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VIET NAM METEOROLOGICAL AND HYDROLOGICAL ADMINISTRATION

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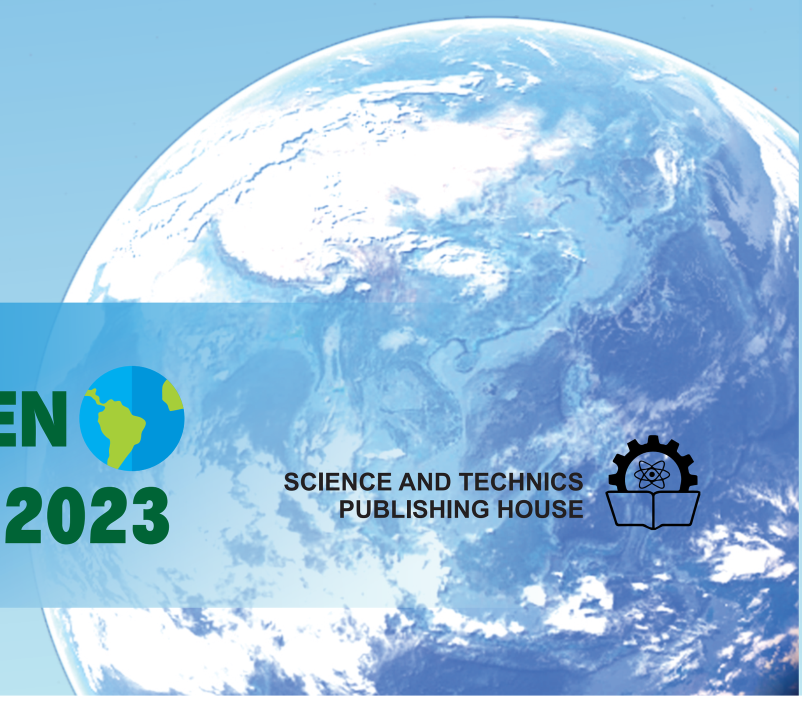
Proceedings of the Sixth International Scientific Conference

EARTH AND ENVIRONMENTAL SCIENCES, MINING FOR DIGITAL TRANSFORMATION, GREEN DEVELOPMENT AND RESPONSE TO GLOBAL CHANGE



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SUSTAINABLE AND GREEN ENERGY TRANSITION CIRCULAR ECONOMY IN RESOURCE-MINERAL MANAGEMENT AND SUSTAINABLE DEVELOPMENT

(Wind power, solar power, gas power, geothermal, garbage power, hydrogen, etc.; low carbon emission technologies; resource-mineral management and sustainable development)

CLIMATE CHANGE AND DISASTER MITIGATIONINNOVATION MEASURES FOR EARTH, MINING AND ENVIRONMENTAL SCIENCES (innovative measures for earth, mining and environment sciences to meet sustainable development goals)

IDENTIFICATION OF WEIGHTING EVENT CAUSED BY UNDERGROUND COAL MINING AT QUANG NINH COAL FIELD, VIETNAM

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Abstract: Underground mining is one of the prevalent technologies that matches the national government's attitude towards the Vietnam coal industry. It is considered as a critical component of the brown-to-green transition strategy. One of the problems dealing with sustainable underground coal mining in Vietnam is to exploit the seams in unfavourable ground control conditions. Although a large proportion of national coal reserves is distributed in these conditions, its exploitation remains limited and unsafety due to the critical geo-mechanical associated risks such as roof fall or weighting event. This paper presents an identification on the cause and solution of the weighting event occurring in Vietnam geological-mining conditions. Using collected field measurement, computational modelling and expert methods, the weighting event is found to commonly occur in two typical stratigraphic settings. Corresponding technological solutions to minimising the event are theoretically proposed, contributing to the safe, fully exploited, and efficient mining of Vietnam coal industry.

1. INTRODUCTION

Weighting event is the great concentration and rapid release of roof pressure at underground exploiting face (workplace). This is commonly associated with the overhanging and breakage of roof strata portion at initial face advance (first weighting) and/or after a certain distance of face advance (periodic weighting, Figure 1). This portion of roof strata is the lower part of main roof, has sparse geological structures (e.g., joint, bedding), and typically occurs within 50–70 m above seam floor. This roof is called massive roof (in academic research) or competent strata (in industry report), which are normally stable. Along with the main roof strata conditions, the immediate roof should be of insufficient thickness that cannot fill the mined-out void. This enables the massive roof to directly impact the working face. Weighting is a critical event in underground coal extraction because when occurs, it causes great force that destroys face equipment and injures workers. Weighting may also cause roof cavities and face spall that interrupt normal production, requiring significant time and cost for remedy.

A precursor for identification of the weighting event at Quang Ninh coal field is to classify the stability of roof rock strata in the field. Unfortunately, there have been limited studies in the literature and all are in Vietnamese [2, 3]. According to Pham [3], Vietnam Mining Science and Technology Association (VMST) developed a system for classification of Vietnam roof rock strata stability (Table 1). It is stated that for the gently inclined to inclined coal seams at Quang Ninh coal field, in period of 2021–2025 the proportion of industrial reserves classified as stable, medium and unstable is 25, 69 and 6%, respectively.

The result indicates that the VMST system is basically similar to VNIMI system. The main difference is the reduction of bedding thickness, while the addition of GIG index appears to insignificantly affect the classification result. It is the thinner bedding that results in a significant proportion of medium stable roof (69%) and very small proportion of unstable roof (6%) compared to the classification result in a 10-year earlier research [2]. A common agreement between the two studies is that the roof rock of Quang Ninh underground coal mines is mainly in class of medium-to-stable strata. This facilitates the occurrence of weighting event when mining in such strata, as mentioned earlier in this section.

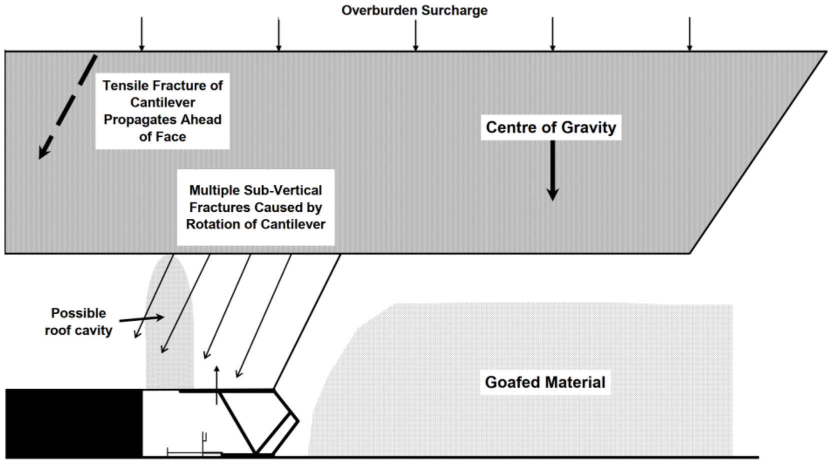

Figure 1. *Concept of weighting event [1].*

Table 1. Stability classification of roof rock strata in Quang Ninh coal field [3].

Rock composition and strength			GIG index	Classification of roof stability			Classification of roof caving	
Composition	Compressive strength (MPa)	Bedding thickness (m)		Class	Exposed area (m^2)	Exposed time (hour)	Class	Caving span (m)
Conglomerate-gritstone, sandstone, thickly bedded siltstone	60–80	> 0.3	> 280	Stable	> 15	> 2	Very hard to cave	> 12
							Hard to cave	6–12
Sandstone, averagely bedded siltstone	30–60	0.1–0.2	60–280	Medium stable	10–15	0.5–2	Medium to cave	2–6
Thinly bedded siltstone, thinly bedded claystone	20–40	0.1–0.15	32–60	Unstable	5–10	< 0.5	Easy to cave	1–2
Claystone, coal-claystone, thinly bedded	10–20	0.05–0.1	< 32	Very unstable	< 5	~ 0	Very easy to cave	< 1

Because Quang Ninh underground coal mines started exploitation under medium-to-stable roof strata, the identification of potential weighting event in this coal field is of practical needs and great importance. Apart from the above two studies, there are only a few others investigating the weighting event for Quang Ninh condition. Vu [4] studied the parameters affecting the characteristics and breakage ability of massive strata in steep condition, which is seam V15, zone III, Quang Hanh coal mine. Also in steep seam condition, Luong [5] proposed the room mining method combined with strip coal pillar for minimization of weighting event. Le et al. [6] computationally modelled the mine pressure law and behaviour of hard-to-cave roof of face TT7.9, zone Nga Hai, Quang Hanh coal mine. Using similar method, Pham and Nguyen [7] studied the effect of weighting on roadway stability. Although all these studies interpreted some characteristics of weighting in Quang Ninh coal field, no generalized cause and solution of the event in the field was identified. This paper aims to identify the typical types of the weighting event in Quang Ninh mining condition. The study results can guarantee the exploitation safety and productivity in the largest coal field of Vietnam, satisfying the requirements from Vietnam practice and government.

2. ANALYSIS OF WEIGHTING EVENTS AT QUANG NINH COAL FIELD

According to Pham [3], the Quang Ninh coal measures have an average sedimentation thickness of 200–1280 m. The measures consist of coal-claystone, claystone, siltstone, sandstone, gritstone, and conglomerate. The rock size increases as its relative location to coal seam increases. In the order of stratigraphic column, roof rocks are usually thickly-to-thinly bedded siltstone overlain by sandstone strata. Sometimes there exists a thin layer of claystone or coal-claystone of 0.3–0.5 m between seam and siltstone. This is called the false roof. The immediate roof is thinly (< 15 cm) to medium (15–30 cm) bedded siltstone. The main roof is commonly sandstone and/or thickly bedded siltstone.

Mining practice in Quang Ninh shows that under hard-to-cave roof, an exploitation panel has a typical overhanging roof of 2–6 m length behind face support. The overhanging roof breaks periodically and causes weighting event at face. Due to the use of hydraulic support and mechanised support, the panel has low risk of face breakdown. However, face spall and roof cavity (roof fall) do occur, especially in top-coal caving mining method. Some examples of hard-to-cave roof panel can be analysed as follows. In 1991, Ha Lam coal mine exploited Seam 10 at section of medium thickness. The roof did not cave after some face advances, and the mine had to change the mining method to maintain safety and recover production. It was reported that in that section, the immediate roof consisted of claystone, coal-claystone, and siltstone (Figure 2a). The claystone had an average caving span of 1–2 m, but it was thinly (0.1–1.5 m) and unevenly distributed in the roof. The siltstone had an average caving span of 6–8 m while the main roof was very competent. As the siltstone was evenly distributed with a thickness of 3–14 m, it made the immediate roof stable and overhanging. It was also reported that the caving thickness of immediate roof was not sufficient to fill the goaf. The competent main roof therefore also contributed to the weighting event at face. A similar problem occurred at Seam 15 Bac Bang Danh coal mine. The seam's immediate roof was of 3–3.5 m thickness and overlain by a competent main roof (Figure 2b).

In 1999, Uong Bi coal mine exploited Seam 46, Trang Khe area at level +350/+390. The first caving in the panel did not occur although the face had advanced 30 m. It was reported that the seam's roof consisted of 0.3–0.7 m of claystone and coal-claystone (false roof) and competent main roof interbedded by thin siltstone layers (Figure 2c). It was believed that due to the absence of sufficient immediate roof, the main roof acted as a massive roof that resulted in the weighting event at area. A similar stratigraphic column setting was seen at Seam 5, Canh Ga area, Vang Danh coal mine (Figure 2d).

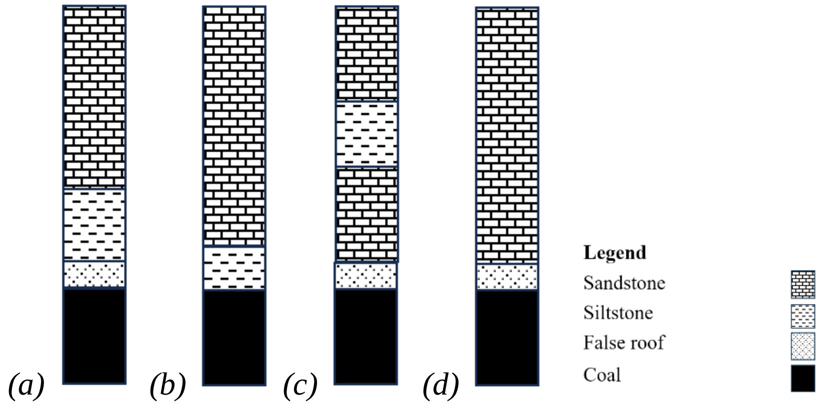

Figure 2. *Stratigraphic column at (a) Seam 10 Ha Lam, (b) Seam 15 Bac Bang Danh, (c) Seam 46 Trang Khe, Uong Bi, and (d) Seam 5 Canh Ga, Vang Danh coal mines (modified from [3]).*

3. MODELLING OF WEIGHTING EVENT AT MONG DUONG COAL MINE

3.1. Model construction

Mong Duong coal mine is located in Mong Duong ward, Quang Ninh province, Vietnam. Using the VMST classification system, the mine is found to have 19 panels under stable and hard-to-cave roof condition [3]. At present, the mine has exploited Seam M6 East Wing where weighting events are reported to occur irregularly. According to the company report [8], for Panel M6 No.2 level -190/-130, the seam has a total thickness of 2.2 m, average dip angle of 34 degrees, and strength index of 1–2. The immediate roof has an average thickness of 4.5 m, compressive strength of 594.7 kG/cm^2, and tensile strength of 91.05 kG/cm^2. The main roof has an average thickness of 22 m, compressive strength of 522.8 kG/cm^2, and tensile strength of 60.23 kG/cm^2.

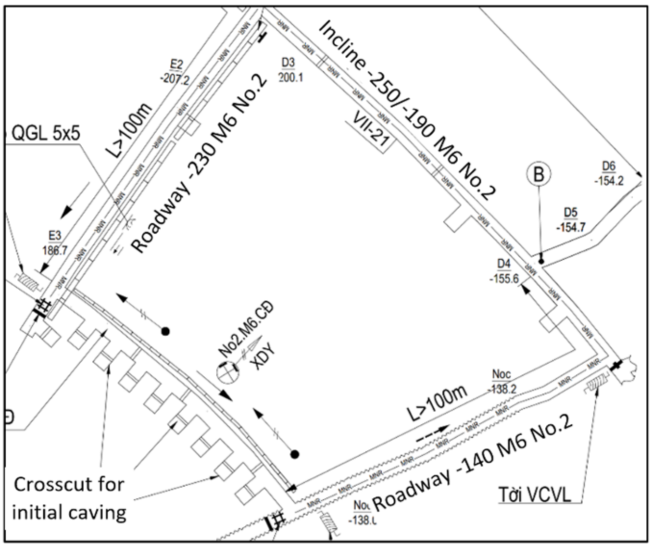

Figure 3. *Location of cross-section for modelling.*

To understand the mechanisms of the weighting event at Panel M6 No.2 level -190/-130, a simplified computational model of the panel along its strike is developed (Figure 3). Based on the above geological conditions, the model consists of a 2.2 m seam thickness, overlain by a 4.5 m immediate roof thickness and a 22 m main roof thickness (Figure 4). Above the main roof is an overburden strata of 40 m thickness. Similarly, below the seam is a floor strata of 40 m. The total model height is 108.8 m. Along the direction of face advance, the modelled exploitation length is 55 m. This corresponds to the practical length in Phase 1 of panel exploitation. The total model width is 220 m.

The altitude of surface is +97.5 and the seam has a cover depth of 257.5 m. Because a strata portion of 68.7 m is explicitly modelled, the remaining portion of 188.8 m is modelled by a boundary stress of 5.02 MPa applied on top of model. The stress regime is modelled with a ratio of vertical stress to horizontal stress of one.

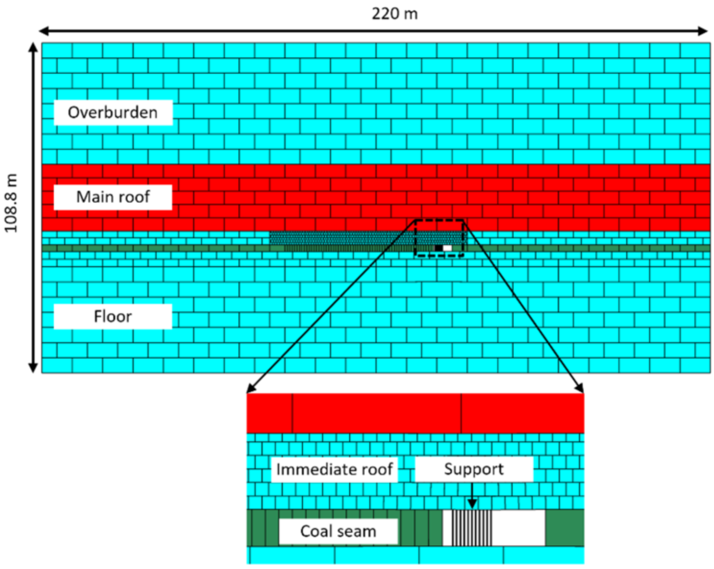

Figure 4. *Computational model of Panel M6 No.2 level -190/-130.*

The available information on engineering geology is at regional scale. Therefore, detailed geological structures at the mine are referred from similar mines. For example, as the coal seam is fully exploited in single cut, the vertical joints are modelled with a spacing of 0.8 m, which is equivalent to one web cut. For the immediate roof, typical sedimentary structures such as joints and beddings are modelled. The spacing between beddings is 0.8 m, which is equal to the lowest bedding thickness. The spacing between joints is 0.8 and 1.6 m, representing two scenarios of medium jointed and sparsely jointed strata. For the strata outside the area of interest, the geological structures are modelled with an increasing spacing of from 2.5 to 10 m.

The two dimensional discontinuum-based code UDEC is used [9]. The plastic model is assigned to intact rock. The Coulomb slip model is assigned to joints and beddings. The input parameters of intact rock for modelling are presented in Table 2. The support is modelled as a set of spring elements with a total width of 2.26 m and a loading capacity of 1.8 MN (Figure 4).

Table 2. Input parameters of intact rock for modelling.

Strata	Volume weight (kg/m^3)	Compressive strength (MPa)	Tensile strength (MPa)	Compressive elastic modulus (GPa)	Tensile elastic modulus (GPa)	Cohesion strength (MPa)	Internal friction angle (degree)
Coal seam	1600	15	4.3	-	-	4.8	25
Immediate roof	2660	59	9.1	0.35	0.12	16	33
Main roof	2630	79	15.3	0.45	0.15	20.6	35

3.2. Model analysis

For the scenario of medium jointed immediate roof (spacing of 0.8 m), the model result shows that when the face advances 20 m (25 web cuts), this roof is visually separated from the main roof (Figure 5a). Within the immediate roof, the layers are also separated from each other, especially for the lower layer. The separation is clearly seen in the middle of hanging roof. At both ends of the hanging roof, the joints and bedding fail, mostly in tension mode. At the same time, Figure 5b shows that the intact rock fails very little in the immediate roof. Intact rock mostly fails in coal seam in shear mode. The hanging roof caves as the face advances 20.8 m (26 web cuts). This is called the first caving or initial caving of immediate roof. The numerical results from Figure 5 confirm that the immediate roof of Panel M6 No.2 level -190/-130 is stable and hard to cave.

After the first caving, the immediate roof caves periodically. The roof caves after one to two web cuts (0. 8–1.6 m), as shown in Figure 6a and Figure 6b. It sometimes caves after three cuts (3.4 m, Figure 6c). These results indicate that for the scenario of medium jointed strata, the immediate roof can cave immediately or overhang after the advance of face support.

a)

b)

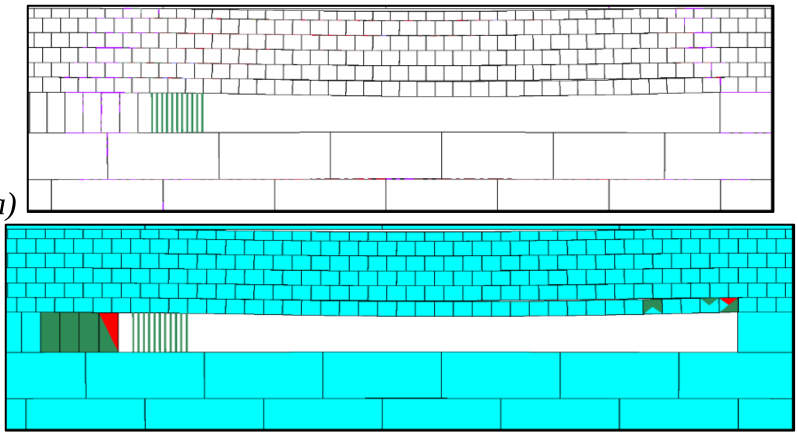

Figure 5. *First caving of medium jointed immediate roof.*

a)

b)

c)

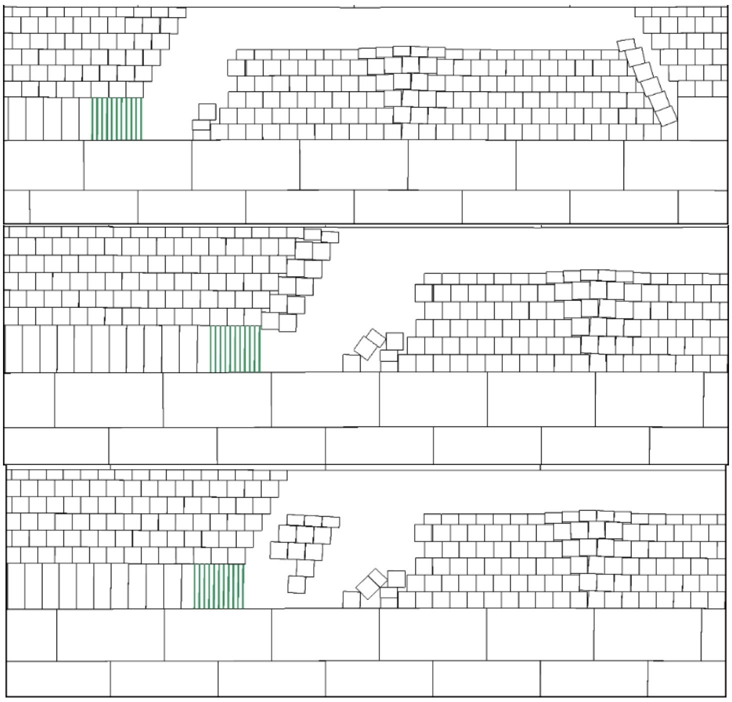

Figure 6 *Periodic caving of medium jointed immediate roof.*

For the scenario of sparsely jointed immediate roof (spacing of 1.6 m), the model results show that when the face advances 28 m (35 web cuts), the roof starts to cave its lowest layers (Figure 7a). The above layers of the roof complete caving after next two cuts (29.6 m). After the first caving, the immediate roof caves periodically along the vertical joints. However, due to the large spacing between the joints, the immediate roof normally caves after two web cuts, which is 1.6 m of face advance. Furthermore, the broken part may not completely detach from the immediate roof due to insufficient void space. This results in the overhanging roof of 4–5 m behing face support (Figure 7b).

a)

b)

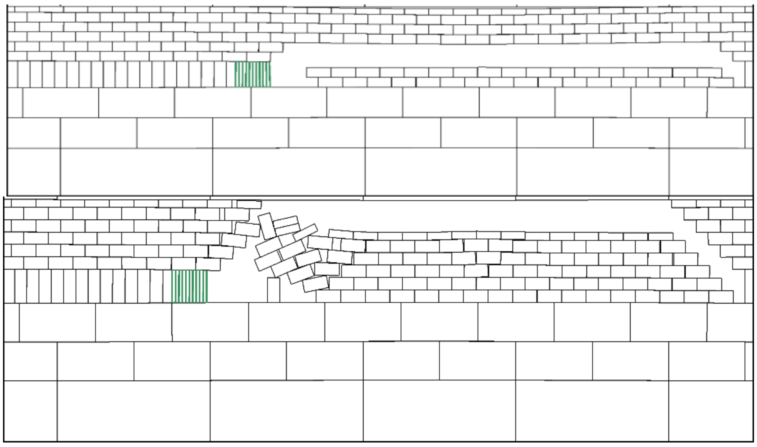

Figure 7 *(a) First caving and (b) overhanging of sparsely jointed immediate roof.*

4. PROPOSAL OF TECHNOLOGICAL SOLUTIONS

As analysed in Section 2, when a face enters hard-to-cave roof condition, most mines in Quang Ninh coal field have to change the mining method (mining system). In particular, the fully caving method (the prevalent ground control technique in coal field) is replaced by the room-and-pillar method. The roof strata are naturally lowered on strip pillars between the room without caving. Although this technological solution enables a mine to safely exploit through difficult mining condition, it results in low production rate (2.000–5.000 tons/month), low labour productivity (1.6–2.2 tons/manshift), high roadway development cost (30–42 m/1000 tons), and high resources loss (33–40%) [10]. In order to minimise the resources loss for sustainable coal industry and based on the literature review [3], this paper proposes a solution approach in which the hard-to-cave roof is first weakened and then caves behind face support. The weakening solution can be implemented by pre-blasting of advancing borehole ahead of face, post-blasting of short holes behind face, and hydraulic fracturing. The solutions are applicable to current Vietnam coal industry but require detailed investigation to interpret the advantages, disadvantages, and conditions for use. For example, the solution of drilling long borehole can be quickly used in practice. However, it requires a significant volume of explosives and thus needs careful consideration. It should be noted that apart from mining method, other solutions such as panel design or operational parameter design (e.g., speed of face advance, setting value and/or yield value of support) can be considered in separate studies.

5. CONCLUSIONS

This paper presents an identification on the cause and solution of the weighting event occurring in Quang Ninh geological-mining conditions—the largest coal field in Vietnam. Using collected field measurement, computational modelling and expert methods, the weighting event is found to commonly occur in two typical stratigraphic settings of roof strata: (i) insufficient immediate roof overlain by massive strata and (ii) false immediate roof overlain by massive strata. The results from modelling confirm that the geological structures (i.e., joints) greatly contribute to the stability of roof strata (manifested as overhanging and caving) and accordingly to the risk of weighting event. Based on the literature review, technological solutions to weakening the roof are proposed for the exploitation in Quang Ninh coal field conditions. Future studies are required for the detailed application of the solutions.

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