Justification for the parameters of extraction panels under the conditions of increased water inflows using computer models of rock mass

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Abstract. The purpose of the research is to increase the efficiency of underground mining of flat coal-bearing seams with powered longwalls in the areas characterized by complex hypsometry and high water inflows. The modern global trend to increase the size of extraction panels (the length of longwall and the length of column) during the development of flat coal-bearing seams is shown. The results of the development of a three-dimensional model of the array are presented, which allows building profiles of the earth surface and the developed seams in the areas with complex hypsometry. The applicability of the use of such models to determine the rational place for the formation of dismantling chamber is shown. The interrelation between the length of longwall and the length of extraction panel during the mining thick coal-bearing seams is shown. The assessment of the additional costs and damages caused by the division of the extraction panels into two parts is carried out to ensure an upward order of mining reserves under the conditions of increased water inflows. The field of rational application of the division of extraction panel into two parts for the conditions of the mine site named after V.D.Yalevsky is determined.

1. Introduction

The main global trend in underground coal mining using longwalls is the constant increase in the size of the extraction panels: the lengths of the longwalls and the lengths of the extraction panels. Thus, in the USA since 2010 to 2018, the average length of extraction panels increased from 3100 to 3600 m, and the average length of longwall increased from 330 to 360 m [1]. The maximum length of the longwall currently reaches 482 m, and the length of the panel is 6850 m. At the same time, about 35% of all longwalls in the USA are longer than 400 m, and 35% has the length of the panel over 4000 m. The increase in the length of the extraction panels allows reducing the number of remounts and thus reduces the downtime of high-performance equipment. The increase in the length of longwall leads to the increase in the volume of reserves in the extraction panels, reducing the unit cost of the preparation of the excavation sections, and also reduces the number of remounts. According to a number of scientists, the increase in the length of longwall is the main direction of increasing the efficiency of the use of treatment equipment, since with the increase in the length of longwall the duration of the productive work of shearer increases [2].

At the same time, the increase in the length of longwall leads to the increase in the cost of the acquisition of equipment and the length of the extraction panels leads to the increase in the duration of the preparatory work. In this regard, the feasibility of increasing the size of the extraction panels requires additional justification, taking into account the specific conditions of its use, which leads to a significant variation in the parameters of the extraction panels even in the leading coal-mining countries. Thus, for example, in the USA in 2018, the length of longwalls at different mines varied from 182 to 482 m, and the length of panels varied from 1200 to 6850 m [1]. In our opinion, such a significant variation is due to the variety of mining-geological and mining-engineering conditions of underground mining. It is necessary to note that a change in
development conditions (both geological and mining) is observed not only in different mines, but also within the same mines and even within the same extraction panel.

During the course of the research we consider the problem of the determination of the rational parameters of mining panels at the mine site named after V.D. Yalevsky in the Kuznetsk coal basin (Russia). Several records were set on longwall load on this mine site in 2016-2018 and in some months it reached 1.5-1.65 million tons per month [4]. The mine processes thick seams: seam 50 with an average thickness of 3.7 m and seam 52 with a thickness of 4.3 m using modern equipment: EickhoffSL-900 combine, DBT 2200 lining, PF 6/1142 conveyor. It is necessary to note that record loads were set in the longest longwalls in Russia, the length of which was 400 m. The achieved success led to the desire to use long walls both in the other mining face of this mine site and in other mines of the company that process thick seams.

The relevance of the solution of the determination problem of rational parameters of extraction panels is reasoned by the significant difference in the conditions of work at mines, as well as within mine field of the mine site named after V.D. Yalevsky. In the sloping part of the mine field there is a significant area within which the seams hypsometry changes, which in conditions of increased water inflows (up to 900 m$^3$/h) can lead to frequent equipment shutdowns during flooding of treatment and preparatory works. One of the possible ways to solve the problem of mining of such sites is to divide them into two parts. Each of this part is worked out in an ascending order of mining, which eliminates the flow of water into the face space of longwall. However, this solution complicates the ventilation scheme [7], requires additional works and additional equipment remounting. Taking into account that at the mine site named after V.D. Yalevsky the length of the longwall reached 400 m (maximum values for Russia), and the length of the panels was 4000 m, the decrease in the length of the panel can have a significant impact on the technical and economic performance of the work [3, 4, 7, 8-12]. In this regard, the profitability of such a solution requires additional justification.

2. Methods
In the course of the research we used the following methods: a comprehensive method, including analysis of the experience of mining panels of the mine site named after V.D. Yalevsky with their division into two parts, the development of a three-dimensional model of the seams and the earth surface in order to clarify the location of the formation of dismantling chamber taking into account the seam hypsometry, the analysis of the efficiency of assembling and dismantling work during the development of thick seams, the analysis of economic damage from equipment downtime, the analysis of the effect of the length of panel on the length of longwall and the feasibility of increasing the length of the longwall when mining sites with limited dimensions. During the calculation of equipment downtime damage, its assessment was carried out on the basis of production costs associated with the operation of the enterprise during the period of lack of production, taking into account the increase in terms of reserves development. The loss of potential profit was not taken into account, since profit is not completely lost, but it delays due to the period of non-productive time.

3. Results and Discussion
At the first stage of the research, we made the analysis of the experience of mining an extraction panel with division into two parts on the mine site named after V.D. Yalevsky. The presence of such experience on the mine site is explained by the cutting of reserves to the mine field and the presence of an undeveloped area (5213) with limited dimensions, the development of which required additional mining to organize ventilation, protected by the bearer with 30-55 m of width, which led to a reduction in the length of the longwall from 300 m to 270-245 m and the mounting chamber to 180 m (Figure 1).

![Figure 1. Layout of extraction districts in the reservoir 52](image-url)
At the second stage of research, we created a three-dimensional model of the rock mass (Figure 2). The use of the developed model allowed obtaining profiles of the earth surface and seams in any of the directions. As an example, Figure 3 shows the profiles of the earth surface and seam 52 by local work: 1) previously worked out mining sites, 2) planned for development in the near future 3) planned for development in the future. It is necessary to note that the profiles shown in Figure 3 have a 2-fold increased scale along the vertical axis.

![Three-dimensional model of seam 52](image)

**Figure 2.** Three-dimensional model of seam 52

At the third stage of the research, we performed the analysis of the effectiveness of assembling and dismantling work during the development of thick flat seams in similar mining and geological conditions using similar equipment. The analysis of the planned and actual duration of assembling and dismantling works was carried out and it was found that the actual duration exceeds the planned in 1.5 times on average and is 93 days when mining thick seams.

### Table 1. Duration of assembling and dismantling work during the development of thick seams

| Mine site | Longmill No. (disassembled/commissioned) | Thickness of seam, m | Bedding angle, degree | Depth of exploration, m | Planned duration of work, days | Start | Finish | Actual duration of works, days |
|-----------|------------------------------------------|----------------------|----------------------|------------------------|-------------------------------|-------|--------|-------------------------------|
| named after the 7th of November | 13-58/13-80 | 4.73 | 5 | 230 | 60 | 30.11.2013 | 23.01.2014 | 55 |
| named after the 7th of November | 13-80/1378 | 4.75 | 4 | 210 | 64 | 02.12.2014 | 25.01.2015 | 55 |
| named after the 7th of November | 13-78/13-58-2 | 4.75 | 4 | 180 | 64 | 16.07.2015 | 17.09.2015 | 64 |
| named after the 7th of November | 13-58-2/13-85 | 4.85 | 3 | 175 | 61 | 28.12.2015 | 16.02.2016 | 51 |
| named after the 7th of November | 13-85/13-86 | 4.71 | 5 | 170 | 61 | 18.04.2016 | 05.06.2016 | 49 |
| named after A.D. Ruban | 804/802 | 4.12 | 11 | 89 | 64 | 17.05.2014 | 21.07.2014 | 66 |
| named after A.D. Ruban | 802/801 | 4.66 | 8 | 98 | 60 | 01.11.2014 | 07.02.2015 | 99 |
| named after V.D. Yalevsky | 52-07/52-09 | 4.49 | 8 | 170 | 59 | 26.07.2014 | 15.11.2014 | 111 |
| named after V.D. Yalevsky | 52-09/52-11 | 4.28 | 4 | 380 | 60 | 10.06.2015 | 12.11.2015 | 156 |
| named after V.D. Yalevsky | 52-09/52-10 | 4.01 | 3 | 343 | 60 | 22.10.2014 | 31.03.2015 | 161 |
| named after V.D. Yalevsky | 52-10/50-02 | 4.13 | 3 | 335 | 60 | 25.03.2016 | 07.06.2016 | 75 |
| named after V.D. Yalevsky | 70-08/70-09 | 5.34 | 4 | 196 | 90 | 08.02.2014 | 22.07.2014 | 165 |
| Taldinskaya-Zapadnaya-2 | 67-10/66-06 | 4.83 | 13 | 318 | 59 | 06.01.2015 | 03.05.2015 | 118 |
| Taldinskaya-Zapadnaya-2 | 66-06/66-05 | 4.65 | 5 | 120 | 33 | 16.11.2015 | 22.04.2016 | 159 |

| Average values | - | 4 | 5 | 256 | 63 | - | - | 93 |
At the fourth stage of the research, we performed the analysis of the damage from downtime of high-performance equipment. At the same time, the analysis of mine data showed that daily costs during periods of lack of production were about 100 thousand US dollars.

At the fifth stage of the study, we analyzed the interrelation between the length of longwall and the length of extraction panels of USA mines sites in order to assess the feasibility of increasing the length of longwall to 400 m for different panel lengths. Figure 4 shows a graph reflecting the interrelation between the length of longwall and the length of extraction panel.

The analysis showed that there is interrelation between the length of longwall and the length of extraction panel (Figure 4) - longer panels are characterized by a longer longwalls. Moreover, for the seams with a thickness of less than 3 m and more than 3 m, the dependences of these parameters differ. When mining thick seams, the length of longwall does not exceed 400 m, and in only one case it exceeds 350 m (Figure 4, B).
The successful experience of mining sites with the division into two extraction panels (Figure 1) confirms the technical feasibility of mining reserves without a significant change in transport schemes and ventilation of all mines. However, the analysis of such experience shows a significant decrease in technical and economic indicators. The decrease in economic indicators when dividing the extraction district into two parts with their separate mining will be associated with the need for costs of additional development, a significant increase in coal losses left in its barrier left for its protection, as well as damage associated with downtime of the equipment during assembling and dismantling and also the costs of additional remounting of equipment.

A large-scale assessment showed that barrier establishing leads to stock losses, the damage from which will be about 5.8 million US dollars with panel length of 2000 m and panel width of 30 m with a reservoir thickness of 4.3 m. The cost of additional development with a length of 2000 m will be about 2 million US dollars. The damage from equipment downtime over 90 days will be about $ 9 million, the cost of remounting equipment will be about $ 1 million. Thus, the division of the extraction district into two parts will result in damage of about 18 million US dollars or 15% of all profits. It is necessary to note that the calculations are valid only for the level of costs at the mine of about $ 10 USA / t and a margin of $ 16 USA / t.

Taking into account the high cost of such a method of eliminating increased water inflows, it is necessary to ensure its maximum efficiency, which can be achieved using the developed three-dimensional model. The three-dimensional model allowed clarifying the place of rational stopping of longwalls (the formation of dismantling chambers) when dividing the extraction panel into two parts and mining them from the borders to the center in order to ensure upward mining of reserves and outflow of water into the processed space. Figure 3 shows that previously developed areas had a constant slope (track 1), which allowed effective

Figure 4. Interrelation between the length of longwall and the length of panel (USA, 2018): A) - during the development of seams of any thickness; B) when mining thick seams
management of increased water inflows by processing extraction panels in ascending order. The mining of the extraction district 5210 and 52-13 was also carried out in ascending order due to the division of the extraction panel into two parts (track 2) and the formation of a dismantling chamber in the areas with the highest elevations. Further prospects for reserves development are associated with the development of an almost horizontal section of the reservoir. It is necessary to note that despite the high costs of mining option with the division into two parts, its use is advisable under the conditions of high water inflows, since the development of reserves when longwall moves in a descending order with water inflows of 600–900 m³ / h is difficult and technically feasible and will be accompanied by periodic flooding of longwall and district processing.

Mining thick coal seams, in contrast to medium-thickness seams (less than 3 m) the maximum length of the longwall does not exceed 400 m in leading coal-mining countries, and in the vast majority of cases it is less than 350 m, even when mining extraction districts up to 5,000 m long. Due to this, the increase in the length of longwall is impractical when mining reserves in areas with complex hypsometry in conditions of increased water inflows.

4. Conclusion
The increase in the length of extraction panels and the length of longwalls is an actual global trend, however, the choice of the length of longwalls and the length of extraction panels requires additional justification, taking into account the specifics of geological and mining conditions. Such conditions are complex seam hypsometry and increased water inflows. One of the possible effective solutions is to divide the long panels in length into two parts in order to ensure the movement of longwall in each part from the bottom up to prevent flooding of longwall and adjacent workings. As a result of the research, we assessed the efficiency of mining extraction panels with complex hypsometry in conditions of increased water inflows at the mine site named after V.D. Yaleyevsky. The assessment of the additional costs and damages associated with the division of the site into two extraction panels showed that the greatest damage (about 9 million US dollars) is associated with downtime of the equipment (mine operation without coal mining) during the equipment re-installation. Significant damage (about US $ 5.8 million) is also associated with the loss of reserves as a whole necessary for the protection maintained by longwall for its ventilation. The amount of additional costs and damages reaches 18 million US dollars or 15% of the total profit of the enterprise, obtained by mining reserves of the site (two extraction panels with a limited length).

Implementing the mining method with the division of the site into two extraction panels, it is important to stop the longwall, which should be in the part of the panel with the highest elevations in order to prevent water from entering the dismantling chamber. The solution to this problem is provided by the application of a three-dimensional reservoir model. The use of a three-dimensional model of seam 52 allowed choosing a rational stopping place for extraction panels and showed that division into two extraction panels is advisable only in two extraction districts, after which the seam hypsometry allows returning to the use of long extraction panels (without dividing it into two panels). In addition, during of the formation of dismantling chamber, it is necessary to take into account the step of collapse of the main roof and conduct work taking into account the recommendations presented in previously published articles [5, 6].

In our opinion, the final decision on the effectiveness of the division of the site into two extraction panels should be made on the basis of mine data on actual water inflows obtained during the development of the reserves of the first extraction panel. Since the dismantling chamber is formed by longwall, then in the case of the possibility of efficient drainage of longwall, it can continue its work without a dismantling chamber, processing the entire extraction panel without the division into two parts.

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