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SUBSTANTIATION OF CONDITIONS OF MAINTAINING STABILITY OF HAULAGE DRIFTS DURING DEVELOPMENT OF STEEP SEAMS

Об'єктом досліджень є процеси забезпечення стійкості бічних порід у відкатних штреках при розробці вугільних пластів крутого падіння. Зі збільшенням глибини гірничих робіт застосовувані способи охорони дільничних підготовчих виробок повинні забезпечувати їх експлуатаційний стан на виїмкових дільницях та відповідати змінюваним гірничо-геологічним умовам в межах шахтного поля. Дослідження проявів гірничого тиску в відкатних штреках по довжині виїмкової дільниці були виконані в натурних умовах. На спеціально обладнаних вимірювальних станціях визначалася величина зміщення бічних порід на контурі підготовчої виробки. Відкаточний штрек охоронявся накатними кострами з дерев'яних шпал або циликами вугілля. В ході досліджень було встановлено вплив жорсткості охоронних споруд на стійкість бокових порід у відкаточному штреку. Зафіксована лінійна залежність зміщень порід покрівлі та навантаження на кріплення у виробці по довжині виїмкової дільниці при охороні відкатного штреку циликами вугілля. Одночасно з цим, при зменшенні жорсткості циликів на 80 % перетин відкаточного штреку зменшується на 50 % від початкового. Відзначено, що використання дерев'яних конструкцій для охоронних споруд дозволяє обмежити зміщення порід на контурі відкаточного штреку. В результаті взаємодії бічних порід з дерев'яними охоронними спорудами, при зниженні їх жорсткості на 80 %, перетин відкаточного штреку зменшується на 30–35 % від початкового. Дослідження показали, що зменшення жорсткості дерев'яних конструкцій відбувається за рахунок їх стиснення, а циликів вугілля – в результаті руйнування. Помічено, що найбільш складні умови підтримки відкатних штреків формуються при застосуванні циликів вугілля. Рекомендується для забезпечення стійкості дільничних підготовчих виробок застосування піддатливих охоронних споруд або закладки виробленого простору. Отримані результати досліджень можуть бути використані при виборі способу охорони відкатних штреків на пластах крутого падіння.

Ключові слова: *гірський тиск, відкаточний штрек, способи охорони, очисні роботи, накатні багаття, цілики вугілля.*

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1. Introduction

The problem of maintaining excavations in the development of steep coal seams is one of the main tasks of increasing the technical and economic indicators of mining in a coal mine. The unsatisfactory condition of the haulage drifts in the excavation areas and the repair work carried out in them adversely affect the excavation faces, worsen the ventilation conditions and reduce the level of safety during mining operations.

An analysis of the known methods of protecting haulage drifts at a steep fall indicates their diversity [1, 2]. At the same time, the experience of the mines shows that in the practice of mining, they still prefer to use the traditional way of protecting haulage drifts using the coal pillars. Moreover, the height of the pillars, limiting production from the influence of the worked out space, is 8 m [3, 4]. It should be noted that protective coal pillars of limited size (up to 10 m) are capable of destruction and rash, which contributes to the formation of voids above the drift and deterioration of stability.

With the floor method of preparing steep coal seams in a coal-mass array, the layers are sequentially separated from the overlying stratum. After this there is a displacement, deformation and collapse of the side rocks. With an increase in the angle of incidence of the strata under the influence of the forces of its own weight, the stratified rock slides down. This contributes to the manifestation of various kinds of loads on the lining of the mine excavations, often provoking their blockages [5, 6]. In this regard, given the layered structure of the carbonaceous massif and the redistribution of stresses in it, the stability of haulage drifts depends on the protection method.

In the traditional way of protecting haulage drifts with coal pillars, reliable protection of mine excavations from harmful manifestations of rock pressure is not provided [7, 8]. The reasons underlying the current situation are primarily associated with an increase in the depth of mining, the deterioration of geological conditions and the intensification of manifestations of rock pressure. Ensuring the stability of haulage drifts throughout their entire service life is one of the conditions for guaranteeing high

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coal production rates. Therefore, for the safety of local excavations in operational condition, an important role is played by the protection method, as well as the properties and parameters of protection structures erected above the haulage drift.

In this regard, *the object of research* is the processes of ensuring the stability of lateral rocks in haulage drifts during the development of steep coal seams. And *the aim of research* is to justify the conditions for ensuring the stability of haulage drifts during the development of steep seams.

2. Methods of research

A study of the manifestations of rock pressure on the mine circuit and the conditions for maintaining it in the influence zone of the sewage treatment along the length of the excavation section was carried out using the example of the haulage drift of the layer l_3 of the horizon 1146 m of the Central mine of Toretskugol state enterprise (Toretsk, Ukraine).

Experiments to study the manifestations of rock pressure on the loop of the haulage drift during the protection by rolling bonfires made of wooden sleepers or coal pillars were performed at measuring stations located in the experimental section with a length of l=100 m (Fig. 1).

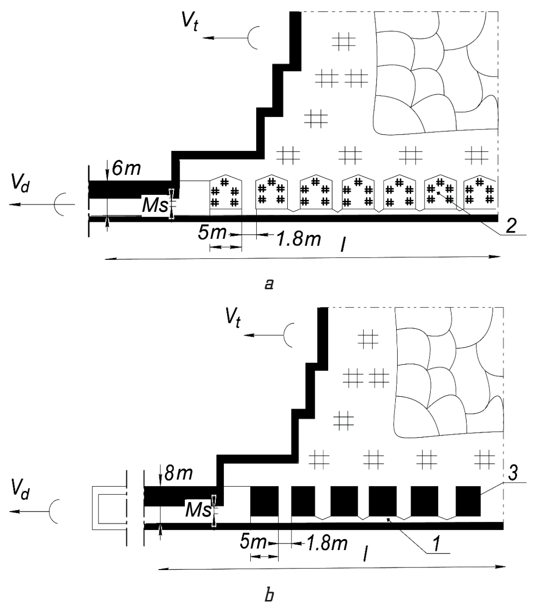

Fig. 1. The scheme of the experimental sections for determining the displacements of the lateral rocks on the contour of the haulage drift and changing its cross-sectional area: *a* – with the method of protection by rolling bonfires from wooden sleepers; *b* – with the method of protecting coal pillars; Ms – metering station; *l* – length of the experimental plot, m; V_d, V_t – speed of drift and treatment operations (m/month); 1 – haulage drift; 2 – rolling bonfires from wooden sleepers; 3 – coal pillars

At the metering station, the amount of displacement of the lateral rocks on the preparatory excavation circuit was determined using a special surveying roulette. To do this, let's fix the convergence of the benchmarks 1, 2 and 3 on the contour of the haulage drift, in the directions characteristic of a steep fall. The measurement error was ±2 mm. The metering station diagram is shown in Fig. 2.

The full-scale experiment was carried out in the haulage drift of the l_3 Mazurka horizon of 1146 m. Production was protected by rolling bonfires from wooden sleepers. Then, after some time, due to technological and economic considerations, the method of protection was changed to coal pillars. The size of the coal h_p=8 m; l_p=5 m, where h_p, l_p – respectively, the height and length of the coal pillar. The cross-sectional area of the drift is S=8.5 m^2, the distance between the frames of the arched ductile lining (AP-3) with a wooden puff of 0.8 m. The speed of the preparatory excavation is V_p=16 m/month, the speed of treatment works is V_t=10 m/month. The drift was carried out using drilling and blasting operations (DBO). The way to control the roof in the lava is a complete collapse.

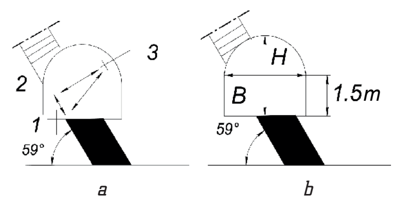

Fig. 2. Scheme of measuring stations for:
a – determining the displacement of lateral rocks on the contour of the haulage drift; *b* – measurements of the cross-sectional area of the mine along the length of the excavation section: 1, 2, 3 – reference; 1–3; 1–2; 2–3 – rapprochement of references 1, 2 in the direction of reference 3; *H* – excavation height, m; *B* – excavation width, m

The characteristics of the coal seam l_3 and lateral rocks are presented in Table 1.

Table 1

Characteristics of the coal seam l_3 and lateral rocks on the experimental site

Thick *m*, m	Incidence angle α, degrees	Elastic modulus *E*, N/m^2	Side rocks	
			Roof	Soil
1.05–1.1	59°	0.35·10^{10}	Clay shale up to *m*=4.0 m thick; sand shale, up to *m*=7.0 m thick	Clay shale up to *m*=15.0 m thick

To assess the conditions for maintaining the haulage drift for different protection methods, the «express method» was used when measuring the cross-sectional area of the mine S (m^2) along the length of the experimental section at the measuring stations. In this case, behind the excavation face, measurements were made of the width B (m) and the height N (m) of the haulage drift. The measurement scheme is presented in Fig. 2.

3. Research results and discussion

Fig. 3 shows the graphs of the displacements of the lateral rocks U (mm) along the contour of the haulage drift of the formation l_3 along the length of the excavation section l (m) for different protection methods.

As a result of the studies, it was found that the greatest displacements of the rocks were recorded for references 1–3 and 2–3 (Fig. 3), which reflect the displacements of the roof rocks along the length of the excavation section. The movements of the roof rocks in the zone of influence of the treatment works are characterized by layer-by-layer bending with subsequent destruction and rash into the mine. At a distance l=100 m behind the face, the displacements of the rocks along references 1–3 were U_{1-3}=390 mm when protected by wooden structures (Fig. 3, *a*) and

U_{1-3}=520 mm when using coal pillars (Fig. 3, *b*). It is noted that the most difficult conditions for maintaining haulage drifts in the zone of influence of treatment works are formed when using coal pillars.

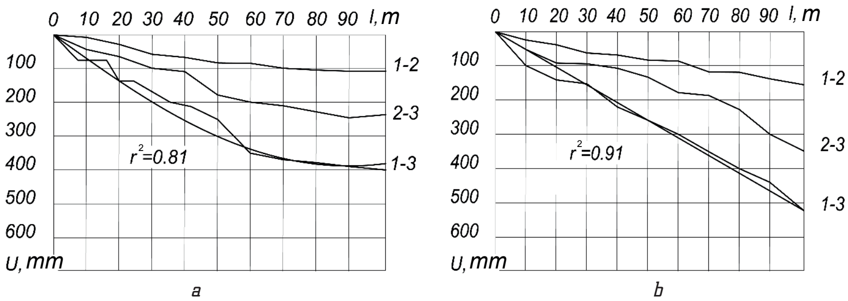

Fig. 3. The graphs of the displacements of the lateral rocks *U* (mm) on the contour of the haulage drift of the formation l_3 along the length of the excavation section *l* (m): *a* – using the method of protection by rolling bonfires from wooden sleepers; *b* – using the method of protecting coal pillars

In order to evaluate the conditions for maintaining the haulage drifts in the excavation section, let's record the change in the cross-sectional area of the mine as the excavation face advances, when the magnitude of the area losses was determined. Thus, when protecting a mine with wooden structures, the section of the haulage drift at a distance l=100 m decreased by 32 % to S=5.8 m^2 (Fig. 4, dependence 1). When protecting the drift with coal pillars, its cross section decreased to S=4.1 m^2 at a distance l=100 m behind the excavation face, which amounted to a loss of 50 % of the initial value (Fig. 4, dependence 2). After processing the experimental data by the methods of mathematical statistics [9, 10], it was found that the displacements of the roof rocks *U* (mm) along the drift contour along the length *l* (m) obey a linear relationship (r^2=0.91) when protected by coal pillars. When protected by wooden structures, the displacements of the roof along the length of the excavation section obey the exponential dependence (r^2=0.81), Fig. 3.

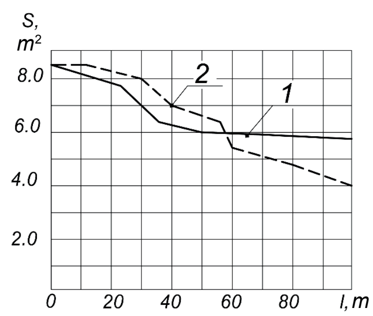

Fig. 4. Graphs of changes in the cross-sectional area *S* (m^2) of the haulage drift of the formation l_3 along the length of the excavation section *l* (m): 1 – when protected by wooden rolling bonfires; 2 – coal pillars

Analysis of the study of the problem of the stability of haulage drifts with different protection methods indicates that the issues of stability of the used protection structures and excavations that support the treatment area in the influence zone were considered separately. In order to determine the patterns of manifestations of rock pressure along the length of the preparatory excavations with different methods of protection and to establish their influence on the stability of drifts, the solution to the problem should be considered comprehensively. The choice of effective methods for protecting mine excavations is determined by the reliability and reliability of the manifestations of rock pressure during various periods of operation of the haulage drift.

According to the recommendations set forth in [11, 12], the stiffness *c* (N/m) of the protection structure is defined as:

$$c = \frac{E \cdot S}{\Delta h},$$

where E – elasticity modulus, N/m^2; S – cross-sectional area, m^2; Δh – change in the height of the protection structure as a result of convergence of lateral rocks (let's believe that $\Delta h = U_{1-3}$), m.

The load *P* (N) on the protection structure located above the drift, and therefore on the support of the mine, can be determined from Hooke's law [13, 14], when:

$$P = \frac{\Delta h}{h} \cdot E \cdot S,$$

where h – the height of the protection structure (equal to the power of the coal seam), m.

Fig. 5 shows graphs of changes in the stiffness *C* (N/m) of protection structures and the load *P* (N) on the support of the haulage drift for different protection methods along the length of the excavation section *l* (m).

It has been established that as the excavation face moves, when the length of the excavation section increases, the stiffness of the protection structures decreases (Fig. 4, dependence 1, 2). At the same time, the load on the lining in the haulage drift increases (Fig. 4, dependence 3, 4). Meanwhile, under conditions when the mine is protected by wooden structures, the load increases smoothly, to a value of P=6.8·10^9 N, and then stabilizes. This is explained by the compression of the protection structure to the maximum values $\Delta h/h$=0.32 (at a distance l=60 m), when the displacements of the side rocks behind the lava are stabilized (Fig. 4, dependence 1).

When protecting the haulage drift by the coal pillars, with intensive displacements of the roof, there comes a moment of loss of the bearing capacity of the pillar. The coal crushed in its entirety is poured out, the design does not limit the displacement of the side rocks, which contributes to an increase in the load on the lining. The coal pillar becomes unsuitable for operation, i. e., unstable. With a decrease in the stiffness of the pillar by 80 %, the load on the support of the haulage drift increases by 4.2 times (Fig. 4, dependence 2).

Thus, in the influence zone of treatment work, deformations of roofing rocks reach values that exceed the structural compliance of the roof support in the mine (U=390–520 mm). In such conditions, in the absence of limitation of displacements of the lateral rocks above the drift, it is practically impossible to maintain its operational state. Therefore, when developing steep coal seams at great depths, in order to ensure the operational state of haulage drifts and reduce coal losses in the excavation area, it is advisable to use above-drift compliant supports or to lay open spaces to protect mine excavations. The displacement of lateral rocks on the contour and the load on the lining of the haulage drift depend on the stiffness and compression during the operation of such protection structures.

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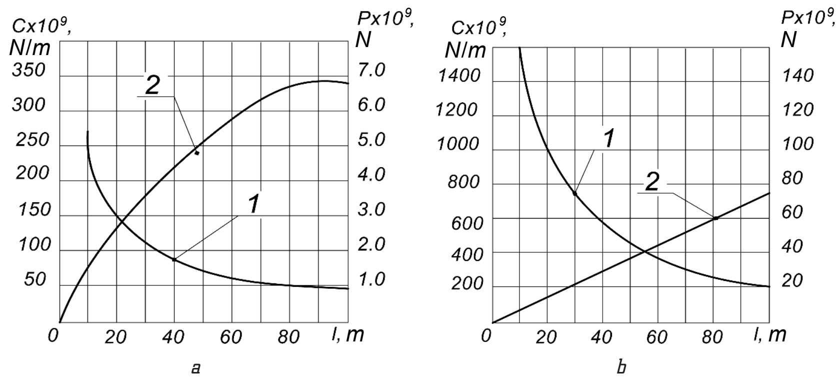

Fig. 5. Graphs of changes in stiffness *c* (N/m) of protection structures and the load *P* (N) on the support of the haulage drift along the length of the excavation section *l* (m): *a* – when protected by wooden structures; *b* – when protected by coal pillars; 1 – *c* (N/m); 2 – *P* (H)

4. Conclusions

1. The specifics of maintaining local preparatory excavations in the zone of influence of treatment works is due to increased disturbance of the roof rocks and deformations of the roof support. It is established that the convergence of lateral rocks on the contour of the haulage drift obeys a linear relationship when protecting the development of coal pillars and exponential when protecting wooden structures.

2. Maintaining the operational state of haulage drifts is ensured under conditions when the above-drift protection structures are stable during unloading of the coal-bearing massif. Then, as a result of compression, they reflect the ability to resist deformations of lateral rocks and limit their displacements in the zone of influence of treatment works.

The obtained research results can be used to justify the choice of a method for protecting local preparatory excavations when developing steep coal seams at great depths.

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