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Abstract

The re-exploitation of coal seams located near the ground is one of the solutions to increase output, reduce mining investment costs, and avoid wasting coal resources. The re-exploitation of coal seams will also cause instability of the surrounding rock mass and may affect surface construction works. Through the process of re-exploiting the longwall in seam H10 at Mong Duong Coal Mine, the authors have studied and evaluated the stability of the rock mass and +30 level surface works (including fan station and gateroad). To achieve the results in this study, the numerical simulation model method and the analytical method were applied. The model analysis results have determined that the displacement and deformation areas of the rock mass around the mining area correspond to the length of the cut in the strike direction of the longwall H10. The analysis and calculation results from the model show that the longwall in seam H10 can be re-exploited when leaving a protective coal pillar about 50 m from the center of the +30 fan station at the east side; this distance ensures the stability of the rock mass that located near the ground and the surface works at +30.

Keywords

re-exploiting, coal pillar, longwall, surface works, numerical simulation, Mong Duong Coal Mine

Research on stability of rock mass and +30 level surface construction works when re-exploiting the seam H10 at Mong Duong Coal Mine, Vietnam

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Abstract

The re-exploitation of coal seams located near the ground is one of the solutions to increase output, reduce mining investment costs, and avoid wasting coal resources. The re-exploitation of coal seams will also cause instability of the surrounding rock mass and may affect surface construction works. Through the process of re-exploiting the longwall in seam H10 at Mong Duong Coal Mine, the authors have studied and evaluated the stability of the rock mass and +30 level surface works (including fan station and gateroad). To achieve the results in this study, the numerical simulation model method and the analytical method were applied. The model analysis results have determined that the displacement and deformation areas of the rock mass around the mining area correspond to the length of the cut in the strike direction of the longwall H10. The analysis and calculation results from the model show that the longwall in seam H10 can be re-exploited when leaving a protective coal pillar about 50 m from the center of the +30 fan station at the east side; this distance ensures the stability of the rock mass that located near the ground and the surface works at +30.

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1. Introduction

Currently, underground mines in Vietnam are more and more deeply exploited, so the mining conditions are more difficult and complicated. Coal mining is still predominant in Vietnam. The country will have to rely on coal as one of the key energy sources for a long time in order to meet its energy needs. Since coal has been mined in Vietnam for a long time, the country is now facing such challenges as the depletion of readily available reserves and an increase in the share of coal mined underground in difficult geological conditions [1]. Therefore, the re-exploiting of coal seams located near the ground has been interested in recent times by some underground mines in Quang Ninh coalfield. However, the re-exploiting seams are directly related to the stability of the topographic surface works, directly related to surface subsidence, displacement, and deformation affecting the surface works [2−6]. To be able to re-exploit these shallow seams, it is necessary to base on specific conditions at the actual site and at the same time, use a calculation method that evaluates many factors to forecast the level of impact on the stability of surface works and ground subsidence when re-exploiting shallow seams [7−10].

In the underground coal mines in Quang Ninh coalfield, although now they have been exploited to a deep level (−300 or −450 m), some mines are still interested in re-exploiting the shallow coal seams (near the surface) to recover minerals, reuse existing mine works to reduce investment costs and increase output. If exploiting seams located near the ground, it may affect the stability of surface works (Residential areas, national works, roads, works for mining of mines, lakes, streams, etc.). The longwall in seam H10 at Mong Duong Coal Mine is located

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below the fan station and gateroad at +30 level. So, when re-exploiting the longwall, it is necessary to have a reasonable solution to ensure the stability of the topographic surface works; at the same time, the size of the protective coal pillar needs to be kept as small as possible. It is necessary to study the stability of rock mass around the longwall area and near the topographic surface for the condition of the longwall in seam H10 at Mong Duong Coal Mine and some mines with similar conditions in the Quang Ninh coalfield.

The size of the protective coal pillar has also been calculated by underground mines based on regulations, experiences, and theories. However, high safety coefficients are still used in the calculation, or some regulations may not be suitable for current mining technology and pressure control method. Therefore, it is necessary to re-evaluate and recalculate the protection limits when exploiting the shallow coal seams to recover useful minerals. Up to now, there have been lots of research and evaluations of the effects of exploiting these coal seams on topographic surface works. Case studies are used, such as: similar material modeling methods [11–14]; numerical simulation methods [15–21]; field monitoring methods [22–25]. These studies were conducted under specific field conditions. A similar material modeling method requires high cost, long research time, a limited number of research options, not to mention many influencing factors. The numerical simulation method can study many options, including many influencing factors, low cost, and fast research time. The article is based on the field conditions of Mong Duong Coal Mine, using numerical simulation methods to simulate the process of re-exploiting the seam H10, leaving protective coal pillars to ensure safety and not cause surface subsidence and damaged fan station, gateroad at +30 level at Mong Duong Coal Mine.

2. Materials and methods

2.1. Current status of +30 level surface works in Mong Duong Coal Mine

On the topographic surface of the level +30 east side in Mong Duong Coal Mine, there is a fan station and a gateroad to serve the work of ventilation, travel, and transportation for the exploitation longwall in seams H10 and G9. Coal seams H10 and G9 are located at a depth of 100–130 m above the ground where the +30 level fan station and gateroad are built.

The +30 level gateway is supported by reinforced concrete, while the fan station is built with brick walls. At this fan station, two fans of type 2K56–N02.4 are arranged, location diagram of the fan station and gateroad at +30 level is shown in Fig. 1 [26].

The longwall from −100 to −170 level at west side in coal seam H10 has been exploited by drilling and blasting technology; the exploitation direction of the longwall is from the border to the center, combining the ZRY soft support, leaving the coal pillar far from the center of the fan station was about 130 m. During the mining process of this longwall, the fan stations and gateroad have not been affected; the topographic surface has not appeared crack.

2.2. Geological conditions of the study area

2.2.1. Basic parameters of longwall in seam H10 [27]

- Average thickness of seam: 2.0 m;
- Average slope angle: 55°;
- The length of the longwall in the dip direction: 145 m;
- The length of the longwall in the strike direction: 220 m.

2.2.2. Characteristics of roof and floor

- Immediate roof: The Immediate roof is siltstone with a thickness of 2.6–12.2 m, an average thickness is 7.4 m, it is light gray, dark gray, layered from 0.2 to 0.4 m, with compression resistance strength 540.2 kg/cm^2, tensile strength 66.41 kg/cm^2, specific weight 2.67 T/m^3, solidification coefficient of average rock mass 6.09.
- Main roof: The thickness of the main roof is 82.4–91.9 m, and the average thickness is 87.2 m. The composition is sandstone and siltstone. Fine-grained to coarse-grained sandstone accounts for 66%, layered 0.3–0.6 m, and it is relatively solid; solidification coefficient 9.1; compression resistance strength 916.34 kg/cm^2; tensile strength 90.17 kg/cm^2, specific weight 2.72 T/m^3. The siltstone accounted for 25%; average compression resistance strength of 540.2 kg/cm^2; tensile strength of 61.4 kg/cm^2, and average consolidation coefficient of 5.4.
- Immediate floor: The thickness of the immediate floor is 8.1–24.9 m, the average thickness is 16.5 m, the composition is siltstone and sandstone, it is brownish gray to light gray, layered from 0.2 to 0.6 m, the average consolidation coefficient 5.34.

2.2.3. Geological cross-section

Two geological cross-sections of the +30 fan station and gateroad are shown in Fig. 2 [27]. Two

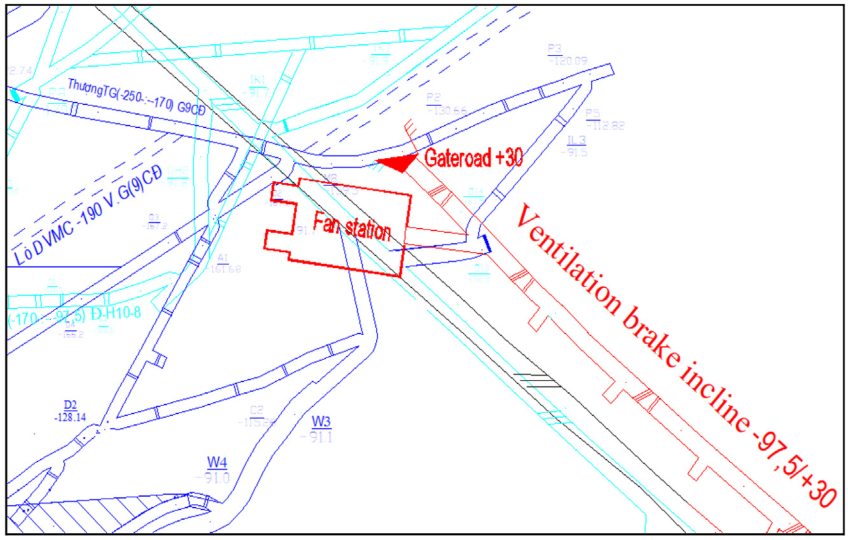

Fig. 1. Location diagram of fan station and gateroad at +30 level in Mong Duong Coal Mine.

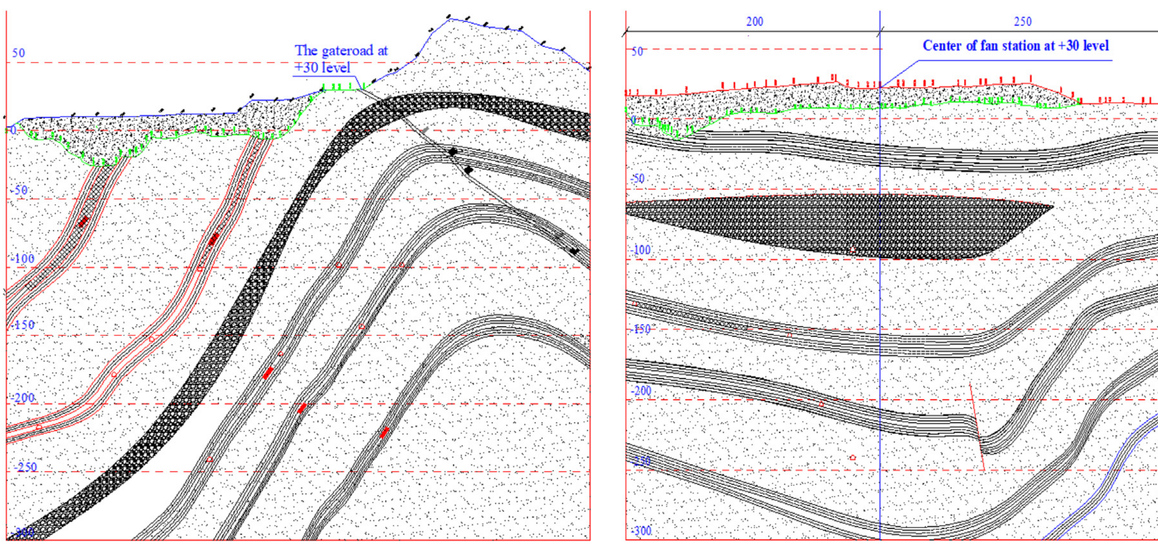

Fig. 2. The geological cross-section in the strike direction and the dip direction of the fan station and gateroad at +30 level.

geological cross-sections show the thickness of the seam, the position of the seam H10 and rock layers, other coal seams in the area, as well as the fan station and the gateroad at +30 level. These cross-sections are used to build a simulated numerical model.

2.3. Establishing of numerical simulation model by RS^2 software

2.3.1. Model input parameter

Based on the geological characteristics of the study side, the parameters of the coal mass and the

Table 1. Analytical results of the roof and floor rock of seam H10.

Rock unit	Compression resistance strength (MPa)	Modul of elastic (MPa)	Coefficient Poisson	Specific weight (MN/m^3)
Sandstone	87	7891	0.2	0.026
Siltstone	54	466	0.2	0.026
Claystone	25	662	0.2	0.027
Coal seam	20	429	0.12	0.014

rock mass used to establish the model are shown in Table 1 [27].

2.3.2. Model size

In this study, RS^2 software was used to simulate the mining process of the longwall in coal seam H10 at Mong Duong Coal Mine. This is a software commonly used in the field of mining. Its characteristics are easy to use, and it simulates the thickness and the actual position of the rock layers, rock layer characteristics such as faults and groundwater levels. The numerical simulation model is built on the basis of geological conditions and geological cross-section in the strike direction passing through the area of the +30 level fan station and the gateroad of with the dimensions of 326.8 m height, 450 m width. The analysis results from the model will evaluate and forecast the effect of re-exploiting the coal seam H10 on the stability of the rock mass near the ground above the fan station and the +30-furnace door. The simulation model is shown in Fig. 3.

2.4. Simulation of the mining process of the seam H10

The total length in the strike direction of the mining area of the longwall in seam H10 is 220 m. The numerical simulation model will simulate the moving process of the longwall in seam H10 with the corresponding length in the strike direction. Thus, the sequence of exploitation in the model from the border to the center follows the following steps: step 1, the length of exploitation is 10 m; step 2, the next exploitation length is 10 m (corresponding to 20 m in the strike direction); step 3, the next exploitation length is 30 m (corresponding to 50 m in the strike direction); step 4, the next exploitation length is 50 m (corresponding to 100 m in the strike direction); step 5, the next exploitation length is 70 m (corresponding to 170 m in the strike direction). The length of the protective coal pillar left is about 50 m. The simulation steps are shown in Fig. 4.

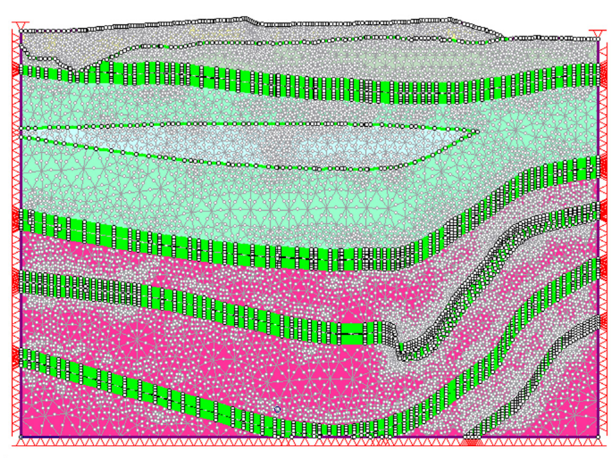

Fig. 3. Simulation model of rock and coal layers at the geological cross-section in the strike direction.

3. Results and discussion

To evaluate the influence of the rock mass near the ground and the +30 level fan station, gateroad, the results of the calculation of stratigraphic stress sigma 1, sigma 3, plastic deformation area, and subsidence area in the rock mass will be presented below:

3.1. Calculation results of stratigraphic stress

Calculation results of sigma 1 and sigma 3 stratigraphic stresses in the rock mass of the geologic section in the strike direction at the location of the +30 level fan station and gateroad are shown in Figs. 5 and 6.

From the results of the model analysis, it is shown that the sigma 1 and sigma 3 stresses distributed in the model have results corresponding to the hypothesis that the stressincreases with depth (stratigraphic stress γH, where γ is the specific weight of rock mass, H is the depth of stress calculation point). With the above stress simulation results, we see that the model built to simulate shows the stress value increasing with depth, so it is consistent with the theory of vertical stress in the rock mass. Also, from the results of stratigraphic stress distribution in Figs. 5 and 6, we can see that the stresses of sigma 1 and sigma 3 increase gradually with the depth of the rock mass. At the surface of the model, the stress is equal to zero and gradually increases to the bottom of the model to a depth of −350 m; the stress sigma 1 is about 8.1 MPa, and the stress sigma 3 is about 4 MPa. Thus, the sigma 1 stress in the rock mass is about 2 times the sigma 3 stress.

3.2. Analysis of plastic deformation zones in the rock mass

3.2.1. The longwall cut 10 m and 20 m in the strike direction

Simulation results of the plastic deformation area in the rock mass when exploiting the longwall in seam H10 cut 10 m and 20 m in the strike direction are shown in Figs. 7 and 8.

Figure 7 shows that when the longwall cut 10 m in the strike direction, the plastic deformation process appeared in the rock mass around the longwall. But due to the small cutting length, the affected area is limited to the claystone layer, where adjacent to the

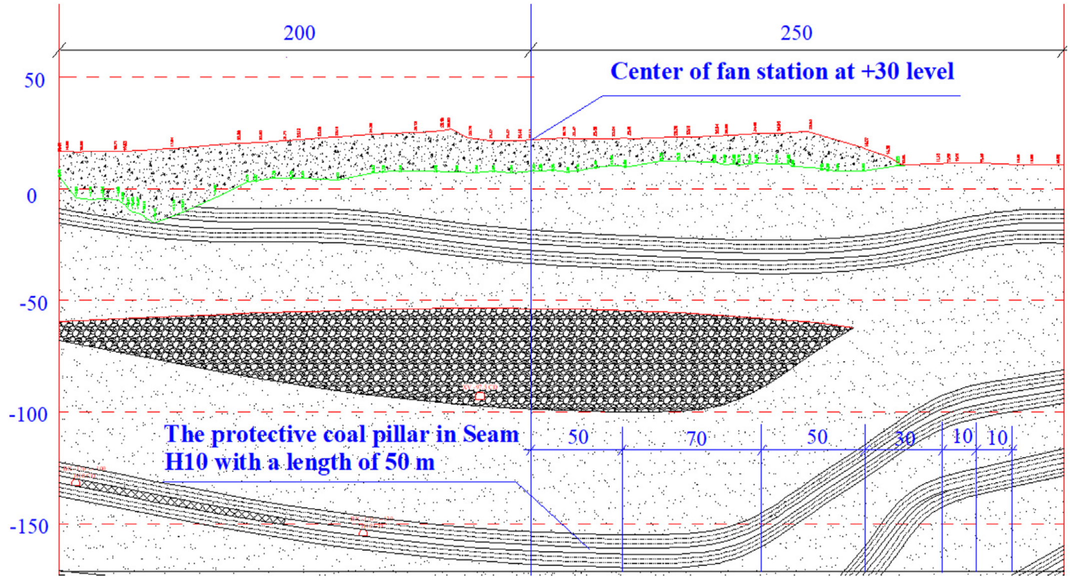

Fig. 4. Simulation steps for the mining process of the longwall in coal seam H10 at Mong Duong Coal Mine.

roof and floor of the longwall. At this time, the plastic deformation area is about 3 m. The simulation results in Fig. 8 shows the plastic deformation area in the rock mass when the longwall cut 20 m in the strike direction. The plastic deformation zone expands both vertically and horizontally; the plastic deformation zone develops strongly in the rock mass on the roof of the longwall. Because the length of the cutting is increased by 10 m, the affected area of plastic deformation begins to develop; the largest plastic deformation occurs in the middle of the roof of the longwall, about 5 m.

3.2.2. The longwall cut 50 m and 100 m in the strike direction

Simulation results of the plastic deformation area in the rock mass when exploiting the longwall in seam H10 cut 50 m and 100 m in the strike direction are shown in Figs. 9 and 10.

The simulation results in Fig. 9 show that when continuing to exploit 30 m of the seam H10 (i.e., the longwall cut 50 m in the strike direction), the plastic deformation area keeps developing and expanding vertically and horizontally in the rock mass, but the plastic deformation zone in the vertical rock mass develops more strongly than in the horizontal direction. This problem is explained by the fact that at this time, the mining distance is large enough that the rock layers on the roof of the longwall have collapsed, so the plastic deformation zone develops deeper into the rock mass above the roof. In this case, the extent of the plastic deformation zone is about 15 m. The simulation results in Fig. 10 show

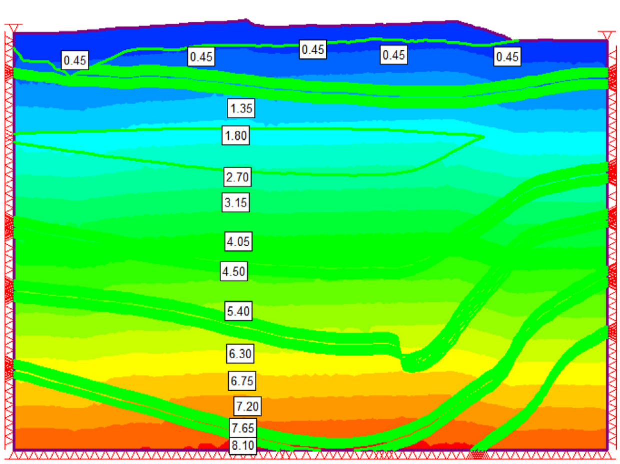

Fig. 5. Sigma 1 stratigraphic stress distribution, simulated cross-section in the strike direction.

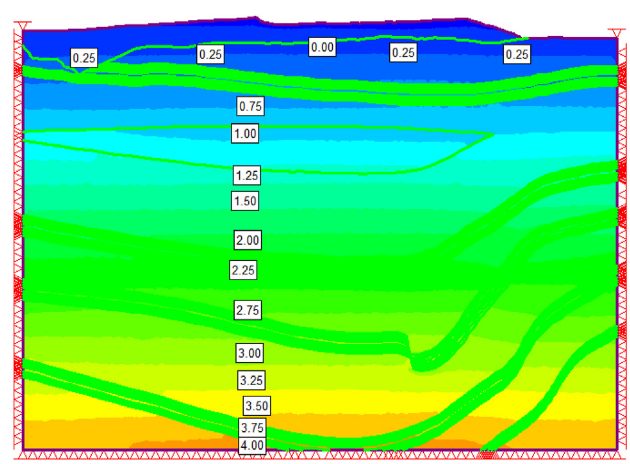

Fig. 6. Sigma 3 stratigraphic stress distribution, simulated cross-section in the strike direction.

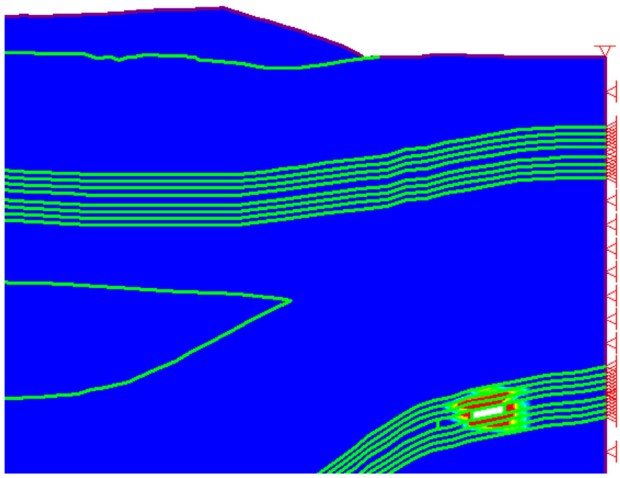

Fig. 7. Plastic deformation zone in the rock mass when the longwall cut 10 m in the strike direction.

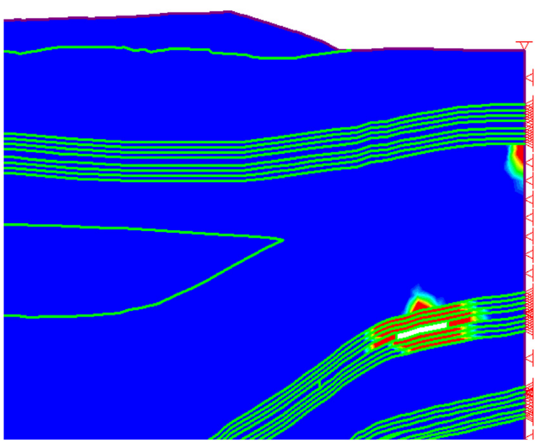

Fig. 8. Plastic deformation zone in rock mass when the longwall cut 20 m in the strike direction.

that when continuing to exploit 50 m of the seam H10 (i.e., the longwall cut 100 m in the strike direction), the plastic deformation area continues to

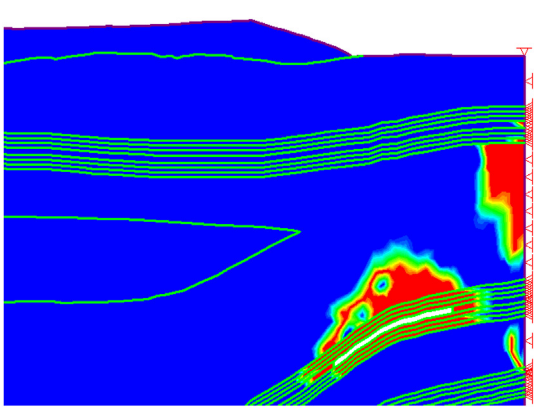

Fig. 9. Plastic deformation zone in rock mass when the longwall cut 50 m in the strike direction.

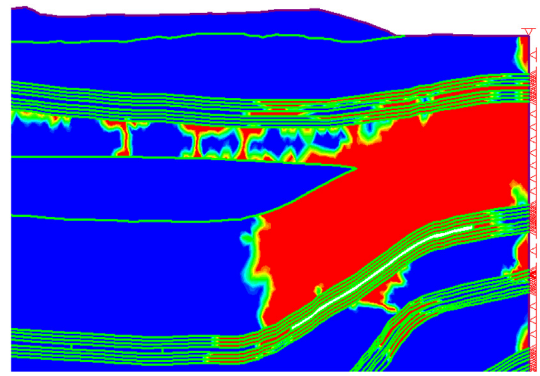

Fig. 10. Plastic deformation zone in rock mass when the longwall cut 100 m in the strike direction.

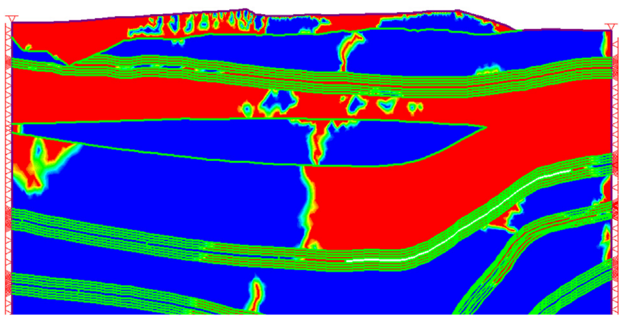

Fig. 11. Plastic deformation zone in rock mass when the longwall cut 170 m in the strike direction.

develop and expand. At this time, the plastic deformation area continued to expand into the siltstone layer on the roof of the longwall and began to develop into the claystone, coal layer of seam II.11 (seam II.11 is located above seam H10). In this case, the extent of the plastic deformation zone is about 50 m.

3.2.3. The longwall cut 170 m in the strike direction

Simulation results of the plastic deformation area in the rock mass when exploiting the longwall in seam H10 cut 170 m in the strike direction are shown in Fig. 11.

The simulation results in Fig. 11 show that when continuing to exploit 70 m of the seam H10 (i.e., the longwall cut 170 m in the strike direction), the plastic deformation area continues to develop and expand. At this time, the longwall is still about 50 m from the center of the fan station (in the vertical direction). This distance is the length of the protective coal pillar to ensure the safety of the fan station and the gateroad on the +30 level ground surface.

Table 2. Results of determining the height of the plastic deformation zone when exploiting the longwall in seam H10 at Mong Duong Coal Mine.

№	The longwall cut length in the strike direction (m)	Height of plastic deformation zone in rock mass (m)
1	10	3
2	20	5
3	50	15
4	100	50
5	170	61

The analysis results from Figs. 7–11 are summarized in Table 2.

3.3. Model analysis to determine the subsidence area in the rock mass

3.3.1. The longwall cut 10 m in the strike direction

Simulation results of the subsidence area in the rock mass when exploiting the longwall in seam H10 cut 10 m in the strike direction are shown in Fig. 12.

The simulation results show that after exploiting the longwall in seam H10 cut 10 m in the strike direction, there is small subsidence around the longwall area. At this time, the subsidence area is concentrated only on the roof of the longwall in the claystone layer, while the layers deep inside the rock mass have not been affected. The simulation results also show that the total value of subsidence in the rock mass at all locations near the ground and the fan station and gateroad at +30 level is zero.

3.3.2. The longwall cut 20 m in the strike direction

Simulation results of the subsidence area in the rock mass when exploiting the longwall in seam H10 cut 20 m in the strike direction are shown in Fig. 13.

The simulation results show that after exploiting the longwall in seam H10 cut 20 m in the strike direction, the subsidence area of the longwall developed and expanded into the rock mass on the roof, the subsidence value on the roof of the longwall has increased, but also only appear mainly in the rock layers near the longwall, and there has been no subsidence at the location near the ground. The simulation results also show that the total value of subsidence in the rock mass at all locations near the ground and the fan station and gateroad at +30 level is zero.

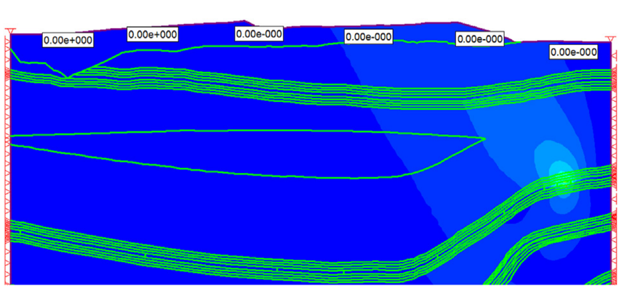

Fig. 12. The subsidence zone in rock mass when the longwall cut 10 m in the strike direction.

3.3.3. The longwall cut 50 m in the strike direction

Simulation results of the subsidence area in the rock mass when exploiting the longwall in seam H10 cut 50 m in the strike direction are shown in Fig. 14.

The simulation results show that after exploiting the longwall in seam H10 cut 50 m in the strike direction, the subsidence area continues to expand deep into the rock mass and spread out over the rock mass near the ground. The rock mass near the ground has small subsidence, and its value at different locations is different. At the east side location near the mining area, the largest subsidence value is 1 mm, while at other locations, it is about 0.075 mm. Thus, when the longwall cut 50 m in the strike direction, the rock mass near the ground begins to be affected but not significantly, so it does not affect the fan station and the gateroad at the +30 level.

3.3.4. The longwall cut 100 m in the strike direction

Simulation results of the subsidence area in the rock mass when exploiting the longwall in seam H10 cut 100 m in the strike direction are shown in Fig. 15.

The simulation results show that after exploiting the longwall in seam H10 cut 100 m in the strike direction, the subsidence area continues to expand above the rock mass near the ground. The rock mass near the ground continues to subside; the subsidence value is also different at different locations. At the location on the east side near the mining area, the largest subsidence value is 3.85 mm. At the fan station and the gateroad, the subsidence value is 1.4 mm, and at other locations, the subsidence value is about 0.035–0.07 mm. Thus, when the longwall is cut 100 m in the strike direction, the rock mass near the ground will continue to be affected but not significantly, so it does not have an impact on the fan station and the gateroad at the +30 level.

3.3.5. The longwall cut 170 m in the strike direction

Simulation results of the subsidence area in the rock mass when exploiting the longwall in seam H10 cut 170 m in the strike direction are shown in Fig. 16.

The simulation results show that after exploiting the longwall in seam H10 cut 170 m in the strike direction, leaving a protective coal pillar far from the

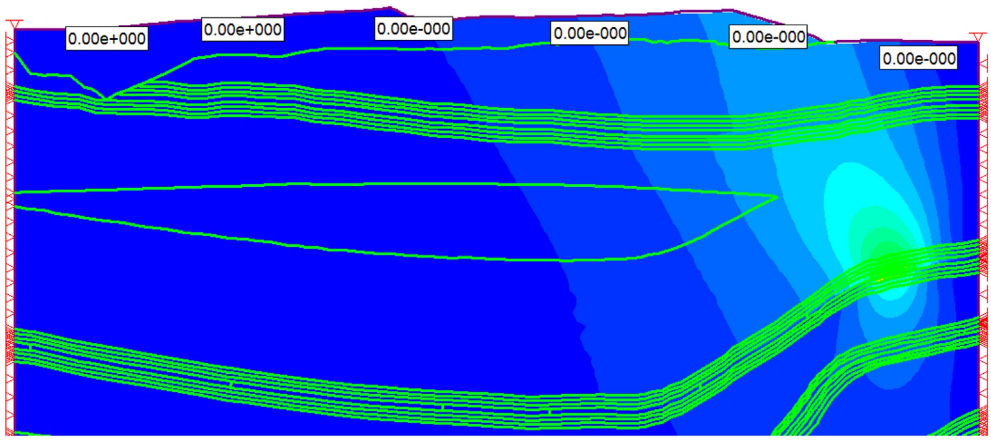

Fig. 13. The subsidence zone in rock mass when the longwall cut 20 m in the strike direction.

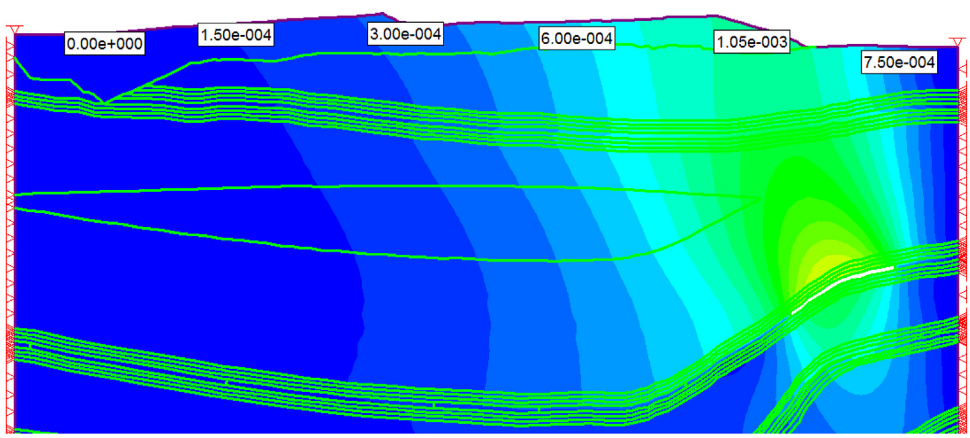

Fig. 14. The subsidence zone in rock mass when the longwall cut 50 m in the strike direction.

fan station and the gateroad at +30 level is about 50 m (in the vertical direction), the rock mass near the ground continue to subside. The subsidence value at different locations is also different; at the east side location near the mining area, the largest subsidence value is 1.05 cm, and at the fan station and the gateroad location, the subsidence value is 6 mm. Thus, it can be seen that when the longwall cut 170 m in the

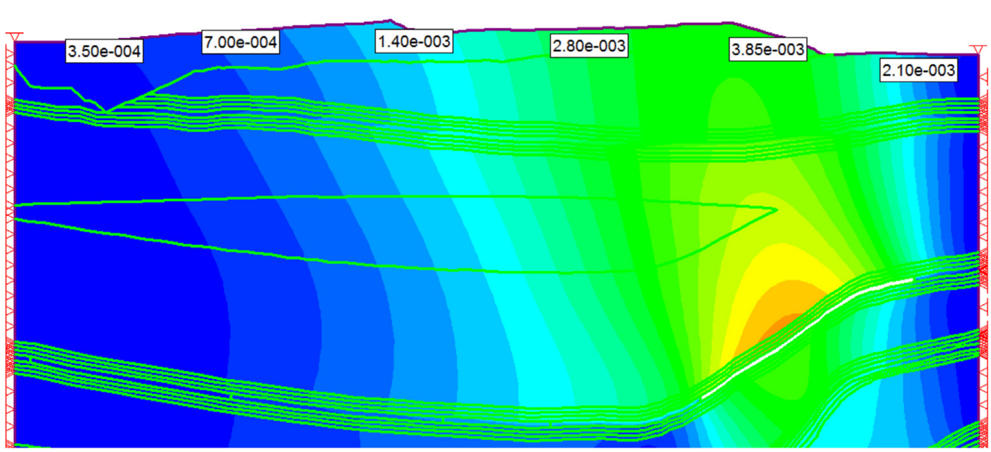

Fig. 15. The subsidence zone in rock mass when the longwall cut 100 m in the strike direction.

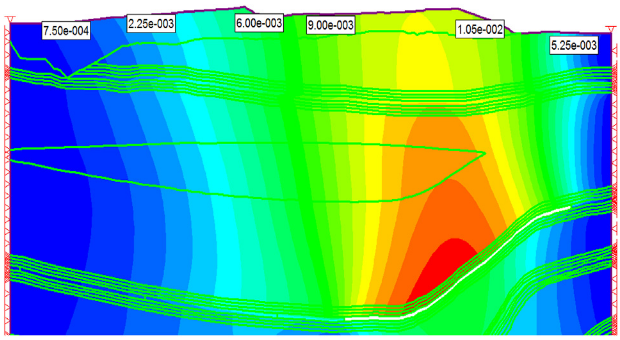

Fig. 16. The subsidence zone in rock mass when the longwall cut 170 m in the strike direction.

Table 3. Results of determining the depth of subsidence on the ground when exploiting the longwall in seam H10 at Mong Duong Coal Mine.

№	The longwall cut length in the strike direction (m)	Depth of subsidence on the ground (mm)
1	10	0.0
2	20	0.0
3	50	0.075–1.0
4	100	0.035–3.85
5	170	1.05–6.0

strike direction, the rock mass near the ground continues to be displaced, but the displacement value is also insignificant. The above simulation results indicate that when exploiting the longwall in seam H10 cut 170 m in the strike direction and leaving a protective coal pillar of 50 m, it will not affect the fan station and the gateroad at +30 level.

The analysis results from Figs. 12–16 are summarized in Table 3.

4. Conclusions

On the basis of RS^2 software, geological conditions, the geological cross-section of the fan station area, and the gateroad at +30 level, the authors have established a numerical simulation model of the re-exploiting process of the longwall in coal seam H10 at Mong Duong Coal Mine. Based on those simulation models, the authors analyzed and evaluated the stability of the rock mass near the ground and the surface construction works at +30 level (including fan station and gateroad) at Mong Duong coal mine.

The results of numerical simulation model analysis show that when the longwall cut is 50 m in the strike direction, the stability of the rock mass near the ground begins to be affected. When the longwall cut is 170 m in the strike direction, at this time the length of the protective coal pillar left is about 50 m (to the center of the fan station), then the rock mass on the ground where the fan station and the gateroad at +30 level has a maximum subsidence depth of about 6 mm. However, because the fan station is solidly built with reinforced concrete, the gateroad is also built and supported by concrete, so this subsidence value of the rock mass near the ground will not affect the fan station and gateroad at +30 level.

The research results of the article are a reliable basis for Mong Duong Coal Mine to consider and apply in actual production. At the same time, it is also used as a basis for Mong Duong Coal Mine to evaluate and adjust the solution to re-exploit the longwall in seam H10 to ensure safety and achieve the best efficiency.

Ethical statement

The authors state that the research was conducted according to ethical standards.

Funding body

None.

Conflicts of interest

None declared.

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