



Original Article

Field Investigation of Face Spall in Moderate Strength Coal Seam at Vang Danh Coal Mine, Vietnam

Le Tien Dung^{1,*}, Dao Hong Quang²

¹*Hanoi University of Mining and Geology, 18 Pho Vien, Duc Thang, Bac Tu Liem, Hanoi, Vietnam*

²*Institute of Mining Science and Technology, 3 Phan Dinh Giot, Phuong Liet, Thanh Xuan, Hanoi, Vietnam*

Received 28 May 2020

Revised 13 July 2020; Accepted 22 July 2020

Abstract: Face spall in moderate strength coal seam occurs less frequently but can be more severe and takes a longer time to remedy compared to face spall in the weak coal seam. This paper presents a field investigation of face spall in moderate strength coal seam at Face I-8-1, Vang Danh coal mine, Quang Ninh coal field, Vietnam. The leg pressure of shield support and face condition were monitored within two months, and on-site remedial measures to the spall were discussed. The monitoring results confirmed that the front and rear leg pressure profiles are consistent with world-wide observations. The coal face condition in actual operation was found to be more stable than that in project design. The face spall occurred along face dip direction, but mostly in small extent of less than 0.5 m deep and during transitional time between working shifts. Proper ground control near gate ends by using higher capacity shield supports and supplemental hydraulic props was identified to improve face stability in the area. On-site remedial measures proved their efficiency in small to moderate face spall extent. For main roof rupture-associated face spall, technical measures have been applied but they need further investigation to clarify their effectiveness. The paper's results can be consulted to improve longwall face stability control in similar coal seam conditions.

Keywords: Face spall, Shield support, Leg pressure, Remedial measures, Vang Danh coal mine.

1. Introduction

Coal extraction is one of the major industries in Vietnam that annually contributes dozens of

trillion Vietnamese Dongs to national budget. Although coal extraction technologies, particularly for underground, have been mechanised to increase productivity and safety at

* Corresponding author.

E-mail address: t.d.le@humg.edu.vn

<https://doi.org/10.25073/2588-1094/vnuees.4639>

work, geotechnical incidents are still unavoidable that must be well controlled. Face spall is one of the most critical incidents because it may occur suddenly and directly causes injury to worker or damage to equipment. While face spall in a weak coal seam is commonly observed, the spall in moderate strength coal seam is less frequent but can be more severe and takes a longer time to remedy. An example of this was seen in Broadmeadow coal mine, Queensland, Australia where it took several weeks to restart production at panel [1]. In Vietnam, due to complex geological structures which make mechanised longwall panels short in strike direction, face spall in moderate coal seam strength has not been reported as a severe incident. However, serious face spall may occur when new panel designs with longer face length in strike direction are in implementation.

Face spall has been well investigated in many countries such as China [2, 3], Australia [4], USA [5], Poland [6] or India [7]. In Vietnam, several studies attempted to understand the mechanics of coal face stability [8, 9]. These studies, however, focused on top coal fall between coal face and shield support, which may or may not be caused by face spall, rather directly on face spall. Furthermore, since the studies mostly used numerical modelling approach, they are limited in adequately representing major geological structures at field scale level—a typical feature of longwall mining. Empirical approach is concerned with experiment, field data and observation [10], and can therefore address the limitation in modelling. This approach has been applied in studying face spall in the world [6, 11] but still limited in Vietnam as can be found in Vu and Do [12], Le et al. [13]. Because most moderate strength coal seams in Quang Ninh coal field are overlaid by highly jointed strong roof strata which are different from those in previous studies, a sufficient understanding of the face spall mechanics in this coal field condition remains very limited.

This paper presents a field investigation of face spall at Face I-8-1, Vang Danh coal mine,

Quang Ninh coal field, Vietnam. The coal seam in the mine was classified as moderate strength and was representative of the coal field [14]. The leg pressure of shield support was daily monitored, and the face condition was visually observed to quantify the spall extent. Several on-site remedial measures to face spall were additionally discussed to assess their practical efficiency.

2. Geological Conditions

Vang Danh coal mine is owned by Vang Danh Coal Joint Stock Company—a member of Vietnam National Coal-Mineral Industries Holding Corporation Limited (VINACOMIN). The mine locates on Vang Danh Ward, Uong Bi City, Quang Ninh Province. There are four districts at the mine including Centre, East Vang Danh, West Vang Danh, and Canh Ga. Currently, the mine is operating in underground level 0/-175, Shaft Section, using fully mechanised longwall technology, as shown in Figure 1.

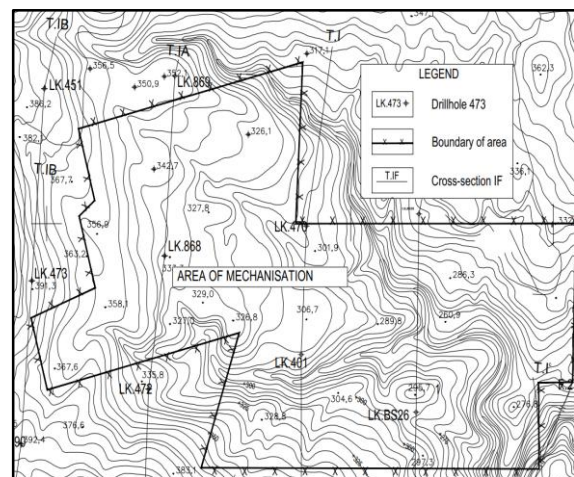


Figure 1. Application area of fully mechanised longwall technology, Vang Danh coal mine [14].

The fracture network within coal deposits is divided into two main systems. The first system in meridian direction includes F₁₃, F₁₂, F₁₁, F₁₀, F₈, F₆, F₅, F₄, F₃, F₂, F₁ and F₀, separating coal seams into differently structured blocks or

sections. The second system in parallel direction consists of F_{40} , N_{20} , F_N and F_M , running in similar seams strike and normally changing seam dip angle. The minor fractures in the site are in tension observed during exploration and mining operations. Previous studies of tectonics stated that the level of damage is great with a factor K_1 of 150–250 m per hectare and K_2 of 4-5 faults per km. A representative cross-section through the area of extraction is displayed in Figure 2.

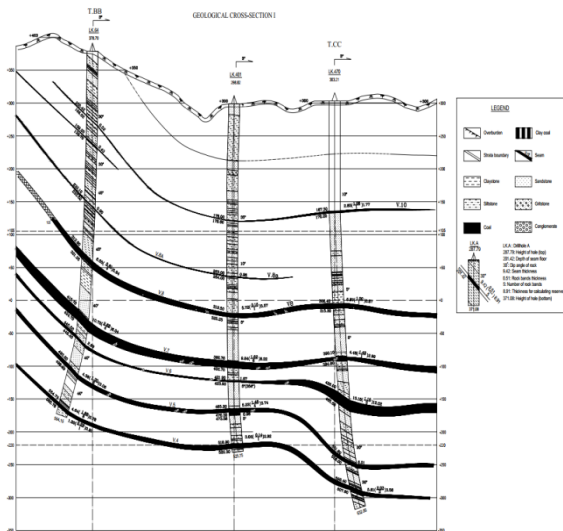


Figure 2. Geological cross-section I of Vang Danh coal mine [14].

According to Vinacomin Institute of Mining Science and Technology [14], rocks in coal-bearing strata are mainly conglomerate, sandstone, siltstone, claystone, clay-coal, and coal seams which are interbedded. Conglomerate rock occupies a small proportion of 1.6% in the

strata, mainly distributing at Seam 4 floor with a thin thickness of 0.5-2.5 m and very strong. Sandstone rock has a thickly layered structure and is sometimes in block shape, with highly developed vertical joints. The strata thickness ranges from 0.5 to 15 m and sometimes up to 25 m in both strike and dip directions. Siltstone rock accounts for 35% of total rocks and in close proximity of coal seams. The strata thickness is in the range of 0.3-20 m with layered structure. Claystone and clay-coal make up 11% of total rocks, mainly in thin layers and of 0.2-2.0 m thickness. These rocks are also distributed near coal seams.

Face I-8-1 has a seam thickness of 5.19-5.91 m with an average of 5.54 m. The seam structure is simple with 0-2 rock band layers in average thickness of 0.24 m. The seam dip angle is in range of 5-15 degrees and its average is 11 degrees. The immediate roof has a thickness of 18.5-25 m and an average of 21 m. According to the assessment of Vinacomin Institute of Mining Science and Technology [14], the immediate roof thickness that directly affects shield support is 14.5 m above the coal seam. They are siltstone with a strength of 468.12 kG/cm². The main roof has a thickness 9.3-14.3 m and an average of 11.3 m. It mainly consists of sandstone and has a strength of 718.38 kG/cm². The immediate floor is similar to immediate roof in constituent, but its strength is slightly weaker, which is 298.66 kG/cm². The face is designed 380 m in strike direction, 93 m in dip direction and 300 m below surface. The development roadways are shown in Figure 3. The properties of major rock types at the mine site are given in Table 1 [14].

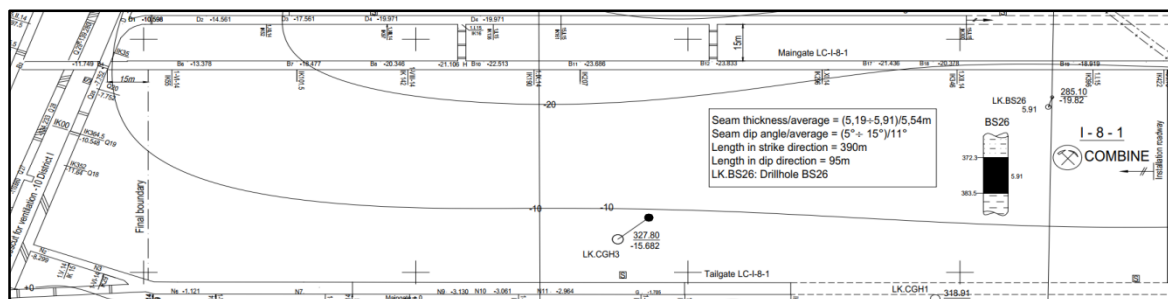


Figure 3. Layout of Face I-8-1 [14].

Table 1. Properties of major rock types at Vang Danh coal mine [14].

Rock type	Compressive strength (kG/cm ²)	Tensile strength (kG/cm ²)	Internal friction angle (degree)	Density (g/cm ³)
Conglomerate	308.14÷2613.00 1224.89	-	-	2.50 ÷ 2.74 2.62
Sandstone	117.00÷2794.12 1019.89	56.56÷295.53 152.58	13°45÷36°15 28°30	2.41÷3.13 2.65
Siltstone	81.51÷2456.77 575.53	27.43÷221.37 88.67	17°45÷34°45 27°00	2.15÷3.37 2.66
Claystone, clay-coal	22.50÷691.06 282.98	29.59÷74.26 49.15	12°00÷34°45 26°17	1.75 ÷ 3.21 2.62

Legend for value: $\frac{\min \div \max}{\text{average}}$

3. Monitoring of Shield Support

3.1. Field Measurement

Face I-8-1 produced coal from January 2018 to September 2018 and then its mechanised equipment (e.g., shearer, shield support, etc.) was moved to the next mechanised face. It was reported by field mining engineers that out of installation roadway, when the face advanced in strike direction 3-5 m, 35 m and 80-100 m, top coal, immediate roof and the main roof caved and/or ruptured, respectively. The observed periodic weighting intervals of the immediate roof and main roofs were 20-30 and 80-100 m, correspondingly. There were two shield support types used in the panel. Shields ZFG4800/20/32 were installed near two gate ends (T-junctions), and shields ZF4400/17/28 were set along the panel dip direction. Key specifications of two shield types are summarised in Table 2. Each shield type has two pressure gauges fixed in front and rear legs, as shown in Figure 4. The pressure was recorded through the gauges at every 10 shields at the beginning and end of working

shifts. Total time of monitoring was two months, from March to May 2018, corresponding to a face advance distance of approximately 80 m. Note that due to national holidays, some data points were not properly monitored and were removed from Figures 5-7 (see Section 3.2).

3.2. Results and Discussion

The front leg and rear leg pressures of Shield #1 near the tailgate, Shield #30 in the middle of face length in dip direction, and Shield #60 near maingate were plotted in Figures 5-7. It is apparent that during the period of monitoring, the recorded pressure at all face positions fluctuated around 25 MPa. This value was equal to 79.4% of the designed working pressure (31.5 MPa) and was only 71.43% of the yield pressure (35 MPa). The difference in working pressure was related to the practical coal seam roof strata, which were stronger than evaluated. Another reason was that if the pressure in the leg was as high as designed, the available hydraulic system such as pump station, cable, hose, or safety valve could stop working or be broken.

Table 2. Specifications of ZF4400/17/28 and ZFG4800/20/32 [15].

Order	Specifications	Unit	Value	
			ZF4400/17/28	ZFG4800/20/32
1	Height	mm	1700-2800	2000-3200
2	Width	mm	1430-1600	1430-1600
3	Number of legs	Leg	4	4
4	Yield load	kN	4400	4800
5	Resistance intensity	MPa	0.75	0.72

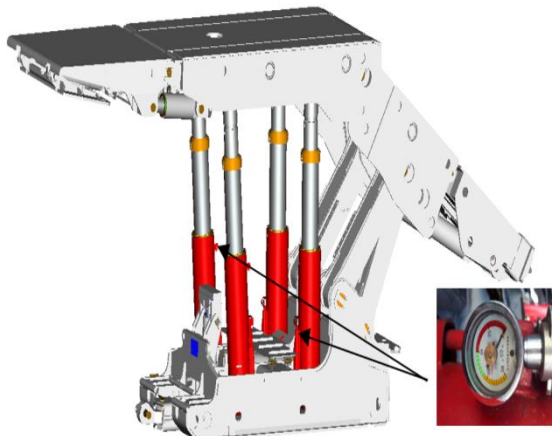


Figure 4. Shield support ZF4400 and pressure gauge [15].

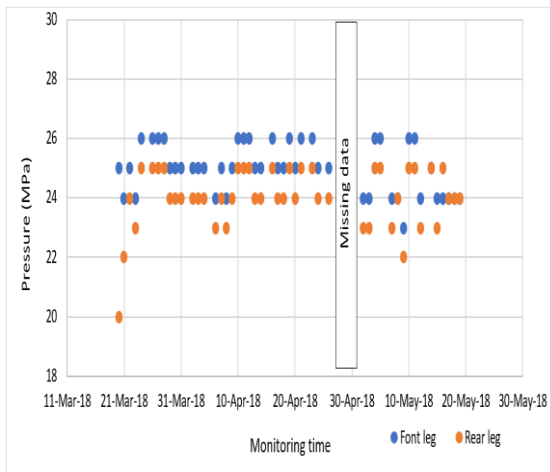


Figure 5. Pressure in front leg and rear leg of Shield #1 near tailgate.

It was also observed in three monitoring positions that front leg pressure was mostly greater than rear leg pressure. This is because toward the rear of the shield support, top coal was largely broken and thus its loading capacity was reduced. Toward the front of shield, top coal and roof strata were less broken that could transmit loading from overburden strata onto the shield canopy. The current monitoring is consistent with world-wide observations. For instance, Cai et al. [16] reported that the loading ratio of front legs to rear legs from 41 longwall

faces in China mostly ranged from 1.05 to 1.94. Yun et al. [17] clearly showed that the front leg pressure was greater than the rear leg pressure in another China longwall face (Figure 8a). The difference between front leg and rear leg pressures was also seen in India's longwall panels, as reported by Verma and Deb [18] (Figure 8b) and Singh and Singh [19].

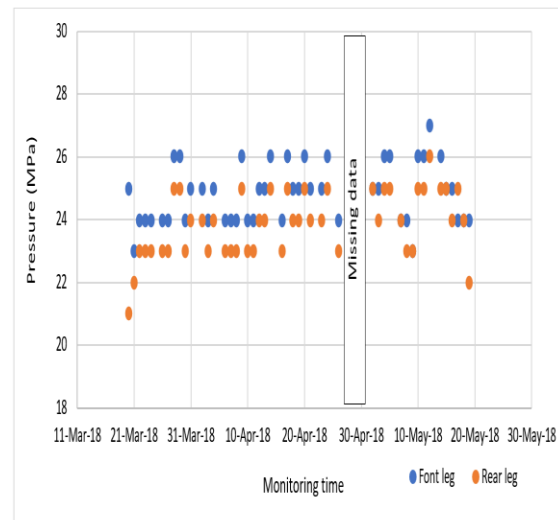


Figure 6. Pressure in front leg and rear leg of Shield #60 near maingate.

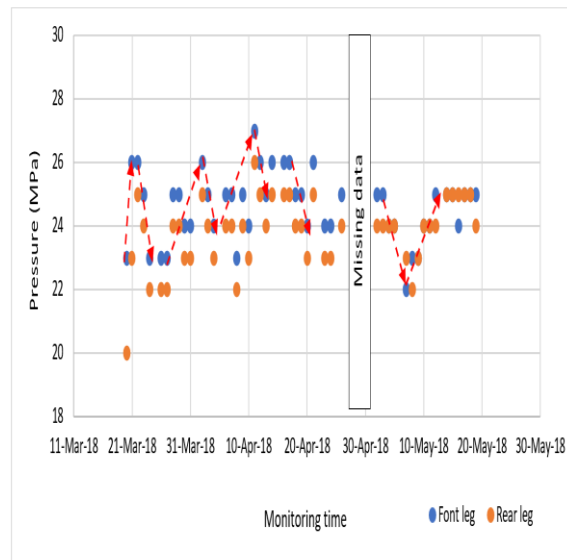
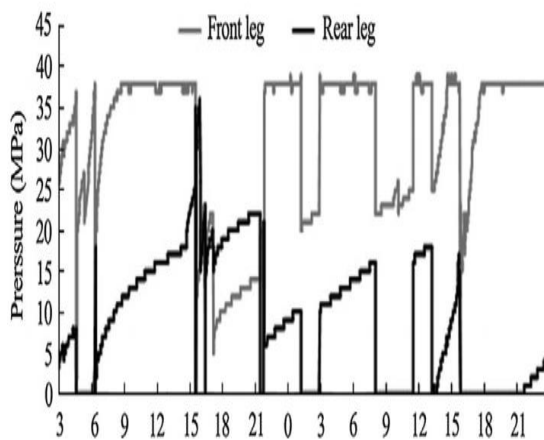


Figure 7. Pressure in front leg and rear leg of Shield #30 in the middle of face length in dip direction.

During the time of monitoring, coal face was, in general, stable. Remarkable spalls were observed near two gate ends on 2-12 May 2018. Other significant spalls occurred locally in the middle of face length in dip direction on 28-31 March and 17-20 April 2018. These spalls occurred to a small extent, which were seen less than 0.5 m deep into upper face line and top coal section. This stable face condition was mainly driven by the moderate coal strength and strong rocks constituting the seam. On the other hand, the spalls happened in short periods, mainly in transitional time between working shifts. This is understandable since the face was exposed for a longer time before a next mining cycle, which was implemented in next shift. The two profiles near gate ends followed a similar trend in which the front and rear leg pressures tended to be unchanged during 2-3 days before reaching a new stable value. Meanwhile, the profile in the middle of face length was different-the front leg pressure repeatedly went up to a peak value of approximately 26 MPa before went down to low value of 22-23 MPa (see red arrows in Figure 7). This can be explained by the fact that while the shields completely inside the face were advanced after every shearer cut, the shields near gate ends were in use for a longer time before were moved to next position. Additionally, the areas near gate ends, as in high stress concentration conditions, were further supported by hydraulic props that ensure their stability.

(a)



(b)

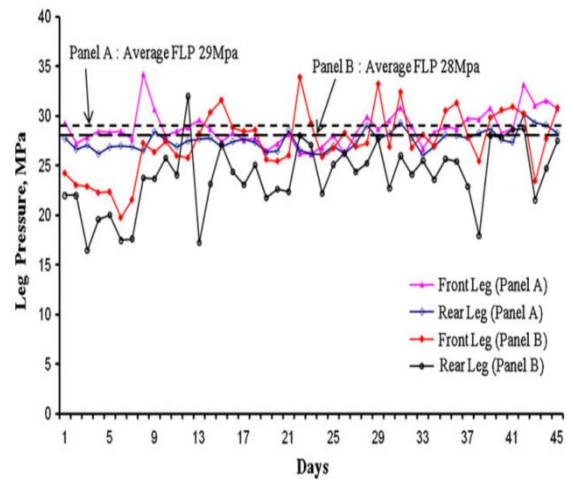


Figure 8. Front leg and rear leg pressures monitored at (a) China [17] and (b) India longwall panels [18].

4. Discussion of Remedial Measures

To remedy face spall incidents, Vang Danh coal mine has developed several technical measures as follows. In cases where the spall depth into coal face is less than 1 m, the extended canopy of shield support is sufficient to cover the roof cavity (Figure 9a). When the spall depth is greater than 1 m, both extended canopy and shield guard are used to increase the cover length for the cavity (Figure 9b). When the spall is more serious (e.g., deeper than 2 m into coal face), steel mesh, hydraulic prop and wooden log are combined for remedy (Figure 9c). That is, hydraulic props act as additional pillars while steel mesh and wooden logs play as a protective plate. These measures, in essence, aim to preventing broken roof coal and coal wall from interrupting normal operation of shield support. Their application was proved to be efficient at the site in where the spall was from small to moderate extent. In the same spall extent range, the measures have also been applied successfully at other Quang Ninh longwall coal faces such as Ha Lam [20] and Quang Hanh [21] coal mines. Although the above measures are flexible, easy, quick and cheap to perform at different face

locations, they require manual labour that increases unsafe and health issues at work. Furthermore, when main roof strata rupture, associated face spall can occur in large extent and magnitude [22]. In such a case, Vang Danh coal company has increased face advance rate and/or injected reinforced chemical to quickly pass through unstable areas. The solutions aim to

minimising the extraction time in the unstable areas and/or strengthening the coal/rock mass. Due to limited time of monitoring, no significant main roof rupture was observed during the field investigation. Thus, the solutions' efficiency needs to be further assessed in future studies through the more cost-effective tools, for example, the numerical modelling method.

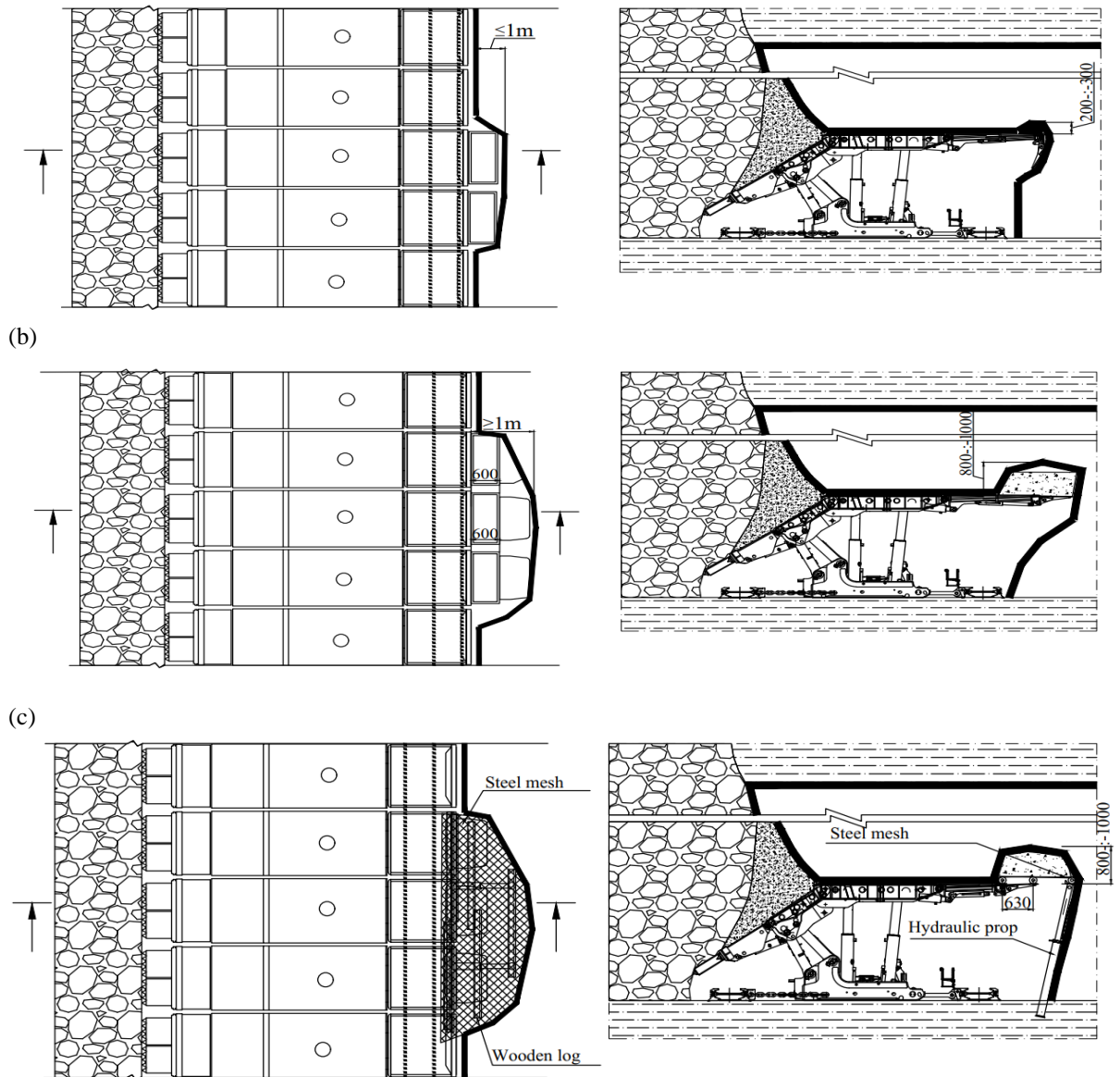


Figure 9. Using a) extended canopy; b) Extended canopy + shield guard; c) Steel mesh + hydraulic prop + wooden log to cover cavity [15].

5. Conclusions

This paper presents a field investigation of face spall in moderate strength coal seam, taking Face I-8-1 Vang Danh coal mine, Quang Ninh coal field, Vietnam for example. The monitoring results of shield support leg pressure confirmed that the front and rear leg pressure profiles are consistent with other longwall observations in the world. The actual working pressure was found approximately 20% less than the designed value, indicating a more stable coal face condition than the project assessment. The face spall occurred along face dip direction, but mostly in small extent of less than 0.5 m deep into upper face line and top coal section, and during transitional time between working shifts. The spall was expected to occur more frequently near gate ends due to high stress concentration; however, proper ground control via higher capacity shield supports and supplemental hydraulic props was identified to improve face stability in the area. On-site remedial measures proved their efficiency in small to moderate face spall extent. For main roof rupture-associated face spall, technical measures have been applied but they need further investigation to clarify their effectiveness. The paper's results can be consulted to improve longwall face stability control in similar coal seam conditions.

Acknowledgements

This research is funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 105.08-2019.09.

References

- [1] International Coal News, Broadmeadow Longwall Production Restarts After October Convergence Incident, http://www.internationalcoalnews.com/storyView.asp?storyID=826957978§ion=News§ion_source=s46&aspdsc=yes, 2015 (accessed on: 13th June 2016).
- [2] W. B. Guo, C. Y. Liu, G. W. Dong, W. Y. Lv, Analytical Study to Estimate Rib Spalling Extent and Support Requirements in Thick Seam Mining, *Arabian Journal of Geosciences*, Vol. 12, 2019, pp. 276-276, <https://doi.org/10.1007/s12517-019-4443-8>.
- [3] D. Kong, Y. Liu, S. Zheng, Sensitivity Analysis of Influencing Factors and Control Technology for Coalface Failure, *Arabian Journal of Geosciences*, Vol. 12, 2019, pp. 550-550, <https://doi.org/10.1007/s12517-019-4714-4>.
- [4] R. Frith, *Structural Engineering Principles in Coal Mine Ground Control-The Common Link between Empirical Models, Numerical Models, and Practical Solutions*, *Advances in Coal Mine Ground Control*, Woodhead Publishing, Duxford, 2017, pp. 67-92.
- [5] D. Pappas, C. Mark, *Roof and Rib Fall Incident Trends: A 10-year Profile*, *SME Transactions Volume 330*, Society for Mining, Metallurgy and Exploration, Inc., New York, 2011, pp. 462-478.
- [6] S. Prusek, S. Rajwa, A. Wrana, A. Krzemień, Assessment of Roof Fall Risk in Longwall Coal Mines, *International Journal of Mining, Reclamation and Environment*, Vol. 31, 2017, pp 558-574, <https://doi.org/10.1080/17480930.2016.1200897>.
- [7] S. R. Islavath, D. Deb, H. Kumar, Numerical Analysis of A Longwall Mining Cycle and Development of A Composite Longwall Index, *International Journal of Rock Mechanics and Mining Sciences*, Vol. 89, 2016, pp. 43-54. <https://doi.org/10.1016/j.ijrmms.2016.08.003>.
- [8] L. T. Dung, B. M. Tung, P. D. Hung, V. T. Tien, D. V. Chi, A Modelling Technique for Top Coal Fall Ahead of Face Support in Mechanised Longwall Using Discrete Element Method, *Journal of Mining and Earth Sciences*, Vol. 59, pp. 2018, pp. 56-65.
- [9] L. T. Dung, V. D. Hieu, N. A. Tuan, Characteristics of Top Coal Fall in front of Face Support in Longwall: A Case Study, *Vietnam Journal of Earth Sciences*, Vol. 42, 2020, pp. 152-161, <https://doi.org/10.15625/0866-7187/42/2/14955>.
- [10] J. M. Galvin, *Ground Engineering - Principles and Practices for Underground Coal Mining*, Springer International Publishing, Cham, 2016.
- [11] R. C. Frith, A. M. Stewart, D. Price, *Australian Longwall Geomechanics - A Recent Study*, 11th International Conference on Ground Control in Mining, Australasian Institute of Mining and Metallurgy, The University of Wollongong, 1992, pp. 131-139.

- [12] V. T. Tien, D. A. Son, Analysis of Causes of Face Fall and Roof Fall in Fully-Mechanised Longwalls and Preventing Measures, Mining Industry Journal, Vol. 6, 2014, pp. 26-29 (in Vietnamese).
- [13] L. D. Nguyen, D. V. Cuong, L. D. Vinh, T. M. Tien, L. T. Chung, T. Q. Tuan, Study on Application of Water Injection to Improve Coal Cohesion at Unstable Area and Weak Coal at Khe Cham III Coal Mine, Mining Technology Bulletin, Vol. 8, 2016, pp. 1-6 (in Vietnamese).
- [14] Vinacomin Institute of Mining Science and Technology, Investment and Mining Project for Level 0 -:- -175 Vang Danh Site, Vang Danh Coal Mine, Hanoi, 2016 (in Vietnamese).
- [15] Vang Danh Coal Company, Mining Passport for Face I-8-1, Quang Ninh, 2018 (in Vietnamese).
- [16] Y. Cai, B. Hebblewhite, U. Onder, B. Xu, M. Kelly, B. Wright, I. Kraemer, Application of Longwall Top Coal Caving to Australian operations, CSIRO Exploration and Mining, Queensland, 2004.
- [17] D. Yun, Z. Liu, W. Cheng, Z. Fan, D. Wang, Y. Zhang, Monitoring Strata Behavior due to Multi-slicing Top Coal Caving Longwall Mining in Steeply Dipping Extra Thick Coal Seam, International Journal of Mining Science and Technology, Vol. 27, 2017, pp. 179-184. <https://doi.org/10.1016/j.ijmst.2016.11.002>.
- [18] A. K. Verma, D. Deb, Longwall Face Stability Index for Estimation of Chock-Shield Pressure and Face Convergence, Geotechnical and Geological Engineering, Vol. 28, 2010, pp. 431-445. <https://doi.org/10.1007/s10706-010-9303-y>.
- [19] G. S. P. Singh, U. K. Singh, Prediction of Caving Behavior of Strata and Optimum Rating of Hydraulic Powered Support for Longwall Workings, Int. J. Rock Mech. Min. Sci., Vol. 47, 2010, pp. 1-16, <https://doi.org/10.1016/j.ijrmms.2009.09.001>.
- [20] Ha Lam Coal Company, Report on Mechanisation of Underground Coal Mining, Quang Ninh, 2018 (in Vietnamese).
- [21] Quang Hanh Coal Company, Report on Mechanisation of Underground Coal Mining, Quang Ninh, 2018 (in Vietnamese).
- [22] R. C. Frith, A Holistic Examination of The Load Rating Design of Longwall Shields After More Than Half A Century of Mechanised Longwall Mining, International Journal of Mining Science and Technology, Vol. 25, 2015, pp. 687-706, <https://doi.org/10.1016/j.ijmst.2015.07.001>.