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COMMUNICATION AND TECHNOLOGICAL SOLUTIONS REGARDING THE CONSTRUCTION OF SHELTER OBJECTS AT UNDERGROUND RAILWAY STATIONS IN FRACTURED AND WATER-LOGGED ROCKS

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Abstract. The purpose of the work is to substantiate the choice of locations of underground shelter objects for the people protection during the warlike situation and methods and facilities for ensuring their stability and isolation, and to develop a combined supporting scheme taking into account mining and geological conditions.

It is proposed to arrange the shelter objects in the vicinity of the boarding platforms of the underground railway stations connecting them with the passages, means for walking downstairs and upstairs and a transport network and providing areas for the long-term stay of people, areas for sleeping and eating, shower room, medical, shopping and other necessary blocks. The shelter should be connected to the networks of the underground railway station - electricity supply, water supply and drainage, ventilation and air conditioning. Sleeping areas should be built in the form of individual compartments and arranged in several tiers along the walls of the shelter object. This arrangement of underground objects will make it possible to create a single complex (the shelter object and subway station), reduce the total cost of the shelter construction, speed up the evacuation of people in the event of natural or man-made disasters or air strikes, and ensure a long-term comfortable stay for people.

Load on supporting and parameters of roof-bolting systems were calculated for three categories of stability, which correspond to the conditions of the construction of underground railways in the Ukrainian crystalline shield. An algorithm for calculating parameters of the strengthened insulating-reinforcing protection system was built, which takes into account three types of support - rock-bolt structure, insulating-reinforcing rock-polymer layer and tubing. The developed technological solutions for the construction of underground objects assumes pre-bolting of their vaulted part according to a scheme which strengthens the interaction between the rows of bolts, improves the condition of the roof of the object, and ensures protection of the roadway and unsecured part near it during construction of the roadway. The rock-polymer layer protects the tubing against metal corrosion and leaching of concrete under the influence of groundwater, and, due to the high adhesiveness of the polymer resin, also binds the rock-bolt structure, the insulating-reinforcing rock-polymer layer and the tubing into a single reinforced system, which distributes the load around the object's perimeter. The use of modern elastic polymer resins in the protection system will contribute to resisting the alternating loads that spread in the soil during surface explosions, and ensures long-term stability and waterproofing of shelter object.

The results of the research can be used in the development of scientific prerequisites for the improvement of methods and means of construction of underground shelter objects in order to ensure the safety of their operation in case of emergency situations.

Keywords: underground structures, underground railway station, support, bolts, polymer resins.

1. Introduction

The events of the last two years show that research into the possibilities of using the underground space of cities for the construction of shelter objects is relevant for Ukraine. In developed countries, in particular, England, Italy, France, Sweden, Norway, Finland, Japan, China, the USA, Poland, the underground space is intensively developed, and considerable experience has already been accumulated in the construction of underground objects of various complexity [1–6].

Today, for sheltering people in the event of an air alert or a natural disaster, the underground premises of the underground railway boarding platforms are used, which have a very limited area and do not provide a comfortable long-term stay of people. In addition, crowds of people interfere with the normal functioning of underground railway services. On the other hand, construction of specialized autonomous underground shelters is very expensive. A reasonable way out of such a situation is the use of underground tunnels and communications of existing underground railway stations to build shelter objects near them. This approach has a number of significant advantages. First of all, it is the availability of a developed network of the underground railway infrastructure, which can be used to ensure the functioning of the shelter objects. In addition, the underground railway stations are always located in the most densely populated areas of the city, which will facilitate the evacuation of a great number of people during an alarm. Such communication solutions will provide a significant economic effect both in terms of the construction cost of the objects and in terms of energy consumption during their operation.

At the same time, an important technical task is to ensure reliable long-term stability of the shelter objects. The stability of underground structures is primarily determined by the mining and geological conditions of their location. The most effective is the arrangement of structures in strong, homogeneous, monolithic soils, at a safe distance from groundwater. At the same time, in the case of construction of dual-purpose structures, the depth of their location should be sufficient for effective reduction of elastic soil vibrations during surface explosions, and on the other hand, should take into account the increase in costs for construction and further operation of the structure due to its deepening. It should also be considered the convenience of communication when using the structures [7–12].

Simultaneous compliance with all the conditions listed above is virtually impossible. Therefore, in order to ensure the stability and isolation of dual-purpose underground structures located in a place convenient for operation, regardless of the geological conditions, the physical and mechanical parameters of soil consolidation around the structure must be substantiated, and the methods and means of the structure supporting effective for the given mining and geological conditions must be determined.

2. Methods

The experience of building and supporting the underground roadways of various purposes points to the need to solve a number of issues to ensure their proper condition during operation. The most effective way to solve the problem of insufficient stability and insulation of underground structures and increase their service life is to use combined methods of supporting, which include the use of modern means and materials [13, 14]. This is, first of all, the use of prefabricated support with a protective insulating layer and bolt systems, which, depending on the hydrogeological conditions of the location of the structure, consist of reinforced concrete or steel-polymer bolts.

The bolts form a reinforced rock layer around the structure, the strength of which is equal to the length of the bolts, which reduces the load on the protective insulating layer and on the prefabricated reinforced concrete or metal support and contributes to the long-term stability of the structure. In conditions of high water inflow, installation of reinforced concrete bolts is problematic due to washing out of cement mortar with water. In this case, steel-polymer bolts should be used, which have high adhesion with wet rocks [15]. The protective insulating layer must have elastic properties, which will prevent the formation of cracks in it during fluctuations of the adjacent soil and ensure reliable gas and water insulation of the structure after the impact of surface explosions.

Therefore, the reasonable choice of locations of underground shelter objects, methods and means of ensuring their stability and isolation, and development of schemes for a rational combination of various types of supporting with taking into account mining and geological conditions is an urgent problem of protecting people during martial law.

3. Results and their discussion

The IGTM of the National Academy of Sciences of Ukraine developed several methods of construction of underground objects of various purposes for use both in peacetime and in wartime in Ukraine [16, 17]. They include various schemes of combined supporting of underground structures, the basis of which are bolt systems.

The normative rate of rock pressure on the shelter object support is determined depending on the depth of its location and engineering and geological conditions. When laying a tunnel deep in stable rocks, a standard rock pressure is determined according to the hypothesis of Prof. M.M. Protodiakonov, according to which the vertical rock pressure on the support is created by the weight of the rock bounded from above by the contour of the pressure vault, and by the collapse planes from the sides.

Support parameters were calculated for the conditions of construction of underground railway in the Ukrainian crystal shield. In these areas, complex conditions for ensuring stability, which refer to support classes 3–5 according to the European classification, or soil stability categories III-V according to the Ukrainian classification, are determined according to the condition of the tunnel face during its construction.

Fig. 1 shows copied excerpt from the engineering geological section of wells No. 1, No. 2 and No. 5 with different categories of soil stability for the conditions of the construction of the underground railway in the Ukrainian crystalline shield. Table 1 shows parameters and conditions for the location of the tunnel near these wells.

The coefficient of strength of rocks according to M. M. Protodyakonov "in the massif"

$$f = a \cdot f_{str},$$

where a is the coefficient that takes into account the cracking of the massif (0.6 for category 3, 0.45 for category 4, 0.28 for category 5).

The size of the span L and the pressure vault (collapse) h_1 are determined by the formulas:

$$L = B + 2h \cdot tg\left(45^0 - 0.5\varphi\right);$$

$$h_1 = 0.5\, L/f,$$

where B and h are width and height of the working.

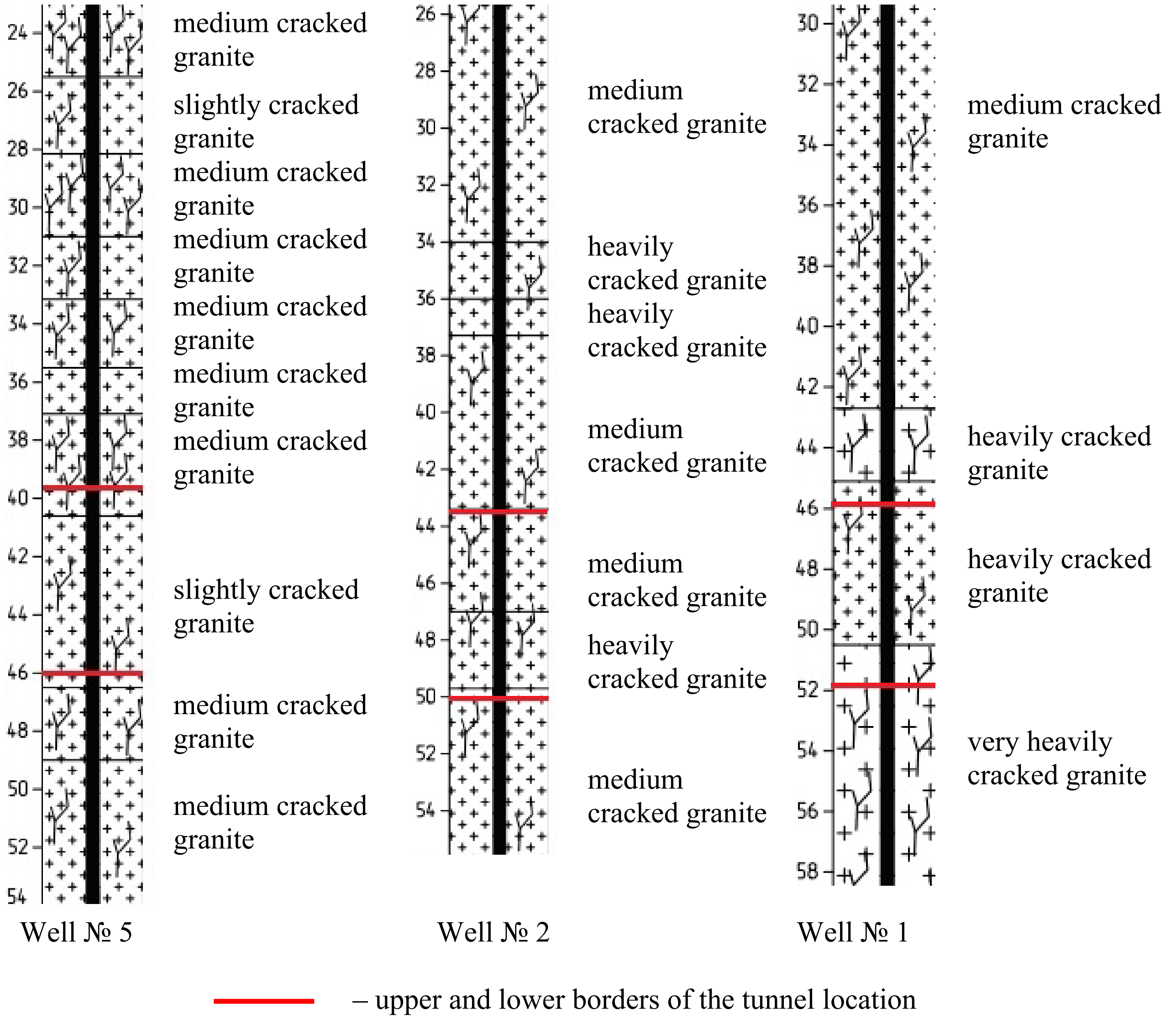


Figure 1 – The copied excerpt from engineering-geological section of the wells typical for the conditions of the construction of the underground railway in the Ukrainian crystalline shield

The standard vertical rock pressure q_s is assumed to be uniformly distributed along the span, and the horizontal rock pressure p_s is taken according to the height of the tunnel and is determined by the formulas:

$$q_s = \gamma \cdot h_1,$$

$$p_s = \gamma(h_1 + 0{,}5h) \cdot tg^2(45^0 - 0{,}5\varphi),$$

where γ is the specific gravity of the rock, kN/m^3.

The size of the calculated loads q_c and P_c is determined according to [18] by multiplying the normative values by the corresponding load reliability factor γ_f = 1.1:

$$q_c = q_s \cdot \gamma_f,$$

$$P_c = p_s \cdot \gamma_f .$$

Table 1 – Parameters and conditions of locating the tunnel near the wells

Parameters	Well №5	Well №2	Well №1
Depth of the tunnel location, m	39.5–46	43.4–50	45.3–52.0
Depths and properties of granite in the roof of the tunnel	14.4–39.5 m fine- and medium-grained, medium- and slightly-cracked granite	12.6–43.4 m fine- and medium-grained, medium- and heavily cracked granite	28.6–45.8 m fine- and medium-grained, heavily and very heavily cracked granite
Depth and size max. specific water absorption	25.5–30.5 m, 0.015 l/(min·m^2)	25.5–29.0 m, 0.20 l/(min·m^2)	35.0–38.0 m, 2.2 l/(min·m^2)
Class (category) of stability	3 (III)	4 (IV)	5 (V)
Working width B, m	6.363	6.463	6.563
Working height h, m	6.507	6.607	6.707
Angle of internal friction of the rock φ	78^0	70^0	54^0
Specific weight of rock γ, kN/m^3	25	23	22
Coefficient of strength of rocks f_{str}	8–10	6–8	5–6

When the tunnel route goes from well DSK-2 to the well DSK-1, its water level increases approximately 10 times, and makes it impossible to use reinforced concrete bolts. Therefore, bolts with polymer fixing should be used.

Taking into account the calculated load on the support, its parameters are calculated for the chosen conditions of construction of the protection shelter. For III-V soil stability category of the rock massif, we calculate the length l_p of the working part of the bolt, m:

$$l_p = 0{,}75B \cdot k_T / f .$$

where k_T is the coefficient of massif cracking.

The length of the locking part l_z for reinforced concrete bolts must be at least 0.40 m. For the conditions of the 3rd and 4th category of soil stability of the rock massif, we accept that l_z= 0.8 m and l_z = 1.0 m, respectively.

The total length of the bolt must be at least (accounting the length of part of the bolt protruding from the rock l_k = 15 cm), m:

$$l_b = \gamma_f \cdot (l_p + l_z + l_k) .$$

The bearing capacity N of reinforced concrete bolts (wells No. 2, 5) is determined by the formula:

$$N = \pi \cdot l_z \cdot d_r \cdot \tau_{ad} \text{ кN},$$

where d_r is the diameter of the bolt rod, m, which is taken as 25 mm; τ_{ad} = 2500 kPa is specific adhesion of concrete to the reinforcing rod with a hardening time of not more than 6 hours (according to table 10 from [18]).

The limit distance between the bolts under the condition of the bearing capacity of the fixed part of the bolt, m, is

$$\alpha = \frac{1}{\gamma_f} \sqrt{\frac{N}{1{,}5\gamma l_\text{p}}} \,.$$

The calculated load on the bolt is, kN:

$$P = 1.5\gamma \cdot \alpha^2 \cdot l_p \,,$$

where 1.5 is the overload factor.

The bearing capacity N_{brc} (kN) of steel-polymer bolts (well No. 1) is determined by the formula [19]:

$$N_{brc} = N_b \cdot k_f \cdot k_{it} \cdot k_c \cdot k_R \,,$$

where N_{b} is the tensile bearing capacity of the bolt rod, kN; k_f is the bolt fixing quality coefficient, which takes into account the length of the bolt fixing section in the hole, $k_f \in [1.0;\ 1.2]$; k_{it} is coefficient of initial tension of the bolt, the value of which increases due to the increase in tension during installation, $k_{\text{it}} \in [0.8;\ 1.1]$; k_{c} is a coefficient which takes into account the conditions of bolt installation, the values of which decrease as the distance behind the installation of bolts from the tunnel face increases, $k_{\text{c}} \in [0.6;\ 1.2]$; k_{R} is a coefficient which depends on the uniaxial compressive strength of the rocks, their density and the depth of the structure location $k_{\text{R}} \in [1.0;\ 2.0]$.

The results of the calculation of loads and parameters of the tunnel support for different categories of soil stability are shown in the table. 2.

Table 2 – Results of calculation of the support loads and parameters

Parameters	№ 1	№ 2	№ 5
Coefficient of strength of rocks "in massif", f_{str}	1.4	2.7	4.8
Span size L, m	10.86	8.83	7.7
Pressure vault h_1, m	3.88	1.64	0.8
Vertical rock pressure q_{c}, kN/m^2	93.88	41.38	22.07
Horizontal rock pressure P_{c}, kN/m^2	17.98	4.01	1.18
Length l_{p} of the working part of the bolt, m	2.75	1.8	0.99
Total length of the bolt l_b, m	2.9	3.245	2.134
Bolt bearing capacity N_{brc}, kN	250.0	196.3	157.1
Limit distance between the bolts α, m	1.0	1.6	1.8
Calculated load on the bolt P, kN	210.0	159.0	120.3

The usage of the proposed parameters of the roof-bolting support makes it possible to create a bolted layer of rocks, which significantly strengthens the interaction between the rows of bolts, prevents the development of inelastic deformations, the soil fall in the unsecured part of the tunnel during its construction, improves the condition of the roof, which contributes to the speed of the tunnel construction due to the separation in time and space of the processes of its construction and installation of tubing.

In the case of construction of shelter objects for the population, the following communication solutions are proposed. In order to speed up the evacuation of people during an air alert, the underground object is arranged in a crowded place, in the vicinity of the boarding platform of the underground railway station and is connected to it by passages, facilities for walking downstairs and upstairs. It also makes it possible to connect the object to the networks of the underground railway station - groundwater pumping systems, water and electricity supply, ventilation and air conditioning, microclimate control, and provides emergency exits.

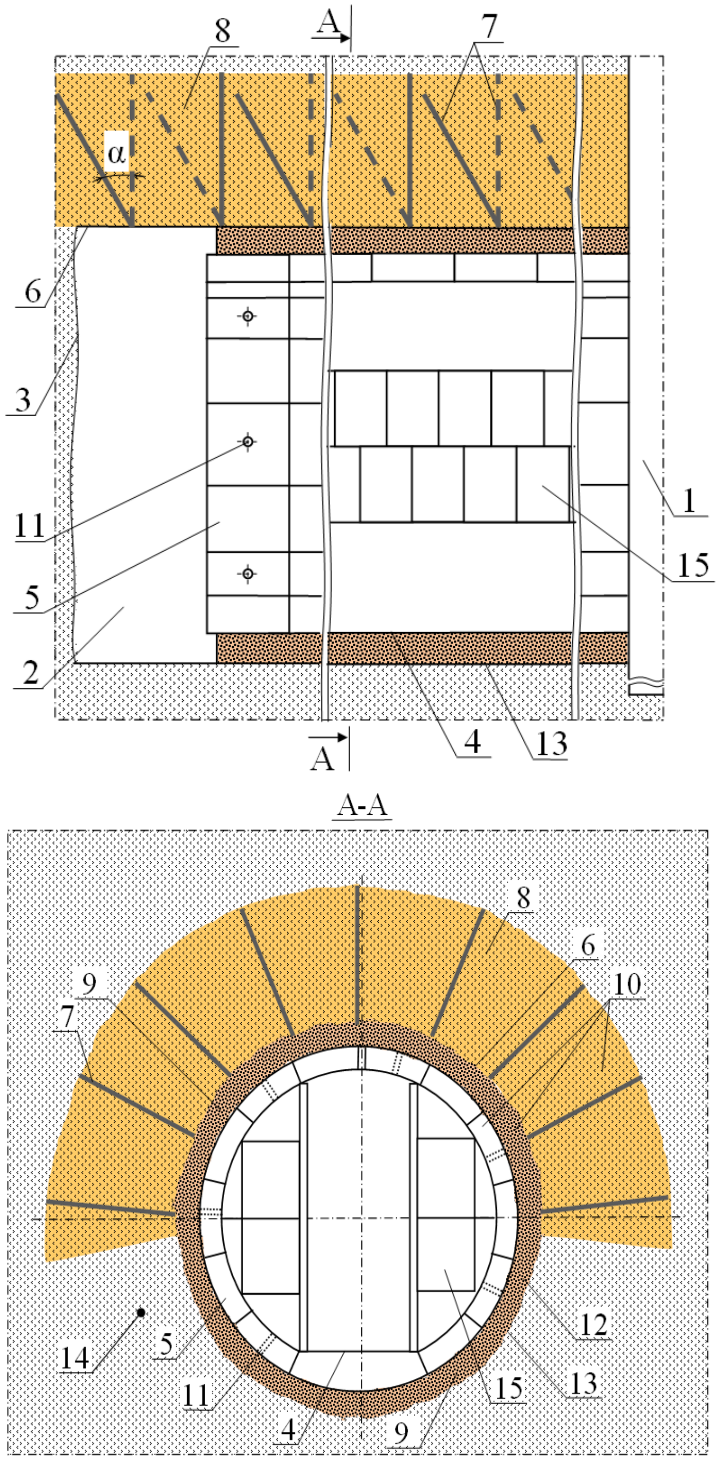
To increase comfort in case of a long stay of people, the object is equipped with areas for sleeping and eating, shower room, medical, shopping and other necessary blocks. Sleeping areas should be built in the form of individual compartments and arranged in several tiers along the transport network on the sides of the tunnel, around which a single reinforced insulating and strengthening protection system is created.

During the construction of the shelter object (Fig. 2), it is necessary to comply with the requirements of the current state construction standards of Ukraine for the construction of the underground railway [20]. The technological process begins with the construction of a vertical shaft 1 and a tunnel 2, which is connected to the vertical shaft 1 by a transport network 4.

Next, the shelter is connected to the networks of the underground railway station - electricity supply, water supply and drainage, ventilation and air conditioning. This arrangement makes it possible to create compatible networks and form a single complex (shelter and underground railway station) that will ensure a long-term stay of people in the event of both daily use of the object and in the event of natural or man-made disasters or an air alert.

Sleeping areas are built in the form of individual compartments 15 and arranged along the transport network in several tiers on the sides of the tunnel (Fig. 2), which provides the possibility of compact and comfortable living of people.

During the construction of the tunnel, following the tunnel face, pre-bolting support is carried out in the vault part of the tunnel with bolts 7 at the first stage, prior to the installation of the tubing. Part of the bolts is installed in the plane of the tunnel section perpendicular to the longitudinal axis, and the other part - with an inclination α towards the face 3 (Fig. 2). This significantly strengthens the interaction between the rows of bolts, provides protection of the face and the part of the tunnel unsecured by tubing from sudden falls of the soil, and improves the condition of the roof of the tunnel as a whole. Pre-bolting support also prevents the development of inelastic deformations and soil separation and makes possible to speed up the tunnel construction and increase the safety of workers in the event of a delay in the installation of the tubing from the side of the tunnel face.



1 – vertical shaft, 2 – tunnel, 3 – tunnel face, 4 – transport network, 5 – sections of tubing, 6 – vault part of the tunnel, 7 – reinforced concrete or steel-polymer bolt, 8 – reinforced rock-bolt structure, 9 – insulating-reinforcing rock-polymer layer, 10 – strengthened insulating-reinforcing protection system, 11 – openings of tubing sections, 12 – crushed rocks, 13 – tray part of the tunnel, 14 – adjacent soil, 15 – individual compartment, α – angle of inclination of the bolt

Figure 2 – Scheme of support the shelter object at the underground railway station

At the next stage of tunnel construction, a layer of crushed rock 12 is poured into its tray 13 and sections of tubing are installed along the entire contour. The space between the tubing and the adjacent soil 14 is filled with crushed rocks, its ends are sealed, and polymer resin is injected under pressure. For this purpose, a resin with high compressive strength should be used (for example, two-component resins Bevedol WFA, MC-Montan Injekt FR / FN / FS, or MasterRoc MP 364 flex with uniaxial compressive strength 80 MPa, 75 MPa and 34 MPa, respectively). The components of these polymer two-component resins are mixed in a 1:1 ratio in a special pneumatic pump and fed into the fixed space through the openings 11 of the sections of the tubing. Thanks to this, an insulating-reinforcing rock-polymer layer 9 (Fig. 1) is created, which protects the tubing against metal corrosion and concrete leaching under the chemical influence of aggressive groundwater, which contributes to the long-term stability and waterproofing of the tunnel in water-saturated soils

In addition, the insulating-reinforcing rock-polymer layer 9, due to the high adhesiveness of the polymer resin, provides good adhesion between the reinforced rock-bolt construction 8 and the tubing 5 and forms a single strengthened insulating-reinforcing protection system 10, which contributes to the distribution of alternating loads along the perimeter of the tunnel during the surface explosion.

The algorithm for calculating protection system parameters.

In the case of combining bolts with other types of support, part of the load equal to the difference between the full load and the bearing capacity of the additional support is applied to the bolts. In case of application of the proposed strengthened insulating-reinforcing protection system:

$$P_b = P - P_t - P_{rp},$$

where P_b is the load taken by the roof bolting support, kN; P *is* a calculated load on the support per 1 linear meter of a long underground structure, kN; P_t is the load taken by the tubing support and determined, kN, according to the technical data of its manufacturer; P_{rp} is the load taken by the insulating-reinforcing rock-polymer layer, kN.

The load P_t taken by the tubing support is determined according to its technical data sheet. The load P_{rp} taken by the insulating-reinforcing rock-polymer layer is determined by the method of calculating the cylindrical shell with accounting the thickness of this layer, the strength characteristics of the rock used and its fractionation, and the parameters of the polymer resin (uniaxial compressive and tensile strength, insulating properties, adhesion with the rock and tubing material) [15, 19].

Determining the strength parameters of the rock-polymer layer P_t is a separate task which will be solved in further research.

4. Conclusions

1. The proposed communication solutions for arranging shelter objects have the following advantages:

– location of the tunnel in the vicinity of the boarding platform of the underground railway station and the connection with the boarding platform and the facilities for walking downstairs and upstairs by means of passages, provides access to premises for long-term stay of people and their quick evacuation in case of natural or man-made disasters and air alarms;

- equipping the shelter with sleeping and eating areas, shower room, medical, shopping and other necessary blocks and the construction of sleeping blocks in the form of individual compartments, arranged in several tiers on the sides of the tunnel allows to increase the period of comfortable stay of people;

- connection to the networks of the underground railway station - electricity supply, water supply and drainage, ventilation and air conditioning - makes it possible to create a single complex (shelter object and underground railway station), will reduce the total cost of building a shelter and ensure a long-term stay of people.

2. The developed technological solutions for the construction of underground shelters have the following advantages:

- implementation of pre-bolting support and creation of a reinforced rock-bolt structure in the vault part of the tunnel with taking into account mining and geological conditions of its location and a long period of operation that includes the installation of part of the steel-polymer bolts in the cross-section plane of the tunnel perpendicular to the longitudinal axis, and other part - with an inclination towards the tunnel face, makes it possible to create an bolted layer of rocks which resists the development of inelastic deformations and rocks separation, significantly strengthens the interaction between the rows of bolts, improves the condition of the tunnel roof, provides protection of the tunnel face and its unsecured part near the tunnel face during its construction.

– creation of an insulating-reinforcing rock-polymer layer by way of resining the crushed rocks in the space between the support and the adjacent soil through the holes of the sections of the tubing supports allows to protect them against metal corrosion and leaching of concrete under the chemical influence of aggressive groundwater and contributes to the long-term stability and waterproofing of the tunnel in water-saturated soils;

– connecting together the rock-bolt structure, the insulating-reinforcing rock-polymer layer and the tubing support into a single strengthened insulating-reinforcing protection system due to the high adhesiveness of the polymer resin contributes to the distribution of loads along the perimeter of the tunnel, which leads to increased stability, waterproofing, operational reliability and term of use of the object.

3. The performed calculations of the load on the tunnel support and the parameters of the bolting systems for three categories of soil stability, which correspond to the conditions of the underground railway structure in the Ukrainian crystalline shield made it possible to justify the use of different types of bolting systems.

4. The algorithm is proposed for calculating the parameters of the strengthened insulating-reinforcing protection system, which takes into account three types of support - rock-bolt structure, insulating-reinforcing rock-polymer layer and tubing. The developed methodology for calculating the rational parameters of the rock-polymer

layer taking into account its thickness, the strength characteristics of the used rock and its fractionation, and the parameters of the polymer resin (uniaxial compressive and tensile strength, insulating properties, adhesion to the rock and tubing material) requires further research with using methods of physical modeling.

REFERENCES

1. Trigub, R.M. (2019), "The role of underground space in a modern city", *Modern technologies and calculation methods in construction*, vol. 12, pp. 207–212, https://doi.org/10.36910/6775-2410-6208-2019-2(12)-25

2. Kaufman, L. (2020), Underground space of cities: planning and development, available at: https://club.berkovich-zametki.com/?p=53194 (Accessed 08 November 2023).

3. Besner, J. (2017), "Cities Think Underground – Underground Space (also) for People", *Urban Subsurface Planning and Management Week*, SUB-URBAN 2017, 13–16 March 2017, Bucharest, Romania.

4. Jasińska, K. (2016), "Underground as an Integral Part of the Contemporary City: Functional, Spatial and Visual Aspects", *Technical Issues*, 1/2016, pp. 37–43, http://technical-issues.com/paper/2016-01/full_037-043.pdf

5. Lysikov, B.A. and Kaufman, L.L. (2004), *Podzemnaia struktura horodov (Obzor zarubezhnoho stroytelstva)* [Underground structure of cities (Review of foreign construction)], Nord-press, Donetsk, Ukraine.

6. Samedov, A.M. and Kravets V.H. (2011), *Budivnytstvo miskykh pidzemnykh sporud* [Construction of urban underground structures], NTUU «KPI», Kyiv, Ukraine.

7. Cui, J., Broere, W. and Lin, D. (2021), "Underground space utilisation for urban renewal", *Tunnelling and Underground Space Technology*, vol. 108, article 103726, https://doi.org/10.1016/j.tust.2020.103726

8. Von Der Tann, L., Sterling, R., Zhou, Y. and Metje, N. (2020), "Systems approaches to urban underground space planning and management. A review", *Underground Space (China),* vol. 5, no. 2, pp. 144–166. https://doi.org/10.1016/j.undsp.2019.03.003

9. Xiangsheng Chen (2018), "Research on combined construction technology for cross-subway tunnels in underground spaces", *Engineering*, vol. 4, no. 1, pp. 103–111, https://doi.org/10.1016/j. eng.2017.08.001

10. Yajie Xu and Xiangsheng Chen (2020), "Quantitative analysis of spatial vitality and spatial characteristics of urban underground space (UUS) in metro area", *Tunnelling and Underground Space Technology*, vol. 111, article 103875, https://doi.org/10.1016/j.tust.2021.103875

11. Wout Broere (2016), "Urban underground space: Solving the problems of today's cities", *Tunnelling and Underground Space Technology*, vol. 55, pp. 245–248, https://doi.org/10.1016/j.tust.2015.11.012

12. Hashash, Y.M.A., Jeffrey J. Hook, J.J., Schmidtb, B. and Yaoa, J.I. (2001), "Seismic design and analysis of underground structures", *Tunnelling and Underground Space Technology*, vol.16, no 4, pp.247–293, https://doi.org/10.1016/S0886-7798(01)00051-7

13. Krukovskyi, O.P., Kurnosov, S.A., Makeyev, S.Yu. and Stadnychuk, M.M. (2023), "Determination of the reliability of mine support equipment considering its deformation risks", *Strength of Materials*, vol. 55, no. 3, pp. 475–483, https://doi.org/10.1007/s11223-023-00540-5

14. Yalanskiy, A, Slashchov, I, Makeiev, S and Seleznjov, A. (2022), "New technical solutions in the field of protection and fastening of mine workings", *Essays of Mining Science and Practice:* III International Conference, IOP Conference Series: Earth and Environmental Science, 06/10/2021 - 08/10/2021, Dnipro, Ukraine, https://doi.org/10.1088/1755-1315/970/1/012015

15. Stadnichuk, M.M., Krukovskyi, O.P., Kurnosov, S.A., Makeiev, S.Yu. and Semenyuk, M.I. (2022), "Calculation of parameters of the protection means for roadway districts in which cement-mineral mixtures are used", *Geo-Technical Mechanics*, no 163, pp. 108–118, https://doi.org/10.15407/geotm2022.163.108

16. Bulat, A., Vozijanov, V., Kurnosov, S., Krukovskyi, O., Makeiev, S., Parkhomenko, O., Pryymachenko, A. and Zerkal, V., M.S. Poliakov Institute of Geotechnical Mechanics under NAS of Ukraine (2023), Sposib pidvyshchennya stiykosti ta hidroizolyatsiyi transportnykh tuneliv i perehinnykh tuneliv metropoliteniv [The method of increasing the stability and waterproofing of transport tunnels and subway tunnels], State Register of Patents of Ukraine, Kiev, UA, Pat. № 153187.

17. Bulat, A., Vozijanov, V., Kurnosov, S., Krukovskyi, O., Babyi, E., Makeiev, S., Kliuev, E. and Sheiko, A., M.S. Poljakov Institute of Geotechnical Mechanics under NAS of Ukraine (2023), Sposib zakhystu ob'yektiv krytychnoyi infrastruktury hospodarchoho ta spetsial'noho pryznachennya [The method of protection of objects of critical economic and special infrastructure], State Register of Patents of Ukraine, Kiev, UA, Pat. № 154374.

18. Ukraine Ministry of Regional Development and Construction (2011), *SBR B.2.3-7-2010. Sporudy transportu Metropoliteny. Derzhavni budivel'ni normy Ukrayiny* [SBR B.2.3-7-2010. Transport buildings Metropoliten. State building regulations of Ukraine], Ukraine Ministry of Regional Development and Construction, Kiev, Ukraine.

19. Ukraine Ministry of Energy and Coal Industry (2014), *10.1.05411357.010:2014. Systema zabezpechennya nadiynoho ta bezpechnoho funktsionuvannya hirnychykh vyrobok iz ankernym kriplennyam. Zahal'ni tekhnichni vymohy: Normatyvnyy dokument Minenerhovuhillya Ukrainy. Standart* [10.1.05411357.010:2014. A system for ensuring the reliable and safe functioning of mine workings with bolt fastening. General technical requirements: Regulatory Document Energy and Coal Industry of Ukraine. Standard], Ukraine Ministry of Energy and Coal Industry, Kiev, Ukraine.

20. Ministry of Regional Development of Construction and Housing and Communal Services of Ukraine (2019), *DBN V.2.3-7-2018. Metropoliteny. Osnovni polozhennya: Normatyvnyy dokument Minregion Ukrainy. Standart* [DBN V.2.3-7-2018. Metropolitans.

Substantive provisions: Regulatory Document Regional Development, of construction and housing and communal services of Ukraine. Standard], Minregion Ukraine, Kiev, Ukraine.

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КОМУНІКАЦІЙНІ ТА ТЕХНОЛОГІЧНІ РІШЕННЯ ЩОДО СПОРУДЖЕННЯ ОБ'ЄКТІВ УКРИТТЯ ПРИ СТАНЦІЯХ МЕТРОПОЛІТЕНУ В ТРІЩИНУВАТИХ І ОБВОДНЕНИХ ПОРОДАХ

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Анотація. Метою роботи є обґрунтування вибору місць розташування підземних об'єктів укриття для захисту людей під час військового стану, способів і засобів забезпечення їх стійкості і ізоляції та розробка комбінованої схеми кріплення з урахуванням гірничо-геологічних умов.

Запропоновано об'єкти укриття розташовувати в околиці посадочних платформ станції метрополітену та з'єднувати з ними переходами, засобами спуску і підйому та транспортною мережею, оснащувати приміщеннями для довготривалого перебування людей, які слід обладнувати спальними, харчовими, душовими, медичними, торговими та іншими необхідними блоками. Здійснювати приєднання укриття до мереж станції метрополітену – електропостачання, водопостачання і відведення, вентиляції та кондиціювання повітря. При цьому спальні блоки споруджують у вигляді індивідуальних купе та розміщують в декілька ярусів по боковим сторонам об'єкту укриття. Таке розташування підземних об'єктів дасть можливість створення єдиного комплексу (об'єкт укриття та станція метрополітену), зменшить загальну вартість побудови укриття, прискорить евакуацію людей у разі стихійних, лих техногенних катастроф або повітряної тривоги та забезпечить довготривалий термін їх комфортного перебування.

Проведено розрахунки навантаження на кріплення та параметрів анкерних систем для трьох категорій стійкості, які відповідають умовам будови метро в Українському кристалічному щиті. Побудовано алгоритм розрахунку параметрів посиленої ізолююче-зміцнюючої охоронної системи, який враховує три типи кріплення – породно-анкерну конструкцію, ізолююче-зміцнюючий породно-полімерний шар та тюбінгове кріплення. Розроблені технологічні рішення щодо побудови підземних об'єктів передбачають випереджаюче анкерування їх склепінної частини за схемою, яка посилює взаємодію між рядами анкерів, поліпшує стан покрівлі об'єкту, забезпечує під час його проведення охорону вибою та незакріпленої частини біля вибою. Породно-полімерний шар захищає тюбінгове кріплення від корозії металу і вилуговування бетону під впливом ґрунтових вод, а також зв'язує між собою анкерно-породну конструкцію, ізолююче-зміцнюючий породно-полімерний шар та тюбінгове кріплення за рахунок високої адгезійної здатності полімерної смоли в єдину посилену систему, що розосереджує навантаження по периметру об'єкту. Використання в охоронній системі сучасних еластичних полімерних смол сприятиме протидії знакозмінним навантаженням, що розповсюджуються в ґрунті при поверхневих вибухах, та довготривалій стійкості і гідроізоляції об'єктів укриття.

Результати досліджень можуть бути використані при розробці наукових передумов до удосконалення методів та засобів побудови підземних об'єктів укриття з метою дотримання безпеки їх функціонування у разі виникнення надзвичайних ситуацій.

Ключові слова: підземні споруди, станція метрополітену, кріплення, анкери, полімерні смоли.