RESEARCH OF DEPENDENCIES OF STOPE STRESS-STRAIN STATE CHANGE UNDER VARIOUS CONDITIONS OF PARTIAL STOWING OF DEVELOPED SPACE

Sotskov V.O.
Candidate of Technical Sciences, Associate Professor of the Mining Department, Dnipro University of Technology, Dnipro, Ukraine

Dereviahina N.I.
Associate Professor at Department of Hydrogeology and Engineering Geology, Dnipro University of Technology, Dnipro, Ukraine

Abstract. The main goal of the paper is to determine the optimal parameters of stope roof deformation depending on different mining and geological conditions for a selected technological scheme of stowing, as well as load distribution in structural elements of powered roof supports for selecting the optimal configuration of the stoperoof support unit. Modelling is performed for three variantsof stope stowing when the stope is developed through a thinly stratified rock massif under different mining and geological conditions in a three-dimensional representation with realization of conditions for mutual slipping of rock strata. It is determined that the designed unit of powered roof support allows overcoming structural features of a roof support used during partial stowing by increasing the safety margin of elements supporting the tail console. The safety marginincreaseis achieved by introducing additional rigid structural elements what reduces the level of stress concentration in joints of a roof support structure.Using an integrated approach to determine the efficiency of selected roof supporting scheme allows estimating reliability of the selected modelling scheme when predicting changes in a state of a geomechanical system. This is a new method for evaluating the efficiency of various technological solutions. The results indicate that when using packs, a process of crack formation in an immediate roof of stopesis stopped by localizing areas and stress values that contribute to growth of main cracks.The optimal selection,from astandpointof dynamic stabilityof animmediate roof of stopes and packs, isselection of the minimum permissible height of extracted rocks while ensuring a statistical equilibrium of sides of packs.This allows determininga mechanism ofselection of stope movement velocity, a type and geometric parameters of erected packs.

Introduction

Mining and geological conditions of stope operation in Ukrainian mines needs solving complicated technological problems providing an opportunity of mineral mining [1-3]. Rock mass features, and mechanical characteristics of rocks, composing it, form the conditions under which deformation of a mine working boundary may achieve up to 90% of its initial linear dimensions. Nature of such phenomena is as follows: even significant reinforcement of supports in mine workings cannot provide rock convergence decrease. Analysis of deformation features of geomechanical system of mine workings has revealed the two dominating alternatives of deformation development within the rock mass: deformations being oriented close to a vertical axis, and deformation, being oriented close to a horizontal one [1, 3]. It is obvious that nonhomogeneity of mechanical characteristics of rocks is the basic factor determining directions of the dominating deformations if only the mine workings were driven in the undisturbed rock mass. Mutual effect of the mine workings varies shaping conditions of a deformation field of the geomechanical system which results in the necessity of extra protective measures. In this context, the rocks, being cut in the process of selective coal mining and left within a production unit, may be used to erect protective structures providing satisfactory deformation mode of geomechanical system of a stope-mine working conjugation.

Efficiency of various structures of the powered support legs depends directly upon mining and geological conditions as well as upon technological conditions of a specific production unit. For instance, in terms of *Samarskaia* mine [1, 2] the powered support was reinforced with the help of pit props providing immediate roof holding within the operating area of a shearer. Hence, design characteristics of the powered support in the context of backfilling technique implementation have been determined for two alternatives – rigid alternative, and flexible one.

Statement of the problem. To carry out comparative analysis of the efficiency of different structural features of the powered support, a model of rock mass, corresponding to actual operation conditions, has been developed.

Longwall 4205 of C_4^2 seam is equipped with the powered complex КД-80, coal shearer КА-200, conveyor СП-251.14. The longwall length is 180 m. Ventilation scheme of the longwall is direct-flow 3-В-Н-г-пт. The first part of the simulation results is given in [3]. Modelling is performed for three variants of stope stowingwhen the stope is developed through a thinly stratified rock massif under different mining and geological conditions in a three-dimensional representation with realization of conditions for mutual slipping of rock strata. Deformational and mechanical characteristics of elements of the studied geomechanical massif are defined considering the results of laboratory studies and a natural experiment, which determine the behavior mechanism of a granular medium of stowing. The analysis of deformations of a geomechanical system allows determining the degree of influence of different variants of a technology of protecting a stope and deformational characteristics of a rock massif.

Analysis of a state of the disturbed rock mass

The identified discontinuities and areas of rock softening have been analyzed as for their interaction and integral effect on a stope support. As a consequence, 3-D model of the layered rock mass has been developed involving maximally each feature of strengthening characteristics and deformation characteristics of the rock and coal seam.

Stage one is the longitudinal stratification of a rock block, neighbouring the coal seam. The process takes place at the expense of the effect of a high-stress closed area occurring within the rock mass at the depth of 4-7 m down from the stope face. Stage two is the process when the forming blocks of layer one develops excessive pressure bearing on the lower plane of layer two from the top of the rock layer. Through a minor height of the layer, critical concentration of the deformation energy forms a plane of the block separation with 2.5-4.5 m intervals henceforth forming chain of plastic hinges providing smooth lowering of coal lumps. Stage three of rock block formation takes place owing to grouping of stress concentration areas being shaped within the upper boundary and lower boundary of a rock layer located as the third one from above the coal seam. Therefore, through different types of the geomechanical processes, formation of a block structure takes place within a stope roof. Parameters of the block structure are determined unmistakably in the process of the computational experiment which will provide in future adequate research as for the efficiency of the powered support sections with different designs [3].

Standard form of vertical stresses within the stratified rock mass accords well with general ideas concerning rock pressure formation which can also be indirect confirmation of correctness of the parameters selected to describe geomechanical model for the computational experiment. The obtained curves of vertical stresses are separated into two areas of compressive stresses and tensile stresses by means of a parallel plane passing at the distance of 1.5 m from the stope face towards the mined-out area. Certain share of the analytical model, neighbouring the undisturbed rock mass, experiences compressive loads and the share, around the mined-out area experiences tensile loads. Ultimate compressive stresses are concentrated right behind the stope face.

Analysis of rock mass deformation development in terms of different backfilling methods.

Taking into consideration the computational experiment parameters, distribution of deformations within the rock mass is analyzed only from the viewpoint of qualitative evaluation if continuity of each component of the analytical model is preserved which excludes naturally origination of considerable rock mass deformations directed lengthwise stratification plane.

Figures 6 represent fragments of 3-D analytical model of geomechanical model of a stope-mine working conjugation in the process of use of packs and complete backfilling respectively.

Distribution of total deformation, if heights of the rocks being cut are 0.5 and 0.6 m, is similar which means lack of effect of backfilling alternatives on the processes of roof rock deformation under prelimiting conditions. Deformation nature of the undisturbed rock mass deformation coincides both qualitatively and quantitively. Hence, in the context of the computational experiment, the selected parameters of the powered support provide comparably effective resistance to the neighbouring rock mass deformation under various conditions of a stope backfilling.

Within the edges of parallelepipeds, distribution of deformations varies depending upon the selection of either packing or complete backfilling. In this context, the two specific areas of roof rock layers deformation can be singled out: upper rock layers of the model; and two rock layers neighbouring superiorly the coal layer. Behavior of the rock mass within the stope roof in the process of complete backfilling is of more complex structure in deformation area one, and in deformation area two in the process of packing. Thus, determine two different approaches for the analysis of deformations within the areas – the generalized analysis in the selected vertical plane, and comparison of a certain rock layer along the stope.

Fig. 1. Total deformations of rock mass in front of the stope face in the process of complete backfilling if height of the rocks being cut is 0.7 m [3]

Fig. 1 represents distribution of deformations within a plane, selected in the process of stress pattern. The curves demonstrate that increase in height of the rocks being cut results in the decreased deformation value of roof rocks of a stope according to a law being close to linear one. Rock mass deformation in the neighbourhood of a mine working for the calculations, performed for partial backfilling, is of similar value and pattern. However, if calculations are made for 0.7 m height rocks, being cut, deformation value in the neighbourhood of a mine working decreases by 18%. The above is followed by the decreased deformations in the rock layer one of the immediate roof of the mine working.

Hence, due to the varied patterns of deformation distribution within the rock layers of a mine working roof, rock mass discontinuity along stratification plane is observed resulting in the formation of a local area with minor transverse strength inside o rock layers one and two. In this context, above rock layers form a block lowering uniformly into the mine working. In actual practice, partial failure of the immediate roof of a stope takes place with the transition to following state of stable equilibrium. The calculation results show: the greater the value of such a failure is, the less time it takes for stage two of the immediate roof failure in the process of packing.

It is typical for deformation curves to preserve quality of deformation distribution within a roof of a stope irrespective of the height of rocks being cut. However, 22% decrease in absolute deformation values as for 0.5 m height of rocks being cut takes place to compare with calculations for 0.6 and 0.7 m heights. It means that in terms of complete backfilling, increase in the height of rocks being cut impacts bearing capacity of protective structures; as for the rocks, having low strength characteristics, selection of the parameter value is critical.

To compare with the calculation results concerning packing (see Fig. 2), in terms of complete backfilling, changes in height of rocks being cut factor into the increased deformations of rock mass in the neighbourhood of a mine working. If height of the rocks being cut is 0.5 m then roof rock deformations are comparable for packs and complete backfilling. If the heights are 0.6 and 0.7 m then the deformations experience 12-15% increase. Thus, mine working support takes up the increased wall pressure which worsens its operational characteristics [5, 6].

Effect of operational parameters of packs and complete backfilling

Deformation processes of a stope boundary takes place due to displacement of roof and floor of a mine working. That depends upon significant length of a stope together with minor height of the mine working. Roof fault and floor heaving follow the rule of plane-parallel displacements oriented perpendicularly to a gravity force axis [6, 9]. In such a case, vertical stresses become the dominating conditions providing equilibrium of geomechanical system of a mine working. The stresses also exert forming influence on other components of stress-strain state of the rock mass within areas neighbouring the stope and the mine workings.

Fig. 2. Vertical stresses in a cross section at 0.5 m distance from a mine working in the process of packing when height of rocks being cut is 0.5 m

Rapid growth of deformations, caused by vertical stresses within the mine working roof, results in the high-speed fissuring. Origination of the main cracks prevents from dissipation of the accumulated energy of rock deformation factoring into the uncontrolled breakdown of boundary rock layers. Stope advance gives rise to the increased rock pressure within the powered support area; loss of roof rock strength of the mine working takes place resulting in its performance degradation. Thus, to understand the processes involved in the deformation of boundary of the conjugated mine workings, it is required first to analyze the pattern of vertical stress distribution within the rock mass.

Start consideration of volumetric curves of vertical stresses from the degree of effect of operational parameters of packs within the mined-out area of a stope on SSS in a mine working wall. Fig. 3 explains stress pattern in a section, being cross relative to a stope face of rock mass located at 0.5 m distance from mine working-stope conjugation plane. A model of the powered support in the form of 1 m height and 5.5 m width parallelepiped in at the center. Undisturbed rock mass is to the left of the model; mine working with packs or complete backfilling is to the right. Such an arrangement is preserved for each further similar curve.

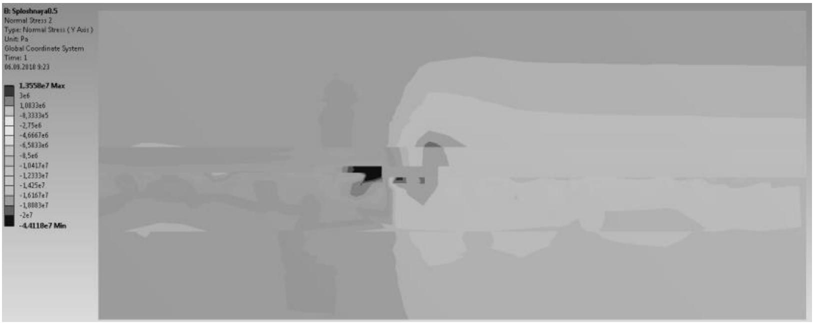


Fig. 3. Vertical stresses in a cross section at 0.5 m distance from a mine working in the process of complete backfilling when height of rocks being cut is 0.5 m

Total analysis of curves in Figures 2 and 3 has shown the following: more than 90 % of the analytical model experience compressive stresses to be correct for elastic problem statement while corresponding to conditions of vertical stress application to upper and lower edges of the model; maximum compressive stresses are in front of the stope face towards the undisturbed rock mass which corresponds to the practices of stress measurements under full-scale conditions; formation of tensile stress areas depends upon the effect of the powered support model on the neighbouring rock layers which is in the good agreement with its actual operational conditions [7]; and vertical stresses within the mine working roof exceed stresses in its floor and the fact is supported by operational practices of stopes in Western Donbas mines.

Range of maximum stresses for the three computational options coincides almost completely; less than 5% deviations are fall into the analytical error. Qualitative distribution of vertical stress is of the nature, being typical for all the calculations; however, both value and size of stress intensity gradient within a mine working roof increases from alternative 0.7 m height of the rocks being cut to 0.5 m height. In this context, stresses within the mine working floor decrease but the velocity drops twice.

Effect of the tensile stresses on the state of a mine working roof localizes within the area neighbouring the powered support. As a result, at 5 m distance from the powered support model, vertical horizontal directional stress gradient in the mine working roof is equal to zero.

Hence, use of packs to provide reasonable operational performance of a stope-mine working conjugation makes it possible to obtain uniform distribution of load on the support and on the protective structures of a mine working support in a vertical direction which should cut the likelihood of the main fissuring as well as dimensions of areas loss of strength within neighbouring rock mass. On the other hand, changes in height of the rocks being cut leaves invariant operation of the powered support and, having no influence on the stress distribution within the undisturbed rock mass behind the stope face.

Curves in Fig. 2 involve characteristic features, which are not typical for calculation options where packing is applied. Change in stress pattern within the stope roof in the area of rock mass neighbouring the powered support model is the principal distinction of the model.

First, the powered support effect on the stress distribution within the stope roof covers 10-15 m towards the mined-out area if increase in maximum stresses is 21-24% to compare with calculations concerning use of packing. It means that complete backfilling makes it possible to engage greater rock amount to a process of roof stabilization. However, the feature is neutralized completely by the increase in vertical stresses. Thus, accumulation of potential energy of roof deformation for the calculation options, demonstrated in Figures 2 and 3, is similar quantitively. At the expense of the varied value and geometry of vertical stress gradient, distance between the main fissures increases relative to packs if complete backfilling is applied which results in the formation of larger rock blocks [7].

Second, maximum compressive stresses are in front of a stope face within the undisturbed rock mass. Values of the stresses, obtained for packs, experience 20-50% exponential increase along with the increase of height of rocks being cut. In this context, a curve in Fig. 3 demonstrates abrupt jump of compressive stresses within the powered support model-stope roof contact zone. Such a feature is also typical for other curves represented in Fig. 3, which points to the varied nature of the powered support-rock mass interaction. Both front share of leg of the powered support and rare share are under the effect of alternate load, which increases the likelihood of "rigid" setting [8, 11]. Henceforward, the *alternate load* is understood as a state when a stress field, characterizing material compression and tension, is formed simultaneously within the selected volume of analytical model.

The obtained results help conclude that the behaviour of boundary rock mass in the context of packing and complete backfilling is described with the help of linear regularities and exponential regularities stipulating difference increase in maximum vertical stresses depending upon the height of rocks being cut.

a

b

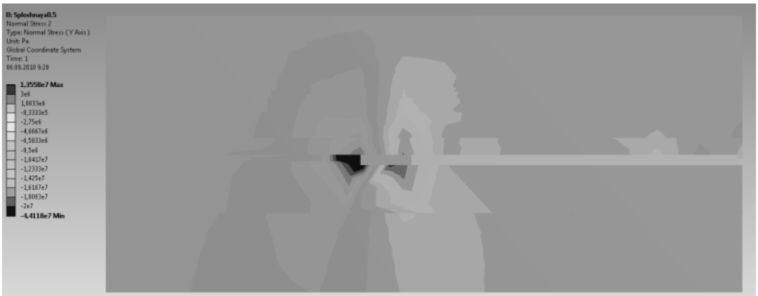


Fig. 4. Vertical stresses within the central cross section of a mine working at 0.5 m height of rocks being cut when: *a* - packing is applied; and *b* - complete backfilling is applied

If longwall length is 250 m, at 120 m distance from a stope-mine working conjugation, rock mass area is formed within which factors of technogenic impact on the rock mass stress-strain state are almost minimized. Hence, use the area to analyze stress distribution taking into consideration three typical longitudinal sections of packs: first – in close proximity to a pack within empty of a stope (see Fig. 4*a*); and second - along a side surface (see Fig. 4*b*).

Stress distribution within a roof in Fig. 10, a shows that it resists uniformly a displacement to the stope cavity lengthwise and the resistance is by 17% less to compare with floor resistance. Stress distribution within the stope floor is of regular nature with 9-12% stress value vibrations of maximum. Stresses, taken by the pack model, exceed greater vertical stresses than rocks neighbouring it; distribution of the stresses is of a regular nature as well.

Therefore, the pack operates like an equalizing damper in the process of effort transmitting from a roof to a floor. Minimum vertical stresses within the pack are located at the beginning at $L_н$=2.5 m distance from the edge of the powered support model. The $L_н$value is the determining parameter to select a velocity of a stope face displacement in the process of packing.

If the broken rock is laid down continuously along the stope in case of complete backfilling which results in natural compaction of the stowing, the formation of packs needs certain time interval, determined on the basis of mechanical disintegration conditions, during which the bulk rock will gain carrying characteristics. The characteristics can form naturally if only minimum external loads are available not initiating dynamic phenomena within the packs being formed. Hence,

$$v_{оп}=L_н \cdot t_{ст}, \quad (5)$$

where $v_{оп}$ s a stope advance; $L_н$ is a length of a pack area rejecting mine pressure; and $t_{ст}$ is stabilization period of the pack meter.

Stabilization period of a pack meter may be determined either experimentally or with the help of methods of extrapolation of findings obtained for different rocks and their failure conditions [10]. However, the parameter also depends upon the height of rocks being cut since it experiences effect by a value of total pack amount. Moreover, variation of the parameter, stipulated by the considered system state, is of nonlinear nature preventing from the use of mathematical scaling methods.

The calculations have shown that maximum $L_н$ value corresponds to 0.6 m height of rocks being cut reaching 3.4 m; if the height is 0.7 m then minimum value (i.e. 1.2 m) is obtained. Thus, the parameter has nonlinear characteristic too.

Ultimately, determination of a stope optimum advance in terms of a factor, providing carrying capacity of a pack, takes place according to the results of full-scale experiments. The development of physical and mathematical model of the process needs further research which tendency and volume do not correspond to the area under consideration.

In Fig. 3, the coal seam and rock layers, neighbouring it, experienced high compressive stresses. At the mean, the stresses within the area are 4% higher than stress values in the undisturbed rock mass but the area extent is 18-22 m. Within the central cross-section plane (see Fig. 4*b*) such an area is not available and area of high vertical stresses formed vertically. Stress increase within the area is up to 12% of maximum theoretical values. Thus, in the context of complete backfilling, changes in vertical stresses along the stope are of qualitative and quantitative nature being expressed in the high stress area reorientation from horizontal to vertical as well as in 6-9% increase in the stress values.

Comparative analysis of the curves has explained that in the context of the two cases, geometry of the area of high compressive stresses is similar to a gradient value. Stresses, experienced by rocks of a stope (see Fig. 3), are 8% less to compare with those in Fig. 4*b*. In terms of complete backfilling alternative, no vertical floor stresses along the stope cross section are observed.

As a whole, when complete backfilling is used, rock mass loading is uniform; nevertheless, concentration of compressive stresses within the undisturbed rock mass is higher to compare with the use of packs. Thus, qualitative variations in stress distribution among curves, represented in Figure 4*a*, and Figure 4*b*, are as follows:

- in terms of computational alternative one, local stress concentration within the disturbed rock mass and within a stope floor is 22% less to compare with alternative two; and
- material at a wall surface of a pack takes stresses by 18% more to compare with complete backfilling.

The abovementioned points to the formation of conditions for dynamic phenomena origination in packs along the whole length of the mine workings. Loose rock thickening takes place under the effect of high rock pressure. Depending upon loading conditions, it may result in the geomechanical system stabilization or, instead, in the active development of the main fissures within immediate roof of the mine working. Determination of the geomechanical system stress-strain state development under the conditions is a separate problem solved with the use of multiparameter system to analyze conditions of complicatedly structured enclosing rock mass [8-11].

In the context of complete backfilling, area of high compressive stresses to be calculated for 0.6 m and 0.7 m heights of rocks being cut is of a similar shape differing qualitatively from 0.5 m alternative. 1.5 times increase of compressive stresses in the stope immediate roof above the powered support is typical for such calculation options. Hence, increase in the amount of rocks being cut in the process of complete backfilling does not result in the change of stress-strain state of the rock mass. Nevertheless, pressure on the powered support also increases consistently for 0.5 m height of rocks being cut meaning incremental probability of a of "rigid" setting of the powered support legs.

Analysis of curves of vertical stresses has helped conclude the following: under the considered mining and geological conditions, operations of a mine working are provided better in the context of packing to compare with complete backfilling; if packing is used, changes in roof and floor of the stope follow a regular law along the stope advance axis and across it; height of rocks being cut effects the immediate roof state change during packing and complete backfilling but following different laws; and in the context of packing, vertical stress are distributed more uniformly along the stope face within the undisturbed rock mass to compare with complete backfilling being 12-16% less in terms of absolute values.

Analysis of stress distribution within stratification planes of rock mass along a stope advance

Under the conditions of high structuredness of rock mass, enclosing a mine working, horizontal stresses are among the basic factors determining parameters of the controlled roof rock caving during a stope advance. Changes in the stress values along the stope face as well as transversely to it identify both shape and time frame of the formation of a destructive breaking wave within the rock layers making a roof of the considered geomechanical system.

Following analysis is a comparison of horizontal stress characteristics in different sections of one and the same calculation. Determine backfilling effect on the state of the fine-grained rock mass within a roof of geomechanical system of a stope and a mine working.

Availability of a vertical plane, oriented along the stope face and located above the powered support, is the common feature of the curves. Within the plane, analytical stress sign changes from compressive to tensile.

Parameters of the plane, its dimensions, and changes in its geometry (i.e. transformation into the curved surface) help determine dimensions of the rock mass being involved to a process of axial deformation of a stope roof.

Moreover, it is required to take into consideration variations of horizontal stresses in the depth of the undisturbed rock mass as well as from the worked-out area of the stope since it identify both degree and conditions of effect of maximum horizontal stresses on the backfilling method being applied in the specific case.

Hence, along with the stress analysis within the equilibrium plane, it becomes possible to determine the conditions of axial loading of a stope backfilling.

Comparison of Figure 5, a, and Figure 5, b helps understand that a height of alternate stresses increases by 27% from the mine working edge to a central share of the stope.

Local areas of high compressive and tensile stresses also increase towards the stope central share.

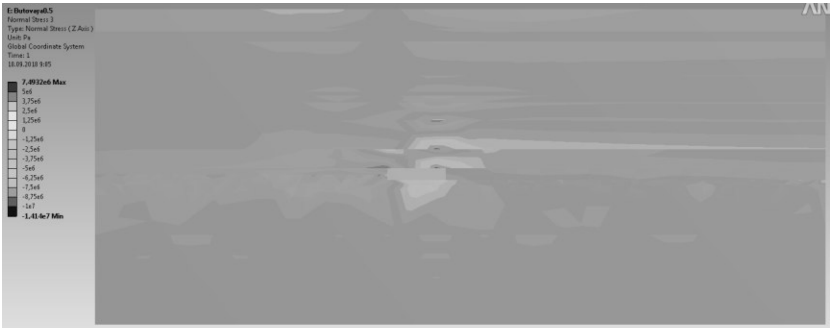
In terms of absolute values, the increase is 2 to 53% and change in dimensions of the areas achieves 145%.

However, the increase is observed only vertically.

Relying upon the results, it is possible to conclude that the increased height of the sign-variable plane results in the increase of horizontal stresses within the local area of a roof of the mine working neighbouring the powered support model pointing to the intensification of horizontal displacements depending upon distancing from the stope edge.

That factors into the formation of an ovoid-like front of the progress of the main fissures directed across the stope.

a



b

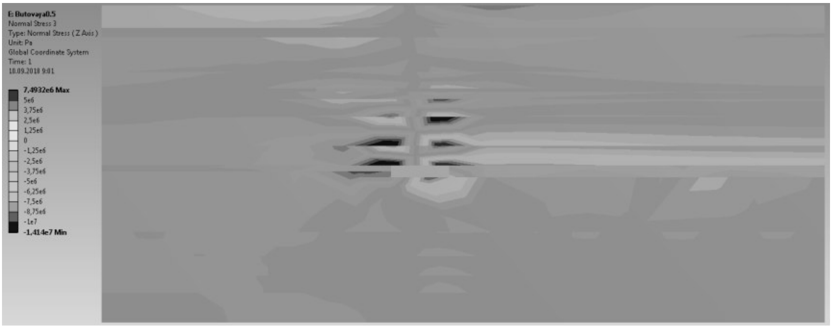


Fig. 5. Horizontal stresses in cross section in the process of packing when height of rocks being cut is 0.5 m: *a* - at 0.5 m distance from a mine working; and *b* - within a central transverse plane

To compare with curves in Fig. 5, Fig. 5*b* demonstrates increase in horizontal stresses within the undisturbed rock mass, and within the stope floor meaning the increased share deformations arising when rocks are converged to the stope cavity. If in the neighbourhood of the mine working effect of the undisturbed rock mass within walls of mine working helps decrease a level of horizontal stresses, significant distance neutralizes the effect. Thus, the less difference among stress distribution within sections in Figure 5*a*, and Figure 5*b* is, the more stable is the roof of the considered geomechanical system. Basing upon the statement, formulate rule one – optimum backfilling conditions are possible if only minimum deviations take place in the alternating-sign plane along the whole length of a stope.

Comparative analysis of curves in Fig. 6 has shown that 12% stress increase within the undisturbed rock mass in front of a stope results in 7% load increase on stowing within the mined-out area. Hence, for Ukrainian mines, the two factors are related and their connection helps evaluate strength degree of structural bearing capacity of protective measures as for the original rock mass. Thus, we obtain rule two – decrease in the difference of horizontal stress increment within the undisturbed rock mass in the context of packing or complete backfilling shows the increase in the bearing capacity of the protective structure to compare with other alternatives.

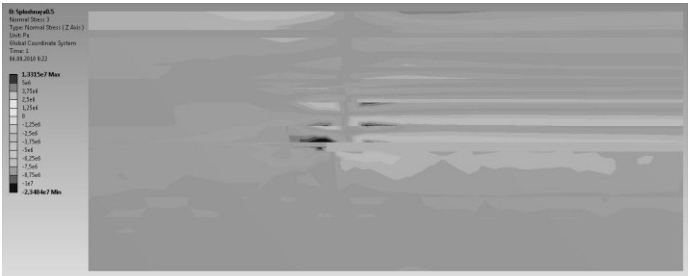
As for the calculation alternative, the intensity of changes in horizontal stresses along a stope is 1.3 times higher to compare with packing. Height of alternating-sign stress plane achieves upper boundaries of rock layers of the analytical model. Thus, mechanical state of rock layers within the considered geomechanical system deteriorates in the context of complete backfilling.

Stresses inside immediate roof of a stope within its central cross section (see Fig. 6) shape a pattern being close to a vertical section formation above the powered support legs. Within a central share of a stope, legs of the powered support resist to loads, increased by 40%, which are directed towards the mined-out area; i.e. despite complete backfilling, the mine working roof demonstrates intensification of deformation processes intended to separate certain share of the immediate roof along the stope face. It turns out that for complete backfilling conditions, stress-strain state of rock mass is less stable to compare with packing (see Fig. 5) but is still out of keeping the criteria of rock failure with the formation of the main fissures [13].

When complete backfilling takes place and height of rocks being cut is 0.6 m, sharp increase in the value of horizontal stresses is observed in the neighbourhood of a mine working as well as in the central share of a stope.

Shaping nature of the areas of high stresses remains invariable; nevertheless, their dimensions experience 17% increase. Therewith, in the neighbourhood of a mine working, average increase in tensile stresses is 14% and increase in compressive ones is 9 % which can be explained by sharp increment of load on the support and on protective structures of the mine working. The above mentioned may accelerate a process of rock heaving and arch lowering [9, 10].

a



b

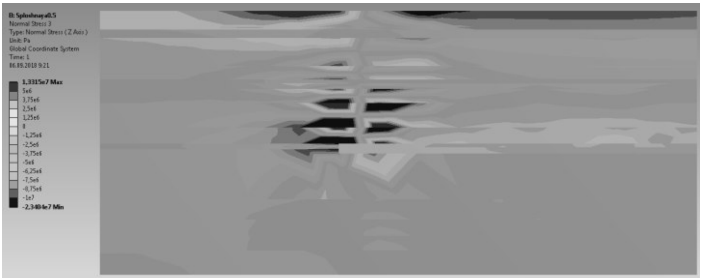


Fig. 6. Horizontal stresses in cross section in the process of complete backfilling when height of rocks being cut is 0.5 m: *a*- at 0.5 m distance from a mine working; and *b*- within the central transverse plane

In addition, a height of alternating-sign stress plane remains invariable for each computational alternative. That also means the lack of fundamental changes in the shaping of areas of ultimate rock state within the stope roof. Nevertheless, the constant increase in the absolute values of horizontal stresses shows that heightening of rocks being cut increases a risk of roof rock softening right above the powered support section. The dependence is nonlinear, and experiences its decrease in proportion to the heightening of rocks being cut.

In view of the fact that in the context of complete backfilling horizontal stresses within a roof of a stope are of maximum values, it is required to analyze specific features of their distribution in the immediate roof. In terms of the mining and geological conditions, immediate roof of the stope consists of three rock layers ordered in the analytical model from one to three starting from the coal seam being mined.

Findings

Assume a stope face-its central vertical section junction as the area to be analyzed. Levels one and three take up stresses with a wider scatter but degrees differ. Such a specific feature of the graphs denotes effect of rock deformation characteristics on the stress distribution within the rock mass substantiating indirectly the adequacy of the calculations.

However, there is a specific feature concerning horizontal stress distribution when heights of rocks being cut are 0.6 m, and 0.7 m. If in rock layer one, stress values increase gradually, in layers two and three, values of maximum stresses are less for 0.7 m height of rocks being cut to compare with 0.6 height meaning changes in the conditions of equilibrium state of the model of a stope roof. Such a change in maximum stress values is followed by partial transition of rock layers to the limit state resulting in the immediate roof softening under the effect of compressive horizontal stresses.

Analysis of graphs of tensile stresses (see Fig. 7) [3] demonstrates a pattern opposing the graphs of compressive stresses. If height is 0.5 m, then changes in maximum stresses in terms of rock layers of the immediate roof differ markedly from 0.6 and 0.7 m heights of rocks being cut; layer one is loaded greater and load, taken up by layer three, is quite lesser.

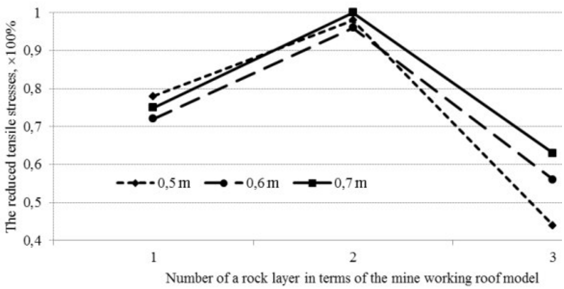


Fig. 7. Changes in the reduced maximum tensile horizontal vertical stresses on the stope face within the central share of the mine working in the process of complete backfilling in terms of different heights of rocks being cut [3]

On the whole, calculation alternative for 0.6 m height demonstrates indices of the limit efficiency state as for the provision of a stope immediate roof in the context of complete backfilling. Furthermore, effect of compressive stresses on the stable state of a mine working immediate roof is greater to compare with the effect by tensile stresses.

Conclusions

1. Modelling is performed for three variants of stope stowing when the stope is developed through a thinly stratified rock massif under different mining and geological conditions in a three-dimensional representation with realization of conditions for mutual slipping of rock strata. Deformational and mechanical characteristics of elements of the studied geomechanical massif are defined considering the results of laboratory studies and a natural experiment, which determine the behavior mechanism of a granular medium of stowing. The analysis of deformations of a geomechanical system allows determining the degree of influence of different variants of a technology of protecting a stope and deformational characteristics of a rock massif.

2. It is established that a concentration of horizontal stresses directed along a stope face over a powered support in a roof of a mine working is the main factor affecting a mode of development of main cracks in a roof of a working during stowing. The interaction mechanism at junctions of a stope and another working is studied to determine a development mechanism of a stope roof collapse considering the influence of stowing parameters. Analysis of a stress-strain state of a stope roof by selected mining, geological, and technological parameters allows determining the conditions of rock strata interaction, the result of which is a roof collapse on packs.

3. It is determined that the designed unit of powered roof support allows overcoming structural features of a roof support used during partial stowing by increasing the safety margin of elements supporting the tail console. The safety margining crease is achieved by introducing additional rigid structural elements what reduces the level

of stress concentration in joints of a roof support structure.Using an integrated approach to determine the efficiency of selected roof supporting scheme allows estimating reliability of the selected modelling scheme when predicting changes in a state of a geomechanical system. This is a new method for evaluating the efficiency of various technological solutions.

4. The results indicate that when using packs, a process of crack formation in an immediate roof of stopes is stopped by localizing areas and stress values that contribute to growth of main cracks. The optimal selection, from a standpoint of dynamic stability of animmediate roof of stopes and packs, is selection of the minimum permissible height of extracted rocks while ensuring a statistical equilibrium of sides of packs. This allows determining a mechanism of selection of stope movement velocity, a type and geometric parameters of erected packs.

References

1. **Sotskov V.A., Malashkevich D.S. and Russkikh V.V.** (2016). Analysis of the influence of partial laying of the mined-out space on the VAT of a carbon-bearing massif during the selective mining of thin coal seams. Geotechnical mechanics, №129. 54–64.

2. **Fomychov, V.V.** (2012). Bases of calculation models plotting of bolt-frame support considering non-linear characteristics of physical environment behavior. Scientific herald of National Mining Ukraine, 4, 54-58.

3. **Fomichov V.V., Sotskov V.O., Dereviahina N.I. & Leonenko O.V.** (2019). Analysis of the results of a computational experiment to determine operational parameters for partial backfilling of the worked-out area. Modernization and engineering development of resource-saving technologies in mineral mining and processing. Multi-authotrf monograph. Romania: UNIVERSITAS Publishing. 410-430.

4. **Buzilo V.I., Sulaev V.I., Koshka A.G.** et al. (2013). The technology of mining thin layers with the laying of the developed space. Dnipropetrovsk.

5. **Ma, C., Yao, W., Yao, Y., Li, J.** (2018) Simulating Strength Parameters andSize Effect of Stochastic Jointed Rock Mass using DEM Method. KSCE Journal of Civil Engineering, 22 (12), 4872-4881.

6. **Fomychov, V., Sotskov, V.** (2018). Determination of parameters of non-uniform fractured rock massif in computing experiment. Journal of Geology, Geography and Geoecology, 26, 26-32.

7. **Fomichev, V.V., Sotskov, V.A., Malykhin, A.V.** (2014) Definition and analysis of changes in acceptable indicators of the stress-strain state of the elements of the frame-anchor lining of the dismantling drift when approaching the face. Naukoviy vísnik NGU, 1, 22 - 25.

8. **Bondarenko V.I., Russkih V.V. and Yarkovich A.I.** (2014). Materials On the issue of abandonment of rock in the worked out space of coal mines. Materials of the VIII international scientific-practical conference "School of underground mining", 19-24.

9. **Bondarenko V.I., Kovalevska I.A., Simanovich G.A., Koval O.I., Fomichov V.V.** (2012). Experimental studies of the stability of reusable excavation workings on the flat layers of the Donbass: Monograph. Dnepropetrovsk.

10. **Zakharov Yu.N., Kantovich L.I.** Interaction of mechanized roof supports with the roof during the development of the Starobinsky potassium salt deposit. Moscow.

11. **Li, J., Nie, Y.-F., Fu, K., Guo, J.-B., Xu, M.-X.** (2018) Experiment and analysis of the rock breaking characteristics of disc cutter ring with small edge angle in high abrasive grounds. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 40(10), 505.

12**. Fomichev, V.V.** (2015). Scientific bases of control of geomechanical systems with the use of recursive methods in the underground development of deposits: Diss. … Doctor of Engineering. Sciences: 05.15.02. Dnepropetrovsk.

13. **Hu, F., Li, Z., Hu, R., Zhou, Y., Yue, R.** (2018) Research on the deformation characteristics of shear band of soil-rock mixture based on large scale direct shear test. Yanshilixue Yu Gongcheng Xuebao / Chinese Journal of Rock Mechanics and Engineering, 37(3), 766-778.