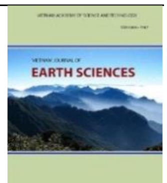
Vietnam Journal of Earth Sciences, 42(2), 152–161

(VAST)

Vietnam Academy of Science and Technology

Vietnam Journal of Earth Sciences

http://www.vjs.ac.vn/index.php/jse



Characteristics of top coal fall in front of face support in longwall: A case study

Tien Dung Le*, Dinh Hieu Vu, Anh Tuan Nguyen

Faculty of Mining, Hanoi University of Mining and Geology, Hanoi, Vietnam

Received 13 December 2019; Received in revised form 24 March 2020; Accepted 03 April 2020

ABSTRACT

Top coal fall in front of face support severely affects the safety and productivity in mechanized longwall mining. This paper presents a discontinuous numerical analysis on the important characteristics of the fall such as abutment stress, material failure, and fall mode. A top coal fall model is validated against site observation and past numerical and empirical studies. The numerical results provide further evidence confirming that horizontal stress relaxation, vertical stress concentration, and strength and structure of coal seam control the failure of top coal ahead of support. Top coal fall in longwall mining with large caving height is found in "stress caving" mode or, in other words, "horizontal stress-driven guttering" mechanism. A pre-existing fault running into a mined-out area can facilitate the occurrence of face spall but may not lead to top coal fall. The results of this study are particularly helpful to engineers in developing proper remedy or prevention solutions to top coal/roof fall incidents.

Keywords: Top coal fall; face spall; front abutment stress; material failure; numerical modelling.

1. Introduction

Top coal fall (or roof fall) in front of face support severely affects the safety and performance in longwall mining as it normally occurs without distinct warning signs. Bai et al. (2016) reported that nearly half of the fatal accidents in 2012 were caused by roof fall in longwall faces/roadways with 459 casualties in China. Pappas and Mark (2011) listed that during 1999–2008, there were more than 1,000 roof fall injuries and 12 roof/rib fall fatalities in longwall mining in the USA. In Vietnam, top coal fall has occurred in most of the mechanized longwalls (Khe Cham Coal Company, 2017; Vang Danh Coal Company, 2018; Ha Lam Coal Company, 2018b) those results in significant economic loss due to production interruption. Although technical measures based on reinforcement of coal face/roof strata have been applied, roof fall still occurs in many coal mines. A thorough understanding of the characteristics of top coal/roof fall is one prerequisite to maintain safety at work and longwall performance.

Basic understanding of top coal/roof fall ahead of face support has been early obtained from field measurements. Based on-site observation at Belgium coal faces, Vervoort

*Corresponding author, Email: t.d.le@humg.edu.vn

(1988) found that the formation of the relaxed zone above and ahead of face support is a likely explanation for roof fall. Frith (2015) also through intensive monitoring of support at Australia longwalls stated that there are two fundamental roof instability mechanisms in front of face support: (a) horizontal stress-driven guttering and (b) large block delineation due to periodic weighting of near-seam massive strata. Using extensive experience from Poland coal mines, Prusek et al. (2017) identified seven factors categorized into three groups of geology, mining, and technique that control the roof stability. During the past decade, automatic monitoring of support legs has been greatly improved for early warning of roof fall (Hoyer, 2011; Medhurst, 2014). For an in-depth investigation of the fall characteristics, various modeling methods such as continuum numerical method (Bai et al., 2016), discontinuous numerical method (Yao et al., 2017) and physical modeling (Yang et al., 2019) have been developed. These modeling works mainly focused on coal face spall, which is an indirect rather than the primary cause of the fall (Frith, 2015). Le et al. (2019a) have developed a discrete element modeling technique for studying top coal fall in Seam 11, Ha Lam coal mine. Although limited in simulating explicit intact block failure, the work provides a useful technique for more detailed investigations of top coal fall.

A numerical analysis of the characteristics of top coal fall such as front abutment stress, material failure, and fall mode is presented in this paper. The impact of a seam fault on top coal fall has also been investigated. The modeling technique is adopted from Le et al. (2019a) and uses geological conditions of Seam 7-an extra thick seam at Ha Lam coal mine, Vietnam The study's results are particularly helpful to engineer in developing proper remedy or prevention solutions to the fall incidents.

2. Geo-mining conditions of coal seam no. 7, Ha Lam coal mine

Ha Lam coal mine is owned by Ha Lam Coal Joint Stock Company-VINACOMIN and located in Quang Ninh province-the largest anthracite coalfield in Vietnam. The mechanized longwall at Seam 7 is one of the two current longwalls at the mine with a designed production of 1.2 million tonnes per year. The longwall was installed in October 2016 and has produced coal since November 2016. Since the end of 2018, the longwall mechanized complex has been moved to Face 7–3.1 which is located 250 m below previous mining at the north of the mine (Ha Lam Coal Company, 2018a). The seam has an average seam thickness of 12.84 m, a seam dip of 25 degrees and contains 1–10 rock bands (Fig. 1). The immediate roof is composed of siltstone with an average thickness of 17.87 m, a Protodiakonov strength index (f) ranging from 4 to 6, and less fractured. The main roof consists of very thick sandstone strata with a strength index f ranging from 6 to 8. For Seam 7, the cutting height by a shearer is 3.0 m and the above coal is recovered by means of caving. Similar to the operation at Seam 11, top coal fall has frequently occurred at Seam 7 up to several meters in the strike and dip directions.

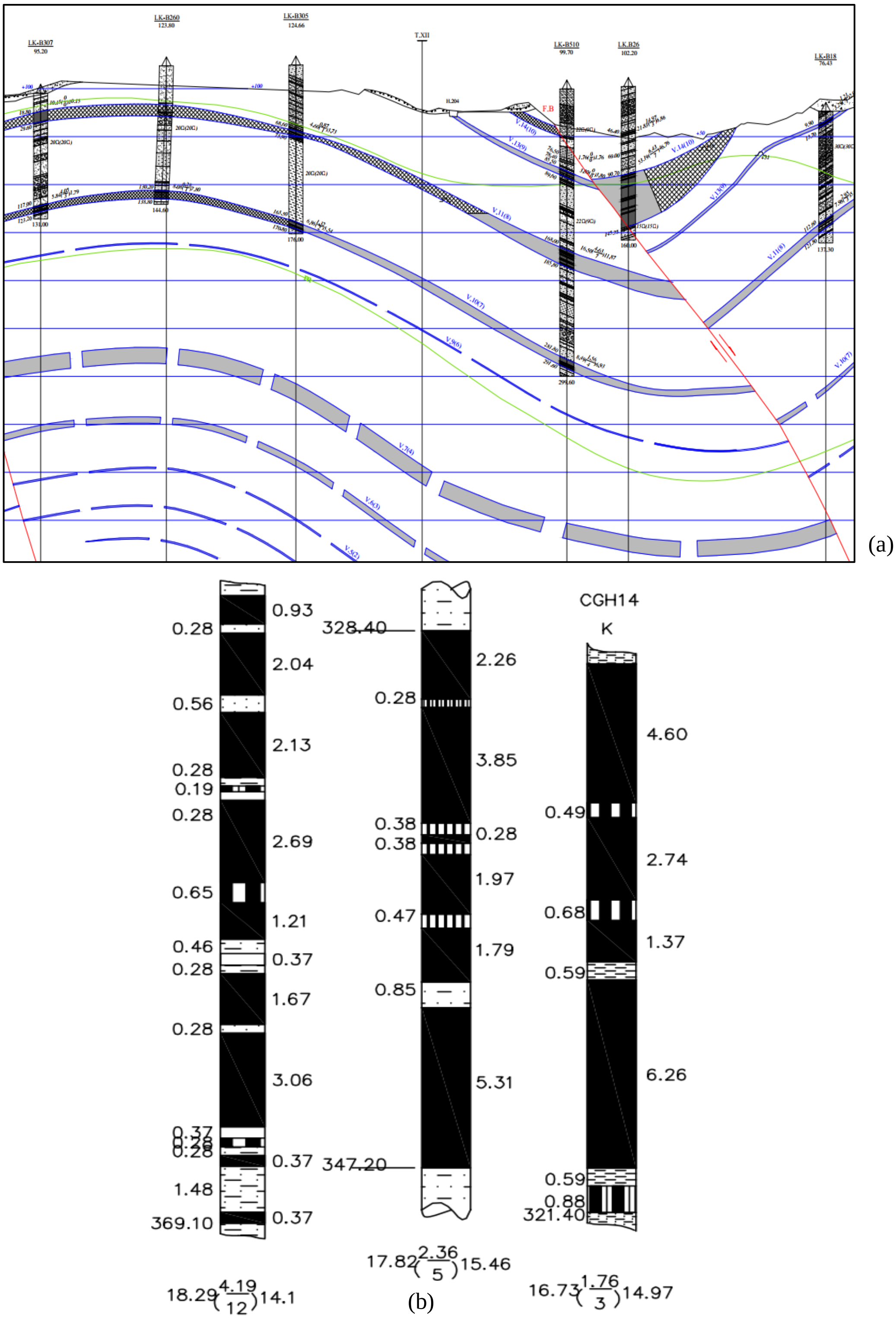


Figure 1. a-Geological cross-section IVA (East-West); b-Lithological columns at Seam 7, Ha Lam coal mine

3. Discrete element modelling using plastic material

As adopted from Le et al. (2019a), the Universal Discrete Element Method-UDEC (Itasca Consulting Group, 2004) combined with its plastic rock constitutive models are used to represent a cross-section longwall face located at the mid-panel width at Seam 7, Ha Lam coal mine. The model dimension along panel length is 250 m with an extraction length of 50 m in the model center. The model height is 131 m, including 50 m thickness of siltstone in-floor strata, 13 m thickness of Seam 7, 18 m thickness of siltstone in the immediate roof and 50 m thickness of sandstone in the main roof. Since Seam 7 is approximately 250 m below surface, an additional load caused by 169 m thickness of overburden is applied on the top boundary. The vertical stress is at a rate of 2.6 MPa per 100 m cover depth. The bottom and side boundaries are fixed in X and Y directions, respectively. In the area of interest (extraction area), top coal, immediate roof and main roof are simulated with block sizes of 0.5×0.5, 2×2.5 and 5×10 m, respectively. The top coal fall model is displayed in Fig. 2.

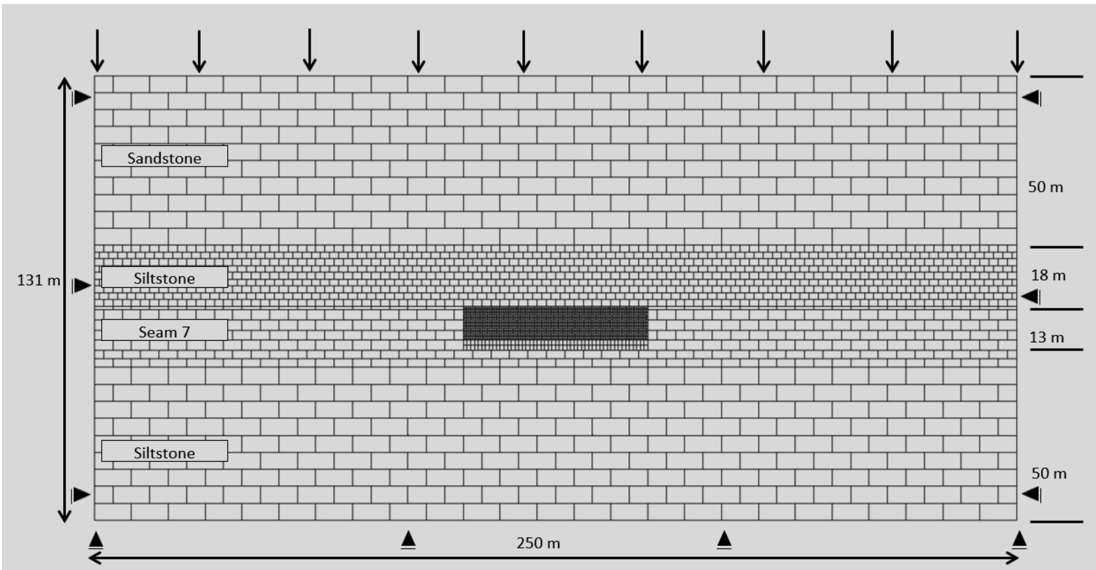


Figure 2. Top coal fall model

The perfectly plastic model with tension cut-off is used for floor rocks where no rock caving is expected. Meanwhile, the strain-softening model is applied for coal and roof rocks where material fall/caving is a critical feature to be captured. All discontinuities are assigned with a simple joint constitutive law-Coulomb slip model. The theoretical background of the material constitutive models was described in detail in Itasca Consulting Group (2004). Due to the proximity between Seam 7 and Seam 11, intact block and discontinuity properties are the same with those presented in Le et al. (2019a) (Table 1), which were based on available rock tests from the site and in the literature (Pham, 2012; Ha Lam Coal Company, 2018a). Additionally, a horizontal-to-vertical stress ratio of 1 is assigned to all strata.

The model extraction is similar to that in the field. Seam 7 is divided into 3 m thickness of the cutting section, which is cut by shearer, and 10 m thickness of the caving section, which is allowed to cave immediately behind the face support. The shield support has a setting force of 6990 kN and a yield force of 8400 kN, representing the real support characteristics in practice. A detailed description of support simulation was presented in Le et al. (2019a). The installation road is 7 m wide while the face advance is 1 m each cut. By adjusting the damping ratio, the model is calibrated against the face distance where top coal starts to cave, which was reported 6–8 m at the field. The model has a total of 3803 blocks and takes around seven days to finish the coal extraction.

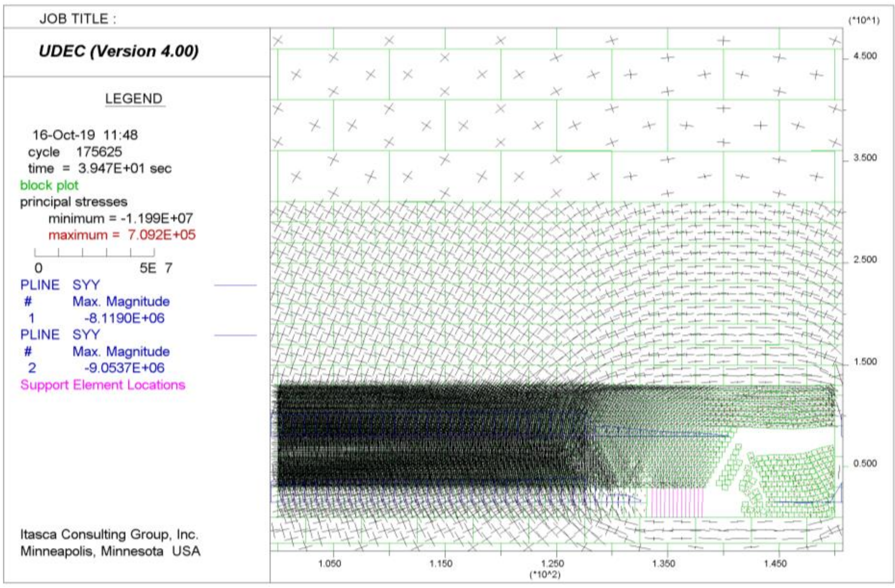
Table 1. Rock mass properties in top coal fall model (adopted from Le et al., 2019a)

Material	Block properties								Discontinuity properties				
	Uniaxial Compressive Strength (MPa)	Young modulus (GPa)	Friction (degree)	Cohesion (MPa)	Tensile strength (MPa)	Residual cohesion (MPa)	Residual tensile strength (MPa)	Critical strain (%)	Normal stiffness (GP/m)	Shear stiffness (GPa/m)	Cohesion (MPa)	Friction (degree)	Tensile strength (MPa)
Coal	5.176	1.821	32	1.52	1.55	0.304	0.155	0.5	10	1	0	15	0
Siltstone	15.325	5.749	32	4.73	3.05	0.945	0.305	0.1	10	1	0	20	0
Sandstone	29.7	11.143	34	9.15	5.25	1.83	0.525	0.1	10	1	0	25	0

4 Characteristics of top coal fall

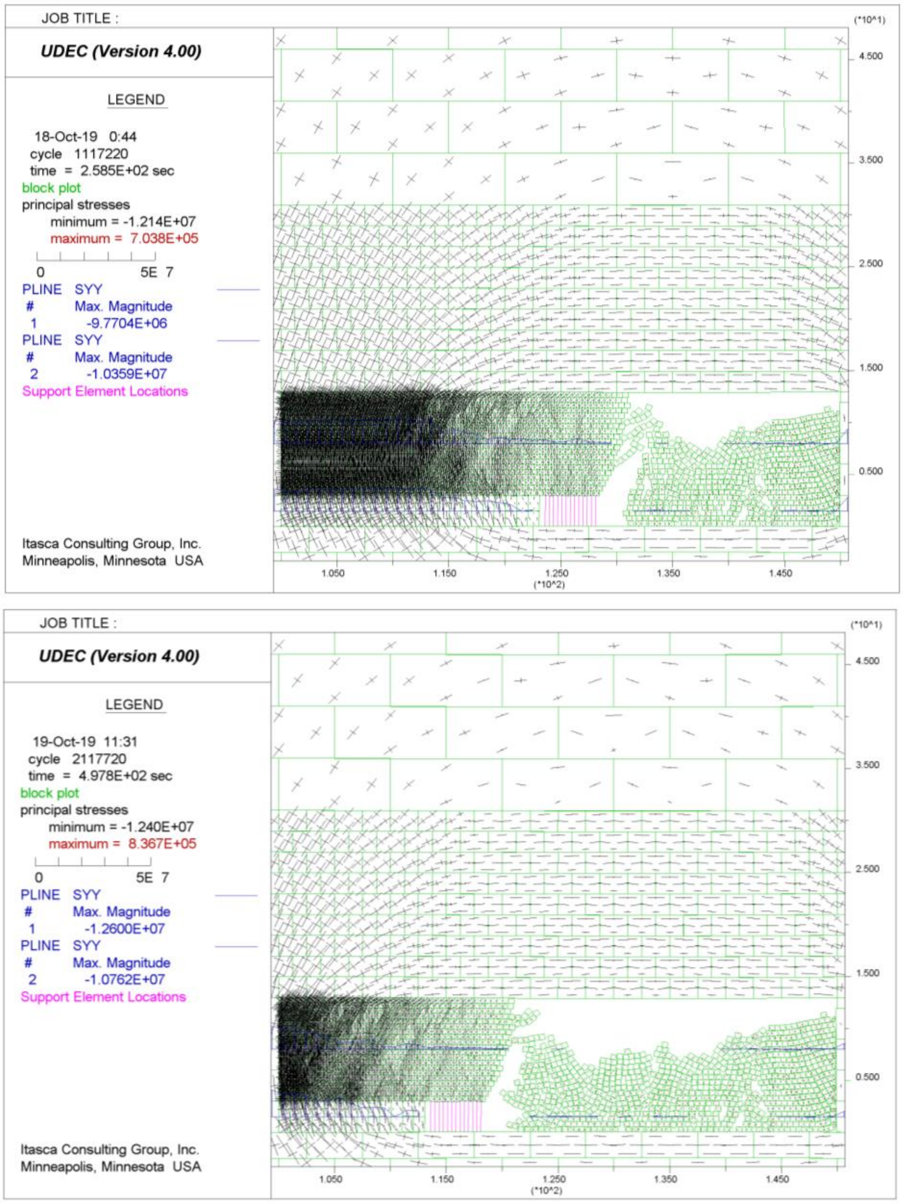
4.1. Front abutment stress

(i) The distribution of principal stresses and front abutment stress is monitored during the extraction simulation, as displayed in Fig. 3. The abutment stress is monitored along one horizontal line located in the middle of the cutting section (1.5 m above seam floor) and another horizontal line in the middle of the caving section (8 m above seam floor). It is seen that due to mining, the vertical stress is relieved from, above and below the mined-out area and simultaneously concentrates in the abutments. As the face advances, the area of relieved zone and magnitude of concentration increase. For instance, after 10 m, 20 m and 30 m of face advance, the peak stress locates at 7 m, 10 m, and 15 m ahead of face line with the corresponding magnitude being 9.05 MPa, 10.36 MPa and 10.76 MPa in the cutting section. Similarly, in the caving section, the peak stress is at 7 m, 10 m, and 15 m ahead of face line with the magnitude being 8.12 MPa, 9.77 MPa, and 12.60 MPa. Apparently, the peak abutment stress moves far away from the face line and increases in magnitude as the face advances. This result is in agreement with past numerical studies (Le et al., 2018). Figure 3 also indicates that the horizontal stress is released from the mined-out seam and accumulates in the near roof and floor strata until these strata fail.



(a)

Figure 3. Principal stress tensors distribution at (a) 10, (b) 20 and (c) 30 m of face advance



(b)

(c)

Figure 3. Continue

4.2. Material failure

As discussed in Le et al. (2019a), above face support, discontinuities mostly fail in tension while further into unmined seam, discontinuities mainly fail in shear. At the same time, top coal block above and in front of face support mostly fail in shear. Similar numerical results are obtained in the current study (Fig. 4). The failure modes here are in accordance with previous site observation and empirical work (Le et al., 2019b). The relaxation of horizontal stress at/near coal face and concentration of front abutment stress combined with the strength and structure of coal seam are the controlling parameters of coal failure in front of face support.

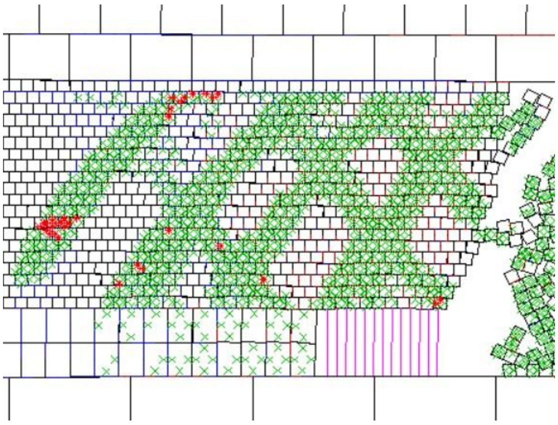


Figure 4. Material failure at 28 m of face advance (NOTE: sign * denotes zone at yield surface; × denotes zone yielded in past; and ○ denotes zone in tensile failure)

4.3. Fall mechanism

Block failure forms new fractures that, along with pre-existing discontinuities failure, greatly facilitate top coal fall ahead of support. If the broken top coal is small enough in size or if the support is not timely set at new face line, top coal may fall. One limitation of UDEC is that intact block fails implicitly (through indicators) rather than explicitly. Meanwhile, too small block size could result in excessive computation time for any longwall problem simulation. Therefore, in this study, one case in which the support lags behind a new face line is modelled, as illustrated in Fig. 5. The numerical result shows that when the distance between tip of roof canopy and face line (tip-to-face distance) is sufficiently large, failed top coal can easily fall onto floor. At the same time, the remained top coal blocks in failed zone displace into void space while the discontinuities are extended. The coal blocks at face also tend to displace but not enough to move out of the seam (Fig. 6). Top coal fall in this case, according to Brown (2002), can be attributed to "stress caving". This mode is different from "gravity caving" as seen for top coal behind face support.

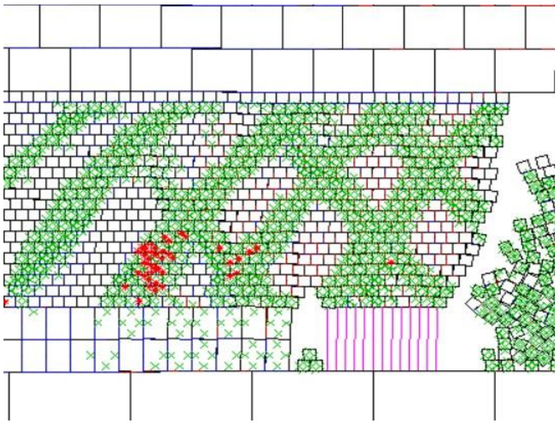


Figure 5. Top coal fall at 29 m of face advance (NOTE: sign * denotes zone at yield surface; × denotes zone yielded in past; and ○ denotes zone in tensile failure)

4.4. Effect of pre-existing fault

In order to study the effect of the geological fault on top coal fall, a similar top coal fall model with a pre-existing fault, which is located within coal seam and runs into the mined-out area, has been developed. The fault's properties are the same as discontinuity's properties given in Table 1. The extraction simulation is then carried out. It is seen in Fig. 7 that as the face approaches the fault, the upper portion of coal face slides along the fault and rests on the floor. Although the tip-to-face distance is increased, the top coal ahead of face support, however, remains stable. This is because as the fault runs into the goaf, top coal blocks slide along the fault and cause a resistance force. The implicitly failed top coal ahead of support is clamped by this force and the top coal above support. Further investigation of the fault's effect considering other fault orientations and explicit block failure are implemented by the authors.

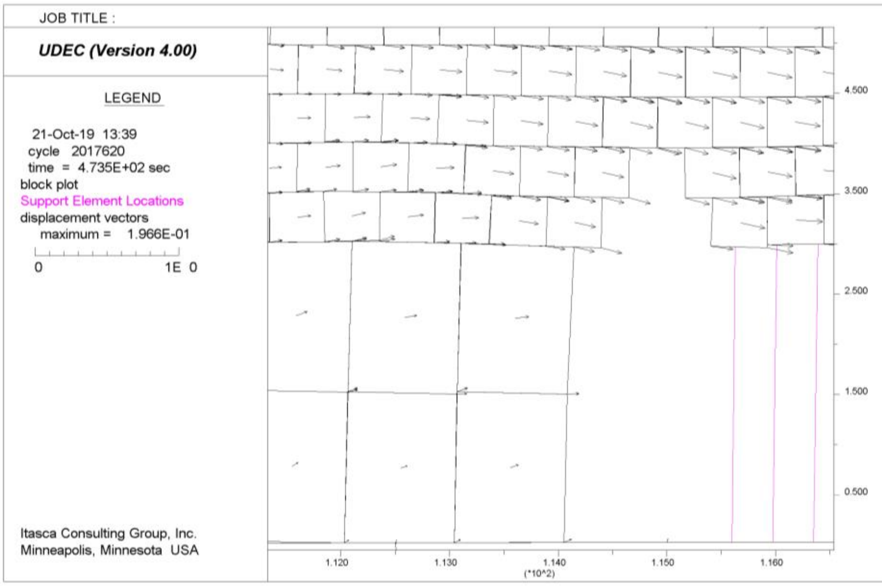


Figure 6. Block displacement at 29 m of face advance (NOTE: caved blocks are hidden)

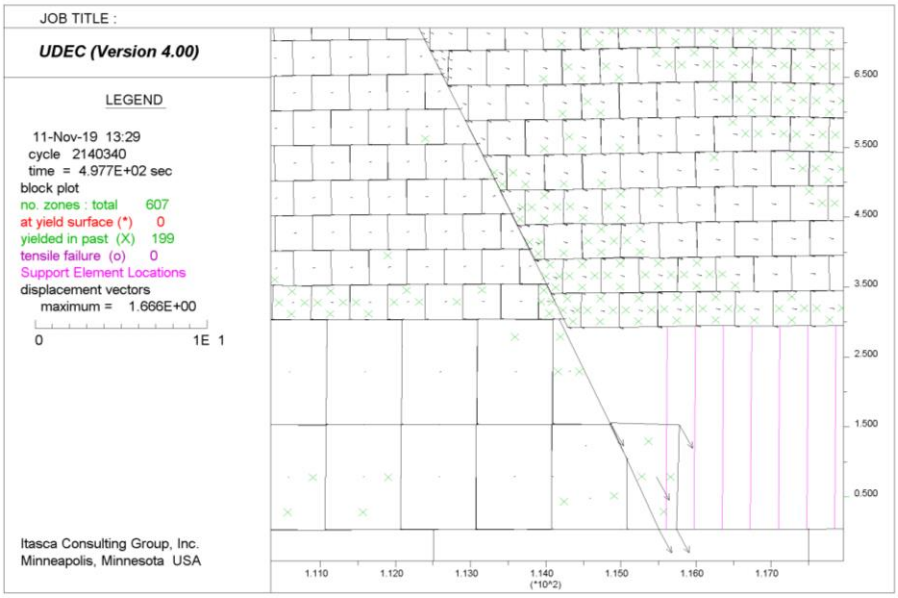


Figure 7. Top coal fall model with a pre-existing fault (NOTE: sign * denotes zone at yield surface; × denotes zone yielded in past; and ○ denotes zone in tensile failure)

5. Conclusions

This paper presents a numerical study using the DEM method on key characteristics of top coal fall ahead of face support using the geo-mining conditions of Seam 7 a thick coal seam extracted by using LTCC at Ha Lam coal mine, Vietnam. The top coal fall model is validated against site observation and past numerical and empirical works. The study provides further evidence confirming that the relaxation of horizontal stress, the concentration of front abutment stress, and the strength and structure of the coal seam drive the failure of coal in front of face support. For longwall mining with large caving height as in Seam 7, top coal is likely to fall depending on the size of failed top coal and/or practical operation of face support. The fall mechanism is found in "stress caving" a caving mode which was presented in Brown (2002), or in other words, horizontal stress-driven guttering according to Frith (2015). Alternatively, a pre-existing fault running into goaf can facilitate the occurrence of face spall but may not lead to top coal fall, which depends on the size of failed materials as well. The paper's findings provide engineers with a better understanding of top coal/roof fall characteristics in longwall mining based on which corresponding solutions can be efficiently developed.

Acknowledgements

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

References

Bai Q.-S., Tu S.-H., Chen M., Zhang C., 2016. Numerical modeling of coal wall spall in a longwall face. International Journal of Rock Mechanics and Mining Sciences, 88, 242–253.

Brown E.T., 2002. Block caving geomechanics, Indooroopilly, Qld., Julius Kruttschnitt Mineral Research Centre, The University of Queensland.

Frith R.C., 2015. 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, 25, 687–706.

Ha Lam Coal Company 2018a. Mining passport for Face 7-3.1. Quang Ninh: Ha Lam Coal Company.

Ha Lam Coal Company 2018b. Report on mechanisation of underground coal mining. Quang Ninh: Ha Lam Coal Company.

Hoyer D.I. Early warning of longwall weighting events and roof cavities using LVA software. In: BARCZAK, T., ed. International Conference on Ground Control in Mining, 2011 Morgantown. West Virginia University, 207–213.

Itasca Consulting Group, 2004. UDEC Universal Distinct Element Code v4.0 users' manual.

Khe Cham Coal Company 2017. Report on mechanisation of underground coal mining Quarter I 2017. Quang Ninh: Khe Cham Coal Company.

Le T.D., Bui M.T., Pham D.H., Vu T.T., Dao V.C., 2019a. A modelling technique for top coal fall ahead of face support in mechanised longwall using Discrete Element Method. Journal of Mining and Earth Sciences, (accepted).

Le T.D., Oh J., Hebblewhite B., Zhang C., Mitra R., 2018. A discontinuumdiscontinuous modelling approach for investigation of Longwall Top Coal Caving mechanisms. International Journal of Rock Mechanics and Mining Sciences, 106, 84–95.

Le T.D., Vu T.T., Dao V.C., 2019. Mechanism and solution to top coal fall at Ha Lam mechanised longwall face, Vietnam. In: Truong Q.H., Tran T.H., Phan V.T., eds. Conference on Advanced Researches in the Earth and Environmental Sciences (CAREES2019), 2019b Ho Chi Minh, Vietnam (accepted).

Medhurst T., 2014. Dynamic response of longwall systems and their relationship to caving behaviour. ACARP Project C20032. Australian Coal Association Research Program ACARP.

Pappas D., Mark C., 2011. Roof and rib fall incident trends: a 10-year profile. In: WORTMAN-WUNDER, E. (ed.) SME Transactions Volume 330. Society for Mining, Metallurgy and Exploration, Inc.

Pham D.H., 2012. Development of geomechanical database for mechanisation of coal industry in Vietnam. Hanoi: Institute of Mining Science and Technology.

Prusek S., Rajwa S., Wrana A., Krzemień A., 2017. Assessment of roof fall risk in longwall coal mines. International Journal of Mining, Reclamation and Environment, 31, 558–574.

Vang Danh Coal Company 2018. Report on mechanisation of underground coal mining. Quang Ninh: Vang Danh Coal Company.

Vervoort A., 1988. Influence of longwall support on the occurrence of roof cavities. International Journal of Mining and Geological Engineering, 6, 313–326.

Yang S., Song G., Kong D., 2019. An evaluation of longwall face stability in thick coal seams through a basic understanding of shield-strata interaction. Journal of Geophysics and Engineering, 16, 125–135.

Yao Q., Li X., Sun B., Ju M., Chen T., Zhou J., Liang S., Qu Q., 2017. Numerical investigation of the effects of coal seam dip angle on coal wall stability. International Journal of Rock Mechanics and Mining Sciences, 100, 298–309.