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EFFECTS OF LINING JOINTS ON THE STABILITY OF ROADWAYS IN VIETNAMESE COAL MINES

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ABSTRACT: Using heavy supports with a high bearing capacity of the load by precast concrete lining is a limited problem in other underground mines in Viet Nam. This solution avoids the excavation for expansion and increases the stability of roadways during operation. Most of the cases reported in the literature focus on considering the effect of geological conditions, roadway size, the depth of roadways, and excavation methods on the stability of roadways in a continuous rock mass with behaviors of isotropic and linear-elastic. In addition, these reports only consider the types of supports such as rock bolts, steel ribs, shotcrete and the combination of these supports. These cases also do not consider the effect of joints between segments in the precast concrete lining and roadways excavated in bedding rocks. This paper introduces the analysis of the stability of roadways in weak rocks using precast concrete lining base on using a two-dimensional finite element model in the Quang Ninh underground mines of Viet Nam. The results show a certain influence of joint distribution, joint number on the stability of roadways in the continuous and bedding rock mass.

Keys: Stress, Displacement, Roadways, Underground mines, Segments, Lining, Numerical methods.

1. INTRODUCTION

The development of numerical methods for designation rock support in tunneling can be used other numerical methods. In general, there are many methods for analyzing the stability of roadways, such as finite element method (FEM), Difference Element Method (DEM), Confinement Convergence Method (CCM), Boundary Element Method (BEM), and Discrete Element Method (DEM) [2-6].

Segmental concrete lining used widely for the construction of urban underground tunnels in the soft ground because shield-driven tunneling method is widely adopted due to its flexibility, cost-effectiveness and its minimal impact on the ground surface. However, using these concrete lining in the field of underground coal mines is limited not only in Viet Nam but in the other countries. The segmental concrete lining is commonly used in most shield-driven tunnels which generally comprises a sequence of rings placed side-by-side (Gruebl, 2006). These rings are divided into sectors and each of these elementary units is called a segment (Fig.1). The main difference between a segmental lining and a continuous one is the existence of joints in the lining. Under the influence of the joints, the behavior of the structure and the surrounding ground will be different from the ones induced by a continuous lining.

There are current numerical and analytical studies conducted to estimate the stability of roadways in weak rocks as guidelines for the Design of Shield tunnel lining (ITA, 2000), the tunnel boring machines advances (ITA, 2007), and other reports of ITA from 2000 to 2015 [2], [7-10].

a) Roadways in Kemerovo zone (Russia)

b) Segment concrete

Fig.1 Segment lining by precast concrete in underground mines in Russia

In addition, analysis the stability and selection supports of roadways can be also estimated with empirical methods (Peck, 1969, Attewlle et al., 1986, Lee and Rowe et al., 1992). Most of the cases reported in the literature focus on considering the effect of rock mass condition, roadways size, the depth located roadways, and excavated methods on the stability of roadways. However, these cases do not consider the effect of joints between segments in the precast concrete lining (Maranha and Neves, 2000; Melis et al., 2002; Jenck and Dias, 2003; Barla et al., 2005; Phienwej et al., 2006; Chehade and Shahrour, 2008; Afifipour et al., 2011; Hossaini et al., 2012; Mirhabibi and Soroush, 2012) [10-17]. In this paper, a numerical study of the stability of roadways on the rock supports in Mong Duong underground coal mine which made it possible to include the influence of joint's characteristics such as joint number, joint distribution inlining.

2. GEOLOGICAL AND MINING CONDITION

2.1 Introduction of Mong Duong coal mine

According to the strategic development of Vietnam's coal industry until 2015 with the review into 2025, which was approved by the Prime Minister in Decision No. 89/2008/QD-TTG dated 07/7/2008, Mong Duong Coal Mine topped as one of the old mines, which has an investment priorities and expansion mining boundary in the future from The Vietnam National Coal-Minerals Industries Group [1].

Mong Duong coal mine, a typical mine in Viet Nam with more than 35-year operation, is selected as a case study for this research. Mong Duong coal mine locates at the Cam Pha coal area with the designed production capacity of 2.0 Mt/a (Fig.2).

Fig.2 Location of the Mong Duong coal mine and research area

The mine boundary was taken according to the Decision No.112/QD-HDQT dated on May 16, 2008, by the Chairman of Vinacomin's Board of Directors on Approving the master plan for coal mines boundary of Viet Nam National Coal-Mineral Industries Holding Corporation Limited. From explorations results, there are total 22 coal seams in the Mong Duong mine. To date, the coal is excavated in various seams and multi-layer seams, mainly vary from -100 m to -250 m below the sea level. The consisting of seams H10, G9 in the East Wing, G9 in the West Wing, G9 in Vu Mon area, II (11) and K8, etc. There are two vertical shafts in the Mong Duong coal mine including the main shaft and the auxiliary shaft, which were built correspondingly from + 188 m and + 6.5 m down to - 97.5 m.

2.2 Traditional Support for Surrounding Rock

The experimental roadway is dragged under the floor of 10# coal with the distance of 8.0-15.0 m, the average elevation of the roadway is at -250 m level. To investigate the traditional support technology (i.e. U steel support), this support technology has been applied in two sections at the same roadway. The length of experimental roadway is 200 m, with the cross-cut area from 13.2 m^2 - 17.9 m^2 outside of support and using area inside from 10.4 m^2 to 14.5 m^2. The original support for surrounding roadway is typical U-shaped steel shrinkage bracket, the back reinforcement net of the bracket adopts Φ 5 mm round bar welding or reinforced concrete slab, the bracket is 0.5-0.75 m. As shown in (Fig.3), from which the deformation of surrounding rock and the corrosion of the steel support have been observed. Considering that the service time of the roadway is about 15 years, traditional support technology should be evaluated to make sure the safety mining.

Fig.3 The outline of the roadway with traditional support -250 level Vu Mon area

Moreover, compared with concrete lining ease-install, the potential manual risk is another concern for U-shape support. Therefore, it is emergent to take new types of support to control the deformation of rock mass around the roadway.

2.3 Rock mass properties of roadway -250 level Vu Mon area

The rock-mass detection recorder (GD3Q-GA) was used to detect the lithology and the fissure of roof surrounding rock. The vertical borehole with the aperture of 65 mm and the depth of 10 m was drilled ahead with the distance of 10 m.

It is believed that with the increase of depth, the stability of the surrounding rock seems better than that in shallow depth. In detail, there exists a lot of network fissures ranging from 0.5 to 1.5 m. With the increase of the depth, the surrounding rock is characteristic with cut-fracture located at approximate 2.0 m. Then, both the number and the size of cracks gradually reduced out of 2.0 m even though the damage of the borehole has been observed. It is the pretty integrity of the surrounding rock over the depth of 2.4 m. Moreover, no obvious cracks and fracture were observed on the surface of the borehole beyond 4 m, indicating that the influence zone ranges from the surface of the roadway to 2.4 m. Geological conditions surrounding and on the face of the roadway -250 level in Mong Duong coal mine can be shown as in (Fig.4).

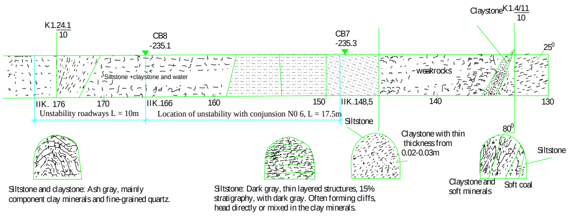


Fig.4 Geological conditions of roadway -250 level Vu Mon - Mong Duong coal mine

3. NUMERICAL MODELLING

3.1 Parameters of the Simulation Model

In this section, the simulation results obtained from Phase 2 (i.e. Rock and Soil 2-dimensional analysis program) are presented due to it is believed to be an effective method for support design which has been widely used in mining engineering, especially in terms of the deformation mechanics of surrounding rock [18].

The length and the height of the numerical model are all 38.7 m respectively. The top boundary of the model is applied to the weight of overlying strata, the bottom boundary is fixed. The left and right boundary of the model are fixed horizontally to simulate the real application. The preload vertical stress on the top of the model is applied according to the depth of 350 m comparisons with the surface with charge load $P = \gamma H = 0.026.(350\text{-}19.35) = 8.6$ MPa. The roadway is symmetrical to the circular shape with a diameter of roadway D = 4.3 m, respectively. Support is applied in the modeling by concrete liner with the thickness 250 mm. Basing on the parameters of rock mass investigated in section 2.3, properties of the rock mass in the model in this research can be selected as in Table 1.

Table 1 Properties of the rock mass

Parameters	Siltstone
Unit weight of rock γ, MN/m^3	0.02
The uniaxial compressive strength of intact rock σ_{ci}, MPa	30
Tensile strength σ_t, MPa	0.0
Cohesion c, MPa	0.2
Friction angle φ, degree	12
Young modulus E, MPa	200
Poisson ratio v	0.35
Dilation angle ψ, degree	0
Residual friction angle is, degree	6
The span of roadways B, m	5
The depth of roadways H, m	350
Lateral earth pressure coefficient K_0	1

3.2 Influence of Segment Joint in Lining

Research models can be built for continuous lining (Fig.5), and then with discontinuous lining with other segments (Fig.6) to assess the effects of segment joint in lining on the stability of roadway.

The influence of joint distribution on the stability of the roadway is estimated by the change of joint number and joint orientation in a ring along the roadway's circumference. Location of joints in a ring is represented by the reference joint defined as the one which is located closest to the roadway crown respecting the clockwise rotation from the roadway crown. Joint distribution is assumed to be uniform along the roadway's circumference.

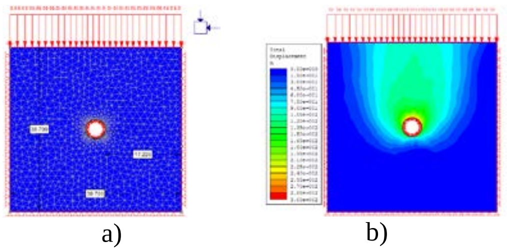


Fig.5 Numerical modeling for the problem (a) and total displacement (b) in case of roadways located in continuous rock mass and continuous lining

By analysis can be received the distribution of displacement around roadways in case of the continuous concrete lining as in (Fig.5b). The bending moment in continuous concrete lining can be shown as in Fig 5. Basing the results of this case should be recommended the location of segments as in (Fig.7).

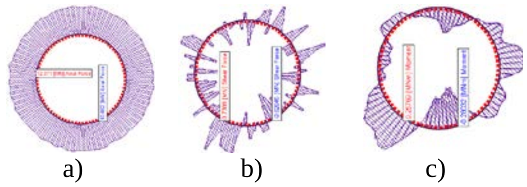


Fig.6 Diagrams of internal forces in the continuous concrete lining: a) axial force; b) shear force; c) bending moment

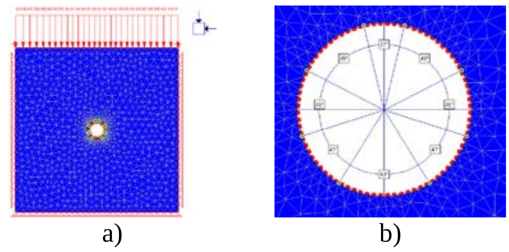
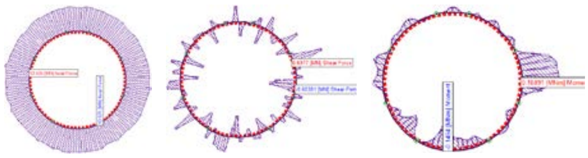


Fig.7 Model roadway with segmental lining in the isotropic rock mass: a) the distribution of joints in the model; b) the coordinates of joints in lining



a) b) c)

Fig.8 Diagrams of internal forces in the discontinuous concrete lining with 8 segments: a) axial force; b) shear force; c) bending moment

The results in the (Fig.8) show that the values of internal forces in the lining are certainly affected by the joint location. However, the joint number will result in a slight increase of the maximum internal forces induced on the stability of roadways. It could be explained by the fact that when the joint number in a lining ring, the higher flexibility of roadway structure is. As a consequent, it will result in a larger deformation of roadway structure and then may be followed by larger movements of surrounding rock mass. The values of internal forces in the lining can be listed in Table 2.

Table 2 Comparison the values of internal forces in the continuous lining with lining 8 segments

	Continuous lining	Lining with 8 segments	(%)
Shear forces, MN	Q_{max} = 0.738 Q_{min} = 0.620	Q_{max} = 0.697 Q_{min} = 0.604	-5.65 -3.54
Bending moment, MN.m	M_{max} = 2.803 M_{min} = 2.576	M_{max} = 0.185 M_{min} = 0.146	-93.4 -94.3

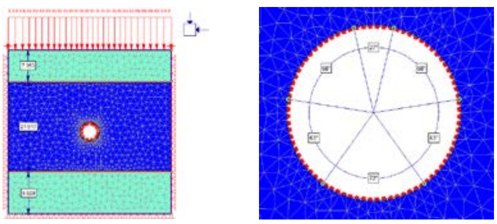
The differences in table 2 can be explained that the roles of the joint number in the discontinuous lining have a larger influence on the values of internal forces in a continuous lining. The values of bending moments can be decreased to approximately 94%.

3.3 Numerical modeling in case of stratification rocks

In this study show the changing of internal force in the discontinuous ring in the stratification rocks. The parameters of the roadway are the same as the section 3.2. Parameters of rock mass can be seen as in Table 3. Roadway located in the center of weak rocks with the thickness of rock layers 21.57 m, the model can be simulated as in (Fig.9) and (Fig.10).

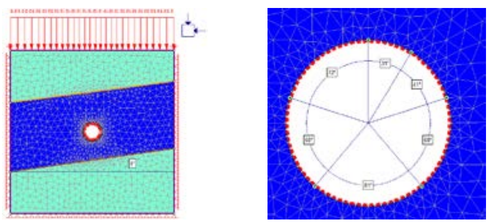
Table 3 Properties of the rock mass in case of stratification rocks

Parameters	Values	
	Sandstone	Siltstone
Unit weight of rock γ, MN/m^3	0.026	0.02
The uniaxial compressive strength of intact rock σ_{ci}, MPa	40	25
Tensile strength σ_t, MPa	0.4	0.0
Cohesion c, MPa	0.8	0.2
Friction angle φ, degree	30	12
Young modulus E, MPa	1800	200
Poisson ratio v	0.3	0.35
Residual tensile strength φ_{re}, degree	0.6	0.05
Residual friction angle is, degree	28	6
The diameter of the roadway, m	4.3	-
The depth of roadways H, m	350	-
Dip angle of rock mass layers α, degree	0; 10	0; 10
The thickness of rock mass layers D, m	336.85	21.517
Lateral earth pressure coefficient K_0	1	
JCS	$0.1\sigma_{ci}$	
JRC	2; 6; 10	



a) b)

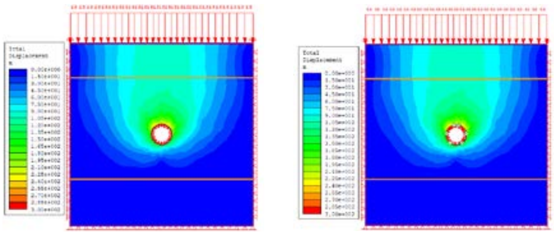
Fig.9 Numerical modeling lining in the horizontally layered rock mass: a) model; b) the coordinates of recommended joints



a) b)

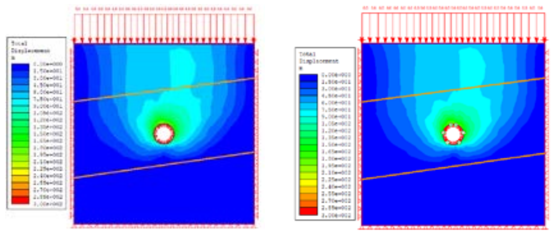
Fig.10 Numerical model in case of inclined rock strata: a) model with continuous lining; b) the coordinates of recommended joints

The distribution of total displacement of rock mass around roadway in case of continuous lining and discontinuous lining with 6 segments in the horizontally layered and in inclined rock strata can be seen as in (Fig.11) and (Fig.12). Diagrams of internal forces in the lining for these cases also are shown as in (Fig.13) and (Fig.14).



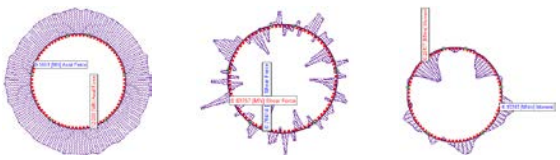
a) b)

Fig.11 The distribution of total displacement around roadway in the horizontally layered rock mass: a) in the continuous lining; b) in lining with 6 segments



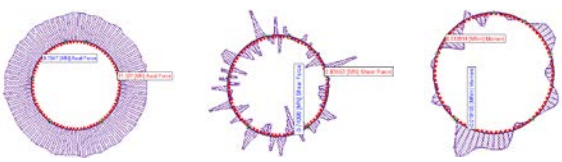
a) b)

Fig.12 The distribution of total displacement around roadways in inclined rock strata: a) in the continuous lining; b) in the lining with 6 segments



a) b) c)

Fig.13 Internal forces in the lining with 6 segments in the horizontally layered rock mass: a) axial force; b) shear force; c) bending moment



a) b) c)

Fig.14 Internal forces in the lining with 6 segments in inclined rock strata: a) axial force; b) shear force; c) bending moment

4. RESULTS AND DISCUSSION

Diagrams of internal forces in the lining in the conditions of the horizontally layered rock mass and inclined rock strata indicate that these values can be reduced to compare with values in the isotropic rock mass comparison as in section 3.2.

The results of comparing the values of internal forces in lining with 6 segments in the horizontally layered rock mass can be obtained in Table 4.

Table 4 Comparison the values of internal forces in the continuous lining with lining 6 segments

	Continuous lining	Discontinuous lining with 6 segments	(%)
Shear forces, MN	Q_{max} = 0.837 Q_{min} = 0.802	Q_{max} = 0.817 Q_{min} = 0.764	- 2.40 - 4.70
Bending moment, MN.m	M_{max} = 0.301 M_{min} = 0.283	M_{max} = 0.292 M_{min} = 0.153	- 2.90 - 45.9

The differences of shear forces and bending moments in Table 4 show that the lining with segment joint consists of the values of bending moments less than the continuous lining. This indicates that the segment joint has a certain influence on the maximum bending moment induced at the deformation of the lining. It also indicates that the roles of the joint number in the concrete lining, which make increasing more stability for roadways. Basing these results can be selected ling with 6 segments. That is the ease-install during excavation roadways. The results of research also show that the stiffness of top layered rock mass has an influence on the load acting to the lining of roadways. In case of roadways driven in the center of the horizontally layered rock mass, which has properties of weak rock and the thickness of rock mass and dimension of roadway L/D = 21.17/4.3 = 5.016 the earth pressures are symmetric and the location of key segments should be located on the crown of the ring.

Consequently, with the problem of stability of roadways in the inclined rock strata. The values of shear forces and bending moments can be recorded as in Table 5. The results in Table 5 indicate that, in the inclined rock strata roadway supported by segmental lining, the values of internal forces in lining are less than the continuous lining.

Table 5 Comparison the values of internal forces in the lining with 6 segments in inclined rock strata

	Continuous lining	Discontinuous lining with 6 segments	(%)
Shear forces, MN	Q_{max} = 0.942 Q_{min} = 0.933	Q_{max} = 0.835 Q_{min} = 0.740	-11.3 -20.6
Bending moment, MN.m	M_{max} = 0.306 M_{min} = 0.217	M_{max} = 0.186 M_{min} = 0.097	-39.2 -55.2

Moreover, the analysis also explains that in the case of inclined rock strata the location of the key segment should be installed on the right of the crown as (Fig.10). This location should be bearing higher load from rock mass around the roadway.

5. CONCLUSIONS

The research results can show that the stability of the roadway which is supported by segmental lining is always higher than the roadway induced by the continuous lining or U steel supports because the values of internal forces in the segmental lining are smaller than continuous lining and U steel supports.

In the detail geological conditions as Mong Duong underground mine and roadway -250 level should be used segmental lining with 6 segments. Because in comparison with the stability and ability bearing load caused by the excavation of a roadway supported by a continuous lining and U steel supports, the stability of roadway induced in cases of using segmental lining with 6 segments is always higher.

The location of key segments on the boundary of roadway perimeter depends on dip angles of rock strata. In the horizontally layered rock mass location of key segments is the center on the crown, in case of an inclined rock strata with dip angle > 10^0 key segments should be located on the right of the crown.

The number and orientation of joints have an insignificant influence on the maximum internal forces in the lining. Generally, the higher the joint number is, however, the higher the maximum internal force is.

Further research calculations should be carried out to study the influence of:

Other stiffness parameters of joints such as axial stiffness, radial stiffness;

The interaction between the lining and rock mass around roadways at close proximity;

Other more sophisticated constitutive models of rock mass and lining.

In addition, comparisons with experimental data obtained from real roadway excavations should be made in order to improve the quality of the numerical simulation.

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