IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

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To cite this article: Oleksandr Krukovskyi *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **970** 012049

Substantiating the parameters for selecting a pillar width to protect permanent mine workings at great depths

Oleksandr Krukovskyi[1,4], Yurii Bulich[1], Serhii Kurnosov[1], Oleksii Yanzhula[2] and Vladimir Demin[3]

[1]Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine, Simferopolska Str., 2a, Dnipro, 49005, Ukraine
[2]Coal Directorate METINVEST HOLDING LLC, Shybankova Sq., 1a, Pokrovsk, Donetsk region, 85300, Ukraine
[3]Karaganda Technical University, Nursultana Nasarbaeva Ave., 56, Karaganda, 100027, Kazakhstan

[4]Corresponding author: igtm@ukr.net

Abstract. Application of a method to protect permanent mine workings by large pillars requires thorough analysis of geomechanical processes aimed at providing stability for a mine working during its long-term operation. The purpose of the paper is to study the processes of coal rock mass deformation to substantiate the selection of the protective pillar width. The examples to be considered are represented by mining-geological conditions of a central panel of PJSC Colliery Group "Pokrovske" where four permanent mine workings are planned to be driven. To substantiate the width of protective pillars, geomechanical stability of mine workings have been assessed in terms of the effect of stoping operations of the adjacent longwalls of the block and beyond their effect. It has been shown that insufficient dimensions of a support pillar result in considerable influence of stoping operations on the stability of permanent mine workings. Along with the increasing dimensions of a support pillar, the pressure in the rocks around the permanent inclined mine workings decreases, and the support load decreases as well. In terms of the appropriate dimension of the support pillar, the boundaries of the effect become smaller; the bolting and frame support provides completely the required mine working stability.

1. Introduction

While developing flat coal seams at great depths, the following methods are applied to protect permanent mine workings from the harmful effect of stoping operations:

- protection with large pillars [1, 2];
- preliminary and following overworking of mine workings [3,4],
- arrangement and support of mine workings within the caved and consolidated rock thickness [5];
- protection of mine workings by gob packs within the regional de-stressed zone [6].

The practices show that while using a pillarless technology, mining of longwalls neighbouring the de-stressed zone in the course of time the parameters of a de-stressed zone are changing up to its complete disappearance or up to the formation of a zone of increased rock pressure [7]. In certain cases, all those facts influence negatively to mine working stability and cause the necessity of repair works.

Considerable influence of a set of mining-geological and mining-technical factors on the formation of a stress field within the layered coal rock mass while stoping and driving stipulates the necessity of thorough analysis of geomechanical processes while selecting the protection method for a permanent mine working and providing of its stability during a long-term operation. A process of stress field transformation near the mine workings is of complicated spatial nature. A stress-strain state of the contour rocks of the rock mass experiences significant changes during the drivage of mine workings and in terms of their mutual interaction [8].

Solution of such a complex task is possible only by involving numerical methods of modelling that helps represent a complex rock mass structure, location and configuration of mine workings, and operation of any support type [9]. Thus, the purpose of the study is to analyze the deformation processes of the coal rock mass to substantiate the selection of width for the protective pillars and provide long-term stability of permanent mine workings.

2. Methods

A stress-strain state of the rock mass near the mine working is described by a system of equations [10]:

$$\sigma_{ij,j} + X_i(t) = 0\,, \tag{1}$$

where $\sigma_{ij,j}$ are derivatives from the components of a tensor of main stresses along the horizontal axis x and vertical axis y, Pa/m; $X_i(t)$ is projections of external forces acting on the unit of body volume, N/m^3.

Boundary conditions for the problem are as follows:

$$u_x\big|_{\Omega_1} = 0; \qquad u_y\big|_{\Omega_2} = 0; \tag{2}$$

where u_x, u_y are components of the vector of displacements, m; Ω_1 is vertical boundaries of the external contour; Ω_2 is horizontal boundaries of the external contour.

A Coulomb-Mohr criterion is used to describe mathematically a process of rock transition into a disturbed state. A stress state of rocks is analysed with the help of following geomechanical parameters characterizing different-component nature of a stress field of the rocks [11]:

$$Q = \frac{\sigma_1 - \sigma_3}{\gamma H}\,, \tag{3}$$

where σ_1, σ_3 are maximum and minimum components of a tensor of the main pressures, Pa; γ is average weigh of the overlying rocks, N/m^3; H is mining depth, m.

The problem is solved in the elastoplastic statement with the application of a finite element method [12, 13].

3. Problem definition

Consider as an example the mining-geological conditions of a central panel of block 11 of PJSC Colliery Group "Pokrovske" where four permanent inclined mine workings are planned to be driven at the depth of 930-1230 m. To substantiate the width of protective pillars, geomechanical stability of mine workings have been evaluated in terms of the effect of stoping operations of adjacent longwalls of the block and beyond their effect. The calculation schemes are represented in figure 1. Table 1 shows the properties of the rocks which are used during the calculation.

The mine workings are planned to be supported by a combined bolting and frame support with the installation spacing of 0.5 m [14, 15]. It includes frame support KSPU-M-20.3 of profile SVP-33. The steel-polymer bolts, being of 2.9 m long, are installed chequerwise – 8 pieces in a paired row and 9 pieces in an unpaired one. Additionally, 2 cable bolts, being 7 m long, are installed in each paired row [16]. The variants without cable bolts were considered for certain schemes of locations of mine workings. Figure 2 represents schemes of bolting.

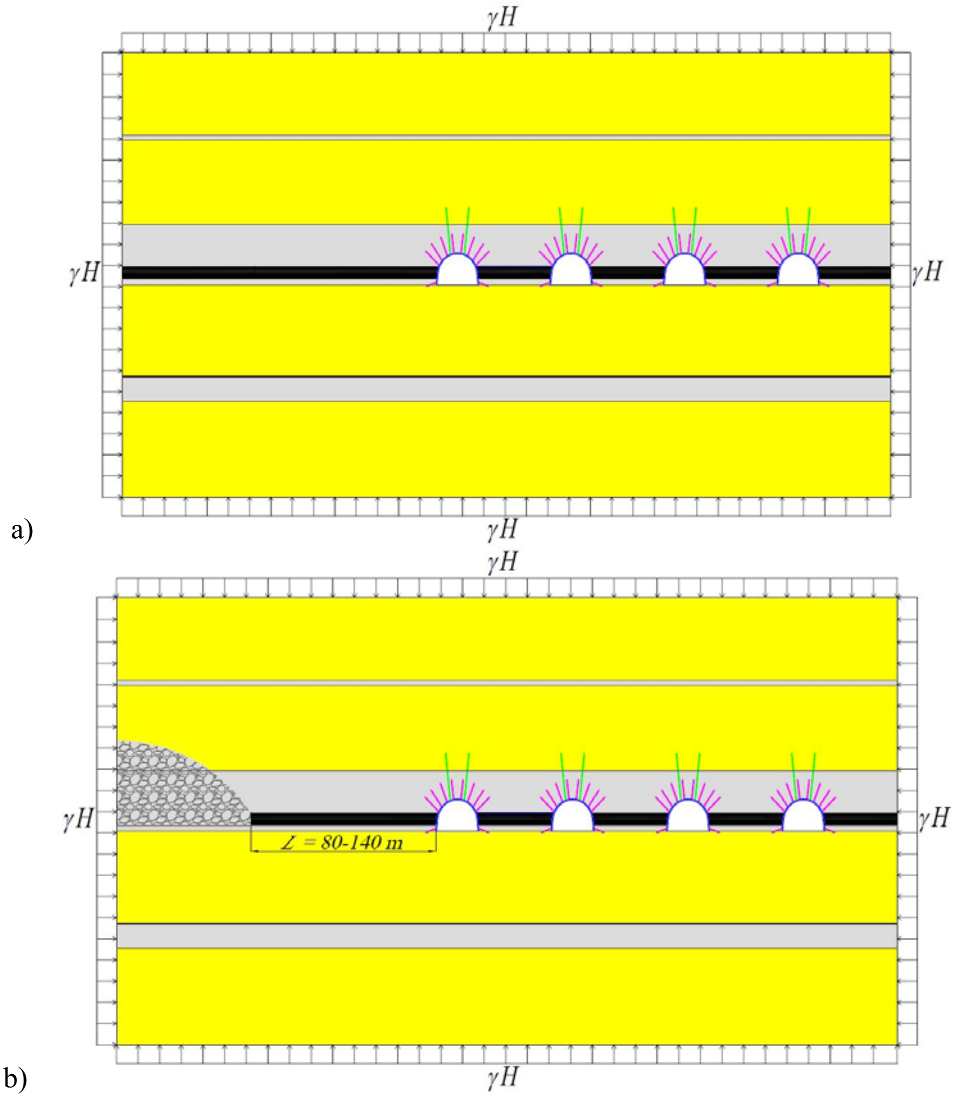
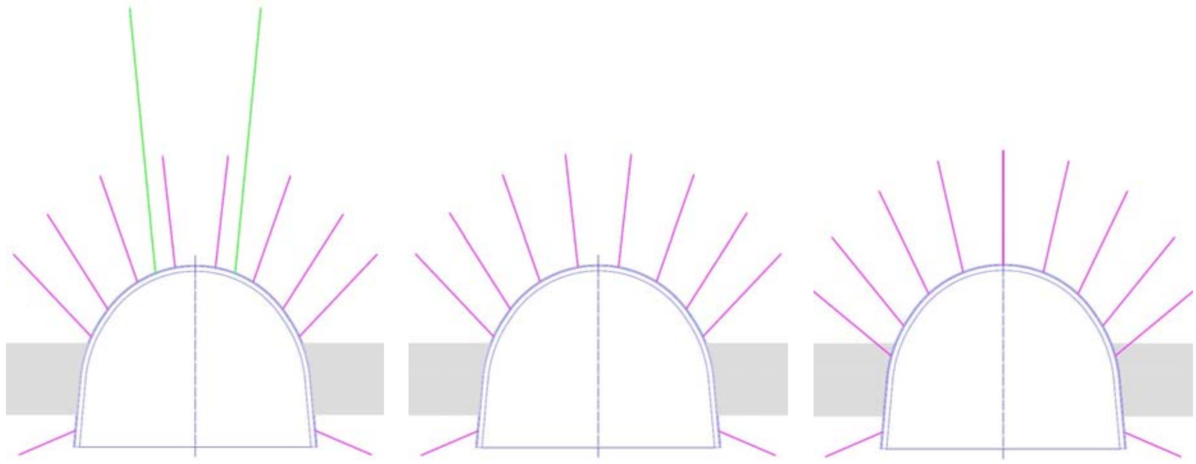


Figure 1. Calculation scheme of the location of permanent mine workings: a) beyond the effect of stoping operations; b) being effected by stoping operations.

Table 1. Mechanical parameters of rock.

Rock	Thickness m, m	Axial compressive strength, σ_c, MPa	Deformation modulus, E, MPa	Poisson's ratio of rock mass, v	Cohesion, C, MPa	Friction angle, ϕ,°
Sandstone	20	82	$1.3\cdot10^4$	0.36	21.3	35
Siltstone	0.8	50	$1.1\cdot10^4$	0.32	14.9	28.5
Sandstone	12	90	$1.3\cdot10^4$	0.36	23.4	35
Siltstone	6.0	35	$1.1\cdot10^4$	0.32	10.4	28.5
Coal	1.6	12	$0.3\cdot10^4$	0.25	3.6	28.5
Siltstone	0.8	27	$1.1\cdot10^4$	0.32	8.0	28.5
Sandstone	13	80	$1.3\cdot10^4$	0.36	20.8	35
Coal	0.2	12	$0.3\cdot10^4$	0.25	3.6	28.5
Siltstone	3.4	35	$1.1\cdot10^4$	0.32	10.4	28.5
Sandstone	13	82	$1.3\cdot10^4$	0.36	21.3	35



(a) (b) (c)

Figure 2. Scheme of bolting: a) for a paired row with 8 steel-polymer bolts and 2 cable bolts; b) for a paired row with 8 steel-polymer bolts; c) for an unpaired row with 9 steel-polymer bolts.

The model was calibrated to meet the real conditions for the conditions of inclined mine workings of block 10 of PJCS Colliery Group "Pokrovske".

4. Results and discussion

As a result of the calculations, the fields of stresses and deformations as well as zones of inelastic deformations have been obtained. The calculations have been performed for the depths of 930 m, 1030 m, and 1320 m in terms of the available pillars between mine workings, being 50 m, 60 m, and 70 m), beyond the effect of stoping operations, and in terms of further effect of stoping operations of the adjacent longwalls at L length of a support pillar, being 80 m, 100 m, 120 m, and 140 m.

Figure 3 and 4 show distributions of the values of *Q* parameter at the depth of 1230 m with the pillars between the mine workings, being 50 m. Figure 3 demonstrates the results throughout the whole site under analysis. Figure 4 represents the enlarged image of a site near the first mine working; that makes it possible to assess the situation on the whole and consider it in more detail near the mine working.

The analysis of distribution of *Q* parameter values (difference in main stresses) around the permanent mine workings beyond the effect of stoping operations shows that along with the growing depth from 930 to 1230 m, rock stresses and support loading increase as well. In terms of pillars between the mine workings, being 50 m, 60 m, and 70 m, the given period of operation demonstrates no mutual influence between the mine workings, figure 3a.

During the effect of stoping operations, stress state of rocks is changing, support load is growing along with the increasing dimensions of a support pillar. If the support pillar is 80 m, such an effect expands beyond the boundaries of the first mine working, being the closest one to the operating extraction area, Figure 3b and 4 b; correspondingly, before the distribution of maximum stresses, it reaches the second mine working, even if the pillar between the mine workings is 70 m. If *L*=80 m, then a combined bolting and frame support cannot withdraw high load from the closely located front of stoping operations, it cannot provide stability for the first mine working. Moreover, support of the second mine working is overloaded as well.

If the dimension of a support pillar is 100 m, the influence expands beyond the boundaries of the first mine working but just a little. If *L=120* m, the boundaries of the influence fall on the first mine working, figure 3c and 4c. If the dimension of a support pillar is 140 m, the effect of the influence decreases, having minor but obvious effect only on the first mine working, figure 3d and 4d. In terms of such support pillar dimension, the bolting and frame support provides completely the required stability of all the four mine workings.

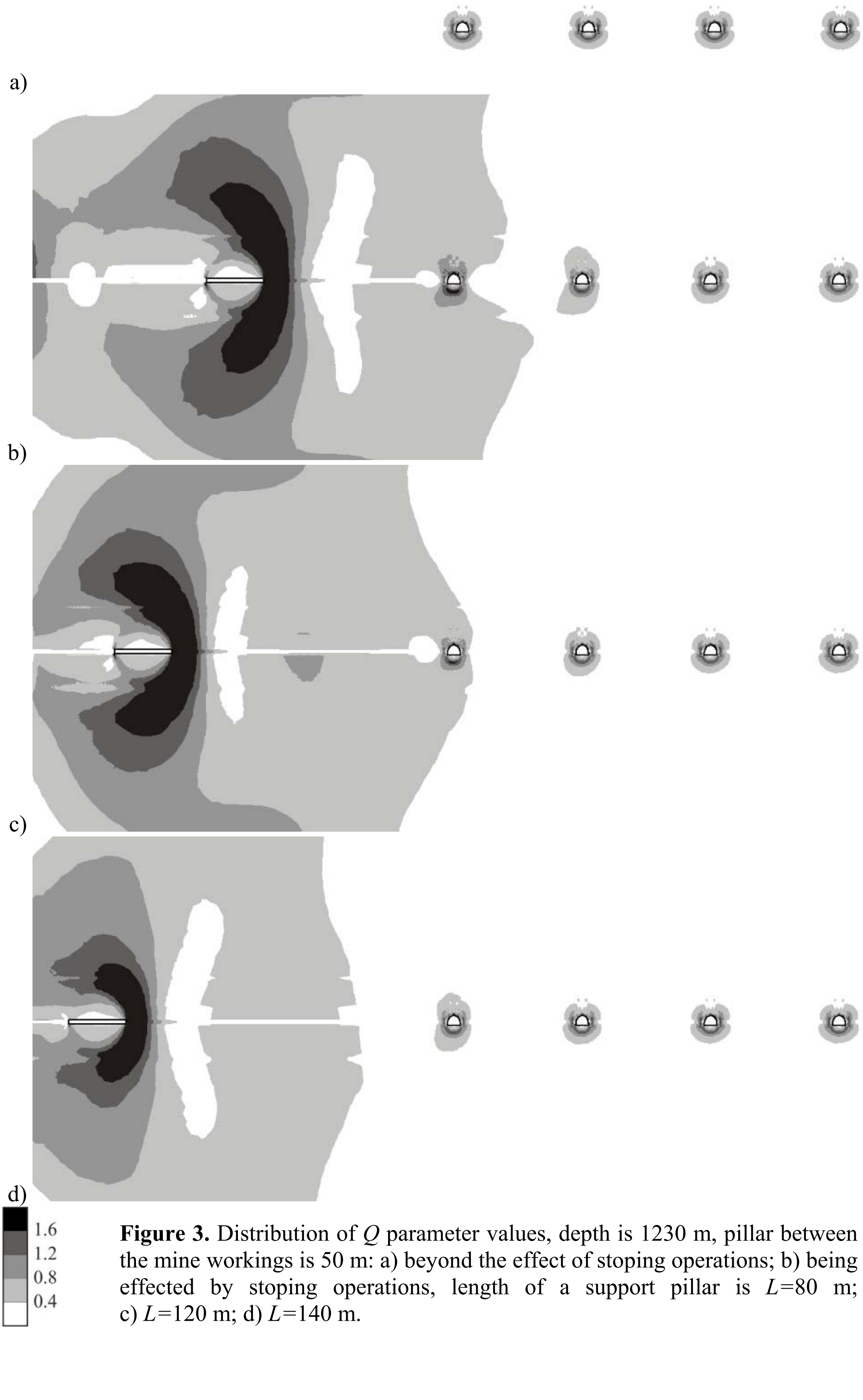


Figure 3. Distribution of Q parameter values, depth is 1230 m, pillar between the mine workings is 50 m: a) beyond the effect of stoping operations; b) being effected by stoping operations, length of a support pillar is L=80 m; c) L=120 m; d) L=140 m.

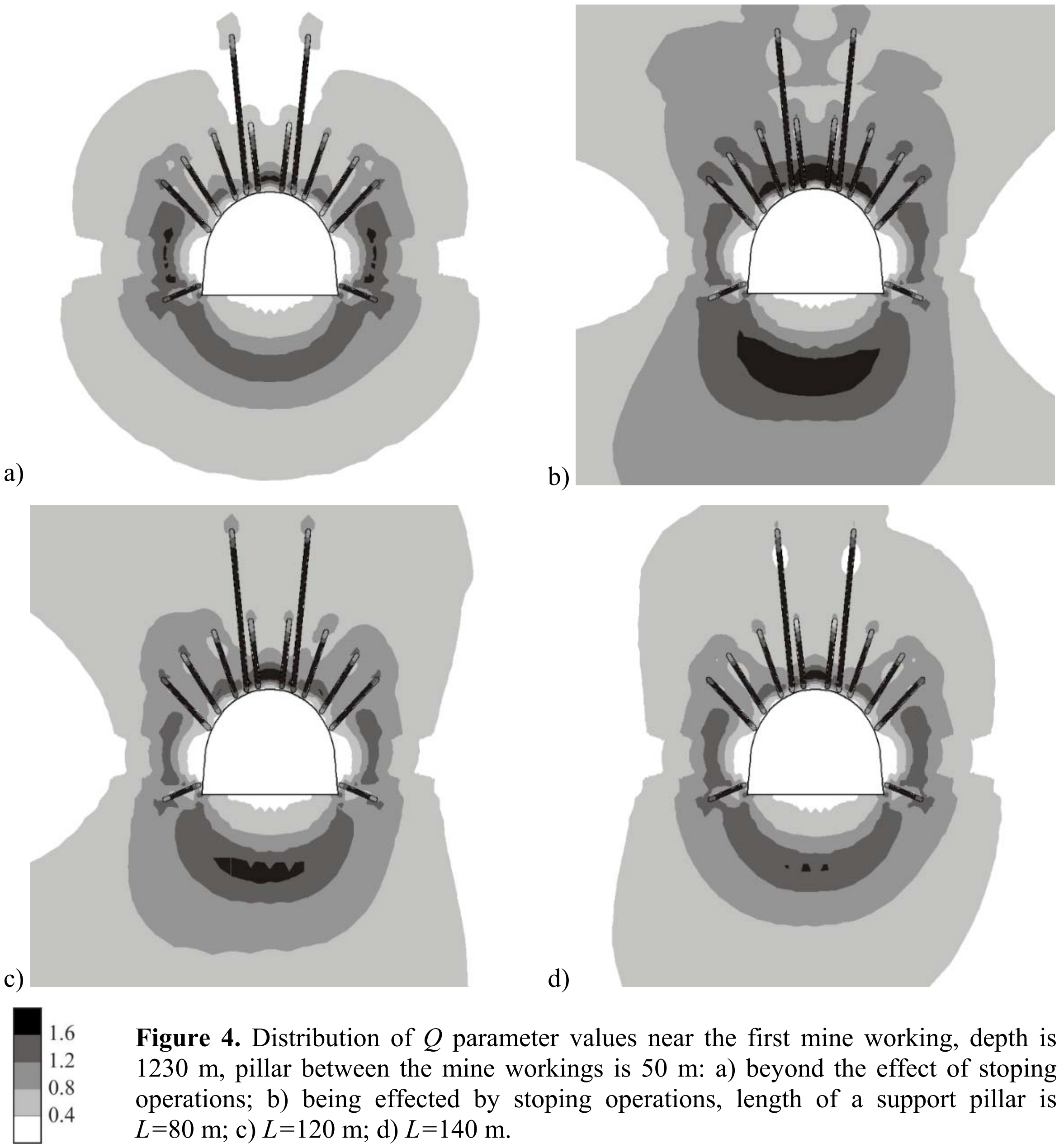


Figure 4. Distribution of Q parameter values near the first mine working, depth is 1230 m, pillar between the mine workings is 50 m: a) beyond the effect of stoping operations; b) being effected by stoping operations, length of a support pillar is L=80 m; c) L=120 m; d) L=140 m.

Figure 5 shows distribution of maximum stresses that determine the location of the support stress zone, at the depth of 1230 m, with pillars between the mine workings, being 50.

Graphs of changes in the value of a reduced minimum component of the tensor of main stresses ($\sigma_1/\gamma H$) along the horizontal straight line passing 1 m above the roof of the mine workings in terms of different values of support pillar length L are represented in figure 6.

The figure makes it possible to see that stoping operations have considerable effect on the value of compressive stresses near the first mine working, being closest to the operating extraction area. Further, their effect experiences its gradual reduction, and the last mine working (the fourth one) is not effected by the stoping operations at all.

At each reduction in the support pillar length L by 20 m, the support pressure ($\sigma_1/\gamma H$) on the first mine working increases by 12%; in case of the second mine working, it increases by 4%.

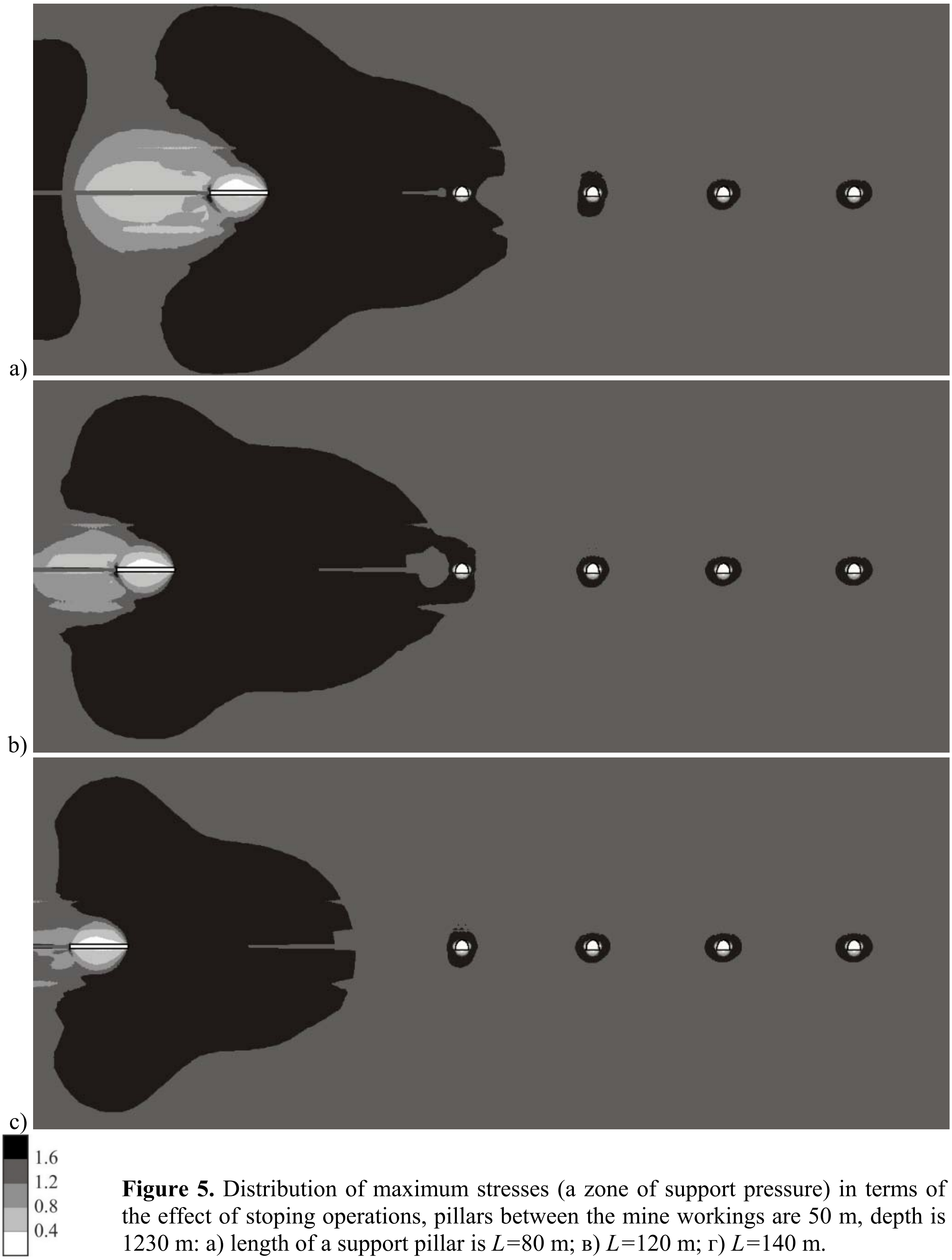


Figure 5. Distribution of maximum stresses (a zone of support pressure) in terms of the effect of stoping operations, pillars between the mine workings are 50 m, depth is 1230 m: a) length of a support pillar is L=80 m; в) L=120 m; г) L=140 m.

Apart from the natural increase in the output stress state of the rock mass $\sigma_0 = \gamma H$ from 23.25 MPa up to 30.75 MPa, growing depth of the inclined mine working drivage from 930 m to 1230 m also results in 10-12% expansion of the boundaries of the influence of support pressure from the stoping operations of the adjacent longwall blocks. If the dimension of the support pillar is 80 m, such an effect expands onto the second mine working as well, figure 5a, including the 70 m pillar between the mine workings. Along with the increasing dimensions of the support pillar, the effect of support pressure from the stoping operations of the adjacent longwall blocks decreases. However, even if the support pillar is 140 m, there is still the insignificant effect on the first mine working, figure 5 c. In terms of the depth of 930 m, the support pressure zone is 130-140 m; in terms of the depth of 1230 m – it is not less than 250 m for the adopted initial and boundary conditions.

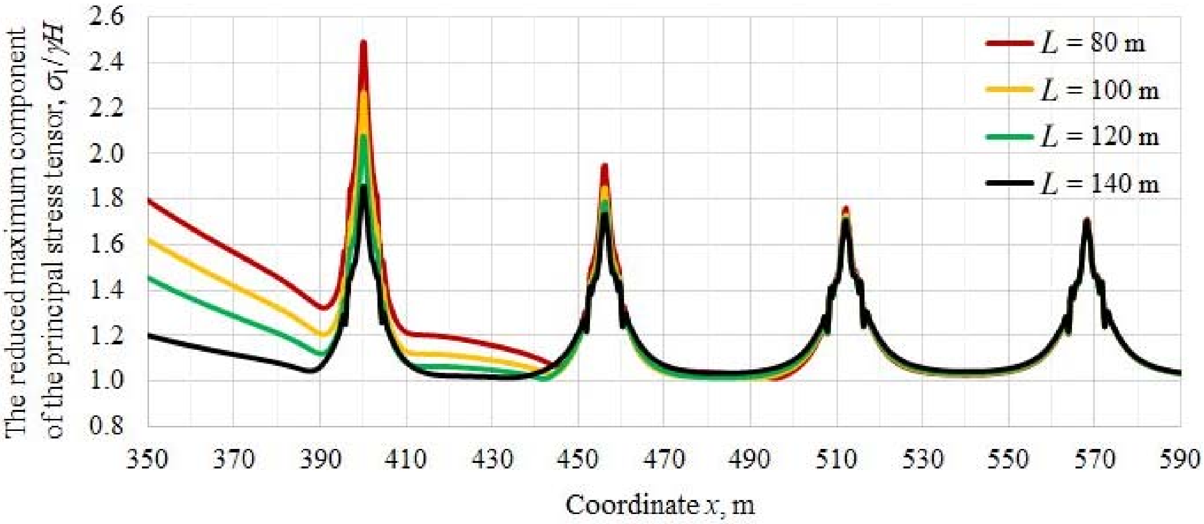


Figure 6. Changes in the values of a reduced maximum component of the tensor of main stresses within the zone of drivage of four permanent mine workings while being effected by stoping operations

5. Conclusions

The methods of numerical modelling have helped study the processes of deformation of coal rock mass and changes in the stress state of the rocks around four permanent mine workings beyond and within the zone of influence of stoping operations in terms of different parameters of protective pillars. The calculations have helped obtain the fields of stresses and deformations as well as zones of inelastic deformations.

Analysis of a stress state of the rocks around the permanent inclined mine workings beyond the effect of stoping operations has shown that along with the increasing depth of their location, rock stresses and support loading experience their increase as well. In terms of 50-70 m pillar width between the mine workings, there is no mutual influence between the mine workings at this stage of operation.

The stoping operations factor into certain changes in the stress state of rocks. If there are insufficient dimensions of a support pillar, the effect of stoping operations expands beyond the boundaries of the first and second mine workings. In this case, a combined bolting and frame support cannot withstand high load from the closely located front of stoping operations and cannot prove stability of the first mine working. The support of the second mine working is overloaded as well.

In terms of maximum dimension of the support pillar, the boundaries of influence become smaller, having insignificant but obvious effect on the first mine working. In terms of such a dimension of a support pillar, the bolting and frame support provides completely the required stability of all the four mine workings.

Apart from the natural increase in the initial stress state of the rock mass, growing depth of the inclined mine working drivage also results in the expansion of the boundaries of the effect of support pressure from the stoping operations of the adjacent longwall blocks.

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