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Article

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Reference: Korol, Anton (2021). The influence of the rigidity of mining security structures on the stability of side rocks in the coal-rock massif. In: Technology audit and production reserves 3 (1/59), S. 19 - 22.
http://journals.uran.ua/tarp/article/download/235403/234379/539554.
doi:10.15587/2706-5448.2021.235403.

UDC 622.834.2:622.274
DOI: 10.15587/2706-5448.2021.235403
Article type «Reports on Research Projects»

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THE INFLUENCE OF THE RIGIDITY OF MINING SECURITY STRUCTURES ON THE STABILITY OF SIDE ROCKS IN THE COAL-ROCK MASSIF

The object of research is the processes of controlling the state of side rocks to prevent the collapse of the stratified rock strata in the coal-rock massif containing the workings. The studies carried out made it possible to establish the influence of the rigidity of the guard structures of mine workings on the stability of side rocks in the coal-rock massif. It is proved that as a result of the action of an external compressive load on the supporting lateral rocks, the structure, in the form of a model of bunches made of wooden posts, increases its rigidity until the destruction of the security structure. After that, there is an increase in the convergence of side rocks and their destruction. The change in the stiffness of the crushed rock in the filling massif model, which is used to support the lateral rocks, occurs as a result of the compaction of the original material. This is due to repackaging of crushed rock fractions of different sizes and its additional grinding. As a result of this interaction of the side rocks with the filling massif, the integrity of the roof and soil is ensured and convergence is limited. To assess the stability of side rocks, it is proposed to use a dimensionless stress concentration factor k. This coefficient takes into account the rigidity of the guard structures of the mine workings and the flexural rigidity of the side rocks. It was found that when the values of the coefficient k are close to zero (k→0), there is a loss of stability of the guard structures of mine workings and the destruction of side rocks in the coal-rock massif. The preservation of the integrity of the side rocks and the stability of security structures is ensured at values of k>0.1, which corresponds to the parameters of the pliable supporting structures. Most favorably on the condition of side rocks in the coal-rock massif is influenced by the method of backing up the mined-out space of crushed rock. The use of this method excludes the collapse of side rocks. When solving the problem of stability of mine workings at the stage of making technical decisions, it is necessary to predetermine the issues of rigidity of security structures with deformation characteristics of side rocks.

Keywords: *side rocks, protective structure, deformation characteristics, mine workings, crushed rock, filling massif.*

Received date: 08.02.2021
Accepted date: 23.03.2021
Published date: 30.06.2021

How to cite
Korol, A. (2021). The influence of the rigidity of mining security structures on the stability of side rocks in the coal-rock massif. Technology Audit and Production Reserves, 3 (1 (59)), 19–22. doi: http://doi.org/10.15587/2706-5448.2021.235403

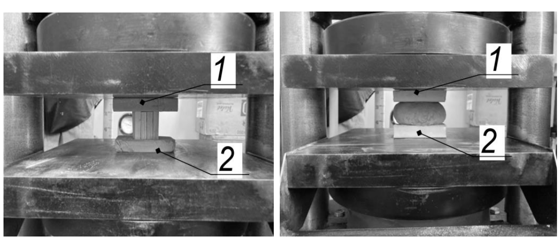
1. Introduction

At present, the extraction of coal from deep mines remains promising, despite the growth in the production of alternative energy sources. Further development of the coal industry is associated with an increase in the depth of mining. The world experience of deep mines shows that the efficiency of coal seam development depends on the operational state of mine workings. With an increase in the depth of mining, deformation of the coal-rock massif occurs, which is a consequence of a change in the stress state of side rocks [1, 2]. The reliability of the maintenance of workings in such conditions largely depends on the method of protection, the stability of the roof and soil, as well as the size of the zones of destruction of rocks in the coal massif after the extraction of a mineral [3]. The destroyed rocks after collapse participate in the formation of loads on the support, as a result of which the cross-section of the supported workings is lost, the ventilation of the excavation areas is disrupted. These negative consequences are the cause of accidents in mines. The practice of using aimless methods for protecting mine workings has shown that when using pillars of coal of various structures made of wood to maintain side rocks in the worked-out area of the excavation area, the satisfied state of the supported workings is not always ensured. When solving the problem of the stability of mine workings, it is necessary to predetermine the issues of the rigidity of security structures with the deformation characteristics of side rocks. The solution to this issue is an urgent task of the study. *The object of research* is the processes of controlling the state of side rocks to prevent the collapse of the stratified rock strata in the coal-rock massif containing the workings. *The aim of research* is to assess the influence of the rigidity of guard structures of mine workings on the stability of side rocks in a coal-rock massif.

 ISSN 2664-9969

2. Methods of research

To assess the stability of side rocks in the coal-rock massif, experimental studies were carried out on models of guard structures of mine workings. In the modeling, let's use guard structures of mine workings in the form of a bunch of wooden posts and filling material from a non-uniform (in particle size) crushed rock. Samples of security structures made of wood (pine) were made on a scale of M1:50 and had the following dimensions: rack length h=0.04 m, cross-sectional area of the security structure S=0.0016 m^2. The heterogeneity of the rock was assessed by the granulometric composition of the initial material according to the method [4]. According to the research results, the characteristics of crushed rock were determined: for a fraction size of 0.1–5 mm, the density of the initial material is ρ_n=1820 kg/m^3, the initial voidness is M=14 %. Roof and soil rocks were modeled in the form of a beam made of a cement-sand mixture, according to the recommendation [5]. Dimensions of the model of beams: width b=0.04 m, height h=0.02 m, length l=0.1 m. Characteristics of the model of beams: density ρ=2310 kg/m^3, modulus of elasticity E=11200 MPa. The samples were tested on a GP-50 press (LLC ZIM Tochmashpribor, Armavir, Russia). Samples were placed between the roof and soil in a coal seam model and positioned between press plates (Fig. 1). The crushed rock was placed in a special bag and represented a model of a filling massif with the possibility of lateral expansion.



a *b*

Fig. 1. Photo of experimental samples of security structures of mine workings in the form of a model: *a* – a bunch of wooden racks (1); *b* – a filling massif of crushed rock in a special bag (2): 1 – roof; 2 – soil

The relative deformation of the experimental samples λ, during testing, was determined by the expression [6–8]:

$$\lambda = \frac{\Delta h}{h}, \quad (1)$$

where h – initial height of the sample, m; Δh – decrease in the height of the sample, m.

The rigidity of guard structures in mine workings c (N/m) was determined as [9, 10]:

$$c = \frac{F}{\Delta h}, \quad (2)$$

where F – load applied to the experimental samples, m.

To assess the stability of side rocks, it was proposed to use a dimensionless stress concentration coefficient k, which represents the ratio of the bending stiffness (EI) of side rocks, presented in the form of a model of a beam having a certain length L (m) to the rigidity c (N/m) of a guard structure of mine workings:

$$k = \frac{EI}{cL^3}. \quad (3)$$

During the experiments, the deformation characteristics of security structures, which were under the influence of external compressive loads, were studied.

3. Research results and discussion

Fig. 2 shows the graphs of the change in the height h (m) of the experimental samples with an increase in the compressive load F (kN). Fig. 2, *a* it can be seen that with uniaxial compression of bunches from wooden posts, a decrease in the height of the model from h=0.039 m to h=0.035 m was recorded, when the compressive load increased from F=0 to F=25 kN. With an increase in the compressive load to values F=26 kN and more, the experimental sample lost its stability and collapsed. As a result of the compression of the filling massif from the crushed rock, the compaction of the initial material was recorded. Under the action of a compressive load of F=60–65 kN, the height of the experimental sample decreased from h=0.04 m to h=0.021 m (Fig. 2, *b*).

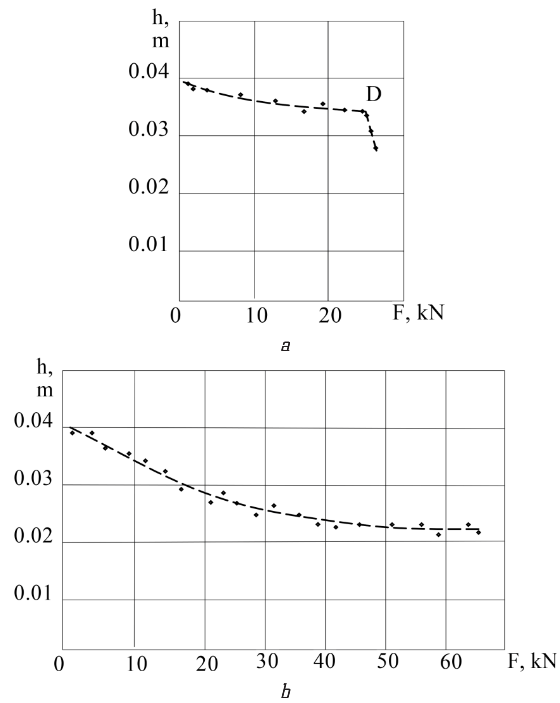


Fig. 2. Graphs of changes in the height h (m) of experimental samples from the value of the uniaxial compressive load F (kN): *a* – model in the form of a bunch of racks; *b* – model in the form of a filling massif; *D* – destruction of the model

Fig. 3 shows the graphs of the change in the rigidity c (N/m) of protection structures of mine workings from their relative deformation λ.

In the course of the experimental studies, an increase in the rigidity of the model in the form of a bunch made of wooden racks was established to values c=4.5·10^6 N/m at λ=0.14.

Then, with an increase in the relative deformation of the sample to λ=0.2, the rigidity of the model decreases. After that, the experimental sample loses its stability, and the side rocks are destroyed (Fig. 3, *a*).

For the crushed rock, which represented the model of the filling massif, the change in stiffness in several stages is characteristic. Under uniaxial compression of the filling material, when $\lambda=0.02$, the stiffness of the model was $c=2.0\cdot10^6$ N/m. With an increase in the relative deformation to values $\lambda=0.2$, the stiffness decreased to $c=1.61\cdot10^6$ N/m, and then increased to $c=3.1\cdot10^6$ N/m at $\lambda=0.47$ (Fig. 3, *b*).

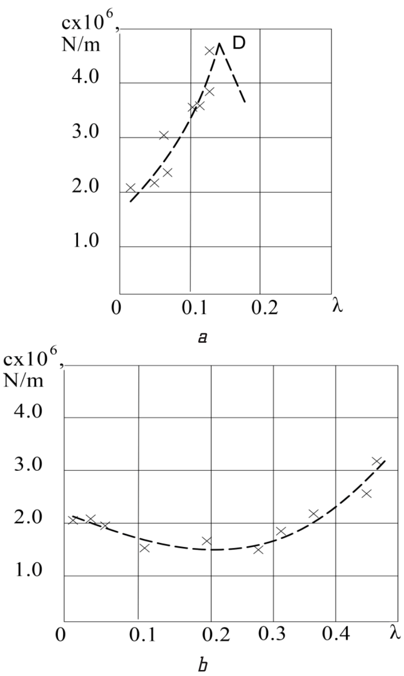


Fig. 3. Graphs of the change in stiffness *c* (N/m) of experimental samples versus the value of the relative deformation λ under uniaxial compression: *a* – a model in the form of a bunch of racks; *b* – model in the form of a filling massif; *D* – destruction of the model

Fig. 4 shows a graph of the change in the dimensionless stress concentration coefficient *k* versus the stiffness *c* (N/m) of the experimental samples. Fig. 4 it can be seen that with an increase in the rigidity of the guard structures of mine workings, a decrease in the dimensionless coefficient *k* is observed. It is fixed that for experimental specimens in the form of a bunch model made of racks at the maximum rigidity of the specimen $c=4.5\cdot10^6$ N/m the value $k=0.07$ (Fig. 4). For the model of a filling massif of crushed rock under its uniaxial compression, when $c=3.1\cdot10^6$ N/m, the value of the dimensionless coefficient corresponds to $k=0.11$ (Fig. 4). It should be noted that the values of the dimensionless coefficient *k* were established at the maximum rigidity of the experimental samples, when their operable state was ensured, which affects the stability of the lateral rocks.

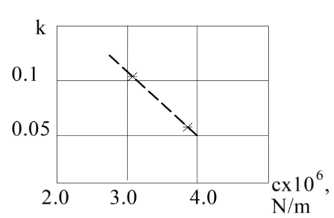


Fig. 4. Graphs of changes in the dimensionless stress concentration coefficient *k* in the roof and soil from the rigidity of experimental samples

Security structures of mine workings, designed to support lateral rocks (Fig. 1), form stress concentration zones in the coal-rock massif. In such zones, the stability of the roof and soil depends on the deformation characteristics of the practiced security structures. Therefore, the nature of the interaction of support structures with lateral rocks under the action of external loads is ambiguous.

As a result of the performed experimental studies, it was found that for rigid security structures in the form of a model of a bunch made of racks when deformed up to 15 %, their rigidity increases (Fig. 3, *a*). In this case, the value of the dimensionless coefficient *k* tends to zero ($k\to0$), Fig. 4. With an increase in the compressive load, when the relative deformation of the security structures exceeds $\lambda\geq0.15$ (Fig. 3, *a*), the security structure loses its stability. Fracture of side rocks is observed (point *D* in Fig. 2, *a*, Fig. 3, *a*) and an increase in convergence. With such an interaction of side rocks with rigid protective structures in real conditions of the development of coal seams, the probability of roof collapse and blockage of mine workings increases.

The deformation characteristics of the filling massifs made of crushed rock of heterogeneous composition (size of fractions 0.1–5 mm) reflect the reaction of the supporting support to the external effect of the compressive load (Fig. 2, *b*).

When compaction of the filling massif as a result of repackaging of crushed rock particles of different sizes, the roof rocks gradually descend. After reaching the maximum rigidity of the filling massif (maximum rigidity of the model $c=3.1\cdot10^6$ N/m, Fig. 3, *b*), the convergence of side rocks is limited.

It was found that at constant bending stiffness of side rocks, with an increase in the relative deformation of workable (stable) guard structures, the values of the dimensionless stress concentration coefficient *k* increase with a simultaneous decrease in the stiffness of the supporting structures or supports (Fig. 4).

In conclusion, it should be noted that the efficiency of mining coal seams and the safety of mining operations largely depend on the method of protecting the development workings. The most favorable for the condition of the side rocks and the workings adjacent to the workings is influenced by the method of protecting the development workings – the backfilling of the worked-out area. When using this method, the roof and soil behind the working face are supported by a filling massif of crushed rock, which excludes the collapse of side rocks and blockages of the workings.

The research results can be used when choosing the methods of protecting the sectional development workings in mines developing coal seams with a thickness of up to $m=1.5$ m.

4. Conclusions

In the course of the study, to assess the stability of side rocks in the coal-rock massif, it was proposed to use the stress concentration coefficient *k*, which takes into account the flexural rigidity of the roof and soil of the coal seam and the rigidity of security structures. It was revealed that with an increase in the relative deformation λ of security structures from $\lambda=0.15$ to $\lambda=0.45$, the values of the coefficient *k* increase from $k=0.07$ to $k=0.11$ with a simultaneous decrease in the stiffness of

ISSN 2664-9969

the supports from $c=4.5\cdot10^6$ N/m to $c=3.1\cdot10^6$ N/m. As a result of such interaction of side rocks with protective structures during their compression, rigid structures are destroyed, and pliable ones are compacted. The research results can be used when choosing a method for protecting mine workings in the excavation areas of deep coal mines, developing seams of a large dip.

Acknowledgement

Postgraduate students of Donetsk National Technical University (Pokrovsk, Donetsk region, Ukraine) took part in the experimental research: Yu. Simonova, Ye. Podkopayev, M. Hryhorets and also an engineer of SE «Selidovugol» (Selidovo, Donetsk region, Ukraine) O. Kayun.

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