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INVESTIGATION OF THE ROCK DESTRUCTION INFLUENCE IN THE INCREASED ROCK PRESSURE ZONES ON THE STABILITY OF PREPARATORY MINE WORKINGS

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Abstract: *The issue of determining the size of pillars of various types and purposes is very important, as it is closely related to the issues of completeness of excavation of mineral reserves, as well as ensuring the stability of protected workings.*
The purpose of this work is to study the behavior of the massif in the zones of increased mining pressure, to evaluate its stress-strain state for justification of the optimal parameters of pillars, which is a very urgent scientific task in the conditions of the converged formations of the Western Donbass.
To analyze the stress-strain state of the rock massif area in the area of preparatory excavations, falling into the zones of increased mining pressure, the volumetric problem was solved using the finite element method. The problem was solved using Cosmos Works software. In order to determine the size of the pillar satisfying the requirements of completeness of excavation and safety of preparatory workings, this parameter was varied from 25m to 40m with an interval of 2m.
The work contains the results of monitoring the condition of mine workings as the longwall is approaching up to its stoppage. On the basis of modeling of the stress-strain state of the massif with linkage of the actual state of the drifts according to the monitoring results, the optimum parameters of the pillar are determined, which in the considered conditions are 37 meters.
Keywords: *mine workings, pillar, zone of increased rock pressure, stress-strain state, surveyor's measurement*

1. Introduction

The main production processes at the mine to prepare reserves for excavation and coal mining, its transportation and processing are inextricably linked in a single technological chain. One of the main links in this connection is preparatory workings. The experience of mines shows that unsatisfactory condition of preparatory workings is a problem restraining the development of production. Against the background of constant increase in the depth of development of coal seams and intensity of their mining, the mining pressure and vertical stresses of the massif significantly increase, which leads to a sharp deterioration of the conditions for conducting and maintaining preparatory workings [1]. Numerous existing ways and means of ensuring their stability are insufficient in many cases. The methods of arch support [2, 3], steel and rope anchors [4, 5, 6], frame anchoring [7, 8], torqueting [9, 10] or use of hydraulic systems [11] are considered. The issues of maintaining excavations when they fall into the zone of increased mining pressure from mining works on adjacent seams and the additional influence of dynamic support pressure from the moving longwall face have been little studied.

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2. Research object characteristics

To elaborate this issue, we considered the real situation that has developed during the mining of c_{10} seam reserves of PSD Heroes of Kosmos Mine of PJSC DTEK Pavlohradvuhillya (Ukraine).

The longwall face № 1061-bis is prepared for excavation of coal reserves in the eastern wing of the mine field along the strike. The panel length is 920m, the longwall face length is 250m, the average depth of mining is 410m, the dip angle of the seam is 3º. The coal seam c_{10} of G grade is predominantly of simple structure, the geological thickness averages 1,02 meters. The coal seam is hazardous in terms of gas and dust, it is not prone to spontaneous combustion.

Mining and geological conditions of mining are complicated by the presence of inelastic deformation zones formed by 1061-bis ventilation drift, 1061-bis conveyor drift and conveyor chamber. The rocks of the main and immediate roof are fractured, very unstable and prone to sudden caving. The soil of the coal seam is very unstable argillite, prone to intensive heaving and soaking in water in 2-2,5 hours.

The expected water inflow into the excavation from the coal seam is expected to be up to 1,5 m^3/hour, dripping from the roof of the excavation is possible up to 1.5 m^3/hour. When the rocks are soaked, the soil is prone to intensive heaving with loss of bearing capacity.

During mining of the coal seam c_{10} of PSD Heroes of Kosmos Mine, a problematic situation arose in connection with the protection of 1061-bis conveyor and 1061-bis ventilation drifts ahead of the moving 1061-bis longwall face (Figure 1). These preparatory workings were passed after the longwall face № 1061 was mined. The panel length of longwall № 1061 was 790m, the longwall face length was 175m.

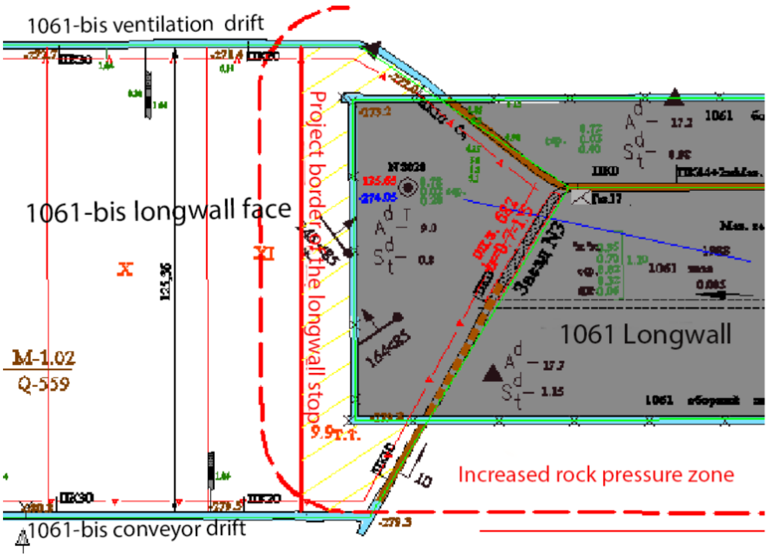

Fig. 1. Excavation from the plan of mine workings on the seam c_{10}

The pillar at the time of longwall 1061-bis longwall stoping was 25 m long. At the time of stopping the face, the preparatory workings were deformed (mostly on the face side) and lost about 60% of their cross-section. Taking into account the actual unsatisfactory condition of the workings, the purpose of this work is to determine the optimal size of the protective pillar, taking into account the maximum possible recovery of coal reserves with minimum deformations of the 1061-bis ventilation and 1061-bis conveyor drifts.

When solving the problem of determining the optimal size of the pillar during mining of the 1061-bis longwall face, the finite element-based computer mathematical modeling method was used. The results of modeling were analyzed together with the data of experimental observations of rock pressure manifestation in the preparatory workings of this longwall face.

The research results can be used in planning mining works with similar mining and geological situation within this seam.

3. Materials and methods

3.1. Analytical research of rational parameters of the pillar during mining of 1061 longwall

The analysis of the normative base [12, 13, 14] and literature sources allowed us to establish that the load on the pillar, other things being equal, depends on the shape and area of mining, the mining system and its elements, the method of rock pressure control [15, 16]. The evolution of the abutment stress, the stress under the mining coal seam and the relief angle were studied [17]. A number of authors study the deformations of the rock mass above the mine by measuring the lowering of the earth's surface [18, 19]. The obtained regularities are used to predict deformations of protected objects on the ground surface and in the subsurface [20]. Thus, the load on the pillar depends on a number of factors, without taking into account which the correct determination of this value is impossible.

The first step in determining the size of the pillar is to study the manifestation of increased rock pressure (IRP) in these conditions, as the main factor determining the load on the pillar part of the massif. Determination of geometrical parameters of the IRP zone from the influence of the 1061st longwall face cleaning works was performed in accordance with the normative document [14]. The boundaries of the IRP zones built on the sections are plotted on the mining works development plan in red color (Figure 1).

When the longwall face approached the zone of increased mining pressure, in order to increase the completeness of excavation of reserves, a decision was made to continue coal mining. At the transition to the zone of high-pressure mining, the rate of advance decreased, which led to the longwall face stoppage due to rock destruction and rock destruction in the sections PK10-PK20 along 1061-bis side drift and in the area of PK10 along 1061-bis conveyor drift.

In this regard, it became an urgent task for this enterprise to optimize and scientifically justify the size of the pillar for the maximum possible full excavation of coal reserves and at the same time to ensure the safety of workings.

3.2. Modeling of the stress-strain state of the massif in the area of the longwall № 1061

One of the methods of research of complex-structured objects in geomechanics is graphical and mathematical modeling of the processes of redistribution of the rock stress-strain state due to anthropogenic influence. The simulated model reproduces in three-dimensional image the process of deformation of the rock massif as artificial cavities are created in it. The most convenient method for studying the manifestations of rock pressure is the modeling method [21, 22]. One of the advantages of the modeling method is the possibility of determining the indicators reflecting the stress-strain state of the massif in the areas of interest, which are practically impossible to carry out in full-scale conditions due to the inaccessibility of the massif areas.

The purpose of the calculations is to evaluate the influence of the 1061-bis longwall face, as well as the zone of previously destroyed rocks from the 1061-bis longwall face on the condition of the 1061-bis ventilation and 1061-bis conveyor drifts, since these preparatory workings serve for ventilation, delivery of materials to the longwall face and transportation of mined coal.

To analyze the stress-strain state of the rock mass in the vicinity of the preparatory workings of the 1061-bis longwall face, a volumetric problem was modeled using the finite element method. The three-dimensional model of the problem to be solved is presented in Figure 2.

The zones of fractured and compacted rocks were modeled by specifying conditional characteristics: Young's modulus *Ep*, Poisson's coefficient *νp*, compressive strength σ_{comp}, which differ significantly from the characteristics of the undisturbed rock mass.

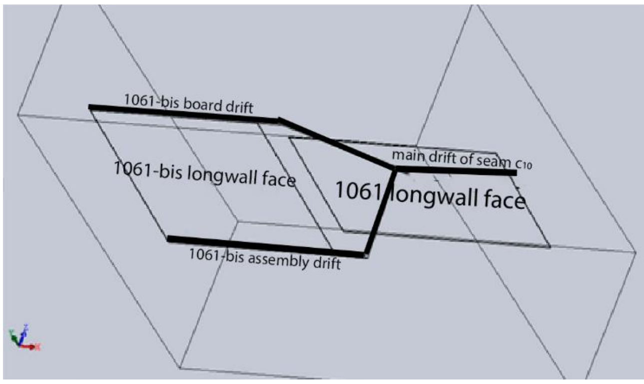

Fig. 2. Three-dimensional model of 1061-bis longwall face

The task was solved using the Cosmos Works software product. The loads to be applied to the constructed three-dimensional model were determined.

The lateral spreading coefficient is determined from the expression:

$$\lambda = \frac{\mu}{1-\mu}$$

In this expression μ is the Poisson's coefficient, which for elastic rocks, not prone to creep, in an intact rock mass can have values ranging from 0,25 to 0,43. For the conditions under consideration, we take it to be 0,3. Hence λ =0,43.

The specific weight (γ) of the rock column for these conditions is equal to 22 kN/m^3.

Let's determine the vertical stress on the whole part of the formation without taking into account the influence of cleaning works:

$$\sigma_y^0 = -\gamma H = 22 \cdot 410 = 9{,}0\mathrm{M}Pa$$

The lateral load on the modeled section of the massif is assumed:

$$\sigma_x^0 = \sigma_z^0 = -\lambda\gamma H = 0{,}43 \cdot 22 \cdot 410 = 3{,}87\mathrm{M}P\mathrm{a}$$

The modulus of elasticity for these conditions is 30 000 MPa.

This model was given a grid parameter of 20 m, and excavations – 1m, which allowed to set the load on all necessary sections quite accurately (Figure 3).

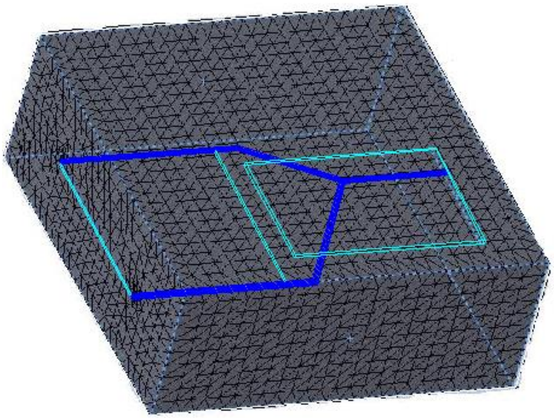

Fig. 3. Three-dimensional model of 1061-bis longwall face using the finite element method

In order to determine the size of the safety pillar that would simultaneously satisfy the requirements of completeness of excavation and safety of preparatory workings, the three-dimensional model for visual assessment of maximum stress distributions was mapped in the 1061-bis plane of the face (Figure 4). After that, the size of the safety pillar was gradually increased by the approximation method. This parameter was varied from 25m to 40m with an interval of 2m. The analysis of the simulation results revealed that the minimum stress on the mine walls to maintain their safety in these areas corresponds to 37 meters. The distribution of normal vertical stresses σu for the case of optimal, in our opinion, target size (37 m) and the actual target at face stoping (25 m) are shown in Figs. 4 and 5, respectively.

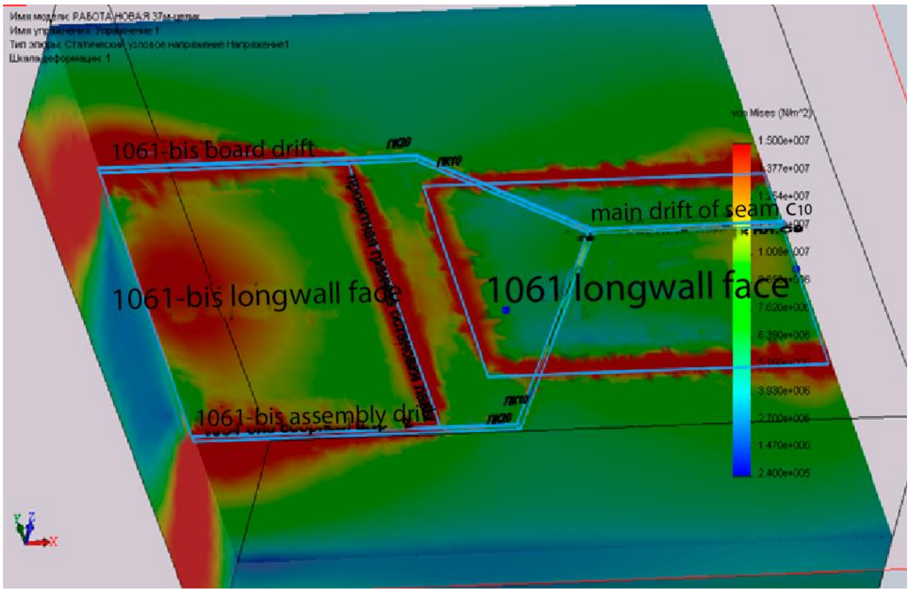

Fig. 4. Tensions in the rock massif at the target size of 37 meters

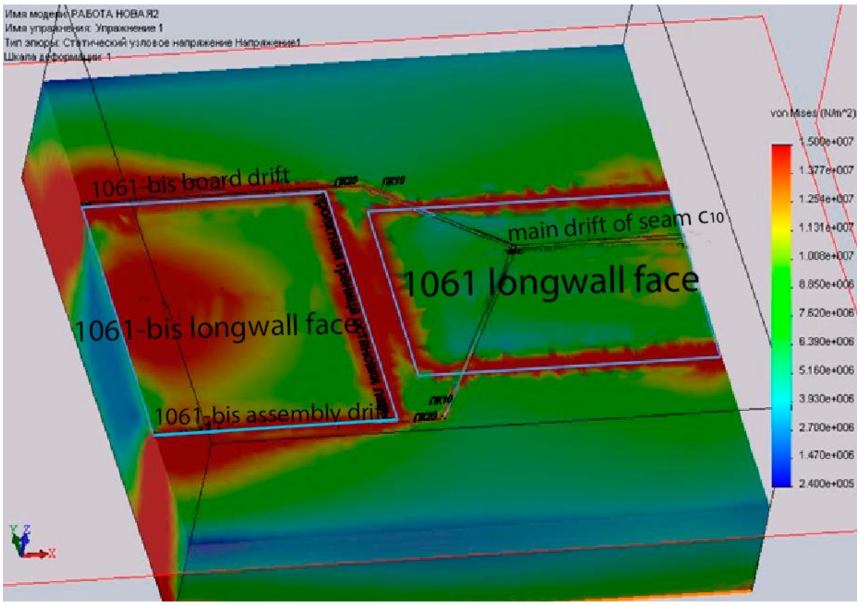

Fig. 5. Tensions in the rock massif at the target size of 25 meters

The highest concentration of vertical tensions in the preparatory workings (red color scale) takes place at the 25-meter pillar. According to the modeling data, rock destruction and, as a consequence, significant deformations of the excavation contour should be expected in the protected sections of 1061-bis ventilation and 1061-bis conveyor drifts.

Thus, based on the values of non-uniform loads on the pillar, obtained as a result of the calculation, it is established that at the pillar size of 37m, the tension along the contour of the preparatory workings will be comparable to the tensions from the influence of the 1061-bis longwall face only. On the contrary, when the size of the pillar is 25 m, corresponding to the size of the actually left pillar, the tensions are 4 times higher than the similar ones in the absence of the influence of the 1061-bis longwall face. The established tension values are critical for the section of 1061-bis ventilation and 1061-bis conveyor drifts, located in the zone of IRP, which led to deformations of the preparatory workings and the need to reinforce them.

4. Results of 1061-bis conveyor and 1061-bis ventilation drifts monitoring

The results of modeling are confirmed by the data of the fastening condition monitoring. At sections PK10-PK20 along the 1061-bis ventilation drift and in the area of PK10 along the 1061-bis conveyor drift, the total vertical convergence was about 0.96m, with intense rock heave. Monitoring of the mine workings condition included visual observations of the fastening behavior, as well as periodic measurements of contour observation stations installed in the 1061-bis ventilation drift (PK10 and PK15) and in the 1061-bis conveyor drift (PK10). A contour station is a wooden stake driven into the rock in the roof and in the sides of the mine workings (Figure 6).

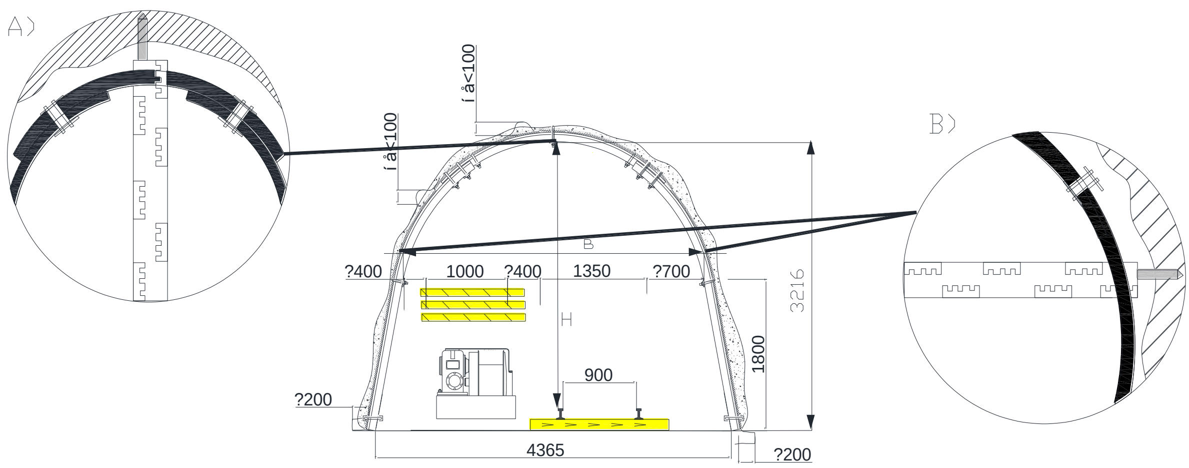

Fig. 6. Fastening of preparatory workings of 1061-bis longwall face and the scheme of measurements; A – measurement of vertical convergence; B – measurement of horizontal convergence

During the measurements of the workings cross-section the total vertical convergence (H) and horizontal convergence of the face (B) were determined depending on the longwall face position.

Systematized and summarized results of observations at contour stations for vertical and horizontal convergence are provided in Figure 7.

The analysis of the obtained convergence results allowed to establish the following. When the longwall face is approaching at a distance of 20 m up to the project border of the longwall stop, the support is not significantly deformed and the convergence does not exceed the background one for these mining and geological conditions. As the longwall face advances, the preparatory workings are significantly deformed due to the increase in horizontal stresses of the massif. This leads to deformation of one of the faces on the face side. Visualization of this process is presented in Figure 8.

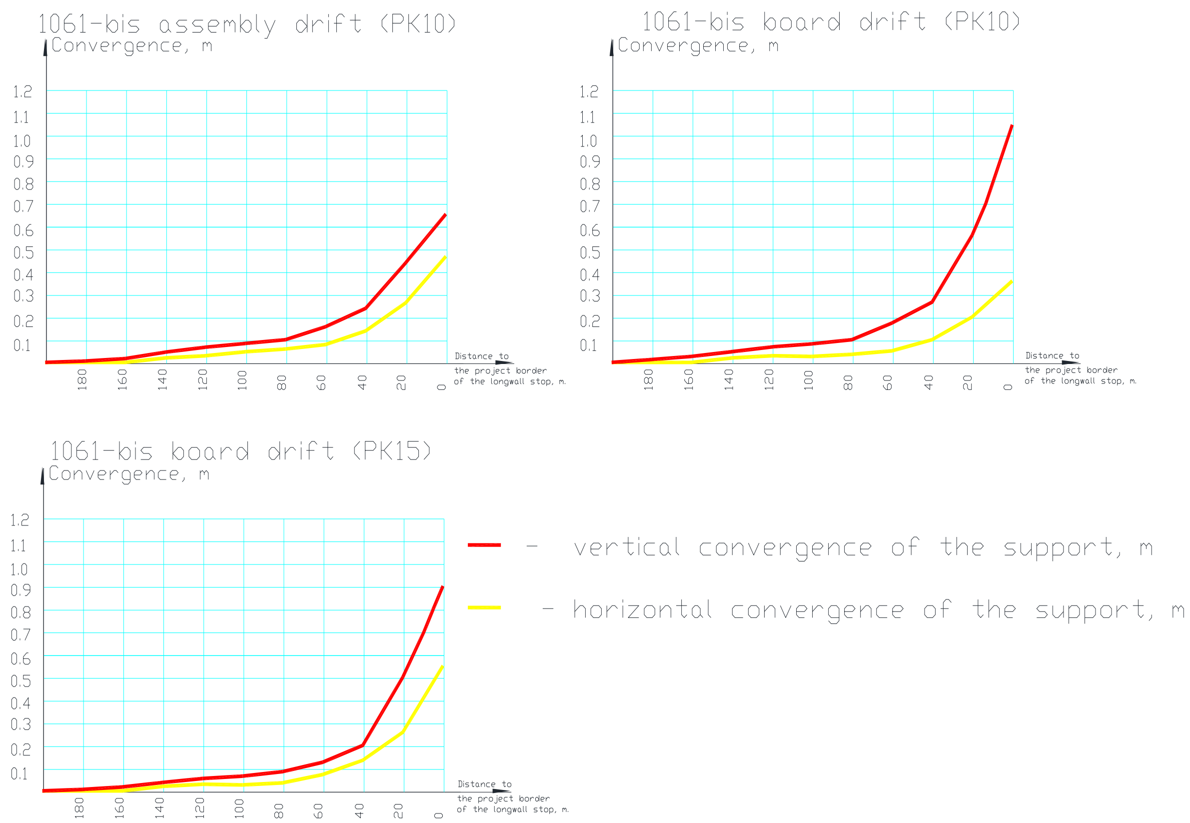

Fig. 7. Graphs of vertical and horizontal support deformations as a function of the distance to the longwall face

Fig. 8. 1061-bis ventilation drift PK10-PK20

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Figure 9 shows the results of observations of vertical convergence after longwall shutdown depending on the time of longwall shutdown. The analysis of the results showed that in the first 10-18 days, the pressure on the support of the preparatory workings and, consequently, its deformation is maximum, and starting from the 25-30th day, a noticeable attenuation is observed. At the same time, the preparatory workings lost about 60% of their original cross-section on the 30th day, therefore, on the 45th day after stopping the face 1061-bis longwall face, work was started to restore the fastenings of deformed sections of the workings. It was not possible to further monitor the condition of the face and the contour rock mass.

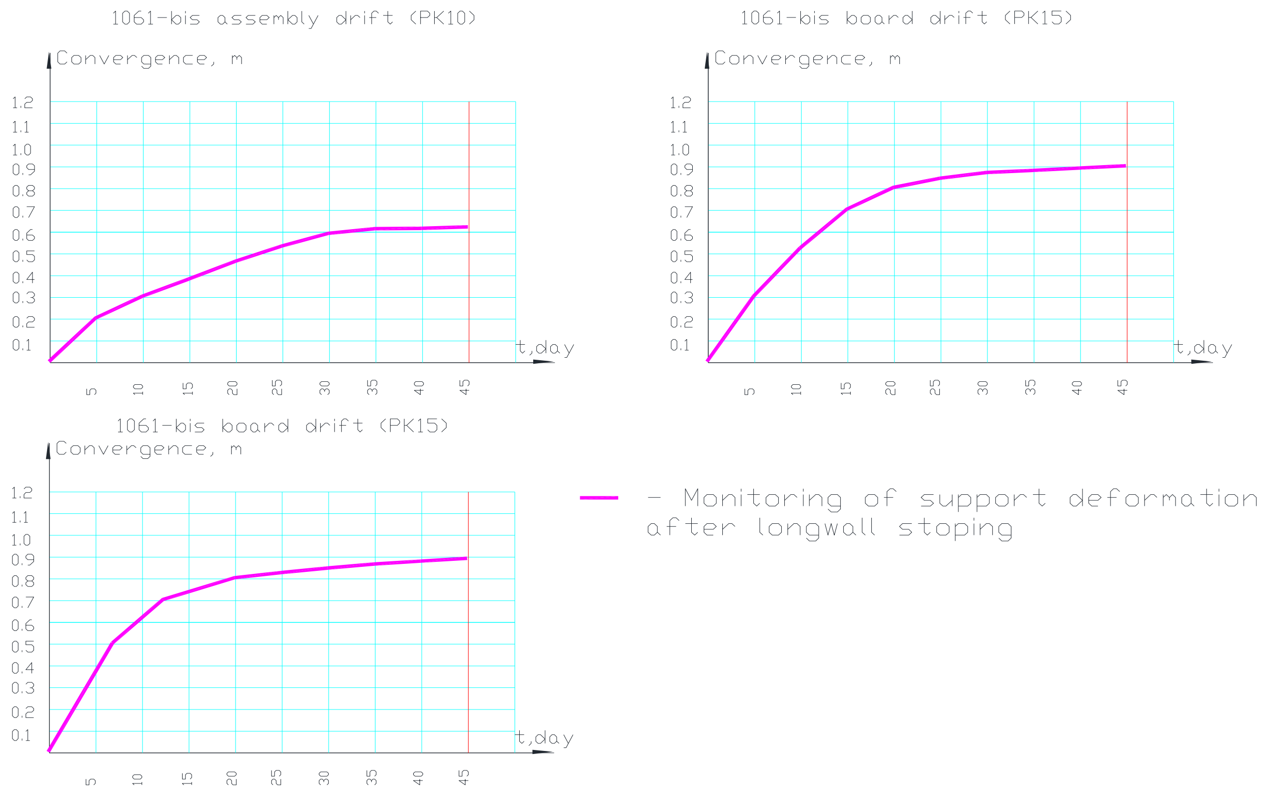

Fig. 9. Graphs of vertical and horizontal deformations of the support as a function of longwall stoping time

5. Conclusions

Analysis of the model of stress-strain state of the massif for the conditions of mining 1061 longwall face c_{10} of PSD Heroes of Kosmos Mine of PJSC DTEK Pavlohradvuhillya has shown that the highest concentration of stresses in the preparatory workings takes place at a 25-meter hedge. According to the modeling data, rock destruction and, as a consequence, significant deformations of the excavation contour and fastenings should be expected at the protected sections of 1061-bis ventilation and 1061-bis conveyor drifts. The results of modeling are confirmed by the data of the fastening condition monitoring. At sections PK10-PK20 along 1061-bis ventilation drift and in the area of PK10 along 1061-bis conveyor drift the total vertical convergence amounted to about 0,96 m, and intensive rock heave was observed.

Thus, based on the values of vertical load on the pillar, obtained as a result of modeling, it was established that at the pillar size of 37m, the stresses along the contour of preparatory workings will be comparable to the tensions from the influence of the 1061-bis longwall face only. On the contrary, when the size of the pillar is 25 m, corresponding to the size of the actually left pillar, the tensions are 4 times higher than in the absence of the influence of the 1061-bis longwall face. These tensions are critical for the section of 1061-bis side and 1061-bis prefabricated drifts located in the increased rock pressure zone, which led to deformations of the preparatory workings and the need to rebuild the fastenings.

Based on the modeling of the stress-strain state of the massif with the linkage of the actual state of the drifts according to the monitoring results, the optimum parameters of the pillar were determined, which in the conditions under consideration are 37 meters.

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