

Problems of mining the prospective coal-bearing areas in Donbas

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Abstract. The prospective coal-bearing areas of Donbas in Ukraine have been identified. Their development will increase the energy security of Ukraine. It has been suggested that the development of these areas will involve mining the coal seams in a weak roof and floor environment, which are characterized by low compressive strength, lower density and a tendency to plastic deformations. The stability has been assessed of the rocks outcrop on the contour of mine roadways for mines operating in these areas. It has been determined that roof rocks in most of these mines belong to a range of groups from very unstable to moderately stable, and the bottom rocks are, in most cases, prone to swelling. This complicates the intensive prospective areas mining with the use of advanced technologies, as well as secondary support for retained goaf-side gateroads with limited yielding property. The mines have been determined, for which this issue is relevant when mining the seams with further increase in the depth. The mechanism of displacement in the secondary supports and has been exemplified and studied using the numerical method. The obtained results allowed us to substantiate the necessity of developing new technical solutions for the protection of gateroads under conditions of prospective Donbas areas.

1 Introduction

At present, coal seams are being mined under complex mining and geological conditions. In most mines, it is conditioned by increasing the depth of mining and weak lateral rocks. There is the largest number of deep mines in Donetsk-Makiivka, Pokrovsk, Lysychansk, Almaz-Marivka and Chystiakove-Snizhne coal fields. The operation of mines in these areas is marked by geomechanical problems associated with the maintenance of operational and safe working conditions due to the deterioration of mining conditions. In particular, there was a critical situation with the maintenance of gateroads under conditions of “Komsomolets Donbasu” mine, O.F. Zasiadko mine, M.M. Bazhanov mine,

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“Shchekhlovska-Hlyboka” mine, M.I. Kalinin mine, Komunarsk mine, L.I. Lutuhin mine, Shakhtoupravlinnia “Pokrovske”, Kapitalna mine, Coal company “Krasnolymska”, etc.

The mine fund of the coal-bearing areas (Donetsk-Makiivka, Central, Amvrosiivka, Chystiakove-Snizhne, Luhansk, Krasnodonsk, Orihivka, Bokove-Khrustalne, Dovzhansk-Rovenky) consists of old and worn-out mines which require reconstruction and rehabilitation. Most of the coal reserves in these areas have been exhausted. In addition, some of these areas have remained partially or completely in the temporarily occupied territory since 2014. Military operations, capture and robbery of the enterprises have led to mine closure, flooding, and loss of reserves. Therefore, in order to ensure Ukraine’s energy security, it is necessary to increase coal extraction in operating mines and develop new prospective areas under complex mining and geological conditions. The urgent task is to identify the main problems of further mining in the Donbas coal-bearing areas.

2 Main part

In terms of density of coal reserves and its quality composition, the prospective areas are as follows: Petrykivka, Novomoskovsk, Lozivske, Pavlohrad-Petropavlivka, Southern Donbas, Pokrovsk, Northern Donbas (Starobilsk area), Lysychansk (Fig. 1). These areas are represented by C_1^3 , C_2^1 , C_2^3 , C_2^5 , C_2^6 , C_2^7 and C_3^2 coal formations, including coal grades from B to K (Fig. 2). In the larger area, there are mostly D and G coal grades with a low metamorphic grade. These formations are characterized by flat coal seams with thickness from 0.6 to 2.5 m (the coal seams with thickness of less than 1.3 m are predominant) [1].

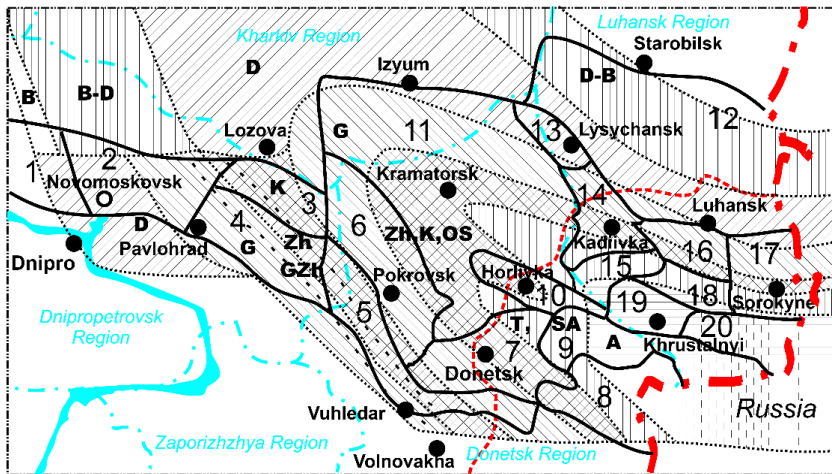


Fig. 1. Map of coal types distribution within the coal-bearing areas of the Donetsk basin in the territory of Ukraine (Symbols: 1-20 – coal-bearing areas of the Donetsk basin in the territory of Ukraine. 1 – Petrykivka, 2 – Novomoskovsk, 3 – Lozivka, 4 – Pavlohrad-Petropavlivka, 5 – Southern Donbas, 6 – Pokrovsk, 7 – Donetsk-Makiivka, 8 – Amvrosiivka, 9 – Chystiakove-Snizhne, 10 – Central, 11 – North-Western outskirts of Donbas, 12 – Northern Donbas, 13 – Lysychansk, 14 – Almaz-Marivka, 15 – Seleznivka, 16 – Luhansk, 17 – Krasnodonsk, 18 – Orihivka, 19 – Bokove-Khrustalne, 20 – Dolzhansk-Rovenky; ———— – the boundaries of coal-bearing areas; - - - - the boundary of the temporarily occupied territory; B...A – coal grades (B – brown coal, D – “high volatile, non-coking coals”, G – “high volatile, weakly cooking coal”, GZh – “gas-bold” (medium coking coal), Zh – “bold” (strongly coking coal), K – “coke” (prime coking coals), OS – “thin-caked” semi-soft coking coals (coking steams coals), T – “thin” (dry steam coals), SA – semi-anthracite, A – anthracite); – the boundaries of the coal types allocation zones).

Rocks containing coal seams of a low metamorphic grade are characterized by low compressive strength [1], a lower density than high grade, high porosity of sandstones, and plastic properties of mudrocks. For example, mudrocks which belong to the D-grade coal area, are characterised by plastic claystones that swell on wetting; G-grade coal areas is characterized by rather plastic claystones [1]. This proves the fact that coal mining in prospective Donbas areas will involve mine workings in the weak lateral rocks, which may be one of the main problems.

Intensification of mining in these areas requires the use of advanced mining techniques and mine layouts, high-performance cutting equipment, etc.

Progressive longwall mining is based on Y-type gateroads layout, which provides coal extraction without protection pillars and stable-holes, by means of effective ventilation schemes of the longwall panels. These mining systems require maintenance of gateroads both in front and behind the longwall face, which presupposes the use of effective support technologies for gateroads, especially in situations of abutment loading. Thus, the gateroads are in a difficult geomechanical state due to complicated mining, geological and technical conditions.

Weak roof and floor environment does not yet indicate an unsatisfactory state of gateroads, since their stability depends not only on the rock strength, but on the depth of mine workings and other factors. The degree of unsatisfactory state can be determined by the criteria of rock resistance, which, as a rule, are used to assess the stability of the roof strata.

To determine the stability of roof rocks in single mine roadways, the criterion $\gamma H_p/R_c$ is used (where γ is the overall density of overburden, MH/m^3 , H_p is the depth of the mine working, m, R_c is the uniaxial compressive strength of the surrounding rocks, MPa) [2]; and H_p/R_c is used for the floor strata. The first criterion determines the stability of roof rocks outcrop, and the second – the propensity of the floor strata to extrusion and the scope of hard secondary supports applications. At values $H_p/R_c \geq 20, 25$ and 15 , it is recommended to take action to mitigate the swelling of floor strata, respectively in retained goaf-side gateroad, which is remained open for reuse [3]. This criterion has been developed in further work [4], where $H_p/R_c = 15$ is a critical value, which determines the possibility of using hard secondary supports.

Depth of mine workings in the prospective Donbas coal-bearing areas vary from 225 to 1090 m, and the compressive strength of rocks – from 5 to 216 MPa. Therefore, the roof rocks in most mines fall into categories from very unstable to medium-stable whereas the floor strata, in most cases, are unstable and prone to extrude under load or to swell. This is confirmed by the research results on the stability of mine roadways in underground coal mines, which are part of “DTEK Pavlohraduhillia” PJSC [5]. According to this, the bottom rock dinting is 77% of all repair work in the gateroads, whereas re-supporting does not exceed 4% in total. At “DTEK Dobropilliavuhillia” LLC [6] the bottom dinting is from 69 to 84% of the length of mine roadways under repair, and at “1/3 Novohrodivka” mine [7] and SE Shakhtoupravlinnia “Pivdenodonbaske No. 1” [8, 9] the proportion of the floor displacement in the roof and floor convergence is 65 – 70%.

While evaluating the possibility of using hard secondary supports under such conditions, it is advisable to use Fig. 2, where the zoning criterion is $H_p/R_c = 15$. When comparing the working conditions with the zones of effective use of hard secondary supports, we can conclude that the greater part of the conditions falls to the zone of ineffective use of these structures. But this question is the most relevant for “Kapitalna” mine, M.S. Surhai mine and those which are part of DTEK Shakhtoupravlinnia “Dobropilske”, DTEK Shakhtoupravlinnia “Bilozerske” and “Lyschanskvuhillia” PJST. In the mines of Lozove and Pavlohrad-Petropavlovsk regions, the possibility of using such structures is particularly relevant at working depths of more than 500 m.

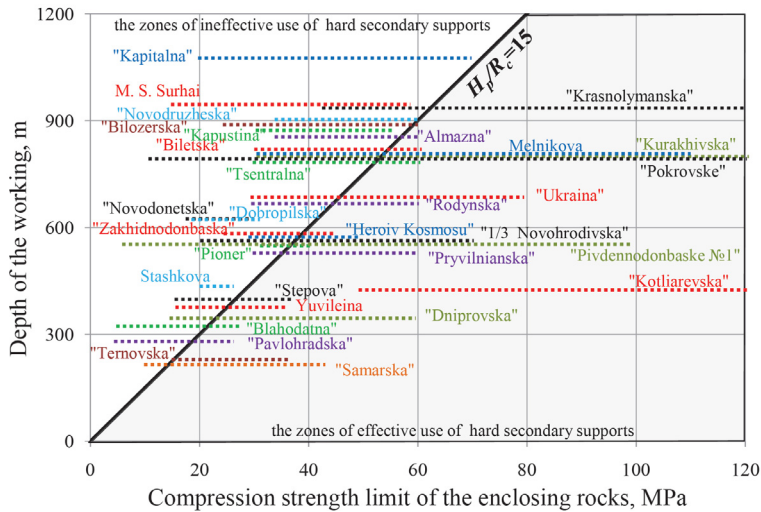


Fig. 2. Schedule on the appropriateness of hard security structures use in conditions of prospective mines in Donbas.

In such conditions, it is rather difficult to maintain retained goaf-side gateroads, since on the one hand there is a coal pillar, and on the other – a goaf (this situation is referred to as single sided abutment loading). Thus, the main task is to create the conditions for providing sufficient resistance when supporting the roof at the gateroad. It is achieved at the expense of secondary supports of limited yielding property, since the harder the secondary support is, the less convergence in the gateroads is [10]. But if the bottom rocks are weak, it is almost impossible, since secondary support works as punch, and the yield limitation is levelled off by their height reduction relative to the bottom surface. This mechanism can be investigated by the results of numerical simulation, which has a number of advantages over other methods, such as universalism, considering a large number of impact factors, low complexity of obtaining results in a relatively short period of time, absence of necessity for materials and special equipment, etc. [11].

Among the numerical methods for the study of geomechanical processes under the conditions of underground mining, the finite elements method (FEM) has become very popular, which contributed to the emergence of software complexes based on this method. These allow solving geomechanical problems with a wide array of parameters very quickly. The following packages are the most popular: ANSYS [12 – 14], Solid Works [14], PLAXIS [11, 15 – 19], FLAC3D [20 – 22] and PHASE-2 [23 – 25]. These software systems give almost identical results [30] but differ in the degree of complexity in constructing the model's geometry and in using different models of material behaviour when setting tasks.

The PLAXIS 2D package is used to simulate the process of compression the rocks that underlie the standing support, since it differs from its analogues by a simple user interface, high accuracy of calculations, and also by taking into account the nonlinearity of the discrete environment, which is the rock solid around the excavation and the standing support.

The study of the deformation mechanism in the rocks underlying the standing support has been carried out under conditions of maintaining the gateroads of the c_{18} seam of Shakhtoupravlinnia "Pivdenodonbaske No. 1" mine. These gateroads are characteristic for the mines of prospective coal-bearing areas and reflect the main features of mining, geological and technical conditions of coal seams with unstable roof and floor strata [9]. In

this seam gateroads are stabilised by pillars, chokes, packfillings and backfill walls. Its development is complicated not only by weak adjacent rocks, but also by the presence of tectonic disturbances and areas with excessive watering.

The problem has been solved in two-dimensional formulation, since the standing support and the solid under it are elongated in the plan and the stresses are distributed coplanar. For this purpose, a geometric model of a unit thickness has been constructed. It consists of rock layers of the immediate and main bottoms above which the standing support is located (Fig. 3).

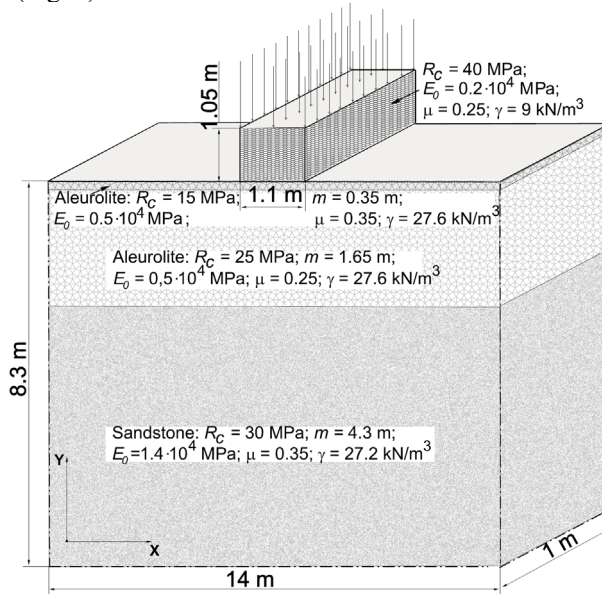


Fig. 3. The geometry of the standing support, located on the solid of bottom rocks (R_c is compressive strength, m is layer thickness, E_0 is modulus of elasticity or general deformation, μ is coefficient of transverse deformation, γ is volume weight).

Considering the boundary conditions, the parameters of the standing support and the problem under study, the following dimensions of the rock massive volume have been taken: height – 8.3 m, width – 14 m.

The standing support width load will be uneven, since the goaf-side loading is 1.5 – 1.6 times more than the road-side loading [12]. This is explained by the fact that as a result of the stress redistribution in the solid around the retained goaf-side gateroad, a destruction zone is formed. It also involves formation of a break line between the main roof rocks and the untouched solid [27]. Behind the longwall face the roof rock strata are based on the standing support. Due to the suitability of the standing support to its possible punching into floor, the surrounding rocks are rotated around the mine working at an angle φ ($\varphi = 3 - 9^\circ$), which leads to the formation of an asymmetric standing support load against the weight of the hanging rocks (Fig. 4). Thus, the maximum displacement of roof rocks above the standing support U_{max} is on the goaf-side.

The peculiarities of the standing support intrusion into the bottom depend on various factors, which include composition and physical and mechanical properties of the adjacent rocks, the seam slope angle, the peculiarities of the gateroad layout, the way of the roof control, the speed of extraction. But it is quite difficult to consider all these factors. Therefore, it is necessary to make certain reservations and use averaged data to assess the impact of the standing support, which is a pressure concentrator, on the floor. We restrict ourselves to the following parameters: the load value, the bottom rock strength, the

hardness of the standing support, its width and height, the thickness and strength of the bottom rock strata.

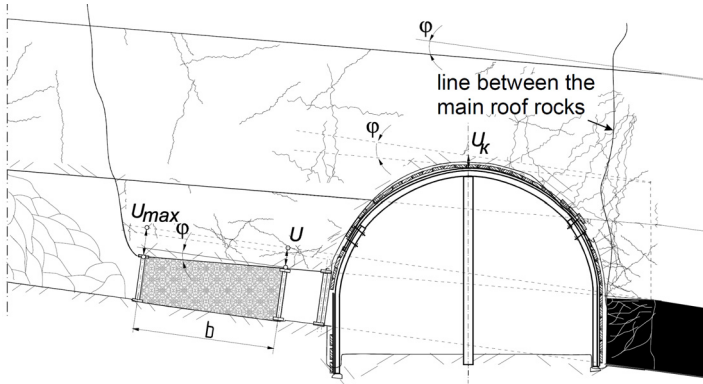


Fig. 4. Scheme of the roof rocks displacement above the standing support.

The main physical and mechanical characteristics of the material specified in PLAXIS 2D are the internal friction angle, the cohesion, specific weight, Young's modulus, Poisson's ratio, and dilatancy angle. As seen, the rock strength is not considered, but this disadvantage can be eliminated by using the formula

$$R = \frac{2C}{\operatorname{tg}\left(45^\circ - \frac{\rho}{2}\right)}, \quad (1)$$

where C is the cohesion, MPa; R is the uniaxial compressive strength, MPa; ρ is the internal friction angle, degrees.

The Mohr-Coulomb elastic-plastic model is used to implement the non-linear relationship between confinement and stress. Since the effect of the standing support on the bottom rocks has been considered, the regime of the given displacements has been adopted. For this purpose, the research results in the main gate 11 of the western longwall development panel of the c_{18} seam at Shakhtoupravlinnia "Pivdenodonbaske No. 1" mine [9] have been taken as input data. It was protected by continuous standing supports of b width equal to 1.1 m. The maximum roof rock displacement above the U_{\max} standing support made up 41% of the extracted seam thickness and equalled 0.43 m. They occurred on the upper platform of the standing support (Fig. 4) on the left side, which is part of the goaf. On the opposite side (right), which is on the boundary line with the gateroad, the displacements have been determined as $U_{\max} - b \operatorname{tg} \phi$ and amounted to 0.31 m.

The implementation of the finite element model (Fig. 5) constructed under conditions of c_{18} seam allows us to obtain the results (Fig. 6), which indicate that under such conditions secondary support with strength greater than the bottom rock starting to punch floor. In general, it negatively affects the displacement of roof rocks and the state of the supported gateroads. With the rock subsidence over the standing support (0.43 m), its flexibility proportion was 79% (0.34 m), and the proportion of its punching into floor strata was 21% (0.09 m). In this case, the ratio of the maximum value of the rock compression (0.21 m) to the value of standing support yield (0.09 m) was 2.3. Thus, the standing support yield is the cause of punching weak bottom rocks into the worked-out area and a slight yield of the structure leads to significant rock displacement into the mine working.

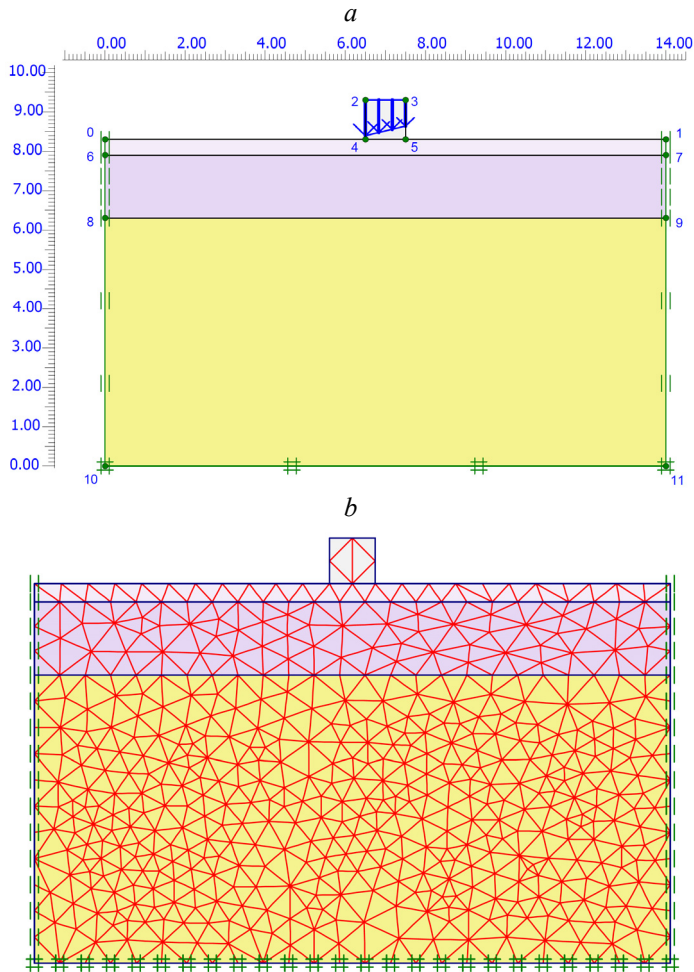


Fig. 5. Geometric model in the data-entry window (a) and finite element grid (b).

In such conditions, the use of hard structures will be complicated. Since the condition for their use is $H_p/R_c \leq 15$ (Fig. 2), it is necessary to ensure strengthening of the bottom rock. Another solution could be to develop new technologies that would consider the mechanism of interaction between the secondary support and the bottom rocks. In our opinion, effective resource-saving secondary support for the conditions of unstable adjacent rocks should be developed. These structures would be constructed of cheap materials. Due to special structural features (change of form, application of reinforcing elements, etc.) they could influence the excavation contour and provide working tension redistribution. An example of such technologies may be stabilisation of retained gateroads by isolated standing support of rectangular or trapezoidal shapes [11, 12, 29], with the compensating bags (packfillings) between them, combined secondary support with hard and flexible elements [30 – 32], etc. In order to substantiate their use in the conditions of prospective mines in Donbas and justify rational parameters of these technologies, further research is required.

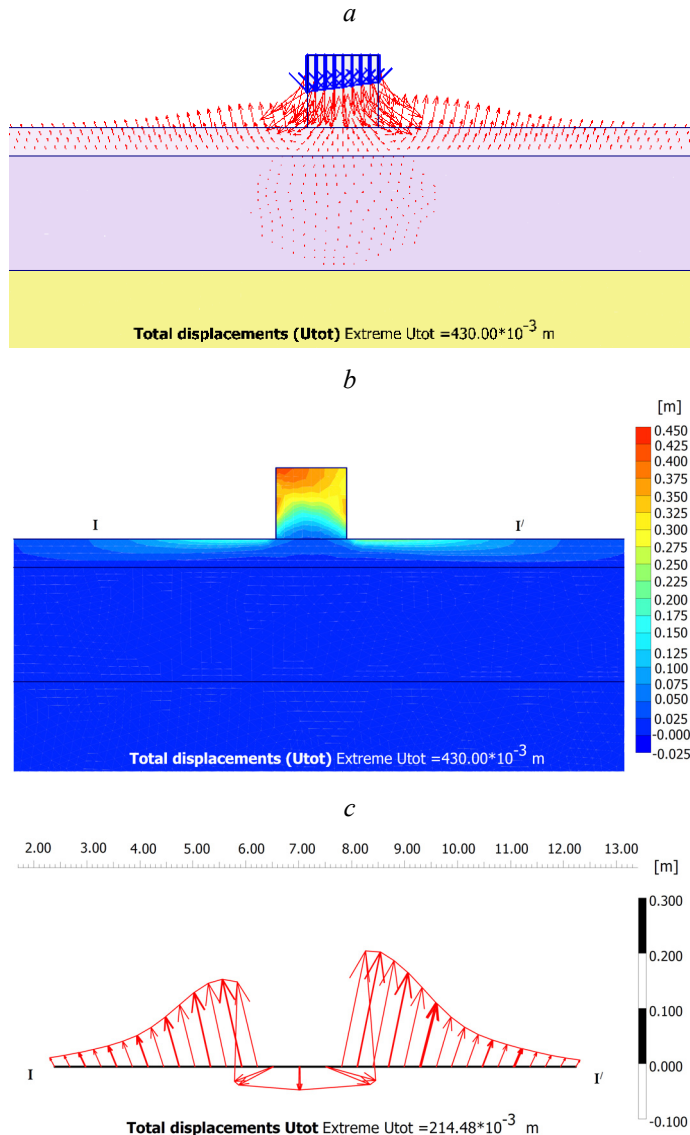


Fig. 6. The results of calculating total displacements in the standing support and the weak bottom rocks according to the findings of numerical simulation (a – displacement vectors distribution, b – displacement isolines distribution, c – displacement vectors directions along the line I-I' on the bottom rock surface).

4 Conclusion

The research findings are as follows:

- to ensure energy security of Ukraine, it is necessary to increase coal production in prospective regions of Donbas: Petrykivka, Novomoskovsk, Lozivske, Pavlohrad-Petropavlivka, Southern Donbas, Pokrovsk, Northern Donbas, Lysychansk;
- the development of coal reserves in these areas will be accompanied by complex of mining and geological conditions and maintenance of mine roadways in unstable adjacent

rocks;

– the main task when supporting retained goaf-side gateroads is to create conditions for ensuring sufficient resistance to rock convergence by secondary support with limited yielding property;

– in weak bottom rocks it will be difficult to use secondary support with limited yielding property, as these structures will be punched into the floor, which will lead to subsidence and extrusion of weak foundation strata. This will negatively affect the condition of the supported gateroad. This requires the application of technical solutions aimed at eliminating the punching of secondary support into the floor;

– to date, numerous attempts to create effective resource-saving secondary supports for retained goaf-side gateroads in the conditions of weak bottom rocks have been unsuccessful. Therefore, the development of new technologies is urgent for the prospective Donbas mines.

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