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Investigation of deformation characteristics impact of water-saturated rocks on the ecology of the coal-mining region

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Abstract. The purpose of the research is to evaluate the deformation properties of water-saturated clay shale to determine the displacements of the earth's surface. The analysis of the impact of mining on the environmental situation of town Shakhty in Rostov region was done. It is noted that the closure of coal mines and pumping termination of underground water led to flooding of the developed spaces of mining enterprises. This led to a change in the mechanical characteristics of clay rocks, their softening and compaction under the influence of rock pressure. Taking into account the significant capacity of clay shale in the structure of the rock mass and the technology of mining coal seams, there are currently surface deformations and the formation of cracks in the structures of buildings. According to the results of experimental studies, the deformation characteristics of clay shale under prolonged moistening have been established, affecting the precipitation of the foundations of buildings and, accordingly, lead to the formation of defects in buildings and structures. The obtained characteristics of fragmented clay shale can be used for modeling the stress-strain state of a rock mass and the development of deformations on the earth's surface by the finite element method.

1 Introduction

Development of mineral deposits is characterized by intensive, multi-year technogenic impact on rock massifs [1]. Development of reservoir coal deposits in the Eastern Donbass is accompanied by the destruction of rocks over vast areas and depths of several hundred meters [2]. A significant part of the mining fields was worked out directly under the settlements. The resulting voids were filled with rock debris, causing displacement in the soil massif and on the surface of the earth.

The greatest intensity of mining directly under the towns of Shakhty, Novoshakhtinsk and Gukovo in Rostov region, was observed in the 70s and 80s of the last century [3]. The impact of mining was taken into account in the design and construction of buildings and structures to minimize its impact on buildings. However, surface displacements were predicted taking into account the loosening of rocks and, accordingly, their attenuation with increasing of

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development depth of the mineral.

The diversification of the coal industry in Russia in the 90s of the last century led to the liquidation of all coal mining enterprises on the territory of Shakhty by means of flooding. This led to the aggravation of the already difficult ecological situation in the mining towns [4].

2 Justification of the research relevance

In the last century, more than 20 mines operated on the territory of town Shakhty, which worked out the mine fields of five coal seams. The mineral layers were located in different areas and at different depths [3].

The structure of the rocks massif of the Eastern Donbass is represented by the alternation of water-proof and watered zones. Therefore, destruction of water-proof formations due to displacement of rocks during operation of mines was accompanied by water availability up to 3 m3 of water per 1 ton of mined coal. The closure of mines and, accordingly, the pumping termination of groundwater to the surface led to the flooding of huge volumes of underground space. The destruction of rock massifs to great depths was accompanied by moistening of waterproofs, which are mainly represented by dense, but weak and prone to moisture clay shale.

After the termination of mining operations on the territory of the town, geomechanical processes had to be stabilized. However, the flooding of underground spaces, changes in the physical and mechanical properties of shale and the rock pressure of the overlying rocks over time are accompanied by the destruction of blocks at the contacts, tectonic movements, moistening of new shale surfaces and compaction of the rock mass. The duration of these processes is characterized by the influence of many factors, and, accordingly, by various deformations in the massif and on the earth surface, causing uneven precipitation of the foundation bases [5].

In this case, on the buildings in use and on those under construction, with an unfavorable combination of factors, an additional load arises, which can lead to uneven precipitation and destruction of building structures [6].

Currently, in various parts of the town, cracks are being formed and developed on buildings that have been in operation for decades, despite the fact that such processes were not observed even during intensive mining operations. Rock displacement is the most important factor determining the steady state of both underground and surface objects [7]. In this case, the magnitude of ground surface displacements will depend on the deformation characteristics of the crushed moistened rocks.

Therefore, the study of the deformation of moist clay shale under the action of stresses commensurate with rock pressure will make it possible to simulate the stress-strain state (SSS) of the soil massif, to determine the stress concentration zones in the foundations and structures of buildings. This, in turn, will help determine the risks of defects and develop measures for the preservation of objects.

3 Methods and materials

The most important indicator characterizing the displacement of a rock mass is the modulus of deformation of rocks [8]. Moreover, it is very important to know its change after water saturation. When choosing a test method, it is necessary to take into account the constrained conditions of deformation, that is, the resistance of the lateral rocks. For this, a special research methodology has been developed, which consists in the following.

The basis is the method of testing crushed stone for crushing (GOST 8269.0-97), which consists in testing a sample of crushed rock of a certain fraction in a cylinder with a diameter of 75 mm in a dry or water-saturated state.

For this, the following equipment was used: a hydraulic press with a force of up to 500 kN, a steel cylinder with a removable bottom and a plunger, electronic scales, a drying cabinet, vessels for saturating crushed stone with water.

For testing, crushed stone, clay shale of fraction from 10 to 20 mm was selected, and poured into a cylinder. Since mining enterprises in the town stopped working at the end of the last century, the sampling of shale with a uniaxial compressive strength of 20 MPa, lying in the top of layer l6, was carried out at the Almaznaya mine.

The sequence for determining water absorption was adopted as follows. Three weighed portions of dry shale particles, 0.25 kg each, were alternately poured into the cylinder, and after vibrating for 30 s, the height of the crushed stone layer was determined by the position of the plunger to calculate the volume and bulk weight. Measurements were carried out similarly for wet samples after removing water from the surface of particles.

To determine the deformation properties of shale, three weighed portions of 0.25 ± 0.001 kg were taken from the crushed, dried to constant weight and sifted through a sieve. The samples were poured into a steel cylinder, which was approximately half of its volume. To reduce errors from varying degrees of voidness during filling, the cylinder with rubble was installed on a vibrating platform and vibrated for 30 s with a plunger load. After that, it was installed on the press plates and compressed with a load of 1.0 ± 0.2 kN, the initial position of the edge of the lower press plate was measured with a clock indicator ICH-50 (Figure 1).

The plunger was loaded in stages by measuring the amount of plunger immersion in the cylinder at various load intervals.

The magnitude of the loading steps was calculated based on the maximum rock pressure at the depths of the mining of mine fields, which within the town ranged from 300 to 900 m. In this case, the vertical pressure of the rocks, taking into account loosening, could reach 18 MPa. Thus, for testing, 6 stages of loading were taken, approximately 13 kN each (Figure 2).

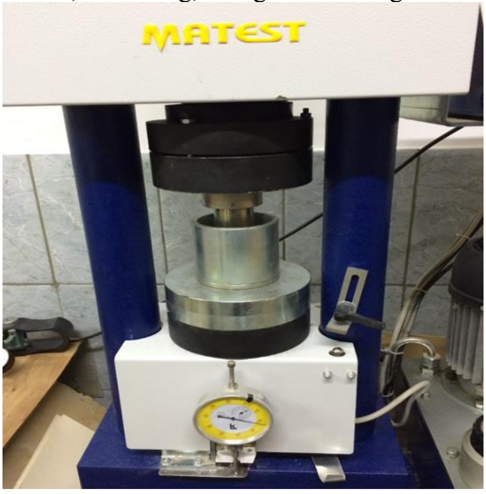

Fig. 1. Testing of crushed clay shale.

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Fig.2. Fixing the loading steps of the samples.

Since moisture reduces the strength of rocks, it is necessary to assess the deformation characteristics of shale after water saturation. For this, crushed stone of clay shale was immersed in water for 2 hours in accordance with GOST 8269.0-97. Then, after removing moisture from the surface of crushed stone with a

cloth, they were placed in a steel cylinder and tested according to the above method.

4 Results discussion

Considering that the flooding of worked-out areas has been going on for more than 20 years, a decision has been made on long-term water saturation of crushed stone. During the research, the shale samples were in the water for 346 days. Water absorption was determined by weighing three shale canopies in a wet state, and then after drying in a cabinet at a temperature of 105°C during the day. As a result of the long-term presence of shale particles in water, water absorption increased to 6.94% (Table 1).

Table 1. The results of determining the water absorption of shale.

Sample characteristics	Weight, kg	Crushed stone layer height, cm	Crushed stone volume, cm^3	Bulk dry weight, kg / m^3	Average bulk dry weight, kg / m^3	Moisture absorption, %
Dry	0.2504	35	154.55	1620.22		
	0.2496	37	163.38	1527.74		
	0.2505	34	150.13	1668.54		
	0.2503	34	150.13	1667.21		
	0.2502	36	158.96	1573.96		
	0.2497	35	154.55	1615.69	1612.23	
Water-saturated (346 days)	0.2742	37	163.38	1678.32		
	0.2750	36	158.96	1729.97		
	0.2882	36	158.96	1813.01		
	0.2768	38	167.79	1649.64		
	0.2804	35	154.55	1814.34		
	0.2711	37	163.38	1659.34	1724.10	6.94

According to the results of the first tests, it was found that the deformations of dry and wetted shale samples during 2 hours are practically the same. This is due to the low porosity of the rock and, accordingly, low water absorption - 1.48% for such a short period of time of water saturation.

When shale particles were removed from the water after 346 days, its stratification was observed, as well as additional random grinding without applying a load. Therefore, when carrying out studies of the deformation properties of water-saturated shale, small particles were removed, instead of them, large ones were selected until the initial weight of a wet sample was obtained. After that, the hangers were poured into the cylinder, vibrated, and stepwise loading was performed.

The results of studies of dry samples of clay shale are shown in Table 2 – 3, Figures 3 – 4. The results of tests of samples with the greatest deviation from the average value of the greatest relative deformation were not taken into account in the calculations.

Table 2. The results of determining the deformation properties of dry shale (sample 1).

Sample condition	Absolute defor-mation, mm	Relative defor-mation	Load, kN	Voltage, kPa	Deformation modulus, MPa	Average modu-lus of defor-mation, MPa
Dry	2.4	0.0686	1.02	231.0	3368.7	
	3.7	0.1057	12.94	2930.5	27721.1	
	5.0	0.1429	16.79	3802.4	26617.0	
	9.4	0.2686	31.88	7219.9	26882.4	
	10.6	0.3029	45.92	10399.5	34337.9	
	11.9	0.3400	54.68	12383.4	36421.7	
	13.6	0.3886	71.94	16292.2	41928.6	75603.2

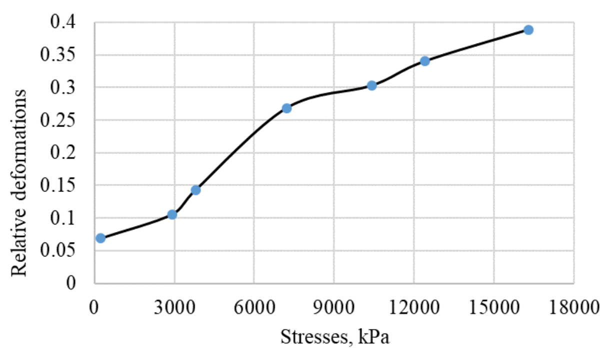

Fig. 3. Graph of the dependence of relative deformations of dry clay shale on stresses (sample 1).

Table 3. The results of determining the deformation properties of dry shale (sample 3).

Sample condition	Absolute defor-mation, mm	Relative defor-mation	Load, kN	Voltage, kPa	Deformation modulus, MPa	Average modulus of defor-mation, MPa
Dry	1.6	0.0432	1.11	251.4	5813.2	
	3.3	0.0892	11.89	2692.7	30191.2	
	3.8	0.1027	16.35	3702.8	36053.4	
	6.5	0.1757	31.13	7050.0	40130.8	
	7.8	0.2108	44.07	9980.5	47343.5	
	10.6	0.2865	52.66	11925.9	41628.1	
	11.9	0.3216	72.12	16333.0	50783.3	63605.7

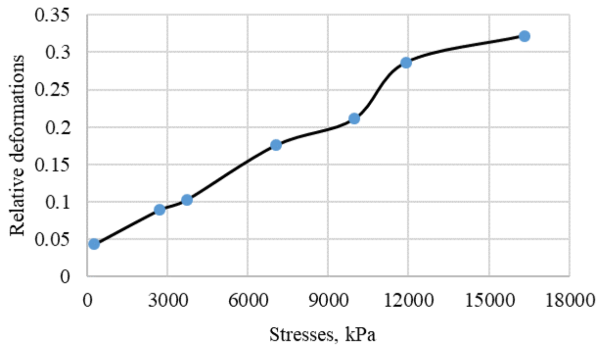

Fig. 4. Graph of the dependence of relative deformations of dry clay shale on stresses (sample 3).

The results of studies of water-saturated samples of clay shale are shown in Table 4 – 5, Figures 5 – 6.

Table 4. Results of determination of water absorption of clay shale (sample 5).

Sample condition	Absolute defor-mation, mm	Relative defor-mation	Load, kN	Volt-age, kPa	Defor-mation modulus, MPa	Aver-age modu-lus of defor-mation, MPa
Clay	1.9	0.0528	1.02	231.0	4376.8	
	5.9	0.1639	10.44	2364.3	14426.5	
	7.8	0.2167	13.91	3150.2	14539.4	
	10.8	0.3000	27.85	6307.2	21023.9	
	13.5	0.3750	36.74	8320.5	22188.0	
	16.6	0.4611	48.22	10920.4	23682.7	
	17.5	0.4861	51.64	11694.9	24058.1	28948.9

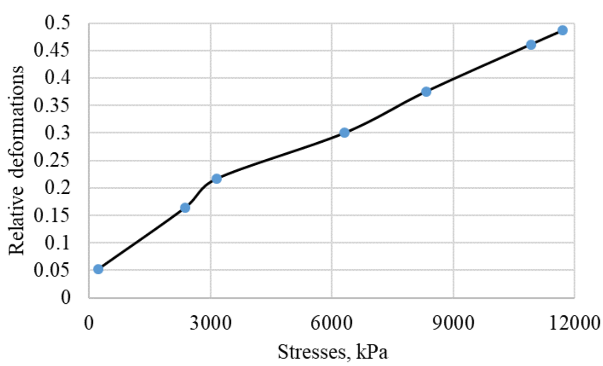

Fig. 5. Graph of the dependence of relative deformations of water-saturated clay shale on stresses (sample 5).

Table 5. Results of determination of water absorption of clay shale (sample 6).

Sample condition	Absolute defor-mation, mm	Relative defor-mation	Load, kN	Voltage, kPa	Deformation modulus, MPa	Average modu-lus of defor-mation, MPa
Clay	2.3	0.0697	0.98	221.9	3184.4	
	4.1	0.1242	9.85	2230.7	17954.6	
	6.4	0.1939	12.58	2849.0	14690.1	
	10.1	0.3061	25.87	5858.8	19142.5	
	12.5	0.3788	31.18	7061.3	18641.9	
	14.2	0.4303	45.92	10399.5	24167.8	
	15.9	0.4818	54.98	12451.3	25842.3	
	16.6	0.5030	58.14	13167.0	26175.3	33381.6

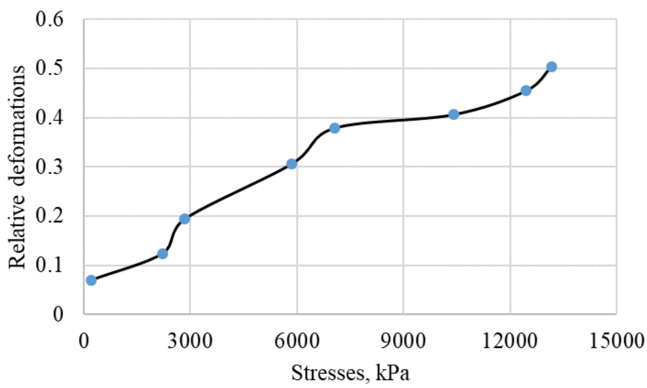

Figure 5. Graph of the dependence of relative deformations of water-saturated clay shale on stresses (sample 6).

The analysis of the obtained results shows that at rock pressure at depths of 500-600 m, which corresponds to the average depth of mining of coal seams in the 70-80s of the last century, the relative deformations of dry samples were 0.36, and water-saturated samples were 0.49, that is, almost 40% more than dry ones.

A significant decrease in the deformation modulus is observed in water-saturated clay shale of 31165 MPa versus 69604 MPa in dry shale, that is, by more than 2 times.

5 Conclusion

Thus, the conducted studies confirm the possibility of significant deformations in flooded ground massifs, which requires a risk assessment of building knowledge on the sites of flooded old mine workings.

Displacements of rocks are determined by many factors; therefore, it is extremely difficult to predict areas with the greatest displacements on the surface of the earth using analytical methods at a large depth of mine workings. In this regard, the results obtained can be used to study the distribution of stresses in the elements of building objects and assess their reliability, by modeling the finite element method (FEM), which is currently used in many software systems.

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