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Modeling the Behavior of Modular Reinforced Concrete Shelters Under Explosion Conditions

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MODELING THE BEHAVIOR OF MODULAR REINFORCED CONCRETE SHELTERS UNDER EXPLOSION CONDITIONS

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Abstract. The purpose of the work is to study the safe operation of modular reinforced concrete shelters under explosion conditions to ensure the safety of people inside while protecting them from the effects of air strikes. The scientific novelty is reduced to a comprehensive analysis and generalization of previous studies on the assessment of the effects of excess pressure from the explosion of military weapons, methods of mathematical modeling based on the method of integrating dynamics equations and stress-strain equations of a solid body when they are approximated by the finite element method in a nonlinear formulation. Practical value - the results of the research proved that ground-based modular shelters are safe in their practical use for protecting the population from the effects of explosions during air strikes, as well as penetrating ionizing radiation. Main results - the results of the analysis of the structural systems of modular shelters substantiated the main provisions and assumptions of the computational-theoretical approach to mathematical modeling of the impact of an explosion on reinforced concrete structures of modular shelters. Calculation schemes and a set of mathematical models of mechanical interaction between elements of protective shelters, structural materials, as well as models of the mechanical impact of an explosion on shelter elements have been developed. Based on the mathematical modeling a conclusion about the safety of modular shelters and their practical application for protection against explosions and penetrating ionizing radiation has been made.

1. Introduction

The effectiveness of ground-based modular shelters is determined by their ability to block the impact of damaging factors of aircraft, missile and artillery attacks, protect people from being hit by debris or fragments of building structures, and ensure safe evacuation. The provisions, assumptions and criteria used to establish the safety of practical use of protective shelters of the proposed design are used. The simulated mathematical models of the mechanical impact of the explosion, the behavior of structural materials in such conditions were consistent with the recommendations of regulatory documents [1-5] and scientific and practical data given in the works included in the international database of scientific references and recognized by the



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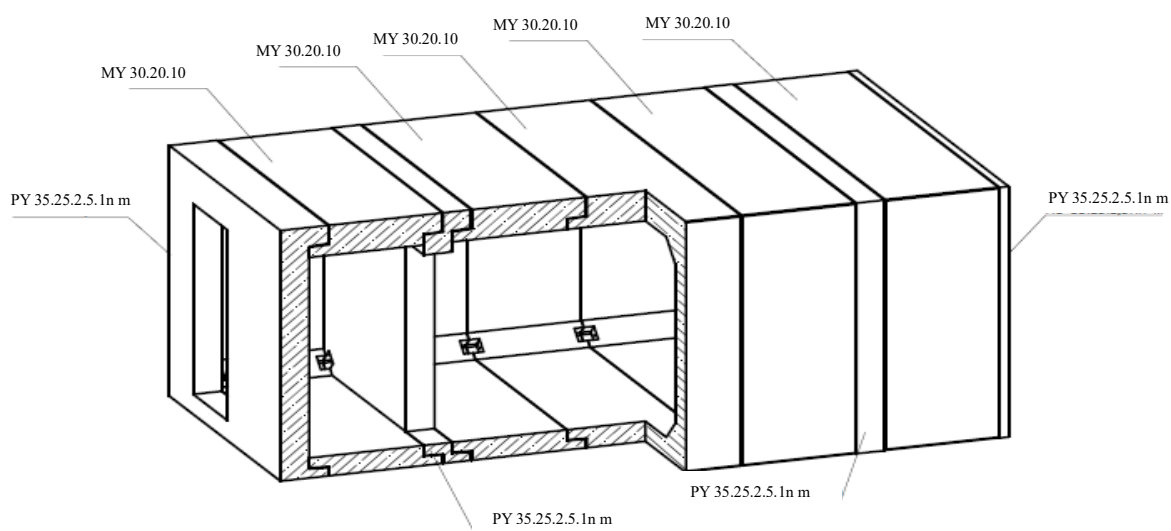
scientific community [6-9]. The disadvantages of these studies on protective shelters are that such properties, as a rule, were determined by underground protective structures, and the criteria were limited to the excess pressure of the explosion from the protective structure and the protection coefficient (attenuation of ionizing radiation). At the same time, the modern construction industry and the experience of foreign approaches indicate the possibility of using ground and above-ground protective structures, the advantage of which is to reduce the time of sheltering the population during military strikes.

The following research objectives were set: to study the behavior of enclosing structures of protective structures and ground shelters under the influence of explosions and mechanical impulse actions. To achieve the set goals, the following tasks were performed: 1. development of general recommendations on the design features, principles of location and operation of protective structures; 2. studying the behavior of the enclosing structures of modular shelters is the classification of the effects on them caused by explosions and the impulse action of warheads; 3. identifying patterns of dependence of the degree and severity of damage to the enclosing structures on the parameters of the effects caused by the action of warheads, as well as the scattering of debris and fragments of building structures.

Thus, the above-mentioned determines the relevance of modernization and improvement of existing or arrangement of new modular shelters, which would correspond to the modern conditions of dense urban development of large cities. The priority issue of the research is the creation of a calculation basis for assessing the preservation of the protective functions of the enclosing structures of modular shelters in conditions of explosions and impulse actions caused by combat shells or flying fragments.

2. Research methodology

The article used a constructive system of protective shelter, which consisted of reinforced concrete blocks fastened together with the help of bolted connections. In fig. 1. a constructive shelter system is given.



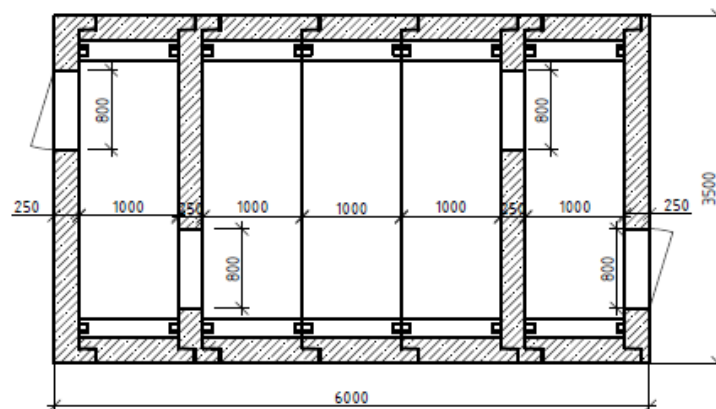


Figure 1. Structural scheme of reinforced concrete protective shelter structures.

The structural system of modular shelters consists of reinforced concrete modules of tubular shape and a module-slab with a doorway, which are fastened together using embedded parts. Fig. 2 shows a general calculation diagram of modular shelter structures [10].

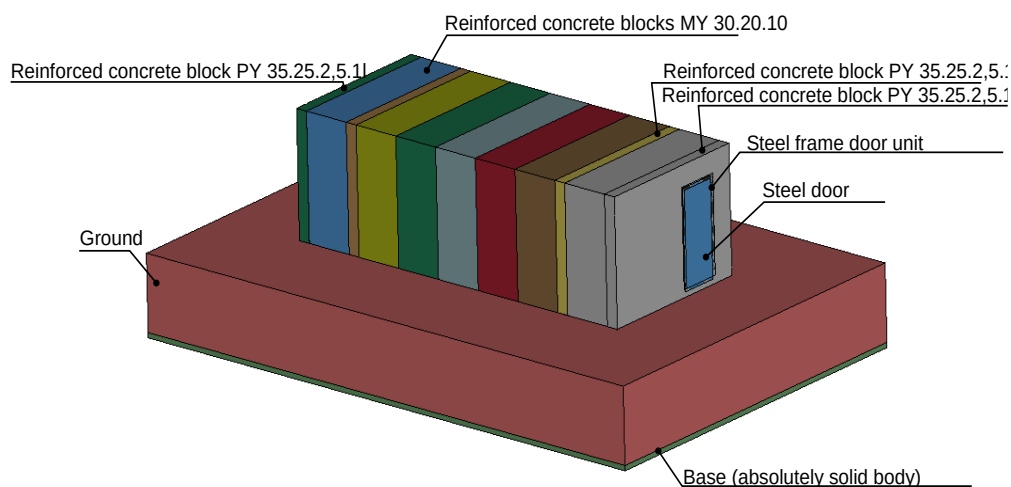


Figure 2. Structural and calculation diagram of a modular shelter.

The calculation diagram shown in Fig. 2 shows the main components of the mathematical model of a modular shelter. The individual components-parts of the protective shelter shown in the diagram in Fig. 2 have different colors so that they can be separated from each other. In this model, each individual component is a separate part that perceives the impact of the explosion and interacts with other components-parts of the model. A feature of this model is the presence of a special component that is the basis for the ground, limiting its global movement and the movement of its points. In this case, this component of the model is represented by an absolutely rigid body [7, 11-13].

Material characteristics of the components of the mathematical model of the shelter. The technical data required for the concrete material model are given in Table 1, which lists the main characteristics for the concrete material model CSCM type No 159 [14].

Table 1. Concrete model parameters CSCM type No 159.

Parameter	Units of measurement	value
Density	kg/m ³	2500
Strength limit	MPa	32
Taking into account the rate of deformation		Considered
The size of the coarse aggregate	m	0.02

The technical data required for the reinforcing steel material model are given in Table 2, which lists the main characteristics for the reinforcing steel material model and anchoring. PLASTIC KINEMATIC MAT type No 003.

Table 2. Parameters of the model KINEMATIC MAT type No 003

Armature element	Poisson's Ratio	Elastic modulus, GPa	Yield strength, MPa	Density, kg/m ³	Limit deformation	Speed Deformation
Anchoring	0.3	210	345	7850	0.15	Considered
Rods			500			

The Drucker-Prager model is used for ground modeling. [8] MAT DRUKER PRAGER type No 193. The main indicators of this model are given in table 3.

Table 3. Parameters of the model MAT DRUKER PRAGER type No 193

Poisson's Ratio	Shear modulus, MPa	Ground cohesion, kPa	Density, kg/m ³	Friction angle, rad	Dilation angle, rad
0.3	154	30	1900	0.15	0.524

Fig. 3 shows a diagram of the elements of the modular shelter samples and the corresponding material models. An additional bottom layer is used to fix the soil layer, for which a model of a completely solid material is used. (MAT RIGID type No 020).

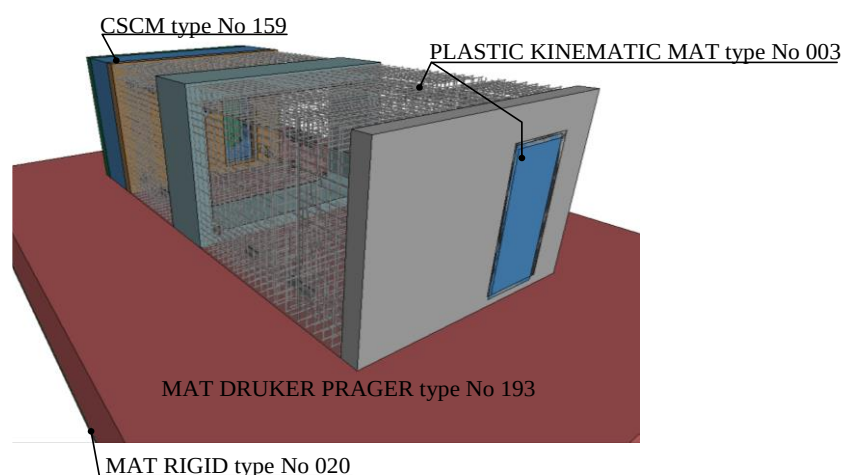


Figure 3. Calculation scheme of materials for the main components of the protective shelter.

Table 4 shows sets of such parameters and, accordingly, the maximum excess explosion pressure. [7, 15]. This overpressure of the explosion was determined by the Kingery-Bulmash model. It is assumed that the explosion occurs in air, and amplification of the blast wave due to reflection is not taken into account.

Table 4. Explosion impact model parameters

Explosion impact option	Distance, L, m	TNT equivalent, m(TNT), kg	Maximum overpressure, kPa
1	1	10	5472.11

Fig. 4 shows options for the location of the epicenter of the explosion above the upper slab of the shelter.

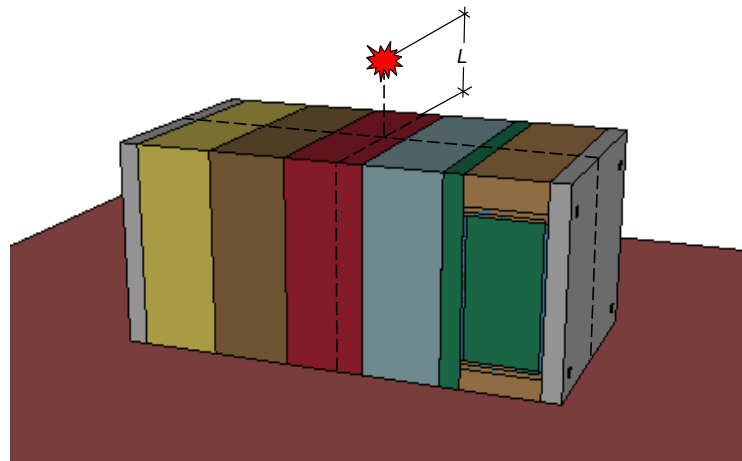


Figure. 4. The diagram of the location of the epicenter of the explosion

3. Results and discussion

3.1. Modeling the impact of an explosion on protective structures

To model the impact of an explosion and the corresponding stress-strain state in reinforced concrete modular shelter structures under explosion conditions, a generalized engineering approach was applied, which is based on the following main aspects [7, 9]:

1. For mathematical modeling of the stress-strain state of a deformed solid, a generalized theoretical approach is used, which is based on the initiation of movements of points of the mechanical system of deformed solids using a system of general equations of dynamics and equations that are integrated using the finite element method.
2. Three-dimensional massive finite elements of hexahedral shape with eight nodes are used to model the concrete base and ground layer of the blocks.
3. To model steel plate elements of the anchoring system and door elements, two-dimensional shell finite elements of rectangular shape according to the method [10] with four nodes and five integration points along the thickness and one-dimensional linear elements with a defined cross-sectional shape are used.

4. To model steel reinforcement in the form of reinforcing bars, one-dimensional linear elements with a defined cross-sectional shape, known as bar beam elements, are used according to the method.

5. To describe the nonlinear behavior of concrete under applied loads, the plastic model of damaged concrete, described in the works, is used, which is built on the basis of nonlinear deformation diagrams with descending branches and takes into account brittle and ductile fracture of concrete based on the task of effective plastic stress based on the ratios of plastic and elastic deformations.

6. As a model of the steel reinforcement material, a material with the possibility of plastic deformations, Prandtl-type deformation, the shape of which includes only the growth section and the horizontal section with a limiting deformation of 15%, taking into account thermal expansion and a decrease in the mechanical characteristics of the reinforcement during high-temperature heating is used.

7. The model is used to simulate nonlinear ground behavior..

8. To describe the interaction between the surfaces of support of reinforced concrete blocks of the protective shelter on the ground, a contact interaction model is used. The surfaces of support of the ground layer on the deep layers, according to the assumptions made, consist of absolutely undeformed material. The application of the load has a dynamic history and occurs gradually over a certain time.

9. The warhead of the shells is assumed to be equivalent to 10 kg in TNT equivalent, as the most common. When modeling the explosion, its chemical and gas-dynamic nature is not taken into account, but its result is considered in the form of a corresponding pressure curve on the walls of the shelter. To determine the change in pressure on the walls of reinforced concrete blocks of shelters and on the ground surface, an appropriate model is used.

10. When studying the process of testing a sample, a computer program LS-DYNA (Livermore Software Dynamic) is used where is the computer system code LS-DYNA is part of a complex of computational engineering systems ANSYS Workbench and also included as a block in a separate part of this complex ANSYS APDL. This program is suitable for research because it is designed to simulate impulse effects on structural systems and simulate the result of these effects using dynamics equations in finite element implementation, dynamic reconstruction of the finite element mesh during its resonance and division into separate parts capable of further contact interaction. [10].

The guidelines for the design of protective structures, recommended in the standards [1-3], valid in Ukraine, the excess pressure of the shock wave as the main influence is defined. This pressure is defined as a reference value and is a force factor applied to the surfaces of the building structures of the bomb shelter. In this case, appropriate coefficients are used to take into account the dynamics of the load application. This approach is somewhat outdated, since it uses a quasi-static approach for calculation. For a more accurate description, it is proposed to use a more physically based approach, which is based on the use of the warhead size of the corresponding projectile in TNT equivalent, the distance of the explosion and the position of the point where the explosion occurs. The pressure determined by these parameters can be used to study its effect on structures.

To model the pressure under the influence of an explosion, a special empirical curve is used according to [9]. This curve is shown in Fig. 5. To model the impact of an explosion and the corresponding stress-strain state in reinforced concrete modular shelter structures under

explosion conditions, a generalized engineering approach was applied, which is based on the following main aspects.

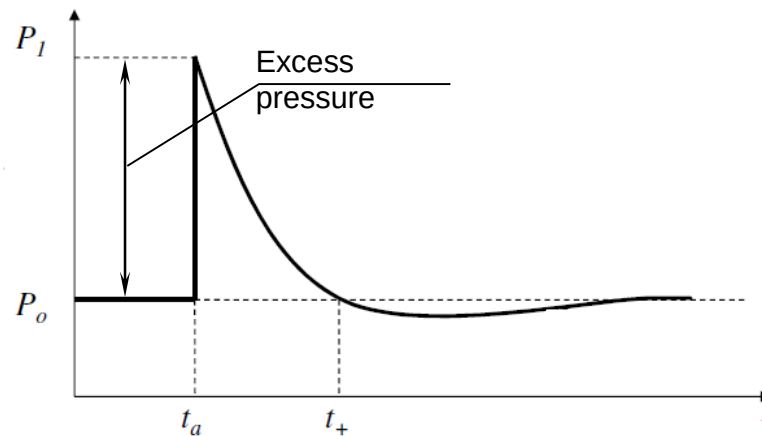


Figure 5. Pressure curve on the surface of the walls of modular shelter structures.

To determine the nature of deformation of the structure, the deformation diagram, the appearance of which is presented in fig. 6.

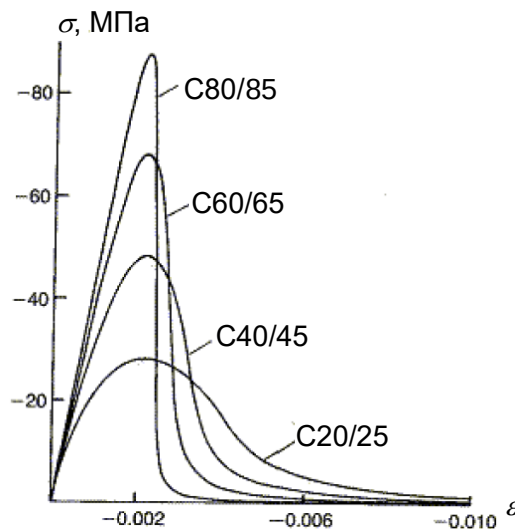


Figure 6. Diagrams of concrete deformation depending on the strength class.

The described model allows formalizing the impact of the explosion, taking into account the attenuation of the shock wave depending on the distance and angle of the surface of the shelter structures. For this purpose, the nomogram shown in Fig. 7 can be used.

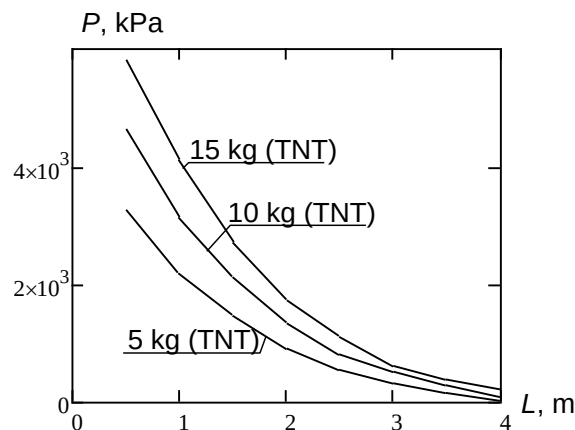


Figure 7. Pressure change curve depending on distance and TNT equivalent of the projectile warhead.

The structural system of modular shelters consists of reinforced concrete modules of tubular shape and a module-slab with a doorway, which are fastened together using embedded parts. Fig. 7 shows a general calculation diagram of modular shelter structures [10].

3.2. Modeling of principal stresses in concrete elements of the system and soil

The loading of the system took place in two stages. In the first stage, the load of the initiated prestress was applied in the connecting bolts due to the tightening force and the gravity load due to the own weight of the system elements. In fig. 8 shows the picture of the distribution of the third main stress in the concrete elements of the system, on which it is possible to trace the occurrence of stresses in the places of anchoring of concrete blocks [15-17].

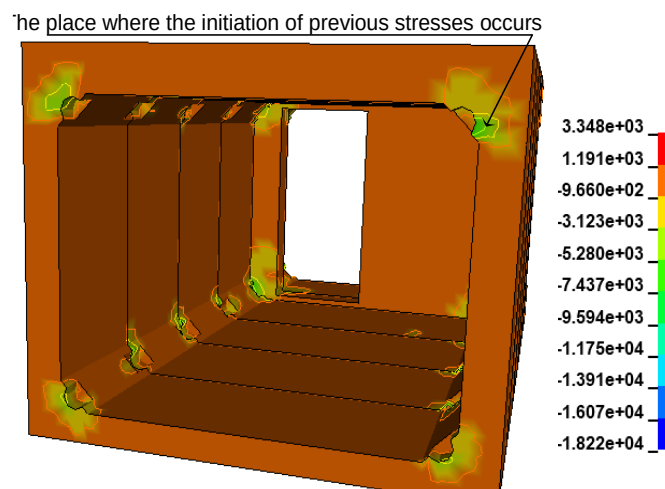


Figure 8. Distribution of the third principal stresses in the concrete elements of the system (Pa) after the initiation of the prestress due to the tightening force of the bolted connection.

In fig. 8 it can be seen that in the anchoring places the initial stresses are initiated due to the tightening force of the bolted connections, where noticeable compressive stresses occur. In fig. 9 shows the picture of the distribution of the first principal stresses in concrete blocks due to the applied gravity load before the application of the load from the blast wave.

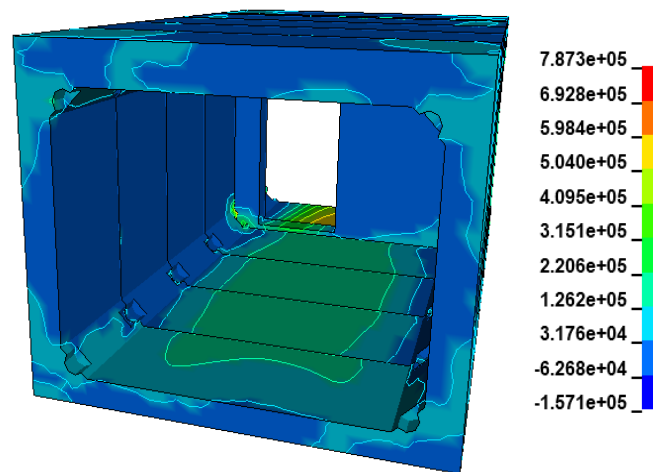


Figure 9. Distribution of the first principal stresses in the concrete elements of the system (Pa) after applying the gravity load.

In fig. 10 shows the picture of the distribution of the first principal stresses in the soil due to the applied gravity load before the application of the load from the blast wave.

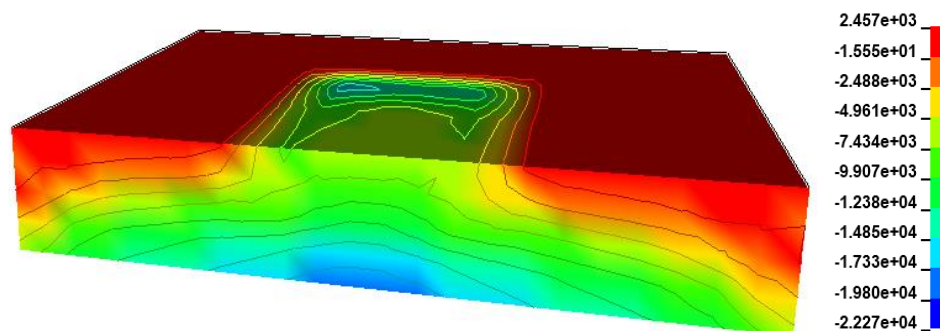


Figure 10. Distribution of the first principal stresses in the soil (Pa) after applying the gravity load.

In fig. 8 - fig. 10, it can be seen that due to the application of preliminary loads to these elements of the system, a stress-strain state is initiated and a blast wave load can be applied to the system.

3.3. Characteristics of the applied load from the explosion

In fig. 11 shows the distribution of excess pressure during the propagation of an explosive wave over the surface of a protective structure [16].

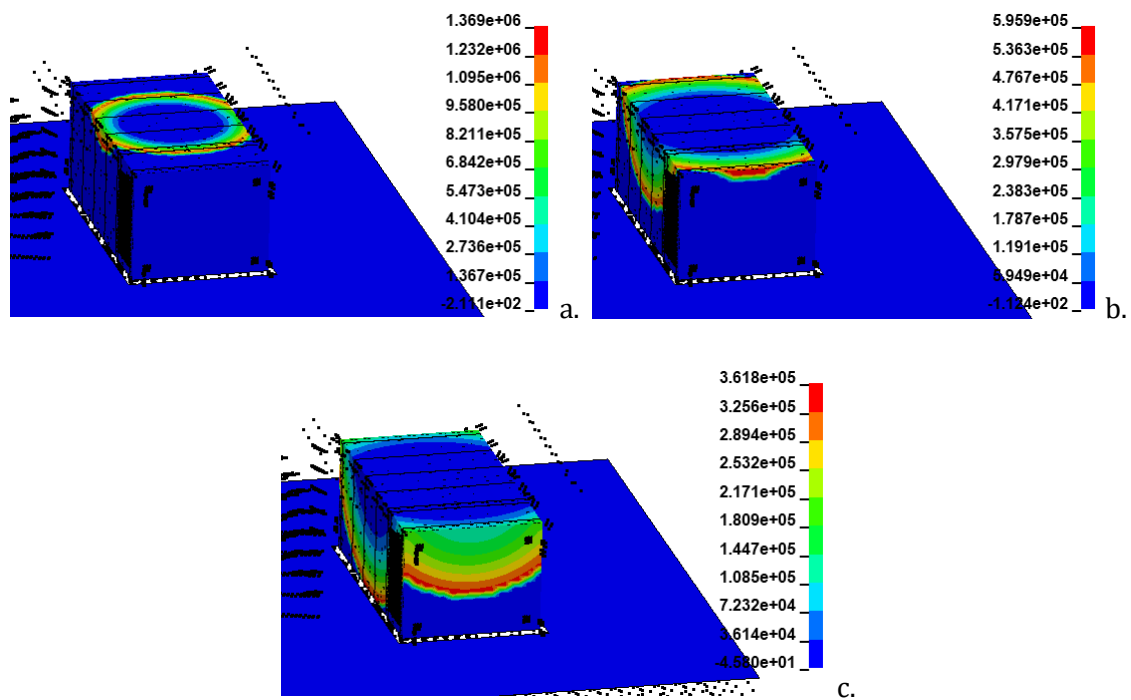


Figure 11. Distribution of excess pressure during the propagation of an explosive wave over the surface of a protective structure at different moments of time: a. – 1 ms; b. – 2 ms; c. – 3 ms.

Figure 12 shows the curve of the change in excess pressure of the explosion at the closest point of the surface of the protective structure to the epicenter of the explosion.

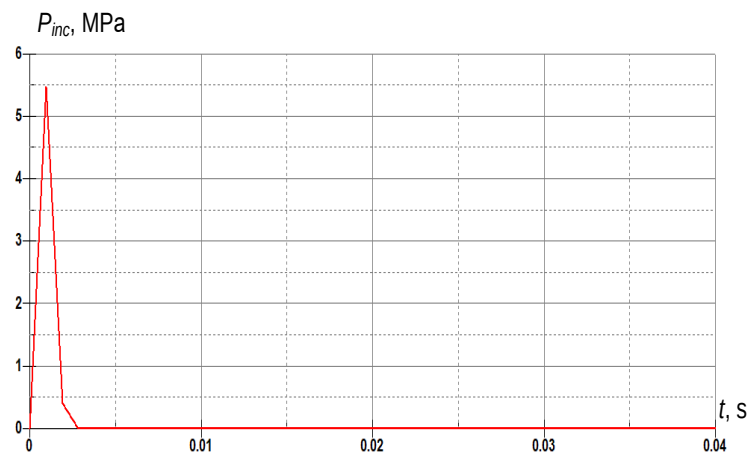


Figure 12. The curve of the change in excess pressure of the explosion at the closest point of the surface of the protective structure to the epicenter of the explosion.

3.4. The results of calculations of the stress-strain state in the structures of the protective structure during the explosion

After calculations, results were obtained that allow studying the mechanisms of destruction or loss of integrity of shelter structures and establishing the relationship between these aspects and ensuring the performance of its protective functions under the conditions of explosion

impact [16]. To analyze the stress-strain state, a simulation of the distribution of plastic deformations after applying pressure from the blast wave to the surface of the shelter structures was created for two different conditions, which is shown in Fig. 13 [17].

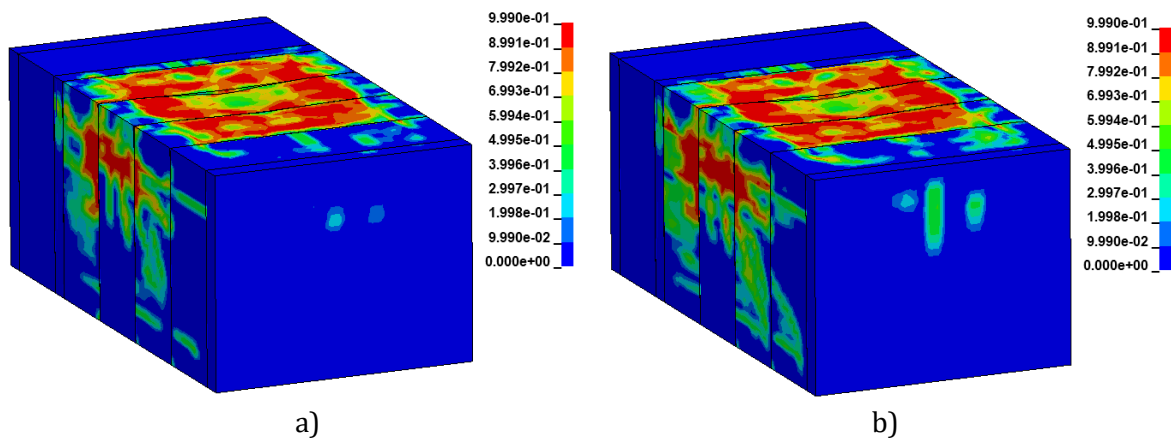


Figure 13. Distribution of plastic deformations after applying pressure from the blast wave at different time points: a) 5 ms; b) 10 ms.

In fig. 14 shows pictures of distributions of vertical movements of the protective structure during the explosion.

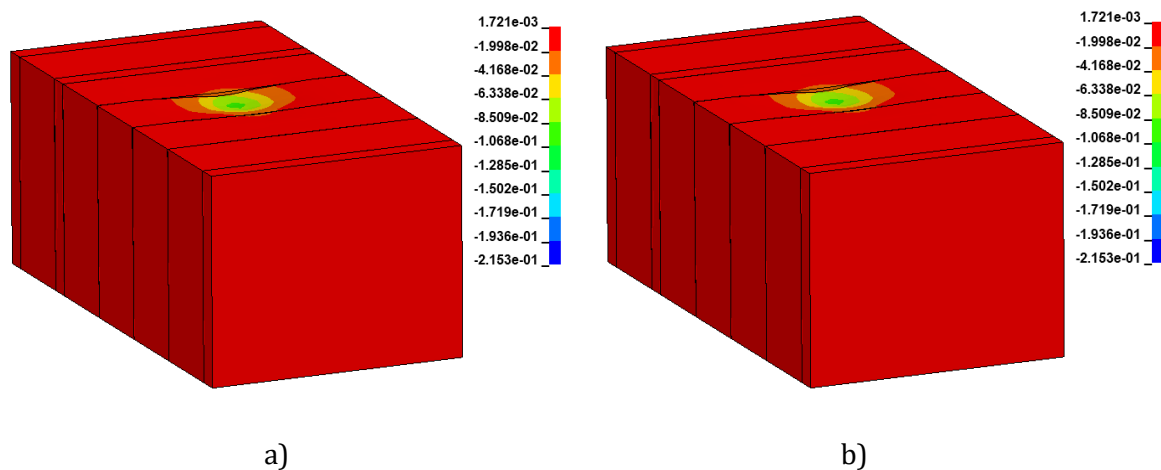


Figure 14. Distribution of vertical displacements of the protective structure after applying pressure from the blast wave at different time points: a) 5 ms; b) 10 ms.

To analyze the possibility of the destruction of the protective structure, a graph of the largest displacement of the point in the middle was drawn. The constructed movement schedule is shown in fig. 15.

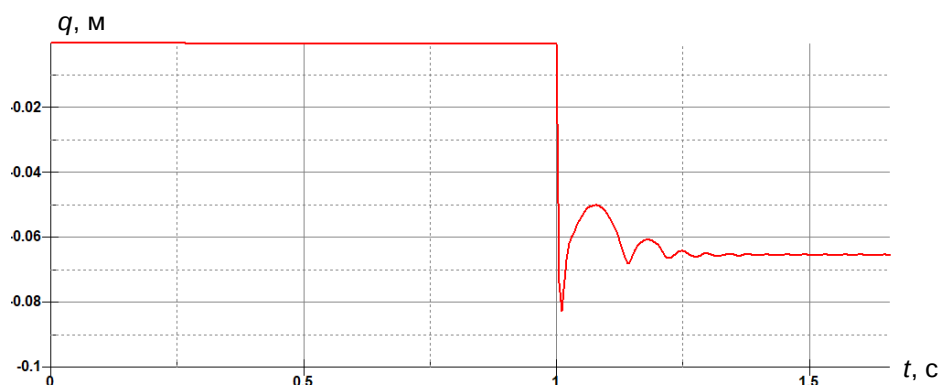


Figure 15. The curve of the change of the largest point displacement in the middle of the modular shelter.

The graph in Fig. 15 shows that the largest displacement at the moment of explosion increases sharply. After oscillatory motion around a certain new equilibrium position of the midpoint of the modular shelter, the motion stops. Considering that the displacements of other points are smaller, it can be noted that the destruction of the shelter under the action of the maximum excess explosion pressure of 5.4 MPa of the shock wave does not occur.

4. Conclusions

As a result of calculations on the mathematical modeling of the behavior of modular shelter structures under conditions of an explosion of a warhead with a mass of TNT equivalent of 10 kg at a distance of 1 m from the upper surface of the protective shelter, it was found that this shelter can withstand it without destruction.

Therefore, this shelter, in terms of its protective functions, in terms of maintaining strength, integrity and the absence of overturning or other significant movements, provides a level of protection and meets the established requirements. It has been established that the destructive ability of military means of destruction depends on their warhead charge characteristics, which can be expressed in TNT equivalent, and the protective properties of the enclosing structures of modular shelters depend on the material from which such enclosing structures are made and its thickness. The dependence of the protective properties of the enclosing structures of ground modular shelters on the charge characteristics of modern military means of destruction requires further future scientific research.

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