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Patterns of Roof and Soil Convergence in Development Workings during Coal Seams Mining in Seismically Hazardous Areas of Kuzbass

Aleksey A. Isachenko[1], Mikhail G. Koryaga[2]

[1]JSC UCC Yuzhkuzbassugol (74 Parkhomenko st., Novokuznetsk, 654025, Russian Federation)
[2]Siberian State Industrial University (15 Tsiolkovskogo st., Novokuznetsk, 654025, Russian Federation)

Закономерности конвергенции кровли и почвы подготовительных выработок при отработке угольных пластов в сейсмически опасных районах Кузбасса

А.А. Исаченко[1], М.Г. Коряга[2]

[1]АО «ОУК «Южкузбассуголь» (Россия, 654025, г. Новокузнецк, ул. Пархоменко, 74)
[2]Сибирский государственный индустриальный университет (Россия, 654041, г. Новокузнецк, ул. Циолковского, 15)

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mine, reservoir, seismicity, yielding support, rocks, development workings, production workings, geodynamic phenomena, rock destruction, geology, geotectonics, heaving, seismicity, convergence, deformation of mine workings.

The work studies the patterns of roof and soil convergence in development workings during coal seams mining in seismically hazardous areas of Kuzbass. The formulation of the research problem, adaptation of methods for studying the processes of geomass deformation, analysis of the geodynamic and mining-technical situation and field studies were completed.
Most of the Kuzbass mines work with coal seams at great depths. This is due to the risks of geomechanical, geodynamic and seismic events that have a negative impact on the safety of mining operations. One of the negative phenomena that has a significant impact on the safety of mining operations is the convergence of the roof and soil of preparatory mine workings. When mining formations of coal seams, areas of preparatory mine workings in the immediate vicinity of the goaf and located in zones of bearing pressure from the working faces are especially susceptible to intense deformation of rocks in the vicinity of mine workings.
To study the convergence of the roof and soil convergence in development workings, full-scale measurements of vertical displacements in preparatory workings were carried out with their location in the zone of supporting rock pressure of the excavation site being mined in seismically hazardous areas of Kuzbass.
Factors influencing the types of deformations and destruction of the host rocks and support elements of development workings were established. The dynamics of the energy of recorded seismic events was revealed at different rates of roof and soil convergence the within the excavation area.
Consequences precursors of the rapid soil convergence in preparatory workings and measures to prevent negative phenomena were substantiated.

Ключевые слова:
шахта, пласт, сейсмика, податливая крепь, горные породы, подготовительные выработки, очистные выработки, геодинамические явления, разрушение пород, геология, геотектоника, пучение, сейсмика, конвергенция, деформация горных выработок.

Изучены закономерности конвергенции кровли и почвы подготовительных выработок при отработке угольных пластов в сейсмически опасных районах Кузбасса. Выполнена постановка задачи исследования, адаптация методов изучения процессов деформирования геомассива, анализ геодинамической и горно-технической ситуации и натурные исследования.
Большинство шахт Кузбасса отрабатывают угольные пласты на больших глубинах. Это связано с рисками проявления геомеханических, геодинамических и сейсмических событий, оказывающих негативное влияние на безопасность горных работ. Одним из негативных явлений, оказывающим существенное влияние на безопасность горных работ, является конвергенция кровли и почвы подготовительных горных выработок. При отработке свит угольных пластов интенсивным деформациям пород в окрестности горных выработок особенно подвержены участки подготовительных горных выработок в непосредственной близости от выработанного пространства и расположенные в зонах опорного давления от очистных забоев.
Для изучения конвергенции кровли и почвы подготовительных горных выработок проведены натурные измерения вертикальных смещений в подготовительных выработках с их расположением в зоне опорного горного давления отрабатываемого выемочного участка в сейсмически опасных районах Кузбасса.
Установлены факторы, влияющие на виды деформаций и разрушений вмещающих пород и элементов крепи подготовительных выработок. Выявлена динамика энергии фиксируемых сейсмических событий при разной скорости конвергенции кровли и почвы в пределах выемочного участка.
Обоснованы предвестники последствий скоротечной конвергенции почвы подготовительных выработок и мероприятия по предотвращению негативных явлений.

© **Aleksey A. Isachenko** (Author ID in Scopus: 57921313000) PhD in Engineering, Deputy Chief Engineer for Technology (tel.: +7 (960) 904 96 13, e-mail: metall_kuzbass@mail.ru). The contact person for correspondence.
© **Mikhail G. Koryaga** (Author ID in Scopus: 58650902100) – PhD in Engineering, Associate Professor at the Department of Geotechnology, Institute of Mining and Geosystems (tel.: +7 (904) 378 88 44, e-mail: R7080@yandex.ru).

© **Исаченко Алексей Александрович** – кандидат технических наук, заместитель главного инженера по технологии (тел.: +7 (960) 904 96 13, e-mail: metall_kuzbass@mail.ru). Контактное лицо для переписки.
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Introduction

The object of the study is the regularities of rock deformation in the vicinity of the preparatory workings of the mined out excavation area in the seismically dangerous area of Kuzbass during the mining of coal series

The purpose of the work is to identify the regularities of convergence of the roof and soil of preparatory workings during the mining of coal seams in seismically hazardous areas of Kuzbass.

The following research methods were used in the work: setting the research problem, adaptation of methods for studying the deformation processes of geomassif, analysis of geodynamic and mining-technical situation, field studies.

Underground coal mining is carried out in a wide range of mining and geological conditions [1, 2]. The experience of operation of high-productive underground coal mining enterprises with a load of more than 10 thousand tonnes per day showed the need for scientific support of works with the implementation of a set of measures aimed at improving safety [3–6].

Factors complicating the mining of working areas:

- unstable roof rocks;
- variability of thickness and structure of seams,
- variability of thickness and structure of rocks between seams;
- variability of physical and mechanical properties of coal and rocks;
- high gas content of the coal-rock strata;
- increasing the depth of mining operations.

During mining of coal seam formations, intensive deformations of rocks in the vicinity of mine workings are especially exposed [7–9]:

- areas around preparatory mine workings in the immediate vicinity of the mined-out space;
- areas around the mine workings in the zones of supporting pressure from the mining faces of the working areas.

To study the deformation of the cross-section shape of the preparatory mine workings, field studies of the convergence of the roof and soil rocks of the ventilation drift were carried out in the zone of influence of the support pressure of the stope of the mining site. The studies were carried out at the geodynamic test site of the existing coal mining enterprise in the Yerunakovsky geological and economic region of Kuzbass. The engineering situation during the studied geomassif mining while developing of formation 2 is characterized as traditional for deep mines of Kuzbass [10].

The scheme of slope mine preparation is panel one-way mining. The system of development is performed by longwalls with coal extraction in a long-around longwall mining with top control by cave-in.

Within the excavation pillar 2–7 the longwall face length is 300 m, seam dip angle is 10–12o, seam thickness is 2.16 m, mining depth is 500–600 m, average strength coefficient according to the scale of Prof. Protodyakonov is equal to 1.0 for coal, 4.0 for immediate roof rocks, 4.6 for main roof rocks. The thickness of the immediate roof rocks is 7.55 m. Predicted values of collapse steps of immediate roof rocks are: primary is 40 m, subsequent is10 m; main roof rocks: primary is 55 m, subsequent is 20 m. Lenses of sandstone can be traced within the main roof.

Maintaining the design size of the excavation section is complicated by the presence of a very close formation 1 in the soil of formation 2.

In the proximity areas of formations 2 and 1, the immediate soil of formation 2 is prone to heaving. The thickness of the rock layers between the formations is variable: they are from 2 to 5 m.

Formation 1, lying at a distance of 0.5–13 m below formation 2, has a complex structure and consists of 4–9 coal layers, with a total thickness of 1.25–1.78 m, its average thickness is 1.42 m. The immediate roof and soil of the formation are composed of siltstone, sometimes false roof and soil represented by coal rocks are found.

The geodynamic situation within the studied underground coal mining enterprise is characterized as increased. This is confirmed by the dynamics of seismic activity (Fig. 1) [11, 12].

From the analysis of seismic activity materials in the area of mining operations [12] and geophysical monitoring GITS [13] it follows that the most active zone of convergence "roof – soil" corresponds to the manifestation of rock pressure in front of the lava 2–7 in the ventilation drift 2–7 and conveyor drift 2–6, as well as when the thickness of the rocks between the mined and over-worked coal beds is less than 3 m.

To eliminate the occurrence of roof-soil convergence in drift 2–7, additional measures were developed to strengthen the drift (Fig. 2) with fire support, wooden posts and anchors.

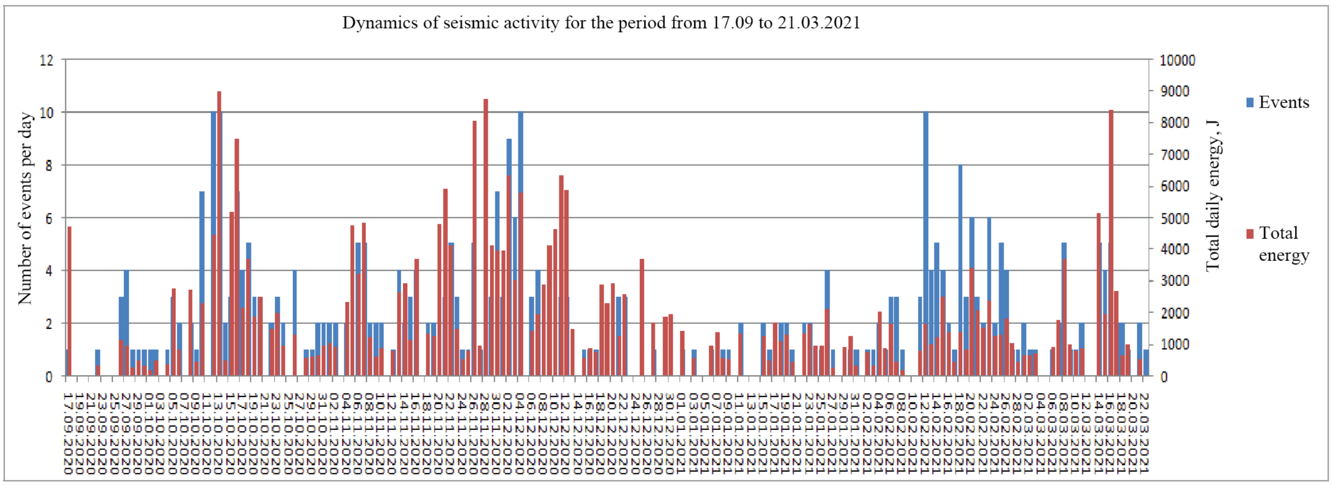

Fig. 1. Dynamics of seismic activity at the mountain branch [11]: the graphs in blue colour correspond to the number of events per day, pcs./day; red colour – total daily energy, J/day

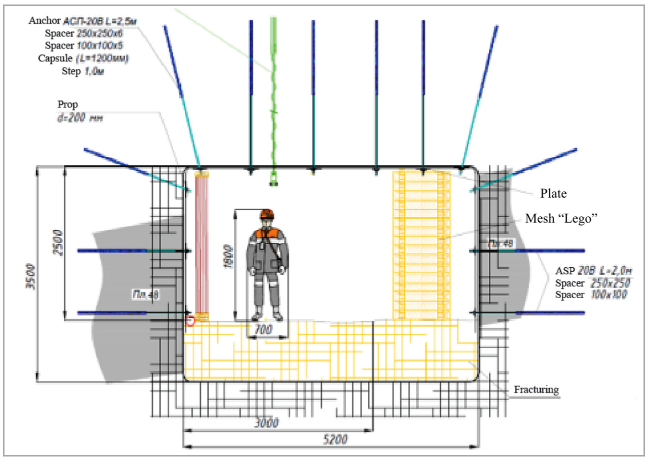

Fig. 2. Scheme of reinforcement of the ventilation drift 2–7 with strengthened wooden support, wooden props and anchors

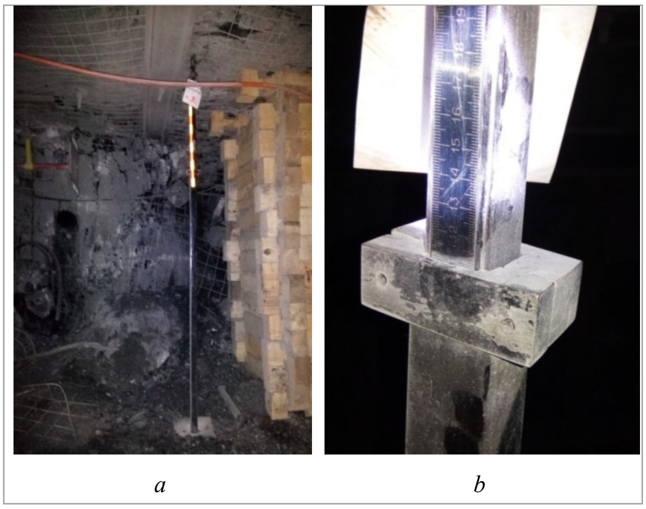

Figure 3. Convergence change device KSH-2 installed in ventilation drift 2–7: *a* – general view of the convergence meter in the mine workings; *b* – measuring scale of the convergometer

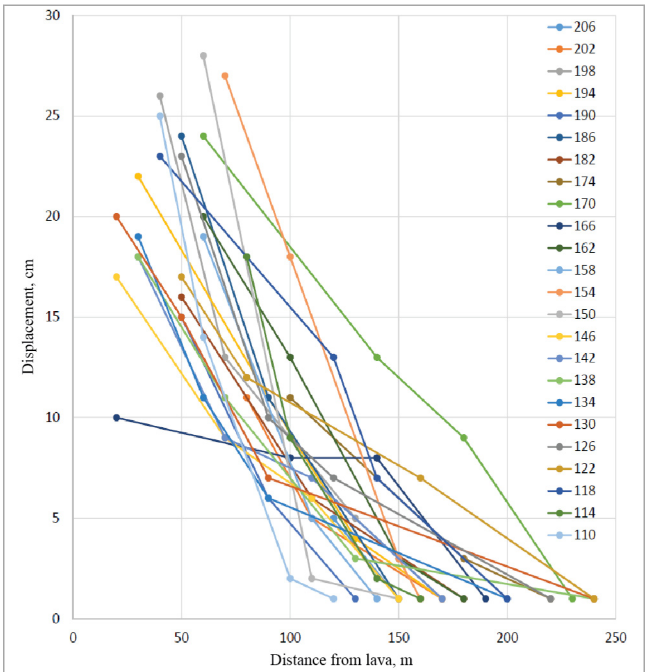

Fig. 4. Top-to-Soil Convergence Trend Plot depending on distance to lava

In order to determine the effectiveness of a set of measures to strengthen the support of ventilation drift 2–7, observation stations in the form of telescopic measuring stands (convergence measuring device KSh-2) were installed to determine the "roof-soil" convergence (Fig. 3). Measurements were taken between September 2020 and March 2021.

The results of observations of the displacement of the measuring stand are shown in the table. Graphs of changes in the roof-soil convergence depending on the distance to the lava are shown in Fig. 4.

According to the graph, as the workings of mining site 2–7 approach the observation station, the convergence of the roof and soil increases in a relationship close to exponential and reaches 280 mm.

Based on the results of statistical processing of the measurements presented in the table and in Fig. 4, an exponential dependence is obtained in the form of:

$$W = ae^{bL}, \tag{1}$$

where W – convergence "roof-soil" of ventilation drift 2–7, m; L – distance from the observation station to the lava, m; a – empirical coefficient, m; b – empirical coefficient, m^{-1}.

According to the data of Fig. 4 and the table in formula (1) after statistical processing is obtained a = –0,035 m; b = –0,021 m^{-1}, i.e. instead of (1) we can write:

$$W = -0{,}035e^{-0{,}021L}. \tag{2}$$

After differentiation by L, the rate of relative convergence "roof - soil" along the length of ventilation drift 2-7 was obtained, i.e.

$$V_k = -0{,}000858e^{-0{,}021L}, \tag{3}$$

where V_k – rate of relative roof-soil convergence along the length of the drift, m/m, at $V_k < 0$ the height of the workings decreases.

The grapht of the rate of the "roof-soil" convergence change is shown in Fig. 5.

In mining practice, the rate of deformation of the excavation contour in time is used to predict the parameters of geomechanical processes in the vicinity of moving mine faces [14]. For the conditions of ventilation drift 2–7 using the given data the velocity graph is plotted in the table as the ratio of the difference of convergence "roof - soil" to the duration of the time interval, i.e.

$$V_{kt} = \frac{W_{L_1} - W_{L_2}}{t_1 - t_2}, \tag{4}$$

where V_{kt} – convergence rate, m/day; W_{L_1} – convergence of roof and soil of ventilation drift 2–7, measured at the observation station at the moment of t_1, located at a distance L_1 from the lava 2–7, m; W_{L_2} – convergence of roof and soil of ventilation drift 2–7, measured at the observation station at the moment of t_1, located at a distance t_2, located at a distance L_2 from the lava 2–7, m.

The increase of convergence rate occurs due to the influence of two factors [15, 16]:

1. The growth of vertical stresses value in the zone of reference rock pressure as the face approaches the observation station (convergometer).
2. Successive decrease in the strength of coal and rocks in the vicinity of the drift during deformation of the rock mass in the mine soil.

Fragment of the table of observations of soil convergence in the ventilation drift

Number of observation station (picket)	Start of measurements: initial count on the stand, date of station installation (number, month, year): distance to the lava, m	Measurement results				Seismicity indicators: magnitude, ML energy E, J
		Counting on the stand, cm; date; distance to the lava, m	Counting on the stand, cm; date; distance to the lava, m	Counting on the stand, cm; date; distance to the lava, m	Maximum convergence rate: V_1, m/m; V_2, m/day	
110	1 10.09.20 120	2 10.09.20 100	14 05.10.20 60	25 11.10.20 40	0.0055 0.0183	2.2 1890
118	1 10.09.20 200	7 25.09.20 140	13 11.10.20 120	23 26.10.20 40	0.0012 0.0067	2.07 3225
122	1 10.09.20 240	7 25.09.20 160	12 11.10.20 80	17 26.10.20 50	0.0017 0.0033	2.07 3225
126	1 05.10.20 220	7 11.10.20 120	10 30.10.20 80	23 16.11.20 50	0.0043 0.0076	2.64 3700

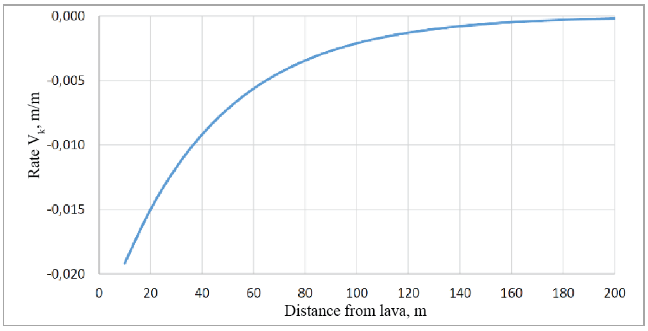

Fig. 5. Graph of convergence rate change "Roof-soil" from the distance to the lava

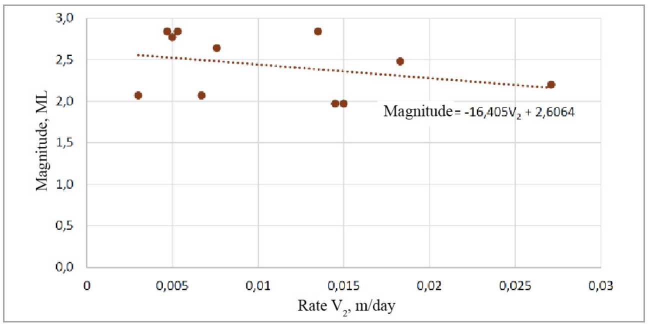

Fig. 6. Graph of dependence of seismic event magnitude on the convergence rate V2 of the roof and soil of ventilation drift 2–7

Fig. 7. Failure types of the elements of props and rocks in ventilation drift 2–7

The energy dynamics of the recorded seismic phenomena under the influence of the convergence rate is shown in Fig. 6, from which it follows that the seismic energy decreases by a factor of 1.2 when the convergence rate increases by a factor of 6.

From the data of Fig. 6 it follows that the decrease in the magnitude of the recorded seismic events is observed with increasing convergence rate of the roof and soil of the drift.

It can be assumed that with the increase of convergence rate the strength of the rocks surrounding the mine workings becomes lower, fracturing enlargers and it is observed the density reduction of the geomassif.

According to [17–21], in this case, stress waves are shielded at the contour of mine workings and at the boundaries of rock fracture zones, seismic waves are refracted and elastic energy is released in denser rock layers.

Based on the results of a visual and instrumental examination of the condition of the reinforced support according to the scheme (see Fig. 2) and side rocks of ventilation drift 2–7 (Fig. 7), a number of changes in the state of workings were revealed:

– as the CMZ approaches the observation station, roof rock fractures are recorded behind the drift support and zones in the form of rock fragments are appeared above the metal lattice;

– increase in the volume of rock heaving by almost 8 times (with the convergence of formations 2 and 1 from 4 to 1 m in the soil of ventilation drift 2–7);

– formation of cracks and rock flaws in the roof.

Deformations in the observed working are represented by:

– destruction of the elements of the pliable support under the influence of oblique or vertical load;

– destruction of the lattice clamp in the sides of the working as a result of block formation during coal sloughing;

– whipping and tearing of the lattice by detached blocks of rock in the drift roof;

– destruction of wooden supports by elements of metal topsides with pushing of wooden supports into soil rocks.

Conclusion

Based on the results of the research it is proposed to take for implementation at mines a set of measures to prevent negative consequences of rapid soil uplift of ventilation drifts:

1. Forecasting of natural-technogenic earthquake precursors by means of organization of continuous automated monitoring of roof and soil convergence in the ventilation drift of the operating mine face.

2. Identification of the limiting rate of convergence at static and dynamic states of the mining system.

3. Withdrawal of people and stopping of mining operations on coal excavation when the limit convergence rate is exceeded.

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