# Research on the Effect of the Mine Waste Dump on the Stability of Tunnels Below in the Quangninh Coal Area by Numecical Method

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## Abstract

*Nowadays, there are many underground coal mines in Quang Ninh, Vietnam have been exploiting coal seams below the mine waste dump such as Khe Cham II, Mong Duong, Mao Khe, and Ha Lam… Coal Company. Many mine waste dumps have reached the height of dumping from 400m, especially up to over 400m. The rock mass pressure due to the weight of the rock mass in the mine waste dump is considered an artificial pressure formed from the process of dumping soil and rock, it will be part of the pressure acting on the furnace lines located under the mine waste dump. The paper presents the current status of the mine waste dump and the coal seams that have been and will be exploited located below the mining waste dump in Cam Pha Quang Ninh and based on the actual conditions of the Bang Nau, Khe Cham II coal mine waste dump. The studies used the 2D FEM RS2 program to create simulation models with the mine waste dump to study the primary stress distribution in the rock mass. The objective of this study is to highlight the influence of the relationship location of tunnels below with the inclined coal/rock mass layer on the rock support behavior of the underground tunnels in the Quang Ninh coal area. The simulation results will help the consulting and construction companies to calculate the rock pressure acting on the tunnels located under the mining waste dump.*

**Keywords:** *Mine Pressure, mine waste dump, rock support behavior, inclined coal/rock mass layer, yielded zone*

## 1. Introduction

Currently, the largest dumping site in Cam Pha area is Dong Cao Son landfill (with a capacity of 295 million $m^3$) which is being used by 3 open-pit mines Deo Nai, Coc Sau and Cao Son. In which, the volume of waste rock from Deo Nai, Cao Son, Coc Sau, Khe Cham II and Dong Da Mai mines accounts for over 94% of the total volume of waste rock in the whole region. In the period 2013–2020, the volume of waste rock in the region has reached over 1.9 billion $m^3$ (Figure 1). The soil and rock of the landfill is in a discrete state, including fragments, broken lumps of sandstone, siltstone, siltstone, claystone, coal clay and quaternary cover soil, size D = 0.1 mm ÷1000 mm (Figure 1 ÷ Figure 3).

The tunnels along the rock seams at Khe Cham III coal mine usually have a cross-sectional area designed according to the purpose of use and suitable according to the exploitation output of each area. In Fig.4.d shows the excavated cross-sectional dimensions of the trench along the rock seam at -190 of the seam 14.5 and the profile along the tunnel after being compacted. Currently, the underground coal mines in the area below the mine waste dump are mainly excavated by drilling and blasting and supported by CBII steel frames. The tunnels in the study area of the seam 14.5 include tunnels through the coal seam or through rock layers with poor stability. The temporary rock support is CBII steel frames will be replaced by permanent concrete lining. Special locations where the floor tunnel may be grow up are also fixed by reinforced concrete anti-reinforced shells combined with inverted arch beams to prevent growing up of floor tunnel.

## 2. The current status of the rock support of tunnels Below Mine Waste Dump in Quang Ninh coal area

High in situ stress of deep underground tunnel Below Mine Waste Dump in Quang Ninh coal area:

The TVT 14.5 tunnel in the Southeast area, Khe Cham III is deformed. According to the design of the tunnel, which is supported by SVP 22 steel, with a cross section of 9.4 $m^2$, the roof is sealed, both sides of the tunnel are staggered by precast reinforced concrete inserts placed and floor tunnel are support by the foundation beams. But due to the time and influence of the upper layer of rock pressure and the landfill area, many tunnels in this area were strongly compressed. The tunnel DVTG 14.4-2, built by Khe Cham Coal Company in 2019, was compressed and cracked, causing the steel frame to crack. To ensure the safety and usability of the tunnel, the Company has resisted cropping to bring the tunnel back to its original cross-section. However, the tunnel continued to be compressed, deformed, pushed both sides of the tunnel to break the entire P24 rail platform, reducing the tunnel cross-section, the actual used section to 5.4 $m^2$, affecting the ventilation, transportation and drainage of the area (Fig.4b) (Fig.5 ÷ Fig.7). Through the assessment of the causes of tunnel destruction, it was found that the selection and calculation of the rock support based on the traditional calculation hypotheses is no longer appropriate because through the process of re-evaluating the structure, the structure is still durable enough in theory.

The study area belongs to the seam 14.5 with the following characteristics: The seam 14.5 is located from 30 m to 60 m away from the reservoir 14.4. The seam 14.5 occurs mainly in Khe Cham I, III and Cao Son open pit mining (Khe Cham IV). The thickness of the entire reservoir varies from 0.24 m (BKC09) to 38.84 m (NKC67), with an average thickness of 5.72 m. The specific thickness of coal varies from 0.00m to 27.37 m (NKC67), averaging 4.99 m. The seam has a very complicated structure, in the reservoir there are from 1÷9 layers of clamped rock, the thickness of clamped rock is from 0.0 m ÷ 11.50 m (NKC67), with an average of 0.53 m. The slope of the seam is from 30÷ 600, the average is 270. The thickness of

Tab. 1. Summary of current situation of Mine Waste Dump in Vietnam

| N⁰ | Name of Mine Waste Dump | Volume of waste ($x10^6$) $m^3$ | Current elevation (m) | Waste floor height (m) | Waste floor slope angle (Degree) | Waste dump heigh (m) | Slope angle of Mine Waste Dump ($^0$) | Width of floor surface (m) | Landfill background structure |
|---|---|---|---|---|---|---|---|---|---|
| 1 | East of Cao Son Mine Waste Dump | 539.7 | +310 | 50÷150 | 36÷40 | 210 | 28÷36 | 30÷50 | Stable |
| 2 | North of Bang Nau Mine Waste Dump | 963.7 | +190 | 40÷180 | 34÷36 | 180 | 30÷36 | 30÷50 | Stable |
| 3 | Southwest Khe Tam Mine Waste Dump | 296 | +320 | 30÷60 | 33÷35 | 200 | 30÷32 | | Stable |
| 4 | East of Khe Sim Mine Waste Dump | 150 | +250 | 30÷50 | 34÷37 | 200 | 30÷32 | | Stable |
| 5 | Chinh Bac Mine Waste Dump | 53 | +256 | 7÷70 | 30÷36 | 186 | 25÷31 | 30 | Stable |
| 6 | Khanh Hoa Mine Waste Dump | 526 | +195 | 11÷81 | 30÷40 | 153 | 25÷33 | 20÷25 | Survey drilling needed |
| 7 | Na Duong Mine Waste Dump | 25 | +365 | 4÷16 | 25÷35 | 80 | 15÷25 | 20÷30 | - |
| 8 | Phan Me Mine Waste Dump N03 | 16 | +190 | 30÷50 | 130 | 130 | 30 | 25÷30 | Weak background |
| 9 | Waste dump of ash and slag of thermal power plants | | +410 | 5÷50 | 30÷36 | 60÷80 | 20 | 15÷30 | Weak background |
| 10 | Mong Gioang Mine Waste Dump | | | 20÷30 | | 170 | 18÷22 | 20÷30 | Stable |
| 11 | Lo Phong Mine Waste Dump (Finished) | | | 40 | 30 | 200 | 24÷27 | 35 | Stable |

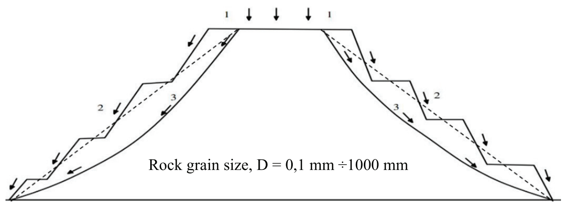



Fig. 1. Diagram of the process of stabilizing the soil and rock of the landfill

Fig. 2. Plane of Bang Nau Mine Waste Dump, Quangninh coal area

Fig. 3. The surfce Plane of Bang Nau Mine Waste Dump, Quangninh coal area

the seam 14.5 gradually decreases from the south to the north. Seam 14.5 has 317 drilling works to control the deep seam, 39 excavation works to control the seam. Soil and rock walls, coal seam pillars are layers of siltstone, claystone, dirty coal or coal clay and the aggregates are often located close to the coal seam wall, this is an easy to recognize sign. Compared to the 2008 conversion report, the average thickness of coal seam 14.5 has decreased from 6.77 m to 4.99 m.

The research results show that the rock support structure is calculated by structural mechanics method or numerical model. However, the above calculation methods have not paid much attention to the influence of the mine waste dump on the surface, or the large surface structures such as the vertical shaft tower, the office building of the mine as well as the upper layers of compacted soil left by the previous mining floors. In addition, the above calculation methods have not paid attention to the special geological conditions of the strongly compressed rock mass. Therefore, studying the influence of the mine surface waste dump on the mechanical behavior of the tunnels below in the Quang Ninh coal region will be very necessary and urgent to find new solutions to improve the stability of the tunnels in order to improve the efficiency of coal mining in the whole corporation, and at the same time apply scientific research achievements in countries with a developed coal mining industry in the world. The study diagram of the influence of the relationship between the tunnel position below the mine surface dump on the mechanical behavior of the tunnel support structure is shown in Figure 8. According to Figure 8, there are two locations that need attention, namely the tunnel located in area (I) – the center of the mine waste dump and the side of the mine waste dump (Area II). The objective of this paper is to highlight the influence of the relationship location of tunnels below with the inclined coal/rock mass layer on the rock support behavior of the underground tunnels in the Quang Ninh coal area.

## 3. A case study at Khe Cham II coal mine

***Introduction to the Khe Cham II Coal Mine:***

The Khe Cham III Coal Mine is in Cam Pha City, Quang Ninh Province, 200 km from Hanoi capital, Viet Nam. It is

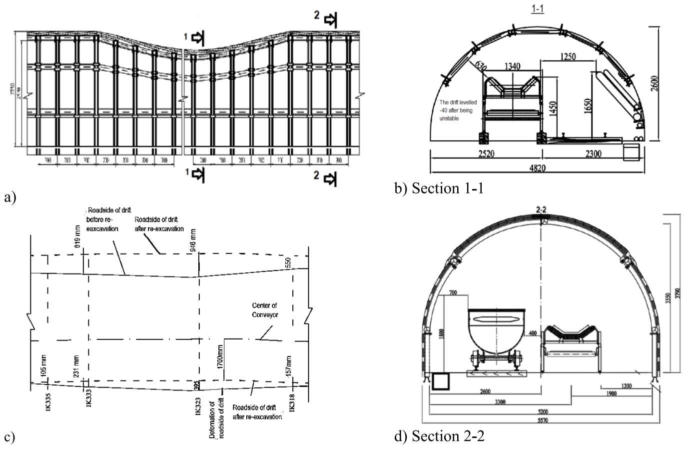



Fig. 4. Failure of the tunnel levelled -40 in the Nam Mau coal company through complex geology conditions below mine surface waste dump

Fig. 5. The collapses of deep underground tunnel floor seam 14.5 southeast area at Khe Cham III coal mine in Quang Ninh coal mine area at 12/05/2021 [1]

Fig. 6. Some typical failures in DVTG 14.4-2 tunnel at Khe Cham III coal mine in 12/05/2021 in Quang Ninh coal mine area at [1] (by authors)

Fig. 7. The collapses of TVT tunnel seam 14.5 southeast area at Khe Cham III coal mine in Quang Ninh coal mine area at 12/05/2021 [1]

one of the big coal mines owned by TKV group, that provides an important energy source for the rapid sustainable economic growth of Viet Nam, producing an annual coal output of more than 30 million tons (Mt) since 2009, reaching a maximum of 3.5 Mt/year.

***Geological profiles of deep underground mine tunnel:***

The haulage and rail DVTG 14-2 tunnel at Khe Cham III coal mine levelled – 150, with a horizontal width of 5.0÷6.0 m in the first mining level of – 150 m, playing a pivotal role in the sustainable development of the Khe Cham II coal mine with high output. The geological profiles of deep underground mine tunnel structures exist that are extremely complex, as shown in Table 1. The area of haulage and rail DVTG 14.4-2 tunnel at Khe Cham III coal mine is located near 14.5 seam. Water depth varies with seasons from 0.3m ÷ 1.0 m. The average flow is 2÷128.8 l/s in the dry season, but the speeed of water is very fast in the rainy season. The average thick of stratified rock seam is (0.4÷0.6) m with the rock consolidating coefficient by M.N. Protodyakonov: f=6÷8, and f=8÷10, some sections was through coal seams with the consolidating coefficient of rock by M.N. Protodyakonov: f=2÷3.

***Numerical model building process***

Based on the actual tunnel excavation data and the processing phases in the simulation, the modeling computation

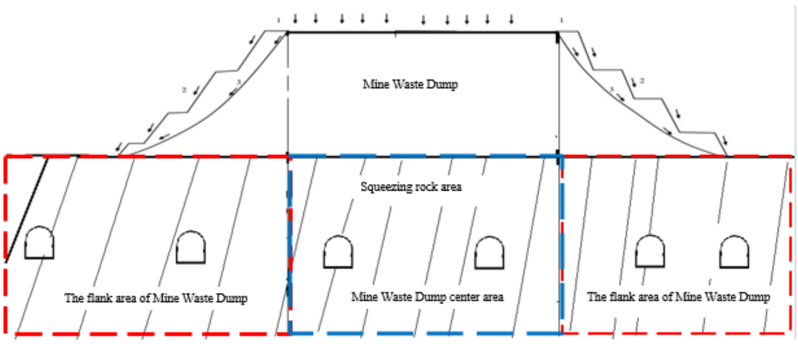



Fig. 8. Diagram of the study of the influence of the mine surface waste dump on the stability of the tunnel below
1. Surface subsidence – vertical displacement; 2. Surface erosion due to the impact of exogenous phenomena; 3. Landslide – landslide mass due to exogenous impact)

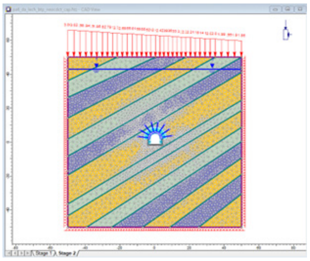


Fig. 9. Numerical model of the DVTG 14-2 tunnel at Khe Cham III

Tab. 2. Analysis Sequence

| Phase | Description |
|---|---|
| Step 1 | Initial Stress |
| Step 2 | Initialize displacement |
| Step 3 | Install SVP steel frame |
| Step 4 | Install supports (Rock bolt & Shotcrete) |
| Step 5 | Hardened shotcrete |

phases are simplified to the following steps. Numerical model of the DVTG 14-2 tunnel at Khe Cham III are presented on Figure 9, the tunnel is located in area II. Flowchart of this study are presented on Figure 10. Analysis sequence of model are presented in Table 2. Properties of the rock mass and joints are presented in Table 3.

***Floor grouting reinforcement technique with pressurization and progressive depths:***

The floor heave of the underground tunnel is critical. The floor must be reinforced given the destructive floor heave. However, the holes drilled in the floor are always subjected to collapse because of the soft broken coal seams with the rock consolidating coefficient by M.N. Protodyakonov: f=2÷3. The bolts and cables cannot be installed in the floor. Based on the industrial testing of the floor reinforcement during working of tunnel, we proposed the floor grouting reinforcement technique with pressurization and progressive depths. Grouting depths in the floor successively increased from shallow to deep, and the corresponding grouting pressure also progressively increased ( see Figure 8). The array pitch and the water-to-cement ratio for 1.5 m-deep holes grouting was 1:1. The earlier shallow holes grouting not only reinforces the shallow rock mass but also forms a stop-grouting layer for subsequent deeper drilling holes grouting and solves the problem of wall collapse in deeper holes. The 6 m-deep holes with grouting with superfine cement reinforces the deep rock mass in the floor and forms a large joint bearing ring with the reinforced deep rock mass in the roof and sidewalls. The displacement velocity of the floor decreased, providing a foundation for secondary enclosed support measures for the long-term stability of the surrounding rock.

***Shallow holes post-grouting with superfine cement:***

Shallow holes pre-grouting with superfine cement was completed (Figure 8). The lengths of the grouting pipes and boreholes were 1500 mm, and the array pitch was 1000 mm. Grouting pressure was generally not more than 3.0 MPa. The strength of the superfine cement was 62.5 MPa. The water-to-cement ratio was 0.8–1.0. The distance of shallow holes pre-grouting relative to the tunneling face was less than 6.0 m.

***Deep holes post-grouting with superfine cement:***

Deep holes post-grouting with superfine cement were bored after secondary shotcrete (see Figure 9). The lengths of grouting pipes and boreholes were 6000 mm. The array pitch average was 1000 mm. The grouting pressure was 6.0÷8.0 MPa.

To improve the grouting effect, deep post-grouting was conducted by a repeated grouting method with alternating intervals; i.e., the odd array holes grouting was first completed along the opening axis direction. Afterward, the grouting of the remaining even array holes was conducted. In addition, the deep holes post-grouting sequences at the same cross-section were from holes No.1 and No.9 on the sidewalls; then holes No. 2 and No. 8 in the shoulders, to the last hole No.3 to No.7 in the arch crown; No.10 and No.11in the floors (see Figure 9).

**4. Numerical model the post-grouting to improve the stability of the underground mine tunnel**

Tab. 3. Properties of the rock mass and joints

| No | Parameters | Symbol | Values | | Units |
|---|---|---|---|---|---|
| | | | Sandstone | Siltstone | |
| 1 | Unit weight of rock | $\gamma$ | 0.026 | 0.027 | MN/m$^3$ |
| 2 | Uniaxial compressive strength of intact rock | $\sigma_{\chi\iota}$ | 60; 70 | 45; 50 | MPa |
| 3 | Tensile strength | $\sigma_{\tau}$ | 0.5 | 0.7 | MPa |
| 4 | Cohesion | $\chi$ | 2 | 4 | MPa |
| 5 | Friction angle | $\varphi$ | 30 | 35 | Degree |
| 6 | Young modulus | E | 1500 | 2000 | MPa |
| 7 | Poisson ratio | $\mu$ | 0.3 | 0.28 | - |
| 8 | Dilation angle | $\psi$ | 0 | - | Degree |
| 9 | Residual tensile strength | $\varphi_{\rho\varepsilon}$ | 28 | 32 | Degree |
| 10 | Residual friction angle | $\chi_{\rho\varepsilon}$ | 1 | 0.5 | MPa |
| 11 | Span of adits | B | 5 | - | m |
| 12 | Criterion of material | M–X | - | - | - |
| 13 | Ratio of initial stress | $\sigma_3/\sigma_1$ | 1 | 1 | - |
| 14 | Depth of adits | H | 100 | - | m |
| 15 | Incline angle of rock mass layers | $\alpha$ | 45 | 45 | Degree |
| 16 | Thickness of rock mass layer | $\Delta$ | 2; 4; 8; 16 | 2; 4; 8; 16 | m |
| 17 | Strength tensile on the surfaces between two layers Sandstone / Siltstone | $\rangle'$ | 0 | | MPa |
| 18 | Friction angle on the surfaces between two layers Sandstone/Siltstone | $\varphi'$ | 35 | | Degree |
| 19 | Normal stiffness on the surfaces between two layers Sandstone / Siltstone | $\sigma_{\rfloor}$ | 100000 | | MPa/m |
| 20 | Shear stiffness on the surfaces between two layers Sandstone/Siltstone | $\tau$ | 10000 | | MPa/m |

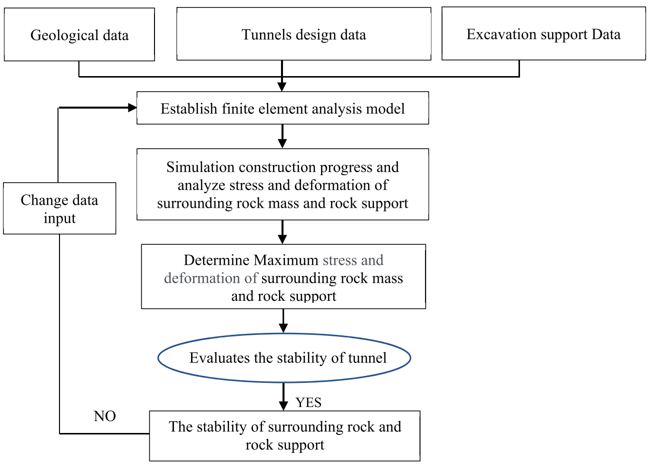



Fig. 10. Flowchart of the study

Numerical simulations were performed using the Finite Element Method with the Phase 2.0 software. The 2D model were used in this research. Using 2D models permits to validate the mesh and investigate some parameters of the model. The rock mass was modeled using the elastic perfectly plastic constitutive model (with a Mohr-Coulomb failure criterion). The parameters of the rock mass see in Table 1. Result of numerical simulations of before post-grouting and after post-grouting are presented from Fig. 10 to Fig. 15. The model is studied on 3 stages: stage 1 – before post-grouting; stage 2 – The grouting work has just been completed; stage 3 – The grouting work has been completed in a time. Parameters of rock mass after being reinforced by grouting using as input ones are friction angle (resid) and cohesion (resid), also Young's modulus (E). The cohesion (resid), Young's modulus (E) is increased by post-grouting process, the rock mass surrounding the tunnel can be able to carry of self loading after grouting.

The criteria to determine whether a tunnel has sufficient capacity to sustain the external load effects is strength factor of rock mass. The strength factor is calculated by dividing the rock strength (based on failure criteria, the model used Mohr-Coulomb failure criterion) by the induced stress at every point in the mesh. All three principal stresses have an influence on the strength factor (Sigma 1, Sigma 3 and Sigma Z).

By the numerical model, the efficiency of grouting solution has been investigated. The result of numerical model on Fig.10 to Fig. 12 shows the stress and displacement induced in the rock mass surrounding the tunnel. The friction angle (resid) and cohesion (resid), also Young's modulus (E) is increased by post-grouting process. It also shows that Young's modulus (E) is increased 1.25 times higher than before grouting by shallow holes post-grouting with superfine cement (Stage 2) and increased 1.5 times higher than before grouting by deep holes post-grouting with superfine cement (Stage 3). Displacement around the tunnel after post-grouting are presented on Figure 13. The strength factor of rock mass after grouting is prented on Fig.14. Strength factor of rock mass at roof, shoulder of tunnel in stage 2 is more than 1.0, but the strength factor of rock mass on some points at left floor is less than 1.0 (Fig.14). Strength factor of rock mass of stage 3 in which the grouting work has been completed in a time is higher than stage 2. All of them are higher than 1.0.

Tab. 1. Physiccomechanical parameters of surrounding rock before post-grouting

| Parameters | Symbol | Value | Unit |
|---|---|---|---|
| Unit weight | $\gamma$ | 0,26 | $MN/m^3$ |
| Tensile Strength | $\sigma_k$ | 0,5 | MPa |
| Cohesion | c | 0,025 | MPa |
| Friction angle | $\varphi$ | 35 | Deg. |
| Young's modulus | E | 1000 | MPa |
| Poisson's ratio | $\mu$ | 0,30 | - |
| Dilation angle | $\psi$ | 0 | Deg. |
| Friction angle (resid) | $\varphi_{re}$ | 28 | Deg. |
| Cohesion (resid) | $c_{re}$ | 0,02 | MPa |
| Material type | - | Elastic-Plastic | - |
| Failure criterion | Mohr-Coulomb | - | - |

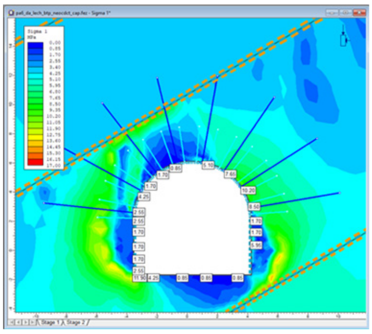


Fig. 10. Damaged zones around the tunnel before post-grounting

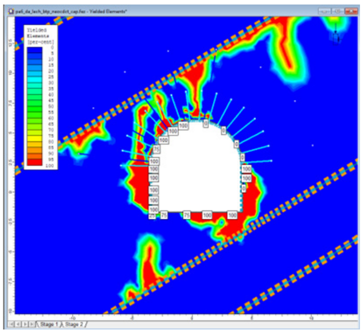


Fig. 11. Stress around the tunnel before post-grounting

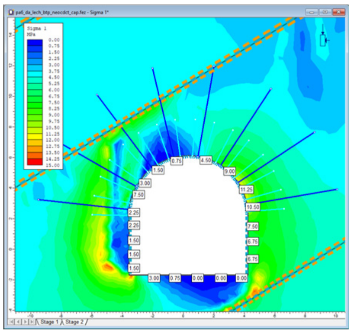
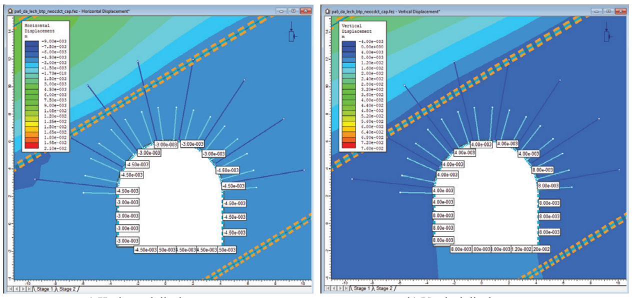


Fig. 12. Stress around the tunnel after post-grounting

The paper also conducts research for a case of tunneling along the seam dug in coal seam 14.5 of Khe Cham III coal mine. The location of the tunnel is located on the slope of the mine waste dump - pressure deflection is a dangerous state with 3 different cases of rock support. The numerical model results show that the rock support case 3 that uses SVP 27 steel frame with distance bettwen each steel frame 0.8 m; rock bolt with length L =2.4 m (axa = 0.8x0.8 m); Cable bolt L = 6 m (axa = 1.6x1.6 m) for the smallest displacement compared to other alternatives. Therefore, the case 3 and the proposed plan is used to prevent the pit lines in the 14.5 reservoir area dug in coal under the Khe Cham III mine surface waste dump area.

## 5. Conclusions and Proposals

The stability of tunnel under mine waste dump during operation determines the sustainable safety production in underground coal mines. This work was a case study on the stability control of DVTG 14.4-2 tunnel at Khe Cham III coal mine is located near 14.5 seam, Campha, Quang-ninh, VietNam. The results were based on the analysis of long-term engineering practices and numerical model that provide valuable practical guidance for the stability control of deep underground mine tunnel in other coal mines with similar geological conditions, such as the Mao Khe, Nam Mau coal mine. Some conclusions and research prospects are summarized below:



a) Horizontal displacement b) Vertical displacement

Fig. 13. Displacement around the tunnel after post-grouting

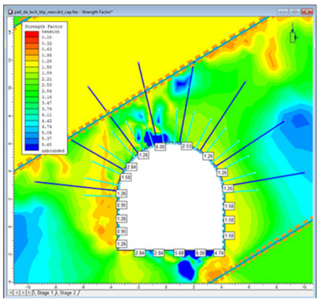


Fig. 14. Strength factor of rock mass

Mine surface waste dumps have a great influence on the mechanical behavior of the tunnels below. Depending on the position of the tunnel relative to the mine surface waste dump site, the pressure acting on the tunnel can be evenly distributed with the tunnel located center area of the mine surface waste dump (I) or skewed with the slope of the mine surface waste dump (zone II), affecting the working of the rock support.

The phenomenon of tunnels being destroyed and distorted, the rock support is quickly destroyed after digging, leading to re-excavate the tunnel many times, affecting transportation the coal, especially for main tunnels. The deformation of the areas around the tunnel appears to be large even though the calculated supporting structures are used, the durability test shows that the traditional calculation hypotheses are no longer correct, these calculation methods have not considered the influence of the mine waste dump as well as the broken loose rock layers in the upper mining strata.

The use of a numerical model built on the Finite Element Method through the Rockscience – RS2-Phase2 software allows effective simulation of pressure, calculation of internal forces and behavior of the rock support, including consideration of the influence of the mine surface landfill, and the stratigraphic characteristics of the research tunnel area.

- Minimum range of pre-grouting and post-grouting reinforcement for deep underground tunnel through complex geology. According to engineering practices and numerical model, the minimum pre-reinforcement range around the proposed deep underground opening through complex rock mass should be 15 m. Moreover, the minimum reinforcement range of deep holes post-grouting should be completed to improve the strength and intactness of the 6-8 m-deep surrounding rock mass.
- Influencing Factors: The main factors influencing safe excavation and the stability of deep underground mine tunnels include high in situ stress, poor mechanical properties and engineering performance of the argillaceous surrounding rock mass, groundwater inrush.
- Pre-Grouting and deep holes post-grouting: The experimental results at DVTG 14.4-2 tunnel at Khe Cham III coal mine shows that the pre-grouting and deep holes post-grouting with superfine cement should be used to block fracture water from seeping, and prevent the deep complex rock mass. Numerical model indicated that deep holes post-grouting with superfine cement were able to improve the intactness of deep rock mass but also improves the bearing load-ability of rock mass.
- Suggestions of coordinated control techniques: According to the deformations and failure characteristics of the surrounding rock, the factors influencing the safe excavation and the stability and geo-hazards encountered, coordinated control techniques, including regional strata reinforcement technique such as Pre-grouting and deep holes post-grouting, primary enhanced control measures of the surrounding rock, floor grouting reinforcement technique with pressurization and progressive depths, and secondary enclosed support are proposed and should be adopted to ensure the tunnel safety and long-term stability of deep underground openings through complex geology.
- The strength factor of rock mass: The criteria to determine whether a tunnel has sufficient capacity to sustain the external load effect is strength factor of rock mass. The result of numerical model show that strength factor of rock mass at roof, shoulder of tunnel in stage 2 in which the grouting work has just been completed is more than 1.0, but the strength factor of rock mass on some points of left floor is less than 1.0. Strength factor of rock mass of stage 3 in which the grouting work has been completed in a time is higher than stage 2. All of them are higher than 1.0. It shows that the capacity to sustain the external load effects of rock mass after grouting is guaranteed.

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