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JUSTIFICATION OF THE REQUIREMENTS FOR THE CONSTRUCTION OF PROTECTIVE STRUCTURES BY MEANS UNDERGROUND WORKINGS IN AN EXPLOSIVE MANNER

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In the opposition of the people of Ukraine to the aggressive policy of the Russian Federation, the question of studying the experience of combat operations in the east of our state is relevant. Analysis of the losses suffered by the Armed Forces of Ukraine and the civilian population during the operation. The Joint Forces (anti-terrorist operation) in Donetsk and Luhansk region clearly point to the need to study the issue of creating safe shelters, especially for the civilian population with limited time and resources. This can be realized provided that explosive methods of underground construction are used alongside traditional earthworks.

The construction of such structures must be strong and have a sufficient internal volume and ensure the safety of the people there and allow the placement of various household and sanitary equipment.

Based on the above, it should be noted that the article considers the topical issue of arrangement of underground structures and shelters in one of the ways, namely explosive. The essence of the explosive method of arranging underground workings is that a well is arranged in the soil, in which the appropriate charge of the explosive is installed and detonation is carried out. Due to the explosion of the charge, a camouflet cavity is formed, which is used for the construction of an underground protective structure or its elements.

The use of this method can significantly reduce and sometimes completely eliminate time-consuming and unproductive work on the development and removal of soil from the slaughter. Accordingly, the conditions of camouflage of buildings are significantly improved and the terms of their construction are reduced.

The purpose of the article is to highlight the methodological approach to substantiate the requirements for the main indicators of construction of protective structures by arranging underground workings in an explosive manner.

The considered methodical approach can be used both at planning of actions for the fortification equipment of shelters for the civilian population and during carrying out scientific researches for the purpose of substantiation of requirements to the basic indicators of construction of protective constructions by arrangement of underground workings by explosive way. As a direction of further research in the subject area is the improvement of scientific and methodological approach to the calculation of a multilayer underground protective structure.

Key words: construction, civilian population, earthworks, blasting, dynamic loading, shock wave, soil, camouflet, deep charge, calculation methods, safety, optimization.

Introduction. The problematic issue in the field of civil protection and engineering support for the preservation of human life and health is relevant [1-3] in conditions of active hostilities in areas of armed conflict.

The solution to this issue becomes possible thanks to the skilful combination of the protective properties of the terrain with the construction of defensive fortifications, mainly underground. Most of the problematic issues of survivability under such conditions require in-depth study.

Fortification equipment (FE) of defensive line systems, areas and positions of troops in the formation of defense is one of the most important tasks. At the same time, the role and significance of FE in modern conditions is growing significantly. This is due to the discrepancy between the spatial scope of the conduct of hostilities and the existing forces taking part in them, as well as the discrepancy between the scope of tasks for the construction of protective structures and the capabilities of troops to create it.

Analysis of the research and publications showed [4-5] that the sufficient attention was paid to the issues of FE and especially to the protective properties of fortifications buildings. At the same time, the issue of protective properties of the structural elements of protective structures, as well as the technology of their construction currently need additional study. There are methods of substantiation of requirements to the specified constructions which are considered in some scientific works [6-7], but the results obtained differ in objectivity and reliability from the generally accepted ones. At the same time, the issue of construction of the protective structures in promising ways, namely the explosive method, is not fully investigated and not to highlight enough. Thus, there is a need in the theory of engineering support, on substantiation of requirements to processes of arrangement of underground workings by explosive way. Given the above, the purpose of the article is to highlight the methodological approach to justify the requirements for the main indicators of construction of protective structures by arranging underground workings in an explosive manner.

The main material of the article. During the detonation of explosive located in the soil (rock), funnels are not always formed on the soil surface. The minimum depth of the charge, at which the funnel is not formed on the free surface, but only some swelling of the soil (rock), is called the critical depth.

The charge that laid at the critical depth $h_{крит}$ is called *the maximum charge of loosening* or the *largest camouflet*. Charges are located at the depths that

exceed the critical depth are called *camouflet*. The mass of the maximum charges of loosening (the largest *camouflet*) is determined if the explosion indicator n = 0.

These zones in the case of concentrated charges have the shape of a sphere, and in the case of elongated charges - the shape of an ellipsoid. The mechanical action of the *camouflet* explosion (Fig. 1) is shown:

in the formation of a cavity (void) or *zone of displacement* of the soil (rock);

in crushing (destruction) of soil (rock) with a violation of the connection of particles within a certain zone, which is called the *zone of destruction*;

in the shaking of the soil (rock) with the destruction or damage of structures located in it within a zone called the *zone of dangerous shaking*.

The radius of the zone of displacement of the soil (rock), which is formed by the explosion of *camouflet* R_v (in meters), is determined by the formula:

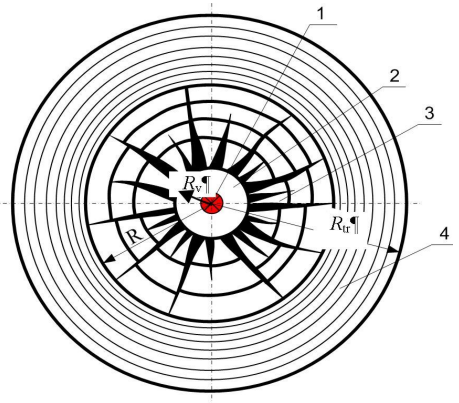

Fig. 1. Scheme of mechanical action of *camouflet* explosion: 1 – charge; 2 – zone of displacement; 3 – zone of destruction; 4 – zone of dangerous shaking

$$R_v = mr_0, \tag{1}$$

where m is the coefficient that depends on the properties of the explosive and the shape of the charge (determined from Table 1); r_0 is the radius of charge in meters.

The charge radius r_0 is calculated by the formula:

$$r_0 = \frac{\sqrt[3]{C_z}}{18,7}; \tag{2}$$

for elongated charges:

$$r_0 = \frac{\sqrt{C_p}}{70}. \tag{3}$$

The radius of the soil destruction zone R (in meters), which is formed during the explosion of the camouflet, is determined by the formula:

$$R = 1,13\sqrt[3]{\frac{C_z}{K}}; \tag{4}$$

for elongated charges:

$$R = 1,2\sqrt{\frac{C_p}{K}}. \tag{5}$$

The value of the radius of the dangerous shaking zone R_{tr} depends on the weight of the charge $C_{z(p)}$, which is detonated, on the characteristics of the soil (rock) K and on the strength of the structure located in it, for which this value must be determined.

Table 1

The value of the coefficient m (of explosive of normal power*)

Name of soils and rocks	Value m	
	for concentrated charges	for elongated charges
Plastic clay	11,2–12,9	37,5–46,0
Ordinary clay	6,4–9,8	16,3–30,8
Soft marl	5,4–7,6	12,5–20,6
Scrap clay dark blue; sandy clay; heavy loam	4,8–6,6	10,4–17,1
Soft chalk, coquina	3,8–4,6	7,4–10,0
Marl of medium strength; marl dolomite; soft chalk-stone and high density	1,8–3,2	2,4–5,6
Fine-grained gypsum; strong shales; high density granite; limestone of medium density	1,8–2,9	2,4–4,9
Medium density granite; dense quartzites; dense limestone; sandstone; dolomite	1,6–2,5	2–4
Marble; strong limestones; dense granite; fine-grained gypsum; strong dolomite	1–2	1–3

* for ammonites, the value of m decreases by 10%, and for ammonium nitrate and dynamos - by 15%.

The meaning of the explosive method of arranging underground workings is as follows. The well is arranged in the soil, in which the corresponding explosive charge is installed along the axis of the planned work and the wellhead is plugged with material (eg soil). Due to the explosion of the explosive charge, a camouflet cavity is formed, which is used for the construction of an underground protective structure or its elements.

The use of this method can significantly reduce and sometimes completely eliminate time-consuming and unproductive work on the development and removal of soil from the slaughter. Accordingly, the conditions of camouflet of buildings are significantly improved and the terms of their construction are reduced.

The disadvantages of this method include the presence in the camouflet cavities and the surrounding soil of harmful gases containing the products of the explosion. Ventilation of such cavities requires additional resources and time.

It should be noted that the main conditions for the application of this method are:

the presence of cohesive, stable and at the same time porous soils (clay, loam, etc.);

appropriate linear planning of the building;

availability of drilling wells.

Two the best common schemes for creating underground camouflet workers are known: due to the explosion of an elongated explosive charge or an explosive chain of concentrated explosive charges located along the axis of the workers at a certain distance from each other [6]. However, studies of practical experience of fortification equipment using an explosive method of soil development have confirmed the working hypothesis of sufficient efficiency of the combined scheme of formation of underground camouflet excavations by explosive method (Fig. 2).

The technology of formation of underground camouflet workings by explosive method may include [7] the following technological processes:

well formation;

fabrication and supply of explosive charge to the well;

preparation of an explosive network (for example: electric networks);

plugging wells with driving material;

activation of the explosive network and explosion of charges;

opening, airing and inspection of camouflet workings;

penetration and strengthening of workings for an entrance;

completion of camouflet cavities to the required profile, installation of excavation and removal of excess soil.

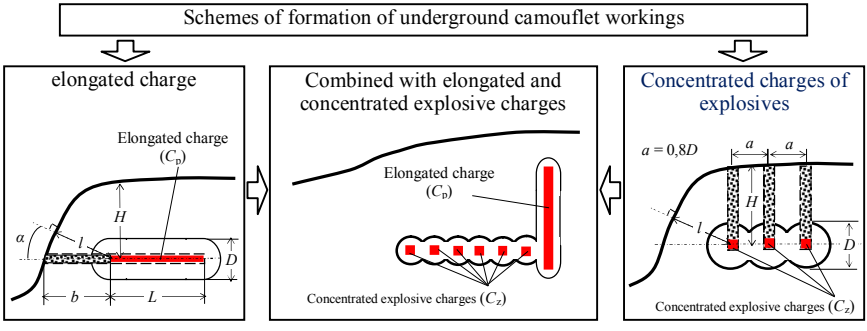

Fig. 2. Options for erection of protective structures according to different schemes by arrangement of underground camouflet workings by explosive method.

At the same time the necessary preparatory and auxiliary works are performed.

Each of these processes is characterized by heterogeneous parameters (time, labor costs, cost, probability, cost in terms of charges, detonators and other material means, etc.).

Consider the sequence of calculation of the cost of explosives for blasting in soils of different categories required for the formation of underground camouflet excavations.

The required mass of the elongated explosive charge (C_p, kg) to obtain the desired diameter of the camouflet cavity (D, m) depends on the depth of the

explosive charge, the properties of explosives and soil. The mass of explosives per 1 running meter of elongated charge is determined by empirical formula

$$C_{\text{p}} = 0{,}25 K_{\text{h}} K_{\text{vr}} K_{\text{gr}} D^2 \ , \qquad (6)$$

where K_{h} is coefficient that takes into account the degree of deepening of the explosive charge in the soil; K_{vr} is coefficient that characterizing the properties of explosive (for calculations taken for TNT equal to 4.1); K_{gr} is coefficient that characterizes the properties of the soil; D - the required diameter of the camouflet cavity, m.

The value of the coefficient K_{h} is taken equal to the value of the established linear dependence on the depth of the explosive charge in the soil, which is presented in table 2.

The value of the coefficient K_{gr} that characterizes the properties of the soil according to [8] takes values from 0,6 to 2,4. More precisely, the value of this coefficient can be determined on the basis of experimental studies according to one - two test explosions of elongated explosive charge.

Table 2

Dependence of the coefficient K_{h} value on the depth of the explosive charge in the soil

Deepening of the explosive charge center (H,m)	3	4	5	6	7	8	9	10
K_{h}	1,4	1,6	1,8	2	2,2	2,4	2,6	2,8

The amount of clogging of the explosive charge in any case must be not less than 3.5 of the diameter of the production to ensure the conditions of formation of the camouflet cavity.

Taking into account the inclination of the axis of production to the daily surface, the amount of plugging is advisable to calculate

$$l_{\text{z}} = K_{\text{y}} D \ , \qquad (7)$$

where K_{y} is the coefficient depending on the angle of inclination (Fig. 3); D – the required diameter of the camouflet cavity, m.

The mass of the explosive of the concentrated charge of the explosive is proposed to be defined as

$$C_{\text{z}} = \frac{1}{6} K_{\text{h}} K_{\text{vr}} K_{\text{gr}} D^3 \ , \qquad (6)$$

where K_{h} is the coefficient that takes into account the degree of deepening of the explosive charge in the soil; K_{vr} is coefficient that characterizing the properties of explosive; K_{gr} is coefficient that characterizes the properties of the soil; D is the required diameter of the camouflet cavity, m.

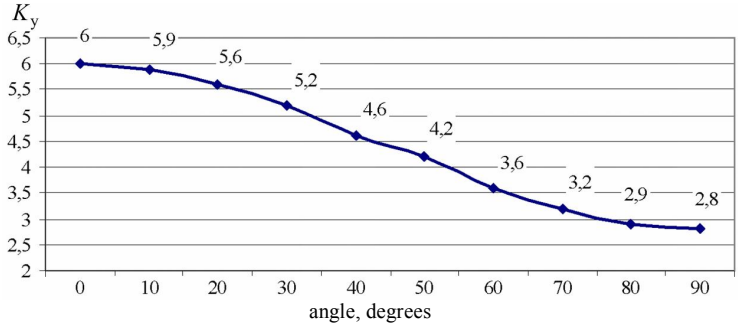

Fig. 3. The dependence of the coefficient K_y on the angle of the axis of production to the day surface

To arrange explosive cavities in the soil drill a vertical well (the depth of the well should be greater than the diameter of 100-120 times), the depth H and the diameter d, which is determined by the formulas

$$H = h + D, \tag{7}$$

$$d = 1{,}25\frac{D}{m} + 0{,}01, \tag{8}$$

where H is well depth, m; d – well diameter in meters; D – the diameter of the required cavity (wells), m; h – the required thickness of the protective layer of soil, m; m – coefficient that depends on the properties of the soil (determined by table 1).

Depending on the mass of the chain of concentrated explosive charges, their minimum depth is defined as

$$H_{\min} = \frac{1}{10} K_n K_{vr} K_{gr} \sqrt[3]{C_z}, \tag{9}$$

where K_n is the coefficient that takes into account the number of explosive charges (Fig. 4); K_{vr} is the coefficient that characterizing the properties of explosive; K_{gr} is the coefficient that characterizes the properties of the soil; C_z is mass of one explosive charge, kg.

It should be noted that the dependences shown in Figures 3 and 4 are established on the basis of a number of experimental studies and fairly accurately reflect the studied process. The permissible error in the results of calculations using the proposed methodological approach does not exceed 5%.

It is advisable to remove the concentrated charges of explosives are considered equal

$$a = 0{,}8D. \tag{10}$$

Then the required number of concentrated explosive charges can be calculated by expression

$$n = L/a, \tag{11}$$

where L is the required length of the camouflet cavity, m.

The number of charges is rounded to a larger value.

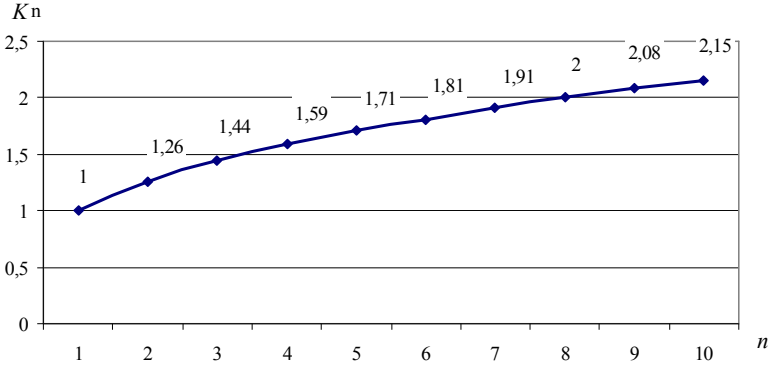

Fig. 4. Dependence of the coefficient K_{n} on the number of explosive charges

Here is an example of calculations using the proposed methodological approach. As initial data we will accept the following. It is necessary to substantiate the parameters of the explosive arrangement of the camouflet cavity in the soil with concentrated explosive charges with a length of 6 m and in diameter $D=2$ m. The required thickness of the protective layer of the soil $h=3$ m, the coefficient of the soil $K_{\text{gr}}=1{,}5$.

The depth of the well is determined by the formula (7)

$$H=3+2=5\,\text{m}.$$

In Table 2 we determine the value of the depth factor $K_{\text{h}}=1{,}8$. By formula (6) we calculate the mass of explosives of one concentrated explosive charge

$$C_{\text{z}}=\frac{1}{6}1{,}8\cdot 4{,}1\cdot 1{,}5\cdot 2^3=14{,}76\approx 15\,\text{kg}\cdot$$

The distance between adjacent charges is calculated by formula (10):

$$a=0{,}8\cdot 2=1{,}6\,\text{m}.$$

The required number of concentrated explosive charges is calculated by formula (11):

$$n=\frac{6}{1{,}6}=3{,}75\approx 4.$$

The required diameter of the well is calculated by formula (8):

$$d=1{,}25\cdot\frac{2}{8}+0{,}01=0{,}32\ \text{m}.$$

Calculate the minimum depth of the chain of concentrated explosive charges by formula (9):

$$H_{\min}=\frac{1}{10}1{,}29\cdot 4{,}1\cdot 1{,}5\cdot\sqrt[3]{15}=1{,}95\ \text{m}.$$

Based on the fact that $H > H_{\min}$, the rate of action of the explosion $n = 0$, that indicates compliance with the conditions of formation of the camouflet cavity.

Additionally, according to formulas (1) - (5), the parameters of the zones of displacement, destruction and dangerous shaking, which are shown in Fig. 1, can be substantiated.

Thus, the methodological approach considered in the article can be used both when planning activities with FE and in the course of research to substantiate the requirements for the main indicators of construction of protective structures by arranging underground workings in an explosive manner. As a direction of further research in the subject area is the improvement of scientific and methodological approach to the calculation of a multilayer underground protective structure.

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ОБҐРУНТУВАННЯ ВИМОГ ЩОДО ЗВЕДЕННЯ ЗАХИСНИХ СПОРУД ШЛЯХОМ УЛАШТУВАННЯ ПІДЗЕМНИХ ВИРОБІТОК ВИБУХОВИМ СПОСОБОМ

У протистоянні народу України агресивній політиці Російської Федерації є актуальним питання вивчення досвіду бойових дійна сході нашої держави. Аналіз втрат, яких зазнали Збройні Сили України та мирне населення, за час ведення операції Об’єднаних сил (антитерористичної операції) на території Донецької та Луганської областей чітко вказують на необхідність вивчення питання щодо створення безпечних укриттів в першу чергу для

цивільного населення при обмежені часу та ресурсів. Це можливо реалізувати при умові застосування на ряду з традиційними землерийними роботами вибухових способів улаштування підземних споруд.

Конструкція таких споруд повинна бути міцною і мати достатній внутрішній об'єм та забезпечувати безпеку людей що там знаходяться і дозволяти розміщення різноманітного побутове та санітарного обладнання.

Виходячи з вищезазначеного слід відмітити що в статті розглянуто актуальне питання улаштування підземних споруд та укриттів одним із способів, а саме вибуховим. Сутність вибухового способу улаштування підземних виробіток полягає втому що в ґрунті влаштовується свердловина, у яку встановлюється відповідний заряд вибухової речовини та здійснюється підрив. За рахунок вибуху заряду утворюється камуфлетна порожнина, що використовується для зведення підземної захисної споруди або її елементів.

Використання такого способу дозволяє значно знизити, а іноді й повністю виключити трудомісткі та непродуктивні роботи щодо розробки та видалення ґрунту із забою. Відповідно значно покращуються умови маскування споруд та скорочуються терміни їх зведення.

Метою статті є висвітлення методичного підходу щодо обґрунтування вимог до основних показників зведення захисних споруд шляхом улаштування підземних виробіток вибуховим способом.

Розглянутий методичний підхід може бути використаний як під час планування заходів з фортифікаційного обладнання укриттів для цивільного населення так і у ході проведення наукових досліджень з метою обґрунтування вимог до основних показників зведення захисних споруд шляхом улаштування підземних виробіток вибуховим способом. Як напрямок подальших досліджень у предметній галузі є удосконалення науково-методичного підходу щодо розрахунку багатошарової підземної захисної споруди.

Ключові слова: споруда, цивільне населення, землерийні роботи, вибуховий спосіб, динамічне навантаження, ударна хвиля, грунт, камуфлет, заглиблений заряд, розрахункові методи, безпека, оптимізація.

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У статті висвітлюється методичний підхід щодо обгрунтування вимог до основних показників зведення захисних споруд шляхом улаштування підземних виробіток вибуховим способом.
Бібл. 12, рис. 4, табл. 2.

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Kotsiuruba V.I., Datsenko I.P., Dachkovsky V.O., Tkach M.Y., Holda O.L., Holda M.A., *Klontsak M.Y., Mykhailova A.V.* **Justification of the requirements for the construction of protective structures by means underground workings in an explosive manner** // Strength of Materials and Theory of Structures: Scientific-and-technical collected articles – Kyiv: KNUBA, 2021. – Issue 106. – P. 129-140.

The article highlights the methodological approach to substantiate the requirements for the main indicators of construction of protective structures by arranging underground workings in an explosive manner.
Ref. 12, Fig. 4, Tabl. 2.

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