FEATURES AND REGULARITY OF ZONAL CHANGES IN THE PHYSICOMECHANICAL CHARACTERISTICS OF ZAKHIDNYI DONBAS ROCKS

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ОСОБЛИВОСТІ ТА ЗАКОНОМІРНОСТІ ЗОНАЛЬНОЇ ЗМІНИ ФІЗИКО-МЕХАНІЧНИХ ХАРАКТЕРИСТИК ПОРІД ЗАХІДНОГО ДОНБАСУ

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ОСОБЕННОСТИ И ЗАКОНОМЕРНОСТИ ЗОНАЛЬНОГО ИЗМЕНЕНИЯ ФИЗИКО-МЕХАНИЧЕСКИХ ХАРАКТЕРИСТИК ПОРОД ЗАПАДНОГО ДОНБАССА

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Abstract. Purpose of the work is summarizes the results of numerous experimental studies of the physicomechanical properties of rocks from deposits of Zakhidnyi Donbas, defined by both mechanical and geophysical methods, to identify regularity of change. The analysis of the obtained data allowed us to reveal the zonal nature of their change. Regularity has been established for increasing the strength parameters of rocks in the direction from west to east. The mechanism of increasing the strength parameters of coal and host rocks, in our opinion, is explained, among other things, by the influence of Coriolis forces arising from the daily rotation of the Earth. Besides, for the most important rocks indicators the limits of change are obtained, namely: the compressive strengths, the resistance of rocks to cutting and their abrasiveness for both the roof and the floor of mine workings. It has been established that for more durable rocks, such as sandstone, the change in strength characteristics in the roof and floor is insignificant, whereas for weaker mudstones and siltstones, there is a significant difference in the above strength parameters. A generalization of the test results of Zakhidnyi Donbas rocks showed a large variation in their properties under the conditions of the achieved depth of the reservoir under development, which is due to the variability of the composition, structure, texture of the rocks and the degree of epigenetic transformations.

It has been established, as the depth increases to 400 m, the strength of the rocks grows rapidly, then from a depth of 400 – 600 m, the intensity of the growth of rock strength remains constant, and from a depth of 900 m and more it rises again.

On the basis of the data obtained, the planned rates and methods of preparatory workings are determined, when the workings are carried out using the mine combine method, the cutting tool consumption is planned, the technique and methods of securing the workings are selected. The results can be used in the preparation of forecast passports of lavas and excavation drifts, as well as in substantiating the technical conditions for the use of mining and sinking complexes.

Keywords: rocks, physicomechanical properties, strength, minings of Zakhidnyi Donbas.

Introduction. One of the important factors determining the parameters of mineral development systems, the nature of the various production processes in mining and processing, as well as during mining for various purposes, is the availability of a certain set of data on the physical and mechanical properties of the massif. Knowledge of the rocks properties is necessary not only in the extraction of minerals, but also in the construction of various buildings, the erection of hydraulic structures, tunnels, road construction, etc [1, 2].

In this connection, the study of the physicomechanical properties of rocks, which are an important component in calculating the stability of underground structures, roof supports and guard structures of mine workings, acquires great importance.

Many scientists, both in our country and abroad, paid great attention to the problem of assessing the stability of the rock massif in their works [3 – 5].

The modern state of theoretical developments in rock mechanics makes it possible to qualitatively and, in some cases, quantitatively assess the degree of stability of the massif in the marginal zones. The Ukrainian scientists V. V. Vinogradov, A. S. Kosmodamiansky, S. V. Kuznetsov, A. A. Levshin, N. S. Khapilova and others made a great contribution to the development of this direction.

A. T. Ayruni, A. F. Bulat, V. I. Nikolin, S. I. Skipochka, B. M. Usachenko and others successfully dealt with the development of methods for increasing the stability of the massif in the marginal zones and their effectiveness. research in the direction of choosing the most informative indicators to assess changes in the properties of rocks and the degree of the rock mass stability.

To characterize the stress state of rock massif surrounding production, the following rock parameters are used: specific gravity, density, uniaxial compression strength parallel and perpendicular to the bedding, tensile strength, Young's and shear moduli, Poisson's ratio, as well as rock cutting resistance and abrasiveness of rocks.

The purpose of this work is to summarize the obtained results of experimental studies to determine the physicomechanical properties of Zakhidnyi Donbas rocks to identify regularity of their zonal change.

Methods. In the Institute of Geotechnical Mechanics named by N. Poljakov of National Academy of Sciences of Ukraine, in the department of rock mechanics, work was carried out on the complex definition of the physicomechanical characteristics of the coal formations rocks in the mines of Zakhidnyi Donbas region that are part of Pavlogradvugillia PASC ("named by Geroiv Kosmosu", "Blagodatna", "Pavlogradska", "Ternivska", "Zakhidno-Donbaska", "Samarska", "Dniprovska", "Stepna", "named by Stashkova", "Yuvileina").

Zakhidnyi Donbas covers an area in the form of a 40 – 50 km wide strip and about 300 km long, covering the Petropavlovskyi, Pavlogradskyi, Novomoskovskyi and Tsarichanskyi districts of the Dnipropetrovsk region and the Lozovskyi district of the Kharkiv region. At present, 15 coal layers are being developed in the mines of Zahidnyi Donbas (from top to bottom): C_{11}, C_{10}^t, C_9, C_8^t, C_8^b, C_6^1, C_6, C_6^b, C_5, C_4, C_2^1, C_2, C_1. The layers roof is represented by mudstone (84 %), siltstones (13 %), sandstones (3 %); floor –mudstone (68 %) and siltstone (32 %). The depth of the reservoir development at the field is 100 – 600 m and is different at different mines.

Roof rocks of coal layers are represented by low-strength mudstone and siltstones, with a small strength from one lithological difference to another and rather weak contact between the layers. The direct roof of the C_1 and C_{10}^B layers, whose thickness varies from 0.5 to 2.5 m, is mainly represented by alternating layers of mudstones and siltstones, in some areas it is composed of sandstones. Describing the direct roof of the C_2, C_2^1, C_4^b, C_5 layers, it is necessary to note the presence in it of a large number of thin layers of mudstones and siltstone. The thickness of the layers varies from 0.15 to 0.5 m, but layers with a thickness of 0.15 to 0.25 m prevail. The average value of the direct roof thickness of the C_2, C_4^b and C_5 layers varies from 2 to 2.7 m, for the

C_2^1 formation its value is 1.2 m. The main roof of the indicated layers is composed of large layer mudstones and siltstones.

The direct roof of the C_6, C_6^1 layers is distinguished by a large variability of the lithological composition and structure of the massif. Within the developed areas, the structure varies from thin-layer to layered-block. The main roof of the C_6 and C_6^1 layers is represented by dense layered mudstones and siltstones.

The peculiarity of the direct roof structure of the C_8^b stratum is the presence of weak interlacing mudstones and siltstones with a sometimes lumpy texture. In the main roof of this layer, as a rule, more dense mudstones lie.

The coal layer floor is represented by mudstones and siltstones, which are characterized by the so-called curly texture.

The coal content of Zakhidnyi Donbas is confined to the sediments of the lower and middle carbon. Coal deposits of the region have natural limitations in the south and north: in the south − the Ukrainian crystalline shield, in the north - the Mykhaylovskyi reset. The data of geological exploration and field geophysics indicate that the coal content of the lower and middle Carboniferous spreads to the north-west, north and northeast to a depth of 3000 m.

To determine the indicators of the physicomechanical properties of coal formations rocks, the material selected in the mines of DTEK Pavlogradvugillia PASC was used.

Samples for determining the strength and elastic characteristics of rocks were made by dry cutting on a stone-cutting machine, followed by grinding and fine-tuning of the working surfaces on grinding machines.

Physicomechanical parameters of rocks, such as: density ρ, porosity p, humidity W, dynamic elastic modulus E and Poisson's ratio μ were determined by methods regulated by DSTU BV 2.7-170:2008, DSTU BV.2.7-42-97 and GOST 21153.0-75.

Determination of strength indicators (uniaxial compression strength σ_c) was carried out according to DSTU BV. 2.7-59-97 on the hydraulic test press PSU-10. The uniaxial tension strength (GOST 21153.3-85) was determined by the method of splitting plates perpendicular and parallel to the layering.

The resistance of rocks to cutting (A) was determined by the correlation dependence of the form:

$$A = 1{,}1 \; \sigma_c / 10.$$

The abrasiveness of rocks g was evaluated by the formula:

$$g = 20 \; (\sigma_c / 10)^{1{,}4}.$$

Results and discussion. The complex of physicomechanical parameters of rocks, defined by both mechanical and geophysical methods, is presented as an example for the mine named by Geroiv Kosmosu in the Table 1.

Similar tables are compiled for other mines of Zakhidnyi Donbas ("Blagodatna", "Pavlogradska", "Ternivska", "Zakhidno-Donbaska", "Samarska", "Dniprovska", "Stepna", "named by Stashkova", "Yuvileina").

Table 1 – Physicomechanical characteristics of rocks mine named by Geroiv Kosmosu

Layer	Depth, m	Lithological difference	Density, $\rho \cdot 10^{-3}$, kg/m³	Compression strength σ_c, MPa	Tension strength σ_t, MPa	Elastic modulus E, MPa (parallel/ perpendicular to the layering)	Poisson's ratio μ (parallel/ perpendicular to the layering)	The resistance of rocks to cutting, kH/см	The abrasiveness, mg/km
C_5	540-600	Coal	1.22	44.2	6.1	3400/2100	0.27/0.26	4.9	150
		Sandstone (roof)	2.27	22.4	2.2	9100/8400	0.32/0.29	2.5	60
C_9	390	Coal	1,17 – 1.19	17.5 – 38.6	2.9 – 4.0	2600/2400 – 5300/4600	0.21/0.20 – 0.30/0.24	1.9 – 4.2	45 – 90
		Mudstone (roof)	2.34 – 2.45	13.8 – 18.8	2.2 – 3.1	8800/7900 – 11900/11200	0.30/0.26 – 0.40/0.37	1.5 – 2.1	35 – 45
		Siltstone (roof)	2.46	16.3	3.1	15500/10400	0.41/0.40	1.8	40
		Mudstone	2.26 – 2.33	8.2 – 14.4	2.2 – 3.4	9800/7900 – 7400/3200	0.25/0.24 – 0.22/0.17	1.0 – 1.6	15 – 35
$C_{10}{}^{в}$	370	Coal	1.20 – 1.22	33.7 – 38.6	3.4 – 3.6	3500/1200 – 3800/2100	0.18/0.16 – 0.25/0.33	3.7 – 4.2	105 – 125
		Mudstone (roof)	2.36 – 2.48	14.6 – 24.8	3.1 – 3.6	11200/8800 – 16400/9100	0.32/0.24 – 0.32/0.30	1.6 – 2.7	35 – 70
		Mudstone (floor)	2.46 – 2.51	12.3 – 15.1	1.6 – 2.9	10100/9400 – 17500/14300	0.32/0.31 – 0.36/0.27	1.4 – 1.7	30 – 40
C_{11}	350	Coal	1.18 – 1.26	14.9 – 32.5	2.9 – 4.8	2300/1400 – 4700/3200	0.25/0.19 – 0.30/0.28	1.6 – 3.8	35 – 105
		Mudstone (roof)	2.15 – 2.46	11.5 – 20.3	3.6 – 3.9	6000/5300 – 13000/12900	0.30/0.28 – 0.42/0.41	1.3 – 2.6	25 – 55
		Mudstone (floor)	2.30	10.0	3.5	8900/7300	0.31/0.27	1.3	20
		Siltstone (floor)	2.42	16.6	2.9	15400/13600	0.41/0.38	1.8	40

We have previously obtained a pattern of zonal distribution around the working of increased stresses and fracturing, is as which is analytically expressed as follows:

$$\sigma = \sigma_0 \exp\left(-\left(\alpha r + \frac{t}{\tau}\right)\right)\cos\frac{\pi}{2R_0}r,$$

where σ_0 – the initial stress on the working contour, MPa; r – the distance from the working contour deep massif, m; t – the current time, s; τ – the relaxation time, s; R_0 - radius of working, m; α – attenuation coefficient of a quasi-stationary wave, s^{-1}.

The zonal nature of the changes in the physicomechanical parameters of Zakhidnyi Donbas rocks as a result of the analysis of the experimental data has also been established. The regularity of increasing the strength parameters of rocks in the direction from west to east has been established. The mechanism of increasing the strength parameters of coal and host rocks, in our opinion, is due to the influence, including Coriolis forces, arising from the Earth's daily rotation. Besides, for the most important rocks indicators the limits of change are obtained, namely: the compressive strengths, the resistance of rocks to cutting and their abrasiveness for both the roof and the floor of mine workings (Table 2).

Table 2 – The limits of changes in the strength characteristics of rocks in the layer roof and layer floor of the Zakhidnyi Donbas mines

Type of rock	Sampling point	Compressive strength, MPa	The resistance of rocks to cutting, kH/sm	The abrasiveness, mg/km
Coal		14.3 – 70.7	1.0 – 7.8	35 – 310
Mudstone	roof	7.7 – 43.4	0.9 – 4.7	16 – 156
	floor	10.0 – 31.8	1.1 – 3.5	23 – 110
Siltstone	roof	11.0 – 32.5	1.2 – 3.6	26 – 111
	floor	14.4 – 31.3	1.6 – 3.4	38 – 106
Sandstone	roof	17.7 – 73.7	1.9 – 8.1	48 – 344
	floor	18.5 – 73.5	2.0 – 8.1	52 – 344

Analysis of the results presented in the table shows that for more strong rocks, such as sandstone, changes in the strength characteristics in the roof and floor are insignificant. Whereas for weaker mudstones and siltstones, there is a significant difference in the above strength parameters in the roof and in the floor.

It should be noted that the compressive strength can be determined by geophysical methods: ultrasonic and shock pulse methods [6]. For these methods, the following correlation relations are defined:

– for ultrasound method

$$\sigma_c = aV_1 + b,$$

where V_1 – the velocity of longitudinal ultrasonic waves, m/s; a and b – the coefficients determined experimentally for each type of rock;

– for the shock pulse method

$$\sigma_{c.} = a\tau^{-b},$$

where τ – the duration of the shock pulse, s.

Rock strength also changes with increasing depth. Using the results of our own research, we evaluated the variability of the physicomechanical properties of rocks at the reached depth. The importance of such an assessment is determined by the

ambiguity of opinion on the change in strength and intensity of strength growth with depth and its effect on the stability of rocks. In the general case, the strength of rocks increases with increasing depth of working, since the influence of the softening factor decreases, i.e. the degree of epigenesis. As the depth increases to 400 m, the strength of the rocks grows rapidly, then from a depth of 400 – 600 m, the intensity of the growth of rock strength remains constant, and from a depth of 900 m and more it rises again.

The strength of the roof or floor rocks is defined as the weighted average, including layers of rocks (coal) in the roof – to a height of 1.5*b*, and in the floor – to a depth of 1*b*, where *b* is the width of working, m.

$$\sigma_c^{r.s.} = \frac{\sigma_{c1} m_1 + \sigma_{c2} m_2 + ... + \sigma_{cn} m_n}{m_1 + m_2 + ... + m_n}, \text{ MPa,}$$

where σ_{c1}, σ_{c2}, … σ_{cn} – the strength of the corresponding layer of rock (coal), MPa; m_1, m_2, …m_n – thickness of the corresponding layer of rock (coal), m.

The strength of the rock massif, containing the working, is determined as the arithmetic average of the strength of the roof rocks and floor:

$$\sigma_c^m = \frac{\sigma_c^r + \sigma_c^s}{2}, \text{ MPa.}$$

It has been established that the change in the density of coal in Zakhidnyi Donbas is in the range $(1.08 - 1.31)\cdot10^3$ kg/m^3; mudstones – $(2.13 - 2.51)\cdot10^3$ kg/m^3; siltstone – $(2.11 - 2.56)\cdot10^3$ kg/m^3; sandstones – $(2.08 - 2.62)\cdot10^3$ kg/m^3.

There is a correlation between the density of the rock and its strength for uniaxial compression, expressed by the formula:

$$\rho = 2{,}17 + 0{,}01\sigma_c.$$

Analysis of the data shows that only sandstones at a depth of up to 300 m and siltstone up to 160 m can be classified as stable rocks in the Zakhidnyi Donbas. The unstable rocks become from the following depth: mudstones - 230 m, siltstone - 300 m and sandstones - 450 m. Considering the structural features of the productive stratum, related to the fact that almost 33 % of it is composed of weak clay lithological varieties, the justification of the maximum depth of the stability state of the rocks must be made according to the most common and least then lasting – mudstone.

Conclusions.

1. The zonal nature of the changes in the physicomechanical properties of the rocks of Zakhidnyi Donbas has been revealed.

2. Regularity has been established for increasing the strength parameters of rocks in the direction from west to east, the mechanism of which is explained by the influence, including Coriolis forces, arising from the daily rotation of the Earth.

3. It was found that for more durable rocks, such as sandstone, the change in strength characteristics in the roof and floor is insignificant, whereas for weaker mudstones and siltstones there is a significant difference in the above strength parameters.

4. Generalization of the test results of the Zakhidnyi Donbas rocks showed a large variation in their properties under the conditions of the achieved depth of the reservoir under development, which is due to the variability of the composition, structure, texture of the rocks and the degree of epigenetic transformations.

5. On the basis of the data obtained, the planned rates and methods of preparatory workings are determined, when the workings are carried out using the mine combine method, the cutting tool consumption is planned, the technique and methods of securing the workings are selected.

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Анотація. Метою даної роботи є узагальнення результатів численних експериментальних досліджень фізико-механічних властивостей гірських порід родовищ Західного Донбасу, що виконані як механічними, так і геофізичними методами, для виявлення закономірностей їх зміни. Аналіз отриманих даних дозволив виявити зональний характер зміни параметрів, що досліджувалися. Встановлено закономірність збільшення міцнісних параметрів гірських порід у напрямку із заходу на схід. Механізм збільшення міцнісних параметрів вугілля та вміщуючих порід, на наш погляд, пояснюється впливом, у тому числі, сил Коріоліса, що виникають внаслідок добового обертання Землі. Крім того, визначені межі зміни найбільш важливих показників гірських порід, а саме: меж міцності на стискання, опору порід різанню та їхньої абразивності як для покрівлі, так і для ґрунту гірських виробок. Встановлено, що для більш міцних порід, яким є пісковик, зміни міцнісних характеристик у покрівлі і ґрунті незначні, тоді як для більш слабких аргілітів і алевролітів спостерігається істотне розходження наведених міцнісних параметрів. Узагальнення результатів випробувань порід Західного Донбасу показало велику варіацію їхніх властивостей в умовах досягнутої глибини залягання розроблювальних шарів, що обумовлено мінливістю складу, структури, текстури порід і ступенем епігенетичних перетворень. Встановлено, що зі збільшенням глибини до 400 м міцність порід інтенсивно зростає, потім від глибини 400–600 м інтенсивність зростання міцності порід залишається постійною, а від глибини 900 м і більш знову підвищується.

На підставі отриманих даних визначаються планові темпи і способи проведення підготовчих виробок, при проведенні виробок комбайновим способом планується витрата різального інструменту, обираються способи і методи кріплення виробок. Результати можуть бути використані при підготовці прогнозних паспортів лав і виїмкових штреків, а також при обґрунтуванні технічних умов використання добувних і прохідницьких комплексів.

Ключові слова: гірські породи, фізико-механічні властивості, міцність, шахти Західного Донбасу.

Аннотация. Целью данной работы является обобщение результатов многочисленных экспериментальных исследований физико-механических свойств горных пород месторождений Западного Донбасса, выполненных как механическими, так и геофизическими методами, для выявления закономерности их изменения. Анализ полученных данных позволил выявить зональный характер изменения исследуемых параметров. Установлена закономерность увеличения прочностных параметров горных пород в направлении с запада на восток. Механизм возрастания прочностных параметров угля и вмещающих пород, на наш взгляд, объясняется влиянием, в том числе, сил Кориолиса, возникающих вследствие суточного вращения Земли. Кроме того, определены пределы изменения наиболее важных показателей горных пород, а именно: пределов прочности на сжатие, сопротивления пород резанию и их абразивности как для кровли, так и для почвы горных выработок. Установлено, что для более прочных пород, каким является песчаник, изменения прочностных характеристик в кровле и почве незначительны, тогда как для более слабых аргиллитов и алевролитов наблюдается существенное различие приведенных прочностных параметров. Обобщение результатов испытаний пород Западного Донбасса показало большую вариацию их свойств в условиях достигнутой глубины залегания разрабатываемых пластов, что обусловлено изменчивостью состава, структуры, текстуры пород и степенью эпигенетических преобразований. Установлено, что с ростом глубины до 400 м прочность пород интенсивно растет, затем от глубины 400 – 600 м интенсивность роста прочности пород остается постоянной, а от глубины 900 м и более снова повышается.

На основании полученных данных определяются плановые темпы и способы проведения подготовительных выработок, при проведении выработок комбайновым способом планируется расход режущего инструмента, выбираются способы и методы крепления выработок. Результаты могут быть использованы при подготовке прогнозных паспортов лав и выемочных штреков, а также при обосновании технических условий использования добывающих и проходческих комплексов.

Ключевые слова: горные породы, физико-механические свойства, прочность, шахты Западного Донбасса.