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ИССЛЕДОВАНИЕ ВСКРЫТИЯ НАКЛОННЫХ МЕСТОРОЖДЕНИЙ ПРИ КОМБИНИРОВАННОЙ СИСТЕМЕ РАЗРАБОТКИ НА ПРИМЕРЕ КУРЕИНСКОГО УЧАСТКА

Мартьянов В.Л.[1], Марков С.О.[1], Колесников В.Ф.[1], Тюленева Е.А.[2], Цехлар М.[3], Яночко Ю.[3], Марасова Д.[3], Цаганова Д.[4]

[1]ФГБОУ ВО «Кузбасский государственный технический университет имени Т.Ф. Горбачева»
[2]Прокопьевский горно-проектный институт
[3]Технический университет в Кошице
[4]Словацкий технологический университет в Братиславе

Аннотация.
В условиях Кузбасса, где преобладающее количество запасов представлено пластами наклонного и крутого залегания, восстановление земель по мере развития горных работ представляет сложную задачу. Дело в том, что общепринятое для разрезов Кузбасса направление перемещения горных работ по падению пластов ведет к постепенному увеличению карьерного пространства по мере углубления работ и не позволяет совмещать восстановление поверхности с процессом разработки месторождения. Кроме того, весь объем вскрышных работ в этом случае располагается во внешних отвалах, для размещения которых изымаются новые площади. Поэтому получаемый при указанном направлении перемещения фронта работ экономический эффект, а именно относительно малый коэффициент вскрыши в начальный период развития разрезов и возможность обеспечения значительной производственной мощности при относительно небольших капитальных вложениях, становится менее существенным в сравнении с ущербом от нарушения земель, пригодных для сельского хозяйства. Восстановление земель, нарушенных в результате ведения горных работ, потребует значительных затрат, сопоставимых с затратами на подготовку запасов. В связи с этим, направление подвигания фронта горных работ по падению или по восстанию с точки зрения использования земли содержит существенный недостаток, с целью устранения которого целесообразно осуществлять перемещение фронта работ по простиранию. В этом случае фронт работ, располагаясь от выходов пластов до линии предельной глубины и перемещаясь по простиранию, создает выработанное пространство для размещения вскрышных пород. При соответствующем построении технологии горных работ каждый нарушенный в этом случае участок будет возможным компенсировать восстановлением равноценного участка в выработанном пространстве. Таким образом в обороте будет находиться относительно небольшая часть нарушенной площади.
Размещение вскрышных пород в выработанном пространстве будет способствовать уменьшению расстояния их перевозки и совмещению процесса подготовки запасов с горнотехническим или даже биологическим этапом рекультивации.

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General information

The technology of the mining of inclined deposits with the front movement of excavation along the strike provides for the development of the quarry field in two periods: the preparatory period and the period of the operation of the main field of the open pit.

It should be noted that a significant number of works have been devoted to the study of the transportless technology, including the development of complex structure seams [1-25]. However, there are practically no studies on the possibility of using dragline when mining inclined seams.

In the preparatory period an initial capacity is created which is necessary to organize the internal dumping according to the approved technology. During this period, the development of the initial stage of the field is carried out with the placement of overburden in the external dumps. Development of the second part of the section field is carried out with placement of the main volumes of rock in the mined-out space.

During the exploitation of the main field, the entire thickness of rocks and minerals in depth is divided into three zones: the upper, middle and lower (Fig. 1). Excavation of the upper zone is envisaged by the transport technology, and the middle zone – by transportless technology. The lower zone, which includes the formation of coal seams, can be mined either by transport or transportless technology.

The upper and lower zones are mined by horizontal layers across the strike. The middle zone is mined by one inclined bench on the downdip. The general movement of the work front in all three zones is along the strike.

The upper transport zone is independent and connected with the mining of the underlying zones mainly in time. Therefore, the choice of a set of excavation and transport equipment and its number for this zone should be made primarily on the basis of ensuring the same speed of mining front movement in all three zones of the open pit. The most expedient for this zone should be considered the use of excavators of ECG type (both domestic and foreign production) – rope shovels – with loading of rocks in dump trucks and hauling to the internal dumps.

The only requirement for the development of the upper zone is the need to leave horizontal sites at the boundary between the upper and middle transportless zones, which should allow drilling and blasting operations in the middle zone.

Parameters of drilling and blasting operations during the preparation of the middle zone rocks should be selected in such a way as to ensure the movement of the main part of the rock into the mined-out space. The remaining rock after blasting is moved by draglines.

The dumped rock is further re-excavated to expose the side of the lower zone. In this case the dragline route is partially located on the top of the lower zone, as well as on temporary and permanent dumps in the mined-out space.

Proceeding from the necessity of placing the middle zone rock in the mined-out space and taking into account that the height of the dump in this case should be equal to the thickness of the lower zone, the thickness of the middle and lower zones can be set. The type and number of draglines for excavation the transportless zone is determined depending on the production capacity of the open pit, which defines the necessary mining front movement speed in the lower (coal) zone.

The lower zone is an inclined part of the thickness, including coal seams and rock between the seams (partings, interburden). Mining of this zone is carried out according to the transport technology by horizontal layers. The overburden rock is transported by dump trucks to the internal dump, which moves following the movement of the mining front. Coal from the working zone of the open pit to the industrial site is transported by quarry road, which in the form of a serpentine located on the dumps of the transportless zone.

In this technology of mining works, the working zone in the coal-bearing stratum is limited along the strike on one side by the working flank of the open pit, and on the other - by transportless internal dumps. Therefore, from the point of view of mining safety in this zone, the stability of the working flank and dumps is very important. Here we should distinguish the ***overall*** *stability of the working flank and transportless dumps*, which is determined by the total pressure of rocks on the non-working flank of the opencast, and the *stability of the* ***slopes*** *of the working flank and transportless dumps*.

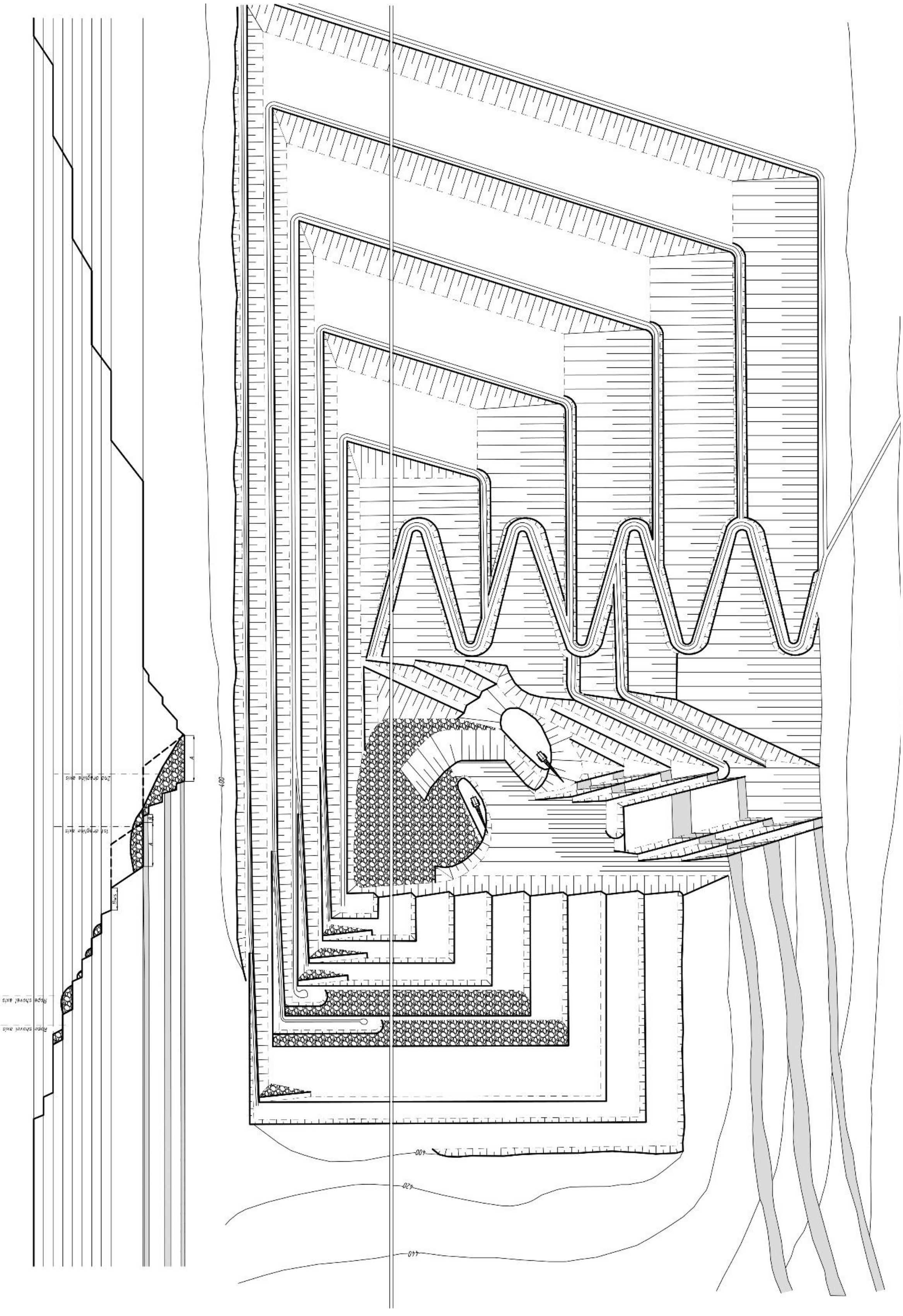

Fig. 1. Plan of mining operations at the time of the development of full internal dumping

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The overall stability determines the height of the working flank of the opencast and the transportless dumps and the angle of their turning relative to the strike line of the strata.

Depending on the angle of the working flank turning, three schemes of mining of inclined deposits with moving the mining front along the strike (Fig. 2) are possible.

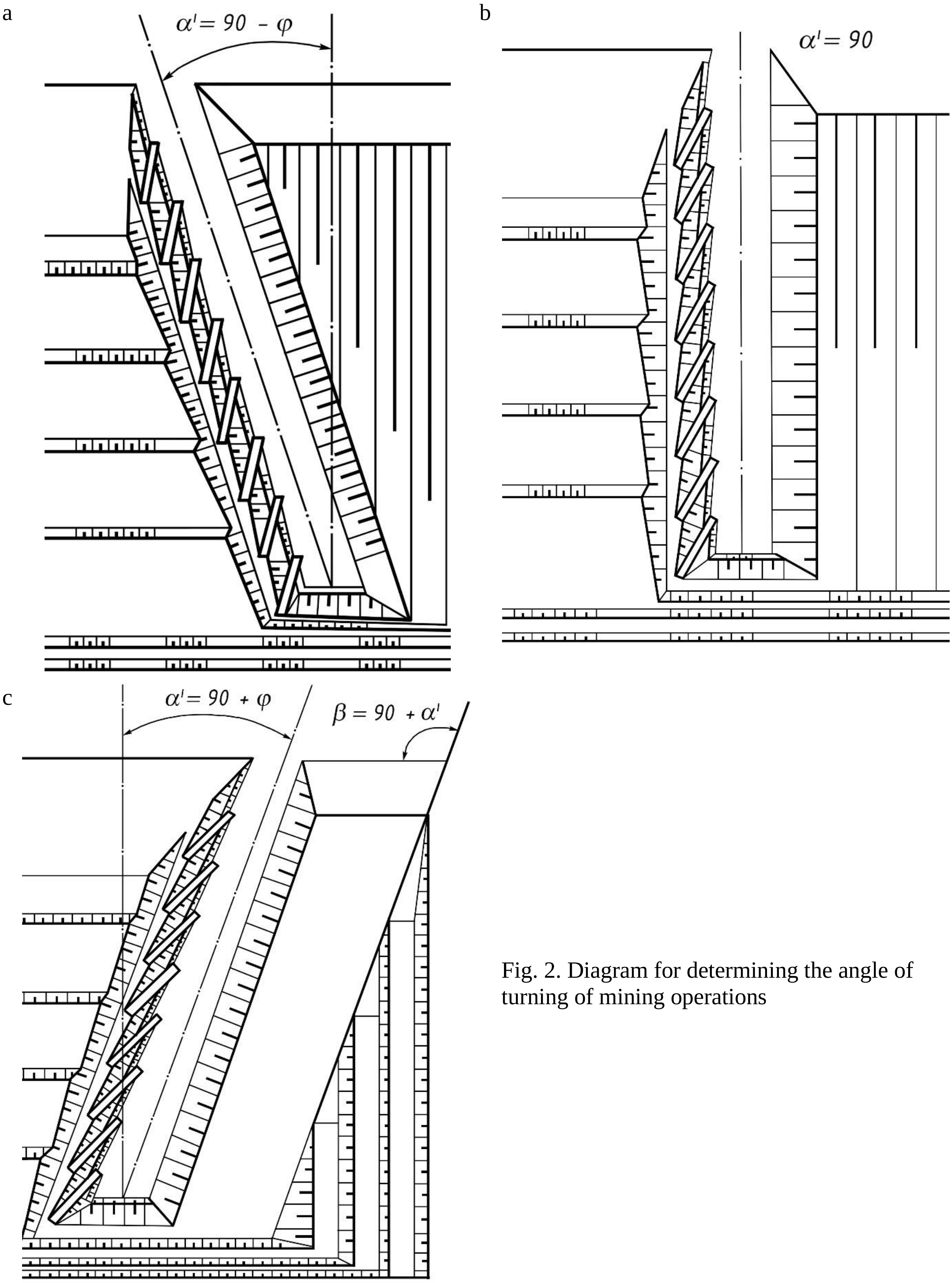


Fig. 2. Diagram for determining the angle of turning of mining operations

In order to reduce the distance of transporting rock from the lower zone to the internal dumps and to simplify the organization of draglines' work when mining the transportless zone, it is most expedient to apply the scheme (Fig. 2-c), taking the angle of turning of the mining front (α′) equal to the angle of turning of the internal transport dumps (β′). However, as a result of preliminary studies carried out by the mining research institutes, it was found that by the conditions of stability the working flank of the opencast and the transportless dumps should be positioned on the downdip (Fig. 2-a). When their position deviates to one or another side, the overall stability of either the working flank or the transportless dumps is sharply reduced. Therefore, in this article the angle of a turn of mining front is accepted equal 90°.

Stability of slope angles of the working flank and transportless dumps depends on their height, physical and mechanical properties of rocks and is determined for each field separately.

Parameters of the first stage quarry

The initial capacity or the first stage quarry is essentially a mine working, passed on the downdip from the seams incrop under sediments to the target depth of the open pit. Its size along the strike is determined by the adopted parameters of the mining system of the main field of the open pit.

The necessity of creating the initial capacity is dictated by the essence of the technology, which provides for the mining of the main field of the open pit with internal dumping. In order to ensure the possibility of the middle zone transportless mining, it is necessary to have sufficient capacity to place the rocks of this zone and sufficient space for the construction of the main quarry road, designated for coal transportation.

Location of the first stage quarry depends on the relief of the surface and the features of the deposit and is chosen taking into account the distance of transportation of overburden and coal. It can be located both in the center and on the flanks of the quarry field.

The main criterion for assessing the choice of the location of the first stage quarry should be the minimum cost of its construction. It is practically always economically advantageous to use ravines, depressions, hillsides, i.e. areas with the lowest stripping ratio to create the initial capacity.

So, for example, in the conditions of "Kureinsky" site the initial capacity is most expedient to place in the area of exploration lines Karyernaya and Kureinskaya in the north-northeast of the quarry field. In this area, coal seams are crumpled in a gentle saddle-shaped anticlinal fold (Fig. 3). In addition, this site has a significant lowering of the surface topography with a difference in heights of 170 meters.

The length of the first stage quarry along the strike, as mentioned above, is determined on the basis of the required capacity for overburden placement from the transportless zone and laying the route of the main road (Fig. 4):

$$W_i^u = B_s + b + A + Z + M\left(\cot\gamma_1 + \cot\gamma_2\right), \text{m.} \quad (1)$$

The width of the initial capacity at the top will be determined from the expressions:

1) at the moment of completion of quarry first stage construction:

$$W_{i.1}^u = N\left(H_b \cdot \cot\gamma_u + W_{wa}\right) + M\left(\cot\gamma_1 + \cot\gamma_2 + \frac{\cot\gamma_b}{R_{lr}}\right) + B_s + b + 2A + Z, \text{m.} \quad (2)$$

2) at the time of full development of internal dumping:

$$W_{i.2}^u = W_{i.1}^u + \sum_{i=1}^{n}\left(H_{t.i} \cdot \cot\gamma_t + W_t\right), \text{m,} \quad (3)$$

where N – number of benches in the upper zone; H_b – bench height in the upper zone, m; γ_u – slope angle of benches in the upper zone, deg; W_{wa} – width of the working site in the upper zone bench, m; M – thickness of the lower zone, m; γ_1 – angle of slope of the lower zone working flank, deg.; γ_2 – angle of slope of transportless (internal) dumps, deg.; γ_b – angle of slope of the middle zone working flank, deg.; R_{lr} – loosening factor of transportless zone rock after its shrinkage for the time of excavation of cut; $H_{t.i}$ – height of the *i-th* dump tier, m; γ_t – angle of slope of the dump tier, deg.; W_t – width of the dump tier on top, m; n – number of dump tiers; B_s – safety berm between the middle and upper zones, m; b – distance between the bottom edges of the internal transportless dump and the bottom zone, m; A – width of the transportless cut, m; Z – width of the zone within which the main quarry road route is located, m.

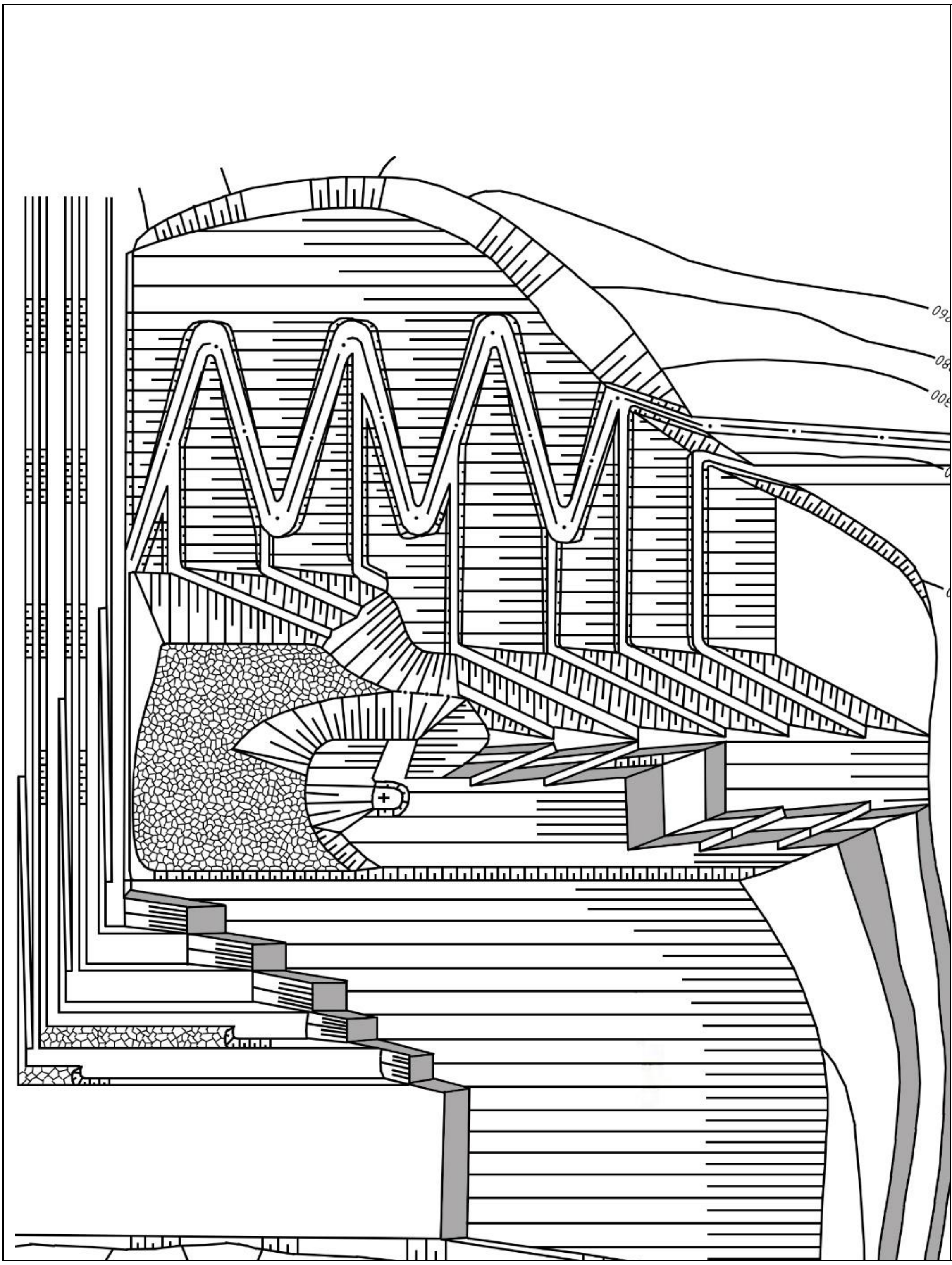


Fig. 3. Mining technology of the first stage of the open pit

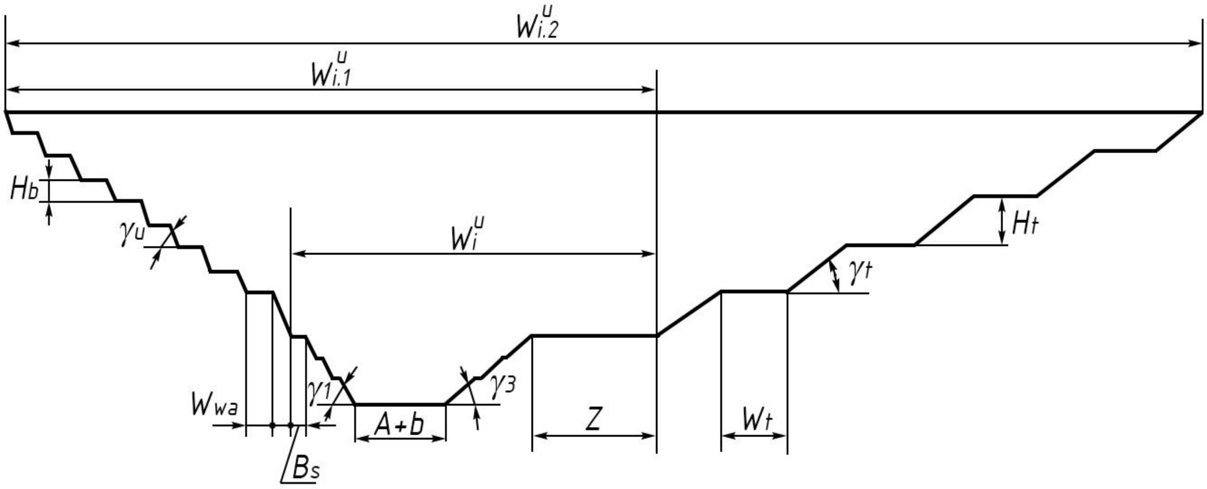


Fig. 4. Diagram for determining the parameters of the initial capacity

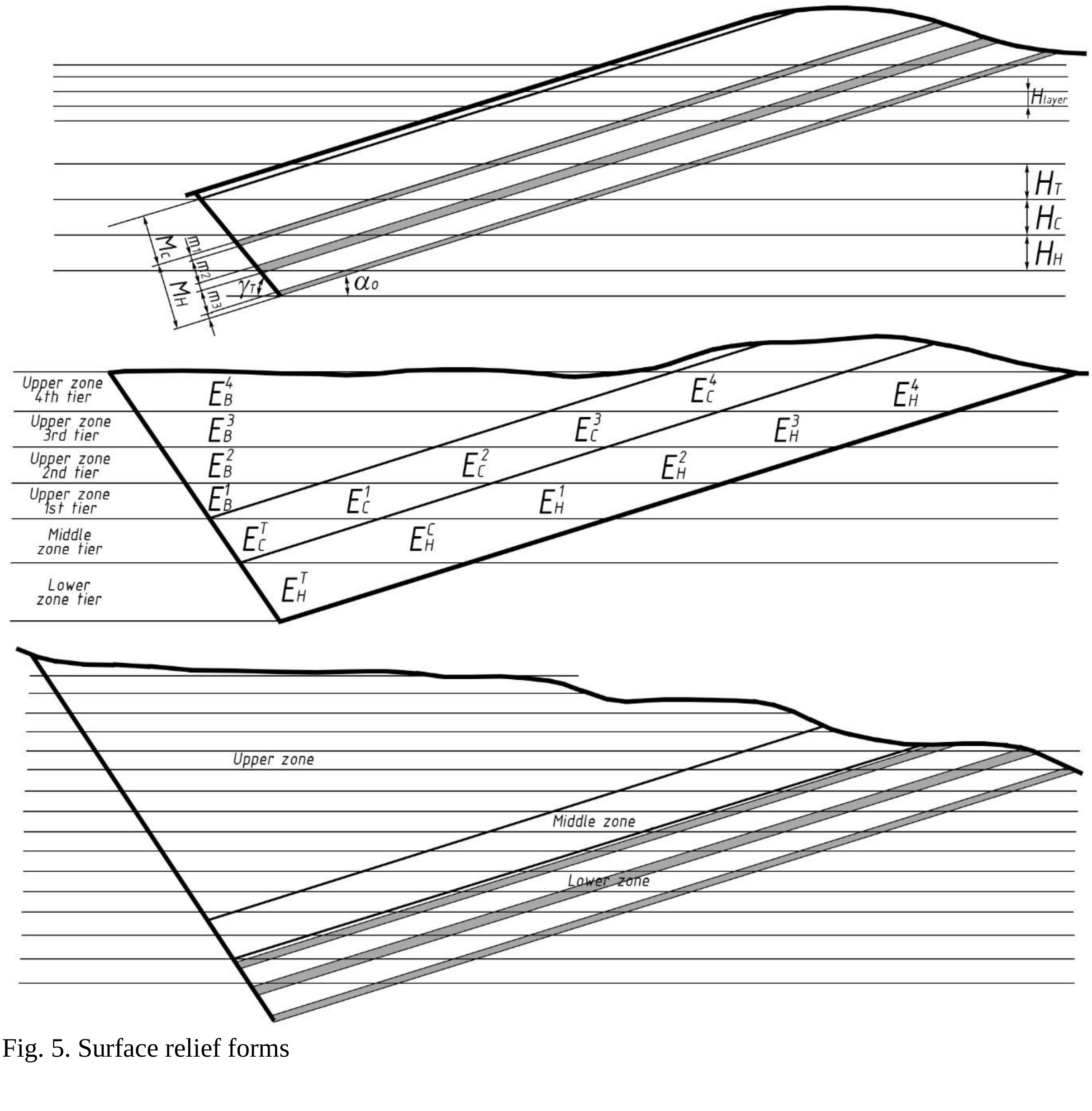


Fig. 5. Surface relief forms

 DOI: 10.26730/2618-7434-2021-4-64-88

The main parameters of the initial capacity and volumes on its creation for the site "Kureinsky" are shown in Table 1.

Table 1

Parameters of the initial capacity and volume of mining operations on its creation for the conditions of Kureinsky area

Width of initial capacity, m			Blocks between transverse profiles	Total rock volume (thous. m^3)	Total coal reserves (thous.t)	Average stripping ratio (m^3/t)
At the time of commissioning		At the time of full internal dumping at the top				
at the top	at the bottom					
630	520	1400	1-2	24766.5	6451.2	3.81
			2-3	9536.4	3758.4	2.54
			3-4	1346.6	766.2	1.75
			Total	35649.5	10975.9	3.24

The mining system during the construction of the first stage of the quarry is determined by the specific mining and geological conditions. In most cases, during this period, the most expedient will be a combined mining system with the use of a set of excavation and transport equipment, which will later be used in the mining of the main field of the open pit.

Under the conditions of the investigated technology, during the period when the initial capacity is put into operation, the route of the main quarry road will be located on the internal dumps, the height of which should correspond to the capacity of the lower zone. To create these dumps, in addition to the rocks of the middle zone, it is advisable to partially use the rock between the seams of the coal-saturated zone, which can be mined according to the transportless technology during the creation of the initial capacity.

The lack of rock volume to ensure the required height of these dumps is delivered by motor transport from the overlying zones, which are mined by the transport system.

When preparing the first stage of the open pit in the conditions of the Kureinsky site, we recommend the usual and most common technology for inclined deposits: the incrop seams are mined by transportless technology, and the rest of the rock is mined by transport technology. In this case, a certain amount of rock is removed into internal dumps and used to bring their height to the required level. The connection of the working benches with the internal dumps and the daylight surface during this period will be carried out using the area topography and transport berms located on the non-working flank of the opencast.

However, the mining and geological conditions and the surface topography at the location of the initial capacity of the Kureinsky site also allow for the development of the first stage of the opencast to apply the proposed technology of mining of inclined deposits with a moving of the mining front along the strike. Application of this technology will allow to increase the share of transportless overburden in the total volume of mining and transportation works from about 5 to 17 million m^3. But at the same time increases the total time of development of the first stage of the opencast from 3.6 to 4.8 years.

With this variant of creating the initial capacity, it is reasonable to start stripping and winning operations in the site between transverse profiles 3 and 4 (Fig. 3). After mining this site by the transport system to the depth limit of the opencast in the area of transverse profile 2, it becomes possible to switch to the combined technology with the following parameters. The thickness of the lower zone, which includes coal seams IV-V and VI and their parting, is 32 m. The middle zone in this case will be the partings of III-IV-V coal seams with a thickness of 30 meters. The upper zone includes coal seam III and its overburden.

Opening-up in this period is carried out by means of transport berms, located on the non-working flank of the opencast.

All other parameters of the development system and work organization are discussed below. After completing the creation of the initial capacity in the area of cross-sectional profile I, it is possible to switch to the recommended technology of mining the main field of the quarry.

DOI: 10.26730/2618-7434-2021-4-64-88

Top zone opening-up

Coal deposits of Kuzbass, suitable for development by combined technology with transverse location of the mining front, are represented by the three most characteristic forms of surface relief (Fig. 5):

- surface relief has a slope according to the dip of coal seams;
- the relief of the surface is flat;
- the surface relief has an upland part.

The task of opening-up the upper zone is to provide cargo transport connection of working benches of this zone with the internal dumps and the surface. For deposits with the upland part, the transport connection of the working benches of the upland part with the external dumps is carried out along the surface relief. Opening-up of the underlying benches of the upper zone in the presence of the upland part or when the surface relief is flat can be carried out according to two variants.

Variant I. The upper zone is opened with the help of sliding ramps and transport berms located on the working benches of this zone from the side opposite to the non-working flank of the opencast (Fig. 6). Rock from the upper zone benches is removed through the surface and transported to the dumps, and then by the road located on the transportless dumps is distributed to the appropriate tiers.

Variant II. The upper zone is opens with the help of periodic ramps and transport berms located on the non-working flank of the opencast (Fig. 1). Rock of the upper zone is transported by working benches and transportation berms of the non-working flank in the appropriate dump tiers.

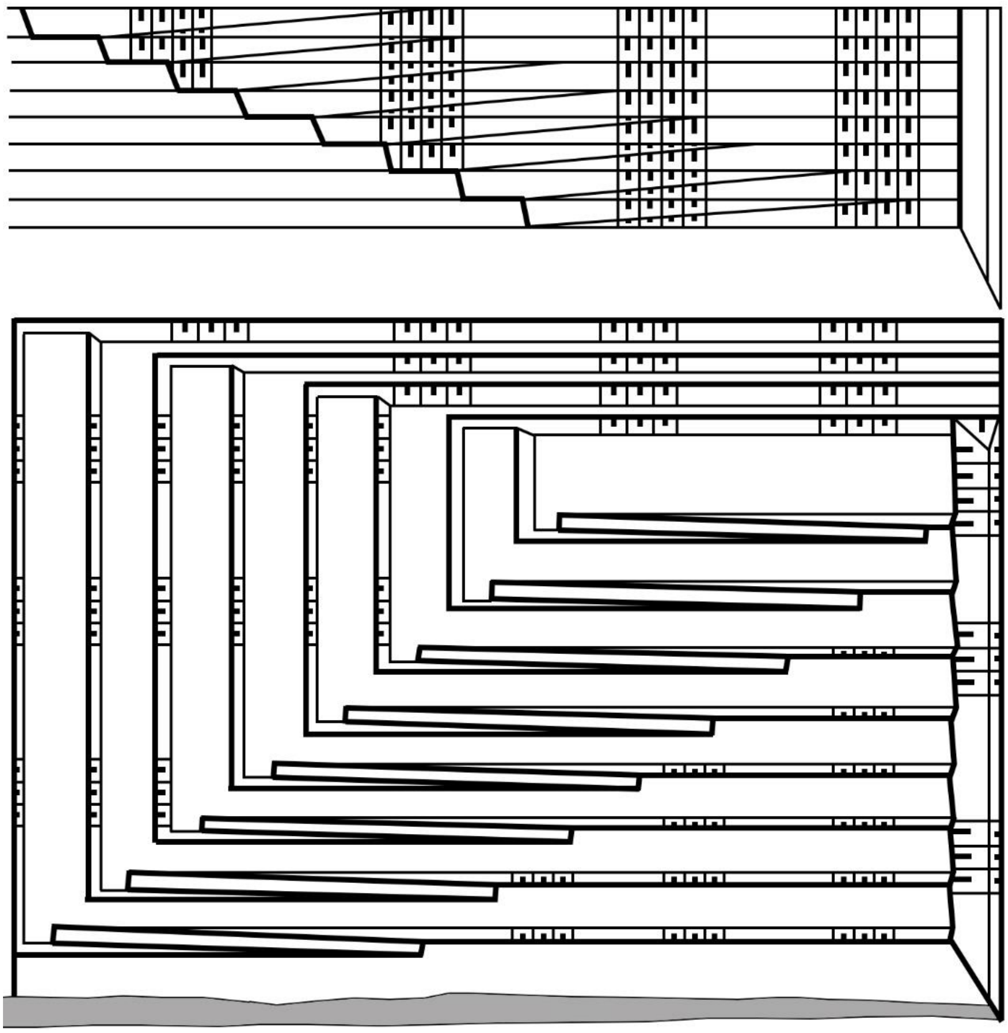


Fig. 6. Opening-up of the upper zone with sliding ramps located on the working side of the open pit

Comparison of these options for conditions of the Kureinsky area shows that it is most expedient to carry out opening of the upper zone from the side of the non-working flank of the opencast. This significantly reduces the time of construction of the initial capacity and the cost of constructing sliding ramps.

The number of transport sites on the non-working flank of the opencast depends on the height of the benches of the upper zone and the thickness of this zone, as well as on the height of the tiers of internal dumps and the adopted order of distribution of rock over the tiers. It is obvious that in order to reduce additional flank spacing, the number of transport sites should be minimal, i.e. rock from two or more benches of the upper zone should be placed in one dump tier.

For hard rocks the ultimate height of the tier ensuring the stability of dumps is 60 meters, and the height of working bench when using existing types of quarry excavators with bucket capacity of 4.6-12.5 m^3 and more varies from 15 to 21 m.

In accordance with the known provisions on simplification of the organization of the drive from the transport sites to the dump tiers and the exclusion of additional work on their construction the height of the dump tier should be a multiple of the height of the upper zone bench. Therefore, for the investigated conditions the multiplicity of the ratio of the dump tier height to the upper zone bench height is accepted equal to two, that is the rock from two benches of the upper zone is placed in one dump tier.

This reduces the number of transport berms on the non-working flank of the opencast and, accordingly, decreases the flank spacing.

Determining the slope angle of the non-working side of the cut

The maximum angle of the non-working flank of the opencast is determined by its stability, which must ensure the safety of work. In addition, the slope angle of the working flank and its stability have a certain influence on the depth of the quarry and the technology of mining. When the depth of the quarry is large, even a slight change in the angle of the non-working flank leads to a significant increase in the volume of overburden. Excessive slope angles can lead to loss of stability of the flank, occurrence of landslides, disturbance of technological process, as well as to large losses of minerals ready for excavation and increase of work volume due to the need of multiple rehandling of landslide masses.

Determination of maximum slope angles of the opencast flanks, at which their stability is provided, requires a detailed study during the exploration of the quarry field of all the main determining factors, including lithology and physical and mechanical properties of rocks, their fracturing, watercut and tectonics.

With regard to the considered technology of inclined deposits development, some changes in the elements of a non-working flank are envisaged in comparison with the previously known ones. First of all, this is expressed by the division of the entire rock thickness into three zones and technological features of their development and opening. With a particular mining technology, the angle of slope of the non-working flank of the opencast can be different, but the following inequality must be true

$$\gamma_n^{lim} \geq \gamma_n^a, \qquad (4)$$

where γ_n^{lim} – the limit stable angle of slope of the non-working flank, deg.; γ_n^a – the actual angle of slope of the non-working flank, deg.

The value of the angle of stable slope of the non-working flank for the conditions of the Kureinsky site was determined on the basis of a detailed study of the geological structure of the deposit and equal to 41°. For this deposit, with the selected thickness of the lower zone and stable slope angles of benches on the non-working flank, the general angle of slope will be determined by the total width of transport and safety berms and the number of benches in the upper zone (Fig. 7).

The value of stable angles of slope of elements of the non-working flank berm of the upper, middle and lower zones depends on physical and mechanical properties of rocks, height of benches and must be defined for each deposit independently. The width of safety berms must be equal to at least one third of the vertical distance between adjacent berms. In accordance with this, the safety berm between the middle and lower zones B_{ml} is defined as

$$B_{ml} = \frac{M}{3 \cdot R_{rl}}, \text{ m}, \quad (5)$$

where M – thickness of the lower zone, m; R_{lr} – loosening factor of transportless zone rock after its shrinkage for the time of excavation of cut.

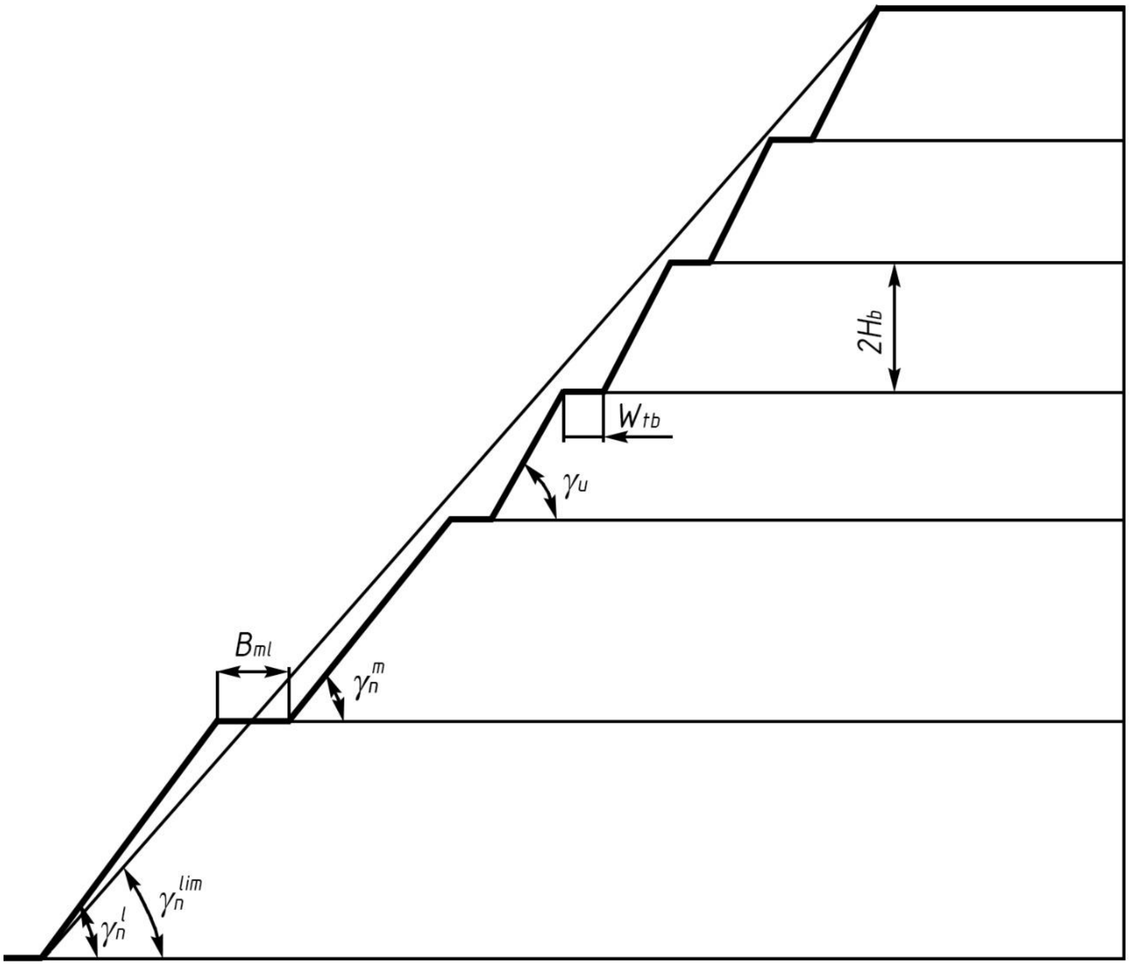


Fig. 7. Diagram for determining the general angle of the slope of the non-working flank

In addition, there will be transport berms on the non-working flank of the opencast in the upper zone to connect it with the surface, which simultaneously serve as safety berms. The width of transport berms is calculated on the condition of placing on them transport communications, platforms for concentrating the weathered rocks of the overlying benches and safety zones between the road and the bench crest. In general, the width of the transport berm for the accepted type of dump trucks is calculated by the following formula

$$W_{tb} = P + B_d + B_s, \text{ m}, \quad (6)$$

where P – width of the transport lane for the accepted type of dump truck, m; B_d – width of the area for the concentration of weathered rock debris, m; B_s – width of the safety berm between the bench crest and the road, m.

In turn,

$$P = k \cdot c + (k-1) \cdot d, \text{ m}, \quad (7)$$

where c – roadway width in single-lane traffic, m; k – number of traffic lanes, pcs; d – gap between traffic lanes, m.

 DOI: 10.26730/2618-7434-2021-4-64-88

The number of transport sites and benches in the upper zone is determined by the depth of the quarry and the height of the bench, as well as the accepted order of distribution of the upper zone rock. With this technology, the value of the angle of slope of the non-working flank will generally be determined from the expression

$$\gamma_s^n = \arctan \frac{Q_d}{\sum B + B_{ml} + \sum H_b \cdot \cot \gamma_u + \dfrac{M}{\cos \alpha}\left(\cot \gamma_n^l + \dfrac{\cot \gamma_n^m}{R_{lr}}\right)}, \text{deg}, \quad (8)$$

where Q_d – quarry depth, m; ΣB – total width of upper zone berms, m; B_{ml} – width of safety berm between upper and middle zones, m; γ_n^l – angle of slope of the lower zone non-working flank, deg.; γ_n^m – angle of slope of the middle zone non-working flank, deg.

Based on the calculations performed for the conditions of the Kureinsky site, the dependence of changes in the angle of slope of the working flank of the opencast on the thickness of the lower zone when using low-capacity dump trucks: BelAZ-540, BelAZ-548, BelAZ-549 was built.

Comparing the obtained values of non-working flank slope angles with the angle of steady slope equal to 41° it's possible to determine the minimum thickness of the lower zone at which the additional spacing of non-working flank is excluded. So, for the considered conditions minimum thickness of the lower zone is equal to

- for BelAZ-540 – 24 meters
- for BelAZ-548 – 32 meters
- for BelAZ-549 – 60 meters.

Constructed graphically the non-working flank of the Kureinsky site has a convex shape. In an anisotropic environment, the flank profile is important. The advantage of convex shaped flanks as compared to concave and flat ones is that this profile increases the retaining prism, which increases the overall stability of the flank and creates the possibility of some increase in the active pressure prism. In this regard, with convex profile average angle of sidewall slope is 4-6° steeper than that of flat profile and 8-10° steeper than concave profile flanks. Therefore, with convex profile of the flank, the volume of overburden is reduced with unchanged position of the lower point of the non-working flank of the opencast.

Lower zone opening-up

The opening of the lower zone of the opencast should provide the provision of cargo transportation connection of the working benches of the lower zone with the internal dumps and industrial site of the opencast. The opening of this zone can be carried out according to several options.

Transport support of the coal-saturated stratum is carried out by means of a road, one part of which is located on the transportless dumps, and the other on the day surface of the quarry. To this semi-stationary road, located on the transportless dumps, on both sides adjoin temporary roads, which on the one hand connect it with the working benches of the lower zone, and on the other hand – with the internal dumps (Fig. 1). As the working zone moves along the strike, so does the semi-permanent road. The frequency of moving this road is related to the number of draglines cuts and the parameters of the transportless technology.

Temporary haul roads, providing the connection of the internal dumps with the semi-stationary route, are located along the strike of the quarry field on the dumps of the transportless zone. The distance between the points of adjacency of these roads to the main route (r_o) depends on the height of the dump tiers and the dip angle of the seams and can be determined from the expression

$$r_o = \frac{H_{dt}}{\sin \alpha_o}, \text{m}, \quad (9)$$

where H_{dt} – height of a dump tier, m; α_o – seams dip angle, degrees.

Based on the condition of construction of roads on a sloping plane the distance between the adjacency points must satisfy the condition

$$r_o \geq 2B_{road} \frac{\sin\gamma_o}{\sin(\gamma_o - \alpha_o)}, \text{m}, \quad (10)$$

where B_{road} – width of temporary roads, m; γ_o – angle of the natural slope of the dumps of the transportless zone, m.

As the next cut is mined, these roads are gradually filled in with transport dumps, and after the semi-stationary road is relocated, they are built up again. Thus, ensuring the connection between the main road and the internal dumps does not cause technological difficulties and has no effect on the mining of the lower and middle zones.

Cargo transport connection of working horizons of the lower zone with the main road can be carried out according to the following three variants.

Variant 1. Temporary roads connecting the main route with working horizons of the lower and middle zones are placed on specially created transport sites (bridges), one part of which is located on the temporary and the other on permanent dumps of the transportless zone (Fig. 8-a). Creation of these crosspieces consists in the following.

Re-excavation of rocks of the transportless zone is carried out so that the temporary and permanent dumps of rocks in this zone by the time of creating a crosspiece to the preparation for mining the next layer of the lower zone were shifted by the line of dip relative to the axis of the crosspiece (AA_1) by half of its width. As soon as this crosspiece is created, mining of the prepared layer in the lower zone begins. Consequently, opening of the lower zone through crosspieces is closely connected with the technology of mining the middle and lower zones. The distance between the points where the temporary roads from the working zone connect to the main road is determined from the following expression

$$r_p = \frac{H_{hl}}{\sin\alpha_o}, \text{m}, \quad (11)$$

where H_{hl} is the height of the horizontal layer in the lower zone, m.

Thus, distances between points of adjacency of temporary roads to semi-stationary, both from the side of internal dumps and from the side of working benches, are proportional to the ratio of the height of the dump tier to the height of the bench in the lower zone. Hence, it is obvious that in order to reduce costs for construction and maintenance of these roads, the height of dump tiers and bench height in the lower zone should be taken as much as possible. In addition, an increase in the height of the bench in the lower zone allows to reduce the number of ramps along the length of the cut, which in turn creates opportunities to reduce equipment downtime and increase the production capacity of the quarry.

The advantage of this type of opening is the possibility of excavation the lower zone at maximum value of both angles of stable slope of the lower zone and slope of transportless dumps. It considerably simplifies organization of draglines' work and allows to excavate the transportless zone with the minimum re-excavation ratio. The main disadvantage of the considered variant of the lower zone opening is a rigid interrelation between excavation of the lower and middle zones due to the fact that re-excavation of rocks in the area of the lower zone layer is possible only after total working out of this layer.

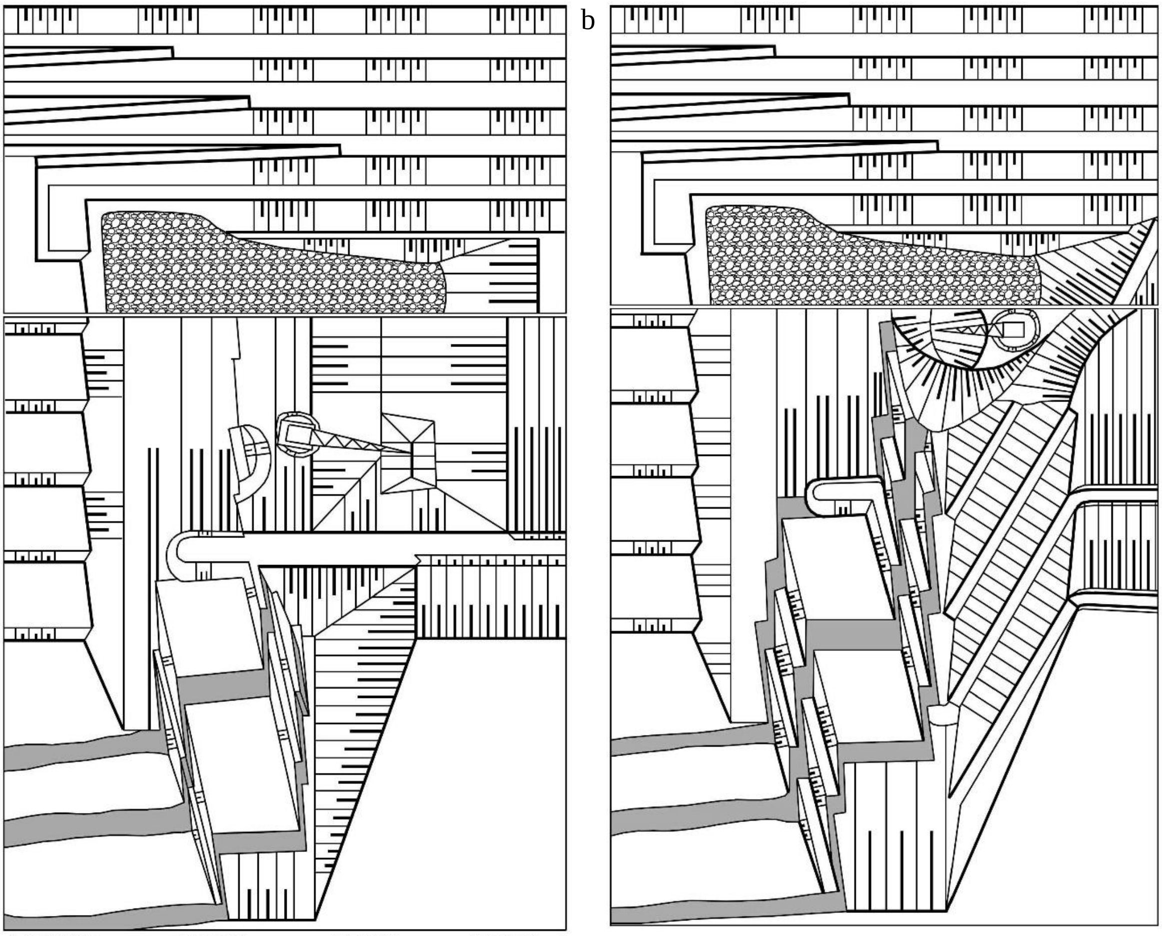
Variant 2. After re-excavation of rocks of the middle zone, on the slope of the newly formed transportless dump a horizontal site is built on which a road is partially located which connects the opened bench of the coal-saturated zone with the route of the main road.

The rest part of this road is located on specially created transport berm, located on the working flank of the lower zone (Fig. 8-b).

In such a way of providing load-transport communication of working benches of coal-saturated stratum with the main motor road, mining of the lower zone will not be in such a rigid interrelation with stripping works in the transportless zone.

a

b



c

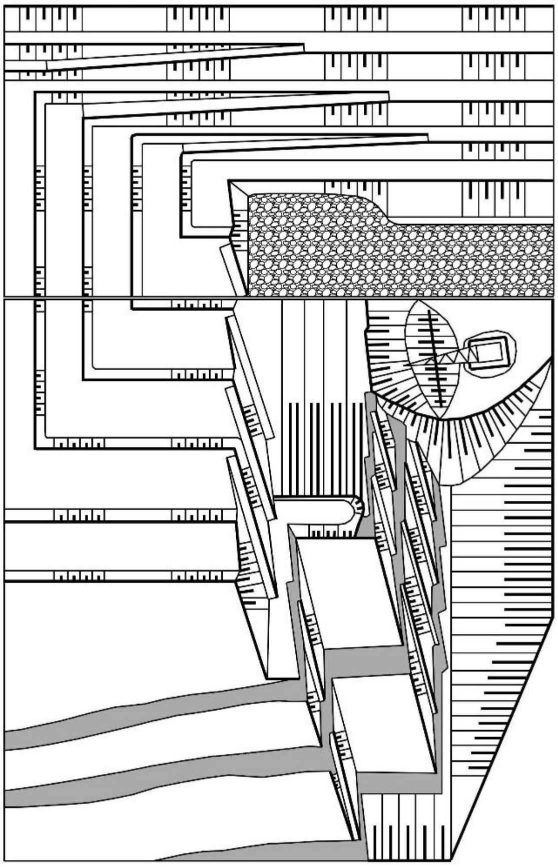


Fig. 8. Lower zone opening-up

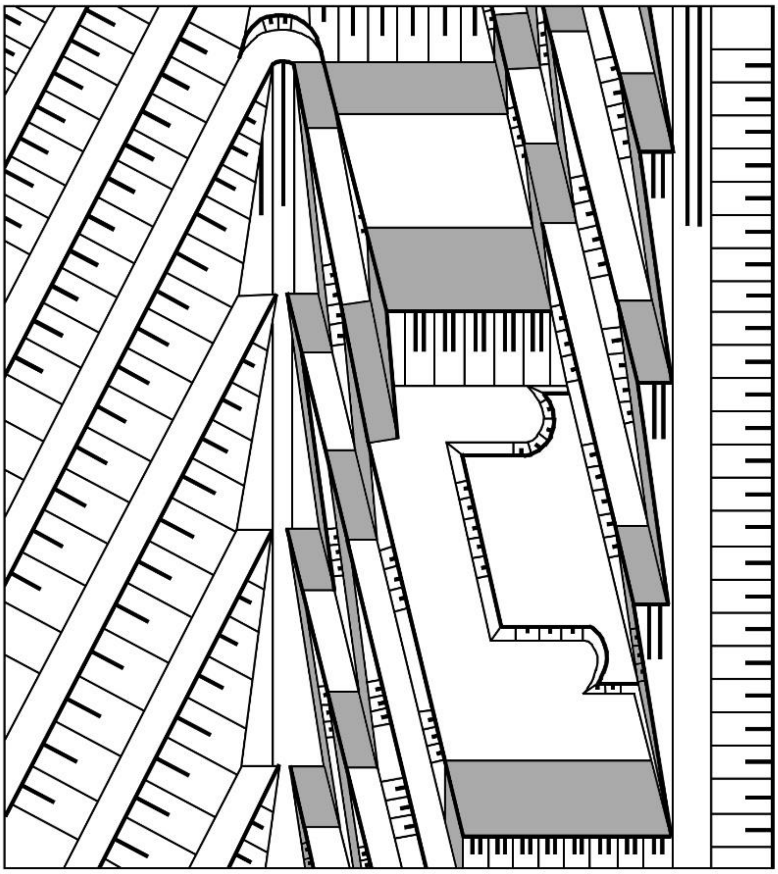


Fig. 9. Scheme of opening-up two layers of the lower zone by one transport site

However, in this case, there is a need to reduce the angle of slope of the working flank of the lower zone and transportless dumps, which are related to the width of transport sites and their number by the following dependence

$$\gamma_{1,3}^{\Delta} = \operatorname{arccot}\left(\cot\gamma_{1,3} + \frac{\sum_{i=1}^{n} T}{M}\right), \text{degrees}, \quad (12)$$

where $\gamma_{1,3}$ – angles of slopes of the layers of the working flank of the lower zone and transportless dumps when the transport sites are located on them, degrees; n – number of transport sites located on the working flank of the lower zone, units; T – width of the transport sites located on the working board of the lower zone, m.

In turn, reduction of slope angles with unchanged thickness of the lower zone leads to increase of the width of the mined-out space on top, and therefore to increase of re-excavation ratio and complication of dragline work organization. As it can be seen from expression (12), in order not to allow reduction of slope angles, either the number of sites and their width should be reduced, or the height of layer in the lower zone should be increased. However, it cannot be acceptable, because the height of the bench and the width of transport sites are regulated by the parameters of the adopted excavation and transport equipment.

Depending on quantity of coal seams and their location in coal-saturated stratum, one (Fig. 1) or two (Fig. 9) layers can be opened with one transport berm. In the first case, the rock and coal are taken out immediately along the transport site to the main road. In the second case, in order to start mining the underlying layer, it will be necessary first to create a temporary ramp. This ramp has to be along the downdip line at the border of the lower zone with the mined-out space.

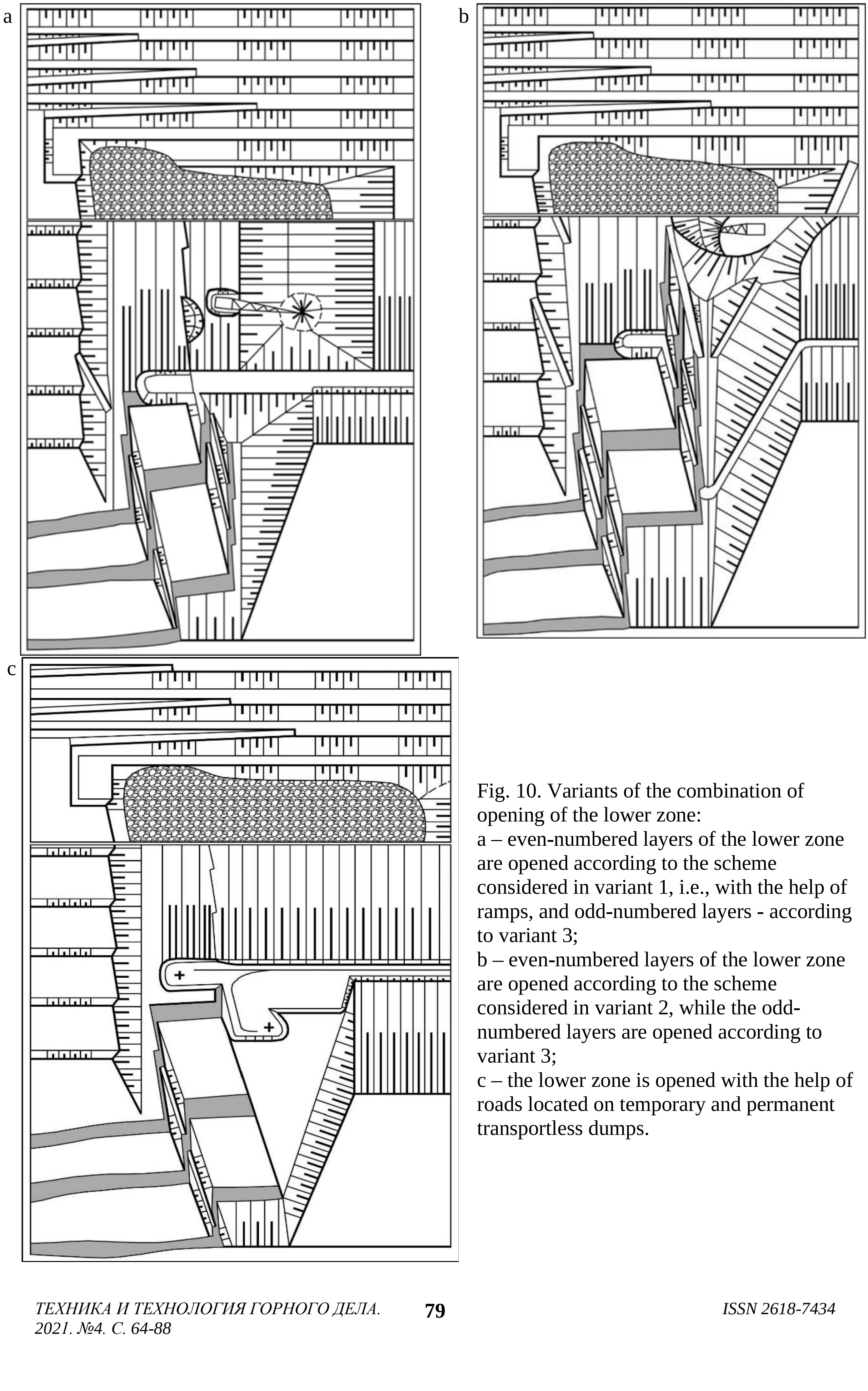


Fig. 10. Variants of the combination of opening of the lower zone:
a – even-numbered layers of the lower zone are opened according to the scheme considered in variant 1, i.e., with the help of ramps, and odd-numbered layers - according to variant 3;
b – even-numbered layers of the lower zone are opened according to the scheme considered in variant 2, while the odd-numbered layers are opened according to variant 3;
c – the lower zone is opened with the help of roads located on temporary and permanent transportless dumps.

After excavation of the underlying layer, the rock from this ramp is dumped with a mechanical shovel into the mined-out space of the lower zone.

Variant 3. Opening of the lower zone is carried out with the help of ramps, located on the working flank of the transportless zone (Fig.8-c). In this variant the bedrocks of the coal-saturated stratum are moved by the ramps to the working sites of the upper zone, and then by the transport communications connecting this zone with the mined-out space and the surface are directed to the internal dumps. Coal is also transported through the upper zone to the industrial site. If necessary, it can be transported through the top zone via the non-working flank and via the main road to the surface. With this option, one or two layers of the lower zone can also be opened through each transport site. But due to the fact that the temporary ramp here is located on the border of the middle and lower zones, its excavation is associated with significant technological difficulties and causes large downtime of equipment.

The main advantage of this version of opening is the absence of rigid interrelation between the mining of the lower and middle zones. The disadvantages include a significant increase in the range of transportation of rock mass from the coal-saturated zone in comparison with the version of the opening considered above, high costs for the construction of ramps on the working flank of the middle zone. Flattening of the working flank of the middle zone is also undesirable, because it leads to the necessity of increasing the distance of rock transportation by blasting, and hence to the increase of specific consumption of explosives. In addition, the very presence of ramps on the flank of the middle zone will make drilling and blasting extremely difficult. It also complicates excavation of the endwall of the lower zone.

Besides the variants of the opening considered above, some their possible combinations also deserve attention.

Variant 4. Even-numbered layers of the lower zone are opened according to the scheme described in variant 1, i.e., with the help of ramps, and the odd-numbered ones – according to variant 3 (Fig. 10-a).

Variant 5. Even-numbered layers of the lower zone are opened according to the scheme considered in variant 2, and the odd-numbered ones – according to variant 3 (Fig. 10-b).

Variant 6. The lower zone is stripped by means of roads located on temporary and permanent transportless dumps (Fig. 10-c). The thickness of the middle zone is selected so that the volume of rock from this zone was enough to fill the entire mined-out space of the lower zone. In this case, during the mining of the lower zone, the excessive volume of rock (ΔV_d) is transported by motor transport to the internal dumps.

The advantage of this variant is that there is no rigid interrelation when working in the middle and lower zones. It simplifies the scheme of opening the lower zone. Its main disadvantage is the increase in the volume of work of stripping equipment in the middle and lower zones.

Analysis of the variants of the lower zone opening discussed above shows that the second and sixth variants are the most reasonable.

Calculation of the parameters of the route of the semi-permanent road

The route of the road located on the non-transport dumps has a stepped shape with slightly inclined inserts. The need for such a shape of the route is caused by a large difference of absolute marks of the initial and final points of the route and by the conditions of motor transport safety. Technical and economic calculations show that it is reasonable to arrange softening inserts of at least 50 meters in size after 200-300 meters along the length of the prolonged ascent.

The main parameters of the road route are determined by the angle of dip of layers, the technical characteristics of the selected type of dump truck and the width of the dumping area between the working zone and the dumps of the upper transport zone. Technical characteristics of the selected dump truck and the angle of dip of layers are constant for specific conditions. The width of the dump pad or the width of the route zone is determined from the conditions of placement on it of the road, which provides cargo transport connection between the working horizons and the day surface.

The route of this road consists of two recurring elements: linear inserts and sections of curves (Fig. 11). The angle of inclination of linear inserts to the horizon (or the longitudinal slope of the highway) φ, the dip angle α_o and the angle of turning of linear inserts β are related to each other as follows:

$$\beta = \arcsin\frac{\tan\varphi}{\tan\alpha_o}, \text{degrees.} \tag{13}$$

Thus, the location of the road route should provide:

a) the presence of horizontal sites between linear inserts necessary to change the direction of motor vehicle traffic;

b) the minimum amount of construction work;

c) maximum closeness of the route axis to the intersection trace of the seams downdip plane with the plane of the road.

These requirements are met by such an arrangement of linear inserts on the surface of transportless dumps when one part of them (b) is located on the half-excavation and the other part (a) – on the half-embankment (Fig. 11-b). The line *ABC*, which is the trace of the intersection of the plane of linear inserts (Q_1) with the plane parallel to the plane of the dip of the seams, is the axis of the road, which allows to ensure the cargo transportation connection of working horizons with the day surface. The distance between the closest parallel inserts will be

$$D_{pi} = CD + AD.$$

Expressing *CD* and *AD* through the width of the trace zone *Z*, we obtain

$$AD = \frac{Z\cdot\sin\beta}{\sin(\alpha' - \beta)};\ CD = \frac{Z\cdot\sin\beta}{\sin(\alpha' + \beta)}.$$

Substituting these expressions into equation (14) and solving it with respect to *Z*, we find the width of the trace zone without regard to curves

$$Z = \frac{D_{pi}}{\sin\beta\left[\frac{1}{\sin(\alpha'+\beta)} + \frac{1}{\sin(\alpha'-\beta)}\right]}, \text{m.} \tag{14}$$

Then the total width of the trace zone will be determined from the expression

$$Z = \frac{D_{pi}}{\sin\beta\left[\frac{1}{\sin(\alpha'+\beta)} + \frac{1}{\sin(\alpha'-\beta)}\right]} + 2\cdot(\tan\beta\cdot B_{road} + R), \tag{15}$$

where Z – the width of the route zone, m; β – angle of turn of the route, deg.; B_{road} – road width, m; α' – angle of turn of the mining front, deg.; R – radius of curves, m.

However, in this way of constructing the route, the direction of motor transport will be parallel to the line OO_1, but not to the line *AB*, and the angle β will not be equal to β'. Therefore, when calculating the angle of rotation of linear inserts β it is necessary to increase its value by the value of δ, which is equal to

$$\delta = \arcsin\frac{2\cdot B_{road}\cdot\tan\varphi}{D_{pi}\cdot\sqrt{\tan^2\beta + 1}}, \text{degrees.} \tag{16}$$

With the selected mode of transport for specific conditions the distance between the two nearest parallel inserts remains uncertain, which determines to a greater extent the width of the route zone between the two nearest parallel inserts and the number of linear inserts. The minimum size of this distance is limited by the conditions of the construction of the route

$$D_{\min} \geq \frac{2B_{road}\cdot\sin\gamma_o}{\sin(\gamma_o - \alpha_o)}, \text{m,} \tag{17}$$

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where γ_o – angle of slope of the road embankment, deg.; D_{min} – minimum step of the route under construction conditions, m.

As noted above, softening inserts are required every 200-300 meters of uphill. The role of these inserts will be performed by circular curves. So, the distance between the closest parallel inserts will be limited not only by the minimum, but also by the maximum by the following ratio:

$$D_{\max} \leq 2L_{li} \cdot \sin\beta, \text{m}, \quad (18)$$

where L_{li} – length of linear inserts, m.

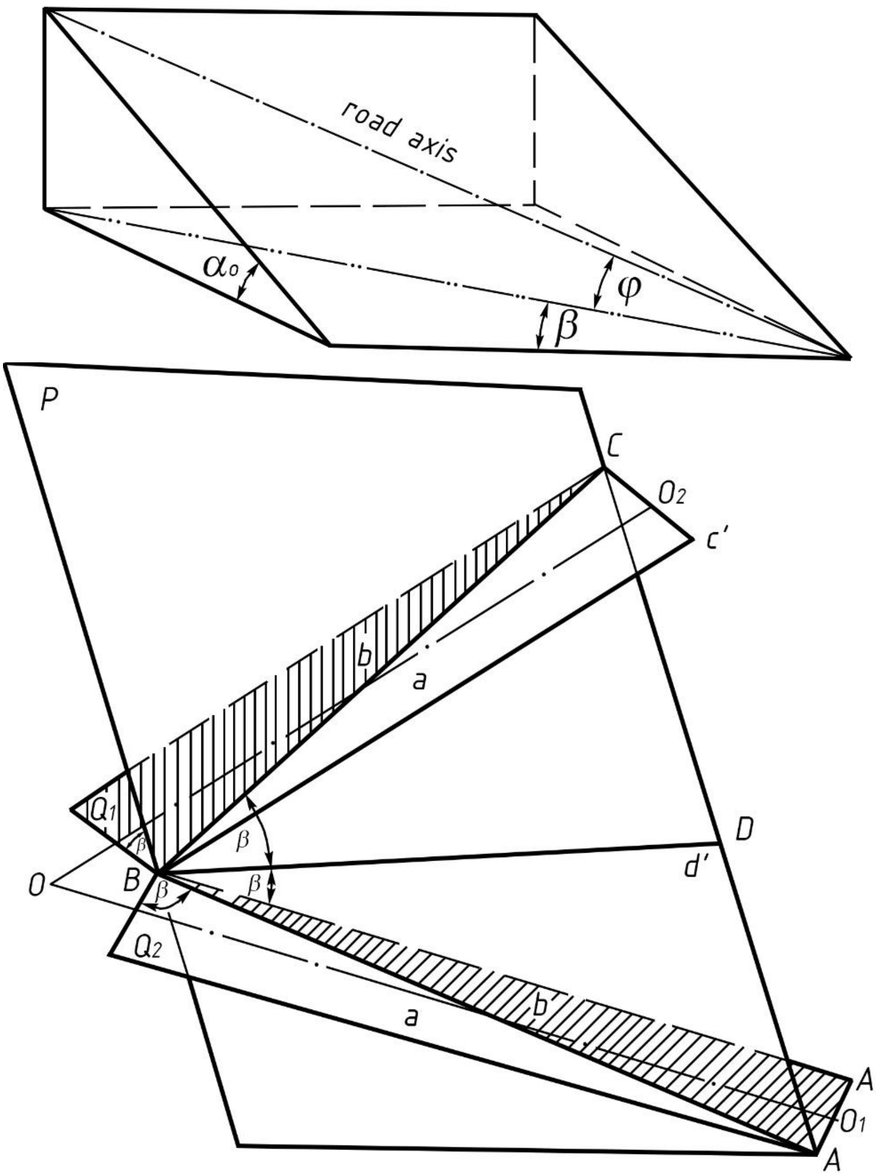

Fig. 11. Schematic for determining the parameters of a semi-stationary road

It should also be noted that if this distance is taken equal to the distance between the points of adjacency of temporary roads, the length of the latter will be minimal.

Fig. 12 shows the dependence of changes in the width of the main road route zone on the value of the distance between the two nearest parallel inserts at different seams dip angles. As can be seen, the width of the trace zone increases with the increase in the value of the trace step and seams dip angle.

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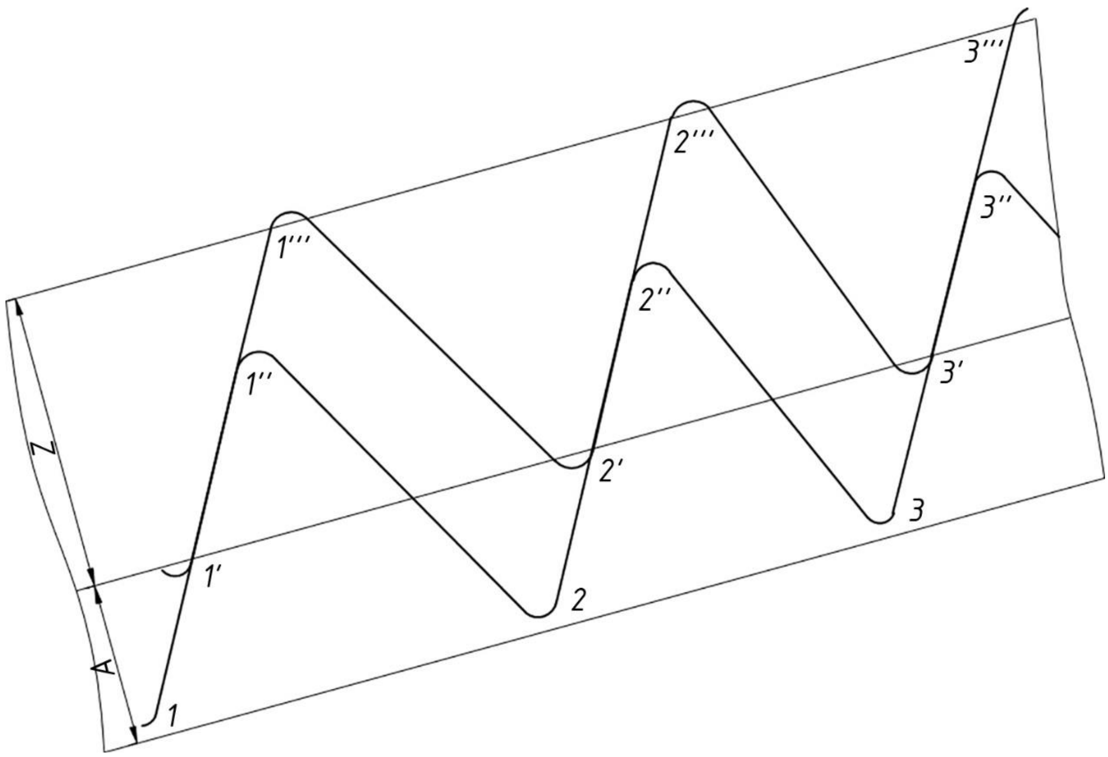

Fig. 12. Option of moving the route of the semi-stationary road

The total length of the road is defined as the sum of lengths of linear road segments and circular curves connecting these segments

$$L_{total} = \left(Q_d - LZ_d\right)\left[\frac{1}{\sin\varphi} + \frac{2B_{road}\left(\pi - 2\beta\right)}{\sin\alpha_o \cdot D_{pi}}\right], \text{m}, \quad (19)$$

where Q_d – depth of a quarry; LZ_d – depth of a lower zone, m.

The route of this main road can be constructed with the use of different equipment: bulldozers, rope shovels or draglines. It is most expedient to use for this purpose overburden equipment of the middle and lower zone in the period of idle run from the end of the worked-out cut to the beginning of the new one.

In order to reduce the volume of construction work on the construction of a new road, it seems possible to use part of the road from the previous cut for the next cut. This is possible due to partial relocation of the motor road to the mined-out space (Fig. 18), the essence of which is as follows. As the lower transport zone moves along the dip, a part of the new road (1-1'; 1"-2-2'; 2"-3-3') is built on the newly formed dump whose width is equal to the width of the cut. The second part of this road is constructed on the previously formed dump (1"-1'"; 2"-2'"). In this case a part of the old road (1'-1"; 2'-2"; 3'-3") can be used as the last segment of the newly created road. Such relocation of the road allows to reduce the volume of construction work on the creation of the road on the transportless dumps by 15-17%.

Conclusions

1. With the adopted combined technology of excavation of sloped deposits with moving of the general mining front along the strike it is reasonable to open the upper transport zone with the use of periodic ramps and transport sites, located on the non-working flank of the opencast. Such opening scheme excludes additional spacing of the non-working flank if the thickness of the lower zone will be more than 30 m.

2. Rational scheme of opening the lower coal-saturated zone should be selected on the basis of technical and economic comparison of various options for opening. Preliminary analysis of variants of the lower zone opening shows that it is most expedient to carry out it, placing transport communications entirely or partially on the transportless dumps in the mined-out space.

3. Parameters of the route of the semi-stationary road, which is most expedient to place on the surface of transportless dumps, are determined by mining and geological conditions of the deposit and the parameters of transport equipment.

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Конфликт интересов

Авторы заявляют об отсутствии конфликта интересов.

Информация об авторах

Мартьянов Виктор Леонидович, канд. техн. наук, доцент
e-mail: martvic2005@yandex.ru
Марков Сергей Олегович, канд. техн. наук, доцент
e-mail: markovso@kuzstu.ru
Колесников Валерий Федорович, докт. техн. наук, профессор
e-mail: kolesnikovvf@kuzstu.ru
Кузбасский государственный технический университет им. Т.Ф. Горбачева
Российская Федерация, Кемеровская область – Кузбасс, 650000, г. Кемерово, ул. Весенняя, 28

Тюленева Екатерина Александровна, руководитель группы, отдел открытых горных работ
e-mail: e.a.tyuleneva@pgpi.su

Прокопьевский горно-проектный институт
Российская Федерация, Кемеровская область – Кузбасс, 650099, г. Кемерово, пр. Ленина, 90/5

Цехлар Михал, докт. техн. наук, профессор, декан факультета
e-mail: michal.cehlar@tuke.sk
Яночко Юрай, докт. техн. наук, профессор, заместитель декана по международным связям
e-mail: juraj.janocko@tuke.sk
Факультет горного дела, экологии, управления проектами и геотехнологии
Технический университет Кошице
Летняя 9/А, 042 00, Кошице, Словакия

Марасова Даниэла, канд. техн. наук, профессор, директор института
e-mail: daniela.marasova@tuke.sk
Факультет горного дела, экологии, управления проектами и геотехнологии, институт логистики и транспорта, Технический университет Кошице
Парк Коменского 14, 042 00, Кошице, Словакия

Дагмар Цаганова, канд. техн. наук, доцент, заместитель декана по международным проектам
e-mail: dagmar.caganova@stuba.sk
Факультет материаловедения и технологии,
Словацкий технический университет в Братиславе
Паулинска 16, 917 24 Трнава, Словакия

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STUDY OF INCLINED DEPOSITS OPENING UNDER THE COMBINED MINING SYSTEM: KUREINSKY AREA CASE-STUDY

Victor L. Martyanov[1], Sergey O. Markov[1], Valery F. Kolesnikov[1], Ekaterina A. Tyuleneva[2], Michal Cehlár[3], Juraj Janočko[3], Daniela Márasová[3], Dagmar Cagáňová[4]

[1]Federal State Budgetary Educational Institution of Higher Education «T.F. Gorbachev Kuzbass State Technical University»
[2] Prokopyevsk mining and design institute, LLC
[3] Technical University of Kosice
[4] Slovak University of Technology in Bratislava

Abstract.
In the conditions of Kuznetsk Coal Basin, where the predominant amount of reserves is represented by complex structured inclined and steep seams, restoration of lands as the development of mining operations is a difficult task. The fact is that the generally accepted direction of movement of mining works along the dip of strata in Kuzbass leads to a gradual increase in the pit space as the work is deepened and does not allow to combine surface restoration with the process of field development. The disturbed surface, as a rule, is not subject to restoration and thus is withdrawn from agricultural use practically forever. In addition, the entire volume of overburden in this case is located in the external dumps, for the placement of which new areas are withdrawn.
Therefore, the economic effect received at the specified direction of moving of the front of works, namely rather small overburden ratio in the initial period of development of cuts and possibility of maintenance of considerable production capacity at rather small capital investments, becomes less essential in comparison with damage from disturbance of the lands suitable for agriculture. Restoration of lands disturbed as a result of mining operations will require significant costs comparable to those of stockpile preparation.
In this connection, the direction of moving the front of mining works on the dip or on the rise in terms of land use contains a significant disadvantage, in order to eliminate which it is advisable to move the front of works along the strike. In this case, the front of works, being located from outcrops of strata to the depth limit line and moving along the strike, creates a mined-out space for overburden placement. With appropriate construction of mining technology, each disturbed area in this case will be possible to compensate by restoration of an equivalent area in the mined-out space. Thus, a relatively small part of the disturbed area will be in circulation.
Placement of overburden rocks in the mined-out space will help to reduce the distance of their transportation and to combine the process of stockpile preparation with the mining technical or even biological stage of reclamation.

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Conflicts of Interest

The authors declare no conflict of interest.

Information about the authors

Victor L. Martyanov, Ph.D. (Tech.), Associate Professor
e-mail: martvic2005@yandex.ru

Sergey O. Markov, Ph.D. (Tech.), Associate Professor
e-mail: markovso@kuzstu.ru

Valery F. Kolesnikov, Dr.Sc. (Tech.), Professor
e-mail: kolesnikovvf@kuzstu.ru

T.F. Gorbachev Kuzbass State Technical University
Russian Federation, Kemerovo region – Kuzbass, 650000, Kemerovo, 28 Vesennyaya st.

Ekaterina A. Tyuleneva, Eng. (Tech.), Team leader of open-pit mining department
e-mail: e.a.tyuleneva@pgpi.su

Prokopyevsk Mining and Design Institute
Russian Federation, Kemerovo region – Kuzbass, 650099, Kemerovo, 90/5 Lenina av.

Michal Cehlár, Dr.h.c., Professor, Dean of the Faculty BERG
e-mail: michal.cehlar@tuke.sk

Juraj Janočko, Dr.Sc. (Tech.), Professor, Vice-dean for International relations and Project Coordination
e-mail: juraj.janocko@tuke.sk

Faculty of Mining, Ecology, Process Control and Geotechnologies (BERG), Letna 9/A, 042 00,
Technical University of Kosice, Slovakia

Daniela Márasová, Ph.D. (Tech.), Professor, Director
e-mail: daniela.marasova@tuke.sk

Faculty BERG, Institute of Logistics and Transport, Park Komenského 14, Košice
Technical University of Košice, Slovakia

Dagmar Cagáňová, Ph.D. (Tech.), Assoc. Prof., Vice Dean for International Projects
e-mail: dagmar.caganova@stuba.sk

Faculty of Materials Science and Technology, Paulínska 16, 917 24 Trnava, Slovak Republic
University of Technology in Bratislava, Slovakia