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GEOMECHANICS OF INTERFERENCE BETWEEN THE OPERATION MODES OF MINE WORKING SUPPORT ELEMENTS AT THEIR LOADING

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Abstract: The problem has been studied of reducing the materials consumption of a combined support in extraction mine workings and increasing their stability in a zone of stope works influence when reused mining of flat-lying coal seams at adjacent mining site. The mechanism has been developed of rock pressure manifestation in the vicinity of mine working and the loading of its support elements on the basis of the following key positions: the formation of zones of unloading and increased rock pressure around the mine working; the formation of areas of weakened and broken rocks, their interaction with support and holistic rock massif; development of stratification along the planes of weakening by thickness of a lithological variety and along the planes of bedding the adjacent lithotypes; partitioning of rock layer into blocks by fractures, by perpendicular planes of weakening and bedding planes, and other factors. The specific tasks have been solved by the finite element method according to the four-parameter spatial optimization scheme of the support interaction with a rock massif. The patterns have been determined of connection between the rational operation modes of mine working support elements and basic geomechanical factors, affecting significantly on the loading of these elements, as well as their interaction with different deformation and force characteristics.

Keywords: *Geomechanics, mine workings, stress-strain state, computer simulation, finite elements, frame support, roof-bolting systems*

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1. MINING AND GEOLOGICAL CONDITIONS FOR MAINTAINING THE EXTRACTION MINE WORKINGS

The studies have been conducted under conditions of sufficiently persistent occurrence of two contiguous coal seams C_8^L and C_8^T with a relatively small thickness fluctuations of a parting (argillite) in the range of 3.6–3.85 m. The compressive resistance of argillite in the sample is σ_{comp} = 9–20 MPa, but enclosed between two coal seams, it is likely to be watered with a decrease in strength by 2–2.5 times. With account of argillite fracturing and its tendency to creeping (Bondarenko, V. at al, 2014, 2018), the value of the calculated compressive resistance decreases by 4–5 times, amounting to R_{comp} = 2.0–5.0 MPa. Such a low strength characteristic, the presence of difficulties and poor contact with coal seams C_8^L and C_8^T make it possible to predict an unstable state of argillite (constituting an immediate and lower part of the seam C_8^L), which will be broken immediately after its outcropping. To this thickness of unstable rocks should be added the thickness of highly fractured coal seam C_8^T (0.66–0.8 m); then, the total height of a possible dome of ultimate rock equilibrium will be 4.3–4.65 m. In terms of the vertical load on the fastening system of prefabricated drift, the weight of the specified rock volume creates a pressure of about 100–110 kPa, which is equivalent to a load of 450–500 kN per 1 long meter of the mine working and corresponds to the boundary of the maximum load-bearing capacity of supports of demountable pliable series with elongated props (TSYS). Thus, even without the consideration of stope works influence, the frame support needs to be strengthened by other fasteners.

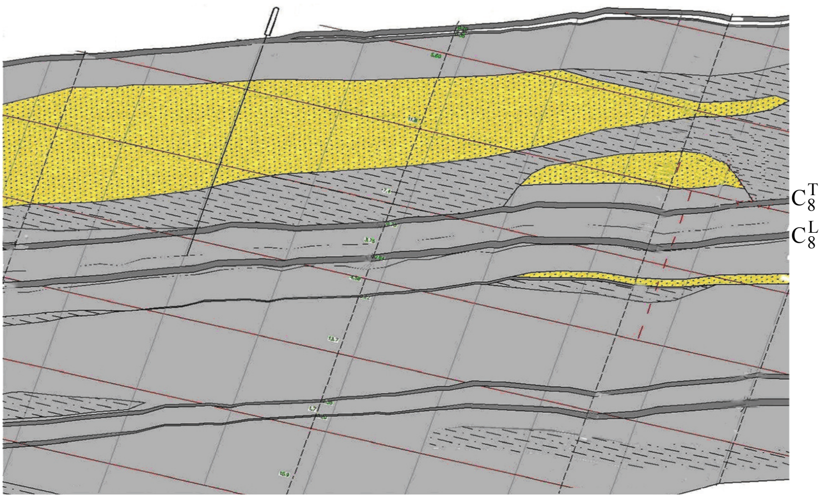

Fig. 1. Fragment of mining and geological section of the area with the most unstable state of the roof rocks in the location of prefabricated drift (scale of 1: 200):
– sandstone; – siltstone; – coal; – argillite

The least stable state of the main roof is in the area of periodic replacement of siltstone with watered sandstone (Fig. 1). Here, above the seam C_8^T, a layer of argillite with average thickness (about 2.5 m) and sandstone (2.5–3.0 m) occur, however at the peripheral area of sandstone it is of lens-shaped form. The adhesion between the layers is low, and the layer of argillite is also watered with two water-bearing lithotypes (from the bottom seam C_8^L, from above – sandstone). Its low strength characteristics with account of factors weakening the rock allow to predict an unstable state with a probable up to 50–60% additional loading from supporting system of the prefabricated drift. The probability of an unstable state of sandstone at the edge of its lens should be added to it, which doubles the possible additional loading of the fastening system with the spread of the dome of ultimate rock equilibrium to 9–10 m. Such loads, obviously, will require the use of the so-called "deep" strengthening of the massif with the application of rope bolts and the creation of a fastening system with high load-bearing capacity. This area of the prefabricated drift, as the most dangerous in terms of intensity of the rock pressure manifestations, has been adopted for modeling by performing a computational experiment based on the finite element method (FEM) with the ANSYS program use.

2. SUBSTANTIATION OF GEOMECHANICAL MODEL FOR EXTRACTION MINE WORKING

In accordance with the substantiated method for performing a computational experiment on research of coal-bearing massif displacement processes in the vicinity of extraction mine workings in the zone of stope works influence (Mamaikin et al. 2018), a geomechanical model has been developed (Fig. 2), which includes all necessary and sufficient positions to reflect the state of the research object:

- coal-bearing massif to the roof height, to the bottom depth and to the width along the strike is of sufficient dimensions to fully reflect the parameters of rock pressure anomalies in the zone of stope works influence;
- zone of uncontrolled collapse from the side of mined-out space with parameters substantiated in the works (Sotskov et al. 2013; Kovalevska et al. 2013; Fomichov et al. 2014);
- zone of hinged-block displacement over the mined-out space with thickness according to the recommendations (Bondarenko et al. 2010; Piwniak et al., 2007); and the peculiarities of blocks interaction according to the research (Fomichov et al. 2018);
- zone of smooth deflection of layers without discontinuity (Sotskov et al., 2014; Bondarenko et al. 2010) and modeling of contact disturbances along the surfaces of formation of adjacent lithological varieties, that were substantiated in the works (Bondarenko et al. 2010);

- location of prefabricated drift in relation to the seam C_8^L, in accordance with the technical documentation of mining the extraction panel;
- an adequate reflection of structural and technological features of the fastening and security systems for prefabricated drift according to methodological development (Inkin 2018; Malashkevych 2018; Sotskov et al., 2015).

The calculation by means of a bilinear function of the stress-strain state (SSS) has been performed in an elastic-plastic formulation with a real diagram "stress-relative deformation" representation of each lithological variety and fastening materials. This allows, with account of the plastic deformation of geomechanical system elements, to avoid significant failures in the calculation technology and to increase the reliability of its performance.

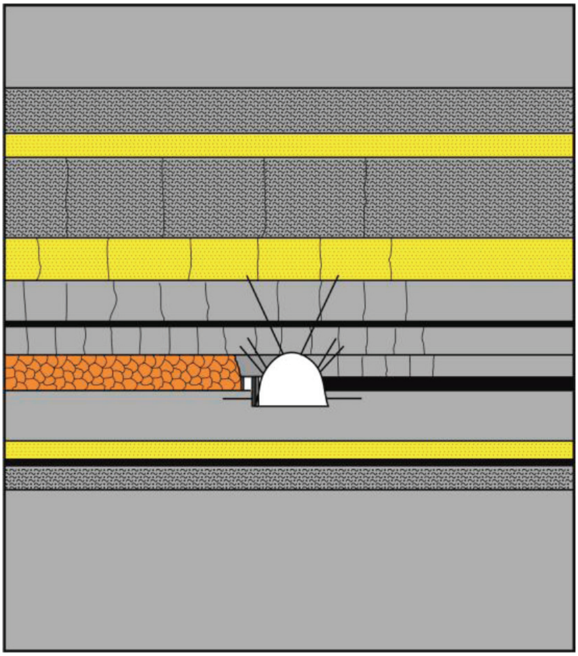

Fig. 2. General geomechanical model for the research into the stability of prefabricated drift

The mechanical characteristics of lithological varieties were taken according to mining and geological prediction of a longitudinal section of prefabricated drift; the lack of deformation characteristics has been replenished according to studies (Fomichov et al. 2014). The accounting of an impact of factors weakening the rock: fracturing, water content, and rheology has been made in accordance with the normative documents and the research results (Usachenko et al. 1990). Mechanical characteristics of fastening materials were introduced into the calculation according to the reference data (Kovalevska et al. 2013).

The recommended fastening and security scheme for the prefabricated drift, shown in Fig. 3, has both common and distinctive features in comparison with the project from a maintenance passport (the so-called "basic scheme"), which is conditioned by the following reasons.

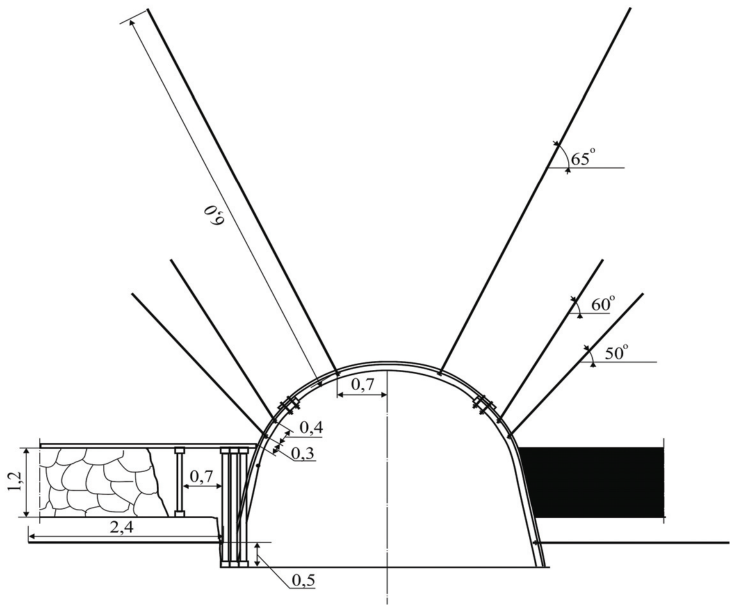

Fig. 3. Recommended scheme of maintaining the prefabricated drift

First, the original basic way of the mine working security has been assessed, providing for setting on the drift berm of only one breaker-prop row made of wooden props with small diameter (10–12 cm); it is approximated to the mine working contour at a distance of 0.7–1.0 m. Any other elements of the security structure (e.g., chocks, cast strips, etc.) are absent. Obviously, the low load-bearing capacity of this security way implies its short-term operation in the hard mode in the adjacent area behind the longwall face with the main task to induce (provoke) the collapse of the immediate roof and the lower layers of the main roof. A preliminary assessment indicates that even a single breaker-prop row is able to resist to the collapsing the roof rocks to the coal seam C_8^L inclusive. Further development of the main roof lowering (as the longwall face recedes) leads to contortion (destruction) of a single breaker-prop row, but already at some distance behind the stope face. At the same time, the thickness of collapsed rocks (including the undermining seam C_8^T) is quite sufficient to create an active bearing to overlying roof layers, that is, a similarity to a rubble band with extensive dimensions is formed, which further resist to the vertical rock pressure.

Secondly, to hold the rocks of the main roof to the height of the hinged-block displacement area in the border zone of the massif from the side of mined-out space, the three rows of side wooden props of the strengthening support have been set. Their limited-yielding mode of operation is intended to break the rock cantilevers in the layers above the seam C_8^T, and, thereby, reduce the concentration of both vertical and lateral rock pressure in the area of mine working location.

These two positions in the scheme of maintaining the prefabricated drift are considered quite reasonable experience when applying in the Western Donbas mines. Therefore, these technical solutions are used in the recommended scheme for fastening and security of the drift. Now let us focus on separate sides of the recommended fastening system in comparison with the basic one:

1. The most dangerous drift area, under study, is characterized by an unstable main roof with a very likely development of stratification and intensive deformation of rocks to a height of up to 12–15 m in the roof. Then, in the case of formation of an extensive arch of limiting state of rocks above the drift, it can be predicted a high vertical and oblique rock pressure, since the width of the arch will definitely extend beyond the limits of the mine working. Therefore, an effort is evident in the basic scheme to maximally strengthen the frame support (along the contour of its arch) with central wooden props of strengthening support (with diameter 20 cm or more) in the amount of 4 pieces per one frame. When qualitative setting of central props of strengthening support, the load-bearing capacity of such a fastening system will be increased (presumably) not less than by 2 times. However, there are some disadvantages due to technological difficulties: high-quality mounting of props, their dismantling after the subsequent bottom ripping, providing the necessary distances and clearances, a reduction of the effective mine working cross-section for air supply and, finally, a high consumption of timber.
2. Despite the significant strengthening of the frame support, there is no certainty that the required drift cross-section is preserved for its reuse without very substantial repair work. The reason for this is the probability of exceeding the total load-bearing capacity of the basic fastening system by the vertical load (with the weight of unstable rocks). An alternative to such a direct resistance to vertical loads is the strengthening of the roof rocks by combined roof-bolting systems. They allow, on the one hand, to "exclude" part of the rock volume from the process of forming a load on the frame supports, and, on the other – to create in the mine working an armored and rock structure with high load-bearing capacity, resisting the remaining value of the rock pressure. In this regard, the recommended combination of resin-grouted roof bolts and rope bolts implies the creation of an armored and rock plate with thickness of up to 6 meters or more. This plate (even in case of roof partitioning into blocks) is able to take up a load, which is many times higher than the total load-bearing capacity of the basic fastening system.

3. The parameters of the combined roof-bolting system location (Fig. 3) are designed to perform a number of tasks:
   - to create a load-bearing thrust system, based on the rock massif beyond the width of the supported mine working and protecting it from excessive rock pressure;
   - for "expanding" the bearings of load-bearing armored and rock structure beyond the mine working width, the certain setting places and angle of gradient are provided for resin-grouted and rope bolts in such a way as to strengthen the rock volumes above the side props of the strengthening support and the breaker-prop row from the side of the working flank of mine working, as well as from the side of nonworking one; then, the wooden props will not be 'overworked' and the most probable collapse of rock cantilevers will occur beyond the border (in vertical direction) of a breaker-prop row, and the bearing pressure will move into the virgin massif, and a relatively monolithic rock beam (plate) will be preserved in the roof of mine working;
   - the rope bolts, connected with the peripheral part of the frame cap boards by means of flexible longitudinal crown runners, dramatically increase a load-bearing capacity of the cap boards and allow them to be stable in the area of the longwall face "window" at mounting/dismounting of the frame props; this makes possible not to use the central props of the strengthening support;
   - the lateral horizontal roof-bolts in the immediate bottom of the seam C_8^L (in depth of bottom ripping of the drift) strengthen the rock volumes of the weak bottom to create a more rigid props for load-bearing plate in the roof; moreover, the lateral roof-bolts in the immediate bottom of the coal seam contribute to the reduction of swelling intensity as a factor of the drift section loss (see Fig. 3). In view of the above considerations, a scheme has been developed for fastening and security of the prefabricated drift, which has become an integral part in the model of general geomechanical system, by which a computational experiment was carried out.

3. CALCULATION RESULTS AND ANALYSIS OF STRESS–STRAIN STATE OF RECOMMENDED FASTENING AND SECURITY SYSTEMS

The parameters of SSS anomalies of the coal-bearing massif in the vicinity of the prefabricated drift (bearing pressure and unloading zones) in qualitative terms are consistent with the known results (Mamaikin et al. 2018), and the peculiarities of the quantitative indicators are most evident in assessing the fastening and security systems of the mine working. Therefore, a detailed SSS analysis has been performed of each main load-bearing element of the recommended scheme of maintaining the mine working, in terms of achieving the fundamental objective, i.e., to ensure the conditions for its reuse. The SSS analysis of the fastening and security systems of mine working has been made through the stress components: vertical σ_y, horizontal σ_x, and the stresses intensity σ.

4. THE DISTRIBUTION OF VERTICAL STRESSES

The curve of vertical stresses distribution σ_y is shown in Fig. 4, during the analysis of which the following conclusions have been obtained. The component σ_y in the frame support reflects the following distribution features, typical for the mining and geological conditions of the Western Donbas. Thus, frame cap board is in the unloaded state with the action of alternating stresses σ_y in the range from 30 MPa of compression to 30 MPa of tension, which is only 11% relative to the value of the estimated yield limit of steel SCP (special concave profile). At the same time, the frame props are under the action of uniform field of compressing stress with a value corresponding to or exceeding the estimated yield limit of steel St. 5. The uniformity of the field σ_y indicates the absence of any significant bending moment in the props, but their limiting state predicts a high probability of plastic bending into the mine working cavity. Therefore, we consider it expedient to connect the frame props with lateral roof-bolts by means of longitudinal pliable binders (Bondarenko et al. 2010).

The rope bolts are characterized by different distribution of σ_y, depending on their place of installation – from the side of massif or from the side of mined-out space. Along the length of rope bolts, set from the side of massif, there is a periodic alternation of areas with high tensile σ_y (about 30–80% of the load-bearing capacity) with areas of the same level of compression. This phenomenon is caused by different-sized deformation of individual rock layers and blocks relative to each other along the length of the rope bolt. This indirectly confirms the significant shifts in the volumes of roof rock, on the one hand, and an active resistance to lateral bearing pressure acting from the massif as a result of stope works, on the other hand. The rope bolt from the side of mined-out space is prone to action (by 90% of its length) of compressive σ_y; this indirectly indicates the effort of the roof-bolt to link the rock layers and blocks into a holistic formation, since there are no sudden drops in σ_y along the length of the roof-bolt. Thus, it is arguable that the rope bolts form in the roof some similarity of a relatively holistic rock plate with considerable thickness (up to 5.0–5.3 m), which is able to withstand the vertical load, exceeding many times the load-bearing capacity of the frame support.

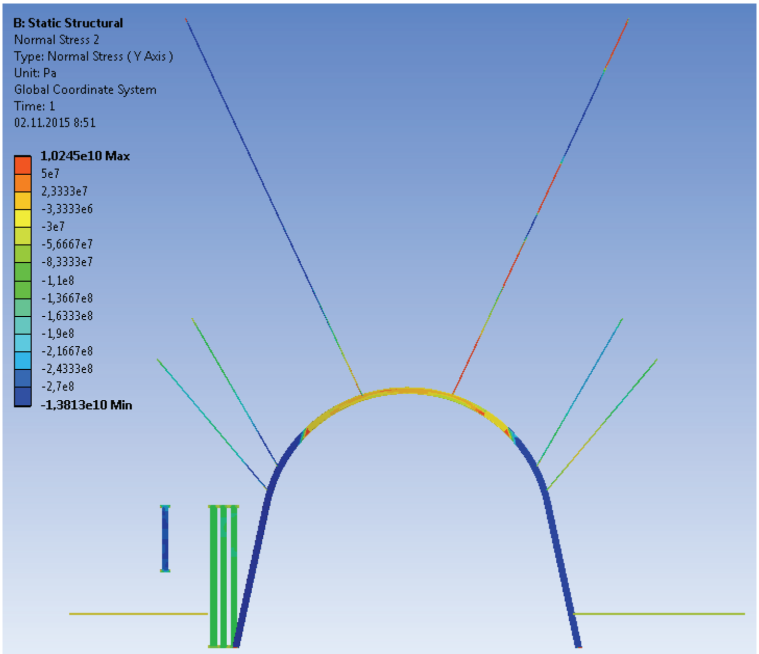

Fig. 4. The curve of vertical stresses σ_y distribution

The work of resin-grouted bolts in the immediate roof of the seam C_8^L should also be assessed as positive. This conclusion arises from the "smooth" nature of compressing σ_y change along the length of the roof-bolts, which indicates the reliable binding of the rock layers and blocks into a sufficiently holistic structure, creating a bearing for armored and rock plate in the main roof.

The lateral roof-bolts, located in depth of bottom ripping of the drift (in the immediate bottom of the seam C_8^L), are very low-loaded with vertical stresses σ_y, since they are horizontally oriented. The assessment of their work efficiency will be given when considering the curve of the horizontal stresses σ_x distribution.

The three rows of side wooden props of the strengthening support are distinguished by a very uniform distribution of the component σ_y, and in quantitative terms, the vertical load, as a rule, exceeds the calculated resistance of pine to compression. But, as a whole, the stable state of the props is predicted due to their "deviation" from excessive rock pressure by way of contortion of wooden substrates (longitudinal girders) and their pressing in the rocks of immediate roof and bottom.

In the single breaker-prop row, the level of σ_y is much higher than the calculated resistance to pine compression, and it is possible to predict with certainty the destruction of the props in the process of development of coal-overlaying formation displacement behind the stope face.

When assessing, in general, the curve of vertical stresses σ_y distribution in elements of the fastening and security systems, it can be concluded that the recommended scheme of maintaining a prefabricated drift is advisable.

5. THE DISTRIBUTION OF HORIZONTAL STRESSES

The curve of horizontal stresses is shown in Fig. 5, from which the obtained results indicate a rather intense manifestation of rock pressure in the vicinity of prefabricated drift after longwall face passing.

The cap board of frame support is exposed to component σ_y with a high gradient of change along the entire length. Thus, the peripheral areas (near the yielding joints of frame) are unloaded: the σ_y of different sign occurs up to 10–15 MPa, with a sufficiently uniform distribution in the cross-section of SCP, which indicates the absence of any substantial bending moment. As approaching the arch keystone, the compressing stresses increase in the range of 50–140 MPa, and in the most central part of the arch with length of 1.2–1.3 m, the compressive σ_y reach 65–85% of the estimated yield limit of steel. At the same time, there is an important feature of σ_x distribution – almost along the entire length of the cap board there are no significant bending moments. This indirectly confirms the expediency of creating additional bearings for the cap board by means of longitudinal pliable binders with the rope bolts.

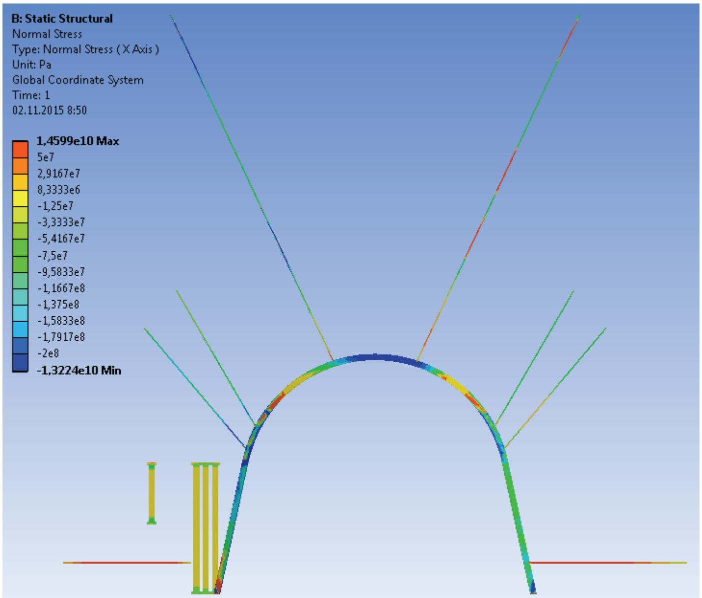

Fig. 5. The curve of horizontal stresses σ_x distribution

In the props of the frame support from the side of massif, the compressive σ_x = 100–130 MPa are also relatively uniformly distributed in the cross-section of the SCP; the special profile bending is observed in the area of the curvilinear part of the prop, where two vertical lateral resin-grouted bolts are placed. The bending is directed towards the mine working cavity and the binding of lower lateral roof-bolts with the frame props contributes effectively to its elimination. This confirms the loading of the roof-bolt with tensile forces σ_x. In props from the side of the mined-out space, a similar pattern of σ_x distribution occurs, but with an increased value in the range of 140–220 MPa. Thus, the expediency of binding the frame props with the lower lateral roof-bolts, set in the immediate bottom of the seam C_8^L is clearly observed.

The rope bolt from the side of massif actively resists horizontal movements of the rock layers and blocks, linking them into a relatively holistic structure. This is evidenced by the periodic change of the sign σ_x along the length of the roof-bolt. The rope bolt from the side of the mined-out space also prevents horizontal movements of the rock layers and blocks relative to each other, but here fluctuations of σ_x occur within the range of compressing stresses.

The resin-grouted roof bolts in the immediate roof are loaded more uniformly along their length, which indicates their moderate resistance to horizontal movements of the massif in this area; besides, their predominantly vertical setting does not allow the horizontal component σ_x to assess the effectiveness of their work to the full extent. This is not true of the lower lateral roof-bolts in the immediate bottom: almost along the entire length, they are subjected to tension and resist actively to the movement of immediate bottom rocks into the cavity of mine working.

The rows of wooden props of the strengthening support and a single breaker-prop row is unloaded from the horizontal stresses (from 8 to 12 MPa of compression), which is conditioned by their free transverse deformation and small transverse dimensions.

In general, the results of the field σ_x analysis do not contradict the previously expressed judgments about the rationality of the work of the fastening and security systems of prefabricated drift.

6. THE STRESSES INTENSITY DISTRIBUTION

In the final part of the analysis, the stresses intensity diagram σ (Fig. 6) is studied as the most informative and generalizing parameter. The revealed features of σ distribution confirm in general the previously stated opinions (at the level of expert assessment) about the intensity of rock pressure manifestations and the expediency of application of combined roof-bolting system consisting of resin-grouted roof-bolts and rope bolts, which strengthen the adjacent massif along the entire contour of the frame support. Results are presented for each element of the recommended scheme of maintaining the prefabricated drift.

In general, the cap board of the frame is in a stable state with a different level of loading along its length. The central area near the arch keystone with the length of 0.8–1.0 m is exposed to σ = 200–240 MPa, which is 74–89% of the estimated yield limit of steel St. 5. On the peripheral areas of the cap board, the stresses intensity is gradually reduced from 120–190 MPa up to 20–80 MPa near the yielding joints. There appears a significant impact (on reduction of σ) of additional bearings in the form of pliable binders, connected to the rope bolts. Nevertheless, despite the shortened cap board, along the most part of its span length, it is loaded by more than 50%. It is also should be taken into account the active resistance of the roof-bolting system to vertical rock pressure. The combination of the mentioned factors indirectly confirms the previously made assumption about the formation in the roof of an extensive arch of ultimate rock equilibrium due to the unstable state of the layers in the main roof. And the high loading of props in the frame support, almost throughout their length, supplements this conclusion. Predominantly, the limiting state of the frame props requires their strengthening in order to avoid plastic bending and deformation into the cavity of mine working. It is therefore advisable, in our opinion, to use the well-known (Bondarenko, Kovalevska et al. 2010) technical solution for joining the side roof-bolts and frame props with pliable binders.

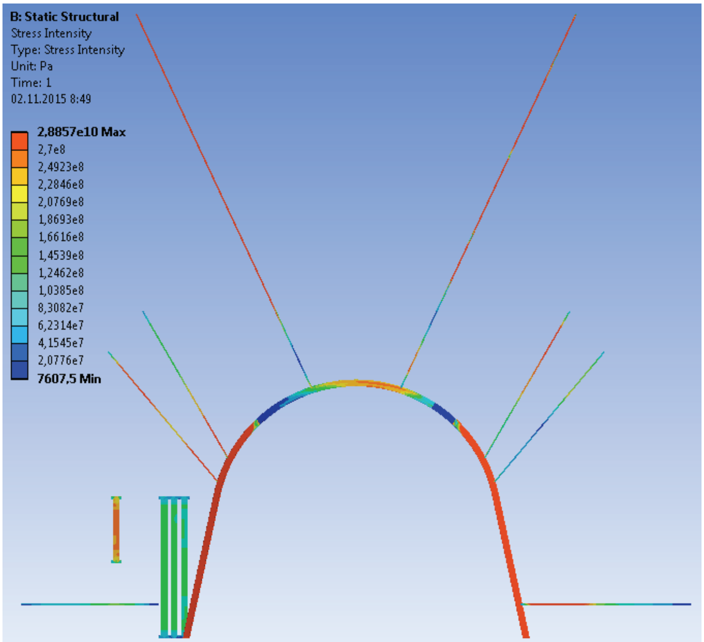

Fig. 6. The curve of the stresses σ_x intensity distribution

An analysis of the stresses intensity distribution in the rope bolts demonstrates their high load, the level of which significantly exceeds the results of computational experiments carried out for other mining and geological conditions (Kovalevska et al. 2013). More specifically, we note that the rope bolts operate at 85–100% of their load-bearing capacity in length, which amounts to 75–80% of the active length of the roof-bolts located in the main roof of the seam C_8^L, consisting of weak fractured argillite and a very fractured coal seam C_8^T. High loading of rope bolts indicates the effectiveness of their work on the formation of the rock plate in the roof and appropriateness of the selected parameters of setting. If to assume that the rope bolts have been able to fasten the mentioned lithotypes of the main roof into a single plate, then, even with account of their partitioning into blocks by fractures, the load-bearing capacity of such a thick armored and rock structure, according to the lowest assessments, is 3–5 times higher than the load-bearing capacity of the frame support. Therefore, the conclusion is evident about the expediency of the rope bolts application in such a specific mining and geological situation of unstable rocks of the main roof.

The immediate roof of the seam $C_8{}^L$ and part of the lower layer of the main roof are strengthened with the resin-grouted roof bolts in sides of mine working. They, as previously mentioned, are designed to create a relatively holistic and stable bearings in the sides of mine working for effective resistance of the rock plate in the roof. The loading of the resin-grouted roof bolts is very high, both from the side of the massif and from the side of mined-out space; that is, they actively resist not only to vertical, but also to oblique rock pressure. The specific quantitative values of this resistance are as follows:

- the upper roof-bolt in the immediate roof from the side of mined-out space is loaded at 80-100% (of the load-bearing capacity) along 40% of its length, adjacent to the mine working; its remaining deepened part resists with efforts 30–75% of the maximum;
- the lower roof-bolt in the immediate roof from the side of mined-out space for 90–95% of its length has a load in the range of 80-100% of the load-bearing capacity;
- from the side of the massif, the upper lateral roof-bolt is similarly loaded at 50% of its length, located in the deepened part of the roof-bolt, and on the rest of the length adjacent to the mine working, the relative resistance is 40–75%;
- the least loaded (up to 70–80% of the load-bearing capacity) is the lower lateral roof-bolt in the immediate roof from the side of the massif.

These data once again place the emphasis on the rational choice of the parameters for setting the lateral resin-grouted roof bolts in the immediate roof of the seam C_8^L.

The need to set the lateral roof-bolts in depth of bottom ripping of the drift (in the immediate bottom of the seam C_8^L) is substantiated by their considerable loading with stresses σ. The level of stresses intensity in the roof-bolt from the side of mined-out space is 30–55% of the load-bearing capacity, which is explained by the relative unloading of border area of the drift berm: it is loaded with only one breaker-prop row and slightly consolidated collapsed rocks. At the same time, the lateral bearing pressure from the side of the massif contributes to the 100% loading of the appropriate roof-bolt at 40–45% of its length, adjacent to the mine working. These results confirm the expediency of the roof-bolt strengthening of the immediate bottom of the drift in depth of its ripping, especially taking into account that the specified roof-bolts actively resist the horizontal displacements of the border rocks of the immediate bottom into the cavity of mine working: this is evidenced by the results of the analysis of the horizontal stresses curve.

Thus, the data of the SSS calculation confirm the effectiveness of the combined roof-bolting system as a whole: the rope bolts (and partly the upper resin-grouted roof bolts) create a rock plate with high load-bearing capacity, and the remaining lateral resin-grouted roof bolts provide reliable bearings for it.

In terms of the reliability of the bearing of the armored and rock plate from the side of mined-out space, its strengthening by three rows of side wooden props of strengthening support, has been assessed. All of them are loaded sufficiently uniformly both in length and in cross-section with a high resistance reaction corresponding to their load-bearing capacity or greater than that.

The protection of wooden side props from destruction is provided by pliable substrates, as well as the phenomenon of pressing the props in the weak rocks of the bottom. The work of all three rows of side wooden props at the level of their load-bearing capacity indicates the effectiveness of such technical solutions to resist the high loads from the side of roof rocks. It can be affirmed that the side wooden props perform their function for induced collapsing the main roof layers and creating a reliable bearing to the armored and rock plate in the roof.

A single breaker-prop row of wooden props is one of the most loaded elements of the scheme of maintaining the prefabricated drift. Here, the level of effective stresses σ greatly exceeds the calculated resistance of pine to compression and quite predictably destroys the props, even with account of their yielding property, pressing in the rocks of immediate roof and bottom. As suggested earlier, the breaker-prop row functions as breaker timbering in a limited area behind the longwall face. Further, as the longwall face recedes, the rocks of uncontrolled collapse zone, consolidating, provide a sufficient bearing to lowering of overlying main roof layers and stabilize the process of coal-overlaying strata displacement.

7. RECOMMENDATIONS ON THE CHOICE OF PARAMETERS FOR FASTENING AND SECURITY SYSTEMS OF THE PREFABRICATED DRIFT

On the basis of the analysis of mining and geological conditions of maintaining the prefabricated drift and the results of a computational experiments on the SSS calculation of the studied geomechanical system, the recommendations have been developed on the choice of parameters for fastening and security systems of the mine working, for the purpose of its reuse. The proposed technical solution is represented in Fig. 3 and is characterized by the following parameters.

The frame support of the TSYS series is set according to the passport for carrying out and maintaining the prefabricated drift.

The rope bolts with a length of 6.0 m are arranged symmetrically (in cross-section) relative to the vertical axis of the mine working making an inclination angle of 65° with respect to the horizontal. In terms of extraction mine working, the rope bolts are set in a checkerboard with a step of $L_{c.a.}$ = 3.2 m, i.e., for every four frames in the middle of interframe gap. For the most dangerous area of the mine working, the step of rope bolts setting is halved ($L_{c.a.}$ = 1.6 m). In the cross-section of the mine working, the distance between the tail joints of the rope bolts is 1.4 m (0.7 m from the vertical axis of the mine working). This scheme of setting will allow the so-called "deep" strengthening of the main roof rocks and form a load-bearing armored and rock plate resting on strengthened (resin-grouted roof bolts) rocks of the immediate roof and bottom, rows of wooden props of strengthening support and a single breaker-prop row from the side of mined-out space.

The cap board connected (along the mine working) with pliable binders (e.g., second hand ropes) will provide a number of technological advantages:

- the cap board strengthening, especially when dismantling the props near the "window" of the longwall face, which increases the safety of work in the junction area;
- there is no need to dismantle/mount the central props of the strengthening support in the subsequent bottom ripping when passing the longwall face;
- the "useful" cross-section of the drift increases and the resistance to the air stream movement reduces, which increases the ventilation efficiency of the extraction area;
- it is easier to provide distances and gaps in the cross-section of the mine working, in accordance with the standards and safety regulations.

The resin-grouted roof bolts of standard length 2.4 m are set in the immediate roof of the seam C_8^L in the middle of the interframe gap. Setting parameters: lower roof-bolts – at a distance of 0.3 m from the edge of the coal seam at an angle of 50° into the roof; the upper roof-bolts – at a distance of 0.4 m from the lower roof-bolts at an angle of 60° into the roof. Such a scheme of the roof-bolts arrangement provides the formation of a holistic rock bearing, transferring the load from armored and rock plate in the main roof onto the three rows of side wooden props of the strengthening support and onto the single breaker-prop row. Increased resistance of bearings limits the lowering of armored and rock plate in the roof and reduces the drift section loss.

In the immediate bottom of the seam C_8^L, the resin-grouted roof bolts of 2.4 m length are set horizontally in the interframe gap in the middle of the bottom of the drift ripping depth. Along the length of the drift the tail joints of the resin-grouted roof bolts and the frame props are connected with pliable binders. This provides:

– the creation of a sufficiently rigid lower part of a bearing for the armored and rock plate due to strengthening of soft rocks in the immediate bottom;
– limitation of the bending of the frame props into the mine working cavity and reducing the swelling intensity, which leads to lower section losses of the drift.

The three rows of side wooden props of the strengthening support are fully loaded and provide the induced collapsing of the rock cantilevers in the main roof beyond the width of the mine working, which reduces the intensity of rock pressure manifestations.

A single breaker-prop row functions as a temporary in the junction area and in a limited area behind the longwall face. Its task is to induce the collapse of the immediate roof and the lower layer of the main roof (to the seam C_8^L) in order to create the bearing from the collapsed rocks sufficient to stabilize the rock pressure behind the stope face at short distance of its passing.

The above recommendations, in our opinion, will ensure the reuse of the prefabricated drift as a boundary adjacent extraction site with the minimum volume of necessary repair work.

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