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DEVELOPMENT OF A MOBILE SHELTER DESIGN IN UNSTABLE SOILS FOR PROTECTION OF DEFENSE FORCES PERSONNEL FROM ENEMY'S MEANS OF ATTACK

Over the past centuries, the rapid development of fortification equipment for strongholds has been clearly evident during periods of active hostilities. The dynamic progress of armaments and the direct experience of warfare are powerful catalysts for the continuous search for innovative forms, advanced designs, the latest materials and specialised equipment. The main goal of this search is to ensure the maximum preservation of own firepower and human resources.

The problem of soldiers' survival is especially critical on the front line of defence, where they are under constant, intense enemy fire control. Fortifications built in such extreme conditions are often of primitive design and demonstrate a low ability to effectively protect personnel from modern weapons. As a rule, such fortifications are built directly on the ground, manually, using available materials and structures, dominated by wood elements.

However, in the context of the hostilities that have unfolded on the territory of Ukraine, there is a serious problem with the availability of natural wood reserves of the required quality and in sufficient quantity directly in the conflict zone. This creates difficulties associated with the need to organise complex and costly timber deliveries from remote regions. In this regard, it is important to find alternative engineering solutions that would provide the military with reliable shelters without depending on local resources.

One of the promising ways to solve this problem may be the development and implementation of a mobile collapsible shelter made of lightweight but durable metal elements. The key requirement for such a kit is its weight, which should be optimised to ensure that it can be transported and installed by one person without significant physical effort. This will allow each soldier to independently and quickly set up the shelter at their position and use it repeatedly, depending on the tactical situation and the need to move. Such mobility and autonomy in providing protection can significantly increase the survival rate of personnel on the contact line.

Keywords: *mobile collapsible shelter; self-installation; fortifications; metal structures.*

Statement of the problem. In conditions of direct contact with the enemy, when setting up defensive positions, personnel who are manually constructing the positions are poorly protected. In the horizontal projection of the position, they are protected from small arms fire and debris by an earthen parapet. In the vertical projection of the position, there is no protection. With the advent of modern weapons, the level of losses increases significantly. Therefore, it is very important to create conditional safety at this stage of the work. The solution to this problem may be the development of a mobile, individual, collapsible metal shelter that can be quickly installed in the side wall of a trench. When danger arises, soldiers will be able to quickly take cover, which significantly increases their level of safety and, on a larger scale, the level of safety of the unit. The design of such a shelter will be proposed in this article.

Analysis of recent research and publications.

In the period after the World War I, the approach to the construction of fortifications changed. Influenced by positional warfare and improvements in weapons (aircraft ammunition, chemical weapons), new trends in defence organisation emerged: dispersal of units across the defence area, construction of long-term underground fortifications, and improvement of field fortifications to protect personnel [1, pp. 204-207]. In field fortifications, dugouts and shelters of a non-reinforced construction provided more reliable protection for soldiers, but their construction required time, materials and, most importantly, trained specialists [2, pp. 101-105].

Simpler and more common structures and shelters for personnel were in the form of niches and dugouts in trenches. Their construction was mainly without supports, i.e. the stability of the ceiling, walls of dugouts and niches was ensured by the outline of the earthwork and the strength of the earth mass in which the structure was located. There were shelters whose outlines were reinforced with improvised means (boards, half-logs, brushwood), no calculations were made for reinforcing the walls and ceiling, and the outline and design of the shelters were passed on as combat experience [3, p. 7].

Different countries had their own ways and experiences of using fortifications. In NATO member countries, the active use of niches and dugouts took place after the participation of the United States in the Vietnam War. Learning from the enemy's experience, the American military built a single trench for firing in the form of a cup, which

was equipped, in the course of combat operations, with a niche for shelter and rest. In the Soviet Union, their purpose, design and construction sequence were described in guidelines and manuals. They were made from wooden shields, wooden frames or planks. The guidelines specified their dimensions and the type of soil in which they should be used. No calculations were provided. S. Gerbanovsky and A. Yermolaev dealt with issues of fortification and the development of field engineering structures, describing practical experience of their use in wars and armed conflicts.

Due to the widespread use of metal elements and structures in public life, solutions and constructions for bolted metal structures for the construction of fortifications began to appear. In the 1960s, NATO guidelines and instructions considered the use of corrugated metal sheets for the construction of shelters, bunkers, and command posts. The protective structure was assembled with bolts and was in the form of an arch [4, pp. 30-31]. Such structures were intended to be used in a backfilled design. The Soviet army used designs for prefabricated metal fortifications (KVS-A, KVS-U) in an underground design.

Thus, summarising the above:

1. Niches have long been used as a means of protecting personnel during combat operations.
2. The only material used to make niches is wood.
3. There are metal prefabricated structures with bolted connections, but their calculations are not provided.

In view of the above, there is a clear lack of in-depth scientific justification and calculation methods for designing niches in trenches. Previous studies have focused on describing structures and rules for their use, without providing engineering calculations. There is a particularly urgent need to develop such calculations for modern materials and conditions, which will improve the effectiveness of personnel protection and optimise the construction process. This highlights the relevance of this study, which aims to develop a prefabricated metal structure for individual shelters in trench niches at unit strongpoints to improve their protective properties.

The purpose of the article is to highlight the calculations for shelters, check the strength of the structure, provide recommendations for its intended use, and draw attention to the need to provide units with structures that will effectively prevent soil from collapsing under load.

Presentation of the main material. One of the main types of fortifications is trenches. The construction of trench shelters, as part of the fortification equipment of a unit strongpoint, is a critically important task for preserving the lives of military personnel. Fortifications allow defensive combat to be conducted and provide basic protection against most of the damaging effects of enemy weapons [5, p. 38]. Niches can also be used to store ammunition and other supplies. The crumbling and collapse of unfortified niches under load prevents them from being used for their intended purpose.

To achieve the goal of this work, the following tasks are to be solved:

- draw and calculate the structure to determine the necessary materials;
- develop a structure based on the calculation scheme;
- conduct experimental tests to determine the technical characteristics of the structure;
- describe the sequence of installation of the structure and provide recommendations for placing the design in the trench wall;
- conduct an analysis of the increase in the survivability of units as a result of using individual shelters.

This work proposes a structure for a mobile shelter for personnel and ammunition, which is installed in a niche cut into the side wall of the trench and provides basic protection from collapses (Fig. 1, 2).

The proposed structure is a steel parallelepiped (without a front wall) reinforced with stiffening ribs consisting of: four upper corners to which a 1500 x 600 steel sheet is attached, and four corner posts to which 500 x 600 side steel sheets and a 1500 x 500 wall are attached. The overall dimensions of the assembled structure are 1500 x 500 x 600 mm, and when disassembled, 1500 x 500 x 60 mm. The main structural elements are made of 3 mm thick hot-rolled steel sheet and 40 x 4 mm and 63 x 5 mm equal-sided angles. Material is steel St.3. The weight of the structure kit is 70 kg. M8 bolts and nuts are used to connect the structural elements.



Figure 1 – View of the assembled shelter from the wall side

Source: photo developed by the authors



Figure 2 – View of the shelter from the front

Source: photo developed by the authors

The finite element method (FEM) was chosen as the method for studying the stress-strain state of the mobile shelter structure. FEM is currently the main tool for engineering analysis due to the availability of computer software packages that not only implement the FEM calculation process, but also have a convenient interface for entering initial data, controlling the calculation process and processing the calculation results. In this work, the Structure CAD (SCAD) software package [6, 7] was used to perform the calculations.

The essence of the finite element method is that the structure is broken down into a number of small but finite elements. The latter are called finite elements (hereinafter FE), and the process of breaking down is called discretisation. Finite elements are connected at nodal points.

Depending on the type of structure and the nature of its deformation, FE can have different shapes: beams, plates (triangular and rectangular) and volumetric FE (tetrahedrons or parallelepipeds). Beam and plate FE were used to construct the finite element model of the shelter.

Calculations are performed for the first limit state under the action of a vertical distributed load from the pressure of loose soil at a depth of 1.2 m – the depth of the horizontal sheet of the load-bearing structure. For the calculation, we assume the density of loose soil to be

$$\gamma = 1,3 \text{ т/м}^3, a = 1,5 \text{ м}, b = 0,6 \text{ м}, h = 1,2 \text{ м}.$$

We determine the volume of soil that creates pressure on the horizontal sheet of the structure $V = a \times b \times h = 1,5 \times 0,6 \times 1,2 = 1,08 \text{ м}^3$

$$\text{Soil mass } m = V \times \gamma = 1,08 \times 1,3 = 1,4 \text{ т}$$

$$\text{Weight of soil } F = m \times g = 1,4 \times 9,81 = 13,6 \text{ кН}$$

$$\text{Distributed load } P = \frac{F}{S} = \frac{13,6}{0,9} = 15,1 \text{ кН/м}^2$$

We assume a distributed load of 15.1 кН/м^2 .

Finite element analysis. Calculation scheme.

A finite element 3-D model of the shelter structure was constructed using beam and plate finite elements in the Structure CAD environment (Fig. 3) and is intended for calculating and evaluating the strength of the structure.

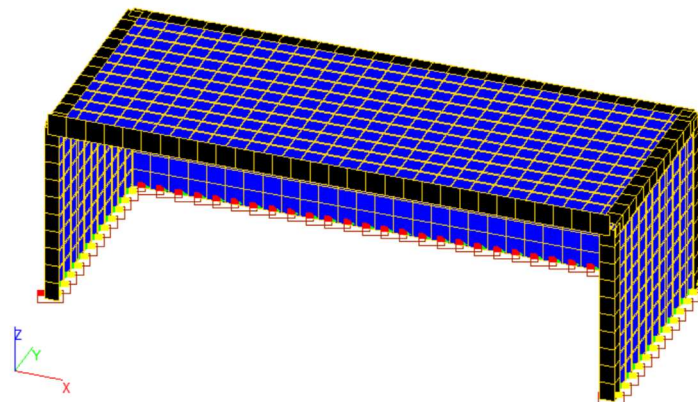


Figure 3 – Finite element shelter structure
Source: model developed by the authors

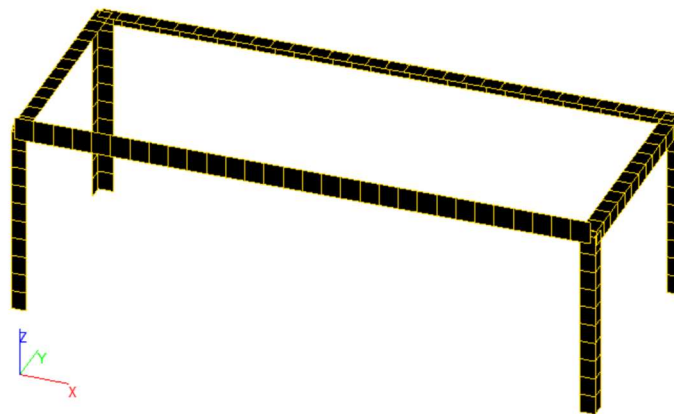


Figure 4 – The frame of the structure consists of angles to which steel sheets are attached
Source: model developed by the authors

The frame calculation diagram is shown in Fig. 4. It consists of rod elements with a cross-section in the form of angles, the dimensions of which are indicated above.

After loading the model, the programme provides an overview of the deformed structure (Fig. 5). The greatest deformation is observed on the upper plate elements.

Analysing the values of displacements from the action of vertical load (Fig. 6), it can be concluded that along the Z-axis, the greatest displacement occurs in the middle of the upper plate and amounts to -27 mm (Fig. 7), along the X-axis – 2 mm (side sheets, Fig. 8), and along the Y-axis – 8 mm (rear sheet, Fig. 9).

Stress fields under the action of a vertical distributed load are shown in Fig. 10. The most stressed area of the sheet is marked in dark grey and amounts to 226 MPa (Fig. 11).

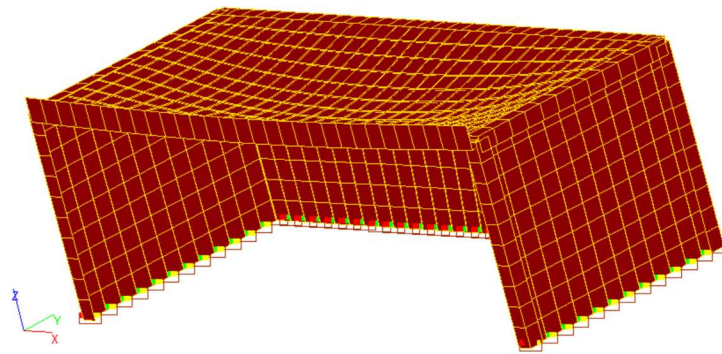


Figure 5 – View of the deformed structure
Source: model developed by the authors

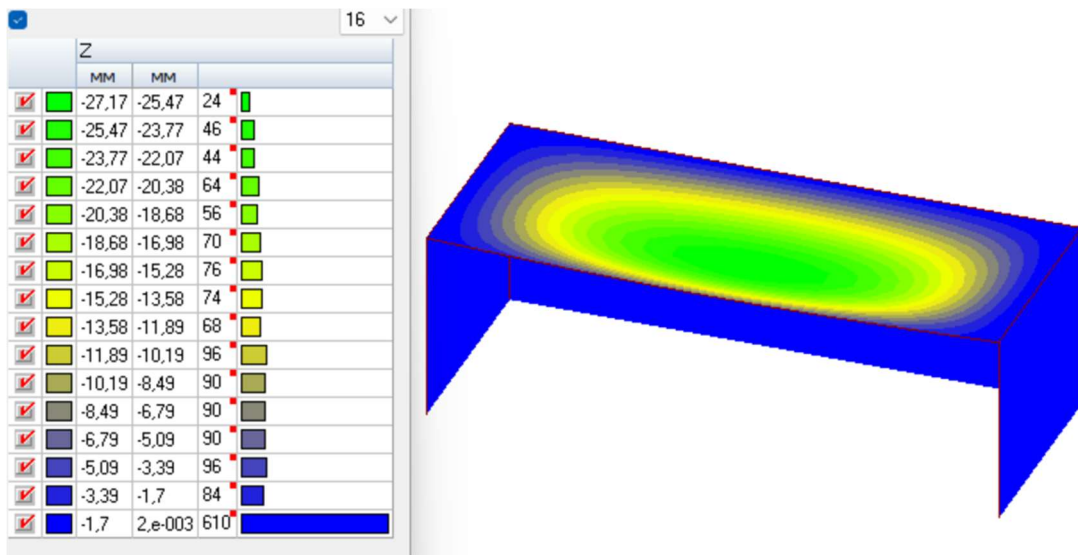


Figure 6 – General view of model displacements
Source: model developed by the authors

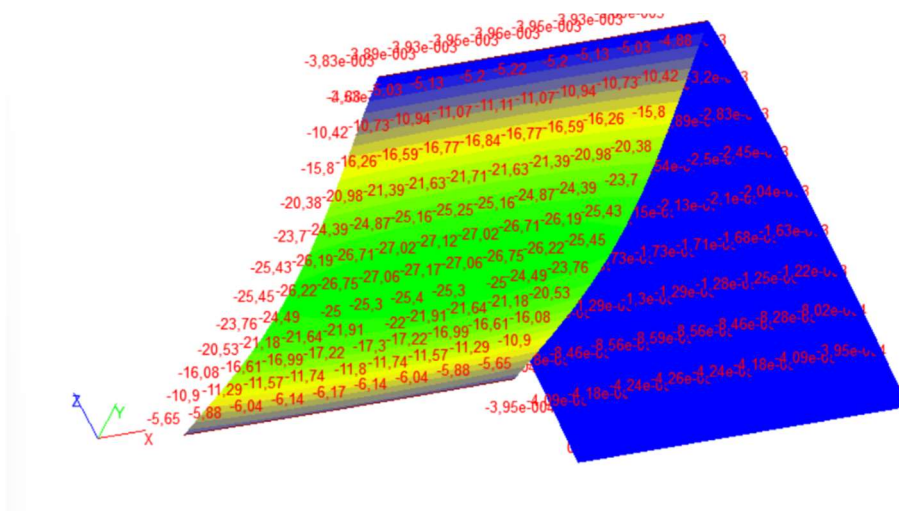


Figure 7 – Maximum numerical values of displacements along the Z axis.
Source: model developed by the authors

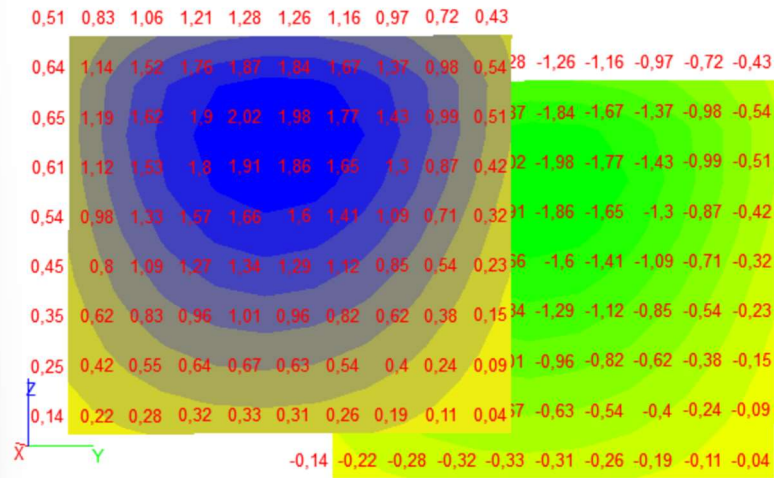


Figure 8 – Maximum numerical values of displacements along the X-axis
 Source: model developed by the authors

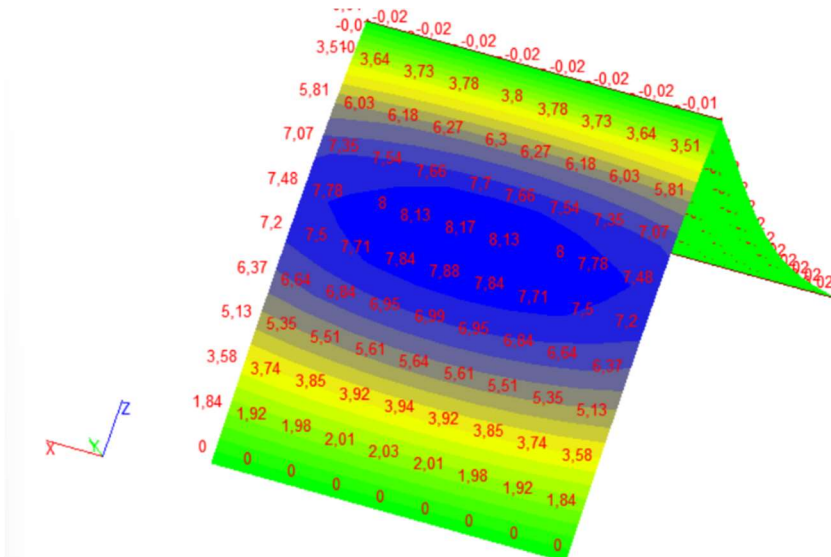


Figure 9 – Maximum numerical values of displacements along the Y-axis
 Source: model developed by the authors

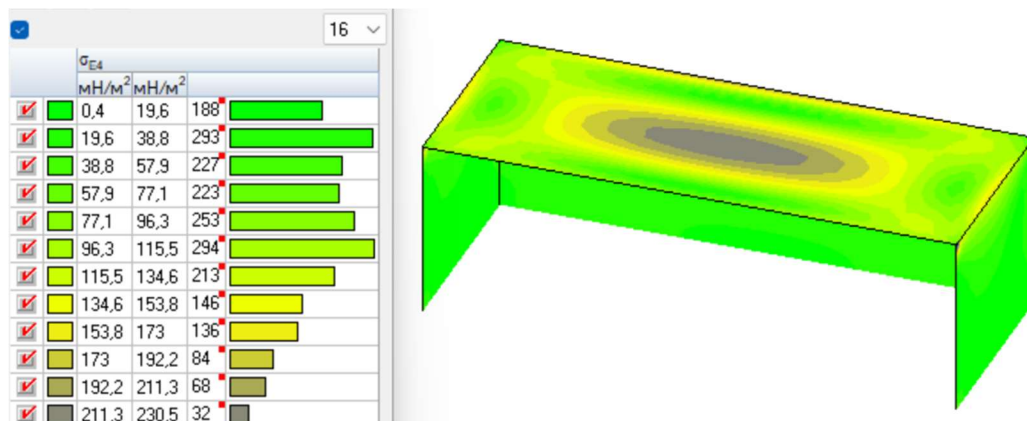


Figure 10 – General view of stresses
 Source: model developed by the authors

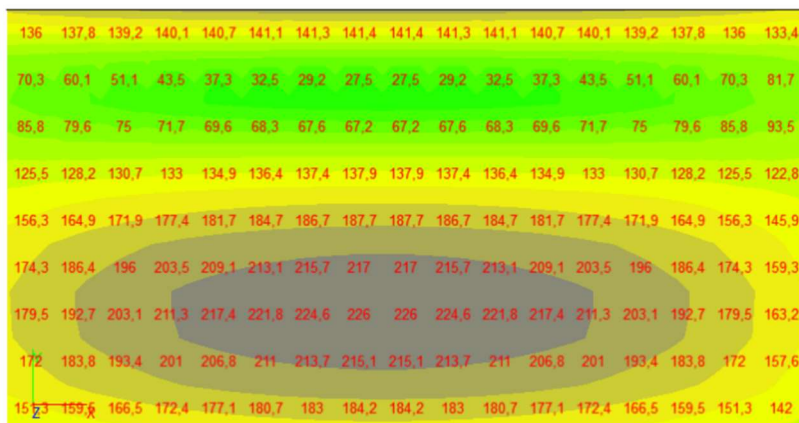


Figure 11 – Maximum numerical values of stress in the upper plate elements
Source: model developed by the authors

Analysis of the calculation results showed that the maximum equivalent stresses (according to the 4th theory of strength) in the structural elements of the shelter are 226 MPa and do not exceed the yield strength of St.3 steel – 245 MPa [8, p. 5]. Thus, the structure can withstand a calculated distributed load of 15.1 kH/M² s and can be used for its intended purpose.

The calculations, design development and practical application can be the subject of further study and development.

Sequence of work on the construction of the shelter:

1. Preparatory work for the construction of niches.

Dig out a niche according to the dimensions of the shelter. The volume of soil removed from the trench wall is $\approx 0,5 \text{ m}^3$. Time required to construct the niche 30 – 35 (хв);

2. Assembling the structure.

Install vertical elements (side elements and wall) in the trench opposite the niche and connect them with bolts using corner brackets; Attach a horizontal sheet with a 63 x 63 x 5 mm corner bracket to the connected vertical elements;

3. Installing the structure.

Install the structure in the niche and tighten the bolts. The time required to assemble the structure and install it in the trench niche is 45 minutes.

4. Dismantling the structure.

The dismantling of the structure is carried out in the reverse order of its installation and assembly. The dismantling time is 15 minutes.

Recommendations for installation. For ease of use, an OSB sheet measuring 1500 x 500 x 3 mm can be used (Fig. 2).

To close the niche from the trench side, wooden shields and other improvised means can be used to protect and camouflage the shelter (not considered in this work).

When constructing the shelter, it is important to remember that when digging out the niche, the protective top layer of soil (at least 1 m) must be preserved, and the bottom of the shelter must be at least 30 cm above the bottom of the trench to prevent flooding by surface water.

In special conditions (sand, high groundwater levels), it is advisable to install the shelter on the ground, protecting it around the perimeter with loose gabion structures. In the vertical projection of the positions, it is possible to lay bags with local soil in 1-2 rows [9, pp. 90-94].

Analysis of the improvement of unit survivability as a result of using individual shelters. It should be noted that the time and labour intensity of work on the construction of group shelters (covered trenches, dugouts) are significantly higher than those of the structure under consideration. The average time required to construct a shelter is 1.5 hours, and a covered trench is 2 hours 20 minutes. One of the criteria for increasing the survivability of a unit is the time it takes to construct fortifications and occupy them, as well as the time it takes for the enemy to detect their location [10, p. 5]. Therefore, the construction of shelters in the side walls of trenches is a priority measure.

Conclusions and prospects for further research.

The design of the proposed mobile shelter has been verified by calculations and can be used to protect personnel in conditions of loose soil up to 1.5 m thick.

This structure is not intended to withstand a direct hit from an artillery shell or equivalent external load, but it is effective in protecting against primary and secondary debris from enemy weapons; it significantly reduces the impact of the blast wave (especially when using side shields).

A single copy of the proposed shelter was manufactured and sent to one of the Defence Forces units, where it received positive feedback – the shelter design increases the protective properties of the unit stronghold. It is advisable to place such a shelter next to the place where a soldier is firing in a trench, as this will significantly reduce the time it takes to take cover in the event of a sudden barrel, mortar or rocket salvo fire, drops and other means of destruction from UAVs. At the same time, based on the results of field use, there are suggestions to refine the structure in order to reduce the overall weight and add protective doors to the kit.

Based on the results of the work description, the following areas for improvement of the structure are identified:

1. Connection of structural elements. The proposed structure features bolted connections. It takes 45 minutes to assemble. To reduce assembly time, it is advisable to use welded canopy-type connection elements for vertical and horizontal structural elements.

2. Protective and camouflage elements on the trench side were not considered in this work, although they are of great importance. Options for the side wall on the trench side: wooden shield, camouflage net, metal hatch, or a combination of these options.

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**РОЗРОБЛЕННЯ КОНСТРУКЦІЇ МОБІЛЬНОГО УКРИТТЯ У НЕСТІЙКИХ ҐРУНТАХ
ДЛЯ ЗАХИСТУ ОСОБОВОГО СКЛАДУ СИЛ ОБОРОНИ
ВІД ЗАСОБІВ УРАЖЕННЯ ПРОТИВНИКА**

Активний розвиток фортифікаційної науки відбувається у періоди ведення війн. Удосконалення озброєння і досвід війни змушують здійснювати пошук нових форм, конструкцій, матеріалів і обладнання для збереження своїх вогневих засобів і людських ресурсів. Особливо гостро постає питання виживання військових на першій лінії оборони в умовах постійного вогневого контролю противника.

Однак, в умовах бойових дій, що розгорнулися на території України, існує серйозна проблема з наявністю природних запасів деревини необхідної якості та в достатній кількості безпосередньо в зоні конфлікту. Це створює труднощі, пов'язані з необхідністю організації складних та дорогих поставок деревини з віддалених регіонів. У зв'язку з цим важливо знайти альтернативні інженерні рішення, які б забезпечили військових надійними укриттями без залежності від місцевих ресурсів.

Проаналізовано наявні фортифікаційні споруди. Споруди, що будуються в умовах постійного вогневого контролю противника, мають примітивну конструкцію і низьку здатність до захисту особового складу. Вони облаштовані вручну з використанням підручних матеріалів і конструкцій, а найчастіше – із дерев'яних елементів. З огляду на те, що на території України, де відбуваються бойові дії, природні запаси деревини необхідної якості дуже незначні, необхідно або підвозити деревину з іншої місцевості, або шукати альтернативні рішення.

Розроблено і запропоновано мобільне збірно-розбірне укриття, виготовлене з металоелементів. Вага найважливого елемента комплексу дає змогу переносити його одній людині. Військовослужбовець здатен самостійно встановити укриття і використовувати його багаторазово.

Ключові слова: *фортифікаційні споруди; ніша для укриття; утримання обвалів; мобільні укриття.*