



Identification of the Rock Pressure when Excavation Tunnels Underneath the 790 Open-Pit Mine Edge in the Mong Duong Coal Mine, Vietnam

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Abstract

Studying and identification rock pressure when excavation tunnels are very necessary. Calculating the rock pressure will help us to choose the suitable type of support, thereby building a reasonable support plan. The Mong Duong Coal Mine is one of the coal mines in Quang Ninh coalfield with part of its reserves or coal seams located under the edge of the open-pit mine that has ended exploitation. So, it is very difficult and complicated to excavate and support, as well as calculate the rock pressure for the tunnels arranged under this area. If the excavation and support methods are not good, potential unsafe risks may occur. One of the most dangerous phenomena may occur, that is the phenomenon of sudden inrush into the tunnel.

In this paper, the numerical simulation method was used. On the basis of Phase2 software and geological conditions of the Mong Duong Coal Mine, the authors established a simulation model to identify the rock pressure acting on the tunnels that are located underneath the open-pit mine edge area. Through the actual study at Mong Duong Coal Mine, the authors calculated the rock pressure when excavation the tunnels underneath the 790 open-pit mine edge of the Seam L7 at West Side at -50 level. The 790 open-pit mine is located on the longwall in the Seam L7.

The findings of the study serve as the foundation for the practical application at the Mong Duong Coal Mine. On the basis of calculating the rock pressure acting on the tunnels at the coal Seam L7, from which the tunnel support plan has been developed. This research method will also serve as a basis for other mines with similar geological conditions in Quang Ninh coalfield to consider and apply.

Keywords: rock pressure, tunnels, numerical modeling method, open-pit mine, Mong Duong Coal Mine

1. Introduction

The process of excavating and protecting tunnels located under open-pit mine that have been completed and filled with waste rock often encounters many difficulties and complications. When open-pit mine was filled with waste rock, forming a complex geological structure in this area, the stability of waste rock in the open-pit mine depends on many factors such as dumping method, type of waste rock, dumping time, etc. [1]. Therefore, calculating the rock pressure acting on tunnels under open-pit mine is often more difficult because it is affected by many different factors. To ensure safe and effective exploitation of coal seams located under open-pit mine, not only is a suitable mining technology solution needed, but also a reasonable support solution is needed to protect and maintain those tunnels. Calculating and determining the rock pressure acting on the tunnel is one of the most important bases for selecting and establishing an effective tunnel support passport that meets the requirements for use in actual mine production [2].

In reality, although the open-pit mine has been completed and filled with waste rock and soil, according to monitoring, forecasting and calculating, the amount of water in the open-pit mine is very large. Thus, the amount of groundwater is also one of the other complex factors that make it more difficult to calculate and determine the mine pressure acting on the tunnel [3]. Under normal conditions, to avoid groundwater flowing into the tunnel, or causing sudden inrush and mud, the solution to drain groundwater in the open-pit mine out of the mining

area and the tunnel is the safest and most effective solution. In underground coal mining, the phenomenon of sudden inrush into the longwall or tunnel is one of the most dangerous phenomena. This is an extremely complex phenomenon because it can not only endanger people, equipment, destroy the tunnel, but also lead to heavy economic losses.

Mong Duong Coal Mine is one of the mines exploited by underground mining method in Quang Ninh coalfield. This is also one of the coal mines with coal seams exploited under the open-pit mine area that has ended exploitation. This problem is currently facing many difficulties due to the complexity of the stratigraphy of the dumped rock layers and the hydrogeological conditions under the open-pit mine area. In fact, the phenomenon of sudden inrush into the tunnel has occurred many years ago at Mong Duong Coal Mine. Every year, research and finding solutions to prevent potential risks of sudden inrush is still carried out at this mine. The 790 open-pit mine at Mong Duong Coal Mine has been exploited and has been filled with waste rock and soil, the bottom of this open-pit is at -25, the groundwater level through monitoring is at +15. Because the dumping was carried out for a long time, this area formed a very large waste dump with a height of up to hundreds of meters. Below the 790 open-pit mine area, there are a number of coal seams that will be exploited by underground mining method according to the plan of Mong Duong Coal Mine [4]. Of which, the Seam L7 is exploited first, to ensure safety during the longwall mining process in the Seam L7, the tunnels also need to have a rea-

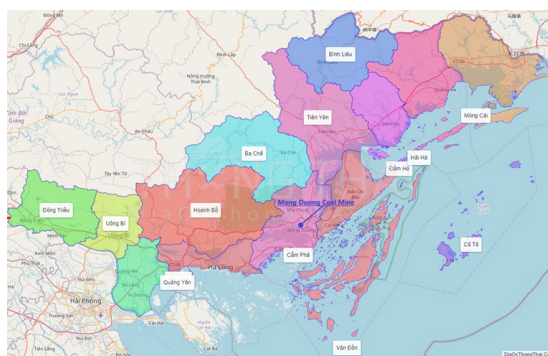


Fig. 1. The geographic position of Mong Duong Coal Mine (modified from [32])

Rys. 1. Położenie geograficzne kopalni węgla Mong Duong (zmodyfikowane na podstawie [32])

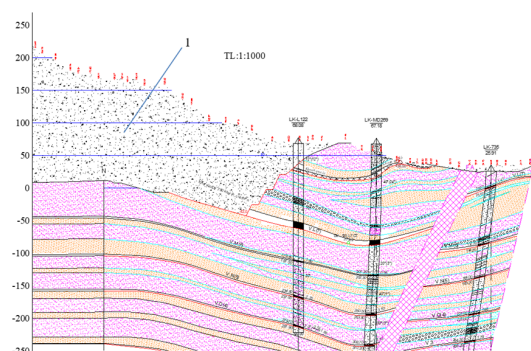


Fig. 2. The typical geological cross-section of the 790 open-pit mine filled with waste rock [33]. 1 – The 790 open-pit mine area of the Mong Duong Coal Mine

Rys. 2. Typowy przekrój geologiczny kopalni odkrywkowej 790 wypełnionej skałą płonną [33]. 1 – Obszar kopalni odkrywkowej 790 kopalni węgla Mong Duong

sonable support plan to meet production requirements. This means that it is necessary to calculate and determine the rock pressure acting on the tunnel under the edge of the 790 open-pit mine area, from which to choose the appropriate support type as well as establish a support passport for this tunnel.

Currently, there are many methods for calculating and determining the rock pressure acting on the tunnel, depending on each condition, the appropriate method is selected for application. There are many studies on the mine pressure acting on the tunnel, selecting the type of support, as well as establishing a support passport. Some typical studies on assessing the stress of the rock mass around the tunnel [5, 6, 7], determining the impact of tunnel excavation on the surface, assessing the geological conditions when digging the tunnel [8, 9, 10], assessing the deformation of the tunnel and improving the effectiveness of the support by numerical modeling [11, 12, 13, 14], studying the stability of the rock mass around underground works [15, 16, 17].

In Vietnam, research related to rock pressure has also been conducted using many different methods. Some typical studies in recent years have also been carried out in the Quang Ninh coalfield such as determining the impact of tunnel excavation on the surface [18, 19, 20], selecting support for the tunnel under soft rock conditions [21, 22], determining the rock mass load and rock mass stability using numerical models [23, 24, 25], evaluating mine pressure and blasting efficiency during tunnel excavation [26, 27], and determining rock pressure under the waste dump, determining tunnel protection pillars [28, 29, 30, 31].

The above domestic and foreign studies have mentioned the method of calculating and determining rock pressure,

solutions for selecting tunnel support, solutions for assessing the stability of rock mass as well as determining the impact of the tunnel excavation process on surface structures, solutions for assessing the stability of tunnels excavated under the waste dump area. However, the research, survey of tunnels, as well as calculation and determination of rock pressure for tunnels under the open-pit mine area at Mong Duong Coal Mine have not been carried out. Therefore, it is necessary to assess the current situation and determine the rock pressure acting on the tunnel under the 790 open-pit mine edge area to ensure safety in production. These research results are the basis for application in actual production at Mong Duong Coal Mine.

2. Materials and research methods

2.1. Study area

The study was conducted at the Mong Duong Coal Mine, located in Mong Duong Ward, Cam Pha City, Quang Ninh Province, Vietnam. Mong Duong Coal Mine belongs to Mong Duong Coal Joint Stock Company – Vinacomin is an underground coal mine and a member of Vietnam National Coal – Mineral Industries Holding Corporation Limited. The Mong Duong Coal Mine was established on April 1, 1982. From a few small mining sites, it has now become a company with large production scale and modern mining technology.

Mong Duong Coal Mine is allowed to manage and exploit three areas including the East side, the West side and Vu Mon. These three areas include coal seams I(12), II(11), Ha(10a), H(10), G(9), K(8), L(7), M(6), N(5), O(4). In 2024, the resources of the coal seams from level -97.5 to the above level have ended exploitation, the Company has built a project to go deep to exploit to level -250 and it is opened up by inclined

Tab. 1. The parameters of rock mass at the 790 open-pit mine area of the Mong Duong Coal Mine [33]
 Tab. 1. Parametry masywu skalnego w rejonie kopalni odkrywkowej 790 kopalni węgla Mong Duong [33]

Descriptions	Unit	Value	Descriptions	Unit	Value
Gravelstone layer parameters			Sandstone layer parameters		
Compression resistane strength	kG/cm ²	1318.09	Compression resistane strength	kG/cm ²	1118.32
Tensile strength	kG/cm ²	121.63	Tensile strength	kG/cm ²	103.91
Volumetric weight	g/cm ³	2.62	Volumetric weight	g/cm ³	2.67
Poisson's coefficient	-	0,2	Poisson's coefficient	-	0,2
Siltstone layer parameters			Claystone layer parameters		
Compression resistane strength	kG/cm ²	491.49	Compression resistane strength	kG/cm ²	332.80
Tensile strength	kG/cm ²	55.38	Tensile strength	kG/cm ²	43.39
Volumetric weight	g/cm ³	2.68	Volumetric weight	g/cm ³	2.66
Poisson's coefficient	-	0,2	Poisson's coefficient	-	0,2
Coal layer parameter			Interbedded rock layer parameters		
Compression resistane strength	kG/cm ²	222.270	Compression resistane strength	kG/cm ²	363.65
Tensile strength	kG/cm ²	27.223	Tensile strength	kG/cm ²	42.67
Volumetric weight	g/cm ³	1.361	Volumetric weight	g/cm ³	2.64
Poisson's coefficient	-	0,12	Poisson's coefficient	-	0,12

tunnels at the sides down to level -250. Currently, The Mong Duong Coal Mine is focusing on exploitation to maintain mine output. Along with that, the Company is organizing the excavation of basic tunnels down to level -400 to prepare new areas for exploitation.

Mong Duong Coal Mine is located about 15 km North of Cam Pha city center. It is bordered by the sea to the north, Bac Quang Loi and Bac Coc Sau two Coal Mines to the south, the sea to the east, and Khe Cham Coal Mine to the west. The mining area and the operating building are close together, the traffic system is convenient for staff and workers to participate in production, creating labor attraction. The location of the Mong Duong Coal Mine is illustrated in Figure 1.

2.2. Geological conditions characteristics and typical cross-section of the study area

+ Features of Geological conditions

The 790 open-pit mine area of the Mong Duong Coal Mine includes layers of rocks including gravelstone, sandstone, siltstone, claystone and coal [33].

Gravelstone: This type of rock is usually light gray in color, it accounts for an average of about 5.3% of the rocks in the strata, distributed mainly in the middle of the coal seam strata, its thickness varies from 1.5 m to 7.0 m. Its main component is quartz grains and is bonded by durable, very solid silica cement.

Sandstone: This type of rock is usually ash gray or light gray, its structure is thickly layered, sometimes blocky and has developed cracks. Its thickness varies complexly from 0.5 m to 15 m, with some layers up to 40 m thick, remaining quite continuous in both strike and dip direction, the main components are fine and coarse grains and are bonded by silica cement. In the cross-sections, this type of rock in Mong Duong Coal Mine area accounts for an average proportion of 33.3%. Sandstone layers are often located between two coal seams.

Siltstone: This type of rock is ash gray, dark gray, accounting for an average of about 53.5% in the stratigraphy of Mong Duong Coal Mine, its main components are clay minerals and fine-grained quartz grains, bonded by solid silica glue. The structure is thickly layered, sometimes in the form of dense blocks. The thickness of the siltstone layers varies very complexly, from 0.3m to 35m and is often located near the roof and floor of coal seams.

Claystone: This type of rock is dark gray, accounting for about 6.82% of the stratigraphy in the Mong Duong Coal

Mine center. Claystone layers are often located close to the roof and floor of coal seams, belonging to the semi-hard rock type, many places are soft and flexible, the structure is mainly thin layered. During the exploration drilling process, this type of rock often swells, making the borehole diameter narrow, making construction difficult. At the same time, at the top of the longwalls, this layer often collapses along with the coal cutting process.

Coal: In the stratigraphic columns of Mong Duong Coal Mine, there are 22 coal seams, of which 17 seams have industrial value. The existence and distribution of coal seams range from relatively stable to very unstable in the mine area and the distance between seams is not uniform. The coal is from anthracite to semi-anthracite. The coal is black, metallic, blocky, thickly layered, brittle, easily broken, with medium to weak hardness. The average thickness of coal seams ranges from 0.94 m to 4.12 m.

Seam L7: It is exposed in the Northeast, Southeast of the mine area and along the South from line T.VIII B to T.XI, about 750m long, Seam L7 is located about 60.0 m from seam M(6). The seam is distributed from level +20 m down. The total thickness of the seam varies from 0.14 m (B.2019) to 15.48 m (B.2247), averaging of 3.41 m. The specific thickness of coal varies from 0.14 m to 15.48 m (B.2247), averaging of 3.16m. The slope angle of the coal seam varies from 5 degrees to 80 degrees. Seam L7 has a relatively complex structure, containing from 0 to 6 layers of interbedded rock, the thickness of interbedded rock varies from 0.00 to 4.99 m (B.2023), averaging of 0.25 m.

The parameters of rock mass at the 790 open-pit mine area of the Mong Duong Coal Mine have been analyzed and shown in Table 1. These parameters are also the input parameters of the numerical simulation model.

+ The typical geological cross-section of the study area.

The typical geological cross-section of the 790 open-pit mine at Mong Duong Coal Mine is shown in Figure 2. Data analysis in Figure 2 shows that the coal Seam L7 belongs to the West side of Mong Duong Coal Mine. The Seam L7 is also located below the 790 open-pit mine edge. The upper part of the Seam L7 from level -25 and above has been fully exploited by open pit mining method, the lower part from level -25 and below will continue to be exploited by underground mining method. The bottom of the 790 open-pit mine is at level -25. According to forecasts and calculations, the groundwater lev-

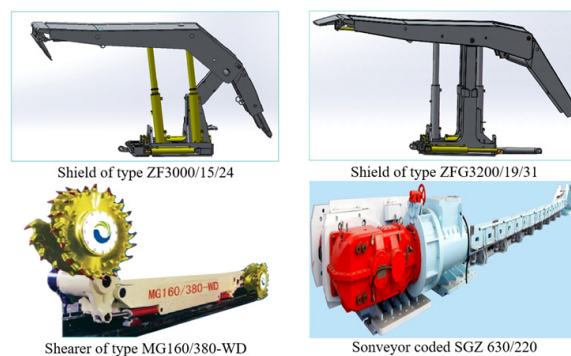


Fig. 3. A group of equipment used in the longwall at Seam L7 of Mong Duong Coal Mine [35, 36]
 Rys. 3. Grupa urządzeń stosowanych w ścianie wydobywczej pokładu L7 kopalni węgla Mong Duong [35, 36]

Tab. 2. A tunnel excavation plan table at Mong Duong Coal Mine in 2025 [34]
 Tab. 2. Tabela z planem drążenia tunelu w kopalni węgla Mong Duong w 2025 r. [34]

Nº	Tunnel/Heading	Area, m ²	Type of support	Level
1	Haulage crosscut of -380 level at Vu Mon side	13.2	Bolt	-400
2	Haulage level of the CGH L7 longwall at Vu Mon side	13.2	SVP-27 steel	-400
3	Haulage level of M6-8.CD at -250	13.2	Bolt	-250
4	Crosscut of M6.CD at -250	13.2	Bolt	-250
5	Opening heading of L7-5A.CD at -200/-150	9.6	CBII-22 steel	-200/-150
6	Haulage crosscut from Seam L7 to M6.CD at -250	13.2	Bolt	-250
7	Ventilation incline of L7-5.CD at -250/-150	9.6	Bolt	-250/-150
8	Ventilation incline of K8.CD at -170	6.8	Bolt	-170
9	Haulage incline of K8.CD at -140/-120	6.8	Bolt	-140/-120
10	Opening heading of K8-3A.CD at -120/-100	6.8	Bolt	-120/-100
11	Haulage incline of H10-2.CT at -180/-200	9.6	CBII-22 steel	-180/-200
12	Ventilation-haulage crosscut of H10.CT at -100	6.1	Bolt	-100
13	Ventilation level of M6.CT at -160	6.1	CBII-22 steel	-160
14	Ventilation-haulage incline of VM G9	9.6	CBII-22 steel	-360/-250
15	Ventilation incline of L7.VM at -250/-180	9.6	CBII-22 steel	-250/-180
16	Haulage level of the CGH L7-4 (DH) longwall at Vu Mon side	13.2	CBII-22 steel	-220/-210
17	Haulage level of L7.VM at -400	13.2	CBII-27 steel	-400
18	Haulage level of the CGH L7-9 longwall at Vu Mon side	13.2	SVP-27 steel	-400
19	Ventilation incline of M6.VM at -400/-250	9.6	CBII-22 steel	-400/-250
20	Haulage level of M6.VM at -250	13.2	Bolt	-250
21	Haulage incline of M6.VM at -180	6.8	Bolt	-180
22	Haulage level of M6.VM at -400	13.2	SVP-27 steel	-400
23	Haulage level of M6-4.CD at -250	13.2	Bolt	-250

el of the open-pit mine is at level +15. The 790 open-pit mine has been filled with waste rock and soil for a long time, so a large waste dump has been formed here, which is one of the causes of rock pressure on the tunnel dug below it. Although the waste rock in the 790 open-pit mine has stabilized, but the amount of water in this open-pit mine is predicted to be very large, the amount of groundwater contained in the 790 open-pit mine is a complex problem, it affects the mining and excavation process in this area. In fact, the groundwater in this open-pit mine is the cause of the potential risk of sudden inrush and mud entering the mining area and tunnels. This is a dangerous phenomenon for underground coal mines, so it is extremely necessary to have appropriate mining and excavation solutions.

2.3. Current status of mining and tunneling at Mong Duong Coal Mine

+ Current status of mining technology [34]

Type of mining technology applied at the Mine: Mong Duong Coal Mine is simultaneously exploiting 09 longwalls, including: 08 longwalls are exploited by drilling and blasting technology, longwalls support technology with XDY hydraulic support, ZH1600 hydraulic support, ZH1800/16/24ZL chain support and ZRY soft support; - 01 longwall is exploited by fully mechanized technology to recover top coal. This fully mechanized longwall has been researched and exploited

by Mong Duong Coal Mine since 2019, with a mining capacity of 300,000 tons/year at the L7 seam in Vu Mon area, equipment includes: shield of type ZF3000/15/24, shield of type ZFG3200/19/31, shearer of type MG160/380-WD, conveyor coded SGZ630/220. This technology has contributed to improving labor productivity and working conditions for workers. The fully mechanized longwall equipment complex is shown in the Figure 3.

To operate 09 longwalls simultaneously, Mong Duong Coal Mine maintains 09 mining workshops, from KT01 to KT09 workshops. Coal mining output in 2025 is expected to reach 1.6 million tons.

+ Current status of tunnel excavation [34]

Currently, Mong Duong Coal Mine is exploiting at -250 level, preparation for exploitation at -400 level is being carried out, many construction items and tunnels have been completed. The number of tunnels to be excavated is very large and they are mainly excavated by drilling and blasting methods. Therefore, it is very necessary to study the application of advanced technology in tunnel excavation at Mong Duong Coal Mine to meet production requirements, ensure safety and increase tunnel excavation speed. In 2025, Mong Duong Coal Mine plans to excavate 19,000 m, tunnels are excavated with cross-sections from 6.1 to 23 m², to excavate such a volume of tunnels, the mine has 06 tunnel excavation workshops, from

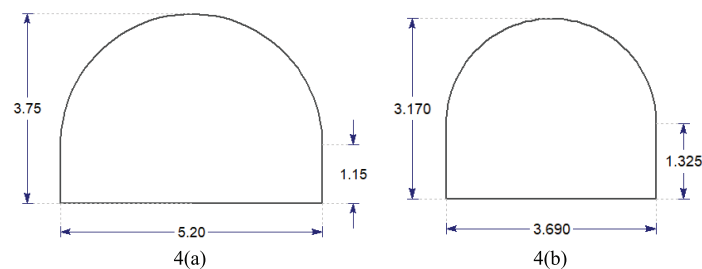


Fig. 4. Cross-sectional dimensions of the tunnels [39] (a) double railway tunnel, (b) single railway tunnel
 Rys. 4. Wymiary przekroju poprzecznego tuneli [39] (a) podwójny tunel kolejowy, (b) pojedynczy tunel kolejowy

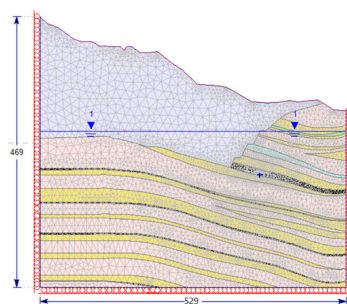


Fig. 5. Layout of numerical simulation model
 Rys. 5. Schemat modelu symulacji numerycznej

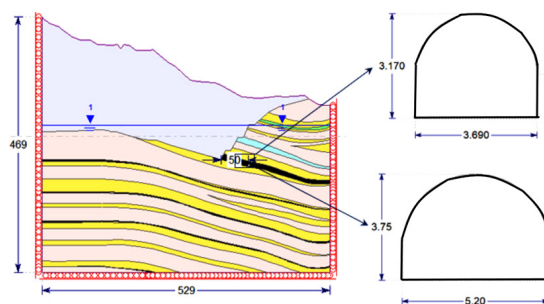


Fig. 6. Location and size of tunnel in the numerical simulation model
 Rys. 6. Lokalizacja i wielkość tunelu w numerycznym modelu symulacyjnym

DL01 to DL06 workshops. Table 2 shows some tunnels to be excavated in the Mong Duong Coal Mine's plan in 2025.

2.4. Research methods

In this study, the authors used three combined research methods: field survey method; numerical simulation model method (using Phase2 software [37, 38]) and data analysis and evaluation method to calculate and determine the rock pressure acting on the tunnel dug under the 790 open-pit mine edge area of Mong Duong Coal Mine. The field survey method provides important information and data, the method of analyzing and evaluating data from the simulation model results.

Currently, there are many research methods to calculate and determine rock pressure, in which the numerical simulation model method is one of the methods being used in the mining field, this method is also one of the tools to predict rock pressure during the tunnel excavation process as well as the exploitation of the longwall. In this study, the authors used Phase2 software to simulate the tunnel excavation process. This software is a program built on the basis of the finite element method (FEM - Finite Element Method) widely applied in the design of mining works. Phase2 software can

simulate complex mining methods in the longwall, construction of tunnels dug in soft rock. Phase2 software is capable of simulating the destruction process of rock mass around the longwall and tunnels, as well as the impact of mining on ground surface subsidence. The results after simulation can analyze the stress, deformation, displacement of rock mass, rock mass destruction zone around the longwall and tunnels.

2.5. Establishing a simulation model

+ Implementation sequence

- Determine the study area, model and tunnel size

The tunnel location is excavated under the 790 open-pit mine edge area, this is the haulage level of the Seam L7.

Simulation model size. The size of the simulation model is very important, affecting the accuracy of the calculation and analysis results. To determine the appropriate size of the model, the authors conducted a series of experiments on numerical models with different sizes. From there, the minimum model size was determined while still ensuring the necessary accuracy. In other words, the displacement and stress at points near the model boundary are approximately the corresponding values of the original stress field. The size of the simulation model of the 790 open-pit mine of Mong Duong

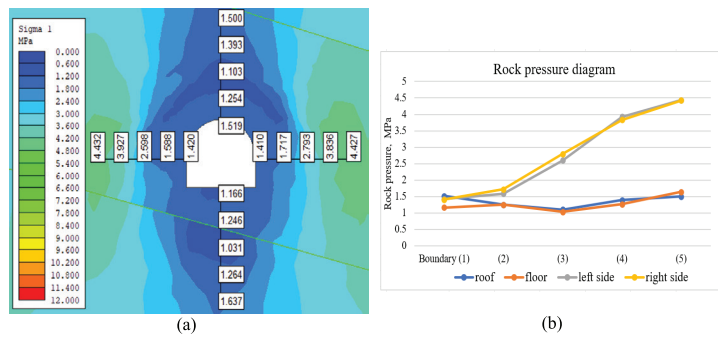


Fig. 7. The maximum main stress (a) and rock pressure diagram (b) in the rock mass around the single railway tunnel
 Rys. 7. Wykres maksymalnego naprężenia głównego (a) i ciśnienia skały (b) w masie skalnej wokół pojedynczego tunelu kolejowego

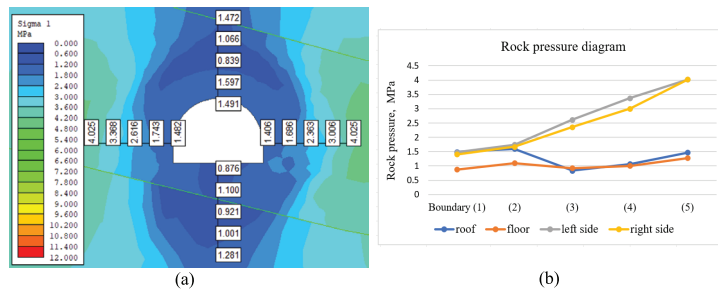


Fig. 8. The maximum main stress (a) and rock pressure diagram (b) in the rock mass around the double railway tunnel
 Rys. 8. Wykres maksymalnego naprężenia głównego (a) i ciśnienia skały (b) w masie skalnej wokół podwójnego tunelu kolejowego

Coal Mine is a 2-dimensional plane deformation model simulated according to the actual cross-sectional size with a width of 529 m and a maximum height of 469 m.

Tunnel size. The dimensions of the tunnels in the survey model were selected based on the typical cross-sectional dimensions of single and double railway tunnels, which are currently being used in underground coal mines of the Vietnam National Coal – Mineral Industries Holding Corporation Limited. The tunnels were dug with a semicircular cross-sectional shape. Of which, the single railway tunnel was 3.69 m wide, 3.17 m high, its cross-sectional area was 9.6 m², and the double railway tunnel was 5.2 m wide, 3.75 m high, its cross-sectional area was 17.9 m². The parameters of those tunnels are shown in Figure 4.

- Set initial boundary conditions

Determine initial boundary conditions, which will also determine the displacement limit at the simulation model boundary.

- Set primary stress conditions and groundwater level conditions.

When setting these conditions, it is necessary to pay attention to the change in stress according to the depth of the tunnel excavation or longwall mining process.

- Set up the properties, characteristics and parameters of rock blocks.

It is necessary to determine the properties and parameters of rock mass around the 790 open-pit mine area and the tunnel excavation area.

- Excavate soil and rock inside the tunnel boundary.

According to the tunnel excavation progress, according to the tunnel excavation cross-section that has been determined.

+ Simulation model

Thus, based on the implementation sequence of the numerical simulation model establishment process above, and based on the typical geological cross-section of the 790 open-pit mine in Figure 2 and the parameters of the rock block in Table 1, a numerical simulation model has been established with a height of 469 m and a width of 529 m, the groundwater level in the 790 open-pit mine at level +15, it is shown in Figure 5. The location of the tunnels in the numerical simulation model is shown in Figure 6. The Haulage levels (single railway or double railway tunnel) are excavated in the coal Seam L7 at -50 level and the distance from the ground surface to these tunnels are 120 m.

3. Results and discussion

To determine the stress acting on the tunnel under the 790 open-pit mine edge area of Mong Duong Coal Mine, the results from the numerical simulation model were analyzed according to three types of stress acting on the tunnel including a maximum main stress; a minimum main stress and a vertical stress.

3.1. Analyze the maximum stress acting on the tunnels.

The maximum main stress in the rock mass acting around a single railway tunnel is shown in Figure 7(a), a double railway tunnel is shown in Figure 8(a). Figures 7(b) and 8(b) show rock pressure diagrams for single railway and double railway tunnels, respectively.

Analysis of the simulation model results in Figures 7 and 8 show that the maximum main stress (sigma 1) is distributed according to the decreasing rule from the inside of the rock mass to the tunnel boundary. In other words, the main stress on the tunnel boundary is observed to have the smallest value. This rule is also true for the minimum main stress and the

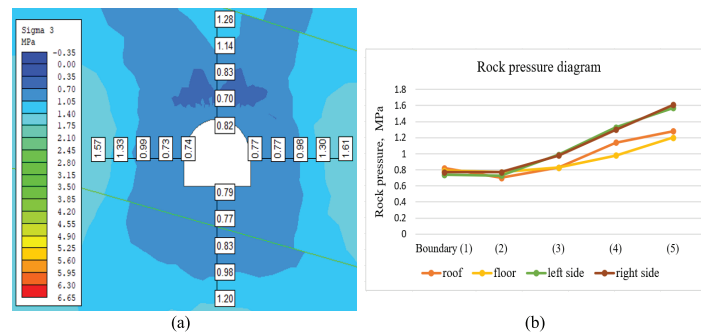


Fig. 9. The minimum main stress (a) and rock pressure diagram (b) in the rock mass around the single railway tunnel
 Rys. 9. Wykres minimalnego naprężenia głównego (a) i ciśnienia skały (b) w masie skalnej wokół pojedynczego tunelu kolejowego

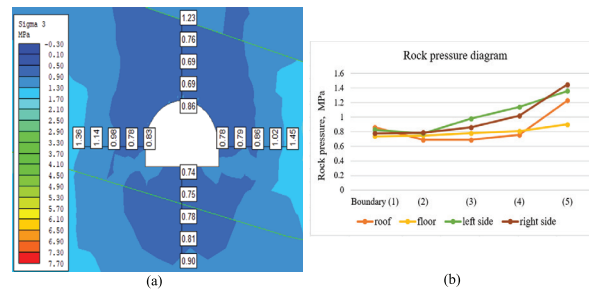


Fig. 10. The minimum main stress (a) and rock pressure diagram (b) in the rock mass around the double railway tunnel
 Rys. 10. Wykres minimalnego naprężenia głównego (a) i ciśnienia skały (b) w masie skalnej wokół podwójnego tunelu kolejowego

vertical stress. This happens because during the tunnel excavation process, the primary stress in the rock mass is released, the rock mass tends to move into the tunnel space, so at the tunnel boundary the maximum main stress has the smallest value. When the tunnel is excavated, the primary stress state of the rock mass is broken, forming a secondary stress state (new stress), the stress state in the rock mass is redistributed. The deeper into the rock mass, the influence of the stress distribution gradually decreases, the rock mass returns to the original primary stress state.

In addition, in Figures 7(b) and 8(b), they can be seen that, there is an asymmetry of the maximum main stress on both sides of the single railway and double railway tunnels. Specifically, the maximum main stress on the left side is greater than that on the right side due to the unbalanced rock pressure from the 790 open-pit mine edge and the asymmetry of the rock mass or the inclined layering of the coal Seam L7 acting on the tunnel. The level of asymmetry is different between the single railway and double railway tunnels. This proves that, with a large cross-sectional area of the tunnel, the difference in stress is greater than that of the tunnel with a smaller cross-sectional area. In other words, the tunnel with a smaller cross-sectional area tends to be more stable. The Figure 7(b) shows that the maximum stress inside the rock mass at the left side of the single railway tunnel has a value of 4.432 MPa, and at the double railway tunnel has a value of 4.025 MPa as shown in the Figure 8(b).

Furthermore, when the cross-sectional size of the tunnel changes, the impact level on the rock mass also changes, leading to a difference in stress. Specifically, it can be seen that the largest main stress at the border of the roof (1.519 MPa) and the floor (1.166 MPa) of the single railway tunnel is larger than the largest main stress at the border of the roof (1.491 MPa) and the floor (0.876 MPa) of the double railway tunnel.

This is explained that because the roof and floor of the tunnels are mainly subjected to compression, the tunnel with a larger cross-section has a larger displacement level of the rock mass into the tunnel space. In other words, the stress release level is greater than that of the tunnel with a small cross-section.

3.2. Analyze the minimum main stress acting on the tunnels

The minimum main stress in the rock mass acting around a single railway tunnel is shown in Figure 9(a), a double railway tunnel is shown in Figure 10(a). Figures 9(b) and 10(b) show rock pressure diagrams for single railway and double railway tunnels, respectively.

Analysis of the simulation model results in Figures 9 and 10 show that the minimum main stress (σ_3) in the rock mass around the tunnel is distributed according to the increasing rule from the boundary of the tunnel to deeper inside the rock mass, but the stress begins to decrease more than 15 m from the boundary of the tunnel and gradually returns to the original stress state. This can be explained that when excavating the tunnel, the rock mass around the tunnel is divided into 4 zones including fracture zone (zone of reduced stress); plastic zone (stress zone begins to increase); elastic zone (zone of increased stress) and primary stress zone (zone of rock mass not affected by tunnel excavation).

Also analysis of the data in Figures 9 and 10 indicates that the stress at the tunnel boundary is the largest at the tunnel roof position of 0.86 MPa (Figure 10 double railway tunnel), the stress on both sides of the tunnel is 0.83 MPa (Figure 10 double railway tunnel) and the stress on the tunnel floor is 0.79 MPa (Figure 9 single railway tunnel). In Figures 9(b) and 10(b), the rock pressure diagram shows that the deeper into the rock mass, the largest main stress appears on both sides of the tunnel. This is explained that when digging the tunnel, a void is created, the rock mass under the tunnel roof is re-

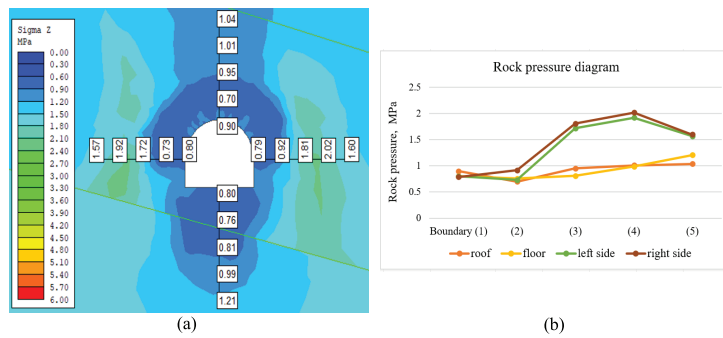


Fig. 11. The vertical stress (a) and rock pressure diagram (b) in the rock mass around the single railway tunnel
Rys. 11. Wykres naprężeń pionowych (a) i ciśnienia skał (b) w masie skalnej wokół pojedynczego tunelu kolejowego

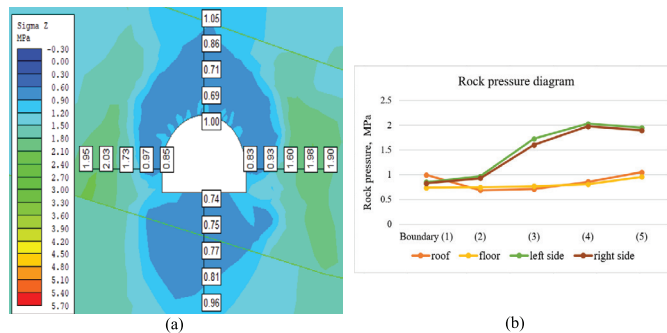


Fig. 12. The vertical stress (a) and rock pressure diagram (b) in the rock mass around the double railway tunnel
Rys. 12. Wykres naprężeń pionowych (a) i ciśnienia skał (b) w masie skalnej wokół podwójnego tunelu kolejowego

moved and thus the load on the tunnel roof is not supported by the rock mass below but its load is transmitted directly to the rock mass on both sides to receive, so the rock mass on both sides of the tunnel is subjected to the largest concentrated stress. The Figure 9 shows that the maximum stress inside the rock mass at the right side of the single railway tunnel has a value of 1.6 MPa, and at the double railway tunnel has a value of 1.45 MPa as shown in the Figure 10.

3.3. Analyze the vertical stress acting on the tunnels

The vertical stress in the rock mass around a single railway tunnel is shown in figure 11(a), and a double railway tunnel is shown in Figure 12(a). Figures 11(b) and 12(b) show that the vertical rock pressure diagrams for a single railway and double railway tunnels, respectively.

From the simulation results in Figures 11 and 12 show that the vertical stress (σ_z) is distributed in the rock mass around the tunnel also tends to increase gradually from the tunnel boundary to deeper inside the rock mass. However, deeper than 15 m from the tunnel boundary, the stress also begins to decrease and gradually returns to the original stress state. Also from Figures 11 and 12 show that the vertical stress on the double railway tunnel boundary is the largest at the tunnel roof position of 1 MPa, the largest stress on the left side of the double railway tunnel is 0.85 MPa, and the largest stress on the single railway tunnel floor is 0.80 MPa. From the rock pressure diagram in Figures 11(b) and 12(b) show that the deeper inside the rock mass, the largest principal vertical stress appears on both sides of the tunnel, this rule is similar to the rule of the smallest and largest stress and it is also explained similarly. The Figure 11 shows that the maximum stress inside the rock mass at the right side of the single rail-

way tunnel has a value of 2.02 MPa, and at the double railway tunnel has a value of 2.03 MPa as show in the Figure 12.

4. Conclusions

Mong Duong Coal Mine is one of the underground coal mines in the Quang Ninh coalfield with the most complex geological conditions. At the same time, this is also one of the mines with coal seams that are located under the edge of the open-pit mine that has ended exploitation and has been filled with waste rock mined by underground mining method. Mong Duong Coal Mine is also one of the underground mines with potential risks of unsafety during mining and excavation due to the influence of groundwater in the open-pit mine, especially in the rainy season, the amount of groundwater flowing into the open-pit mine area is very large. Therefore, it is very necessary to study a reasonable solution for mining and excavation under the 790 open-pit mine area to ensure the safety of the mine.

Based on the typical geological cross-section of the 790 open-pit mine at Mong Duong Coal Mine, the parameters of the rock mass and the geological conditions of the coal Seam L7, as well as the parameters of the tunnels, combined with Phase2 software, a numerical simulation model was established to identify the rock pressure acting on the haulage level of Seam L7 at -50 level below the edge of the 790 open-pit mine at Mong Duong Coal Mine. The typical dimensions of the selected tunnels include a single railway tunnel with a cross-section of 9.6 m² and a double railway tunnel with a cross-section of 17.9 m².

The results of the numerical simulation model analysis and rock pressure diagram show that all three types of maximum, minimum and vertical stresses acting on the tunnels

under the 790 open-pit mine area at Mong Duong Coal Mine have a decreasing rule from deeper inside the rock mass to the tunnel boundary, which means that at the tunnel boundary, the stress has the smallest value. At the same time, the stress gradually returns to the original stress state at a position greater than 15 m deeper inside the rock mass from the tunnel boundary. The analysis results from the simulation models also show that the rock pressure acting on the tunnel side (left and right side) always has a greater value than the rock pressure acting on the tunnel roof and floor, and the tunnel excavated with a smaller cross-section will tend to be more stable than the tunnel with a larger cross-section.

Finally, to ensure safety during the exploitation of the longwall in Seam L7 and the tunnel under the 790 open-pit mine edge area, it is very necessary to study reasonable mining and excavation solutions. Mong Duong Coal Mine also needs to regularly monitor rock pressure, survey the site to propose timely reinforcement support solutions or handle unusual situations when necessary.

Contribution of authors

Vu Trung Tien, reviewed and wrote the introduction, results and discussion; Do Anh Son, Dao Viet Doan collected documents and wrote the conclusions; Vu Trung Tien and Le Quang Phuc wrote the materials and research methods, edited the writing.

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Identyfikacja ciśnienia skał podczas drążenia tuneli pod krawędzią kopalni odkrywkowej 790 w kopalni węgla Mong Duong w Wietnamie

Badanie i identyfikacja ciśnienia skał podczas drążenia tuneli jest niezwykle istotne. Obliczenie ciśnienia skał pomoże nam wybrać odpowiedni rodzaj obudowy, a tym samym opracować rozsądny plan jej zabezpieczenia. Kopalnia węgla Mong Duong jest jedną z kopalni węgla w zagłębiu węglowym Quang Ninh, której część zasobów lub pokładów węgla znajduje się pod krawędzią kopalni odkrywkowej, która zakończyła eksploatację. W związku z tym drążenie i obudowanie, a także obliczanie ciśnienia skał dla tuneli znajdujących się pod tym obszarem, jest bardzo trudne i skomplikowane. Niewłaściwe metody drążenia i obudowy mogą prowadzić do potencjalnych zagrożeń. Jednym z najgroźniejszych zjawisk jest zjawisko nagłego wtargnięcia do tunelu.

W niniejszym artykule wykorzystano metodę symulacji numerycznej. Na podstawie oprogramowania Phase2 i warunków geologicznych kopalni węgla Mong Duong, autorzy opracowali model symulacyjny w celu identyfikacji ciśnienia skał oddziałującego na tunele znajdujące się pod krawędzią kopalni odkrywkowej. W ramach badań przeprowadzonych w kopalni węgla Mong Duong, autorzy obliczyli nacisk skał podczas drążenia tuneli pod krawędzią kopalni odkrywkowej 790 w pokładzie L7 po stronie zachodniej na poziomie -50. Kopalnia odkrywkowa 790 znajduje się w ścianie wydobywczej w pokładzie L7.

Wyniki badań stanowią podstawę do praktycznego zastosowania w kopalni węgla Mong Duong. Na podstawie obliczeń nacisku skał oddziałującego na tunele w pokładzie L7 opracowano plan obudowy tunelu. Ta metoda badawcza posłuży również jako podstawa do rozważenia i zastosowania w innych kopalniach o podobnych warunkach geologicznych w zagłębiu węglowym Quang Ninh.

Słowa kluczowe: *ciśnienie skał, tunele, metoda modelowania numerycznego, kopalnia odkrywkowa, kopalnia węgla Mong Duong*