Nazarenko et al., 2025. Mongolian Geoscientist 30 (60)
https://doi.org/10.5564/mgs.v30i60.3592

Mongolian Geoscientist

Original Article

Investigation of reused preparatory workings deformations of as a result of cleaning operations

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ARTICLE INFO

Article history:

Received: 25 September, 2024
Revised: 05 January, 2025
Accepted: 07 January, 2025

ABSTRACT

To achieve economically efficient and safe underground coal mining, the technology of preserving and reusing workings is most effective. However, due to the effects of moisture and rheological processes, the deformation characteristics of rocks diminish. This results in actual displacements in the workings that exceed the calculated values, a factor not considered in the calculations but significant for the mines in Western Donbass. The aim of this study is to perform field measurements to identify the main patterns of deformation in the roof and floor of the workings within the influence zone of cleaning operations. The displacement calculation method for Western Donbass mines assumes a constant and uniform increase in rock contour displacements over time (except for the initial 20-40 days post-excavation), even outside the influence zone of cleaning works. The monitoring data presented here reveal the poor condition of reused workings, highlighting flaws in the calculation methodology. This study provides results from instrumental measurements and monitoring of the condition of preparatory workings during their reuse. The established patterns of deformation development in the preparatory workings allow for predicting the stability of workings supported in the worked-out part of the longwall faces in the conditions of Western Donbass mines, assessing their suitability for venting gas-air mixtures, and implementing timely technical measures to support the workings.

Keywords: observation station, roof displacement, convergence, surveyor's measurement

INTRODUCTION

There are several methods available to calculate the displacements of the roof in mine workings, including those applicable to the conditions in Western Donbass mines (Krukovskyi et al., 2022; Pylypenko et al., 2022; SOU 10.1.00185790.011:2007, 2007; GD 12.01.01.201-98, 1998; Bulat and Chekhov,1992). However, these calculations often fail to reflect the actual state of the mine workings after longwall mining. Many factors, particularly rock hydration and their rheological properties, are not considered in these calculations.

The poor condition of preparatory workings poses a significant challenge to production development. The worsening conditions for conducting and maintaining these workings are due to increased depth of coal seam development and mining intensity, leading to higher mining pressure and stress on the rock mass (Voloshyn and Riabtsev, 2019). Existing methods to ensure the stability of workings in the influence zone of cleaning operations are often inadequate. Scientific literature discusses various support methods for mine workings: arch support (Krukovskyi et al., 2023), steel and rope anchors (Wang et al., 2022), frame anchoring (Šňupárek and Konečný, 2021), shotcrete (Mei et al., 2020), and preloading (Zberovskyi et al., 2018). One of the basic methods of strengthening workings, especially when reusing them, is the use of wooden cribs (Novak et al., 2021; Skrzypkowski, 2020). The authors (Wu et al., 2024) concluded that of natural hazards such as rockburst and water hazards, mining support, especially: cable anchors should be specially secured and individually selected for specific geological and mining conditions (Chen et al., 2024). However, the issues of supporting workings under increased mining pressure from operations on neighboring seams and the additional dynamic pressure from the moving longwall face in weak, water-saturated rocks are not well-studied.

Regulatory documents consider the shape and area of the workings, the mining system, and the method of rock pressure control when calculating the load on the support (Guidelines., 2022; SOU 10.1.00185790.011:2007, 2007; GD 12.01.01.201-98, 1998). Studies (Kuchin et al., 2023a.b; Chetveryk et al., 2017) have conducted joint analyses of ground surface subsidence in mining areas and boreholes ahead of the moving longwall. The observed patterns are used to predict deformations of protected objects on the ground surface and subsurface (Bazaluk et al., 2023; Bubnova, 2024). Therefore, the load on the workings support depends on numerous factors, and accurate determination of this value is impossible without considering them.

It is assumed that the movement of the rock contour of mine workings is constant and uniform over time. However, the deformation and change in contours of actual mine workings contradict this assumption.

The aim of this research is to conduct field measurements to determine the main patterns of behavior of the roof, floor, and sides of mine workings in the influence zone of cleaning operations. Utilizing the results of these field experiments will enable timely measures to strengthen the necessary sections of preparatory workings, which are reused in weak host rock conditions. Experimental studies were conducted at two mines in Western Donbass.

RESEARCH OBJECT CHARACTERISTICS

At the PSD Stepnaya mine, PJSC DTEK Pavlohradvuhillya (Ukraine), preparatory workings for longwall faces No.57 and No.161 have been completed (Fig. 1).

The ventilation drifts No.157 and No.161 are sealed after the cleaning face, while conveyor drifts No.159 and No.163 are maintained to remove the gas-air mixture to the drainage drift. The reinforcement of the gateroad support ahead

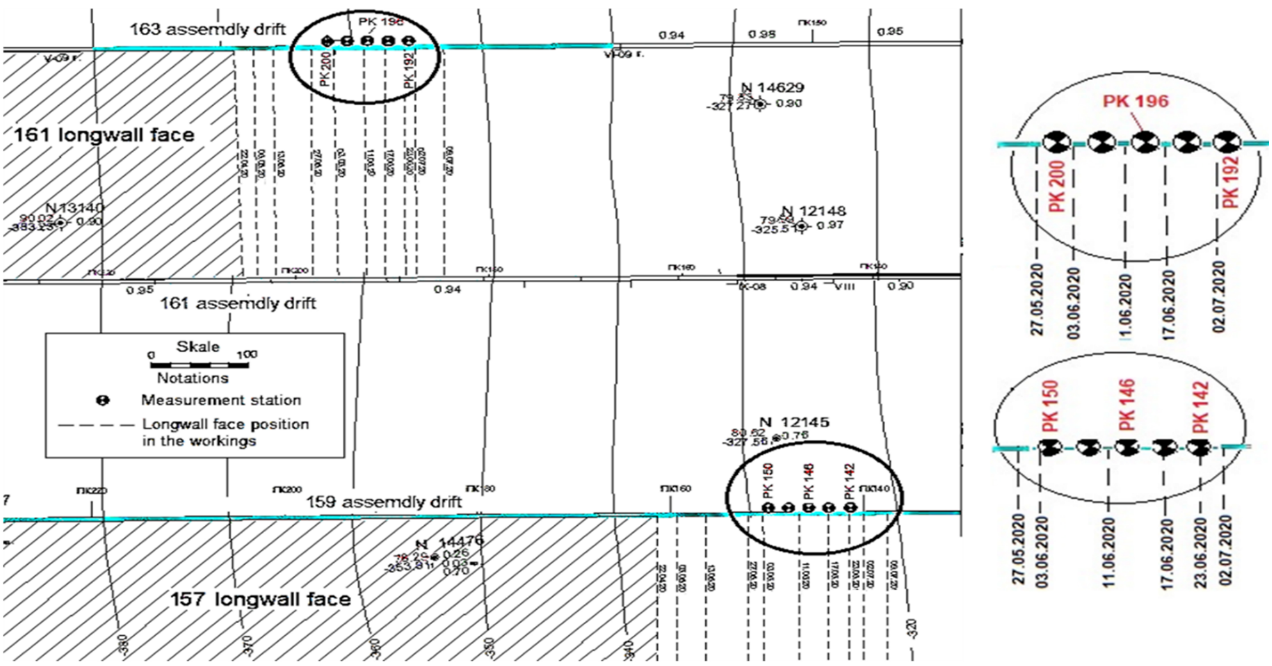

Fig. 1. Extract from the mine workings plan of the Stepnaya mine

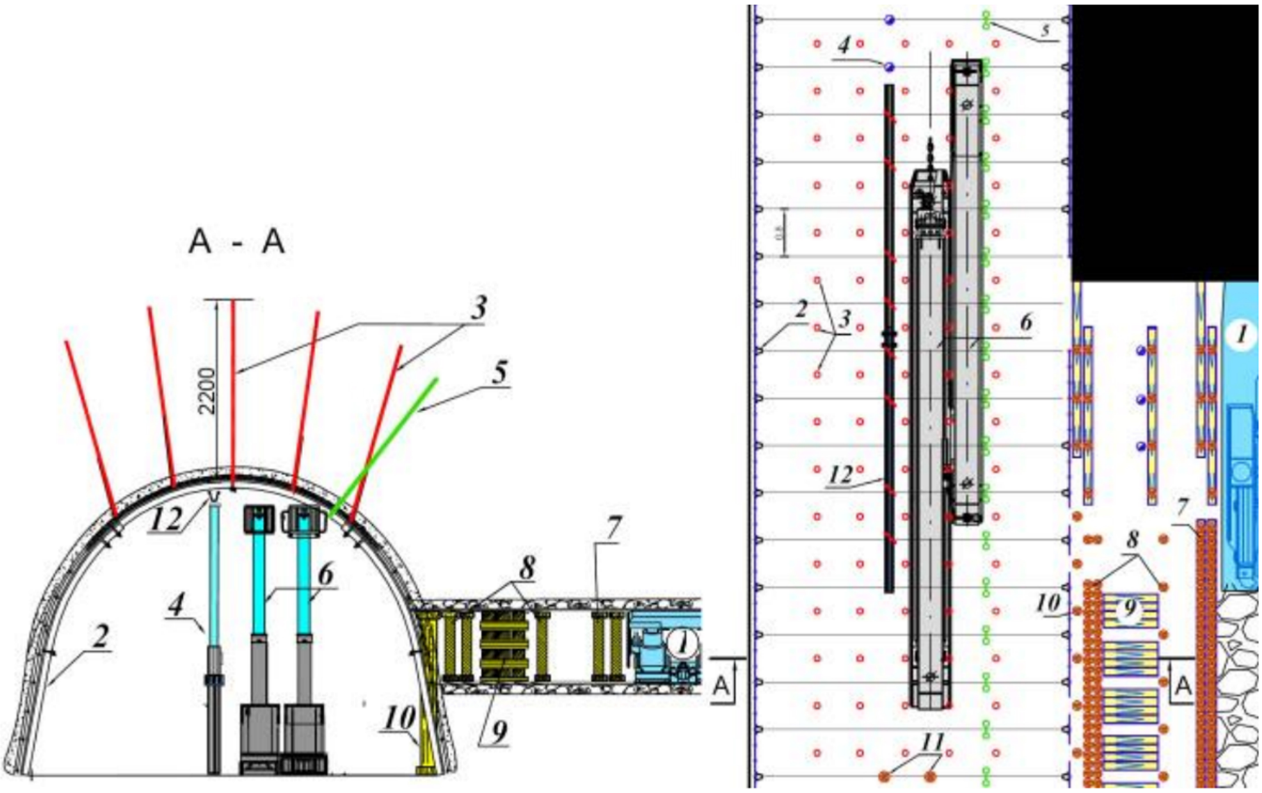

Fig. 2. The "classic" support and reinforcement pattern of the gateroad #163 at intersection with #161 longwall: 1 -longwall set of equipment; 2 -steel arch support KShPU-17,7; 3 -rock bolts; 4 -hydraulic props installed 20 m in front of the longwall face and under the horsehead; 5 -rock bolts connected to the top section of arch support; 6 -face-end supports; elements of roadside pack: 7 -breaker row; 8 -breaker props; 9 -chock; 10 -wooden prop between the roof of the seam and the floor of the gateroad; 11 -wooden props installed under each arch; 12 -steel horsehead

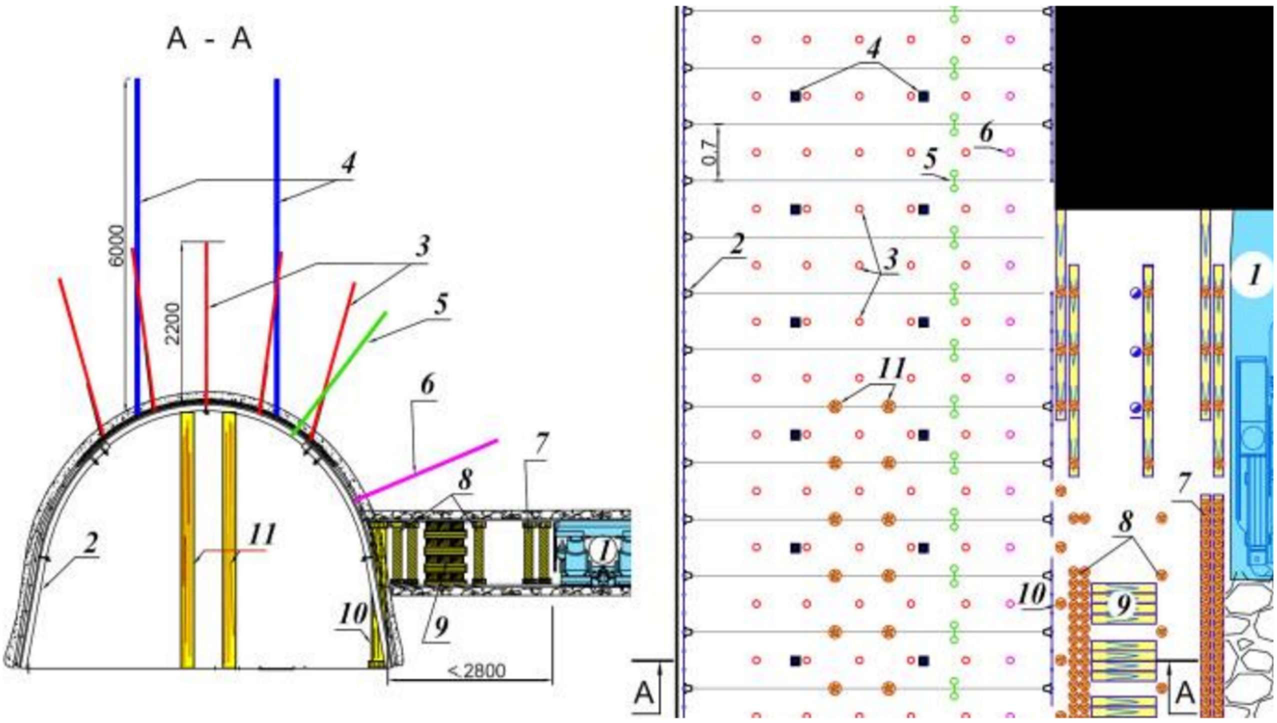

Fig. 3. Support and reinforcement pattern of the gateroad #165 at intersection with #163 longwall: 1 -longwall set of equipment; 2 -steel arch support KShPU-17,7; 3 - rock bolts; 4 -cable bolts, length 6.0 m, paired installation, spacing 1.4 m; 5 -rock bolts connected to the top section of arch support; 6 -rock bolt for strengthening of the roof above the roadside pack; elements of roadside pack: 7 -breaker row; 8 -breaker props; 9 -chock; 10 -wooden prop between roof of the seam and floor of the gateroad; 11 -wooden props installed under each steel arch

of the longwall face by means of props (wooden, hydraulic or friction) is recommended. The usage of face-end support is believed to mechanize the process of intersectional supporting, improve safety and productivity. This type of "classic" system of gateroad support reinforcement is characteristic for the longwall mines of Ukraine (Fig. 2, Fig. 3).

At the PSD Heroes of Cosmos mine, PJSC DTEK Pavlohradvuhillya (Ukraine), during the operation of longwall face No.1061-bis (Fig. 4), there was an issue with protecting the 1061-bis conveyor and ventilation drifts ahead of the advancing longwall face.

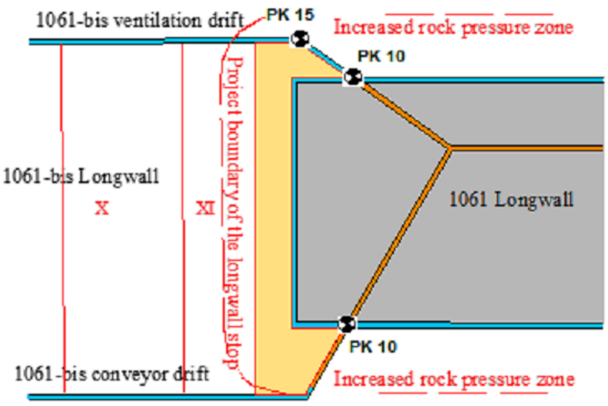

Fig. 4. Extract from the plan of mine workings on the seam c_{10}

The preparatory workings No.1061-bis are situated in similar mining and geological conditions, providing an opportunity to study the general deformation patterns of the workings sections within the longwall influence zone.

Coal extraction is carried out by longwall mining with caving. The panel length ranges from 900 to 1200 meters, the longwall face length is 250 meters, and the average mining depth is between 350 and 420 meters, with a seam dip angle of 3°. The coal seam is primarily of simple structure, with a geological thickness averaging between 0.9 and 1.05 meters. The coal seam is hazardous due to gas and dust but is not prone to spontaneous combustion.

MATERIALS AND METHODS

Instrumental observations in the conveyor drift №159

In conveyor drift No.159, five measuring observation stations were set up at pickets PK142, PK144, PK146, PK148, and PK150. At each station, multiple measurements were taken to evaluate the geometric parameters of the section, their changes over time, and the deformations of the surrounding rocks.

At each of the five observation stations, five measurements were taken from the device horizon level set by the leveler: to the roof of the workings, to the floor of the workings, to the formation roof, and to the marks on the legs of the support. Additionally, the width of the workings was measured at the seam level.

A total of ten series of instrumental observations were conducted at the observation stations in conveyor drift No.159, corresponding to different positions of the face relative to the observation stations on the observation dates.

The collected data were used to calculate the sinking (or rising) values of the floor and roof of the workings relative to the formation

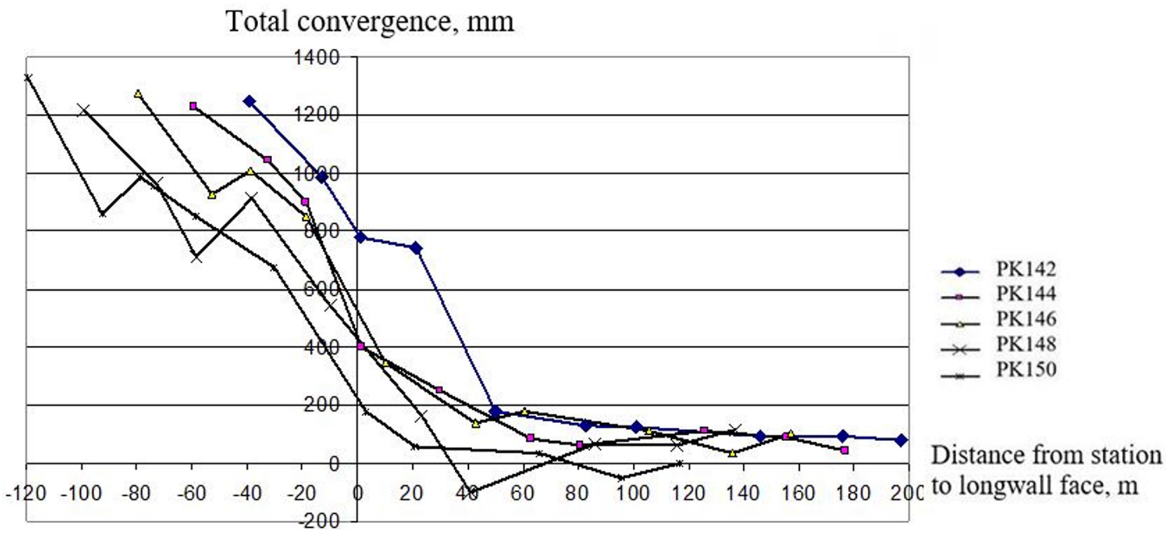

Fig. 5. Summary graph of the overall convergence of the conveyor drift №159

roof, as well as the total vertical convergence. These values were then plotted to show the sinking (or rising) of the floor and roof of the workings relative to the formation roof and the total vertical convergence. For instance, Fig. 5 illustrates the general convergence graphs for conveyor drift No.159.

All graphs share a common reference point: the moment when the longwall crosses the section where the observation station is located (with the distance from the face to the observation station being zero.

Observations in the conveyor drift №163

In conveyor drift No.163, five measuring observation stations were established at pickets PK192, PK194, PK196, PK198, and PK200. The initial observation at these stations was conducted when the longwall face No.163 was 140 meters away from PK200. A total of ten series of instrumental observations were carried out at these stations.

The summary graphs for conveyor drifts No.159 and No.163 show a similar pattern of deformation distribution and comparable values. The similarity in mining, geological,

Table 1. Distances from the cleaning face to the observation stations

Observation station	Date of observation									
	22.04 2020	06.05 2020	13.05 2020	27.05 2020	03.06 2020	11.06 2020	17.06 2020	23.06 2020	02.07 2020	09.07 2020
PK 142	197	176	146	101	83	50	22	1	-13	-40
PK 144	177	156	126	81	63	30	2	-19	-33	-60
PK 146	157	136	106	61	43	10	-18	-39	-53	-80
PK 148	137	116	86	41	23	-10	-38	-59	-73	-100
PK 150	117	96	66	21	3	-30	-58	-79	-93	-120

Table 2. Lowering (raising) of conveyor drift No.159 soil and roof relative to the seam roof and total vertical convergence at PK142

№ observations	Total convergence, mm	Lowering (raising), mm	
		roof*	soil
1	1245	625	620
2	985	150	835
3	780	15	765
4	740	-60	800
5	180	-50	230
6	130	-35	165
7	125	-25	150
8	95	-55	150
9	95	-70	165
10	80	-20	100

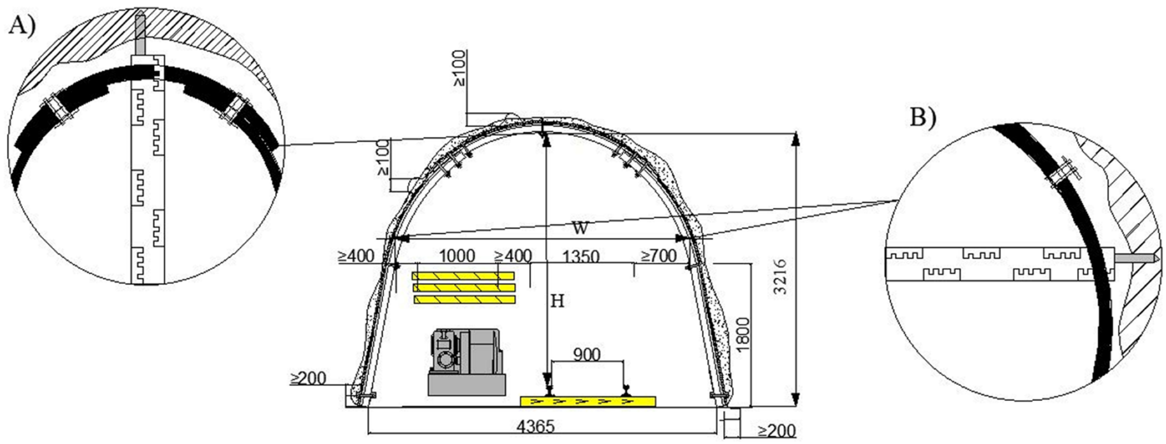

Fig. 6. Scheme of measurements in preparatory workings; A -measurement of vertical convergence; B -measurement of horizontal convergence.

and engineering conditions of longwall faces No.157 and No.161 justifies a combined analysis of the in-situ measurement results from the observation stations in conveyor drifts No.159 and No.163.

The distance from the longwall face No.157 to the observation stations of conveyor drift No.159 is given in Table 1.

Table 2 shows the values of lowering (raising) of the soil and roof of the conveyor drift No.159 relative to the formation roof at the observation station PK142.

During the measurements of the workings cross-section the total vertical convergence (H) and horizontal convergence of the face (W) were determined depending on the longwall face position (Fig. 6).

Smoothed graphs depicting convergence, roof lowering, and floor uplift in conveyor drifts No.159 and No.163 are presented Figs. 7 and 8, respectively.

Observations in 1061 bis ventilation drift and 1061 bis conveyor drift

Monitoring the condition of the excavation involved visual inspections of the support behavior and periodic measurements at contour observation stations installed in the 1061-bis ventilation drift (PK10 and PK15) and the 1061-bis conveyor drift (PK10). During these measurements, the total vertical convergence (H) and horizontal convergence of the face (W) were determined based on the position of the longwall face.

Location of observation stations in the drifts is shown in Fig. 4. Measurements at the observation stations are made in accordance with the scheme in Fig. 6.

ANALYZING THE RESULTS OF OBSERVATIONS

The results of measurements in the conveyor drift No.1061 bis and ventilation drift No.1061

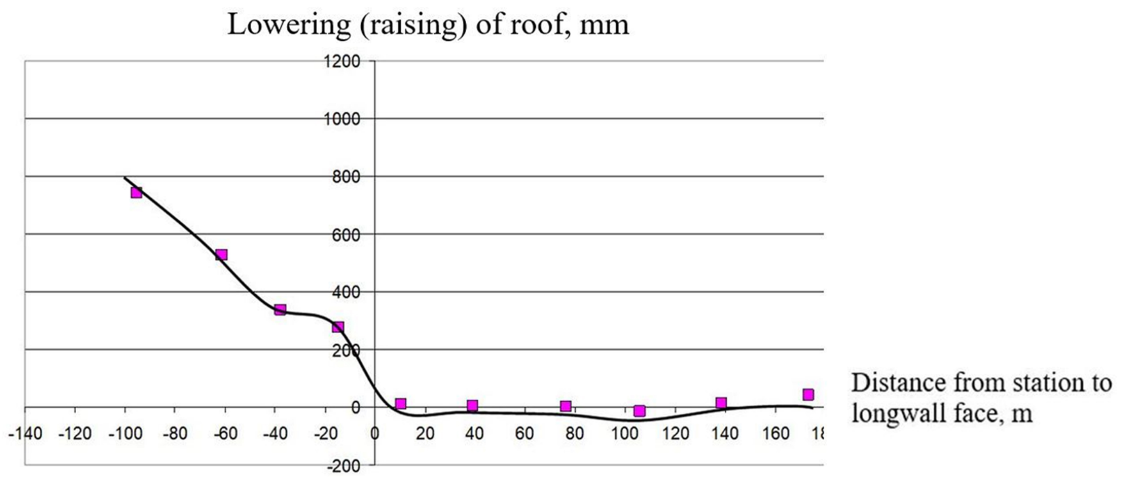

Fig. 7. Smoothed graph of roof lowering of the 159th and 163rd conveyor drifts.

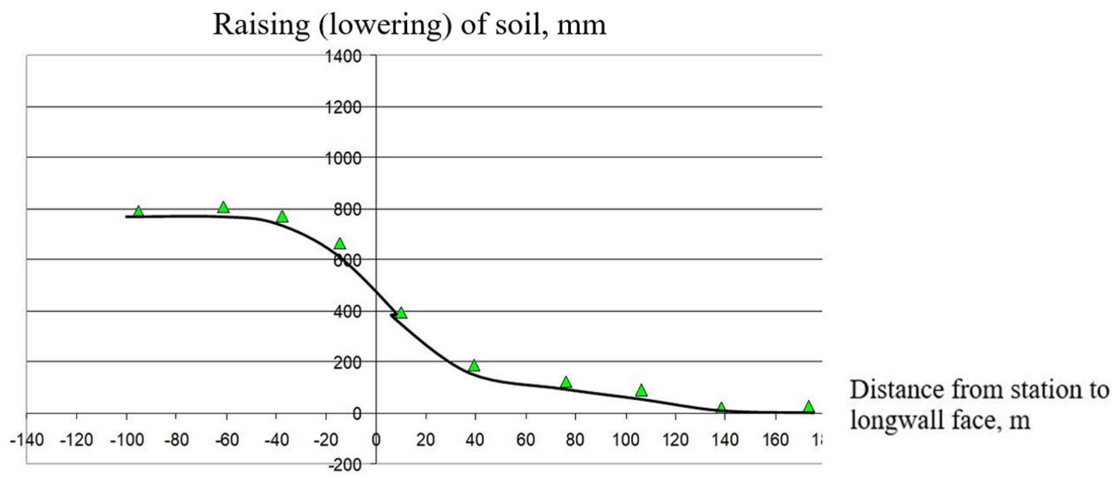

Fig. 8. Smoothed graph of soil raising of the 159th and 163rd conveyor drifts.

Fig. 9. 1061-bis board drift PK10-PK20

bis showed that in the first 10-18 days, the pressure on the preparatory workings support 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 on the 30th day lost about 60% of their original cross-section, in this connection on the 45th day after stopping the face 1061-bis the work on restoring the fastenings of the deformed sections of the workings was started. It was not possible to further monitor the condition of the face and the contour rock massif.

The analysis of the obtained convergence results allowed to establish the following. When the longwall face is approaching at a distance of 20

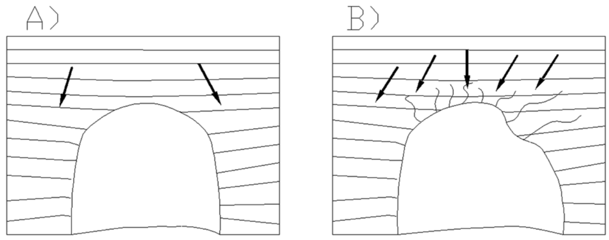

Fig. 10. Scheme of the excavation deformation: A - the excavation is in natural equilibrium, pressure is transferred to the walls of the excavation; B -wedges fall out of the excavation roof, lateral pressure prevails

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 Fig. 9.

At sections PK10-PK20 along 1061-bis side drift and in the area of PK10 along 1061-bis assembly drift, the total vertical convergence was about 0.96m, with intensive rock swelling. The principle scheme of deformation of the excavation is presented in Fig. 10.

The systematized and generalized results of these observations on vertical and horizontal convergence are presented in Fig. 11.

The convergence observations reveal the

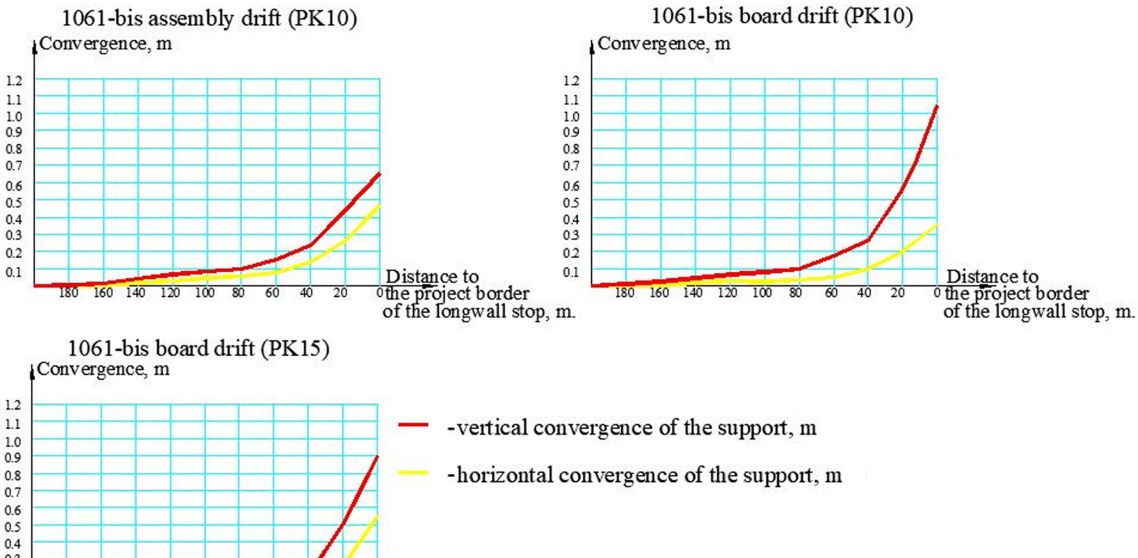

Fig. 11. Graphs of vertical and horizontal support deformations as a function of the distance to the longwall face

following patterns: when the longwall face is within 40 meters of the project border of the longwall stop, the support does not undergo significant deformation, and the convergence remains within the background levels for these mining and geological conditions. As the longwall face advances, the preparatory workings experience significant deformation due to increased horizontal stresses in the rock mass, leading to deformation on one side of the face.

CONCLUSIONS

A general analysis of the experimental observations at the Stepnaya and Heroes of Cosmos mines leads to the following conclusions about the deformation of sections of preparatory workings supported in the influence zone of mining operations:

•Vertical convergence in the preparatory workings begins at a distance of 150 meters from the longwall face and reaches maximum values of 2500-3000 mm when the face is 200 meters away.

•In the section of the excavation that coincides with the longwall face line, the average convergence is 600-1000 mm, or about 25-30% of the maximum.

•The development of convergence over time as the longwall face passes follows a pattern described by the Gaussian integral function.

•The roof of the workings relative to the coal seam roof remains stationary until the longwall face is about 10 meters away.

•Starting from a distance of 10 meters to the longwall face, there is an intensive lowering of the excavation roof, following a linear pattern-every 10 meters increase in distance in the worked-out part from the excavation section to the longwall face results in a consecutive lowering of the roof by 100 mm.

•The development of soil uplift within 150 meters before and after the longwall face follows the Gauss integral law.

•At the moment the longwall face passes, the soil uplift in the excavation cross-section reaches 600-800 mm.

The established patterns of deformation development in the preparatory workings allow for predicting the stability of workings supported in the worked-out part of the longwall faces in the conditions of Western Donbass mines, assessing their suitability for venting gas-air mixtures, and implementing timely technical measures to support the workings.

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