MANAGEMENT AND ECONOMIC EVALUATION OF CHOICE OF TECHNOLOGIES AND EQUIPMENT FOR TUNNEL CONSTRUCTION

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Abstract. The article deals with the issues of management and economic estimation of the costs of existing methods of construction of deep and shallow tunnels in order to increase their efficiency and improve the technical and operational and economic indicators of the consolidated structures.
Keywords: technologies, feasibility study, underground structures, transport networks, efficiency, management, costs, economic estimation.

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Problem solving

To date, the construction of tunnels for underground transport is relevant for solving many problems. Underground transport is a significant component of intra-city transportation of passengers in large cities. Construction of the subway will facilitate the unloading of the transport infrastructure of the city. Solving the problems associated with the construction of underground structures and providing an innovative way of developing a transport network can be accomplished by developing the best construction methods, the use of advanced equipment, advanced technologies for increased stability, complex mechanization and automation of processes to ensure high technical and economic performance in the construction of tunnels.

Analysis of recent research and publications

The study of the management process and the analysis of modern methods of forming the geotechnical properties of soils and the closed methods for the construction of underground structures indicate the need to improve existing construction technologies due to increased costs for materials, high energy intensity, labor intensity, low quality sealing processing. Improvement of bearing capacity and stability of tunnels, improvement of technical and operational parameters of processing is possible due to the use of the potential of materials to increase their strength during consolidation. Investigation of the management process and the assessment of the choice of technologies and equipment for the construction of tunnels were based on the results of fundamental and applied work. Lysikova B. A., Samedov A. M., Grebenkin S. S., Ilyushina O. A., Ishlinsky A.Yu., Galina L. A., Hayko G. I. and others.

Formation of the purpose of the article

The purpose of this article is a feasibility study of existing methods of construction of transport, hydrotechnical and collector tunnels of deep and shallow deposits in terms of increasing the efficiency of the use of materials and equipment, improving the technical and operational and economic performance of constructions

Presentation of the main research material

Feasibility studies are carried out at all stages of design and planning. Effective are solutions that ensure the growth of labor productivity at a minimum total cost and thus lead to the economy of means of production.

Due to the fact that the construction of tunnels is openly accompanied by damage to the earth's crust, it is necessary to carry out a large volume of excavation works and suspend the functioning of the infrastructure of cities, when constructing tunnels prefer closed methods of development that require minimal disclosure of the earth's surface. The block diagram of common methods of constructing tunnels by closed methods is shown in Fig. 1 *(Kalinichev, 1988; Brener, 2009; Samedov, 2011; Salamakhin, 2007).*

Depending on the mining and technological conditions, sizes and designation of the buildings, the following closed methods are used for the construction of tunnels: mining (5%), shield (90%) and special (5%) methods. Mining and special (punching, puncture, etc.) ways of performing work is appropriate in the construction of tunnels of relatively small length and limited to lengths of up to 300 m. When applying special methods of conducting works, limiting the length of the tunnel by the equipment for punching is determined by the values of the efforts of the main jack station and the number of intermediate jack stations, and from the material handling tunnels - its compressive strength.

Special attention deserves special methods, which, in order to increase the stability and reduce the drafts, is based on the use of the bearing capacity of the contour layer to be specially treated. Such methods include the creation of a forward-looking fixture from stabilized soil by soil treatment by means of jet cementation, which allows obtaining the strength of soil cement to 15 MPa. The main drawbacks of this method are the high costs associated with the consumption of cement up to 500 kg / m3 and energy costs up to 675 MJ / m3. For the work of the method of jet cementation, surface drilling is used, which also restricts the application of the method in the case of surface construction and pre-laid open underground utilities. In addition, the conduct of jet cementation does not always lead to the alignment (isotropy) of the properties of the rock mass, and after the penetration there is a violation of the integrity of the contour layer. These phenomena are related to the main factors influencing the strength and deformation properties of rocks in the array, namely the heterogeneity of rocks, the anisotropy of physical properties, depth, form and geological conditions of occurrence, defects of the internal structure, waterloggedness *(Greb'onkin, 2008; Timchenko, 2001).*

Methods that utilize the potential bearing capacity of the soil mass include the method of penetration with the arrangement of an arched vault (the New-Austrian method of tunneling), which is to combine anchorage and spray processing. The application of shuttering is accompanied by a number of negative factors associated with the process of spraying construction mixtures, in particular, dust formation and vapor formation, both in the "dry" and "wet" way, the impossibility of complete mechanization of the process, a large percentage of rebound - up to 60%, especially when the roof is shoved a tunnel that can cause injury to the operator, a strong influence of the rheological properties of the building mixtures on the stability of the process, high costs of cement - up to 500-800 kg / m3 *(Hofler, 2004; Baranov, 2001; EFNARC, 1999)*. Anchoring requires an outcrop of the soil mass, which is possible in rocks with a coefficient of strength fcr = 2-4, when the rock has sufficient strength to perceive the mountain pressure, which also significantly limits the application of this method in complicated geological conditions.

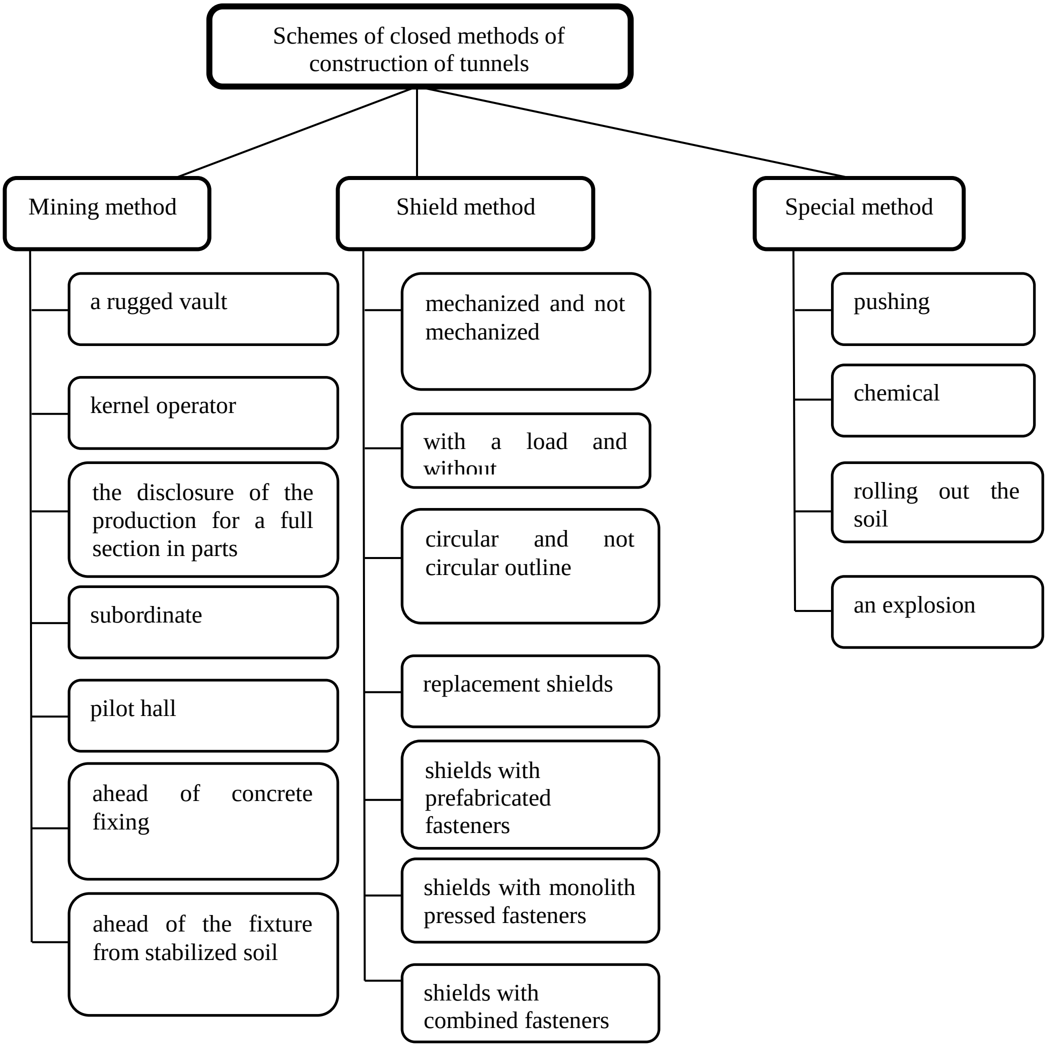

Fig. 1. Closed ways to build tunnels

More than 70% of the territory of Ukraine consists of forest soils of different subsidence *(Sergeyev, Larionov, 1986; Zuevska, 2011; Krieger, 1965; Sergeyev, Bykova, 1986)*, as well as soils with predominant content of clay and significant amounts of sand (loamy loams), which make up 82% of the weight of sedimentary rocks. Under such conditions shield tunneling is often the only possible way of working, since it allows you to build throughout the year in a large range of geological and hydrogeological conditions. Among the large variety of existing shield tunneling technologies (Fig. 1), the most widely used in the territory of Ukraine and the post-Soviet space were mechanized pivot shields with attachment of circular contours with prefabricated reinforced concrete processing of transnational companies Herrenknecht and Wirth.

Unfortunately, the application of domestic developments is impossible due to the fact that in 1991-1995 Ukraine almost completely lost the existing design, technological and industrial potential in the field of development and manufacture of panel machines (*Samoilov, 2004)*.

The mentioned technology of construction of tunnels with the construction of a combined processing, along with the relative simplicity of technology of fastening and cheap equipment (often outdated, service life of which exceeds 10 years), has serious drawbacks. First, part of the fastening process is transferred to specialized plants, where high-precision (2-3 mm tolerance) and high-strength (concrete of the class B40, 52 MPa) elements of processing are manufactured. This entails an increase in transport costs and the use of special non-shrink cement and plasticizers, which also increases the cost of underground construction. In addition, for the assembly of prefabricated reinforced concrete elements, it is necessary during the formation to lay special additional parts from materials based on synthetic macromolecular compounds. When they are mounted under the shield shell protection, the outer diameter of the treatment turns out to be smaller than the outer diameter of the shield. Thus, for the Herrenknecht S 402 shield, which has an external diameter of 6360 mm with an external dimension of the 6100 mm tunnel processing unit (according to the passport data), the volume corresponding to the total space of 250 mm in width of the fixing space is 2.6 m3 per one running meter of the tunnel without taking into account the erosion of the adjoining contour of the tunnel array.

To ensure rigidity, stability and waterproofness of the prefabricated structure, the gap created must be filled with cement-sand (C / P) solution, which is injected in two stages: initially, carry out the initial injection of the mixture (C / P = 1: 2), then the control pressure (C / P = 1: 0). The use of a mortar with a fine filler, which is a cement-sand mortar with a high mobility (with a cone draft of 16-20 cm) and a reduced rigidity, is associated with its transfer by a mortar and requires the preparation of a large number of astringents and plasticizers. The use of primary and control injection of a cement-sand solution to fill the void expands the front of the work, resulting in a slower process of building the tunnel and significantly increases the complexity of work. In addition, at primary and control injection, to fill the cavities, it is sometimes necessary to carry out additional measures to increase the rigidity of the combined treatment in the form of additional supports and screws (Fig. 2).

When conducting tunneling works in unstable wet soils, due to their mobility, it is not possible to execute such injection as a rule, as a rule, because the shield gap formed is immediately filled with ground soils, which leads to the subsidence of the earth's surface directly behind the shield and the formation of zones not available for injection

In order to exclude the operation of injection of cement-sand solution, the technology with compression in the rocks of processing by means of squeezing by collective handling jacks is proposed. This technology has the following benefits:

- immediately after installation in the work elements of processing come along with the surrounding array, which prevents the development of deformation of the development circuit;
- the soil mass is stabilized around the tunnel, and consequently, the mountain pressure for treatment is reduced;
- the soil sediment is eliminated or minimized.

Fig. 2. Measures to restore geometry of transport tunnel processing

However, this method has not been widely used since:

- the soil must have plastic properties;
- it is practically impossible to obtain uniform pressure over the perimeter of the ring due to friction on the outer surface of the treatment, resulting in a repeated reduction of the pressure produced by compression, at the maximum distance from the point of the ring, where the compression effort is applied;
- the pressure generated in the soil by the previous tension may be very uneven along the perimeter of the ring, which results in asymmetrical and uneven loading on the tunnel processing.

Avoid these disadvantages allows the technology of monolith-pressed concrete processing (*Marennyi, 1963; Khrapov, 1989; Gayko, 2006)*, which consists in the supply of concrete mixes in the space between the shield and the formwork (for the case of weak rocks) with subsequent compression. In addition, this method reduces the metal content of a monolithic structure and increases its strength by 30%. The high productivity of this method of finishing the processing led to the creation of a number of domestic (TSCB1-TSCB7) and foreign tunneling complexes of the first, second and third type. However, the use of machines of this type involves compression of building mixtures, which corresponds to a uniaxial load, in which the displacement of the particles forming the skeleton, occurs at the maximum possible values. Increase in pressure of pressing is limited by the action of the working body on the development and strength of the filler of the building mixture.

In tabl. 1 provides technical and economic indicators of some types of equipment for the construction of tunnels in a shield way. Data are taken from directories and avenues of firms, technical documentation, and also obtained on the basis of experts' expert judgment (*Marennyi, 1963; Gayko, 2006)*.

Table 1

Technical and economic indicators of equipment for the construction of tunnels in a shield way

Name of works	Teamwork	Monolith-pressed concrete processing
Soil development, м^3	31,753	31,753
Prefabricated reinforced concrete, м^3	4,836	0
Fittings and foundry metal parts, кг	665	0
Monolithic concrete brand 300, м^3	0	5,163
Pouring for processing, м^3	2,79	0
The complexity of work (in units)	1	0,64
Durability of processing (in units)	1	1,3
Cost of construction (in units)	1	0,61

Analysis of the data given in Table. 1 indicates a significant reduction in the complexity of the monolithic finishing process due to the elimination of additional labor-intensive operations (injection of sand solution, installation of tubing, guide rods, application of glue and emulsion) and increase the strength of the structure, which proves the feasibility of using monolithic treatment.

Technical and economic indicators of the construction of 1 running meter of the tunnel tunnel-complexes of prefabricated reinforced concrete elements and monolith-pressed concrete treatment

Pressing the building mixture in the case of monolith-pressed concrete processing is carried out by pushing it between the shield and the formwork (for the case of weak rocks) or between the rock mass and formwork (for the case of rocks of medium strength and strong). At the same time, considerable frictional forces occur on a section of length from 600 to 700 m, which leads to uneven seals of the mixture. The process of distributing the mixture over the contour is complicated, which also negatively affects the quality of the seal. These phenomena lead to the emergence of sections of variable strength both along the axis of the tunnel and along its contour, which significantly influences the technical and operational characteristics of the tunnel processing.

Pressing of building mixtures for monolithic treatment can be carried out using the technology of pressing the concrete mixture in the radial direction. The concrete mix is pressed by the surface of the formwork due to the increase of its overall dimensions when exposed to the joints of the formwork of the hydraulic device. As well as the previous method of pressing, this method provides for the cyclic performance of work, which increases the duration of work on the construction of the processing.

The critical analysis of tunneling construction technology in a closed way allows us to conclude that the technological processes and the equipment used have significant drawbacks, which include, in particular, the over-consumption of materials and energy, and the high complexity of work.

In order to increase the efficiency of construction of tunnels in a closed way and to improve the working conditions and quality of structures, it is necessary to develop and implement new technologies of geocropping, based on fundamentally new ways of reducing the processing and formation of geotechnical properties of arrays.

With all the diversity of methods of action on a rock massif during the construction of tunnels (explosion, impact, compression, vibration, etc.), the most effective method in the formation of strength, filtration, rheological and dynamic properties is considered a seal, the application of which allows to create in the environment a complex stressed state and lead to the emergence of normal and tangential stresses, which, as a result of which the primary structure will be destroyed at the lowest values of force influence and energy consumption. At the heart of this principle lies the property of soils and materials to vary the resistance, depending on the nature of the load (compression, stretching, displacement). Especially large difference in the values of the emerging resistance manifests itself at the molecular levels of interaction. Thus, the adsorption layer of water of soil particles has a density of up to 1500 kg / m3 and is compressed at pressures above 3-3.5 GPa, but deforms at a shift with stresses of the order of 10 KPa *(Bazaran, 1966; Ahverdov, 1981)*.

One of the ways that this principle is implemented is the roller compression method according to the international terminology "Roller-Compacted Concrete". The method of roller sealing has been well established in the construction of responsible monolithic structures, in particular hydraulic structures, roads *(Berga, 2003; Vahedifard, 2010),* as well as in the manufacture of flat (roller forming) and ring (radial pressing) prefabricated reinforced concrete products *(Garnets, 1998; Korolev, 1970; Shynkarenko, 1989)*.

One of the ways of roller formation during the construction of tunnels is rolling in the ground with the help of a milling head with chemical treatment of soils *(Svirschevsii, Lysikov, 2003)*. Using a shale phenol mixture in the development of a tunnel with a diameter of 6 m will allow for a few hours to obtain a surface strength of 0,3 MPa at a thickness of a densified layer of 2,5-6 m (calculations were made under the conditions of equal weight of the developed and compacted soil and constant porosity in depth).

Analysis of the peculiarities of the technology of construction of tunnels by closed methods, in particular through tunneling complexes, makes it possible to draw the following conclusions:

- the construction of tunnels requires the re-equipment of the production and technical base. Creating new equipment based on advanced technologies will greatly avoid existing disadvantages;

- the method of monolithic treatment of the tunnel is the basis for solving the issue of increasing stability, complex mechanization and automation of production processes. To implement it it is necessary to create a technology capable of ensuring the achievement of high technical and economic indicators in the construction of tunnels.

On the basis of the conducted analysis of the experience of the construction of tunnels in a closed way and the application of the roller formation method in NTUU "KPI", technological circuits and equipment for forming the processing of underground communications structures by roller sealing were developed *(Zaychenko, Pat. 48800, 2010; Zaychenko, Pat. 58984, 2001; Zaychenko, Pat. 82271, 2013)*. The formation of treatment of tunnels underground communications structures according to the schemes is carried out by means of roller pressing.

The implementation of the technology for processing the contour of the soil layer of the tunnel for the formation of soil properties with the help of roller formation is presented in the scheme of work of the tunnel shield with the formation and bending of the soil during the construction of tunnels by the method of roller pressing (Fig. 3). Shield 1 and rotor 4 move in the direction of the face due to the force of shield jacks 3, which rests in the combined processing 2. Shield jacks 3 move the shield, forming section of formwork 2 and rotor 4 in the direction of the face. When rotated, the rotor 4 develops a soil array, and the soil partially falls under the roller working bodies. The rollers 5 press it in the radial direction, and the soil layer is sealed and aligned in the inner periphery of the underground structure. Formed in the annulus, the soil is also densely sealed and, if necessary, mixed with the fixing agent, forming a rigid cement sheath. This technology allows for further work on mounting the tunnel, both with the use of prefabricated, and monolithic treatment.

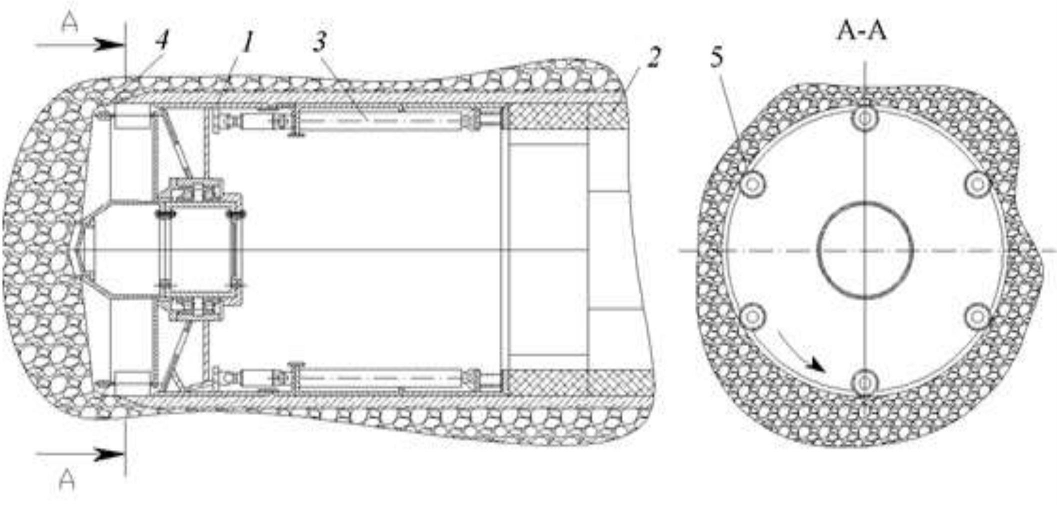

Fig. 3. Scheme of the tunnel shield with soil formation by the method of roller pressing
(the drive of the rotor and the tube maker is not shown)

The reduction of the monolithic processing of the tunnel by the technology of roller formation can proceed according to the scheme shown in Fig. 4. The bladder section 1 moves the shield 2 forming the formwork section 3 in the direction of laying the tunnel. Rotating, the rotor 4 captures portions of the building mixture that come from the hopper 7 in the distribution sleeves 6 and are held by centrifugal forces, while the construction mixture falls into the rolling rollers 5. The rotor 4, rotating along with the roller rollers 6, pushes the construction mixture in the radial direction and In this case there is a consolidation of a monolithic concrete massif.

Application of a roller seal during construction of a monolithic treatment, in contrast to pressing, allows its reinforcement to be carried out. The use of this scheme is possible for soils of varying strength, and it is possible to detach the roof of the tunnel after the formation of the soil or the strength of the rock.

Cost savings for construction work in the construction of tunnels is achieved by introducing into the production of a new sealing technology for the processing elements, which achieves the most efficient use of the bearing capacity of the adjacent contour and high-quality sealing of high-tech building mixtures that are different from the traditional high stiffness with low cement content (up to 18%) and high technical and operational indicators.

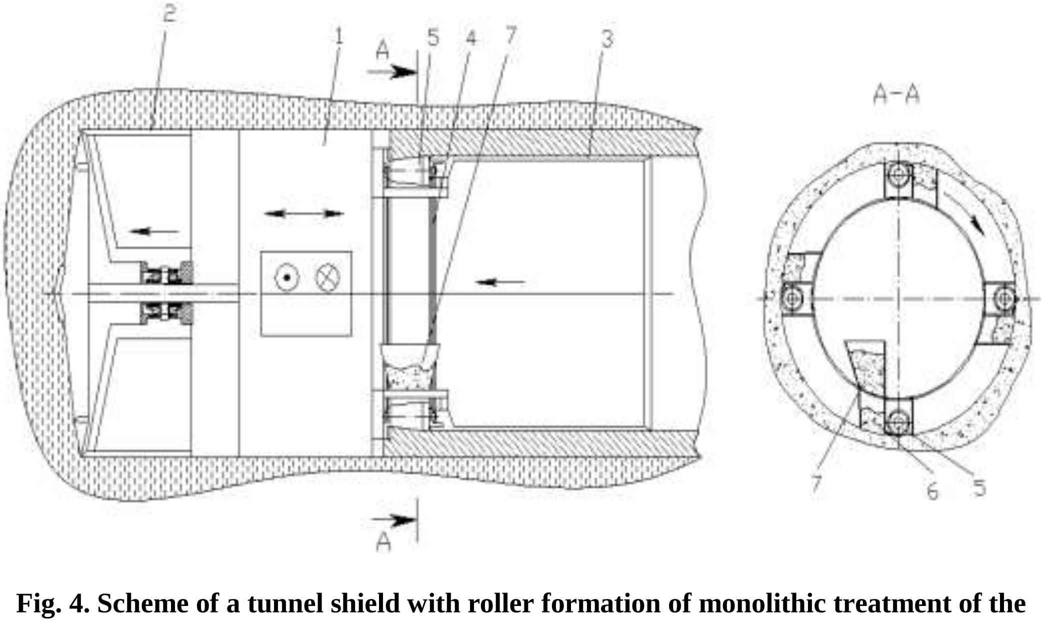

Fig. 4. Scheme of a tunnel shield with roller formation of monolithic treatment of the tunnel (drive rotor, screw conveyor and belt conveyors not shown)

The formation of the soil-cement layer can reduce and evenly distribute the load on the treatment of the tunnel, which, like the ferro-concrete, formed during torque-cutting, can reduce the thickness of the treatment. The savings of the binders are ensured by the addition of a relatively small amount of water (up to 12%), which, while maintaining the optimal value of water-cement ratio, gives the cement savings. The amount of savings from the introduction of the new sealing technology is calculated by comparing the project cost of building the tunnel with the costs incurred in applying the proposed technology of roller sealing of the contour layer and processing the tunnel in accordance with the instruction "Determination of the economic efficiency of the use in the construction of new technology, inventions and innovative proposals" 509-78.

Consider the construction of the underground tunnel underground tunnel S-402 of the multinational company "Herrenknecht", the metro station "Vasylkivska-Exhibition Center", whose operating length is 1.49 km

Table 2

Output data to calculate the economic effect of the introduction of new technology

Indexes	Unit of measurement	The basic option	New technology
Volume of application (length of the tunnel)	м	1490	1490
Volume of concrete for one meter of construction of a tunnel: B40 M200	$м^3$	 5,46 2,6	 4,5 2,6
The cost of manufacturing prefabricated reinforced concrete elements at the plant is given	thousand UAH	22410	18850
Cost of construction works (81/59 persons per hour)	thousand UAH	3521	2565
Specific capital investments into production assets of a construction organization	thousand UAH	853	1064

The economic effect (ths. Hryvnias) of using the technology of roller compaction of the contour layer and processing tunnels is calculated by the formula:

$$\text{E} = ((\text{З}_1 + \text{З}_{c1})\phi + \text{E}_3 \text{-} (\text{З}_2 + \text{З}_{c2}))\text{A}_2 =$$

$$= ((22410 + 1971 + 3649)1 + 0 \text{-} (18850 + 1361 + 2725))1490 = 7590 thdsUAH$$

where A_2 – part of the scope of the new technology; $\text{З}_1, \text{З}_2$ - the costs for the production of prefabricated reinforced concrete structure, taking into account the cost of transportation to the construction site on comparable variants of the basic and new technology, are given, UAH per linear meter of the tunnel; $\text{З}_{c1}, \text{З}_{c2}$ – costs for construction of structures on the construction site (excluding the cost of factory production) are given on comparable variants of basic and new technology, UAH per linear tunnel meter; E_3 – saving in the sphere of exploitation of structures during the term of their service; φ – coefficient of change of the term of operation of a new construction design compared with the basic version.

To simplify the calculations, we assume that the structures have the same service life and do not differ in terms of expenses in the field of exploitation of savings in the field of operation.

The cost of finishing the processing without consideration of the cost of the factory production of the basic version and roller seal technology is given.

$$З_{c1} = 3521 + 0,15 \times 853 = 3649 \text{ thds uan;}$$

$$З_{c2} = 2565 + 0,15 \times 1064 = 2725 thdsUAH \text{ .}$$

The effect of using the technology of roller seals on the contour layer and processing by one running meter of the tunnel:

$$\begin{aligned} &\mathrm{E} = ((З_1 + З_{c1})\phi + \mathrm{E}_3 \text{-} (З_2 + З_{c2}))\mathrm{A}_2 = \\ &= ((22410 + 1971 + 3649)1 + 0\text{-}(18850 + 1361 + 2725)) = 5094\, thdsUAH. \end{aligned}$$

The use of roller seal technology allows to create a monolithic treatment of the tunnel without the formation of a layer of tamped sand-cement mortar and without the need for transportation of prefabricated concrete reinforcement.

In this case, the economic effect of using a roller seal technology on one running meter of a tunnel is:

$$\begin{aligned} &\mathrm{E} = ((З_1 + З_{c1})\phi + \mathrm{E}_3 \text{-} (З_2 + З_{c2}))\mathrm{A}_2 = \\ &= ((22410 + 1971 + 3649)1 + 0\text{-}(18850 + 2725 - 1612)) = 8067\, thdsUAH. \end{aligned}$$

For the conditions of the implementation of this technology on the metro station "Vasylkivska-Exhibition Center" the economic effect will be 13161 thds uan.

Conclusions

Taking into account the conducted research for the construction of tunnels by underground method, the method of roller sealing (pressing, forming) was chosen, according to international terminology "Roller-compact concrete". On the basis of the conducted analysis of the experience of constructing tunnels in a closed way and applying a roller method of formation, technological circuits and equipment for forming the processing of underground communication structures with roller seal were developed. The formation of treatment of tunnels underground communications structures according to the schemes is carried out by means of roller pressing. Cost management at the construction of tunnels is achieved by introducing into the production of a new sealing technology for processing elements, which achieve the most efficient use of the bearing capacity of the adjacent contour and high-quality sealing of high-tech building mixtures that differ from the traditional high-rigidity with low cement content (up to 18%) and high technical and operational indicators. The formation of the soil-cement layer can reduce and evenly distribute the load on the treatment of the tunnel, which is formed during torque and allows to reduce the thickness of the treatment. The savings of the binder components are due to the addition of a relatively small amount of water (up to 12%), which, while maintaining the optimal value of water-cement ratio, leads to cement savings.

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