

CONTROL TECHNOLOGY FOR COAL ROADWAY WITH MUDSTONE INTERLAYER IN NUI BEO COAL MINE

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ABSTRACT: The insufficient effect of traditional supports (e.g. the U-shape structural steel support) has been verified from various vital accidents in terms of roof collapse in Vietnam coal mines. The situation is becoming more complex, particularly, where the overlying strata consist of series weak interlayers such as mudstone and/or coal gangue. This paper starts with the summary of the failure mode of existing supports used in Vietnam coal mines, followed by the FE simulation (RS2 programming) based on the given geological conditions. Then, a case study conducted at Nui Beo coal mine by using the high strength prestressed bolt to prevent the separation of mudstone interlayer is presented. The design based on systematic numerical simulation and careful discussion of the failure mode of traditional support technology has been successfully verified from practical application. The results revealed that the rheological strain is closely related to time, it is about 60 days from the firstly caving to be stable, the maximum displacement of the roof and ribs to ribs are 14 mm and 35 mm respectively. The first ever practical application of prestressed bolt in Vietnam coal mine roadway associated with mudstone interlayers indicated that, compared with current widespread passive support, it is an effective support technology for some other coal mines in Vietnam with similar geological conditions.

Keywords: Mudstone interlayers, Prestressed bolt, Coal roadway, Control technology, RS2 programming

1. INTRODUCTION

It is well known that both the geological condition and construction condition of a coal mine in Vietnam is much complex than that in other countries due to its special process of sedimentation [1,2]. Except for the unstable distribution of coal thickness and dip angle which significantly influence the safety and effective coal mining, another geological factor should be carefully concerned is the unexpected mudstone interlayers existed in the coal seam. A large amount of research has revealed that this phenomenon is very normal for coal mines in Quang Ninh, Vietnam. The thickness of mudstone interlayers consisting of mudstone and coal gangue in Thong Nhat coal mine ranges from 0 to 8.83m. In addition, these discontinuous mudstone interlayers have been observed in Khe Cham mine, Ha Lam mine and Duong Huy mine as well. The thickness of mudstone interlayers in these coal mines varies from 0 to 2.4 m, 1.4 m and 5.43 m, respectively [3, 4]. Definitely, these non-uniform distributions of the number and the physical property of mudstone interlayers must bring side effect on the stability of surrounding rock in the roadway.

Even though, this geological factor has been underestimated for a long time in Vietnamese coal mine mainly because that the scale of the roadway is not as large as enough with the use of

demolition mining method rather than mechanical mining method. During the past decades, with the high-speed economic development of Vietnam, a large amount of modern mining equipment has been put into practical application with the introduction of latest mining method to produce the desired amount of black coal. Correspondingly, the scale of roadway enlarges to meet the requirements of transportation as well as ventilation. Then, vital roof collapse and large deformation of surrounding rock have been occurred, which significantly postpones the advance of working face, leads to serious economic losses and threaten the safety of miners [5, 6].

However, this mentioned situation has not been changed to some extent since that traditional passive support technologies, such as U-shape structural steel and wood crib, are still widely used for most coal mines lacking experience in Prestressed bolt technology which has been popular in other countries to maintain the stability of surrounding rock with sandwich layers [7-11].

Against this background, this present paper firstly introduced traditional support technology used in Vietnam and the failure mode of these supports. Then, the typical finite element simulation program, namely RS2, was applied to investigate the effect of pre-tensioned strength and the influence of mudstone interlayers based on the geological condition of Nui-Beo coal mine. This

paper ends up with the detailed case study including critical parameters of bolt support technology according to in-site investigation with the help of electrical scan and mentioned numerical simulation results. The first ever prestressed bolt technology in coal mine roadway with soft mudstone interlayers in roof suggested that it is an effective and safety development trend for some other coal mines in Vietnam with similar geological conditions

2. VIETNAMESE TRADITIONAL SUPPORT TECHNOLOGY IN COAL MINE

For most coal mines in Vietnam, both the caving of roadway and working face mainly depend on demolition mining method. The elector drilling was widely used for some cases. Correspondingly, traditional roadway support for demolition mining method including wood cribs, U-shape structural steel and I-section structural steel is still accepted for some coal mines. The concrete plate is the common material for these passive-supports to infill the void between the roadway surface and support. Compared with active support, passive support cannot effectively maintain the stability of surrounding rock in coal roadway especially in terms of which are characterized with sandwich layers. Besides, the potential handle injuries for miners is another main concern for passive support because most passive supports are very heavy and not easy to install. In addition, the long-term stability of the support is still uncertain such as the losses of U-shape structural steel.

Due to the main support technology for most coal mines in Quang Ninh, Vietnam belongs to passive support, herein, taking Trang bach coal mine for example (Figure.1) to illustrate the failure mode of passive support [12, 13]. With the increase of the service time, the large deformation of surrounding rock with traditional passive support (i.e. U-shape structural steel support) is out of reach for normal use considering the transportation or ventilation.



Fig. 1 Failure mode of passive support in Trang bach coal mine

It is believed that the number and physical property of sandwich layers are the main influence factors for the large deformation of surrounding rock with U-shape structural steel support.

Particularly, mudstone is sensitive to moisture resulting in ununiform deformation at the uncontrolled site of passive support. Once the large deformation occurs at uncontrolled space, the load-carrying capacity of passive support is significantly descended due to the discontinuous contact with roadway surface. In addition, it is difficult to make sure the tightness between passive support and roadway surface resulting in the large deformation occurs at a very early stage. Most importantly, the installment of U-shape structural steel support is not coordinate with a concrete plate, the side-effective of which may result in the desperate of mudstone interlayers.

Active support is the development trend for modern coal mines. However, the introduction of bolt technology to Vietnam can just be back to 1990s, there is not much successful experience from large scale practical applications. Existing bolt support technology has been mainly applied to rock roadway rather than coal roadway. Therefore, for mudstone interlayers roof roadway, there is no reference from Vietnamese coal mines. On the contrary, there are still many points should be put much attention to. One of the major concern is how to guarantee the coordination of the installment of the active bolt in the roadway by demolition caving method [14]. If this problem cannot be successfully resolved, the same phenomenon will occur as well as passive support. In addition, both the mining operators and miners are not familiar with the bolt technology not only from the primary mechanics but also in practical management. That is, there is a long way to go through for a Vietnamese coal mine to popularize bolt technology as an alternative to traditional support technology.

3. GEOLOGICAL CONDITION AND FAILURE MODES

3.1. Geological Condition of an Experimental Roadway

Nui Beo coal mine locates at the Ha Lam coal area with the designed production capacity of 2.0 Mt/a Figure 2.

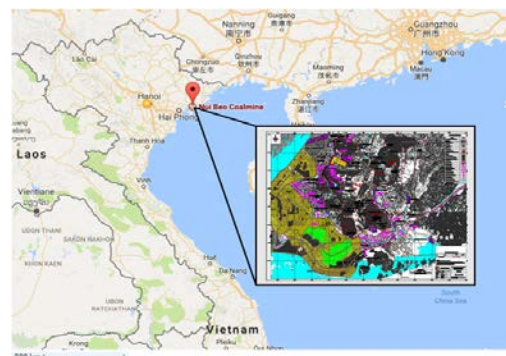


Fig. 2 Location of the test site

The age of the mining production area is 30 years starting in 2015. Nui Beo coal mine pit belongs to the Ha Lam coal area, 7 km north-east to Ha Long City-Quang Ninh. Mineral Coal Area is 5.6 Km²

Nui Beo coal mine of 41101 working face is situated on -120 horizontal level, ground elevation + 35 m. Geological structure is more complicated. Can be mined of the coal seam is 11# coal seam, the coal seam is 3 - 6 m thick, with an average thickness of 4.5 m, coal seam angle 4 - 7°. The coal seam contains 2 - 3 layers of weak mudstone, with an average thickness of 0.3 m. The direct roof is 1.4m claystone, 2.4 m siltstone. The main roof is packed and with an average thickness of 16m. Directly floor is siltstone, the thickness of 1 m - 2 m with an average thickness of 1.5 m. The thickness of the coal seam and the overlying strata changes significantly with the depth. In total, there are 10 layers of the coal seam which have been explored in Figure 3.

Columnar	Thickness (m)	Depth (m)	Rock name	Description lithology
	20	58.6	Packsand	Light gray, mainly composed of particles quartz, sustainable and very hard.
	2.4	78.6	Siltstone	Ash gray, gray, mainly component clay minerals and fine-grained quartz.
	1.4	81.0	Claystone	Dark gray, thin layered structure.
	1.6	82.4	Coal	Simple structure, black, shiny, small slope angle
	0.3	84.0	Partings	Dark gray, loose structure, soften disintegration
	1.4	84.3	Coal	Simple structure, black, shiny, small slope angle
	0.3	85.7	Partings	Dark gray, loose structure, soften disintegration
	0.9	86.0	Coal	Simple structure, black, shiny, small slope angle
	1.5	86.9	Claystone	Dark gray, thin layered structure.
	20.3	88.4	Sandstone	Ash gray, light gray, thick layered structure, some places massive structure, cracks developed.

Fig. 3 The layout of soft mudstone interlayers

3.2. The Failure Mode of Surrounding Rock with Traditional Support Technology

Similar to most other coal mines in Vietnam, U-shape structural steel support is applied for all coal roadway in Nui Beo coal mine. The height and width of the roadway are 2900 mm and 3400 mm, respectively. Figure 4 presents the deformation schemes of the roadway with traditional support technology.

Due to the mudstone interlayers on overlying strata is mudstone which is sensitive to moisture, the strength of surrounding rock is mainly affected by the water in the underground. For some cases, the scale of the roadway decreases to be half of the designed one, which has significantly affected the normal transportation and ventilation. The total roof deformation exceeded 500 mm to 800 mm, while the deformation measured from two ribs

were about 500 mm to 900 mm as shown in the sketch picture in Figure 4. It is believed that the existing of mudstone on overlying strata is the main reason for this out controlled deformation with traditional support technology. Another factor should be put attention to is insufficient of passive support itself which cannot provide active pressure to surrounding rock so that the large deformation develops sharply with the caving of roadway at an early stage.

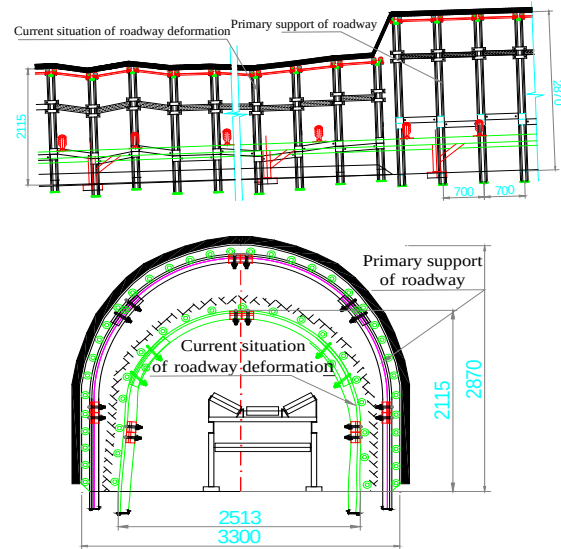


Fig. 4 Sketch of experimental roadway with large deformation

4. ANALYSIS ON INFLUENCE OF MUDSTONE INTERLAYERS

4.1. Modeling Setting Up

RS2 program was applied in the present study to explore the influence caused by mudstone interlayers on the stability of surrounding rock. In total, 7 layers of overlying strata were selected to simulate the effect of the number of mudstone interlayers with a constant thickness of 30 mm. Three different simulation schemes were designed according to the number of mudstone interlayers from 1-layer, 2-layer to 3-layers.

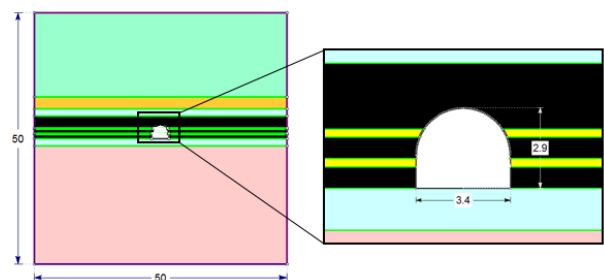


Fig. 5 Rock strata roadway calculation model

The simulation model with the same height and length of 50 m was constrained at boundaries. The applied load on the top boundary was equal to the gravity of overlying strata with a depth of 60 m. The arch roadway with the straight wall is caved at a designed position as shown in Figure 5. More detailed information about the physical properties of surrounding rock was summarized in Table 1.

Table. 1 Mechanical parameters of rock mass

Strat-um	U-W (kg m ⁻³)	Y-M E (GPa)	G S I	U-C-S (MPa)	Cohe- sion C (MPa)	F-A (°)
Sandstone	2650	5.3	55	73.3	2.8	35
Siltstone	2600	8.5	50	41.5	2.4	30
Coal	1400	1.4	20	20	0.7	22
Packsand	2700	8.8	65	85.6	3.0	38
Claystone	2520	3.7	40	26.8	2.1	26
Parting	1700	4.2	25	23.7	1.08	25

4.2. Critical Parameters of a Prestressed Bolt

The detailed analysis of critical parameters of the prestressed bolt was conducted before the discussion of the effect of mudstone interlayers to provide proper support technology. Herein, HRB335 bolt with a diameter of 20 mm is used to explore the proper length of the bolt, bolt interval and pre-tensioned stress.

4.2.1. Effect of length of the bolt

To investigate the effect of the length of the bolt, bolt interval with 800 mm was set up as constant. Four standard lengths of 1.7 m, 1.9 m, 2.1 m, and 2.3 m were compared, total deformation observed from the roof and ribs were presented in Figure.6. Apparently, the measured displacement decreases with the length of the bolt. However, this trend will be constant to some extent once the length of bolt exceeds 1.9 m. With the consideration of experience in Vietnamese mines, the HRB335 bolt with the length of 2.1 m was finally selected for other simulation presented in the later section.

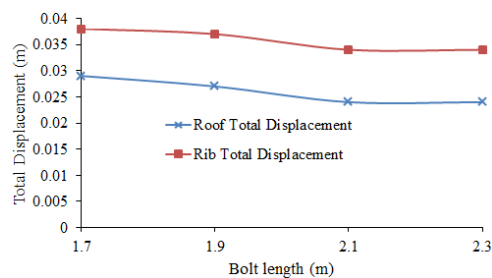


Fig. 6 Relationship between displacement and bolt length

4.2.2. Effect of bolt interval

Four different bolt intervals (i.e. 0.7 m, 0.8 m, 0.9 m and 1.0 m) were selected to explore the influence caused by bolt interval. Total deformation observed from the roof and ribs were presented in Figure 7. Apparently, the measured displacement decreases with the increase of interval. Similarly, this trend will be constant to some extent once the bolt interval exceeds 0.8 m. With the increase of bolt interval, the economic factor should be considered. Therefore, the HRB335 bolt with an interval of 0.8 m was finally selected for other simulation presented in the later section.

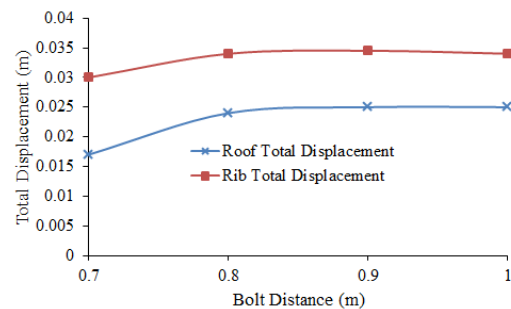


Fig. 7 The relationship between displacement and bolt interval

4.2.3 Effect of pre-tensioned strength

Figure 8 presents the influence of pre-tensioned strength on deformation of surrounding rock. From which it can be found that high pre-tensioned strength can successfully constraint the deformation not only in terms of the roof but also in two ribs. Due to the observed deformation became not too obvious once the pre-tensioned load exceeds 60 kN, herein, 60 kN was selected according to the geological condition used in present simulation.

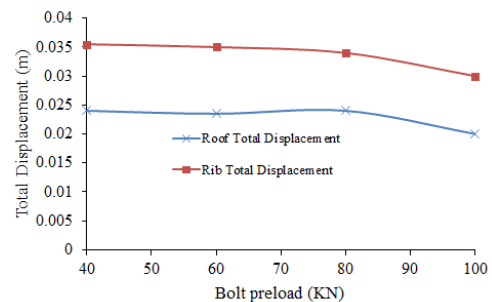


Fig. 8 The relationship between displacement and pre-tensioned load

As a short summary, HRB335 bolt with a diameter of 20 mm and the length of 2100 mm is used for coming simulation of the influence caused by the number of sandwich layer. 60 kN pre-tensioned strength was applied on the bolt to provide sufficient constraint on the roadway surface.

4.3. Side-Effect of Mudstone Interlayers on Surrounding Rock Deformation

4.3.1. Influence on the distribution of plastic zone

Figure 9 shows the comparison of the plastic zone with a different number of mudstone interlayers when there is no extra support and with support applied. With the increase of the number of the sandwich layer from zero to 3, the plastic zone enlarged to some extent, particularly in terms of the roof due to the corresponding development of discontinuous of overlying strata. The integrity of surrounding rock was much worse than that without mudstone interlayers. In addition, the existing of mudstone interlayers make it easier to be extruded during the caving of roadway. In detail, the scale of the plastic zone for that without mudstone interlayers is about 0.8 m in the roof and 2.3 m in two ribs. Compared with the roof and two ribs with an increase of the number of mudstone interlayers, the influence on the plastic zone at the floor is not obvious under 1.0 m due to that no support has been applied on the floor for all four simulation schemes. However, the effect of mudstone interlayers on the plastic zone in two ribs is very serious as shown in Figure. 9.

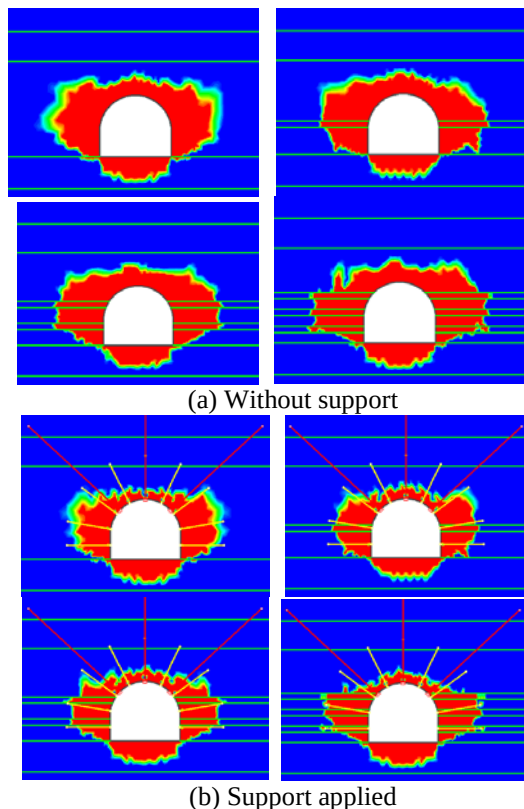


Fig. 9 Distribution of plastic zone with different number of mudstone interlayers

The existing of mudstone interlayers on roof mainly affect the stability of two ribs due to the development of the uncontrolled plastic zone. With

extra support applied on the roadway, this situation has been changed a lot, that is, the scale of plastic zone decreases, indicating that the prestressed bolt can be an effective method to control the development of plastic zone in two ribs.

4.3.2. Influence on the deformation characters

To obtain more detailed information to evaluate the effect of the prestressed bolt, several monitoring points were set up to measure real-time deformation at a different depth (i.e. from 0 m to 6.5 m) of surrounding rock. The detailed layout of the monitoring points can be found in Figure.10 and Table 2.

Table 2. The distribution of monitoring points

Number of mudstone interlayers	Without support	Support applied	Description
0	TH1	TH2	For comparison
1	TH3	TH4	For comparison
2	TH5	TH6	Real application
3	TH7	TH8	For comparison

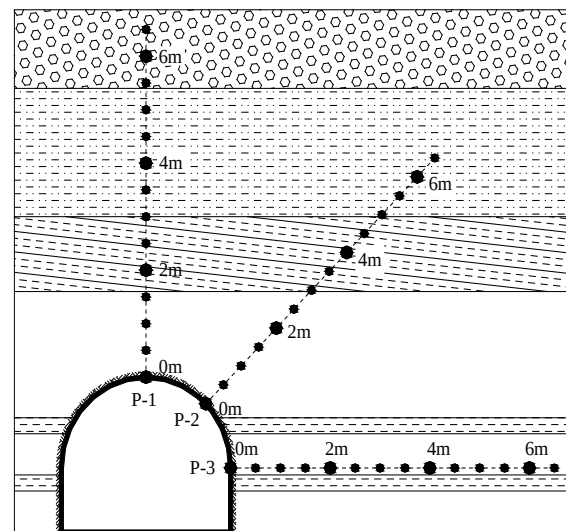


Fig.10. The layout of monitoring points

Figure 11 illustrates the displacement cloud with a different number of mudstone interlayers. It is apparent that the displacement cloud mainly developed to overlying strata with the length of approximate 6.0 m, by the contrary, the cloud zone at two ribs and floor is about 2.0. In addition, the total roof displacement increases with the number of mudstone interlayers. Taking the surrounding rock without support, for example, the roof deformation is about 0.037 m when there are no mudstone interlayers, this value increases to 0.055 mm with three- mudstone interlayers. Meanwhile, these measured valued decreased to 0.028 m and 0.041 m when the prestressed bolt was applied to maintain the stability of surrounding rock.

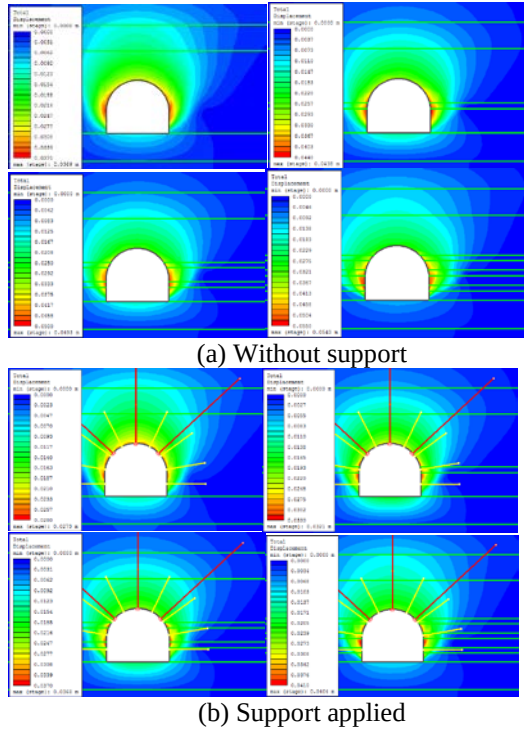


Fig. 11 Distribution of displacement cloud

Figure 12 demonstrates the total displacement monitored from three typical monitoring points. Taking monitoring point 1 for example, it can be found that the deformation at depth is much smaller than that of the surface due to the application of prestressed bolt technology to control deformation occurred at the early stage of caving procedure. In addition, the deformation is much larger at two ribs than that of the roof indicating that the prestressed bolt is much effective to control sandwich layers rather than other surrounding rock without the sandwich layer. It should be noted that the deformation obtained from TH6 decreased with the increase of the depth of the hole. That is, the deformation at point 1, 2, 3 are 0.024, 0.022, 0.031 m, respectively.

5. CASE STUDY

To verify above supposition, the electric scan TV was used to explore the desperate of overlying strata with sandwich layers. The hole was drilled with the depth of 10 m behind the caving site of the roadway. As observed from Figure 10, there are lots of obvious cracks nearby the surface of the hole, namely from 0.2 m to 1.8 m. While, with the increase of depth, both the scale and number of cracks reduce to some extent after 2.0 m. Due to the complex procedure of the installment of U-shape structural steel support, these cracks will develop more than 2.0 m due to insufficient installment speed.

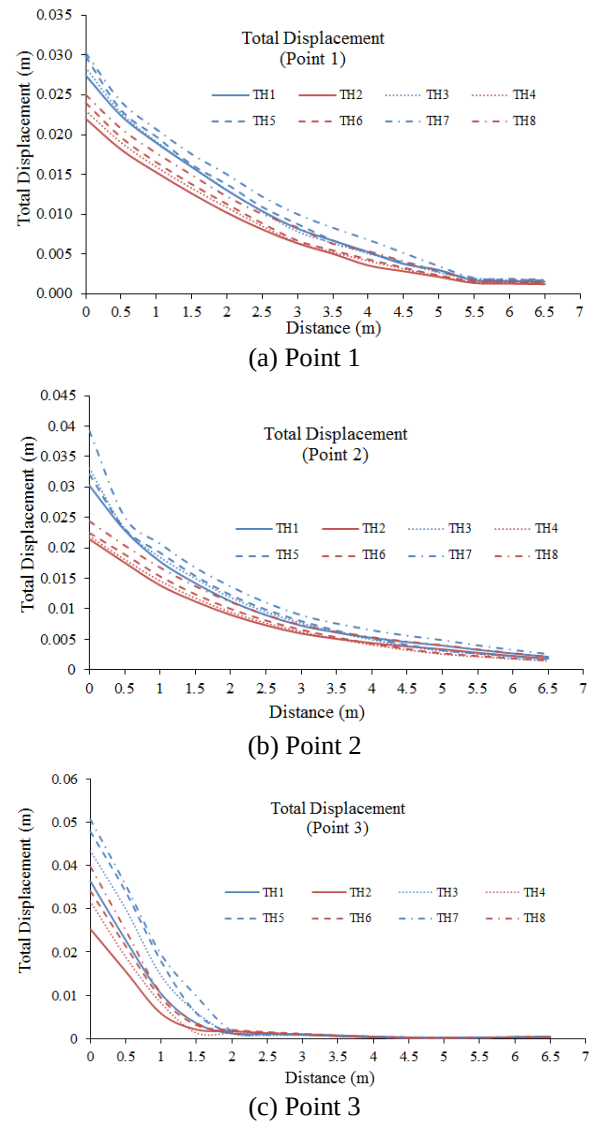


Fig. 12 Displacement measured from different depth

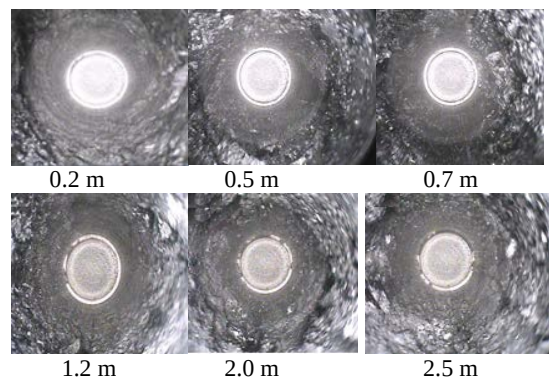


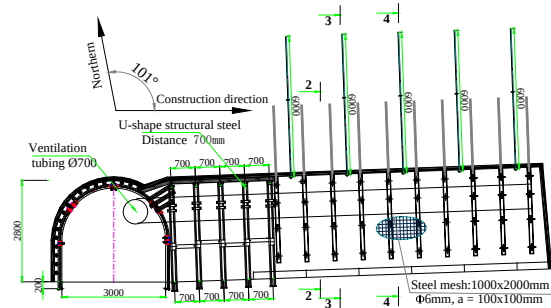
Fig. 13 Peeping at roof drilling

Based on simulation results presented earlier, the novel active support technology through application of prestressed bolt has been applied in the experimental roadway to maintain the stability of surrounding rock with mudstone interlayers.

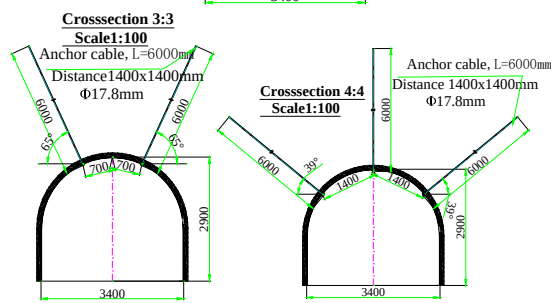
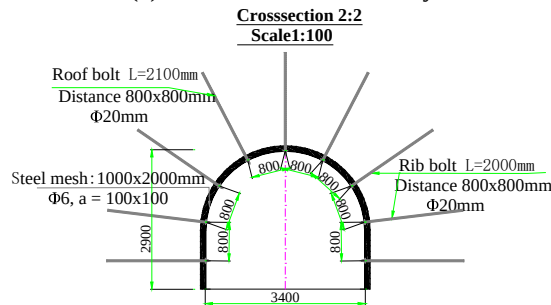
Bolt and anchor cable supporting method is adopted for roadway supporting, it can be seen in Fig. 14.

1) Bolting parameters: The roadway roof adopts rebar bolt with $\Phi 20 \times 2100$ mm was installed with 800 mm distance and 800 mm row space. The roadway rib rebar bolt with $\Phi 20 \times 2000$ mm was installed with the space of 800 mm in a row. All bolts were fixed with the surrounding rock by two CK2335 resin roll, steel pallet with the size of $150 \times 150 \times 10$ mm. The round steel bar with $\Phi 12$ mm as beam used together with the steel mesh manufactured with $\Phi 6$, 2000×1000 mm steel bar. The preload of the bolt is not less than 60 kN.

2) Anchor cable parameters: A set of pre-stress anchor craning beam is collocated on the roof bolt at every two rows (as shown in Figure.14). Steel strand specification is $\Phi 17.8 \times 6000$ mm, Anchor cable holes are installed with 1600 mm distance and 1400 mm row space. Each hole adopts one CK2335 and two Z2360 medium speed resin cartridges as lengthening anchorage, steel pallet with the size of $300 \times 300 \times 15$ mm. The preload of an anchor cable is not less than 150 kN.



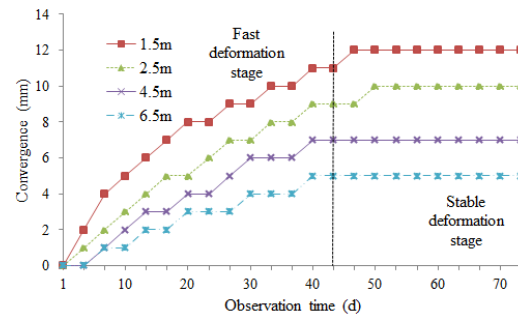
(a) Cross section of roadway



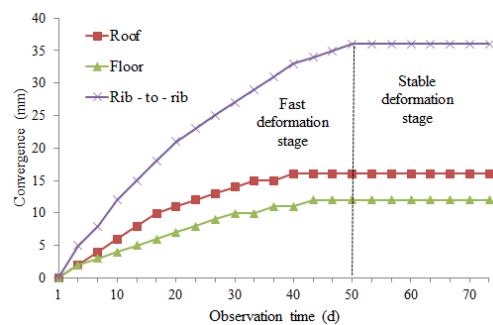
(b) Support sketch with bolts

Fig. 14. Schemes of designed support with prestressed bolt

The in-mine instrumentation results of the roof, floor, and ribs deformation are illustrated in Fig. 15.



(a) Depth displacement of roadway



(b) Surface deformation of roadway

Fig. 15 In-mine instrumentation results for the roadway deformation

Figure 15 shown that the deformation of surrounding rock becomes to be stable within 60 days after the caving of roadway. Finally, the largest convergences at the depth of 1.5 m, 2.5 m, 4.5 m, and 6.5 m are 12 mm, 10 mm, 7 mm and 5 mm, respectively. This trend is in accordance with the simulation results, from which it can be found that the deformation is much larger nearby the surface of roadway than that of deep point. In addition, the deformation of two ribs was a little bit larger than that of the roof. Overall speaking, the large deformation of surrounding rock has been successfully controlled by prestressed bolt compared with traditional support technology.



Fig. 16 Roadway prestressed bolt support result

6. CONCLUSIONS

This paper presents the first ever use of a high-strength prestressed bolt to maintain the stability of

surrounding rock with mudstone interlayers in overlying strata in Vietnam coal mines. The current traditional support technology and its drawbacks have been first discussed and summarized. Then, the typical simulation programs, namely RS2 was applied to investigate the effect of the number of mudstone interlayers. The present paper ends up with a case study conducted in Nui Beo coal mine, Vietnam according to simulation results. Both the FE simulation and case study results show that high pre-tension strength can successfully improve the stress distribution not only on the bolt body but also the spray. In addition, it becomes more and more complex to sustain the stability of surrounding rock with the increase of the layers of soft overlying strata. The first ever prestressed bolt technology in coal mine roadway with soft mudstone interlayers indicates that it is effective and economic. The successful application presented in this paper points out the clear development trend of the prestressed bolt in Vietnam coal mines with similar geological conditions in the future.

7. ACKNOWLEDGMENTS

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8. REFERENCES

- [1] Application of modern mining method in Quang Ninh coalfield. Vinacomin Institute of Mining Science and Technology. 2011. (No. ĐT.10.10/ĐMCNKK).
- [2] Tao Xie Tuan. Research on control technology and Stability of Surrounding Rock in deep multiple coal seam roadway driving along next goaf [D]. China University of Mining and Technology, 2013.
- [3] Ruan Tinh Xin. Study on process parameters of top coal caving mining in longwall working face with gently inclined coal seam and the laws of rock pressure [D]. China University of Mining and Technology, 2009.
- [4] Ngoc Anh Do, Daniel Dias, Pierpaolo Orestec, Van Diep Dinh. Stability of Tunnels Excavated along Anisotropic Rock Masses
- [5] Vu Van Hoa. Uong Bi Coal Mine Company – Large deformation control technology for Trang Bach Coal Mine [D]. Hanoi University of Mining and Geology, 2015.
- [6] Vinacomin Informatics, Technology, Environment joint stock company. General report documents and the coal reserves of Nui Beo coal mine, 2010.
- [7] Vinacomin Informatics, Technology, Environment joint stock company. Geological section I-I line of Nui Beo coal mine, 2012.
- [8] Huang Qing Xiang, Zhao Meng Ye. et al. Mechanisms of outward dislocation sliding of roadway sides and its support in a thick coal seam with a soft mudstone interlayer. Rock and Soil Mechanics. Vol.37 No.8 Aug. 2016.
- [9] Hu Xing Tao. Study on the damage law and supporting technology of shallow-buried horizontal roadway with partings. Shaanxi Coal. 2017.
- [10] Wang Jian Li, Shen Le, Xu Ying. Research on Stability and Supporting Technology of Surrounding Rock of Roadway in Shallow Coal Seam with Thin Bedrock Containing Parting. Coal Technology. Vol.35No.08. Aug. 2016
- [11] Shao Shui Cai, Huang Qing Xiang. et al. Study on Outward Sliding Mechanism of Roadway in Mudstone Interlayers Coal Seam and Support Method. Coal Science and Technology. Vol.42 No.11. Nov. 2014
- [12] Bui Manh Tung, Lu Yan. et al. The research on stability and supporting technology of rock in gob-side entry in thick seam with parting. Journal of Mining & Safety Engineering. Vol.31 No.6. Nov. 201.
- [13] Xiao Tong Qiang, Bai Jian Biao, Yang Feng. Development Status of High Pre – stress Bolt Support Theory and Technology. Coal Technology. Vol.30.No.02 February 2011.
- [14] Kang Hong Pu, Jiang Tie Ming, Gao Fu Qiang. Effect of pretensioned stress to rock bolting [J]. Journal of China Coal Society, 2007,32 (7):680-685.
- [15] Kang Hong Pu, Lin Jian, Wu Yong Zheng. High pretensioned stress and intensive cable bolting technology set in full section and application in entry affected by dynamic pressure [J]. Journal of China Coal Society, 2009,34(9):1153-1159.
- [16] Yu Wei Jian, Wang Wei Jun, Etc. Deformation mechanism and control technology of coal roadway under deep well and compound roof. Chinese Journal of Geotechnical Engineering. 8. 2012.
- [17] Rock Mechanics Technology Ltd. Coal mine roadway support system handbook [M]. Sudbury: HSE BOOKS, 2004.
- [18] Dao Viet Doan, Hong Chao Zhao. et al. Control technology for soft rock roadway in inclined coal seam: a case study in Nui Beo mine, Quang Ninh, Vietnam. International Journal of GEOMATE, March., 2018 Vol.14, Issue 43, pp.175-182.

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