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STUDY OF TECHNICAL SOLUTIONS TO STRENGTHEN THE LINING OF THE BARREL IN THE ZONE OF INFLUENCE OF CONSTRUCTION NEAR-WELLBORE PRODUCTION

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ABSTRACT

The present study considered technological schemes of construction tree trunks workings of vertical shafts. Analyzed studies in the evaluation of the stress-strain state of mining and development of solutions to improve their sustainability. The technique of numerical simulation of the vertical shaft, the input data and characteristics of the materials. Perform step numerical modeling portion of the barrel in the construction zone near-wellbore production. Analyzed the data and the main regularities of stress-strain state of the lining of the trunk. The efficiency gain by bolting the barrel device reinforcing layer of high-strength carbon-fiber laminate. The dependence of the bearing capacity of the lining of the reinforcement ratio and sets out the scope of the solution. Developed a method to determine the required percentage of reinforcement for strengthening concrete lining vertical shafts. Conclusions are based on research findings.

Keywords: vertical shaft, tree trunks generation, construction technology, voltage, the concrete lining, carbon fiber laminate, bearing capacity, the percentage of reinforcement.

1. INTRODUCTION

One of the biggest underground structures in volume, diversity and complexity of solved during the construction and operation tasks are vertical shafts that are complex underground structures mining, underground, road and rail tunnels, hydroelectric power plants. Currently, the depth of today's operating and under construction shafts get over the 4 km and continues to increase, which leads to a deterioration of the geological and hydrogeological conditions of the building.

Vertical shafts of coal mines are built in conjunction with their affiliated mine workings (tree trunks), including coupling, loading facilities, and reducing cameras, drainage etc. Appointment, number and design of tree trunks workings depend on the type of vertical shaft, to which they are attached.

In the operation of vertical shafts and there is a need of additional facilities tree trunks workings. This can lead to an increase in strain and increased stress in the lining of the barrel at the construction site, the formation of new fracture zones and reduced strength of rocks.

Excavation workings tree trunks in the trunk can be operational in two basic schemes. In the first case, the development tunnel works carried out "in the direction of the barrel." Formation and change of the stress-strain state plots trunks at this technology as a whole is the same as in the construction of a new trunk.

The second generation scheme tree trunks were "in the direction of the trunk" and can cause the development of a mechanism for the formation of the stress-strain state of the "lining - rock mass" in need of further study. This will prove the most effective technical solutions to enhance the existing trunk lining where necessary.

2. PROBLEM STATEMENT AND PRELIMINARIES

2.1. Problem statement

Aware of individual works devoted the choice of parameters combined shoring tree trunks workings [1-3], the technology tree trunks workings during shaft sinking [1, 3], analysis of the causes of violations of the lining and the adjacent portions of the barrel [1, 4, 5] and their repair [5-7]. However, issues related to the study of the stress-strain state of the lining and the rock mass in the construction of tree trunks in the operational workings trunks, are not considered.

Study of complex mining systems requires the use of physical and mathematical models with spatial geometry and nonlinear deformation of materials. Scientific framework for modeling mining considered in [8-10]. Examples of solutions to specific scientific and practical problems at the present level of development of computer hardware and software are presented in the works [11-13]. As the most effective possible to allocate the finite element method, implemented in specialized software systems.

Known solutions to improve the sustainability of construction sites workings tree trunks lie in the use of the anchor hardening rocks [1, 3], the inclusion in the design of the lining of additional layers of compliance, expansion joints, etc. [2, 5]. At the same time the possibility of using many of the decisions in the operating shafts are very limited, as it would require disassembly of the existing lining. One promising avenue is the use of technology to strengthen concrete structures fabrics and laminates based on high-carbon fibers. This technology is well proven in the construction and reconstruction of bridges [14, 15], but the efficiency of its use in relation to this problem requires further study.

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2.2. Methods and Materials

Most fully meets the requirement of the problem in the finite element method. To create mathematical models that perform calculations and data analysis software package adopted "Lira - 9.4", which has been tested enough in solving geomechanical problems.

As a result of analysis of the existing geological conditions Donbass parameters operation, under construction and planned vertical shafts, the list of input data modeling and range of variation (Table-1).

Table-1. Initial data for mathematical modeling.

No.	Parameter name	Value
Characteristics of the rock mass		
1	Rock strength at compression, MPa	5, 0 - 120, 0
2	Rock strength, MPa	0, 4 - 10, 0
3	Angle of incidence of the rocks, Grad.	0 - 45^0
4	Modulus of deformation of rocks, GPa	1, 0 - 30, 0
5	Coefficient of transverse deformation of rocks	0, 2 - 0, 4
6	Average volumetric weight of rocks, kN/m^3	28, 0
7	Minimum power rock layers, m	0, 5
Characteristics of the vertical shaft		
1	The trunk purpose	Master, auxiliary, vent
2	The depth of trunk, m	300,0 - 2000,0
3	The diameter of the trunk in light, m	6, 0 - 8, 0 (через 0, 5)
4	Basic design of the lining	monolithic concrete, thick 250 - 500 mm
Characteristics of tree trunks workings		
1	The trunk pairing auxiliary: - sectional shape - cross-sectional area, m^2; - conjugation length, m;	vaulted sloping 18,0 - 50,0 15, 0
2	Luggage boot device: - sectional shape; - cross-sectional area, m^2; - camera height, m;	rectangular with a vaulted roof 25, 0 - 65, 0 to 18, 0

For a more complete model of the real conditions of adequacy adopted volumetric type finite element model of the cylindrical shape.

To eliminate the influence of boundary conditions on the calculation results, the following model dimensions: Diameter - 100 m, height - 100 m. reconstructed horizon is located at around 50 m from the lower edge of the model. Thus, the influence of boundary conditions on the results of calculations in the study area is excluded.

Key elements of the system have plastic properties. Simulation of physical nonlinearity of materials is possible with the help of physically nonlinear finite element perceiving information according to the law of material deformation. In accordance with modern concepts of geomechanics in the study adopted an exponential dependence $\sigma = f(\varepsilon)$. The calculation is carried out steps-iterative method, which is the most accurate model the nonlinear deformation model in the process of phased implementation of the tunnel works.

For a breakdown of the model adopted by the volumetric finite element in the form of an eight universal spatial isoparametric element (KE). When constructing the grid finite element models based on the principle of combining thick and enlarged grids. Array of species in the study area (zone crosscuts tree trunks workings) is divided into a grid with the size of the bulk EC faces 10 cm. The zone surrounding rock mass at a distance of 5 - 10 m of its represented as a grid volume TBE stepper increasing the size of faces from 10 to 50 cm. External

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area of the model presented by finite elements of size 1.0 - 5.0 m.

Concrete lining of the trunk and near-wellbore production in the study area is modeled by finite elements with the size of the verge 2, 5 - 5 cm and at a distance from it - 10 - 15 cm.

The boundary conditions are taken as follows: for the lower bound is given by the restriction of the vertical displacement of the side faces - limit the displacement in the direction perpendicular to the plane of the face. The upper bound of the model is loaded uniformly distributed vertical pressure of the overlying rock strata.

The calculation spreadsheet created an array of data on movements in knots and stresses in finite elements model.

Analysis of the stress-strain state of the model elements is carried out by determining the six axial components of the stress tensor. Further analysis is possible on the various theories of strength. In the present study to evaluate the safety factor of rock strength criterion used Mohr-Coulomb. In accordance with it the equivalent stresses are determined by the formulas:

$$\sigma_Э = \sigma_1 - \chi \cdot \sigma_3 ;$$
$$\sigma_S = \lambda \cdot \sigma_1 - \sigma_3 , \qquad (1)$$

where

$$\chi = \frac{\sigma_0^+}{\sigma_0^-} ; \quad \lambda = \frac{\sigma_0^-}{\sigma_0^+} ;$$

here

σ_0^+ = voltage limit in uniaxial tension;

σ_0^- = However, when compression.

The basic material lining adopted monolithic concrete class B20 and B25. As the basic technical solutions to enhance the effectiveness of the reinforcement investigated lining the inner wall of the trunk on the basis of a laminate of high-strength carbon fibers. This material has a high tensile strength and compressive close to the steel modulus of elasticity, good resistance to aggressive media, available in the mine shafts. Characteristics of the laminate is shown in Table-2.

Table-2. Specifications laminate.

No. п/п	Parameter name	Value
1	Type of laminate	Sika Carbodur S / Sika Carbodur M /Sika Carbodur H
2	Thickness, mm	1,4
3	Width, mm	50-120 / 60; 90; 120 / 50
4	Modulus of elasticity, GPa	155 / 210 / 300
5	Tensile strength, MPa	2400 / 2000/ 1400
6	Elongation, %	1, 9 / 1,1 / 0, 8
7	The range of changes in the percentage of reinforcement lining, μ, %	0,05 - 0,5

Percentage of reinforcement lining is determined from the expression

$$\mu = \frac{S_l}{S_b} \cdot 100\% , \qquad (2)$$

where

S_l = cross-sectional area of the laminate based on 1 meter section of concrete lining;
S_b = area of one meter section of concrete lining.

3. RESEARCH RESULTS

When doing research developed numerical models for the two main stages of construction near-wellbore production. Scheme of work is shown in Figure-1.

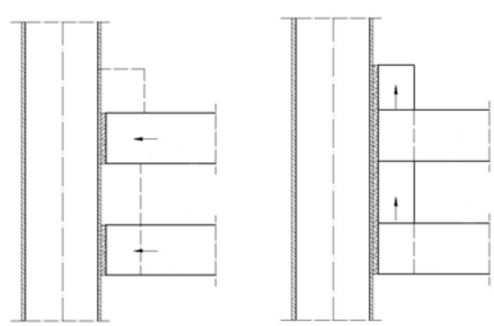

Figure-1. sequence of works on camera crosscuts the boot device in the direction of the trunk:
a) a first step of penetration; b) a second stage of penetration.

At the first stage the trunk summarizes two horizontal generations leaving the trunk rock pillar required size.

At the second stage revolting winze to the design level set camera is passed. Next winze extends to the design dimensions of the chamber, performed demolition of rock pillar, construction of permanent support the roof and walls of camera.

Figure-2 shows an example of the section of the finite element model of a site the barrel after the first stage of penetration with the obtained contour plots equivalent tensions.

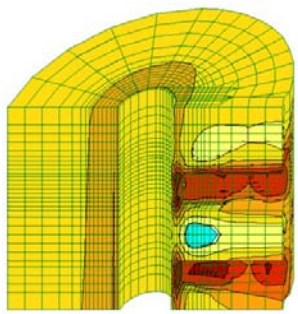

Figure-2. Section of the numerical model with the trunk contour plots equivalent tensions.

Staggering of the consideration stages of penetration near-wellbore production shows that it leads to the construction of additional vertical and radial strain tensile stress and an increase in the existing equivalent tensions in the lining the trunk in the construction zone. The Figure-2 you can see the resulting concentration equivalent stresses in the lining the trunk shown dark brown. In a wide range of geological conditions (Table-1) they cause a loss of stability of the trunk area within the building before the end of work.

For the qualitative and quantitative evaluation of the stress-strain state adopted coefficient K_{in}, which is the ratio equivalent tensions in the lining the trunk in the zone of near-wellbore production to similar values, its existing before the tunnel works. The Figure-3 is a generalized graph of the parameter K_{in} depending on the distance to the toe of the horizontal development of the borehole wall during the first phase of construction.

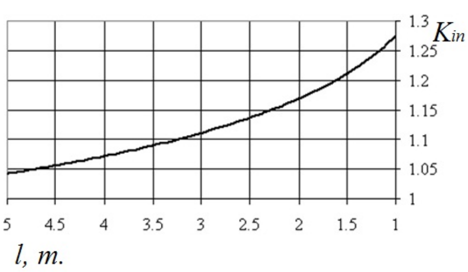

Figure-3. Dependence on the distance parameter KVL face near-wellbore production to the barrel wall.

Analysis of quantitative values of stresses in the lining the trunk shows that their maximum growth in the first phase of construction has reached 31%, and after the second stage - 44% of the initial level of stress in the considered range of conditions.

Increase the carrying capacity of the existing concrete lining the trunk without disassembling it can be achieved by additional reinforcement on the inner surface of the high-strength laminates minimum thickness. This will keep the necessary clearance for the safe movement of the trunk lifting vessels.

To evaluate the effectiveness of this solution in a numerical model the trunk were added to the volumetric finite element modeling layered carbon fiber laminate. They were placed on the inner surface of the lining the trunk in the zone of near-wellbore production under the scheme presented in Figure-4.

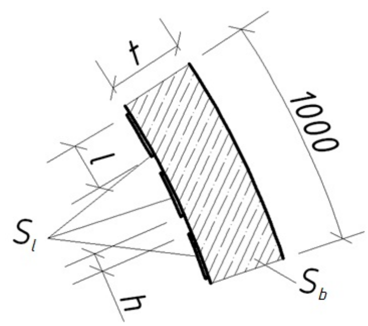

Figure-4. Scheme reinforcement bolting the trunk carbon-fiber laminate.

The calculated model values of the stresses and strains in the lining showed that reinforcing the inner layer comes into operation immediately, but only after the implementation of the lining of the elastic deformation and the transition to the stage of plastic deformation of the concrete lining. The most effective scope of the reinforcing layer are areas the trunk in the future development of near-wellbore opening (in the area leaving the rock pillar) and directly above the opening production at an altitude of (1, 2 - 1, 4) B, where B - width of near-wellbore production. Availability laminate allows you to increase the carrying capacity of the lining, some of the conditions for Mohr-Coulomb strength and reduce the maximum values of the strain lining. The main influencing factor is the percentage of reinforcement. Changes in elastic modulus of the reinforcing material in the range of 155 - 300 GPa no substantial effect on the bearing capacity of the structure. The resulting data dependence of the increase in the bearing capacity of reinforced lining of the reinforcement ratio is shown in Figure-5.

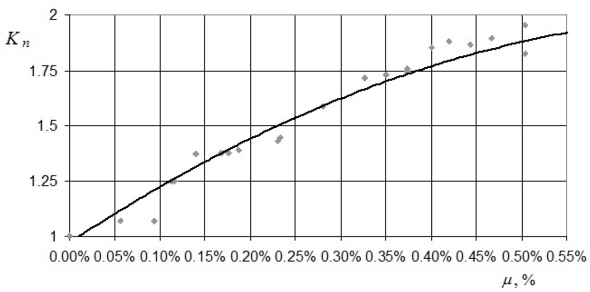

Figure-5. Dependence of the increase in the carrying capacity of the trunk lining reinforcement ratio.

Preliminary study parameters of reinforcing portion lining in the zone of influence of the construction of near-wellbore production can be made when considering the bearing capacity of a ring segment lining as the bend of the beam. Ultimate bending moment by the section width is one meter reinforced reinforcing layer may be determined from the expression

$$M = \sigma_l S_l t - 0{,}5 R_b x^2 \ , \tag{3}$$

where σ_l – voltage limit for the composite material of the reinforcing layer can be identified by the expression [15]:

$$\sigma_л = k_s \sqrt{\frac{R_b E_l b}{\sum t_l}} \le 0{,}9 R_l \ ; \tag{4}$$

R_b = Design strength of the concrete lining in compression, MPa;
x = Relative height of the uncracked concrete, is out of the equation projection of internal forces

$$x = \frac{\sigma_l S_l}{R_b} \ ; \tag{5}$$

k_s = coefficient taking into account the type and amplification circuit, laminates can be taken as k_s =0,45 [15];
E_l = modulus of elasticity of the material of the reinforcing layer, MPa;
b = unit bandwidth of the hardening of the inner layer of lining, mm;
Σt_l = the total thickness of the layers of the reinforcing layer, mm;
R_l = design resistance of the material of the reinforcing layer, MPa.

The final parameters of the reinforcing layer lining area within the building workings tree trunks should be determined on the basis of mathematical modeling and mining studies in specific geological and technical conditions.

CONCLUSIONS

a) Phased consideration stages of penetration in near-wellbore production operational trunk shows that it leads to the construction of additional vertical and radial strain tensile stress and an increase in the existing equivalent tensions in the lining the trunk in the construction zone. Equivalent stress increases nonlinearly with the approach to the development of near-wellbore bottom wall of the barrel, with a maximum height can reach 44% of the initial level of stress. This leads to buckling the trunk portion in a large range of conditions.
b) An effective technical solution to strengthen the lining in the construction zone near-wellbore production unit is an additional reinforcing layer of high-strength carbon-fiber laminate. The field of application of the reinforcing layer are areas of barrel opening and development of near-wellbore over her vault to a height of (1, 2 - 1, 4) B, where B - width of near-wellbore production. The bearing capacity of reinforced lining increases nonlinearly with increasing area and percentage of reinforcement lining. The optimum range of the reinforcement ratio is 0.25 - 0.5%.

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