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MINING RESEARCH AND MODELING GEOMECHANICAL PROCESSES

Antypov I. V., Dr., Prof.
(Donetsk Academy of Management and Public Service under
the Head of the Donetsk People's Republic), Donetsk, DPR

The results of analytical and experimental studies of rock pressure in the longwalls of coal mines are presented. As a result of mine researches new features of interaction of the mechanized support and direct roof are established. This makes it possible to improve the existing mechanized supports and develop fundamentally new ones based on new principles of elements interaction in the "support – rocks" system.

Keywords: mine, powered support, longwall, roof, rock pressure.

1. INTRODUCTION

Donbass is a large industrial region for which the problems of coal industry development are very relevant. Proven coal reserves in Ukraine at the end of 2013 were estimated at 33 873 million tons (Statistical Review of World Energy 2014 [1]), of which more than 12 billion tons are now in the depths of the territory of the Donetsk People's Republic. The coal industry, as the basic industry, determines the economic well-being of not only individual enterprises, but also the entire economy of the Donetsk People's Republic.

Rock mass geomechanical processes during working very thin seams, in particular, by ripping, have some peculiarities in comparison with same processes of thick seams [2]. The investigation of these features and determination of the geomechanical processes relationship makes possible not only to improve the extant powered supports, but to design the fundamentally new ones [3].

2. PROBLEMS, METHODS AND OBJECTS OF INVESTIGATION

The problems of investigation are the following:

– to define the average rate, acceleration and absolute quantity of roof-lowering in the longwall;

– to determine the average setting load and operating resistance of legs (kH) and powered support units (kH/m^2);

– to establish the geomechanical processes relationship in rock mass according to coal winning and support setting technology;

– to verify in practice the hypothesis about a stepwise and s-shaped of roof-lowering in the longwall.

The full-scale observation of rock mass during working coal seam is the main method of geomechanical processes studying. Such investigations are carried out immediately in face area visually or by using special instruments. The geomechanical processes would be better to study by both methods. The Methodology of comprehensive research in operating mines of the Donetsk Coal Basin is an outcome of a joint effort by the Donetsk National Technical University of Ministry of education and science of Donetsk People's Republic, Republican Scientific-research and Design Institute of Mining Geology, Geomechanics, Geophysics and Surveying with participation of the Donetsk Academy of Management and Public Service under the Head of the Donetsk People's Republic experts. The Methodology seeks to explore salient features of support enclosing rock interaction and to determine the geomechanical processes general rules during mining systems working of the coal seams.

3. MINING AND GEOLOGICAL CONDITIONS, OPERATIONAL PROCEDURE FOR STUDYING

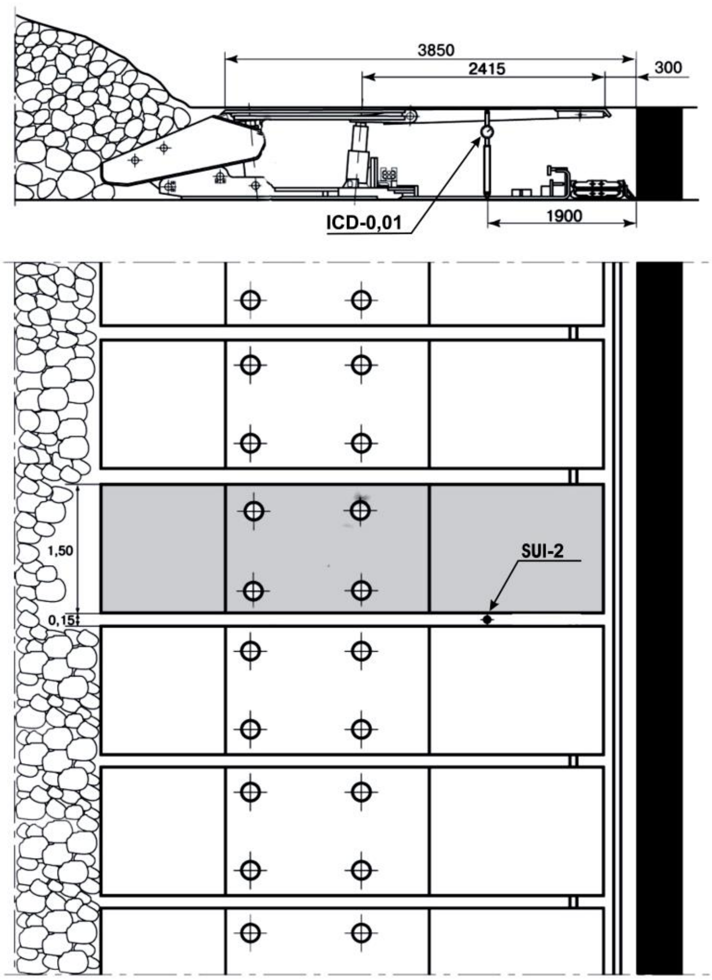
The comprehensive research was carried out in longwall of the l_4 seam at the A.F. Zasyadko mine.

The useful seam thickness ranges from 1,2 to 1,8 m and varies within 1,6 m. The seam angle of dip is 10-11°, coal density is 1330 kg/m^3 and coal resistance of cutting is 250 kN/m. The immediate roof with the thickness from 0,1 to 3,0 m is classified by DonUGI classification as $B_{2\text{-}3}$ category (roof stability average). The main roof consists of predominantly tough rocks and is classified as A_2 category (roof cavability average).

The useful capacity of the formation varies from 1.7 to 2.0 m, averaging 1.8 m. the Angle of incidence of the formation – 10–180, the volume weight of coal – 1330 kg/m^3 and the resistance of coal to cutting – 250 kN/m. the Direct roof of the formation with a capacity of 0.1 to 3.0 m according to the classification of the Donugi belongs to the category B3 (medium stability). The main roof consists of hard sandstones and is classified by category A2 (medium-destroyed).

Mining method is longwall of the length 220 m with roof caving. The longwall is equipped by 2MKD90 mining system. The system includes coal-plough machine, chain conveyor and powered support.

The measure station was built up at the longwall face on the powered support unit for instrumental and visual investigations. Manometers (MP-3 type) were set up at four legs of the unit. Roof-lowering was indicated by SUI-2 special legs and ICD-0,01 (indicator clockwork drive) with the 0,01 mm precision (pic. 1).



Pic. 1. Scheme of equipment placement at the measuring station in longwall

The meters indications were registered by recording device continuously. The useful and extracting thickness of the seam was measured by measuring reel one time per production shift. The duty operator noted the distance from longwall face to the first contact of cantilever roof bar and hanging wall, as well as the thickness of rock cushion upon canopy every advancing of the powered support unit. Roof rock condition (rock jointing, fractures, cleats etc.), as well as space of roof stability in waste were observed visually and made photos. The duty observer supervised duration of working process and fixed chronometer readings every 5 minutes.

The first measure station was built up at the 5 meters distance from the longwall end. The examinations continued 2 production shifts. After that the station was been moving in 5 meters up to longwall and examinations continued 2 shifts at the every location.

4. RESULTS OF OBSERVATIONS

The average value of legs setting load is about 63–69 % of datasheet working pressure. The setting load value of powered support units varies from 181 to 250 kN/m^2. The working support resistance on the average is 278 kN/m^2, that is about 85 % of nominal value.

Space between longwall face and cantilever roof bar changes from 0,3 to 0,7 m, varies within 0,5 m, that is gone over a limit in 1,6 times. The distance from longwall face to the first contact of cantilever roof bar and hanging wall on the average is about 0,8 m and the contacts are not continuous but in 3 or 4 points of cantilever roof bar. The spring and rigid parts of the roof bar contact roof not immediately but through the intermediary of the rock cushion with the thickness from 30 to 100 mm.

The most intensive rate of roof-lowering takes place at a distance of 1,2–1,6 m from longwall coal face just after the coal cutting and advancing of powered support unit. The hypothesis about s-shaped roof-lowering at the longwall face area has been proved. In this annoying case the line of roof lowering approaches asymptotically to exponential curve and the tensile forces are developed in rock mass. It leads to the opening of rock fractures and the roof falling between powered support units.

5. GEOMECHANICAL MODEL

Modeling as a method of knowledge of the validity, is widely applied in various fields of science. At the decision of problems of mountain geomechanics physical, analytical and numerical methods of modeling of a nature are used.

Among methods of physical modeling the greatest distribution has received a method of equivalent materials and optical one. Sometimes they are used with methods of structural models, with electroanalogies and centrifugal modeling. The essence of these methods consists in replacement of natural rocks with such artificial materials in model which physicomechanical parameters are in the certain ratio with similar parameters of objects of a nature. Such replacement of the validity with model is carried out with the help of criteria and constants of similarity.

Methods of physical modeling are widely tested at the decision of the broad set of problems. They have high presentation, but allow to receive only a qualitative picture of a physical nature of investigated processes. Alongside with advantages physical modeling has also some disadvantages: the low accuracy of results connected to significant distortion (scale reduction) of validity, obtaining of results in relative parameters, high specific consumption of materials and complexity of models manufacturing.

These disadvantages are deprived analytical methods of modeling which essential advantage consists in an opportunity of obtaining of quantitative results in the absolute parameters, more full account of real properties of rocks mass, the geometrical sizes and external influences. To analytical methods refer that ones in which required parameters are represented in an obvious view and can be calculated with any degree of accuracy, and to numerical methods refer that ones in which the continuous environment is approximated with quasidiscretical model.

In comparison with analytical methods, numerical ones are more flexible as enable to model heterogeneity of a rocky mass, various inclusions and zones of easing by cracks, and also allow to take into account a lot of physicomechanical characteristics of rocks.

Among numerical methods the greatest distribution has received the finite element method (FEM) having a significant range of opportunities for the decision of various problems of mine geomechanics [4].

At use FEM the rocky mass is replaced with the quasidiscrete model consisting of final number of flat triangular elements. Thus the real geometrical sizes and pressure in a mass are kept.

The comparative analysis of methods of modeling of geomechanical processes has shown that for simulating interactions support with a rocky mass most we accept a method of final elements as less toilful in comparison with modeling on equivalent materials and more exact as application of scale factors is excluded and real conditions of a nature are simulated. This method does not demand significant material inputs as optical one, and allows to take into account a lot of physicomechanical characteristics of rocks, than other methods.

For the decision of problems to simulating of support interactions with a rocky mass it is necessary to develop geomechanical model. Development of geomechanical model includes the consecutive decision of the following questions: an establishment of the geometrical sizes of design scheme and a way of its splitting into elements in view of initial statement of a problem; exarticulation in design scheme of interesting area of research by calculation of internal forces at each stage of calculation and their use as external loadings in the following stage, that is realization of gradual transition from the common decision to individual one.

As to capture all range of various combinations of mining geological factors is not obviously possible, we shall be limited by the most representative conditions seams for Donetsk coal basin.

We assume, that improvement of flat coal seam by capacity of 1,8 m deposited on depth about 1000 m is made. Basic roof contains rocks of category A_1, or A_2 (for example, sandstones, capacity from 3 up to 20 m), an immediate roof – slate of category B_2, or B_3 having capacity 0,1 up to 3,0 m (capacity of an immediate roof varies in models with step 0,1 m) are deposited. There is a homogeneous mass of slates of category $P_{2\text{-}3}$ in the ground.

For rocks are characteristic gravitational, strength and deformation properties. Most full these properties reflect the following physical and mechanical characteristics: density (ρ, kg/m^3), coupling (C, Pa), a corner of internal friction (φ, grade.), the module of elasticity (E, Pa) and Puasson factor (ν). Physical and mechanical characteristics of the rock mass are presented in table 1.

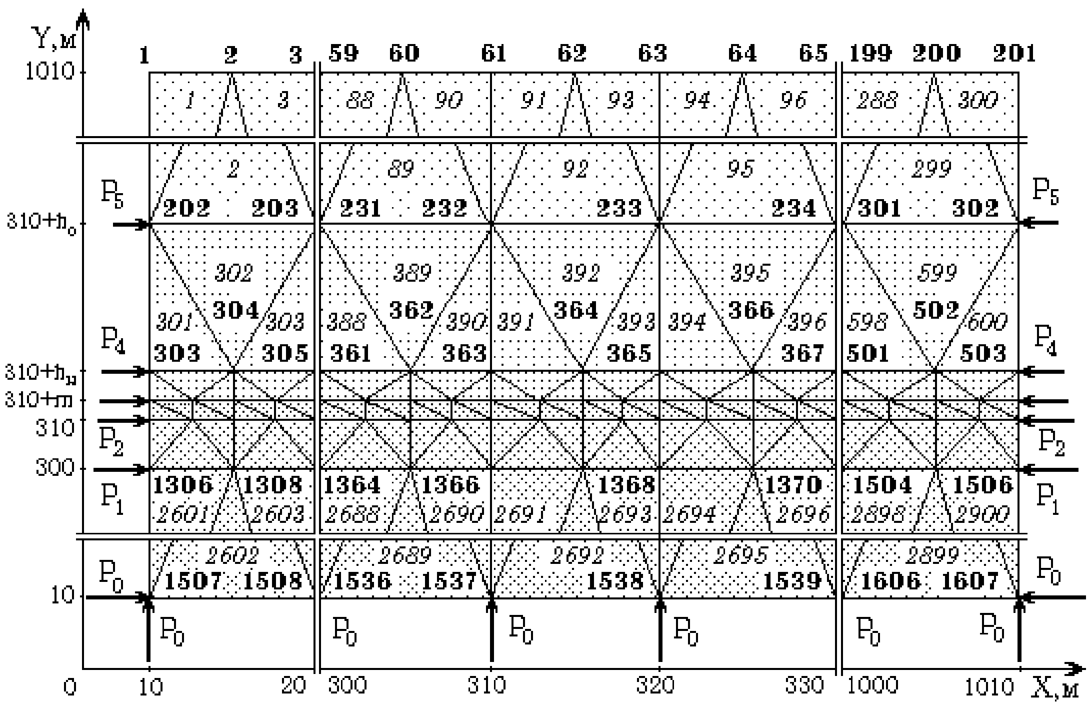
The geomechanical model represents a vertical section from a terrestrial surface up to depth of 1100 m. Horizontal the size of model 1100 m also are accepted. The sizes are accepted a priori under condition of an invariance of geostatic pressure on borders. If prospective shifts come over the borders of model its sizes will be necessary to increase. The grid of final elements is condensed in area of a coal seam where high gradients of pressure are assumed. Total amount of elements in design scheme is 2900, amount of units is 1607 (pic. 2).

At the first stage of the decision of a problem the condition of balance of model is checked. Calculations are carried out for a mass not subject to influence of mining works and the model thus should keep geostatic balance. Distribution of pressure in any arbitrary vertical section should repeat in accuracy a picture of distribution of external forces on borders of model.

Table 1

Physical and mechanical characteristics of the rock mass

Element numbers	Physical and mechanical characteristics						Rock category DonUGI classification
	ρ, kg/m^3	C, Pa	φ,^{o}	E, Pa	ν	σ_p, Pa	
1-300	2500	$10 \cdot 10^6$	22	20000	0,32	$2 \cdot 10^6$	
301-600	Main roof						Collapse:
	2400 2600	$15 \cdot 10^6$ $20 \cdot 10^6$	35 40	25000 30000	0,33 0,31	$3 \cdot 10^6$ $4 \cdot 10^6$	A_1 A_2
601-1200	Immediate roof						Stability:
	2600 2800	$5 \cdot 10^6$ $7 \cdot 10^6$	25 30	10000 15000	0,29 0,26	$1 \cdot 10^6$ $1{,}5 \cdot 10^6$	B_2 B_3
1201-2000	Coal seam						
	1300	$3{,}4 \cdot 10^6$	37	4600	0,3	$0{,}6 \cdot 10^6$	
2001-2900	Soil layer						Stability:
	2700	$13 \cdot 10^6$	35	22000	0,34	$2{,}6 \cdot 10^6$	P_{23}



Pic. 2. Geomechanical model

At the second stage realization of the cutting furnace which presence causes insignificant displacement of rocks and redistributions of pressure is modelled. In the subsequent stages extraction of coal is modeled by increase of unsupported roof in the produced space on size of longwall shift ΔL. Calculations are carried out until destruction of the elements simulating the basic roof will be fixed, that is, will not take place yet initial roof caving. If initial landing has taken place on an n^{th} stage of calculations, previous n-1 decision is accepted as initial for exarticulation in model of a site of the smaller sizes, and the received pressure are boundary conditions for researched area.

In researched area support unit is modeled by the appendix reacting forces to units of the elements simulating rocks of roof in longwall space.

In algorithms FEM the researched area is replaced with the quasidiscrete model consisting of final number of elements (triangular, rectangular, etc.), connected among themselves in units. All external and internal forces are resulted in units, and connection between unit forces and unit moving is established.

The developed algorithm of modeling of geomechanical processes in a mining mass is realized by a complex of applied programs FEM. Contrary to famous algorithms, in programs FEM the analytical problem decision of formation of elements rigidity matrixes received for the first time is used, that considerably raises speed of calculations and does not demand a significant memory size of the computer. The greatest effect from use of a complex of programs FEM is reached at the decision of complicated problems simulating geomechanical processes on the significant area of mining mass, and also at the decision of problems of modeling of interaction support with unstable roof rocks when there is a necessity of a condensation of elements network for places of high gradients of pressure.

6. CONCLUSIONS

In result of mine researches the new peculiarities of interaction between powered support and immediate roof in the very thin seams are established. It makes possible to improve the extant powered supports and to design the fundamentally new ones, based on the new principals of elements interaction in the system support enclosing rock.

It is established, that for increasing of adaptibility of support to conditions of unstable roof rocks it is necessary to provide an opportunity of its work in a mode of the optimum force parameters appropriate to conditions of a seam. For conditions of unstable roof rocks (category B2) specific resistance of support should change from 250 up to 300 kN/m^2, and for category B3 from 300 up to 350 kN/m^2. Overestimated or underestimated resistance of support results in infringement continuity of rocks and falls in longwall space.

Existing hydraulic mechanized supports because of their design features are not capable to provide optimum power modes of interaction with containing rocks. Therefore longwall supports, adaptive to unstable roofs, should have a new design and be based on new principles of interaction with the containing rocks, providing power stability of system "support-rock mass".

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Антипов И. В., д-р. техн. наук, проф.
(Донецкая академия управления и государственной службы
при Главе Донецкой Народной Республики), Донецк, ДНР

ШАХТНЫЕ ИССЛЕДОВАНИЯ И МОДЕЛИРОВАНИЕ ГЕОМЕХАНИЧЕСКИХ ПРОЦЕССОВ

Представлены результаты аналитических и натурных исследований горного давления в действующих очистных забоях угледобывающих шахт. В результате шахтных исследований установлены новые особенности взаимодействия механизированной крепи и непосредственной кровли. Это позволяет усовершенствовать существующие механизированные крепи и разработать принципиально новые, основанные на новых принципах взаимодействия элементов в системе «крепь – вмещающие породы».

Ключевые слова: шахта, механизированная крепь, очистной забой, кровля, горное давление.