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Computer Modeling of Deformation Processes in the Event of Liquidation of a Dip Over a Rock Mine

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Computer Modeling of Deformation Processes in the Event of Liquidation of a Dip Over a Rock Mine

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Abstract. The urgency of the problem of the occurrence of earth surface failures above underground excavations is substantiated. A model of a rock massif in the zone of a dip over a mine excavation has been developed. A new method for eliminating the failure of the earth's surface is proposed. The strength and deformation characteristics of the packing material used to eliminate the dip are investigated. Stresses and deformations in a soil massif are determined for various variants of layerwise deposition of materials into a dip. On the basis of full-scale observations of the development of failures and generalization of the results of their elimination, it has been established that the method of liquidating the failure has a significant effect on the nature of the work of the rock-lining structure being created. It is proved that the strength and deformation characteristics of the formed filling massif exert a significant influence on the stability and durability. The results of modeling the layer-by-layer method of liquidation of the dip confirmed its high reliability and efficiency.

1. Introduction

Operation of buildings and structures in conditions of mining by mining operations is associated with increased deformations of ground bases arising from movements and deformations of the earth's surface. Such processes are characteristic not only in the process of working out mineral deposits at shallow depths, but also after the liquidation of mining enterprises [1]. In a number of cases, significant deformations occur in a very short time, which causes the formation of dips on the earth's surface (Fig. 1).

In the territory of the Rostov region in the period from 2008 to 2018 were found more than 450 fault zones on the mountain outlets of 47 abandoned mines [2].

As a result, the problem of liquidation of gaps in the mining regions is very relevant.

The authors of [3] established on the basis of full-scale observations of the development of failures and generalization of the results of their elimination that the method for eliminating the failure affects the nature of the work of the rock-lining structure being created. It is proved that the strength and deformation characteristics of the formed filling massif exert a significant influence on the stability and durability.

Figure 1. Failure of the earth's surface above the mine workings in the Rostov Region.

2. Methodology

To study the influence of these parameters on the load-strain characteristic of the rock structure formed in the zone of failure before the beginning of its destruction, we shall use mathematical modeling [4, 5]. The application of this method is associated with the use of assumptions, models and some idealized schemes, for example, idealized representations of the continuity of arrays of filling and enclosing rocks. To solve the problem, we use a multifunctional software package for calculating, researching and designing designs of various purposes for LIRA (version 9.4), based on the finite element method (FEM).

In order to simplify the mathematical model of the process of eliminating a dip over a rock formation, the shape of the funnel is reduced to the form of simple geometric figures. The fullest possible funnel of a dip can be approximated by the shape of an inverted truncated cone. Two variants of models of the process of liquidation of a dip over the mine workings are considered (Fig. 2):

1) elimination of failure by filling and subsequent compaction by humidification by burnt-out waste rocks (hereinafter referred to as «backfill»);

2) liquidation of a dip by layer filling and subsequent compaction by humidification with burnt-out waste rocks and a grouting mortar (hereinafter referred to as "backfill and solution layers").

Since the resulting model is symmetric, then for modeling the processes it is sufficient to consider ¼ part of the finite-element mode.
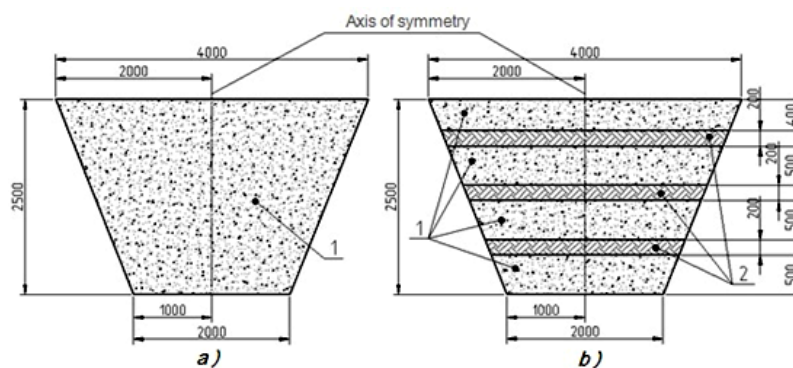

Figure 2. Variants of models of the process of liquidation of a failure: *a* – «backfill», *b* – layers of backfill and solution, 1 – burnt dump; 2 – pressure bath.

On models, the problem of shrinkage volume shrinkage was solved for both options without taking into account the compliance of the existing soil base. The properties of the materials are given in Table. 1.

Table 1. Characteristics of the material used to eliminate the failure, according to options.

Name of characteristics	Material for the elimination of failure	
	backfilling	grouting mortar
Elastic modulus E, кРа	200	$2 \cdot 10^6$
Poisson's ratio v	0,3	0,25
Specific gravity of the material in the compacted state R_0, кН/m^3	16	14,5
Allowance for nonlinearity by exponential law:		
– the initial value of the Young's modulus of compression E_0^-, кРа	200	$2 \cdot 10^6$
– initial value of the Young's modulus of tension E_0^+, кРа	200	$2 \cdot 10^6$
– compression limit value σ^-, кРа	-240	-350
– voltage limit value σ^+, кРа	$1 \cdot 10^{-6}$	10

3. Results

Comparison of the variants was carried out by the relative shrinkage of the buried volume of the dip, determined by vertical displacements (Fig. 3), the results of calculating the vertical displacements and the relative shrinkage according to the variants are given in Table. 2.
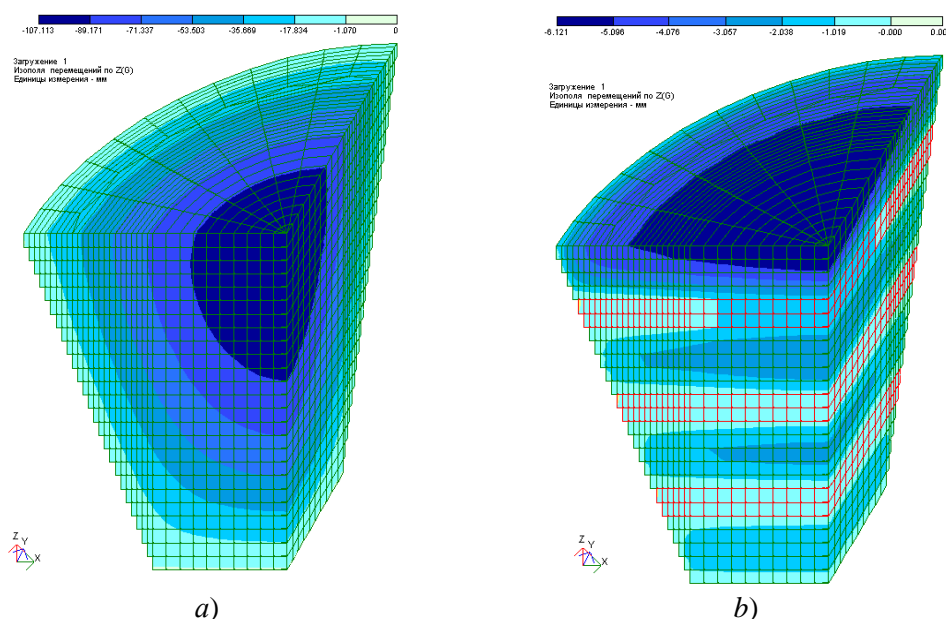

a)   *b)*

Figure 3. Isopoles of vertical displacements Z, mm:
a, *b* – respectively, the 1st and 2nd variants of the bookmark failure.

Table 2. Results of calculation of displacements and relative shrinkage.

Option to eliminate the failure	Maximum Vertical Displacement Z, mm	Relative shrinkage ε_z	The scheme
1. Solid backfill with burned rock	107,1	0,043	fig. 2, *a*. 3, *a*
2. Layered backfilling with rock and plugging material	6,1	0,24	fig. 2,*b*. 3,*b*

Consequently, the option of eliminating the failure by layer filling and subsequent compaction by humidification by burnt-out waste rocks and a backfill solution is more effective than the option of eliminating a dip by filling and subsequent compaction.

It has been established that the relative shrinkage of a volume-by-layer volume is less by 17,6 times than the relative shrinkage of the volume to be filled by burnt-out waste rocks.

In order to determine the stress state arising in the layers of a grouting mortar in the layer filling of the volume of a dip, the following problems were considered: 1) one layer of compacted «backfill» and one layer of «solution» (lower layers); 2) the lower layers of «backfill and mortar», the next layer of compacted «backfill» and the next layer of «solution» (middle layers); 3) the lower and middle layers of «backfill and mortar», the next layer of compacted «backfill» and the next layer of «solution» (upper layers); 4) the entire volume to be filled up.

For all variants, equivalent stresses were determined in accordance with the theory of Coulomb-Mohr strength. The results of investigations for the total volume are shown in Fig. 4.
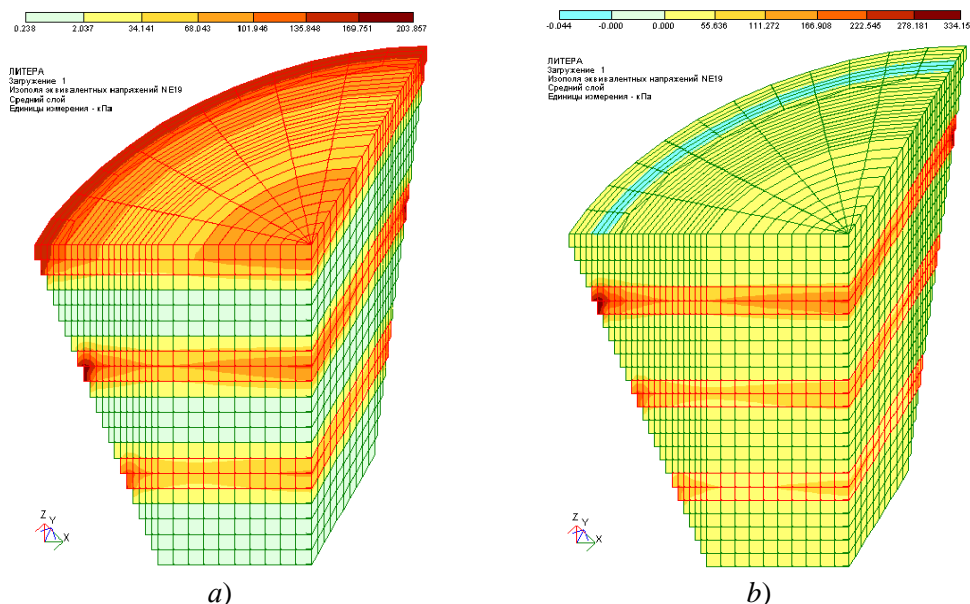

Figure 4. Isopoles of equivalent tensile stresses under different alternations of the backfill and solution: *a* – top layer of the solution; *b* – top layer of backfill.

As can be seen from Fig. 4, the maximum equivalent stresses occur in the boundary zones of the layers of a grouting mortar at all stages of layer filling, which can be explained by the presence of the «edge effect» in the problems under consideration. Also, the largest equivalent stresses occur in the middle part of the layers of the oil well, and, as the number of layers to be filled up increases, the equivalent stresses decrease in the lower layer of the oil well, which corresponds to the vertical stress distribution σ_{zp} in the ground base, depending on the depth of the compressible bed.

The previous options were considered without taking into account the compliance of the existing soil base on an idealized scheme. To assess the stress-strain state of the filled falloff volume, taking into account the compliance of the existing soil base, the following options are considered:

- boundary conditions are set on the side walls of the dip, taking into account the rigidity of the existing ground base E = 10 MPa, E = 20 MPa and E = 30 MPa.

Boundary conditions - the lower part of the volume is rigidly fixed. On the axial faces, symmetry bonds are imposed. Connections perpendicular to the side walls are set by two-node EC # 262, simulating a one-way elastic coupling between nodes (rigidity R); along the side walls are given the CE No. 262 (frictional force F). The results of the investigations are shown in Fig. 5.
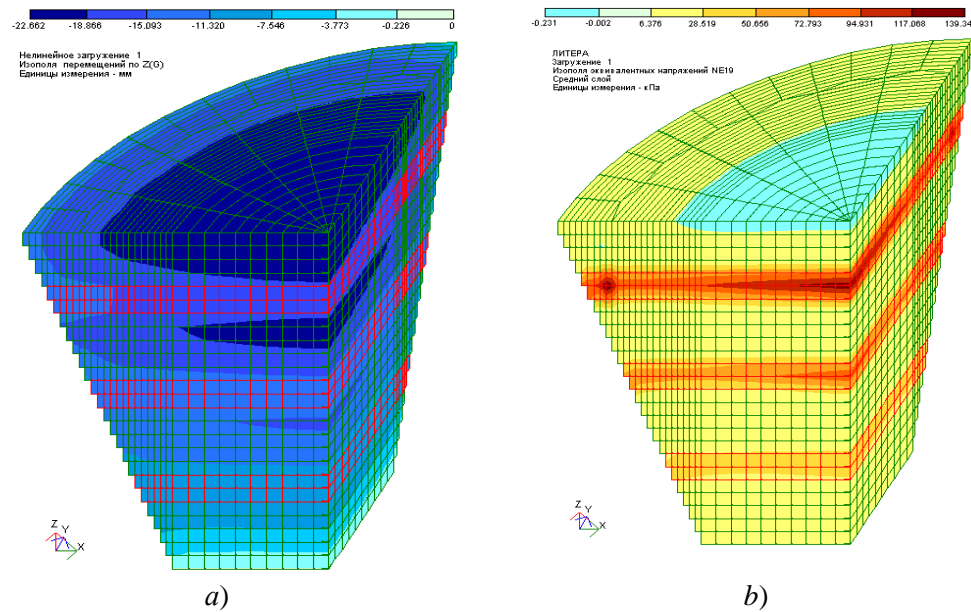
a)   *b)*

Figure 5. Isopole: *a* – vertical displacements, mm; *b* – equivalent tensile stresses, kPa

4. Analysis

When the modulus of soil deformation E = 10 MPa and various values of specific cohesion C of the angle of internal friction φ relative shrinkage amount ε = 1,62...1.66%, when E = 20 MPa and C, φ have various values, ε = 1,12...1.14%, when E = 30 MPa and C, φ have various values, ε = 0,89…0,90% (Fig.6).
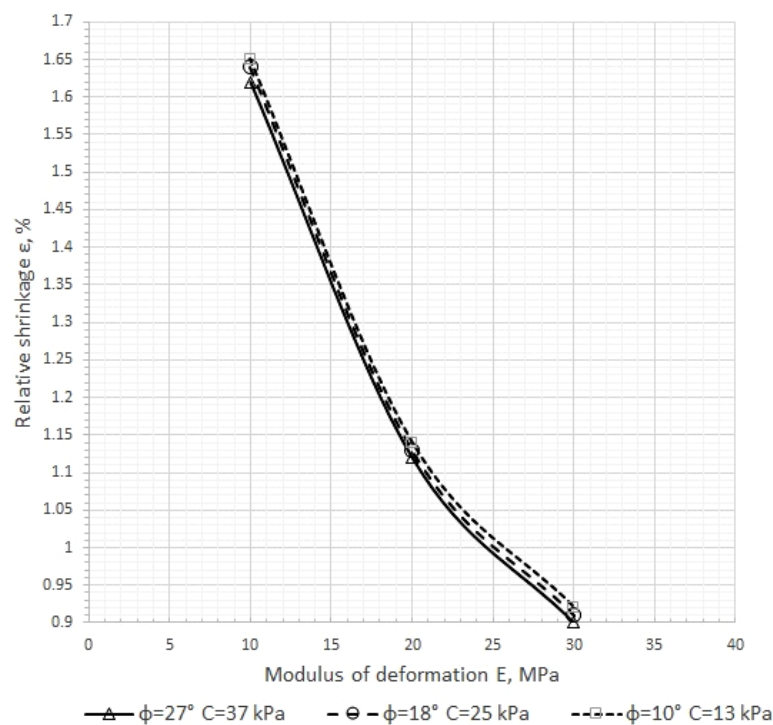

Figure 6. Relative shrinkage of the filled volume of the failure.

Tension in the lower layer of the solution increases with increase of the deformation modulus at 28...44%, stresses in the middle layer of the solution increased by 14.5...18.5% and stress in the upper layer of the solution increased by 7.3% to 10% depending on the modulus of deformation of the existing subgrade, thus, the voltage practically does not depend on the values of specific clutch are with and angle of internal friction φ, the differences are within 0.07...1.8 percent (Fig.7).
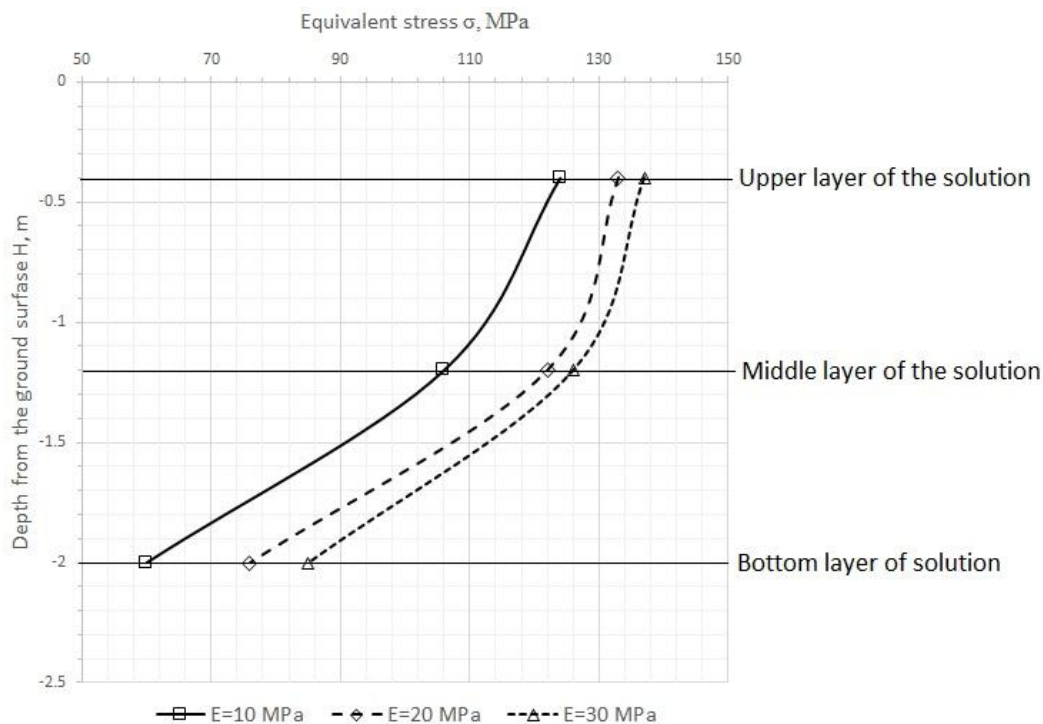

Figure 7. Relative shrinkage of the filled volume of the failure.

5. Conclusions

Consequently, the relative shrinkage of the layered fall-in volume of the dip varies between ε = 0.9 ... 1.7%, depending on the rigidity of the existing soil base, which does not exceed the allowable norm. The results of the modeling of the proposed layer-by-layer method of liquidation of the dip show its high reliability and efficiency.

6. References

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