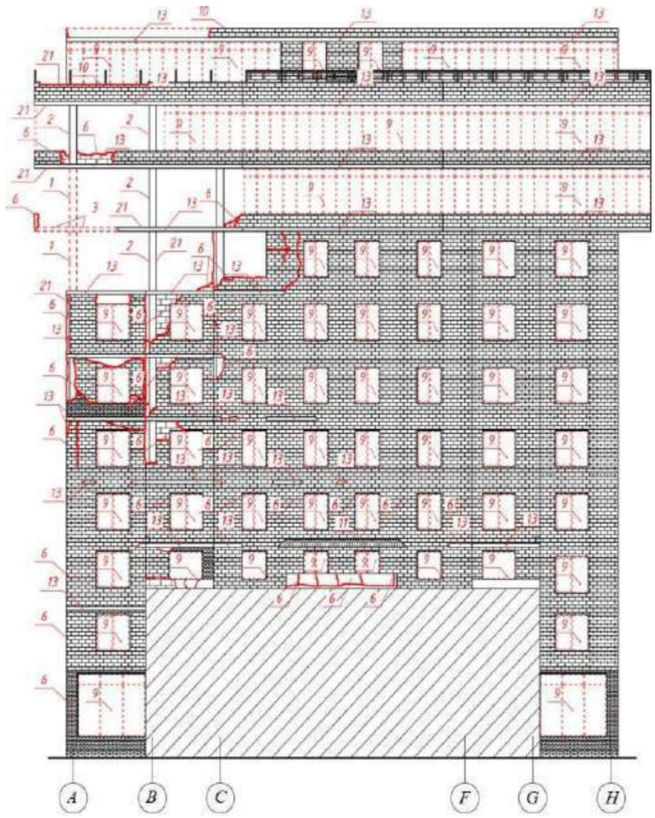

Fig. 5. Diagram of the location of the damage to the A-H facade

1. Significant damage to engineering systems and equipment. Perform dismantling and restoration.
2. Traces of atmospheric precipitation leakage.
3. Emergency area.
4. Corrosion of metal structures.
5. Damage to paving and porches.
6. Traces of fire.

Determination of the concrete strength of reinforced concrete columns and floor slabs was carried out as a result of instrumental studies of building structures using non-destructive testing methods. The study of the strength characteristics of the concrete of monolithic reinforced concrete structures of columns and slabs (f_c, kg/cm^2) was conducted based on the methodology presented in DSTU B V.2.7-220:2009 "Concretes. Determination of strength by mechanical non-destructive testing methods". The concrete strength was determined using a sclerometer MS-225 (Schmidt hammer) with factory number No. 19856422, manufactured by Firma Morek MULTISERW. The sclerometer is based on the rebound method. The instrument underwent state metrological certification No. 430/MX-VDM on 16.05.2023. Testing was carried out at a positive concrete temperature. The characteristics of the concrete of monolithic reinforced concrete structures of columns and slabs were determined in places where the surface areas of the structure had been previously cleaned. Testing was conducted on a structure area ranging from 100 cm^2 to 600 cm^2.

The following minimum distances were adopted during testing:

– between impact points not less than 30 mm;

– from the edge of the structure to the test point not less than 50 mm;

– from the test points to the reinforcement not less than 50 mm.

Concrete testing was carried out in the following sequence:

– determining the location of the reinforcement in the test area according to DSTU B V.2.6-4;

– the sclerometer (Schmidt hammer) was positioned so that the force was applied perpendicular to the tested surface in accordance with the operational documents of the device;

– the position of the sclerometer during the testing of the structure relative to the horizontal was taken to be the same as during the testing of samples to establish the relationship, with corrections made to the readings if the position was different, according to the operational documents of the sclerometer;

– recording the value of the indirect characteristic in accordance with the operational documents of the device;

– calculating the average values of the indirect characteristics in the structure area.

The value of the concrete strength of the columns at each point was obtained as an average of the results of 10 measurements. The obtained strength values are presented in Table 1.

Table 1 – Determination of concrete strength of reinforced concrete columns

№ (№ points)	The edge of the structure	Value of concrete strength according to measurements					The average value of strength f_{cm} (kg/cm^2)	The average strength of concrete construction f_{cm}, MPa	Average square deviation s_m, MPa	Coefficient of variation, V_c, %
		1	2	3	4	5				
		f_i (kg/cm^2)								
Date of concrete tests – 23.09.2023										
1	+90^0	418.1	428.3	448.7	397.7	305.9	399.7	39.2	55.6	14
2	+90^0	387.5	428.3	428.3	428.3	387.5	412	40.4	22.3	5
3	+90^0	448.7	397.7	397.7	428.3	397.7	414	40.6	23.5	6
4	+90^0	428.3	428.3	448.7	489.5	438.5	446.7	43.8	25.4	6
5	+90^0	387.5	418.1	428.3	448.7	397.7	416.1	40,8	24.4	6
6	+90^0	448.7	428.3	418.1	397.7	499.7	438.5	43	38.8	9
7	+90^0	387.5	407.9	407.9	428.3	397.7	405.9	39,8	15.1	4
8	+90^0	428.3	407.9	387.5	418.1	407.9	409.9	40.2	15.1	4
9	+90^0	418.1	387.5	428.3	418.1	438.5	418.1	41	19.1	5
10	+90^0	407.9	407.9	438.5	397.7	387.5	407.9	40	19.1	5

The actual strength of concrete columns, according to the conducted instrumental tests, ranges from 39.2 MPa to 43.8 MPa. According to the results of processing the obtained data, the average value of the group coefficient of variation of concrete strength V_{cm} is 6.4%, and the average value of concrete strength is f_n – 40.9 MPa.

The strength of concrete f_c, MPa when normalizing strength by classes is:

$$f_c = 0.95 \times f_n \times \frac{k_t}{100} = 0.95 \times 40.9 \times \frac{84}{100} = 32.64\ MPa$$

where is f_n – average concrete strength, MPa;

k_t = 84 – coefficient of required strength in percentage for all types of concrete, which is taken according to Table B.1 (DSTU B V.2.7-224:2009) depending on the average value of the group coefficient of variation of concrete strength V_{cm}.

According to the conducted instrumental tests and the processing of the obtained data, it has been established that the strength of concrete columns is f_c = 32.64 MPa, which corresponds to the concrete class C20/25 (B25).

The strength values of concrete floor slabs at each point were obtained as the average of the results of 10 measurements. The obtained strength values are presented in Table 2.

The strength values of reinforced concrete monolithic floor slabs at each point were obtained as the average of the results of 10 measurements. The obtained strength values are presented in Table 2.

Table 2 – Determination of concrete strength of reinforced concrete monolithic floor slabs

№ (№ points)	The edge of the structure	Value of concrete strength according to measurements					The average value of strength f_{cm} (kg/cm^2)	The average strength of concrete construction, f_{cm}, MPa	Average square deviation s_m, MPa	Coefficient of variation V_c, %
		1	2	3	4	5				
		f_i (kg/cm^2)								
Date of concrete tests – 23.09.2023										
1	+90^0	397.7	428.3	443.6	397.7	393.6	412.2	40.4	22.4	5
2	+90^0	407.9	428.3	434.4	423.2	393.6	417.5	40.9	16.6	4
3	+90^0	428.3	424.2	443.6	431.3	397.7	425	41.7	16.9	4
4	+90^0	423.2	372.2	395.6	433.4	413	407.5	40	24.2	6
5	+90^0	390.6	387.5	413	428.3	397.7	403.4	39.6	17	4
6	+90^0	443.6	427.3	438.5	397.7	499.7	441.4	43.3	37.2	8
7	+90^0	403.8	380.4	376.3	448.7	397.7	401.4	39.4	28.8	7
8	+90^0	428.3	387.5	431.3	428.3	410.9	417.3	40.9	18.5	4
9	+90^0	424.2	433.4	428.3	413	438.5	427.5	41.9	9.7	2
10	+90^0	397.7	428.3	438.5	382.4	387.5	406.9	39.9	25.1	6

The actual strength of the concrete floor slabs, according to the conducted instrumental tests, is in the range from 39.4 MPa to 43.3 MPa. According to the results of processing the obtained data, the average value of the group coefficient of variation of concrete strength V_{cm} is 5.0%, and the average strength value of the concrete is f_n – 40.8 MPa.

The concrete strength f_c, MPa for strength classification by classes is:

$$f_c = 0.95 \times f_n \times \frac{k_t}{100} = 0.95 \times 40.8 \times \frac{83}{100} = 32.17\ MPa$$

where: f_n is the average strength value of concrete, MPa;

k_t = 83 – the coefficient of required strength in percentage for all types of concrete, accepted according to Table B.1 (DSTU B V.2.7-224:2009) depending on the average value of the group coefficient of variation of concrete strength V_{cm}.

According to the conducted instrumental tests and the processing of the obtained data, it has been established that the strength of the concrete floor slabs is f_c = 32.17 MPa, which corresponds to the class of concrete C20/25 (B25).

The determination of the diameter of reinforcement, concrete cover thickness, and spacing of working bars of the reinforcement cages of reinforced concrete columns and floor slabs was carried out using non-destructive methods. The research was conducted in accordance with: DSTU B V.2.6-4-95 (GOST 22904-93) "Buildings and structures. Reinforced concrete structures. Magnetic method for determining the thickness of the concrete cover and the location of the reinforcement".

During the research, a non-destructive testing device "Concrete Cover Thickness Measuring Instrument NOVOTEST Armature Scope", factory number №0162120720, calibration certificate №10-0/11484/1 dated 05.10.2022 was used.

The main results of the instrumental testing of the reinforcement of reinforced concrete columns and floor slabs are presented in Table 3.

Table 3 – Main results of instrumental testing of reinforcement

№	The name of the structure	Determined diameter of the rod of the working armature, mm	Design protective layer of concrete/ regulatory layer, mm	The actual protective layer of concrete, mm	Deviation of the actual value from the design/ normative, mm
1	Columns	Longitudinal working fittings 4Ø16 mm, at the corners of the columns. Transverse reinforcement (clamps) Ø8 mm with a step from 200 mm to 250 mm	-/30	from 20 till 40	-/till 10
2	Floor slabs	Upper and lower reinforcing mesh Ø12 mm, with a step of 200 mm. There are sections of floor slabs with additional upper (over the supports Ø14mm, Ø16mm) and lower reinforcement (in spans Ø14mm)	-/20	from 10 till 40	-/ from 10 till 20

According to the research results and determination of the actual strength of concrete and reinforcement of columns, floor slabs, calculations of the main load-bearing structures of the building were carried out to establish their residual load-bearing capacity and suitability for normal operation – taking into account the defects and damages, wear and tear identified during the inspection, the requirements of the regulatory documents in force at the time of the inspection, as well as the loads.

The calculation of the load-bearing structures was performed using the calculation complex PC "LIRA-SAPR". Verification calculations of the structures were carried out for two groups of limit states: I – for load-bearing capacity; II – for suitability for normal operation. Calculation for the first group was carried out to prevent failure (strength calculation), loss of stability (calculation for longitudinal bending, overturning). Calculation for the second group of limit states was carried out to prevent excessive deformations (deflections, angular rotations), the appearance of cracks, limitation of crack width in concrete, etc. Verification calculations were performed in a linear setting. The following conditions were taken into account in the calculations of the structures:

- actual stress-strain state of the structures;
- the need and possibility of partial dismantling, strengthening of damaged load-bearing structures of columns, floor slabs.
- establishment of the possibility of safe operation of the building.

Quantitative characteristics of the calculation scheme.

The calculation scheme (model of existing structures) is characterized by the following parameters:

– number of nodes – 49647;
– number of finite elements – 53080;
– number of unknowns – 234736;
– number of loads – 8;
– number of load combinations – 21;
– number of modes of eigen oscillations (KF) – 8.
– step of triangulation of finite elements is – 0.1 m.

The general view of the calculation scheme is presented in Fig. 6 and Fig. 7.

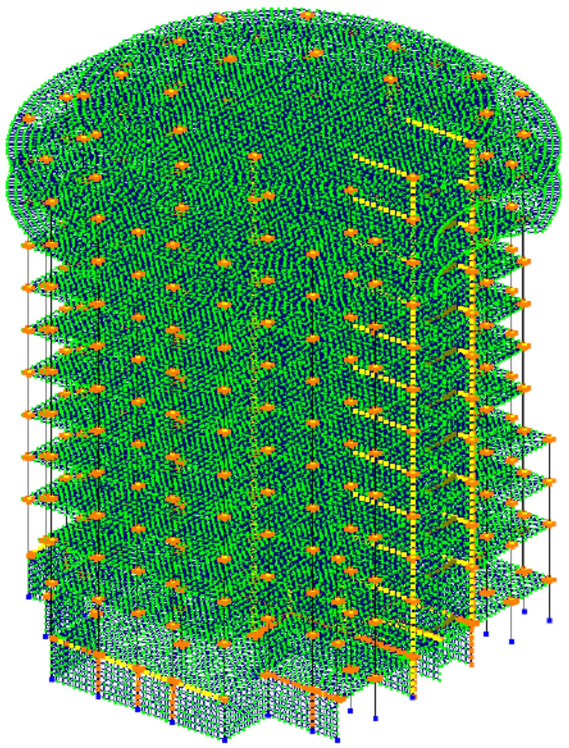

Fig. 6. General view of the settlement scheme

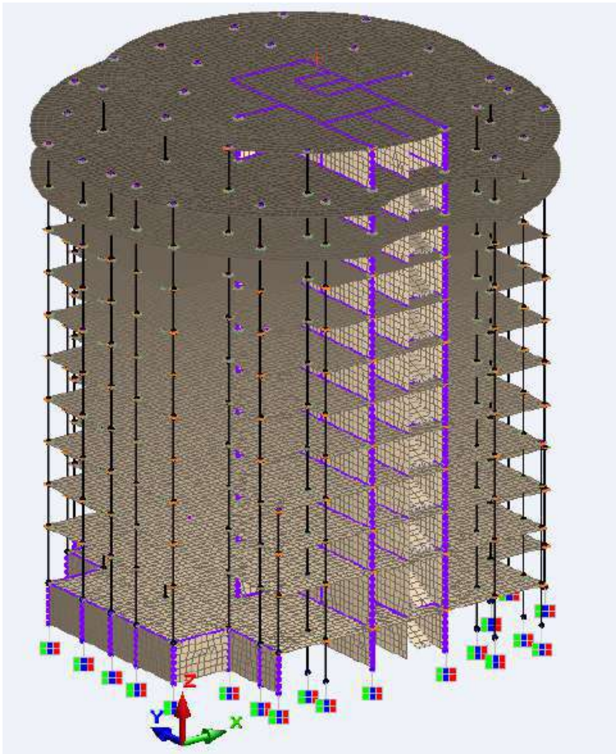

Fig. 7. General view of the settlement scheme

The main results of the calculation of the specified structural elements are presented for the most unfavorable load combinations (ULC) and maximum internal forces (MIF) for three variants of the building's calculation scheme, namely:

Variant №1. Calculation scheme of the building's load-bearing structures without damage.

Variant №2. Calculation scheme of the building's load-bearing structures with identified and modeled main damages of load-bearing structures.

Variant №3. Calculation scheme of the building's load-bearing structures with reinforcement of the main load-bearing structures.

Figures 8-13 show the main results of the verification calculations of a building fragment at the location of the largest deformations and damages.

According to the research results, to ensure the reliable and safe operation of the surveyed object, it is necessary to provide for and implement the following measures through design decisions:

1. Dismantling and restoration of roof structures.
2. Dismantling of damaged and destroyed roof ventilation ducts.
3. Demolition and restoration of columns in axes "A, 7" at levels 8 and 9, in axes "B, 7".
4. Demolition and restoration of damaged structures of external walls and lintels.
5. Complete dismantling of damaged partition structures.
6. Demolition and restoration of damaged finishes of internal staircases in axes "C-D, 7-9".
7. Demolition and restoration of damaged infill structures (windows and doors).

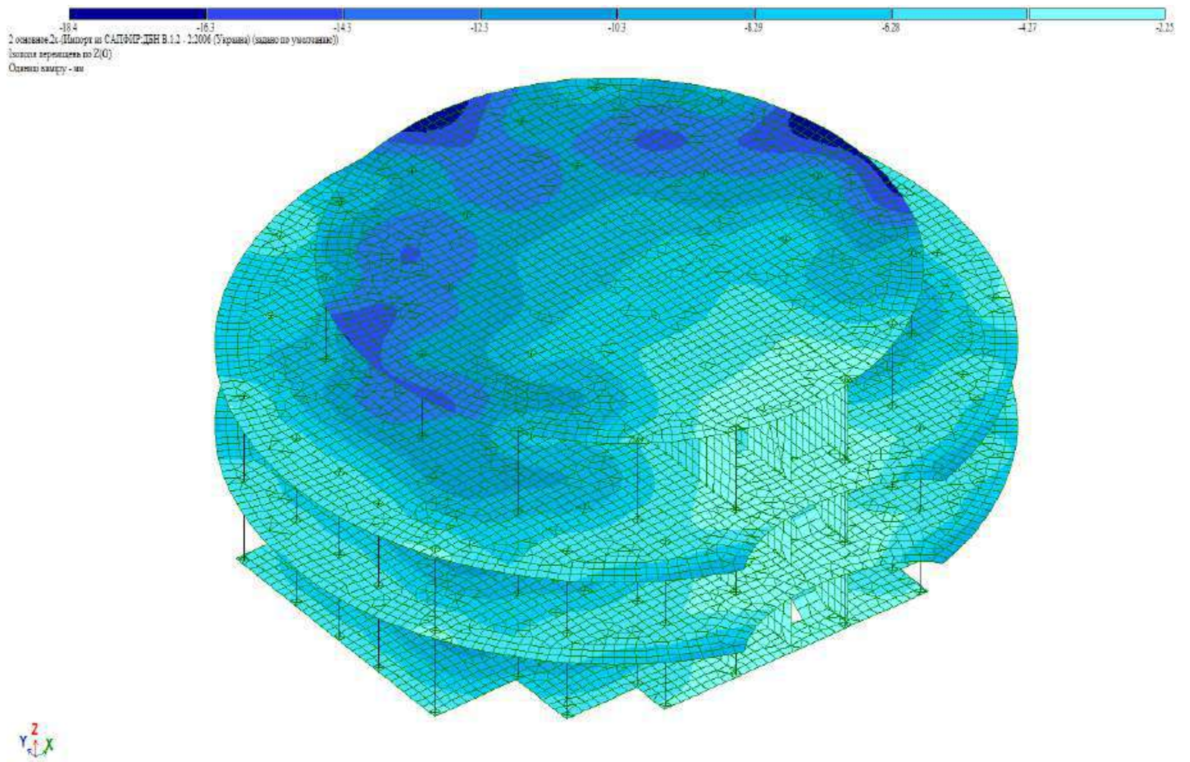

Fig. 8. Mosaic of movements (deflections) of nodes along the Z axis. Option №1.
A fragment of the design scheme of the load-bearing structures of the building without damage.

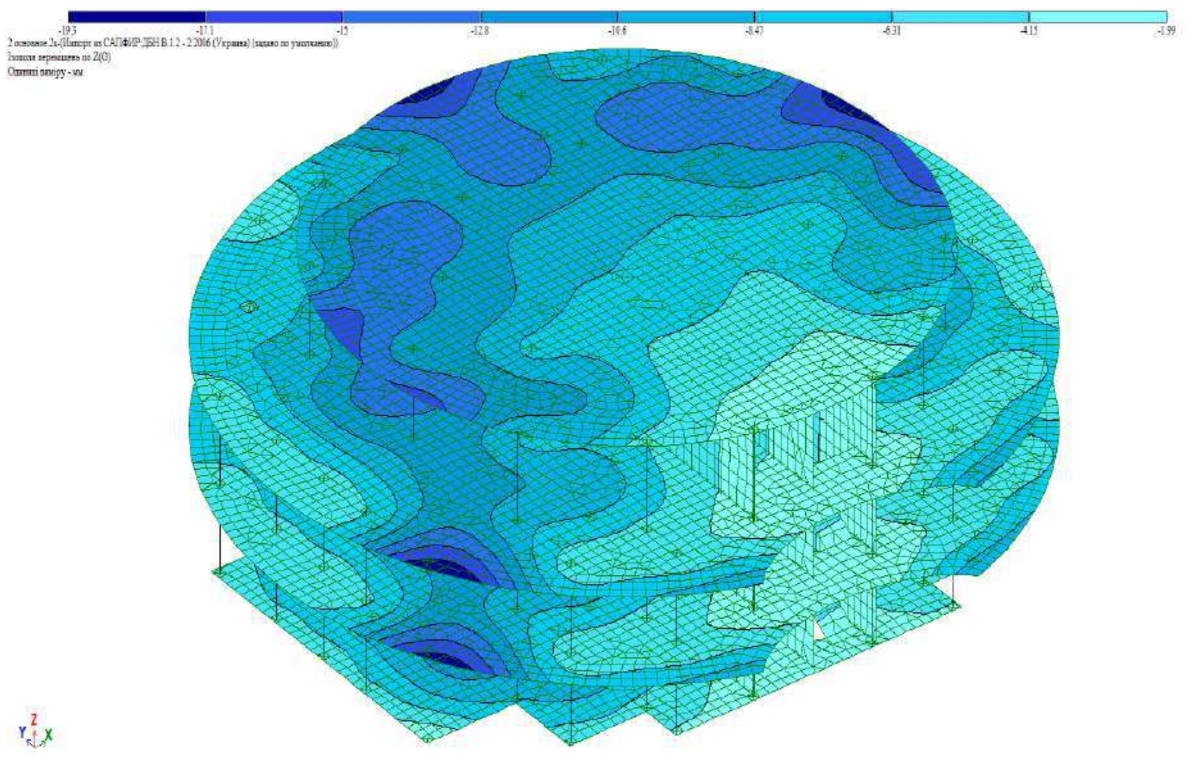

Fig. 9. Mosaic of movements (deflections) of nodes along the Z axis. Option №2.
A fragment of the calculation diagram of the building's load-bearing structures with identified and simulated main damage of the load-bearing structures

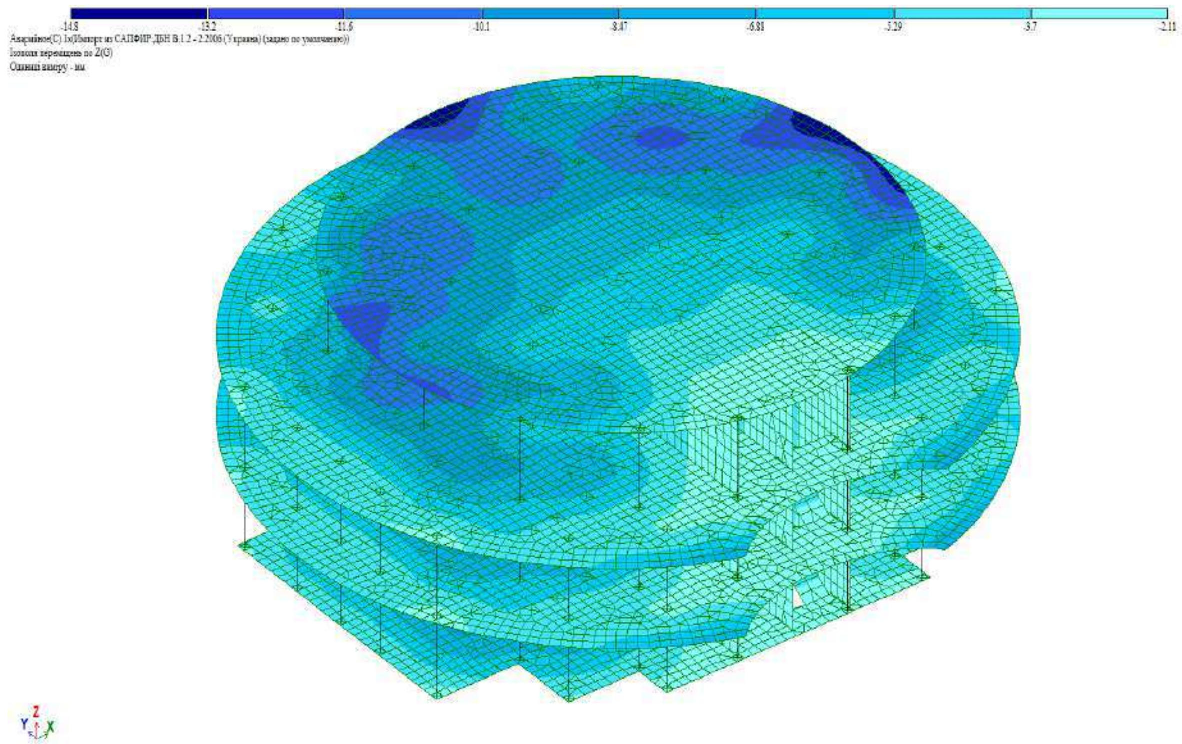

Fig. 10. Mosaic of movements (deflections) of nodes along the Z axis. Option №3.
A fragment of the design scheme of the load-bearing structures of the building with reinforcement of the main load-bearing structures

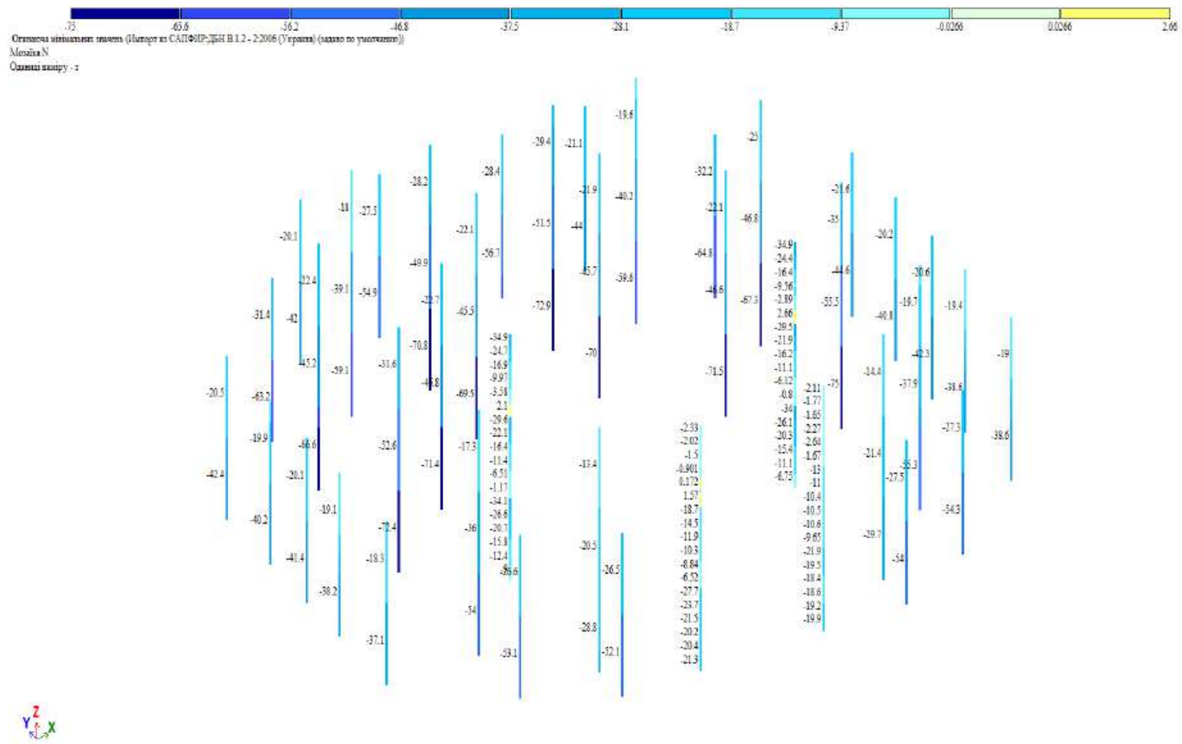

Fig. 11. Mosaic of internal longitudinal forces N. Option №1.
A fragment of the design scheme of the load-bearing structures of the building without damage

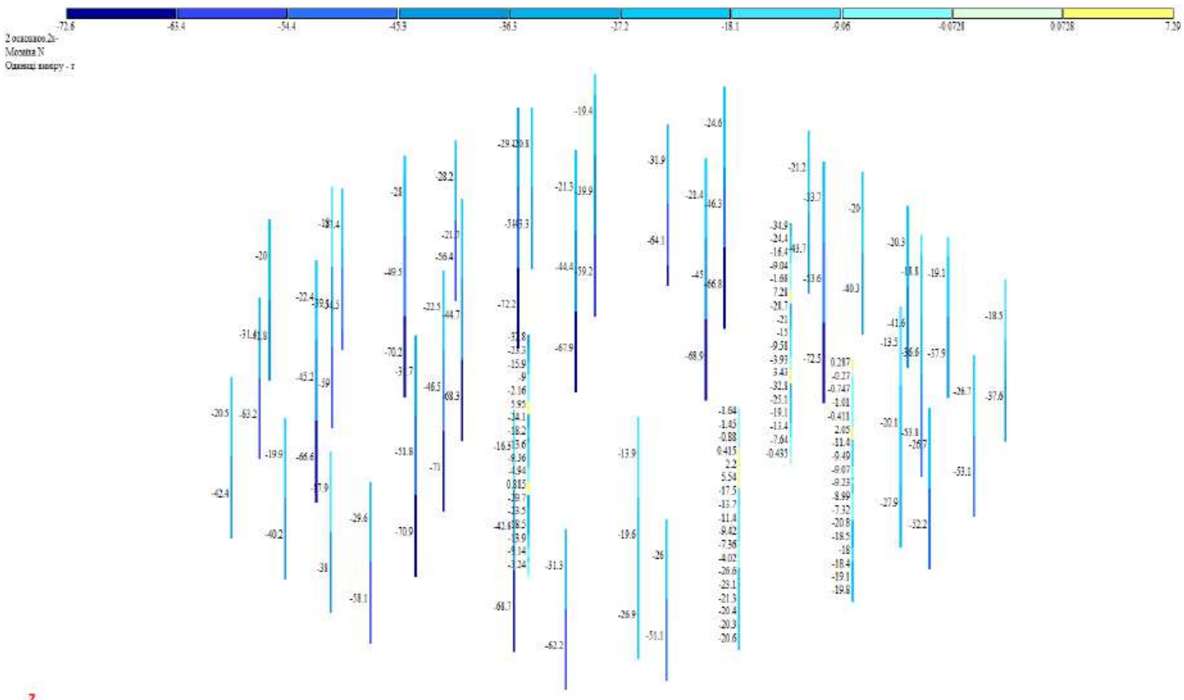

Fig. 12. Mosaic of internal longitudinal forces N. Option №2.
A fragment of the calculation diagram of the building's load-bearing structures with identified and simulated main damage of the load-bearing structures.

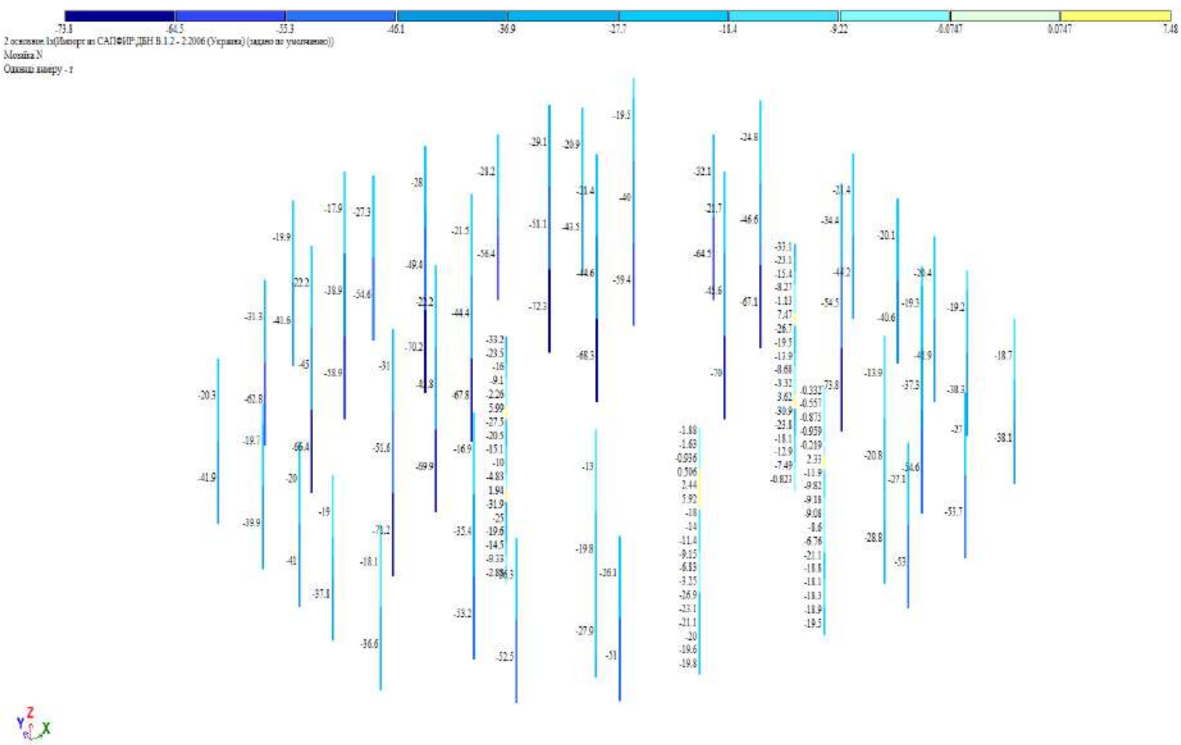

Fig. 13. Mosaic of internal longitudinal forces N. Option №3.
A fragment of the design scheme of the load-bearing structures of the building with reinforcement of the main load-bearing structures

8. Demolition and replacement of damaged floor structures.

9. Demolition and restoration of damaged interior finishes.

10. Demolition and restoration of damaged engineering networks and systems of water supply, sewage, water disposal, heating, ventilation, power supply, fire safety systems, video surveillance,

and low-current systems. Checking the tightness and integrity of systems.

11. Partial dismantling of column and slab structures must be accompanied by simultaneous restoration and reinforcement of adjacent load-bearing structures to redistribute loads and prevent progressive collapse.

12. Partial dismantling of external walls and infill must be accompanied by simultaneous restoration or conservation of structures to prevent the influence of atmospheric precipitation on the existing building structures.

13. Dismantling of load-bearing structures of columns, slabs, and walls without subsequent reinforcement and restoration of structures according to design decisions is prohibited.

14. It is recommended to consider the conservation of damaged and destroyed load-bearing and enclosing structures in accordance with the "Regulation on the Procedure for Conservation and Decommissioning of Construction Objects No. 246 (z1278-16)" dated 02.09.2016.

15. Strengthening of columns at levels 7, 8, 9, and 10 must be carried out.

16. Reinforcement of slab structures above the 7th, 8th, and 9th floors must be carried out.

17. Strengthening of floor sections with cracks wider than 0.5 mm.

18. Installation of monitoring for cracks in slab structures above the 4th, 5th, and 6th floors. In case of cracks wider than 0.3-0.4mm, reinforcement must be carried out.

19. Fastening of AAC external walls to load-bearing structures of the building and fastening of facing ceramic bricks.

20. When restoring wall and partition structures, use lightweight materials for load-bearing and enclosing structures.

21. Exclude additional non-standard loads on existing structures.

22. Do not increase loads on existing load-bearing structures of the building without their prior reinforcement.

23. It is recommended to install monthly geodetic monitoring for the condition of load-bearing brick walls and the dynamics of deformation joint opening according to DBN V.1.3-2-2010 "Geodetic Works in Construction".

24. It is recommended to establish long-term monitoring for the dynamics of existing vertical, inclined, and horizontal cracks in load-bearing structures of columns and slabs.

25. In damaged structures with deformations, installation of mechanical or electronic "beacons" on cracks with mandatory regular monitoring of their condition is necessary. The recommended measurement accuracy is up to 0.1 mm.

26. Until the completion of measures to restore the condition of structures to the level preceding the damage, the operation of the object is not recommended due to the possible collapse of emergency structures. It is recommended to carry out preliminary work to prevent dangerous structural collapse. Install temporary fastening systems to prevent spontaneous collapse, unload load-bearing structures, and reduce existing loads. Perform a complex of anti-accident works.

Conclusions. Research and recording of the actual stress-strain state of damaged structures are the first and crucial stage in determining the building restoration algorithm. For a complete and high-quality study, it is necessary to perform a complex of works to identify and fix damages, determine the strength of materials, reinforcement parameters, and conduct spatial verification calculations of the building as a whole. The absence of a complex of works or improper investigation of damaged buildings usually leads to poor execution of design and estimate documentation for the restoration of structures or even to building collapse. A promising direction in researching the actual state of damaged buildings is 3-D scanning, which allows for building an actual spatial model of the building and reducing the risks of errors in research, design, and building restoration. Considering the analysis conducted, further reconstruction plans include the use of fiberglass mesh.

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ДОСЛІДЖЕННЯ НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ БУДІВЕЛЬНИХ КОНСТРУКЦІЙ, ПОШКОДЖЕНИХ НАДЗВИЧАЙНИМИ СИТУАЦІЯМИ

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Анотація. Стаття присвячена дослідженню напружено-деформованого стану будівельних конструкцій, пошкоджених у результаті надзвичайної ситуації, що сталася через ракетний удар по будівлі в м. Одесі. Мета роботи полягала у всебічному аналізі технічного стану пошкодженої споруди, оцінці впливу удару на несучу здатність і деформаційні характеристики конструкцій, а також розробці рекомендацій з їх відновлення. Автори провели детальне інструментальне обстеження з використанням неруйнівних методів контролю, топографо-геодезичні виміри для визначення вертикальності конструкцій, а також виконали верифікаційні розрахунки з використанням програмного комплексу «ЛІРА-САПР». Було встановлено значні пошкодження колон, плит перекриття та зовнішніх стін, що несуть загрозу прогресуючого руйнування будівлі. Конструкції оцінено як аварійні, зі ступенем пошкоджень до 80%. Запропоновані заходи включають демонтаж та відновлення пошкоджених елементів, посилення несучих конструкцій металевими елементами, встановлення тимчасових підсилюючих конструкцій та постійний моніторинг технічного стану споруди. Окрему увагу приділено визначенню фактичної міцності бетону, що відповідає класу С20/25 (В25). Також було досліджено параметри армування, такі як діаметр і захисний шар робочої арматури колон та плит перекриття. Встановлено, що реальні значення захисного шару бетону мали відхилення від нормативних значень, що потребує врахування при плануванні заходів з відновлення та посилення конструкцій. Дослідження підтвердило необхідність комплексного підходу до аналізу пошкоджених будівель, що включає в себе сучасні методи, такі як 3D-сканування, для створення точних просторових моделей та мінімізації помилок у проєктуванні і відновленні. Отримані результати дозволяють підвищити ефективність проєктних рішень для реконструкції будівель, постраждалих внаслідок надзвичайних ситуацій, а також можуть бути використані для розробки більш ефективних підходів до оцінки стану та експлуатаційної надійності будівельних конструкцій в аналогічних випадках.

Ключові слова: експертиза, дефекти, руйнування, реставрація, неруйнівні методи.

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