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NUMERICAL INVESTIGATION ON THE TUNNELING AND MINING INDUCED GEO-HAZARDS: CASE STUDY IN QUANG NINH, VIETNAM

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Abstract

In the field of rock mechanics, underground construction and mining, there have been many proposed methods for studying geo-hazards and also many research results that have been published in the world. In Vietnam, the numerical method is mainly used for analysis and design but not going deeply to predict the possible causes that lead to geo-hazards due to complex geological conditions. On the other hand, underground constructions and exploitation projects are often designed based on standards, regulations and experiences. The physical mechanism as well as the possibility of geo-hazards occurred when constructing underground structures and mining can take on various forms, depending on geological conditions and construction technology. Therefore, using numerical methods to simulate and analyze the possible geo-hazards is essential. This article presents a number of specific analysis cases, taking into account geological conditions and boundary conditions, and from that, raising a number of issues to note when using numerical methods.

Keywords: underground mining; numerical method; geo-hazards; rock mechanics; FLAC2D.

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1. Introduction

Geo-hazards are types of disaster-related to geological processes induced by natural or human activities. In recent years, various geo-hazard or geo-risks have occurred in tunneling and mining in Vietnam. In the mining field, the geo-hazard is due to exploitation of natural resources from mine including subsidence, slope stability, landslides and other related damage have been reported by numerous authors [1–4]. The prediction and management of geo-hazard are of great importance in the mining industry [5–7].

Understanding the behaviour of rock masses has always been difficult for mining and underground engineers because of the presence of discontinuities, anisotropic and heterogeneity. Empirical, analytical and numerical methods have been widely used for modeling the behavior of rock mass [8–10].

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In recent years, numerical methods have been used in design of underground openings in the world, however, in Vietnam, this issue has received little attention. Numerical modeling application in mining engineering aims to provide a better understanding of the mining and rock mechanics engineers for solving problems related to the design of support systems [7, 11]. The numerical methods are convenient, less costly and less time-consuming for the analysis of stress redistribution and their effects on the behavior of rock mass and designing of support system within the rock mass environment.

In this article, the rock mass layers and underground mine adit in Quang Ninh province of Vietnam were selected to investigate the influence of underground mine adit location and rock layers positions to stress states, yielded zone and displacement of the rock mass surrounding adit by using FLAC2D [12]. The results suggest that the subsidence of the surface could be triggered due to underground collapse.

2. Mechanical parameter and simulation diagram

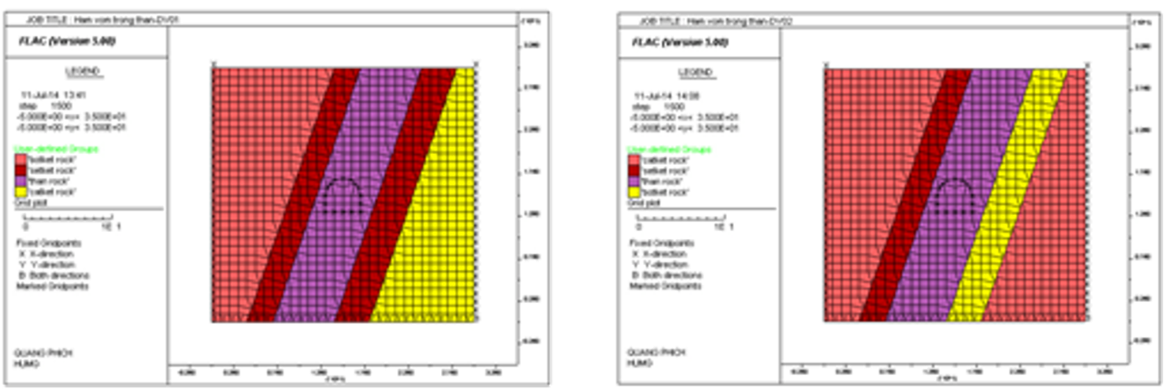
The rock mass in the coal mining in Quang Ninh province, Vietnam consists normally of 4 layers: sandstone, siltstone, clay and coal lying inclined with mechanical parameters as in the following Table 1. The constitutive model of Mohr–Coulomb is used for modeling the behaviour of the rock mass.

Table 1. Mechanical parameters of rock mass

Layer	Density ρ (g/cm^3)	Cohesion c (MPa)	Friction angle φ (degrees)	Bulk modulus K (GPa)	Shear modulus G (GPa)
Sandstone	2.61	1.00	40	11.60	8.70
Coal	1.30	0.01	35	2.60	1.30
Slitstone	2.50	1.00	25	10.00	7.00
Clay	2.60	0.10	30	9.60	2.70

Two cases are investigated with different orders of rock layers:

- Case 1: from upper to lower layers are clay-coal-clay-siltstone layers.



(a) Case 1 (b) Case 2

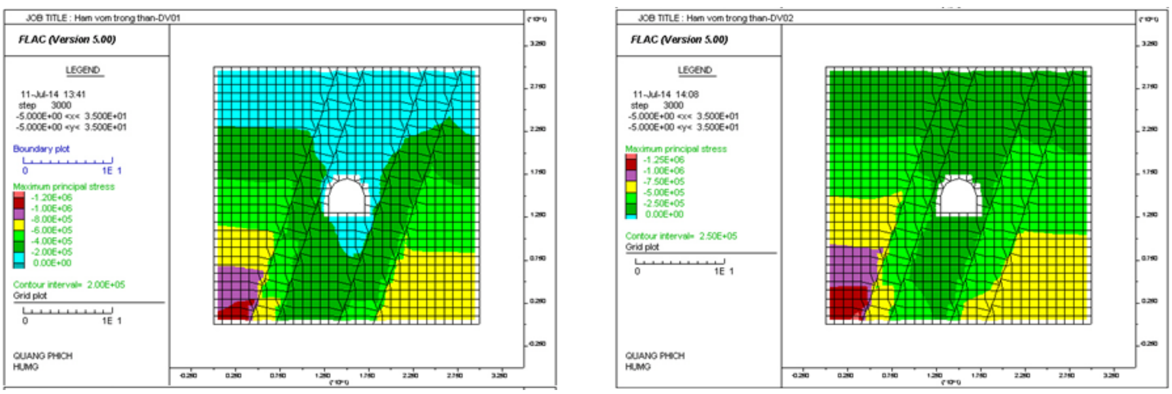
Figure 1. The model of the two cases study

- Case 2: from upper to lower layers are sandstone-clay-coal-siltstone-sandstone.

The tunnel has a semi-circular and straight-walled shape or D-shape with a width and height of 4 m each, excavation in coal layer. The height from top of the adit to the surface is nearly 15 m. The model was built with size of 30 × 30 m. The left and right boundary of model are fixed at horizontal direction; the bottom boundary is fixed in both vertical and horizontal direction and the top boundary of model is free. The analysis model is shown in Fig. 1. The initial boundary condition of the model is in-situ rock mass stress state.

3. Simulation results and discussions

Redistribution of stress induced due to excavation opening is a complex subject in actual mining conditions because of the influence of rock mass layers. The results of the numerical simulation can show all information on the laws of mechanical changes occurring in the rock mass surrounding the adit, including the stress redistribution, displacement, deformation and the failure zones. Based on that information the designers can analyze and choose the possibilities of support systems for reinforcing rock mass to keep the stability of the underground opening. By introducing the simulation results, the advantage of numerical simulation in general as well as in geo-hazard analysis could be demonstrated.



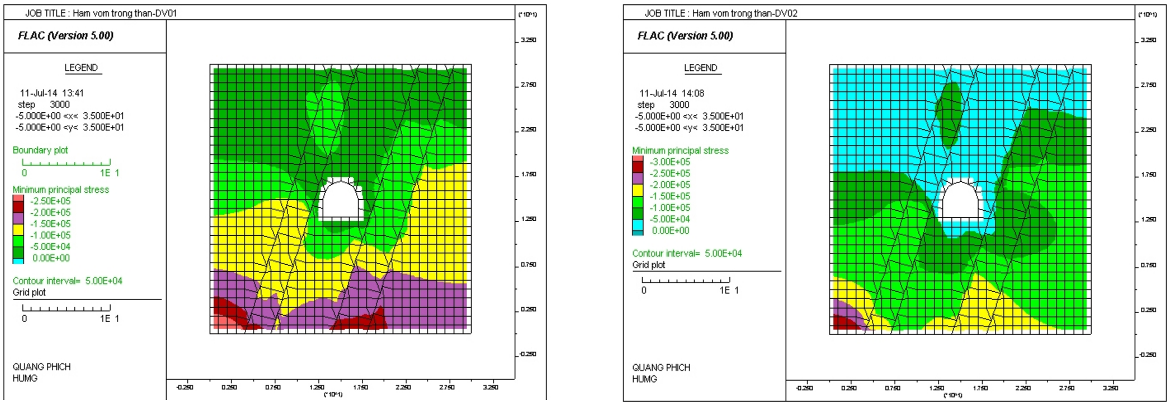
(a) Case 1 (b) Case 2

Figure 2. Major principal stress distribution (Pa)

Figs. 2 and 3 show the distribution of the major and minor principal stresses in the rock mass surrounding the tunnel. It is easy to see in Fig. 2 that the general redistribution principles are that the major principal stresses of peak value occur in the hard rock layers, however due to the order of different rock layers, it can be seen that the average value of the principal stress forming different shapes. In case 2, as the siltstone lies under the coal layer, which is mechanically stronger than the clay layer, the area of the principal stress with an average value of 0.25 MPa spreads deeper in the coal than in case 1.

By comparing the minimum principal stress distribution principles in Fig. 3, the findings show quite similarities in the distribution areas in both cases. However, in case 2, the area with the smallest minor stress components with values ranging from 0 to 0.05 MPa is more widespread than in case 1 with the stress fluctuating in the range of 0.15 to 0.2 MPa. It is smaller in the lower part of the modeling.

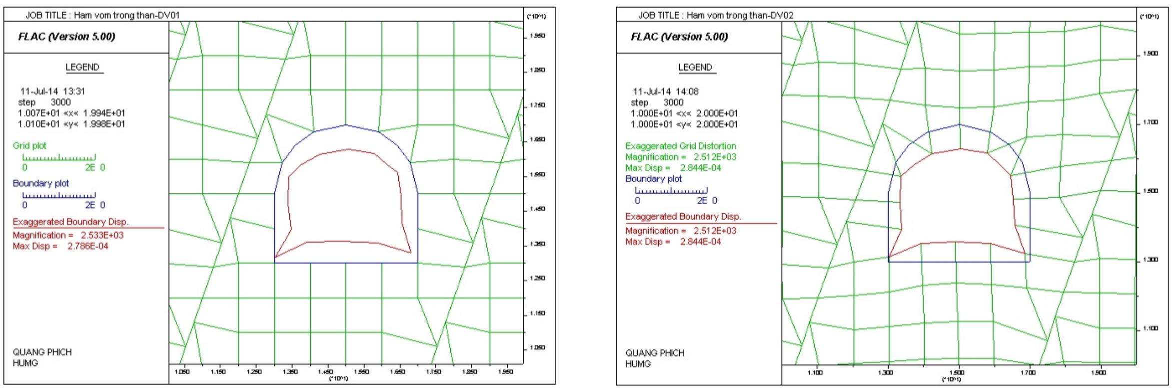
Therefore, the results showed that the effect of the layers is very clear to the stress redistribution, which is very different from the results obtained by analytical methods with the "averagation" or "homogenization" of the model on the rock mass [13–15].



(a) Case 1 (b) Case 2

Figure 3. Minimum principal stress distribution (Pa)

Similarly, the results obtained with the principle of movement show that due to the influence of the rock mass layers, the movement in the rock mass around the underground opening is not symmetrical but dependent on the specific geological structures. Fig. 4 shows the displacement on the boundary of the opening, reflected across the boundary of the opening after the displacement.



(a) Case 1 (b) Case 2

Figure 4. Displacement of the opening boundary after excavation

Figs. 5 and 6 show the formation of failure zone (area with symbol) in the rock mass around the opening. The failure zone in both cases develops mainly in the coal layer and to the surface of the hard rock mass. However, comparing the two cases with different order of rock mass layers shows that in case 2, the failure zone is wider. The results clearly show the influence of the stratification structure as well as the order of the rock mass layers on the formation of geohazards. The failure state occur when the shear stress is more than the shear strength of rock mass element. The symbol of "*" in Fig. 5 is indicated that the rock mass element was failed by shearing and the symbol of "x" indicating the rock mass element was failed in elasticity state.

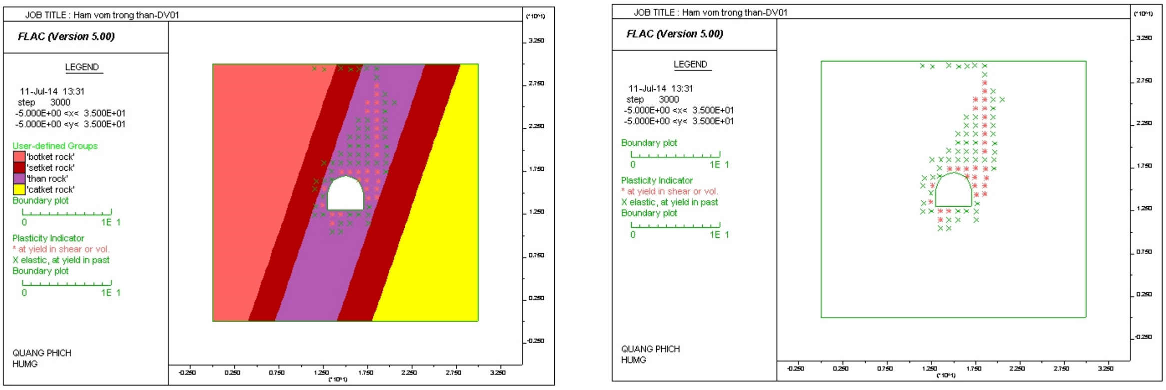


Figure 5. Failure zone around the opening, case 1 (*: shear failure; x: elastic failure)

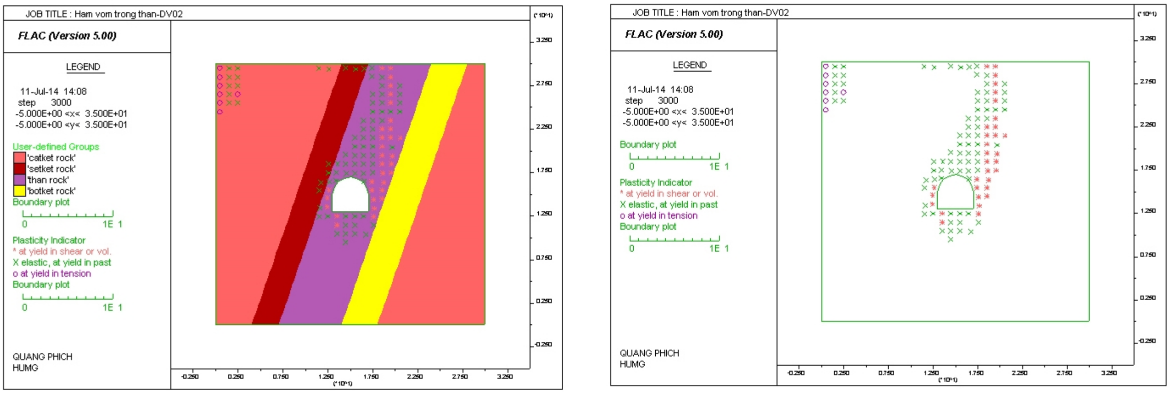


Figure 6. Failure zone around the opening, case 2 (*: shear failure; x: elastic failure)

Several comments can be drawn from the numerical results:

- When the rock mass has a layered structure, principal stress redistribution, displacement of tunnel boundary and the formation of failure zones are complex. Rock formation does not behave as homogeneous material, it requires therefore advanced numerical model to solve the problem;

- It is clear that the mechanical behavior of rock mass depends not only on the location of the opening, but also on the order and distribution of the rock mass layers, which are clearly shown in the numerical results;

- In the second model, the displacement and deformation processes achieve relatively larger values, although in case 2 there are both sandstone layers in pillars and cliffs;

- The change in the position of the layers clearly affects the processes of stress redistribution and movement in the rock masses;

- The development of the failure zone in the latter case is stronger;

- In both cases, as the distance from the top of the structure to the surface is not wide the failure zone is developed to the surface of hard rock mass layers. In this case, it may cause landslide or land subsidence, with varying intensity.

4. Influence of tunnel shape on geomechanical process

To study the effect of the cross-section shape of underground opening to the redistribution of stress states and failure zone, simulations were performed with the case of the circular shape which has a radius of 2 m, with similar mechanical parameters and order of distribution of rock mass layers as in Section 2. The obtained results show that, when the opening is a circular shape, the rules of stress redistribution and displacement also show dependence on the layering of the rock mass. However, the failure zone in this case does not develop to the surface. It also means that it is not likely to lead to landslides or land subsidence under the investigated conditions.

Figs. 7–9 show the rule of the major and minor principal stress redistribution as well as the failure zone, for the case of rock mass layers are sandstone, claystone, coal and claystone.

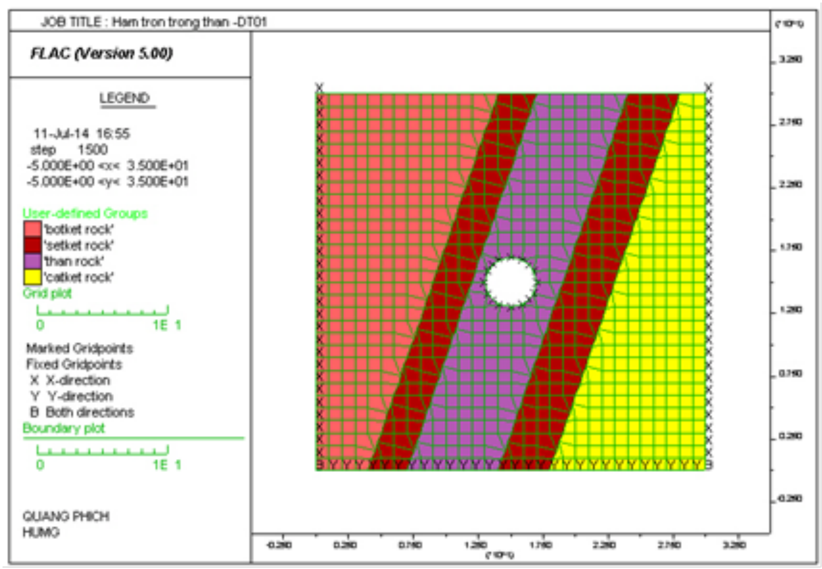
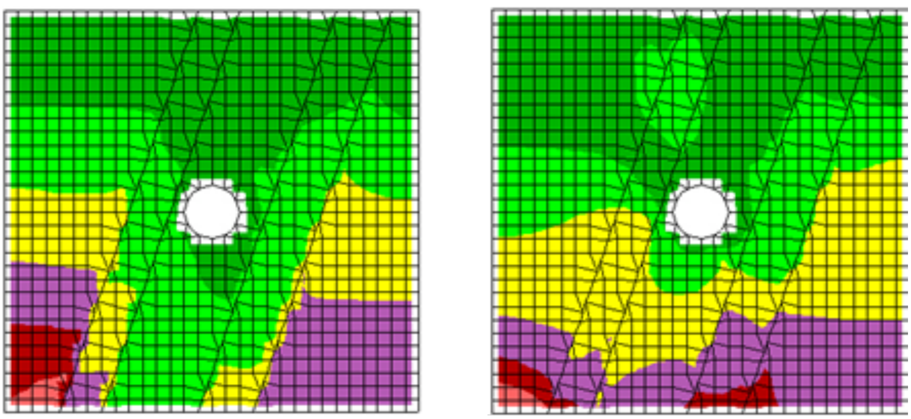


Figure 7. Modeling of a circular opening



(a) (b)

Figure 8. The principle of (a) maximum and (b) minimum stress (Pa) redistribution with the circular cross-section of opening

The numerical modeling results reveal that when the opening is a circular cross-section shape, the rules of principal stress redistribution, displacement and deformation strongly depend on the shape of the opening compared to the two cases analyzed above (Figs. 3 and 8). The failure zone is formed within the coal layer, although there are also some local failure points on the hard rock mass, which are not symmetrical, due to the inclined rock mass layers. Especially, when paying attention to ground subsidence and landslides, it shows that when selecting a circular cross-section of opening the land subsidence decreases, and it is difficult to collapse to the surface (Fig. 9).

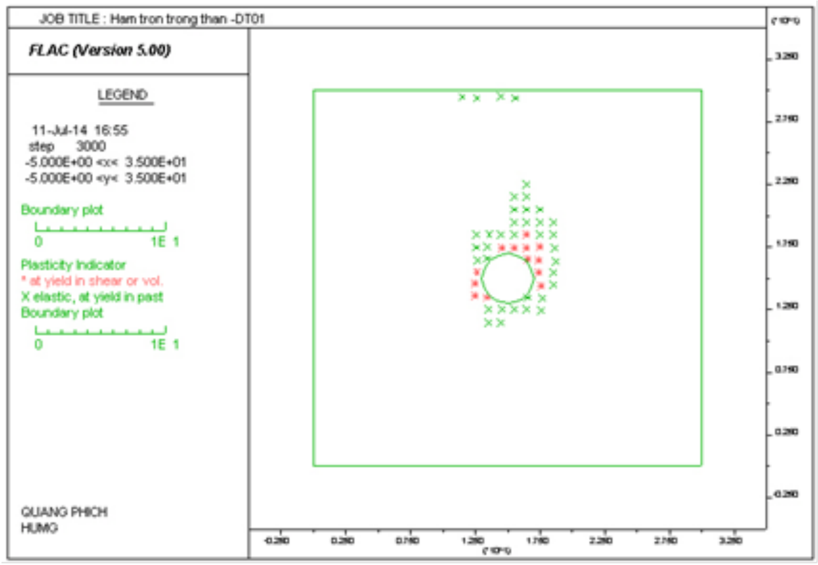


Figure 9. The failure zone around the circular tunnel (*: shear failure; x: elastic failure)

5. Conclusions

The numerical modeling results show that the numerical methods can solve the complex problems of the tunneling and mining in rock masses by taking into account the complex behavior of rock formation such as discontinuities, anisotropic and heterogeneities. The rules for stress redistribution and deformation, the development of the failure zone as well as their magnitude, depend clearly on the structural characteristics, arrangement of the rock mass layers and cross-section shapes of opening. Obviously, in order to obtain accurately, the mechanical behavior in rock mass with complex geological structures, it is necessary to analyse specifically case by case. On the one hand, by using numerical method, it is possible to analyze the possibility and type of development of specific geological conditions that lead to "incidents and accidents", meaning that it is possible to identify the type of "geological disaster" which can be caused by human factors. On the other hand, by clearly understanding the rock masses behavior after excavated opening, it can be helpful for the designer to select suitable cross-section shape, excavation method and support system for the opening to prevent the possibility of incidents and accidents, i.e. limiting the geological disaster.

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