Determination of the movement and deformation areas of strata when exploiting longwall of Seam 11 under the open-pit mine at Ha Lam Coal Mine, Vietnam

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Abstract. Exploiting the face under the finished open-pit area always has potential risks of unsafety. It can be the risk of water flowing into the face or the occurrence of water cracking and mud, which is a very dangerous phenomenon in mining. The larger the dimension of the influence area of exploiting the face is, the greater the risk of water problems entering the face is. Through the assessment and analysis of the coal exploitation at the synchronized mechanized face of Seam 11 located under the open pits that have finished exploitation at the Ha Lam coal mine, the article has determined the movement and deformation areas of strata in the surrounding area to assess the influence of water in the open pit into the face. In order to avoid the risk of water cracking, the impact of these risks on the workers' safety and the exploiting process, the determination of the movement and deformation areas of surrounding rocks when exploiting the longwall face of the coal Seam 11 is very necessary for the Ha Lam coal mine. By collecting and analyzing geological conditions of the rocks around the face, combined with numerical modelling methods, the author has determined the dimension of the collapse and cracking areas when exploiting the face. The results of the research from this article have helped the Ha Lam coal mine take the initiative to choose and organize a rational mining solution. On that basis, it is possible to prevent the influence of water in an open-pit mine to ensure safety during exploiting the face of coal Seam 11.

1. Introduction
Ha Lam coal mine is one of the largest and most modern underground mines in Vietnam. Because the upper part of some coal seams are exploited by the open-pit mining method, when the mining part ends, open-pit pits will be formed [1]. According to calculations and forecasts, although the open pits have been dumped, they still contain a large amount of water, especially in the rainy season [2]. Therefore, when mining work continues by underground mining method in the area under these open pits, there will be many potential risks and insecurity, especially the risk of water cracking and mud [3, 4]. Currently, in a number of mines in the Quang Ninh coalfield, including Ha Lam coal mine, which is facing many difficulties in exploiting the seams, the coal reserves located under the open pit have finished exploitation. This is a problem that is not only concerned by the leaders of the mines, but also by the leaders of the Vietnam National Coal – Mineral industry Corporation [5, 6].
The longwall of Seam 11 in the Ha Lam coal mine is located under the area of open pits, including pit -54; -80; -60. The stratigraphic distance to the bottom of the pit is about 100 ÷ 120 m, the stratigraphy consists of a layer of siltstone lying on the coal seam with a thickness of about 5 ÷ 6 m, followed by a layer of sandstone with a thickness of about 5 ÷ 18 m, above the sandstone layer is the gravel layer has a thickness of about 15 ÷ 35 m, above the gravel layer is a layer of siltstone mixed with sandstone with a thickness of about 12 ÷ 40 m [7]. The exploitation of this seam leads to unsafe risks such as: subsidence; surface deformation; the mine pressure in the mining area affecting the roadways are very complicated, as well as the phenomenon of the influence of the water contained in the open pit on the underground mine is very large, the risk of the water cracking, mud in the mine. In order to avoid potential water risks, it is necessary to observe, forecast and calculate the height of the collapse area and the fractured area when exploiting Seam 11 of the Ha Lam coal mine [8]. On that basis, it is possible to assess the level of influence of water on mining. In this paper, the author uses the numerical modeling method, by using UDEC software to monitor and determine the height of collapse and cracking of the roof when exploiting the longwall of Seam 11. Input parameters of rock and coal conditions are collected from the actual mine, build a model and conduct model analysis on the basis of the mining plan of the respective longwall.

The analysis and observation results from the numerical model have determined the height of the movement and deformation zones of the roof corresponding to the displacement in the strike direction of the longwall. This research result is also the basis for the Ha Lam coal mine to be proactive in deploying and choosing a reasonable mining plan for the conditions of the coal mine.

2. Characteristics of geological conditions of the longwall of Seam 11 and the current status of open pits of Ha Lam coal mine

2.1. Characteristics of geological conditions of the longwall of Seam 11
- Thickness of seams: 12 m;
- Average slope angle: 80°;
- Exploiting height of the longwall: 2.6 m;
- The length of the longwall in the dip direction: 118.5 m;
- The length of the longwall in the strike direction: 550 m;
- Immediate roof: The Immediate roof is siltstone with a thickness varying from 5.0 ÷ 12.0 m, with an average thickness is 8.0 m. Compressive strength 110 ÷ 2104 kG/cm², average 613 kG/cm². Average volumetric weight 2.65 g/cm³.
- Main roof: The Main roof is sandstone with a thickness is from 23 ÷ 48 m, the average is 30 m. Compressive strength 113 ÷ 3132 kG/cm², average 1188 kG/cm². Average volumetric weight 2.62 g/cm³ [9].
- According to the current status of the mining area of Seam 11, the area with potential risk of water cracking of the longwall is located in the distance between the T40 and the T50 with a length of about 163 m (figure 1), in which the area of the longwall is directly located at the bottom of the open pit -54 from the first position of the longwall, which is about 93 m [9].

2.2. Mining technology of the longwall of Seam 11 in the Ha Lam coal mine

In order to exploit the condition of thick seams, gently sloping, Ha Lam coal mine has applied the diagram of mining technology of the longwall advancing methods, cut coal by the shearer, protect the longwall by shield support, and transport coal by scraper conveyors (figure 2). The specific combination of equipment used in the longwall is as follows:
Figure 1. Cross-section IV-IV.

Figure 2. A group of equipment used in the longwall of coal Seam 11 – Ha Lam Coal Mine [10].

- Shield of type ZF4400/16/28, the height of the shield is 1.6 ÷ 2.8 m. The number is 73 shields;
- Shield of type ZFG4800/18/28, the height of the shield is 1.8 ÷ 2.8 m. The number is 6 shields;
- Shearer of type MG150/375-W. Designed capacity 500 tons/h;
- Scraper conveyors coded SGZ 630/264. Designed capacity 600 tons/h.
- In addition to the main equipment mentioned above, the synchronous equipment in the longwall also has a number of other equipment such as emulsifying pump station, winch, etc. figure 3 shows the actual coal mining process in the mechanized longwall of Seam 11 of the Ha Lam coal mine.
2.3. Current status of exploited open pits

The waste dump in the Seam 14 at West Side is dumped by Ha Lam and Nui Beo mines, which is currently at +160 m in the southwest, while the design level is +70 m. The waste dump area in the Seam 14 at West wing includes 03 open pits that have been finished and 01 open pits that is being exploited, specifically as follows:

- Open-pit mining of Seam 14 at West Side at level -80 has finished mining and dumped waste to the level of +30. Open-pit mining is located on the longwall CGH11-1.16, the stratigraphic distance from the longwall to the bottom of the pit is about 85 ÷ 100 m, the stratigraphy consists of a siltstone layer lying on the coal seam with a thickness of about 5 ÷ 12 m, followed by a sandstone layer, the gravel has a thickness of about 15 ÷ 60 m, above the sandstone layer, the grit is a layer of siltstone with a thickness of about 20 ÷ 60 m.

- Open-pit mining of Seam 14 at West Side at level -60 has finished mining and dumped waste to the level of +35. Open-pit mining is located on the longwall CGH11-1.16, the stratigraphic distance from the longwall to the bottom of the pit is about 120 ÷ 150 m, the stratigraphy consists of a siltstone layer lying on the coal seam with a thickness of about 8 ÷ 12 m, followed by a sandstone layer with a thickness of about 50 ÷ 70 m, above the sandstone layer is a layer of siltstone with a thickness of about 40 ÷ 50 m, above the sandstone layer is a layer of sandstone with a thickness of about 20 ÷ 50 m.

- Open-pit mining of Seam 14 at level -53 has finished mining and dumped waste to +40 level. Open-pit mining is located on the longwall 11-3T-13, the stratigraphic distance from the longwall to the bottom of the pit is about 140 ÷ 180 m, the stratigraphy consists of a siltstone layer lying on the coal seam with a thickness of about 5 ÷ 11 m, followed by a layer of sandstone with a thickness of about 38 ÷ 40m, above the sandstone layer is a layer of siltstone with a thickness of about 60 ÷ 100 m.

- Open-pit mining of Seam 14 at West Side at level -54 (figure 4). Open-pit mining is located on the longwall CGH11-1.16, the stratigraphic distance from the longwall to the bottom of the pit is about 100 ÷ 120 m, the stratigraphy consists of a siltstone layer lying on the coal seam with a thickness of about 5 ÷ 6 m, followed by a sandstone layer with a thickness of about 20 ÷ 50 m, above the sandstone layer is a layer of siltstone with a thickness of about 60 ÷ 100 m.
thickness of about 5 ÷ 18 m, above the sandstone layer is a layer of gravel with a thickness of about 15 ÷ 35 m, above the gravel layer is a layer of siltstone mixed with sandstone with a thickness of about 12 ÷ 40 m.

The work of dumping waste at this landfill in recent years has been carried out in the form of a circumference, dumping in the order of exploitation (when the mining is finished, dump the waste there), the height of the waste layer is from 30 ÷ 50m, almost no floor has entered the end position [11].

Figure 4. Open pit bottom of Seam 14 at West Side.

3. Characteristics of hydrogeological conditions around the area of the longwall of Seam 11
Within the study area, the reserves of Seam 14 are exploited by the open-pit method of the Nui Beo coal mine. Mining has destroyed the original topography, creating on the topography open pit and dumps that can be placed for water to accumulate. The reserve of Seam 11 below the upper pits has been mobilized by Ha Lam coal mine to exploit by the underground method according to the planning of the build mining investment project below -50 Ha Lam coal mine. The coal seam in this area belongs to the type of thick and gentle seams, exploited and using the roof control method by full caving, thus creating collapsed and cracked areas capable of developing from the ground to the topographic surface, if the mining depth is not too large [12–14].

Synthesized hydrogeological conditions in the area can be commented that the water source affecting underground mining is mainly water from open pits that have been exploited with a flow of about 500 000 m$^3$ [15]. Therefore, in the process of preparing and exploiting the longwall of Seam 11 in Ha Lam coal mine located under the open pits of Seam 14 in Nui Beo coal mine, it is necessary to have solutions to prevent the risk of water cracking into the longwall. In order to choose reasonable solutions, it is necessary to study and assess the risk of water cracking from the upper open pits into the longwall of Seam 11.

4. Determination of the movement and deformation areas of strata when exploiting longwall of Seam 11 under the open pit mine at Ha Lam coal mine
4.1. Proposing mining options to determine the movement and deformation areas
Option 1: the exploitation height of the longwall is 2.6 m, recovering 90 percent (equivalent to
9.4 m). With a Seam 11 thickness is 12 m, the exploitation height of the longwall is 2.6 m, recovering 9.4 m (90 percent of top coal. Continuously cutting in 3 production shifts (one web cut for each), the longwall advance is 1.8 m/day (corresponding to 3 web cuts/day).

Option 2: the exploitation height of the longwall is 2.6 m, recovering 50 percent (equivalent to 4.2 m).

With a Seam 11 thickness is 12 m, the exploitation height of the longwall is 2.6 m, recovering 4.2 m (50 percent of top coal. Continuously cutting in 3 production shifts (one web cut for each), the longwall advance is 1.8 m/day (corresponding to 3 web cuts/day).

Option 3: the exploitation height of the longwall is 2.6 m, not recovering of top coal.

With a Seam 11 thickness is 12 m, the exploitation height of the longwall is 2.6 m, not recovering of top coal. Continuously cutting in 3 production shifts (one web cut for each), the longwall advance is 1.8 m/day (corresponding to 3 web cuts/day).

4.2. The basis for determining the movement and deformation areas corresponding to the above options

- Determine the distance of the collapsed and the fractured areas in the roof area of the longwall of Seam 11, corresponding to the above options, and compare it with the distance from the bottom of the pit to the mining location of the longwall. From there, assess the risk of water cracking into the longwall from the open pit mining above Seam 11.
- Determine the caving step of the roof in order to propose mining solutions to ensure safety when mining the longwall face of Seam 11 under the open pit at Ha Lam coal mine.
- Ensure the safe height from the cracked area when exploiting the longwall to the bottom of the open pit.

4.3. Building simulation numerical model

Based on geological conditions, the results of determining the physico-chemical parameters of the roof and floor rock in the mining area (shown in table 1 [16]), using UDEC 3.1 software (Universal Distinct Element Code) to build numerical modeling monitoring the state of the roof when mining the longwall. Based on the physicochemical parameters of the roof and floor rock in the mining area, UDEC software is applied to build numerical modeling to monitor the mining process of the longwall of Seam 11 with dimensions of 210 x 210. Corresponding to the three options proposed in Section 4.1 above, exploiting the height of the longwall is 2.6 m with the recovery rates of top coal including 90 percent; 50 percent and not recovering. figure 5 shows the simulation of UDEC 3.10 software and the CGH48 borehole stratigraphic column of Seam 11 in the Ha Lam coal mine. figure 6 shows the simulation of the monitoring process of the roof when exploiting the longwall.

Based on the analysis results from UDEC 3.1 software, determine the distance of the collapse area, the distance of the fracture zone of each of the above options, compare with the distance from the bottom of the pit to the mining location to evaluate the influence of the water from the open pit on mining work at the Seam 11 in Ha Lam coal mine.

4.4. Analyze the results from the numerical model

Based on the analysis results from UDEC 3.1 software, determine the distance of the collapse step of the roof, the height of the collapse and the cracking of the roof of the longwall of Seam 11. Based on the results of the monitoring model, the dimension shows collapse and cracking of the
Table 1. Analytical results of the roof and floor rock of Seam 11.

| Rock unit | Value | Compression resistance strength (kG/cm²) | Tensile strength (kG/cm²) | Internal friction angle (°) | Cohesive force (g/cm³) | Volumetric weight (g/cm³) | Specific weight (g/cm³) |
|-----------|-------|------------------------------------------|---------------------------|----------------------------|------------------------|--------------------------|------------------------|
| gravel (Roof) | Max | 3255.00 | 149.06 | 35°00′ | 590.00 | 2.63 | 2.67 |
| gravel (Floor) | Min | 1052.80 | 89.18 | 33°30′ | 339.00 | 2.50 | 2.62 |
| gravel (Floor) | Medium | 1595.49 | 118.26 | 34°50′ | 436.71 | 2.58 | 2.65 |
| Sandstone (Roof) | Max | 1559.02 | 164.00 | 35°30′ | 525.00 | 2.80 | 2.81 |
| Sandstone (Floor) | Min | 173.01 | 26.88 | 26°00′ | 39.00 | 2.53 | 2.60 |
| Sandstone (Floor) | Medium | 927.35 | 93.64 | 33°34′ | 311.14 | 2.65 | 2.70 |
| Siltstone (Roof) | Max | 1726.00 | 128.00 | 38°27′ | 330.00 | 3.06 | 3.12 |
| Siltstone (Floor) | Min | 110.84 | 24.21 | 16°00′ | 38.50 | 2.47 | 2.54 |
| Siltstone (Floor) | Medium | 521.78 | 55.38 | 32°27′ | 145.42 | 2.66 | 2.74 |
| Claystone (Roof) | Max | 230.68 | 30.45 | 32°06′ | 68.00 | 2.80 | 2.86 |
| Claystone (Floor) | Min | 166.88 | 24.52 | 30°00′ | 53.00 | 2.62 | 2.68 |
| Claystone (Floor) | Medium | 206.22 | 27.35 | 31°12′ | 62.00 | 2.70 | 2.75 |
| gravel (Floor) | Max | 1536.91 | 139.19 | 35°00′ | 460.00 | 2.65 | 2.69 |
| gravel (Floor) | Min | 800.13 | 77.71 | 33°56′ | 244.00 | 2.56 | 2.64 |
| gravel (Floor) | Medium | 1198.45 | 107.24 | 34°22′ | 361.00 | 2.60 | 2.67 |
| Sandstone (Floor) | Max | 2811.42 | 238.00 | 35°35′ | 900.00 | 2.79 | 2.81 |
| Sandstone (Floor) | Min | 127.00 | 42.00 | 31°45′ | 138.00 | 2.52 | 2.63 |
| Sandstone (Floor) | Medium | 1061.93 | 102.37 | 34°16′ | 347.26 | 2.66 | 2.71 |
| Siltstone (Floor) | Max | 1402.80 | 106.20 | 38°56′ | 420.00 | 3.57 | 3.59 |
| Siltstone (Floor) | Min | 172.55 | 5.86 | 27°30′ | 53.00 | 2.02 | 2.35 |
| Siltstone (Floor) | Medium | 472.90 | 51.12 | 32°37′ | 134.75 | 2.65 | 2.73 |
| Claystone (Floor) | Max | 1987.00 | 76.50 | 33°54′ | 116.00 | 2.76 | 2.84 |
| Claystone (Floor) | Min | 103.00 | 22.30 | 29°30′ | 43.00 | 2.44 | 2.55 |
| Claystone (Floor) | Medium | 460.18 | 34.66 | 31°49′ | 71.14 | 2.60 | 2.69 |

options for depreciation and recovery when the longwall moves in the corresponding direction, specifically as follows:

Option 1: the exploitation height of the longwall is 2.6m, recovering 90 percent (equivalent to 9.4 m)  
When the longwall is cut in the strike direction corresponding to specific lengths, the movement of the longwall is monitored, and the model shows the results of the roof collapse and the corresponding crack formation process. In figure 7 the process of collapse and cracking of the roof when the longwall moves 95 m.  
The results from the model show that when the longwall is cut in the 95 m strike direction, the height of collapse and cracking of the roof is from 65 ÷ 70m. However, in this option, some cracks develop to the bottom of the open pit, potentially posing
Figure 5. Simulation of UDEC 3.10 software and CGH48 borehole stratigraphy column of Seam 11 in Ha Lam coal mine.

Figure 6. Simulation of the process of monitoring the longwall when mining [12].

Option 2: the exploitation height of the longwall is 2.6m, recovering 50 percent (equivalent to 4.2 m). The monitoring results on the model of this option are shown in figure 8. The results from the model show that when the longwall is cut in the 95 m strike direction, the height of collapse and cracking of the roof is from 55 ÷ 60m. However, in this option, some cracks develop to the bottom of the open pit, potentially posing a risk of unsafety when mining.

Option 3: the exploitation height of the longwall is 2.6m, without recovering of top coal. The monitoring results on the model of this option are shown in figure 9. The results from the model show that when the longwall is cut in the 95 m strike direction, the height of collapse and cracking of the roof is from 50 ÷ 55 m.

5. Results and discussion
Based on the results of the monitoring model, the height of collapse and cracking of the mining and recovery options when the longwall of Seam 11 when cutting 95 m in the strike direction is shown in table 2.

However, in option 2, and option 3, when cutting 95 m in the strike direction, there is a crack that develops to the bottom of the open pit -80, which will pose a potential risk of unsafety in exploitation.

Option 3 exploits the height of the longwall is 2.6 m, does not recover the top coal, this option
Figure 7. Status of the roof of the longwall of Seam 11 when cutting 95 m in the strike direction (Option 1).

Figure 8. Status of the roof of the longwall of Seam 11 when cutting 95 m in the strike direction (Option 2).

has the monitoring results on the model indicating that it is safer than the two options above. However, this is the option with the largest coal loss among the three options.
6. Conclusions
Through the combined results of the article, the author analyzed the actual conditions of the longwall using the mechanized mining technology of Seam 11 in the Ha Lam coal mine. Based on the proposed 3 mining options, the author calculated and forecasted the height of the movement and deformation zones of the roof. This result is observed for each mining option of the longwall by numerical modeling method, the documents for building the numerical model are provided by the Ha Lam coal mine, so it has the necessary reliability.

The research results of the article can serve as a basis for the Ha Lam coal mine to consider forecasting the movement and deformation height of the roof when exploiting the longwall of Seam 11 for each of the above mining options. Based on the assessment and monitoring of hydrogeological conditions, as well as the calculation of the water flow stored in the open pit, Ha Lam coal mine can choose a reasonable exploitation plan for the longwall of Seam 11. In the process of exploiting the longwall, it is necessary to continue to monitor and evaluate the water appearing in the longwall, and at the same time maintain an appropriate drainage solution, if any abnormality is found, it is necessary to have timely solutions.

The rational exploitation plan applied at the longwall of Seam 11 in the Ha Lam coal mine will bring high efficiency and meet the requirements of actual production. On that basis, improve
the ability to use the equipment effectively, improve the safety in the mining operation of the longwall, and prevent the occurrence of water and mud problems. Therefore, the exploitation of coal seams under the open pit area is an extremely necessary problem. The combined results of the article can also serve as a document for researchers in the field of coal mining technology in the Quang Ninh coalfield.

Acknowledgments
The author would like to thank the Board of Directors of two Ha Lam and Nui Beo coal mines in Quang Ninh coalfield, Vietnam for creating favorable conditions, providing data, and surveying the field for the author to complete this study.

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