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RESISTANCE OF STRUCTURAL ELEMENTS OF CIVIL PROTECTION BUILDINGS AND STRUCTURES TO THE IMPACT OF AN EXPLOSION

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The article presents the results of a comparison of the stability of the structural elements of the underground parking lot of an erected multistory civil building. The results of calculation of structural load-bearing elements (monolithic floor slab and pylons) to the impact of an explosion in the Lira CAD software with consideration of the requirements of the state Building standards of Ukraine are presented. It is shown that an increase in the instantaneous load of explosive pressure from 20 kPa (DBN B.2.2-5-97) to 100 kPa (DBN B.2.2-5:2023) will increase the maximum displacement of a monolithic floor slab by 11.9 times and the maximum reinforcement section by 5.8 times. This creates a real opportunity to develop new approaches to the planning of civil protection buildings and structures to ensure their operational reliability and resistance to the effects of an explosion.

Key words: structural reinforced concrete elements; floor slab; pylons; civil protection; building; blast wave.

Introduction

At present, in the context of russia's large-scale armed aggression against Ukraine, industrial and civilian buildings and structures are being shelled daily with various types of weapons (Molodid, 2023; Babich, 2019). According to engineers' surveys, the main causes of destruction of structural elements of buildings and structures are blast waves, fires, shrapnel and bullet damage (Luccioni, 2004). As a result of this impact, much of the infrastructure is in need of urgent repair or complete rebuilding, which poses a challenge to the government and the international community. It is necessary to take into account the need to apply the latest construction technologies that can ensure increased resilience of buildings to similar threats in the future. This requires an in-depth analysis of existing safety norms and standards, as well as the development of new approaches to the planning of buildings and structures (Poriadok provedennia obstezhennia, 2022; Ivanchenko, 2023).

Ukraine has adopted a draft law to ensure civil protection requirements in the planning and development of territories. This provides for the mandatory placement of civil protection structures (shelters, bomb shelters) during the construction of facilities with consequence class CC2 and CC3 (Zatverdzhenyi postanovoiu KM Ukraine, 2022). The Civil Protection Code of Ukraine establishes requirements for the creation, maintenance, operation and accounting of the fund of protective structures (civil protection structures – shelters and radiation shelters, dual-purpose structures and simple shelters). In order to ensure protective properties against conventional munitions, it is important that the load-bearing and external enclosing structures (walls, floors, coatings) of buildings (structures, premises) are made of reinforced concrete or other materials if they are buried in the ground (Kisil, 2016).

There are four degrees of damage to buildings and structures, which include a description of the limit damage to structural elements, envelopes, and non-structural elements. Numerous destructions caused by the detonation of these types of weapons indicate that reinforced concrete structures are more resistant than brick and metal structures (Daniel, 2013; Qin, 2022).

Building frames with monolithic reinforced concrete ribbed floors and systems of main and secondary beams or cross-arranged beams rigidly fixed to vertical load-bearing structures such as columns, pylons, walls are best able to withstand these dynamic loads (Ngo, 2007). Reinforced concrete redistributes forces between adjacent structures, has high strength and ductility, is fire-resistant, prevents rapid plastic deformation of reinforcement due to the protective layer of reinforcement, and prevents avalanche destruction of the building due to the inclusion of all adjacent structures in work (Hetun, 2023).

The study of the propagation of blast waves caused by missile attacks, attack drones, and artillery shells is of great importance, especially given the need to develop the latest building materials and structural solutions that can provide increased resistance to such impacts. The use of steel fiber-reinforced concrete will help resist explosive loads while ensuring the stability of the reinforced concrete structure (Dvorkin, 2017; Fediuk, 2021). The use of high-performance superplasticizers and various types of fiber will increase the impact resistance of structures (Sanytsky, 2023; Korolko, 2023).

This requires a comprehensive approach to modelling explosive processes and analyzing the impact of blast waves on structural elements of buildings and structures. In addition, the development of innovative solutions to minimize the effects of explosions requires a deep understanding of the mechanisms of interaction between blast waves and various types of structures, which, in turn, contributes to the development of new scientific approaches and techniques in the field of structural engineering.

The purpose of the work is to study and compare the resistance of structural elements of a building and dual-purpose civil protection structure to the impact of an explosive load, taking into account the requirements of the state Building standards of Ukraine.

Materials and methods

In order to compare the stability of the structural elements of the underground car park of a multistorey civil building, the bearing reinforced concrete elements were calculated in the Lira CAD software.

Structural elements were calculated in accordance with DBN B.2.6-98:2009 and DBN B.1.1-12:2014. The building is classified as Class II in terms of durability (service life is 50 to 100 years) and Class III in terms of fire resistance in accordance with DBN B.1.1-7:2016.

The initial parameters for the pylons and walls are as follows: the cross-section and height of the pylons are 0.4×0.5 m, 0.4×0.8 m and 4.4 m, respectively, and the spatial dimensions for the floor slab are: 33.8×66.2 m, 300 mm thick. The pylons are represented in Lira CAD by bars, the walls and the floor slab by plates, the cross-section and characteristics of which are specified in accordance with the architectural and planning task. For each of the parts of the monolithic slab, uniformly distributed loads on the plates are specified: constant (from the structure's own weight, 8.1 kN/m^2), long-term (3.3 kN/m^2), short-term (4.7 kN/m^2) and seismic (in accordance with the seismicity of the area of VI points).

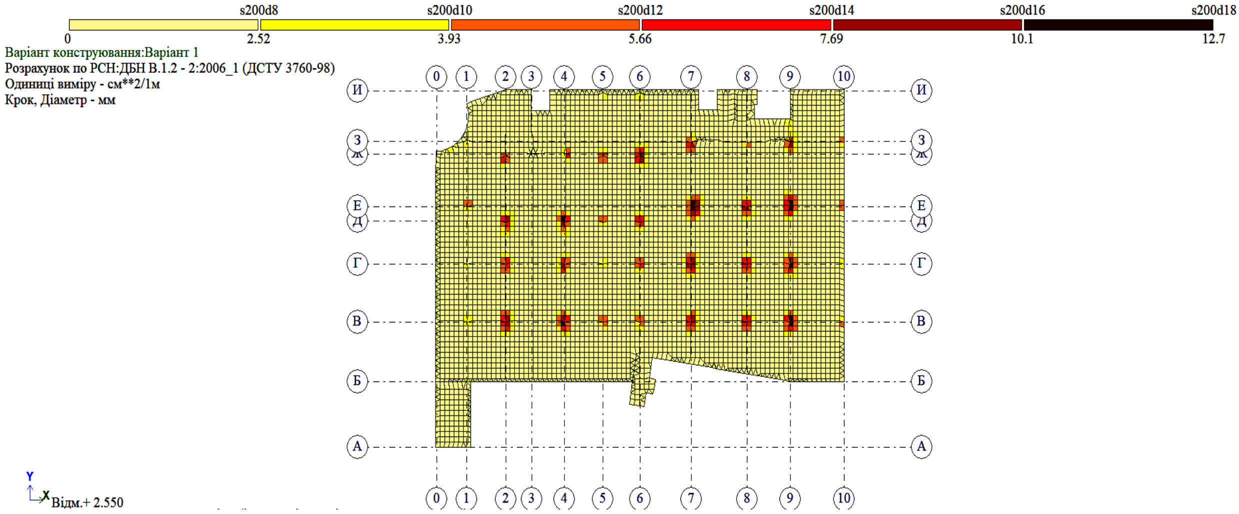
To compare the force distribution coefficients, a FDT table was formed in which the working standard forces that simultaneously exert pressure on the floor slab are specified. To ensure correct connections of the structural components, the ties are set for all lower elevations of the wall and pylon components, the combination of ties includes all available directions − in the X, Y and Z axes.

The concrete class of the projected building is C20/25, the axial compression of concrete is f_{cd}=14.5 MPa, the axial tension is f_{ctd}=1.05 MPa, the coefficient of ensuring proper concrete working conditions is γ_b2=0.9, the longitudinal and transverse reinforcement is of A400C class, the design resistance of which is R_s=365 MPa in accordance with DBN B.2.6-98:2009.

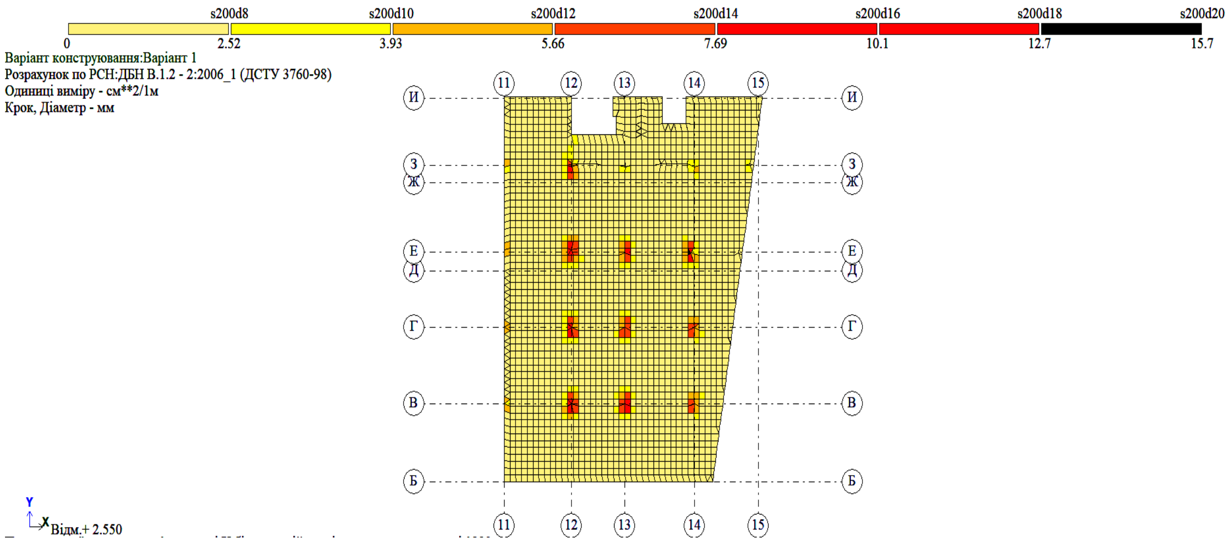
Results and discussion

In accordance with the architectural and planning task, the design spatial scheme of the underground car park of a multistorey building was formed in the AutoCAD software and the spatial scheme was transferred to the Lira CAD software. The monolithic floor slab of the underground car park of a multistorey building was divided into two parts at the expansion joint to compensate for thermal deformation and prevent cracks in the structure.

The design was carried out, and the diagrams of the lower and upper reinforcement of the monolithic floor slab in the X and Y axes were obtained to determine the cross-section of the of the floor slab (Fig. 1, *a, b*). Fig. 1 shows that the maximum reinforcement cross-section is present in the 2nd part of the slab (Fig. 1, *b*) and is 15.7 cm². Based on these results, the background and additional reinforcement were selected, and the layout of the lower and upper reinforcement of the floor slab was designed.



a

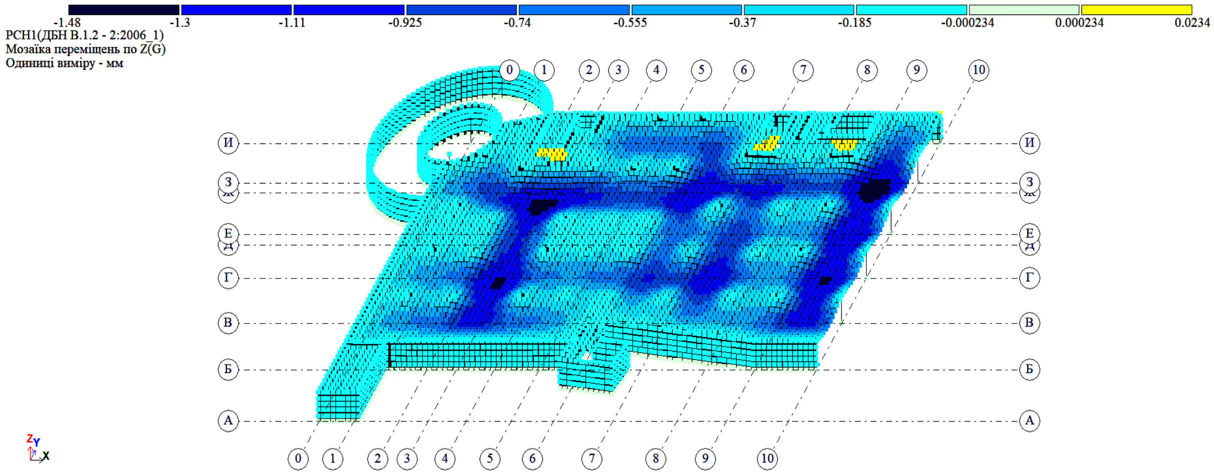


b

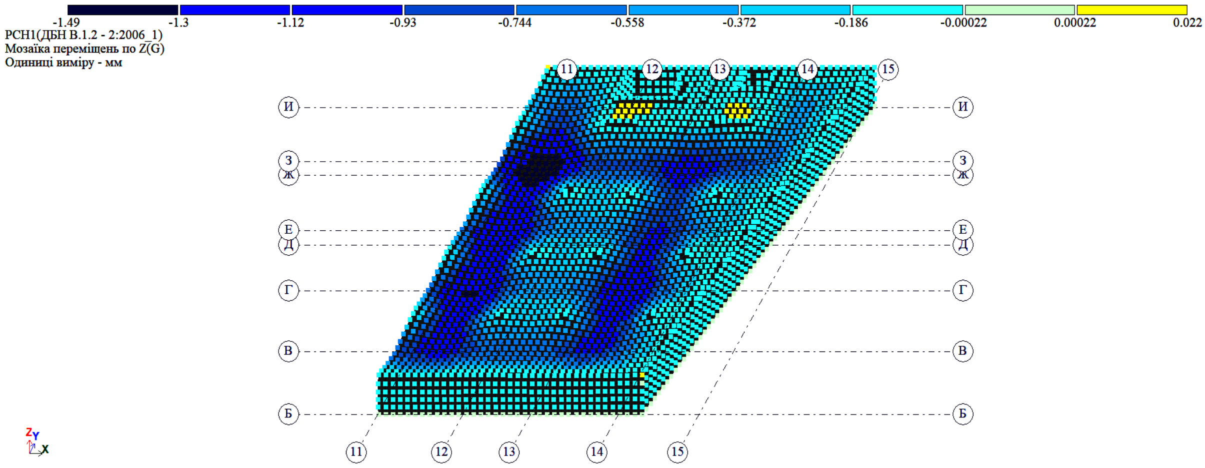
Fig. 1. Upper (Ax) plate reinforcement (taking into account the explosive load in accordance with DBN B.2.2-5-97): a – first part; b – second part

The spatial scheme of the building's parking lot was packaged and the said scheme was calculated. Based on the results obtained, the vertical displacements of the monolithic slab (Fig. 2, *a*, *b*), longitudinal force diagrams, and stress mosaics *Mx* and *My* were studied. According to DSTU B B.1.2-3:2006, for a monolithic slab with a span length of up to 6 m, the vertical limit deflection is l/200, i. e., a slab with a span length of 6 m can have a limit deflection of 30 mm. As can be seen from Fig. 2, *b*, the largest displacements are present in the 2nd part of the slab, in the transverse axes 11–12, the span is 5800 mm, respectively, the maximum permissible deflection is 29 mm, and a displacement of 1.49 mm is permissible for a monolithic slab.

In accordance with the implemented norms of DBN B.2.2-5:2023, the design of structural elements of a building should include an evenly distributed load from an explosion pressure of 100 kPa.



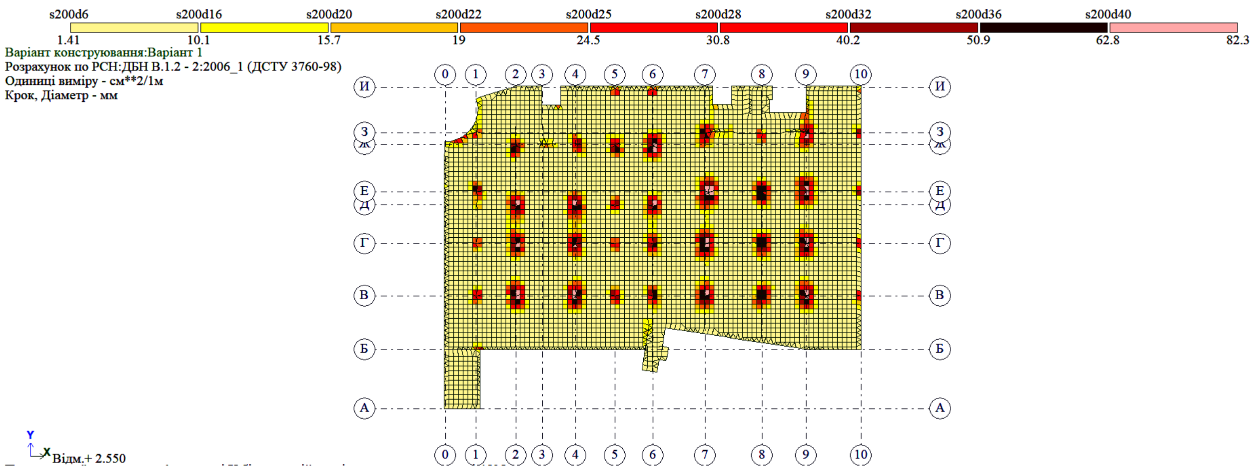
a



b

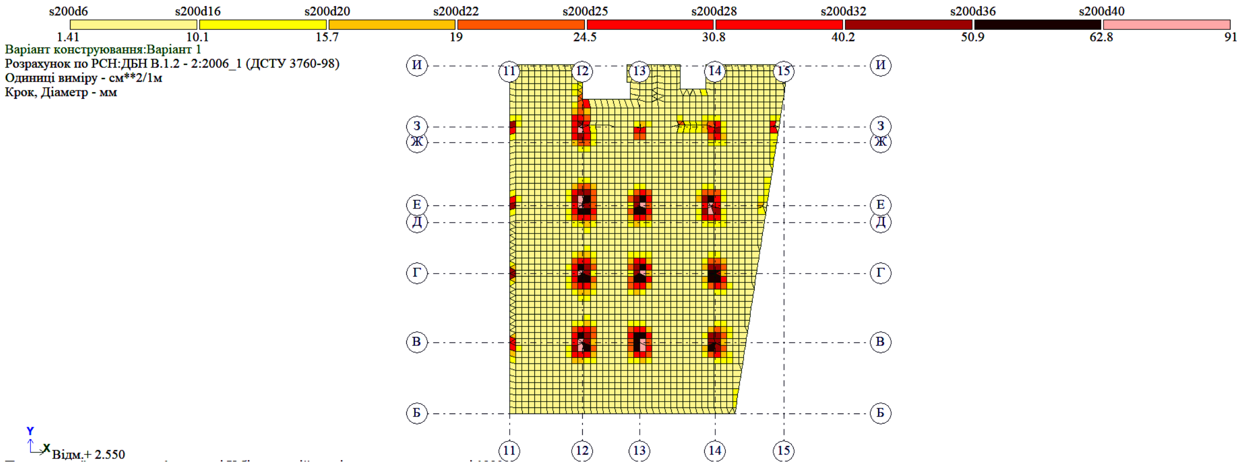
Fig. 2. Movement of the slab (taking into account the explosive load in accordance with DBN B.2.2-5-97): a – first part; b – second part

Based on this, an additional instantaneous load on the floor slab of 100 kN/m² was set and the design was carried out, and the diagrams of the lower and upper reinforcement of the monolithic floor slab in the X and Y axes were obtained (Fig. 3, *a*, *b*). Shows that the maximum reinforcement cross-section is present in the 2nd part of the slab (Fig. 3, *b*) and is 91 cm².



a

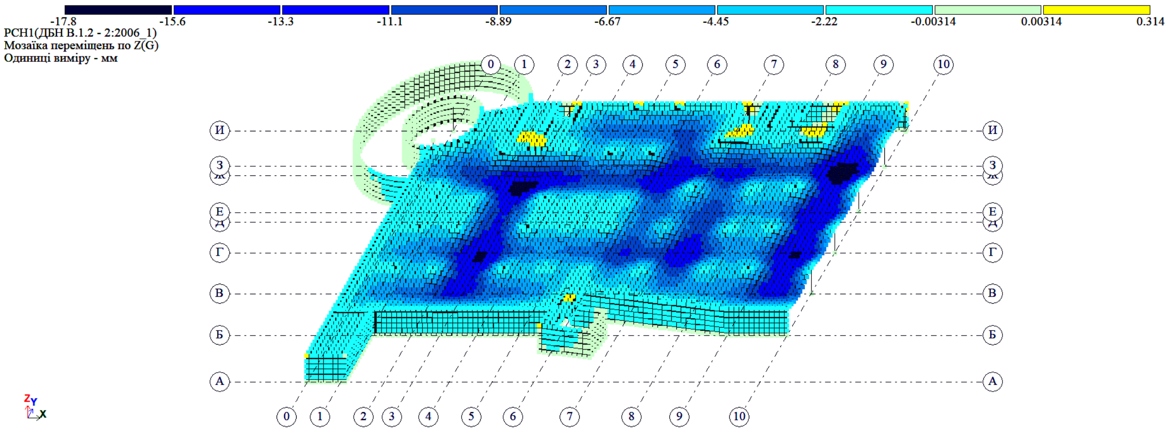
Fig. 3. Reinforcement of the upper (Ax) plate (taking into account the explosive load in accordance with DBN B.2.2-5:2023): a – first part



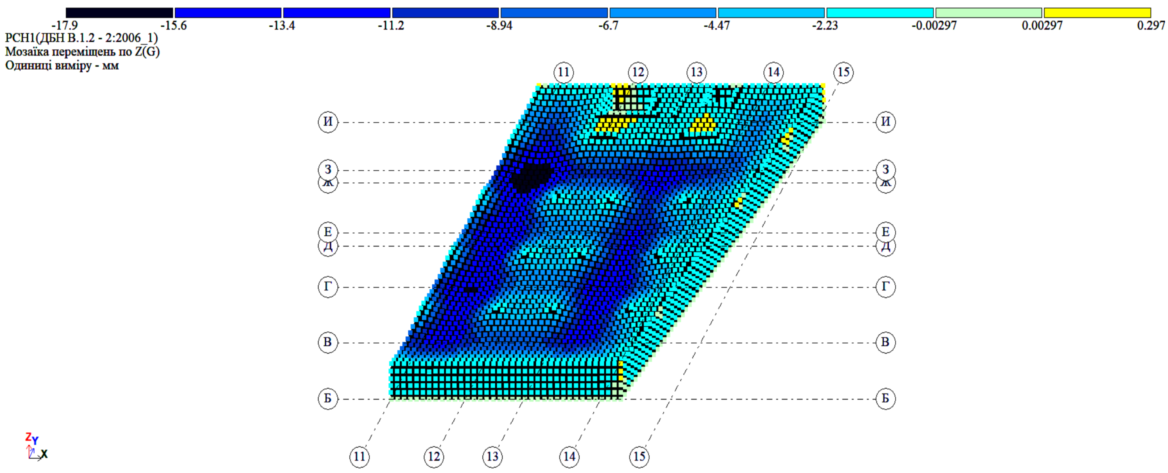
b

Fig. 3. Reinforcement of the upper (Ax) plate (taking into account the explosive load in accordance with DBN B.2.2-5:2023): b – second part

The calculated spatial layout of the building was recalculated taking into account the instantaneous load of the explosive pressure. Fig. 4 shows that the maximum displacement present in the 2nd part of the floor slab (Fig. 4, *b*) in the transverse axes 11–12 is 17.9 mm and is permissible in accordance with the maximum deflection, which is 29 mm for the span in these axes.



a



b

Fig. 4. Movement of the slab (taking into account the explosive load in accordance with DBN B.2.2-5:2023): a – first part; b – second part

Based on the results of these calculations, the maximum vertical displacements of the slab increased from –1.48 mm to –17.8 mm, which are permissible in accordance with the maximum deflections of the spans in which these displacements are reflected. The lower and upper reinforcement in the case of an instantaneous explosive pressure load of 100 kN/m² has changed dramatically – from maximum cross-sections of 15.7 to 91.0 cm² (Table), and, accordingly, the rebar cross-sections should be re-designed for the vertical and horizontal load-bearing elements of the spatial scheme of the underground car park of a multistorey building.

Design results of an underground car park floor slab before and after the introduction of new building regulations

Regulatory documents	DBN B.2.2-5-97	DBN B.2.2-5:2023
Instantaneous load, explosive pressure, kN/m²	20	100
Maximum movements, mm	–1.48	–17.8
Maximum cross-section of slab reinforcement, cm²	15.7	91.0

Thus, the implementation of the new state standards will help protect civilian buildings and structures from the instantaneous load of explosive pressure caused by rocket attacks. The redesign will include an increase in the cross-section of vertical load-bearing elements – pylons – and horizontal load-bearing elements – an increase in the thickness of the monolithic floor slab with a reduction in the reinforcement spacing and an increase in the reinforcement cross-section.

Conclusions

The calculations of the structural elements of the underground car park of a multistorey building have established that the monolithic slab and pylons of the building, designed in accordance with the requirements of DBN B.2.2-5-97, may undergo deformation and destruction in the event of an instantaneous explosive pressure load of up to 100 kPa. According to the new DBN B.2.2-5:2023, when the instantaneous blast pressure load increases to 100 kPa, the maximum displacement of a monolithic floor slab increases by 11.9 times and the maximum reinforcement section by 5.8 times compared to the design values of the structural elements of the buildings in operation. This will ensure the resistance of the structural elements of civil protection buildings and structures to the impact of an explosion under martial law.

Prospects for further research

One of the main tasks facing the military-industrial complex of Ukraine is to maintain, restore and modernize old, as well as create new modern protective structures, shelters, dugouts that meet the latest requirements for strength, reliability and resistance to shock loads. In further research, it is advisable to use high-strength steel-fiber-reinforced concrete for the construction of protective structures, which can better resist sharp dynamic loads. This will ensure improved impact strength characteristics of structural reinforced concrete elements of dual-purpose structures.

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СТІЙКІСТЬ КОНСТРУКТИВНИХ ЕЛЕМЕНТІВ БУДІВЕЛЬ ТА СПОРУД ЦИВІЛЬНОГО ЗАХИСТУ ДО ВПЛИВУ ВИБУХУ

В умовах збройних конфліктів, зокрема широкомасштабної російської збройної агресії проти України, необхідне забезпечення стійкості конструктивних елементів будівель та споруд цивільного захисту до впливу вибуху. Виконано розрахунок елементів конструкцій – залізобетонної плити перекриття та пілонів підземного паркінгу багатоповерхової будівлі цивільного призначення для встановлення відповідності несучих конструктивних елементів до будівельних норм щодо впливу навантаження вибухового тиску. Наведено результати розрахунку конструктивних несучих залізобетонних елементів (монолітна плита перекриття, пілони) підземного паркінгу зведеної багатоповерхової цивільної будівлі до впливу вибуху в програмі "Ліра-САПР" з урахуванням вимог державних будівельних норм України.

Результати розрахунків показують, що монолітна плита та пілони будівлі відповідають конструктивним вимогам ДБН В.2.2-5-97, але за дії миттєвого навантаження вибухового тиску можуть зазнати деформацій і руйнувань. Встановлено, що збільшення миттєвого навантаження вибухового тиску від 20 кПа (ДБН В.2.2-5-97) до 100 кПа (ДБН В.2.2-5:2023) дасть змогу збільшити максимальне переміщення монолітної плити перекриття в 11,9 разу та максимальний переріз армування в 5,8 разу. Відповідно до нових норм ДБН В.2.2-5:2023 регламентовано п'ятикратне збільшення навантаження від вибухового тиску, що забезпечить підвищення максимального переміщення для монолітних перекриттів та істотно збільшить потребу в армуванні порівняно із застарілими нормами для конструктивних елементів будівель та споруд, що експлуатуються як споруди подвійного призначення. Створюється реальна можливість розроблення нових підходів до планування будівель та споруд цивільного захисту із забезпеченням їх експлуатаційної надійності та стійкості до впливу вибуху в умовах воєнних дій.

Ключові слова: конструктивні залізобетонні елементи; плита перекриття; пілони; цивільний захист; будівля; вибухова хвиля.