# Substantiation of Parameters of the Technology of Mining Thick Flat Beds by Underground Method with Splitting the Bed into Two

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**The main aim of the research was to study rational schemes of placing and fastening mine workings of the second layer in course of using a layerwise system of coal beds development. The prospects of developing thick flat coal beds in the Kuznetsk coal basin of the Russian Federation have been considered. It has been shown that in mining beds 7-10 m thick with the use of long wall minings, a layerwise development system with splitting the bed into two followed by processing the beds top-down has become widespread. The problem of the second layer mine opening stability has been considered. The possibility of using the finite element method for solving the problems of mining geomechanics has be substantiated, in particular, for studying the stress-strain state of the rock massif in the vicinity of the mine openings of coal mines. Mining-and-geomechanical models and calculation schemes have been presented for solving the task of determining the influence of the overworking (working of the first layer) on the status of zonal developing workings of the bottom beds. The results of study with the use of the finite element stress-strain state of rock massif have been shown. Diagrams of stress distribution in the area of bearing pressure ahead of the working have been presented. With regard to the stress state of the bottom bed, recommendations have been given about choosing the location of the workings. By results of computer simulation, conclusions have been made about the influence of various factors on stability of local workings of the second layer of the coal bed.**

**Key words:** Underground mining, coal beds, slicing system, mine openings, rock massif, stress-strain state.

Prospects of developing the underground development method in Russia are largely associated with efficiency of mining shallow coal beds 7 to 10 m thick. Commercial resources of valuable coal grades in these beds are mostly concentrated in the Kuznetsk coal basin and amount to over 12.6 billion tons. The main system of developing coal-beds of increased thickness using the underground mining method is currently the system of long-pillar work with splitting a thick coal-bed into two inclined beds (Varfolomeev and Tatarinova, 2014). Urgent practical issues that arise in course of layerwise mining of thick coal beds include the issues of efficient and safe mining of the bottom coal-beds, namely, increasing layer stability of layered zonal workings. Currently, when the minings are transferred from the top to the bottom bed, the technical and economic indicators usually get worse: the cost of excavation increases 1.5-2 times, expenditures for maintaining their operational status greatly increase, and the loss of developed reserves increases by 10-15%.

The zonal developments of the second

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layer are located in a cold massive that influences the overworking expressed as a rule in deterioration of the formation and strength characteristics of coal and increased mountain pressure. The roofs include an interlayer coal pack (also experiencing the impact of the overworking) between 0.5 and 2.5 meters thick. In these conditions, the use of anchoring, which is one of the most progressive ways of reducing the cost and increasing the stability of mine workings, is impossible. The use of metal frames as the main roof supports results in a sharp increase in expenditures and a decrease in the speed of zonal preparatory development workings. Therefore, the cost of making zonal drifts of the second layer fixed with 3-unit braces is about USD 1,300 per meter (the mine named after V. I. Lenin, 2007).

It should be noted that attempts have been made to reduce the cost of the working in the second layer. For example, in the mine n.a. V.I. Lenin, a combined roof support was used: the frame-shaped 3-unit support was placed at increments of 0.8 meters, and an anchor roof support was placed between the frames, thus decreasing the density of the frame-like roof support. These attempts were not successful. The analysis of mining and technical literature, and the experience of layerwise development of thick coal-beds showed that, in spite of the current wide use of the schemes of development without re-using zonal preparatory workings, the working of the 2$^d$ coal-bed lagging behind the cleaning works, and availability of non-notched fireproof monoliths 30 m wide and more between the long faces (Nikishin, 2006), there are significant problems with maintaining the 2$^d$ layer openings in the zones of influence of the bearing pressure of the 2$^d$ layer long faces. For example, at the mine "n.a. V. I. Lenin," in course of developing the 2$^d$ layer at site 0-11-2, at the beginning of the cleaning (the long face had been moved a few tens of meters away from the penstock assembly chamber) there was a sharp increase in the rate of rock convergence in the coal heading in front of the long face 40 m long, which resulted in decreasing the cross-section of the coal heading from 10.2 m² to 4 m². The reinforcement support was destroyed. As a result, for ensuring operational condition of the coal heading, it was completely re-timbered. In addition, efficiency of modern high-performance complexes is largely determined by the state of zonal workings (Nikishin, 2007; Kazanin, 2015). Thus, the state of development workings influences the technical and economic indicators and the success of a mine as a whole.

The goal of the research was to study the influence of primary working of the plots in the 1$^{st}$ (top) layer on the 2$^d$ (bottom) layer and to define the rational location for layerwise development workings of the 2$^d$ layer that ensures their operational status throughout the whole period of use with the minimum cost and maintenance.

## METHOD

As the experience of solving problems of mining geomechanics shows, complexity of structure, properties and states of studied objects require an integrated approach to performing research, the empirical-analytical method in particular. Its specificity is generalization of the data of field studies, building geomechanical models of the studied objects on this basis, and using them for forming the calculation schemes. Usually, in geomechanics of mining, the used mining-and-geomechanical model is the idea about rock as a massif that features quasi-continuity, which makes it possible to use general approaches to solving tasks on the basis of the continuous field analog technique (CFAT) (Zuev and Paltsev, 2010). The main advantages of these methods are versatility, applicability for a wide range of cases, and relative simplicity of calculations. Their disadvantage is the large amount of computation; however, the use of modern computer technology and software helps to overcome it (Glushko and Gavelya, 1986). Preliminary analysis of methods for determining the stress-strain state (SSS) of the rock mass (RM) using the CFAT made it possible to state that the advent of finite element method (FEM) provides the possibility to obtain solutions that cover a wide range of conditions. With that, the accuracy of the solution is determined by the degree and completeness of consideration of the existing factors, and by the degree of compliance of the basic parameters used in the solutions to the parameters of the actual rock massifs. FEM is based on presenting the region, the stress-strain state of which is being defined, as an assembly of flat or spatial elements, such as rod or frame structures. With that, a clear physical interpretation is observed of the tasks being solved. However, the need to define the properties of each element separately provides an opportunity to take into account the heterogeneity of the properties of the deformed area, and to calculate the area of an arbitrarily complex configuration (Fisenko, 1986; Cherniev, 1987). The analysis of the methodical peculiarities for numerical solution of problems with the use of FEM (Shinkevich and Leontieva, 2015; Kovalsky, 2013) is sufficient for using it in studying the SSS of the geomechanical models that reflect the behavior of RM in real conditions of underground mining.

The analysis of mechanical properties and structural characteristics of a rock massif showed the necessity of considering the geomechanical problem for a homogeneous continuous environment, the conditions at the border of the allocated area of which are set to correspond to those in the neighborhood of the considered massif (Vlasenko, 2004). The performed research made it possible to develop a combined mining-and-geomechanical model and a calculation scheme (Figure 1), which adequately reflect the properties of the studied rock massif of the Tom-Usinsky region of the Kuznetsk Basin and the main features of the used technology. The boundary conditions and geometrical parameters of the studied objects are reflected in the mining-and-geomechanical model (Figure 1). The physico-mechanical properties of the rock massif necessary for the study (Table 1) were taken in accordance with "The handbook (registry) of rock physical properties".

It should be underlined that the mined-out space (and the presence of collapsed rock in it) can have a significant influence on the stress-strain state of the massif, therefore it is necessary to identify the degree of influence of this factor within the framework of the task of defining the depth of the destroyed coal area located in the top part of the overworked coal massif. The performed assessments of the completeness of filling the worked-out space with collapsed rocks, the coefficient of loosening the collapsed rocks, and the mechanical properties of rocks in the massif made it possible to quantitatively identify the magnitude of deformation properties of collapsed rocks in the range:

$$0.01 \times 10^4 \leq E_{collapsedrock} \leq 0.3 \times 10^4 \,(MPa),\ \mu_{collapsedrock} \approx 0.4 \quad ...(1)$$

The boundary conditions were taken as the conditions that meet the maximum level of gravitational load at the mining depth of 100-900 m. For example, for depths of 300, which are currently the most typical for the mines of the Tom-Usinsk area of the Kuzbass basin, the maximum level of gravitational loads is the following:

$$Pmax = \gamma \times H = 2.5 \times 300 = 7.5MP \quad ...(2)$$

In order to establish the general regularities of changes in the stress-strain state of the overworked layer in the studied area, the calculation scheme was used, which corresponds to the mining situation encountered in course of mining the first layer, the top boundary of which is the immediate roof (Fig. 1).

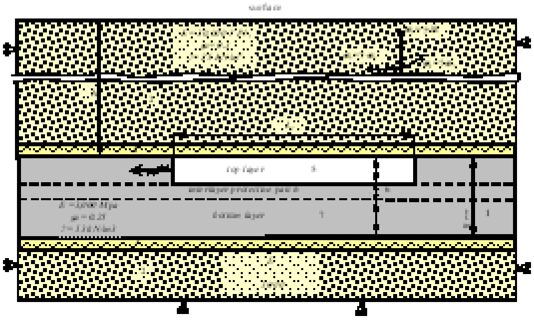
The parameters of the developed scheme were adopted in a wide range of geological and geotechnical conditions that correspond to the Tom-Usinsk region of the Kuzbass area. The depth of mining is 200 $\div$ 900 m. Thickness of the top layer is 2.5; 3.5 and 4.5 m. Coal (in the massif) shearing strength is 0.5 to 4 MPa. Type of roof: $h_n > 6m_v$ – the main roof directly rests on the immediate roof; $h_n < 6m_v$ – the main roof does not directly rest on the immediate roof – the stage roof deformation, and $h_n < 6m_v$ – the main roof does not directly rest on the immediate roof – the stage of roof convergence. In course of performing analytical studies, we considered all possible combinations of these parameters.

## RESULTS

In order to study the effect of various geological factors on the magnitude of the depth of the fracture zone located in the top part of the overworked layer, and the minimum allowed thickness of the interlayer protective coal patch for the developed mountain-geomechanical model and the calculation scheme, all the components of the strain tenser $\sigma_{ij}$, strains $\varepsilon_{ij}$ and displacement vector $\delta_i$ have been calculated using the finite element method. For the necessary theoretical generalization, computer processing of numeric fields and the graphic interpretation of all parameters were performed. As an example that illustrates the nature of the obtained calculation

**Table 1.** The main physico-mechanical properties of rocks in layer III

| Rock | Indicators of the physico-mechanical properties | | | | |
|---|---|---|---|---|---|
| | E, MPa .$10^{-4}$ | μ | γkN/m³ | C, MPa | ρ, degrees |
| Sandstone | 3 | 0.25 | 25 | 12 | 20 |
| Argillite | 1.6 | 0.25 | 25 | 5 | 25 |
| Siltstone | 1.6 | 0.25 | 25 | 5 | 25 |
| Coal (layer III): the top patch | 0.3 | 0.27 | 13 | 2 | 25 |
| the middle patch | 0.4 | 0.27 | 13 | 3 | 25 |
| the bottom patch | 0.2 | 0.27 | 13 | 1.5 | 20 |



1-coal bed; 2-main roof (sandstone); 3-immediate bottom; 4 – immediate roof; 5 – face space of the 1st layer; 6 - interlayer protective coal patch; 7 – second layer.

**Fig. 1.** Mining-and-geomechanical model and the calculation scheme for assessing the impact of overworking in the conditions of the Tom-Usinsk region of the Kuznetsk Basin

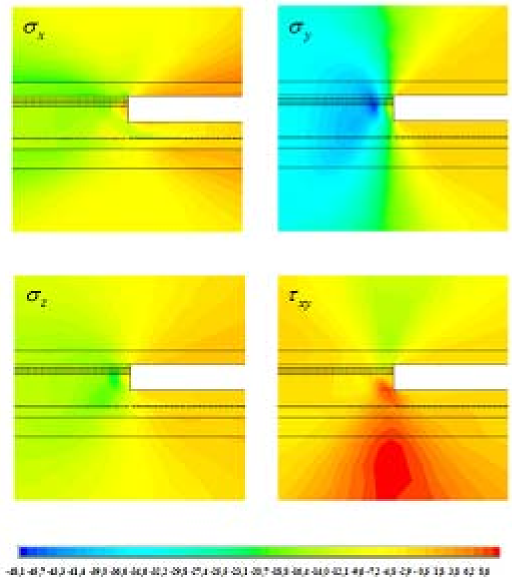


**Fig. 2.** The stress fields before the stopping face, MPa

results, Figure 3 shows the stress field in the top part of the overworked coal massif for the geological conditions of layer III; the depth of mining operations was 300 m, the thickness of the developed top layer was 4.0 m, the shear strength of coal was 3 MPa, and the type of roof – the main roof does not rest on the immediate one. As can be seen in Figure 2, after testing the first layer in the top part of the coal massif, the maximum bearing pressure is shifted from the edge of the massif, due to the destruction of coal in the edge part, with formation of a zone of low tensile stress.

Stress distribution within the excavated layer in the area of the bearing pressure ahead of the long face is shown by the curve in Figure 3. As one can see from Figure 3, ahead of the long face, a zone of bearing pressure is formed, which is characterized by the presence of two zones: the zone of layer limit state - from the backwall to the maximum bearing pressure (about 6.5 m long) and the zone of layer elastic state - from the maximum stress to the initial level of stress (approximately 160 m long). The coefficient of stress concentration in the zone of the bearing pressure is 2.7, which corresponds to the concentrations that occur when hardly collapsible and strong rock layers are located in the roof of the layer. The difference in distribution of stresses in the figures is due to the irregularity of their level within the developed layer, both within the first and the second layers. It should be noted that the stress distribution shown in Figures 2 and 3 does not contradict the generally accepted ideas about distribution of stresses in the zone of bearing pressure (Maximov, 1973; Katsaurov, 1981; Baklashov, 1986; Dudakalov, 2006), which fact confirms the correctness and the validity of using the mining-and-geomechanical model.

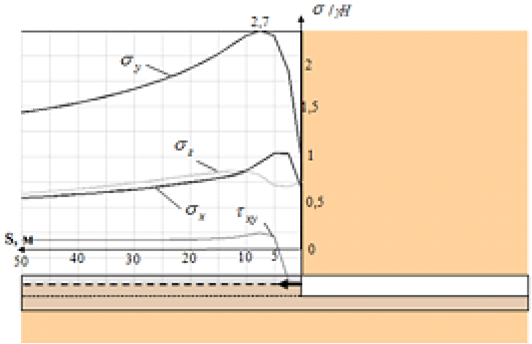
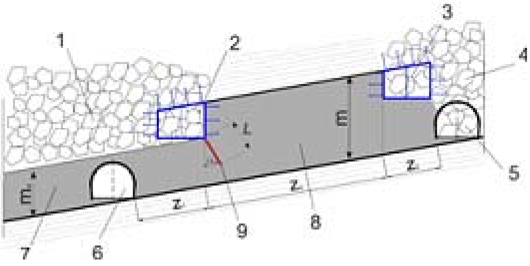


**Fig. 3.** The curve of stresses along the line at the level of ½ of the height of the 1st layer in the central section of the long face



1 – the excavated space of the overworked layer; 2 – the gotten air track in the 1st layer; 3 – the gotten conveyor coal heading of the 1st layer of the previously worked-out site; 4 – the worked-out space of the previously worked-out site; 5 - the gotten conveyor coal heading of the 2[d] layer of the previously worked out site; 6 – the ventilation coal heading of the overworked layer; 7 – the overworked layer of the mined area; 8 – the stope between the long faces; 9 – inclined opening slot; $z^1$ is the distance between the ventilation excavation in the overworked layer and the edge area of the massif (stope) that depends on geological conditions; $z^2$ is the distance between the conveyor excavation of the overworked layer and the edge part of the massif (stope) that depends on geological conditions; $z_s$ is the width of the stope; $m$ is the layer thickness; $m_n$ is the thickness of the 2[d] layer; $L$ is the depth of the slot; and $\alpha$ is the angle of slot inclination to the vertical plane.

**Fig. 4.** The method of ensuring the operational status of zonal development workings that includes making relieve slots

## DISCUSSION

The studies showed that most significantly the stress-strain state of the top part of the overworked coal massif and the interlayer coal protective patch are influenced by:

a ) depth of mining;

b) physico-mechanical properties of the coal massif;

c) the length of the long face;

d) thickness of the top layer;

e) presence of rock interlayers.

Increasing the mining depth, ceteris paribus, results in a significant increase in the size of the limit state zone. Changing the depth from 200 to 900 m results in an increase in the depth of the limit state zone from 0.3 to 0.7 m. In addition, the magnitude of residual deformations in the specified zone significantly increases.

Increasing the length of the long face from 100 to 300 m leads, ceteris paribus, to growing stress level in the middle part of the long face, and increases the depth of the zone of coal limit state.

The state of the overworked massif *y* is mainly determined by the physico-mechanical characteristics of coal. The shearing strength of the massif can be used as a predictor of the degree of overworking influence. It has been established that with decreasing the shear strength, both the size of the zone of coal limit state and the degree of destruction within this zone increase. Decreasing the tensile shear strength of the coal massif from 4 to 0.5 MPa results in an increase in the limit state zone from 0.5 to 1 m and more. In case of the tensile shear strength of 0.5 – 1.5 MPa, the permanent strain zone may cover the entire bottom layer close to the immediate bottom.

The size of coal limit state zone may be significantly influenced by rock interlayers. It has been established that if the thickness of rock interlayers is less than 0.3 m, they usually do not have practically significant influence on the state of interlayer patch. Due to the fact that in the present conditions of the Tom-Usinsk area of the Kuznetsk basin, the interlayer patches typically include interlayers not more than 0.2 m thick, the influence of inter-layers of greater thickness were not considered in this paper.

It should be stressed that the depth of the coal destruction zone and the degree of destruction within the specified area is uneven along the length of the long face, and conclusions made as a result of the research are true for the middle third of the length of the long face.

In addition, the conditions of maintaining local workings of the overworked layers, as shown by the results of research, including those made by other authors (Nikishin, 2006), are largely determined by the influence of earlier worked out extraction columns. The procedure of extraction used in the mining sites determines a significant difference in the conditions of maintaining the conveyor and ventilation workings of the site, due to the fact that some workings are, as a rule, adjacent to the worked-out areas, and the others are not. Thus, it becomes necessary to determine the location of each working of overworked layers, with regard to the existing mining conditions. In our opinion, the schemes used for mining the pillars require allocating at least two situations that are fundamentally different in the conditions of their maintenance: first, the development is located at the edge of the massif, second - close to the stope between the long faces. With that, in case of locating the stope between the long faces, the development is usually located in more severe conditions (Spivak, 1985).

## CONCLUSIONS

According to the results of the computer simulation, the following key conclusions have been made.

1. The factors that influence the change in SSS of the overworked layer include the following: depth of works, physico-mechanical properties of coal, length of the long face, thickness developed layers, and presence of rock interlayers. The main factors that have the most significant influence are the following: depth of works, physico-mechanical properties of coal, length of the long face, thickness of developed layers, presence of rock interlayers and their physico-mechanical characteristics.
2. Ceteris paribus, the increase in the depth of mining is characterized by growth in the size of the limit state zone in the top part of the overworked coal layer due to increasing shear stresses, which, with changing the depth from 200 to 900 m, results in increasing the depth of the limit state zone from 0.3 to 0.7 m, and in substantial increasing of the magnitude of residual deformations in the specified zone.
3. The nature of location and the size of the limit state zone in the top part of the overworked coal massif relative to the upper layer long face depend on coal strength characteristics. Coal strength in the massif can be characterized by coal tensile strength. During development of a layer with coal tensile strength of over 2.5 MPa, the fracture zone is located directly under the line of the backwall. Decreasing coal tensile strength from 2.5 to 0.5 MPa, ceteris paribus, results a substantial increase in the size of the limit state zone.
4. The size of the zone of coal limit state may be influenced by the presence of rock inter-layers. It has been found during the studies that in case of rock interlayer thickness of less than 0.3 m, they usually do not have a significant influence on the interlayer patch, and only in some cases they can lead to a slight increase in the size of the limit state zone.
5. The depth of the fracturing zone located in the upper part of the overworked coal layer should be determined from the depth of mining, tensile strength of coal, the length of the long face and may be determined according to the graph developed in course of the research.

In our opinion, one of the promising directions of reducing the production cost - maintaining excavation of overworked layers and reducing losses of minerals - is using methods of ensuring operational state of the layered workings due to changing SSS of the massif in sites, by, for example, reducing the size of zones of increased horizontal stresses and thus reducing the required displacement of workings in relation to the edge parts of the massif (stopes) by the 1st layer (Sidorenko, 2006).

Analysis of the known methods of ensuring operational state of mine workings due to changing SSS made it possible to propose several methods, the use of which, in the conditions of overworking the layers, ensures the desired economic effect with minimal additional implementation costs. The shown below methods of ensuring operational status of layerwise workings of the 2$^{d}$ layer may be effectively used for mining at the depths greater than 300-400 m. Using these methods makes it possible to reduce the costs of maintaining zonal development workings of the overworking layers and to reduce the loss of coal by reducing the distance (the width of stopes between long faces in the 2nd layer) from the workings of the 2[d] layer to the edge parts of the massif (stopes) in the 1st layer.

The essence of the recommended method is as follows. An inclined opening slot 9 (Figure 4) is made in the soil of the 1st layer excavation, for example, with the use of the “Ural-5”0 or “ESF-70” slot cutting machines. The most appropriate is to create an inclined opening slot at the angle of 30° to the vertical plane, however, if such a solution cannot be implemented, a vertical opening slot may be made. Locating the opening slot under the angle of 30° makes it possible to reduce the first level of horizontal stresses in the zone of bearing pressure close to the edge parts of the massif and stopes.

**Relieve slots**

The efficiency of this method is ensured when the depth of the slot is not less than 2/3 of the thickness of the overworked layer. With increasing the depth of the slot, efficiency of the process increases. In the process of working layer III in the Tom-Usinsk area of the Kuznetsk basin with splitting into 2 inclined layers up to 4.5 m thick, the depth of the slot should be at least 3 m. The necessary condition of ensuring unloading is the long time of slot “operation” (especially in the zone of support pressure of the long face in the overworked layer) that cannot be achieved without additional measures for its maintenance. To ensure slower closing of the slot, we propose to use the method of partial filling the slot with wooden wedges, which ensures the initial spacing. The length of the wedges should ensure the maximum depth of slot filling, and their thickness should ensure tight fit to the walls. The frequency of placing the wedges should be determined empirically for each mining situation, and ensure “operation” of the slot until the moment of depreciation of the layered excavation.

The next possible variant of implementation of the method of unloading the overworked layers in the vicinity of the edge parts of the massifs and stopes is using a row (rows) of inclined unloading bore-holes in the soil (of side) of the 1st layer excavation, instead of the opening slot. The angle of boreholes relative to the vertical plane is defined in the same way as the angle of the opening slot. The distance between the boreholes and their diameter should ensure feasibility of drilling with the use of existing methods and tools, and required level of unloading the overworked layers in the vicinity of the edge parts of the massif (stopes). The depth of boreholes drilling should be at least 2/3 of the thickness of the overworked layer. It is possible to use several (2-3) rows of boreholes, and to place the boreholes in a checkerboard pattern (Sidorenko, 2010). It should be noted that the effectiveness and the possibility to implement the methods of safeguarding the excavations with the use of unloading cavities are confirmed by the experience gained in ensuring operational condition of mine workings at the Starobino deposit of potassium salts.

Further research will be focused on studying the status of the development workings in the lower layers in case of their various location relative to the edge parts of the massif and the stopes in the first layer with regards to the properties of rocks and the parameters of technological schemes of developing the reserves with backwalls, and studying the influence of the proposed methods of unloading the massif in the vicinity of workings on their condition.

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