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ANALYSIS OF THE EFFECT OF A SUPPORTING STRUCTURE AS WELL AS FLOOR ROCKS MOISTURE ON THE STATE OF A DEVELOPMENT MINE WORKING

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ABSTRACT

A problem concerning improved stability of development mine workings under complicated mining and geological conditions of mines in Western Donbas has become extremely important. The tendency is the increase in coal extraction resulting in the fact that KSHPU-arched development mine workings become longer. Analysis of the state of mine workings in Western Donbas mines inclusive of the analysis of expenditures, connected with their construction, and maintenance, shows: the measures to prevent and cure the effects of floor rocks heaving, being a variety of deformation of neighboring rock mass of mine workings, are the most labour-intensive processes while providing operational state of the mine workings. A process of a frame support bearing forcing in a floor of a mine working can be described in the form of a functional dependence between the reduced time interval of the support operation and a depth of its forcing in the mine working floor. To analyze the developed mathematical model, it is required to perform calculations on 160 combinations of the reduced rock strength and area of a foot bearings being used, i.e. four variations of the reduced strength; and 40 foot bearings (75 to 750 mm^2) for each of them. Results of the field studies, described by the paper, have confirmed dependence between area of a support foot bearing and depth of its forcing in a mine working floor. Mathematical model, developed relying upon the data, makes it possible to forecast a depth of a support foot bearing forcing in a mine working floor during its operation in the context of various combinations of rock mass stress-strain properties and geometry of foot bearings being applied.

Keywords: underground mining, workings support, bearing capability of a floor.

1. INTRODUCTION

Prolonged term of maintenance-free operation of mine workings is one of the aspects of the efficiency in the context of coal-mining industry in Ukraine. A problem concerning improved stability of development mine workings under complicated mining and geological conditions of mines in Western Donbas has become extremely important. The matter is that enclosing rocks are characterized by poor mechanical strength as well as a tendency to soaking, lamination, and heaving. All the factors result in the reduced sectional areas of mine workings.

Analysis of the state of mine workings in Western Donbas mines inclusive of the analysis of expenditures, connected with their construction, and maintenance, shows: the measures to prevent and cure the effects of floor rocks heaving, being a variety of deformation of neighbouring rock mass of mine workings, are the most labour-intensive processes while providing operational state of the mine workings (Bondarenko *et al*., 2018;.Cheberiachko *et al*., 2018; Hejmanowski and Witkowski, 2015).

Irrespective of a number of experiments and analytical studies, heaving of floor rocks in mine workings remains one of the least understood phenomena. That is why engineers and technicians of mining industry failed to achieve weighty positive results.

Actually, two processes are available to provide stability of a mine working. Process one is to erect a support being of a high bearing capacity and having the increased nominal size. The process is implemented by means of the erection of supporting frames, made of high-resistance complex steels, or by means of erection of frames, made of heavy-section rolled steel. Process two is to thicken the supporting frames erection. In this context, safety factor is taken as that being overestimated; as a result, excess of support material is significant and construction of mine workings rises in price. However, as experience confirms, the measures cannot provide operational state of the mine workings.

The problem to provide stability of development workings is topical for mines in Western Donbas where coal deposit is characterized by slightly metamorphized watered enclosing rocks. That can be explained by a tendency being visible in the activities of DTEK Pavlohradvuhillia PJSC. The tendency is the increase in coal extraction resulting in the fact that KSHPU-arched development mine workings become longer (Mukha*et al*., 2019).

The efficiency of the widely used support KSHPU for the development mine workings under the conditions of soft unstable enclosing rocks in Western Donbas mines depends heavily on the “bottom of support - floor” system interaction (Fomichov *et al*., 2014; Krukovskyi *et al*., 2017; Inkin *et al*., 2018).

Currently, erection of supports is the basic means to provide stability of district mine workings and maintain them in adequate operational conditions. Currently, KSHPU supports, made of special shape SVP 19-22, is a principal support type applied in Western Donbas mines.

Contrary to all advantages of the support, mining deepening decreases its efficiency in terms of the economic factor since the support unlocks own flexibility when its elements are slipping within its fasteners as well as when the support props are dug into floor rocks of mine workings. It should be noted that retimbering of recycling development workings often makes it impossible to extract the support props from the expanded floor rocks resulting in more expensive maintenance and repair operations (Fomichov*et al*., 2018).

Unsatisfactory state of KSHPU-arched mine workings and related expenditures connected with repair and retimbering are mostly stipulated by unbalance between structural parameters of arch supports and convergence value of enclosing rocks as well as a character of rock pressure manifestation within rock mass containing the mine working (Sotskov *et al*., 2017; Yu *et al*., 2017).

Soft floor rocks exert significant action on the state of mine workings. Bearing capacity, depending upon such factors as structure, moisture, distance from a stope, outcropping period, bearing force etc., is the basic processing characteristic of floor of development mine workings (Lefik, 2013).

Rock moisture is one of the key factors working upon their strength and behaviour within mine workings. Under the action of water, inflowing from water-bearing layers, rocks either lower or lose their strength characteristics. The tendency to complete soaking is especially typical for slightly metamorphized rocks; it particularly concerns geological and industrial areas of Western Donbas.

Research, concerning physical and mechanical properties of floor rocks, carried out by IRM of NAS of Ukraine, shows that in the context of Western Donbas 75% of mine workings have been driven within enclosing rocks where bearing capacity of floor throughout the length of a mine working or within its certain areas is less than 3 MPa. It has been determined that moisture results in considerable reduction of its strength. In turn, bearing capacity is lost and floor rocks displacement intensifies (Lozynskyi *et al*., 2017; Malashkevych *et al*., 2018).

If bearing capacity is low, a support spins into the ground significantly even if pressure on a roof beam is minor; extra flexibility is developed favouring more intensive roof displacements. In this context, false heaving effect is produced and industrial workers are forced to make inadequate decisions on the floor rocks blasting.

Reduced strain within “bottom of support - floor” contact is the main provision to improve stability of floor rocks in the development workings. As practices confirm, even if load on the roof rock support is light, arch props spinning into the slightly metamorphised floor rocks is observed. In this context, nonuniform distribution of rock pressure along arching segments takes place resulting in their skewing and deformation. Thus, the necessity to replace the support either partially or completely arises (Małkowski *et al*., 2016; Mahdevari *et al*., 2017).

To avoid the spinning, S = 100; 225; 400; and 625 cm^2bearings were mounted within four 30-50 m sites of a boundary entry in *Zakhidno-Donbaska* mine of *DTEKP avlohradvuhillia* PJSC.Benchmark stations were also equipped within the sites to determine thrust slips of floor rocks. Certain control unsupported frames were selected to compare the results. The frames were used for underground surveillance over the development mine working state.

2. FINDINGS

To determine both effect and moisture regularities, bearing capabilities of a floor have been analyzed by means of a dynamic express method with the help of HighwayRI harmer (Figure-1) within the development mine workings of *Pavlohradvuhillia* PJSC mines.

Figure-1. Dynamic method to analyze bearing capability of a floor.

Operation principle of the hammer is as follows: from the certain height, a load drops along a bar and strikes against a block making a pricker dig into a floor (Mamaikin *et al*., 2018).

Measurements were performed in advance of a stope at 150; 100; 50; 25; 20; 15; 10; 5; and 3 m distances as well as within a longwall transit. In this context, floor rocks were sampled to determine their moisture. The results in Figure-2 show that the floor rock moisture varies from natural (i.e. 1.5 - 3%) to maximum (6 - 6.5%) only within the area of mining influence at the distance of 50-60 m in advance of the longwall. If distance from the longwall is more, then floor moisture varies slightly and can be neglected. Research within the zone of geological faults was not involved (Sidorenko and Ivanov, 2016; Sotskov *et al*., 2015).

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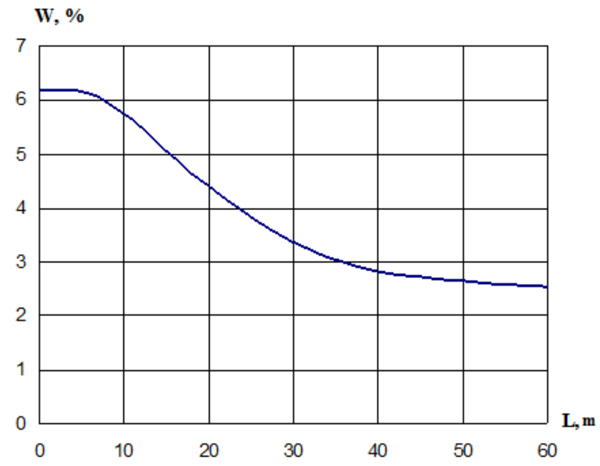

Figure-2. Graph of moisture changes within the area of mining influence.

According to numerous studies, carried out by IRM of NAS of Ukraine in Western Donbas mines, mining operations can effect the state of enclosing rocks at the distance being up to 150 m in advance of a longwall (Rastbood *et al*., 2017). In terms of the development mine workings, changes in floor rock moisture are approximated as follows:

$$\ln W = 3.915 + 0.0722\,L - 0.0854\,L^2 \qquad (1)$$

Where W is rock moisture within sampling areas, %; and L is a distance from the longwall to the research area, m.

Processing of results of more than 350 measurements, carried out in 40 development mine workings of Western Donbas mines, helped obtain experimental dependence of changes in bearing capacity of $\sigma_{вд}$ floor in the development mine working upon W moisture. Theresultsare represented inFigure-3.

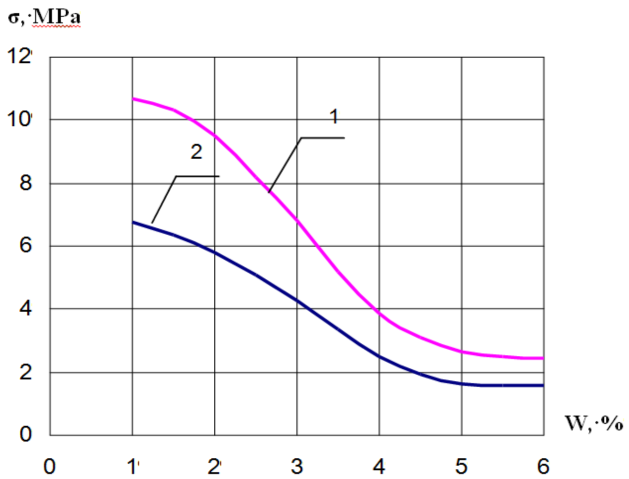

Figure-3. Graph of a floor bearing capacity σ changes within the area of mining influence: 1 -aleurite; and 2-argillite.

Depending upon the moisture increase, changes in floor rocks bearing capacity are approximated as follows:

$$\ln\sigma = 14{,}75 + 3{,}42W - 0{,}21W^2 \quad \text{for aleurite, and} \quad (2)$$

$$\ln\sigma = 9{,}18 + 2{,}12W - 0{,}13W^2 \quad \text{for argillite} \quad (3)$$

Where W is rock moisture within sampling areas, %; and σ and floor rocks resistance to forcing in, MPa.

Figure-4 represents a dependence of a mine working floor rocks heaving obtained at four measuring points equipped with support props. The graph shows that a value of a floor heaving within unsupported site is 230 mm. Within S = 400 cm^2 area, equipped with foot bearings, a floor heaving was 165 mm to be 25% less. It should be noted that while comparing the results of floor rocks heaving within S = 400 and 625 cm^{2}sites, equipped with foot bearings, divergence of heaving values is not more than 3% (Sotskov *et al*., 2014,2019).

Analysis shows that within unsupported sites the floor heaving rate is 0.57 mm/day; in the context of the supported sites with S = 400 i 625 cm^2 areas, the index is not more than 0.4 mm/day. Thus, when the supports have been erected, a floor heaving rate experiences 1.5 times decrease. Moreover, the results have been used to develop a dependence of a floor heaving rate on the area where the supports were applied. The dependence is shown in Figure-5.

The data, resulting from the field studies, are of a discrete nature stipulated by the impossibility to carryout the analysis for all possible sizes of a foot bearing. However, the results make it possible to develop a mathematical model describing a process of the frame support bearing forcing in the mine working floor.

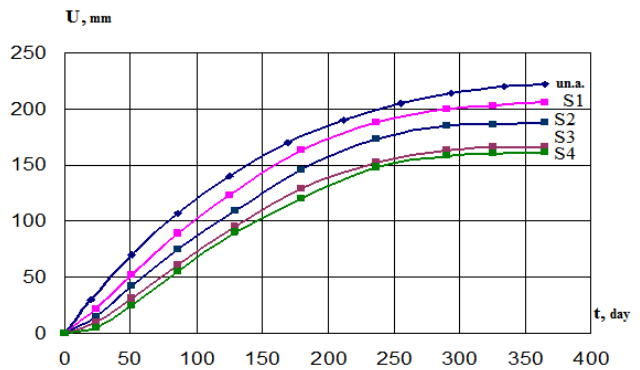

Figure-4. Floor rocks heaving within the development min working: un.a.is unsupported area; S1 is bearing area S = 100 cm^2;S2 is bearing area S = 225 cm^2; S3 is bearing area S = 400 cm^2; S4 is bearing area S = 625 cm^2

In addition to the effect of “support bearing-floor of a mine working” contact area geometry, the mathematical model also involves a balance between strength characteristics of a support bearing material and floor rocks of a mine working. To extend application area

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of the developed model, depth of a foot bearing forcing in the floor of a mine working, is calculated on the basis of the reduced time factor:

$$d = \frac{d_x}{d_a}, \tag{4}$$

where d_x is the current day of the support operation being counted off the defined zero, i.e. a day starting from which a balance between the support forcing-in depends during a prior day and the current one becomes more than 1; and d_a is a complete cycle of the support operation in terms of the days.

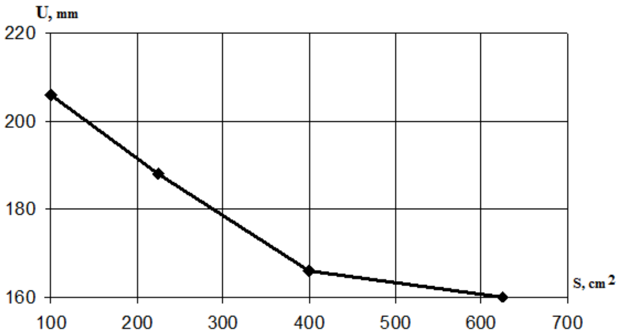

Figure-5. Graph of a floor heaving value dependence upon the area of supports being applied.

A process of a frame support bearing forcing in a floor of a mine working can be described in the form of a functional dependence between the reduced time interval of the support operation and a depth of its forcing in the mine working floor. It stands to reason that the mathematical model, used as a basis of the computational experiment, involves a balance between strength characteristics of support materials and a mine working floor as well as a factor of a rock strengthening within a mine working floor making it possible to obtain numerical solution for $U(d)$ function within the whole plane of possible solutions. The obtained analytical solution is:

$$U = E \cdot L \cdot \left(\sin\left(d \left| \frac{d}{2.1} - 2 \right| \right) + e^{d} \left(1 - \cos\left(\frac{\pi}{24} d \right) \right) \right), \tag{5}$$

where E is the reduced rock strength; and L is the reduced area of the mine working bearing support.

The rock strength is calculated according to the formula:

$$E = \frac{E_O}{E_П \cdot R} \tag{6}$$

where E_O is a tensile modulus of the support frame bearing material; $E_П$ is a tensile modulus of the mine working floor rock; and R is a complex coefficient of a mine working floor rock loosening.

The formula helps determining the reduced area of the mine working bearing support:

$$L = 2 - \frac{S^{1.35}}{S^2} tg\left(\frac{\pi}{4} S \right), \tag{7}$$

where $S = \frac{S_O}{10000}$ is a ratio between the selected area of the frame support and maximum possible (in the context of them a thematical model) reference area of the support bearing, mm^2.

To analyze the developed mathematical model, it is required to perform calculations on 160 combinations of the reduced rock strength and area of a foot bearings being used, i.e. four variations of the reduced strength; and 40 foot bearings (75 to 750 mm^2) for each of them. Figure-6demonstratesonlyfourcurvesofthecorrespondingreducedrockstrengthforfieldstudiesandsuchareasoffoot bearings as 150, 300, 500,and 600 mm^2.

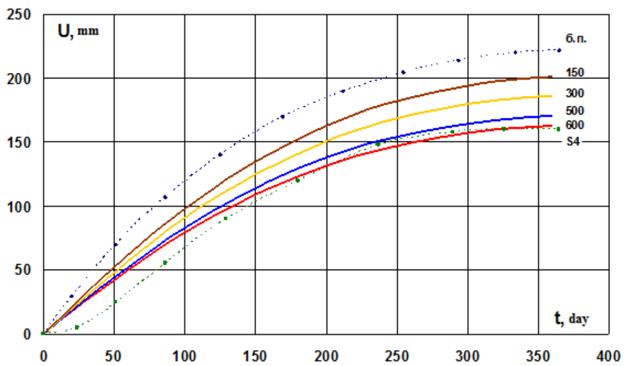

Figure-6. Examples of the calculations for such areas of foot bearings as 150, 300, 500,and 600 mm^2 (dots explain curves of field observations without supports and with S4 = 625 mm^2 supports).

As it is seen, the results confirm fully to the range of values obtained during the field studies. The mathematical model provides a high level of probability of both qualitative and quantitative indices of the support foot bearing forcing in; it especially concerns two third of the time interval of the support operation.

3. CONCLUSIONS

Results of the field studies, described by the paper, have confirmed dependence between area of a support foot bearing and depth of its forcing in a mine working floor. Mathematical model, developed relying upon the data, makes it possible to forecast a depth of a support foot bearing forcing in a mine working floor during its operation in the context of various combinations of rock mass stress-strain properties and geometry of foot bearings being applied. Average deviation of analytical calculation from the corresponding results of the field studies was less than 9% in the context of all pairs under comparison.

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