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The Study of Geomechanical Condition of Unstable Rocks in the Vicinity of Mine Working Junctions

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Abstract: The relevance of research of material strain nature based on physical models equivalent to rocks is substantiated. To identify the dependencies and mechanism of unstable rock strain in the vicinity of mine working junctions, an experimental technique has been developed and presented. The method of physical modeling using equivalent materials was applied in the research. Strength characteristics of the rock equivalent material were calculated using the formulas proposed by G.N. Kuznetsov. The equivalent material was prepared based on two components, sand and paraffin. The mix formulation was selected, and ultimate compressive strength of the equivalent material was determined. The experiment was performed for three options of the physical models: an intact rock mass, a rock mass with a single mine working, and a rock mass with mine working junctions. Testing of the models made of the equivalent material was performed through uniaxial vertical loading using a hydraulic press. Based on the model testing findings, the dynamics of fracture propagation and crushing of the enclosing equivalent material in the vicinity of an artificial cavity, simulating a mine working, has been demonstrated. Besides, the graphs of relative strain versus vertical loading for each stage of the stepwise loading of these three model options were produced. The findings of the strain-stress distribution modeling for the equivalent material around the cavities simulating mine working junctions were analyzed. The strain testing findings for the materials simulating rock behavior are expected to be used as the initial data for analysis of physical and numerical simulation, as well as for developing engineering documentation with regard to the selection of parameters for supporting mine working junctions.

Keywords: physical modeling, testing device, rocks, relative strains, vertical load, equivalent material, similarity criterion, model, method of photographic evidence.

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Исследование геомеханического состояния неустойчивых пород в окрестности сопряжений горных выработок

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Аннотация: Обоснована актуальность исследований характера деформирования материала на физических моделях, эквивалентных горным породам. Для выявления зависимостей и закономерностей деформирования неустойчивых горных пород в окрестности сопряжений горных выработок разработана и представлена методика экспериментального исследования. В работе был принят метод физического моделирования на эквивалентных материалах. Рассчитаны прочностные характеристики эквивалентного материала для исследуемых пород по формулам, предложенным Г.Н. Кузнецовым. Эквивалентный материал выбран из двух составляющих – песка и парафина. Подобрана рецептура состава смеси и определены пределы прочности эквивалентного материала при сжатии. Эксперимент проводился для трех вариантов физических моделей: нетронутого массива горных пород, массива с одиночной горной выработкой и массива с сопряжением горных выработок. Испытания моделей из эквивалентного материала проводились путем одноосного вертикального нагружения при помощи гидравлического пресса. По результатам испытания моделей из эквивалентного материала представлена динамика развития трещин и разрушения вмещающего эквивалентного материала в окрестности искусственной полости, имитирующей горную выработку. Также получены графики зависимости относительных деформаций от вертикальной нагрузки для каждого поэтапного нагружения трёх моделей. Проведена оценка результатов физического моделирования параметров НДС эквивалентного материала вокруг полостей, имитирующих сопряжения горных выработок. Полученные результаты деформирования материалов, эквивалентных горным породам, предполагается использовать в качестве исходных данных при тестировании результатов физического и численного моделирования, а также при разработке технической документации в части выбора параметров крепления сопряжений горных выработок.

Ключевые слова: физическое моделирование, стенд, горные породы, относительные деформации, вертикальная нагрузка, эквивалентный материал, критерий подобия, модель, метод фотофиксации.

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Introduction

At present, in coal mines, at working face sweep rate of up to 300 m per month, the pace of construction of development workings and their junctions is a constraining factor. The main factors that negatively affect the rate of mine workings development are downtimes due to rupture of coal pillars, collapse of roof and sides of a working [4, 5, 12, 13]. Within the extraction front of a complex mechanized working face (KMZ), the number of junctions of development workings reaches 40, more than 80% of which are affected by the weight of the roof rocks snubbed by the working face [16].

Mine working junctions are rather complex objects in mines. However, methods for assessing their stability do not always ensure safe operational state of the workings, since many factors are not fully taken into account: the shape and dimensions of the junctions of the workings, the seam structure, the properties of the side rocks, etc. [2, 3, 4, 7].

The main types of downtimes were identified at the junction of the working face and stoping workings, which need installing reinforcement support, strengthening of the enclosing rocks, elimination of domes and inrushes, etc.

In this regard, it is relevant to study the geotechnical state of unstable rocks in the vicinity of the junctions of mine workings to ensure their trouble-free operation.

For this purpose, identifying the dependencies and mechanism of unstable rock strain in the vicinity of mine working junctions should be performed. This will allow, at the stage of development of design documentation, to make decisions that ensure the stability of the host rocks at mine workings junctions, reduce downtimes of working faces and ensure safe working conditions.

The purpose of this study is to develop a methodology for substantiating the parameters of the support of underground mine workings at the junctions in the course of extraction of coal seams with unstable host rocks.

To achieve this goal, at the first stage of the study, the following challenge was met by physical modeling: the stress-strain dependence of rock equivalent material (EM) in the vicinity of cavities imitating mine workings junctions was revealed.

Table 1.

Types and properties of the simulated rocks

Rock type	Ultimate compressive strength $\sigma_н$, MPa	Rock bulk density $\gamma_н$, kg/m^3
Siltstone	40	2500
Coal	8.2	1200

Experimental approach. For the study, a physical modeling method was adopted, which allows to save time and costs necessary to identify the stress-strain dependences of rock equivalent material (EM) in the vicinity of cavities imitating mine workings junctions [6, 7, 8, 11].

Types and properties of simulated rocks, as well as physico-mechanical parameters of the EM, satisfying the similarity criteria [10], are presented in Tables 1, 2.

In accordance with Table 1, strength characteristics of the rock equivalent material for each rock type were calculated using the formulas proposed by G.N. Kuznetsov [10].

Strength characteristics of the rock equivalent materials were calculated using the formula:

$$\sigma_{\text{пч.с}} = (R_{\text{с}})_{\text{м}} = \frac{l}{L} \cdot \frac{\gamma_{\text{м}}}{\gamma_{\text{н}}} (R_{\text{с}})_{\text{н}}, \qquad (1)$$

where $\sigma_{\text{пч.с}} = (R_{\text{с}})_{\text{м}}$ – ultimate compressive strength of the equivalent material;

$(R_{\text{с}})_{\text{н}}$ – ultimate compressive strength of the native rock samples;

$\frac{l}{L}$ – linear scale of the model;

$\gamma_{\text{м}}$ – bulk density of the material;

$\gamma_{\text{н}}$ – bulk density of the rocks.

Bulk density of the model material was calculated by formula:

$$\gamma_{\text{м}} = 0{,}6\gamma_{\text{н}}. \qquad (2)$$

The equivalent material was prepared based on two components, sand and paraffin. For this purpose, quartz sand with grain diameter of 0.30–0.16 mm was used. Technical paraffin STO 00148636-004-2007 was used.

In accordance with the results of the calculation and tests performed on the samples using the BP-29 Azimut hydraulic press, the composition of the mixture was selected and the ultimate compressive strengths of the equivalent material corresponding to coal and siltstone were determined (Table 2).

A special stand for physical modeling was developed (Fig. 1) [9, 14].

Table 2

Physical and mechanical parameters of the EM

Physical and mechanical parameters	**Simulated rock type**	
	Siltstone (roof-bottom)	**Coal (seam)**
EM composition	sand+paraffin (97 : 3)	sand+paraffin+paint (98,52 : 1,48)
EM blending conditions	with heating to 140 °C	
Laboratory ultimate compressive strength of EM, σ_M, MPa	0,24	0,10
EM stress-strain modulus E_{ss}, MPa	25	15

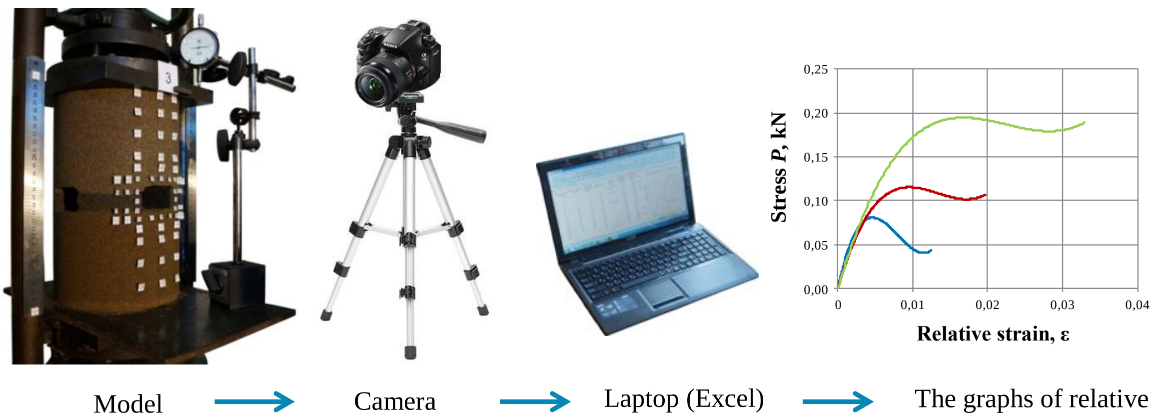

Fig. 1. Stand for physical modeling

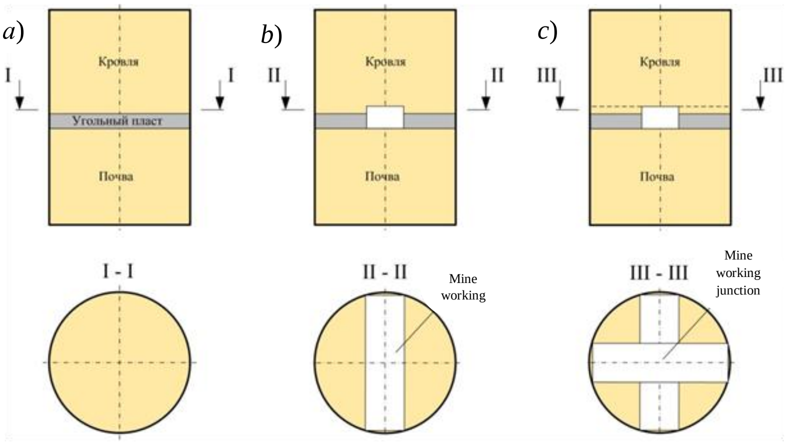

Fig. 2. Schematics of the models for physical modeling:
a – model 1, an intact rock mass; *b* – model 2, a rock mass including a single mine working; *c* – model 3, a rock mass with a mine working junction

The experiment was performed for three options of physical models made of equivalent material (Fig. 2): a) model 1 – an intact rock mass; b) model 2 - a rock mass including a single mine working; c) model 3 - a rock mass with a mine working junction

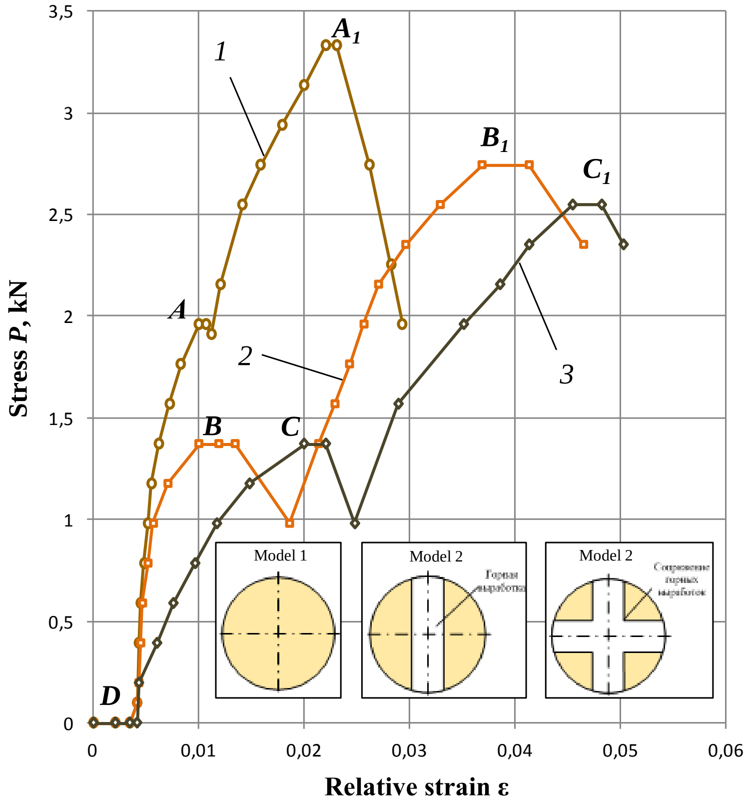

Fig. 3. The graphs of relative strain versus stress for the equivalent material (EM) of the physical models

a) *b*)

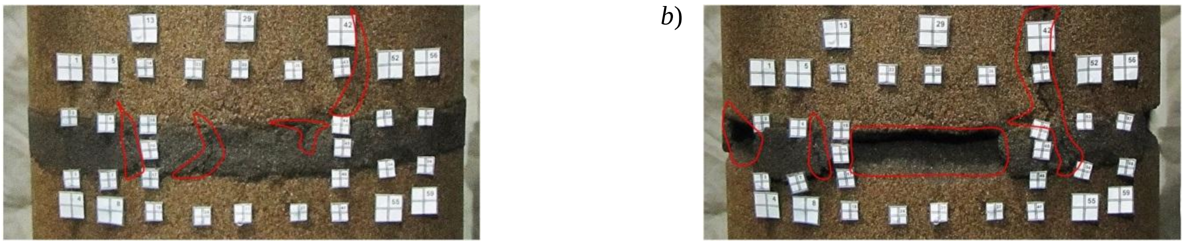

Fig. 4. Seam EM deformation schematic – intact rock mass

a) *b*)

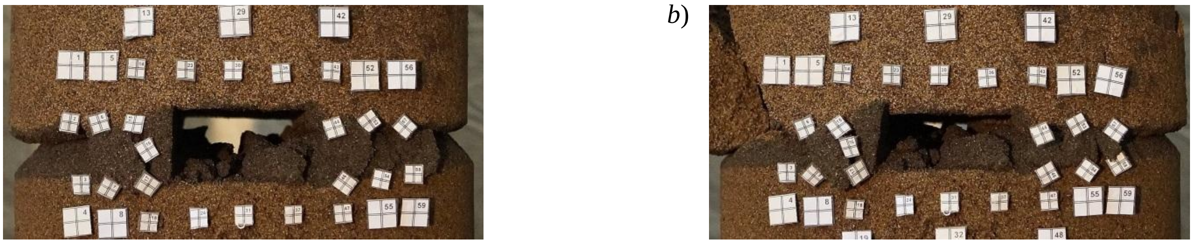

Fig. 5. Seam EM deformation schematic – rock mass including a single mine working

a) *b*)

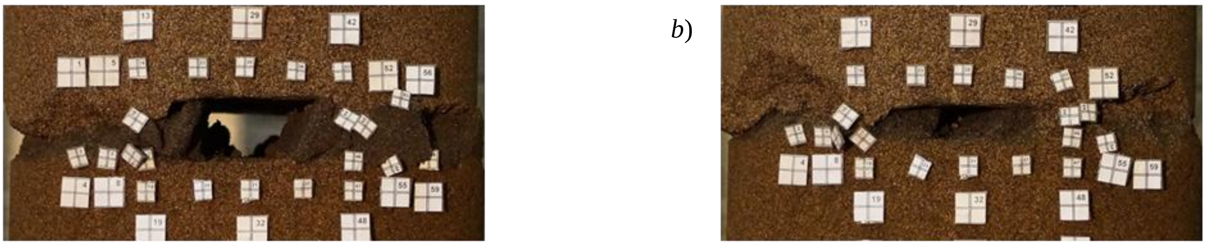

Fig. 6. Seam EM deformation schematic – rock mass with a mine working junction

The study findings. Based on the physical modeling findings, the vertical specific load of three models was determined, as well as the following parameters of the stress-strain behavior of the equivalent material around the cavities simulating mine workings: vertical displacements, relative strains.

Based on the findings of testing models made of the equivalent material and in accordance with the recommendations [15, 18], graphs of the dependence of relative strain on the vertical specific load were built and presented in Fig. 3.

Based on the works [11, 17], the analysis of the research findings was carried out in the following sequence.

During loading of model 1, the EM compression occurs, as can be seen in the graph (OD section), then the EM changes to the elastic state (DA section); when the first fractures appear, the model (rock mass) is compacted; after intensive development of fractures in the formation, it is extruded (Fig. 4a); the load is distributed on the overlying EM layers, elasto-plastic strain begins (section AA_1); after changing the zone (point A1 passed), the EM is ruptured (Fig. 4b); after a fracture appears in the upper layer (in the roof) of the model, stress relaxation occurs.

When loading model 2, weakened by one through cut (a cavity simulating a mine working), intensive propagation of fractures in the seam (section DB) is observed, with extrusion of the EM on the sides of the working (Fig. 5, a); then the EM, similar to siltstone, whose strength is 3–5 times greater than the coal strength, changes to elastic-plastic condition (section BB_1) and, with increasing vertical pressure, reaches the ultimate strength state (point B_1) and finally collapses (Fig. 5, b).

The distribution of strain in the EM, weakened by two cavities imitating junction of mine workings, is shown in graph 3 (Fig. 3). The strain rate of the material equivalent to coal in model 3 is higher compared to models 1 and 2, since the EM (coal seam) was extruded with voids replaced with coal at the intersection (junction) of two cavities; as a result, the upper and lower EM layers (roof-bottom) almost joined (Fig. 6, a, b).

Conclusions.

1) The method of physical modeling allows to save time and costs required to identify the strain mechanism and stress-strain dependences of rocks in the vicinity of mine workings junctions.

2) The strain testing findings for the materials simulating rock behavior are expected to be used as the initial data for analysis of physical and numerical simulation, as well as for developing engineering documentation (specifications) with regard to the selection of parameters for supporting mine working junctions.

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