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# Analysis of Vietnam coal mining pressure under competent strata using field measurement

Nhan Thanh Thi Dinh [1,2], Dung Tien Le [1,2,*], Dung Tien Thai Vu [1,2], Anh Tuan Nguyen [3]

*[1] Hanoi University of Mining and Geology, Hanoi, Vietnam*
*[2] Research Group: Sustainable Development of Mining Science, Technology and Environment (SDM), Hanoi University of Mining and Geology, Hanoi, Vietnam*
*[3] Mine Safety Center, Vinacomin Institute of Mining Science and Technology, Quang Ninh, Vietnam*

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ABSTRACT

*This paper presents an analysis of Vietnam coal mining pressure under competent roof strata. Using classical ground pressure theories, the pressure law around longwall mining from setup entry to first strata caving and cyclic strata caving is strongly confirmed to follow pressure arch, voussoir beam and cantilever beam theories, respectively. Through analysis of shield pressure and shield convergence from a typical longwall mining under competent strata in Vietnam, the study clearly demonstrates the pressure law caused by progressive mining. The pressure change is proved to have a close relationship with roof strata movement and classical pressure theories. The pressure magnitude increases significantly and decreases rapidly when competent roof strata rupture. The difference in pressure and piston displacement between front leg and rear leg is an indicator for the stability of coal face and roof. The shield behaviours at T-junction are found to be less severe than those at the mid-panel width. The study proposes solutions to improving shield capability by increasing maximum support force and using multi-level face guard. The results from this study assist mining engineers in Vietnam in better understanding ground pressure on coal face and properly designing face support. The sustainable mining under unfavourable conditions can be better achieved for the national coal industry.*



*Corresponding author
*E - mail:* t.d.le@humg.edu.vn
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## 1. Introduction

Coal mining industry continues to play a critical role in the global economy at present despite international efforts towards carbon neutrality. For developing countries such as Vietnam, the mining industry has been oriented to sustainably develop following the slogan "green mine, clean mine, and safe mine". To achieve this target, for the past ten years, Vietnam has continuously increased the use of mining methods with less environmental impact such as mechanised underground mining. In 2023, the coal production from underground mines occupies 73% of total production, greatly contributing to the national economy. One major geotechnical risk recently emerging from Vietnam underground coal industry is the mining under competent roof strata, as stated in Le et al. (2026). Mining practice in Uong Bi - Dong Trieu coal region has encountered roof hanging events, for example in Vang Danh and Nam Mau coal mines, causing coal face instabilities and support damage (Vang Danh Coal Company, 2018; Pham, 2022). The risk of roof hanging becomes severe when large coal reserves under competent strata are scheduled for extraction till 2030 in Vietnam.

To facilitate the coal mining under such above condition, researchers and institutions have made efforts to understand the mechanisms of the roof hanging, from which remedial and mitigation solutions can be developed. For example, Vu (2013) analysed the parameters affecting the characteristics and rupture ability of competent roof strata at Zone III, Quang Hanh coal mine. From the analysis, the author proposed a solution by forming coal pillar strips in mined-out area for gradual sagging of roof strata. Similarly, Luong (2017) theoretically analysed and selected the room-and-pillar method for controlling of competent roof at Seam 11(46), Trang Khe zone, Uong Bi coal mine. For detailed mechanism, Le et al. (2018) used numerical method to study the law of mine pressure and hard-to-cave roof. The study contributed to explain the face instability caused by hanging roof at Panel TT7.9 of Quang Hanh coal mine. Also using numerical method, Pham and Nguyen (2021) investigated the effect of competent strata on roadway stability. Although the modelling was idealised, the deformation of roadway and pillar was clearly demonstrated. For a detailed review of remedial and mitigation solutions, the reader is referred to Pham (2022).

It can be seen that the above studies have successfully identified the laws of ground pressure caused by Vietnam coal mining to some extent. The studies, while focusing on a limited number of isolated geo-mining conditions, lacked field data of ground pressure for analysis. The obtained pressure laws may accordingly be limited in reliably representing a law at regional scale. To overcome this limitation, this study uses an integrated approach of theoretical and field analyses. Taking a typical geo-mining condition from Vang Danh coal mine, the ground pressure law is analysed through support behaviours at site. The results from the study assist on-site engineers in better understanding ground pressure on coal face and properly designing face support under competent roof strata.

## 2. Recap of background knowledge

Before using classical theories to explain coal mining-induced pressure, it is necessary to understand the typical movement of roof strata above longwall mining since this method is prevalent in Vietnam coal industry and different stages of strata movement occur during the mining. Figure 1a shows that to start a longwall mining, an

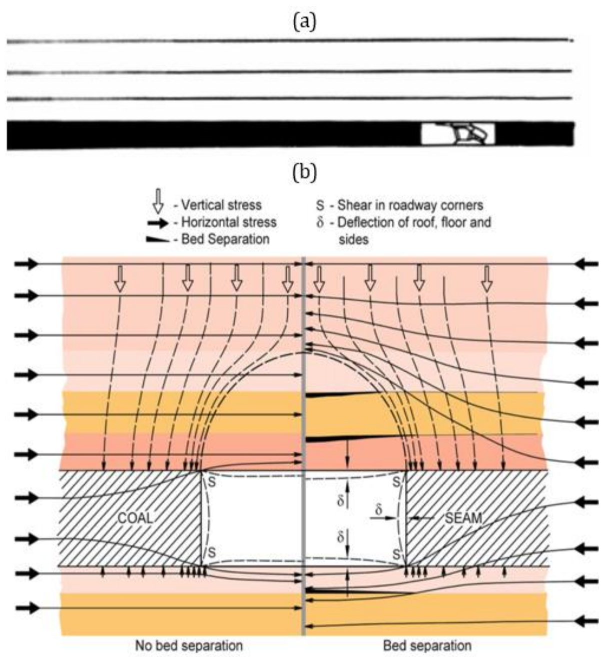


*Figure 1. (a) Longwall entry and (b) pressure arch theory (modified from Peng, 2019; Galvin, 2016).*

entry must be driven to connect transportation roadway with ventilation roadway. The entry is also known as the initial longwall face. For the purpose of installing equipment, the shape and size of entry are commonly similar to those of roadway. The ground pressure caused by mining at this stage should follow the pressure arch theory (Figure 1b). This classical theory was proposed by the German in 1928 (Qian et al., 2010). It explains that around the entry there is a pressure arch within which the vertical stress is destressed while the horizontal stress can still exist. Outside the arch, the stress is vertically concentrated at the entry's abutments. From the perspective of support design, a support should be able to resist the weight of rock inside the arch only. Note that the use of the pressure arch theory is invalid when the arch develops up to surface, or when the entry width is greater than the maximum arch width, which depends on cover depth and rock strength (Stacey & Page, 1986).

Figure 2a illustrates a mining stage at which the width of mined-out area is greater than the maximum width of pressure arch, but main roof strata remain stable and have not ruptured as expected. The voussoir beam theory, which was first proposed by Evans (1941), can be used to explain the ground pressure governing the strata stability (Figure 2b). Because competent strata may consist of one or several layers and joints due to sedimentary formation, one layer (or the whole strata) can be considered as one jointed beam. When the beam sags, it generates a component of lateral thrust at two abutments (Galvin, 2016). An internal pressure arch is accordingly formed in the beam to resist this thrust, transferring the pressure to the abutments and contributing to strata stability. Since face support and coal face are close to abutment, they may suffer great pressure concentration caused by hanging roof. This analysis is evidenced by the excessive deformation of face support during initial caving of roof at Trang Khe area, Uong Bi coal mine.

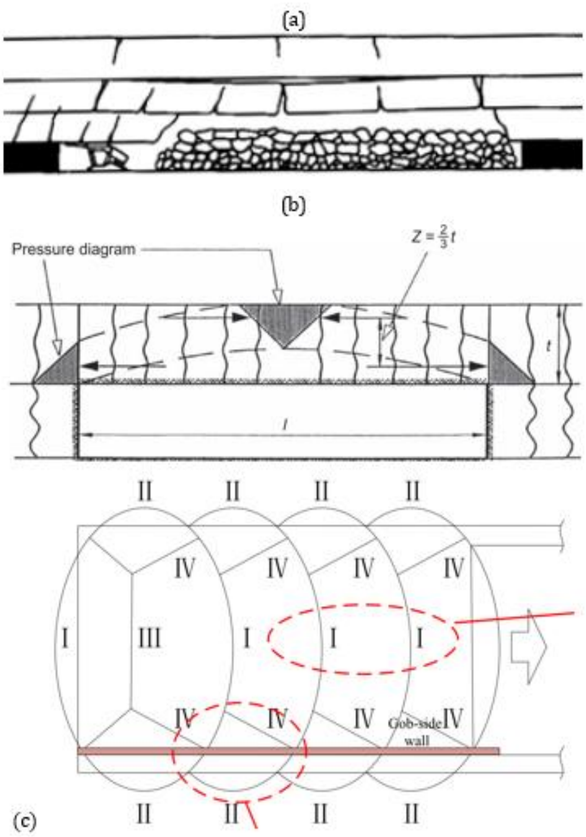


*Figure 2. (a) Before main roof rupture, (b) voussoir beam theory, and (c) key stratum theory (modified from Peng, 2019; Evans, 1941; Qian et al., 2010; Yang et al., 2019).*

It should be noted that according to Wang & Li (2017) and Wang et al. (2025), the voussoir beam was separately developed in China and known as masonry beam theory. Also, since the competent roof strata can control the movement of entire roof strata, the "key stratum theory" (Qian et al., 2010) can be used to outline the pressure law and main roof fracture shape above mined-out area (Figure 2c).

Figure 3a presents a mining stage at which the competent strata rupture cyclically. This stage starts after the initial caving of competent roof and has

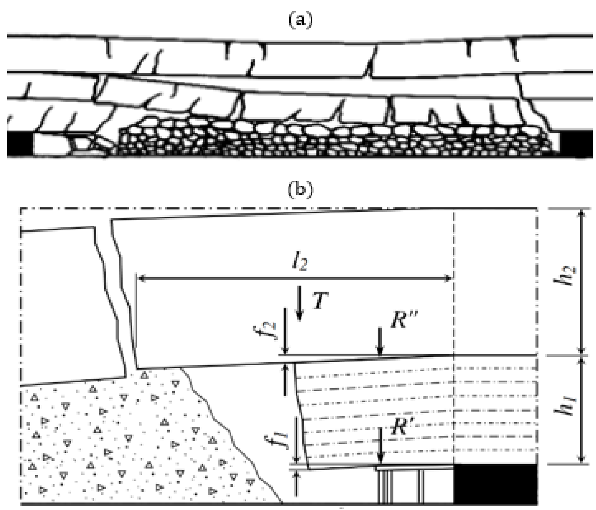


*Figure 3. (a) Cyclic main roof rupture and (b) pressure calculation diagram (modified from Peng, 2019; Do & Vu, 2008).*

been widely explained by the cantilever beam theory (Do & Vu, 2008; Le et al., 2024b). Note that this theory was developed by the German in 1916 (Qian et al., 2010). In the case of competent strata, not only immediate roof but also main roof generates load on face support and coal face. A commonly used concept for pressure calculation in Vietnam coal industry is shown in Figure 3b.

Improvement of shield support capability is one of key solutions to maintaining safe longwall mining under competent roof. According to Peng (2008), the capability can be improved by increasing support ability and strengthening special features. An example of high support force with 3-level face guard is shown in Figure 4. The face guard helps to protect coal face from spall during high loading under competent strata.

*Figure 4. High support force with 3-level face guard (Kang et al., 2025).*

## 3. Field analysis of ground pressure under competent strata

### *3.1. Measurement of shield behaviour at site*

Vang Danh coal mine at Quang Ninh coal field is selected as the case study because this mine has competent roof and available pressure data from mechanised longwall panels. According to Pham (2022), in the production period of 2021-2025, Vang Danh coal mine has operated 13 longwall panels whose roof strata can be ranked as relative to competent strata. The panels are mainly located in Seam 7, Seam 6 and Seam 5 in which the mechanised longwall system has been installed in Seam 7. For detailed characteristics of rock mass and shield support in the panel, the reader is referred to Le et al. (2024a) and Le et al. (2026). At Seam 7, the mechanised panel has a total of 70 shield supports covering a panel width of 105 m (Figure 5).

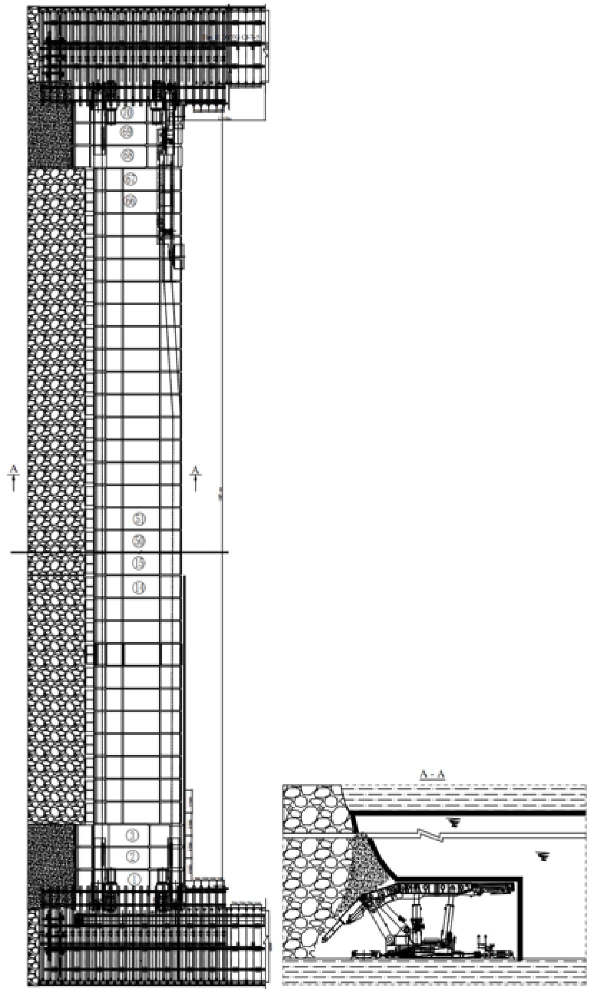

*Figure 5. Mechanised longwall at Seam 7 Vang Danh coal mine (Vang Danh Coal Company, 2023).*

The gateroads have a width of 4.6 m, and the T-junction near each gateroad is supported by three 4800-ton-capacity shields (transitional shield). The shearer is operated in bi-directional mode. The shield is advanced behind shearer movement and is 2 to 3 m away from the shearer drum (Figure 6). A cross section of Seam 7 and strata is shown in Figure 7.

Le et al. (2024a) stated that at Vang Danh coal mine, the pressure near tailgate is more severe than near headgate. Accordingly, the behaviour of Shield 70 adjacent to tailgate is put into analysis. The selection of this transitional shield is due to another fact that its pressure is commonly more severe than

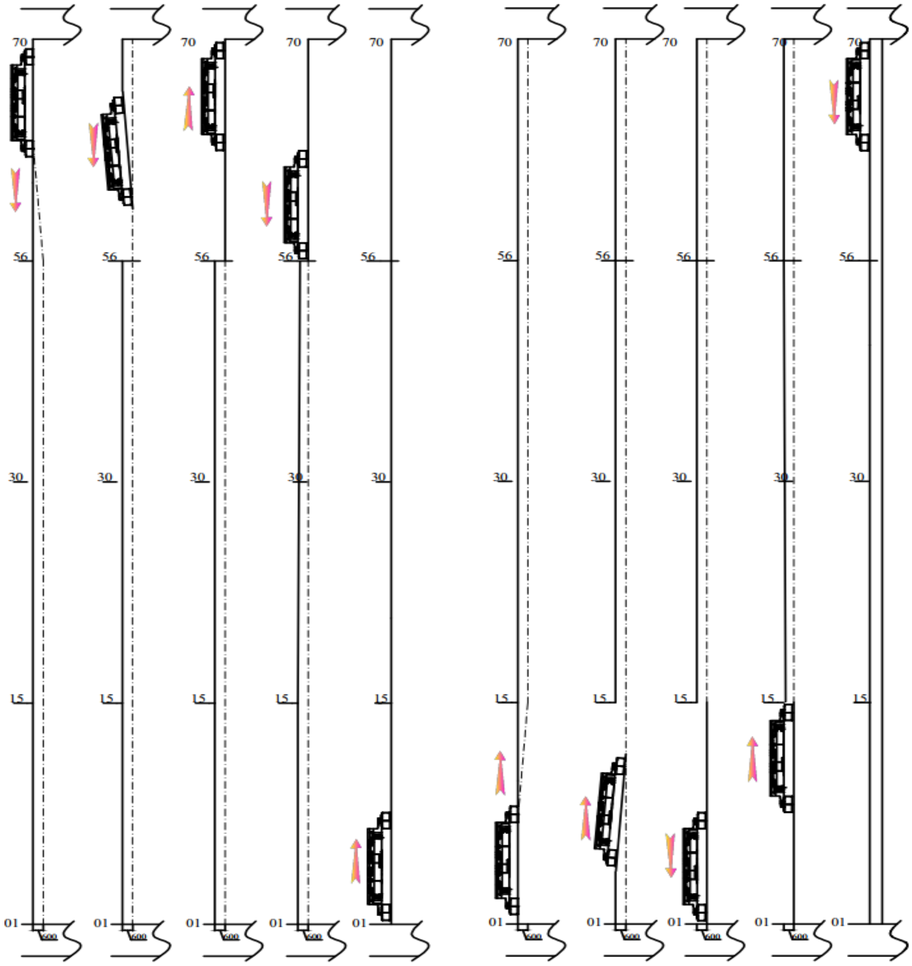


*Figure 6. Shearer direction at Seam 7 Vang Danh coal mine (Vang Danh Coal Company, 2023).*

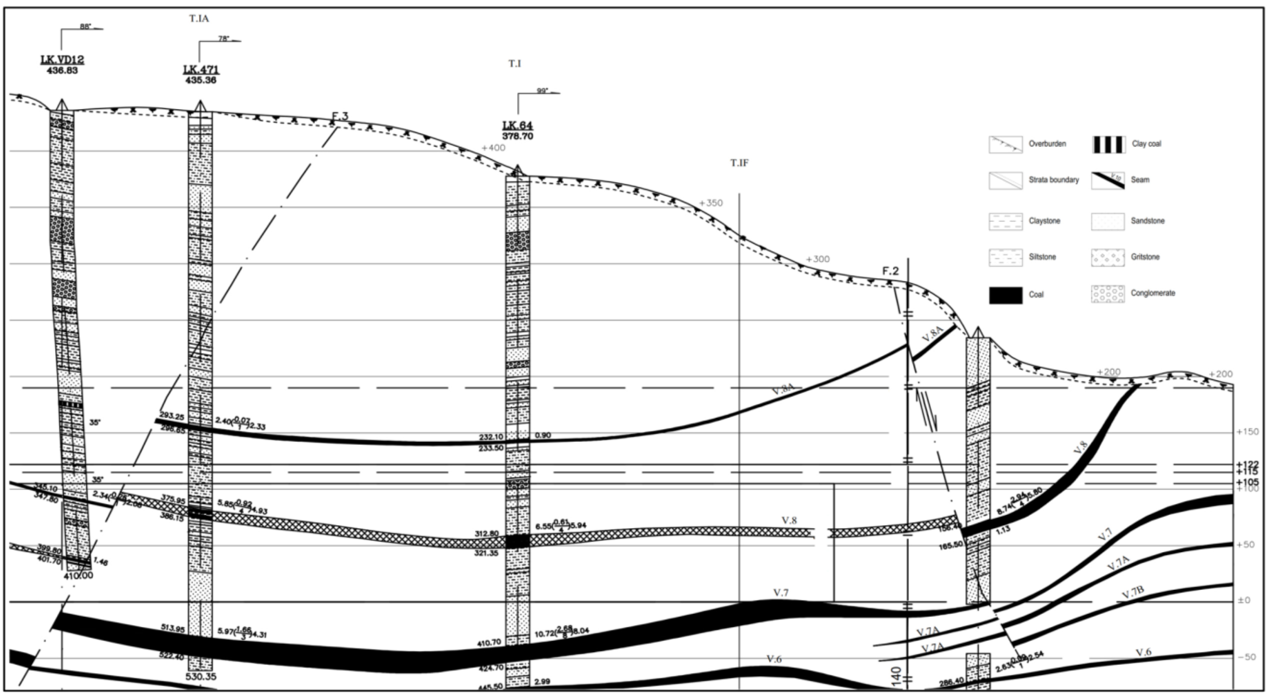


*Figure 7. Cross section representing Seam 7 and other strata at Vang Danh coal mine (Le et al. (2025)).*

that in the mid-panel width. Since each shield has two front legs and two rear legs (Figure 5), the shield pressure and convergence are measured for each row of leg. As there is no real-time monitoring of shield behaviour at site, the shield pressure and convergence are manually monitored. A strategy for monitoring should be developed. According to the panel design, one production cycle is done within three shifts per 24 hours. Since the coal seam is thick up to 9 m, each shift performs one web cut of 2.6 m height and recovers the rest of seam thickness. For safety reasons, the access to shearer and shield during operation is restricted. The shield behaviour can only be measured at the beginning of each production cycle. For pressure, the pressure gauge on each leg (see design drawing in Le et al., 2024a) is recorded. For convergence, the piston displacement is measured.

### 3.2. Analysis of shield pressure and convergence

The shield pressure is analysed in 140 m of longwall retreat since panel commencement, as shown in Figure 8. The figure shows that within the first 140 m of retreat, the leg pressure follows two distinct trends of cyclic change. In the first 54 m of retreat, the leg pressure increases and decreases consecutively mostly in the range of 20÷22 MPa over an average retreat of 10 m per cycle. In the first 10 m of retreat, the pressure increases from 20 MPa at start to a peak of 22 MPa after 5.4 m before dropping to a low of 18 MPa at 10 m of retreat. This first pressure cycle is caused by the initiation and completion of top coal caving, which can be further explained by the voussoir beam theory (see Section 2). After top coal starts caving, the coal and immediate roof cave cyclically according to cantilever beam theory (see Section 2). The cyclic caving results in cyclic change of pressure in 20÷22 MPa from 17.4÷54 m of longwall retreat. The caving of immediate roof does not add significant effect on leg pressure due to its thin thickness of less than 4.5 m.

The leg pressure cycle becomes different in the last 86 m of retreat. The pressure reaches a peak of 25 MPa at 61.8 m before dropping to 20 MPa at 63.6 m. This significant change is attributed to the first rupture of main roof strata. The pressure increases over a retreat distance of 7.8 m before dropping over a distance of 1.8 m (three web cuts of 0.6 m each). The first rupture of main roof is explained by the voussoir beam theory as stated above. The pressure change during first main roof rupture at Shield 70 is less severe than at the mid-panel shield (Le et al., 2025). This can only be explained by the fact that there is no top coal recovery above the transitional shields. After the first rupture, main roof ruptures cyclically. The pressure continues to increase from 20÷25 MPa over an average retreat of 20 m. This cantilever span is twice that caused by seam and immediate roof caving span, which is reasonable due to competent roof strata. Figure 8 also shows that the leg pressure change is quite consistent during the cantilevering effect of main roof.

Another difference between the two retreat periods is related to front leg and rear leg pressure. Figure 8 shows that within the first 54 m of extraction, the front leg pressure is commonly equal and sometimes greater than the rear leg pressure. The comparison agrees with the bending moment distribution caused by cantilever beam. However, for the last 86 m extraction, the front leg pressure is commonly equal and sometimes less than the rear leg pressure. The slightly greater rear leg pressure may indicate a mild deterioration in roof rock contacting canopy tip, reducing the load on front leg. A high concentration of load at coal face due to voussoir/cantilever beam is likely the main cause.

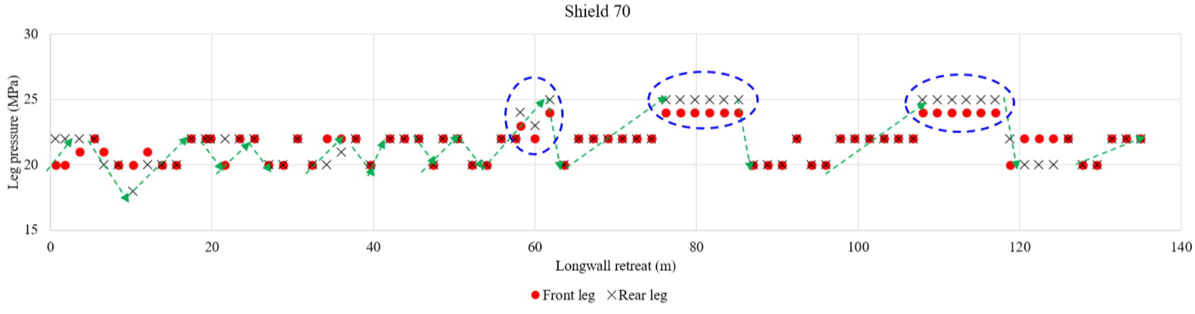


*Figure 8. Leg pressure of Shield 70, mechanised longwall, Seam 7, Vang Danh coal mine.*

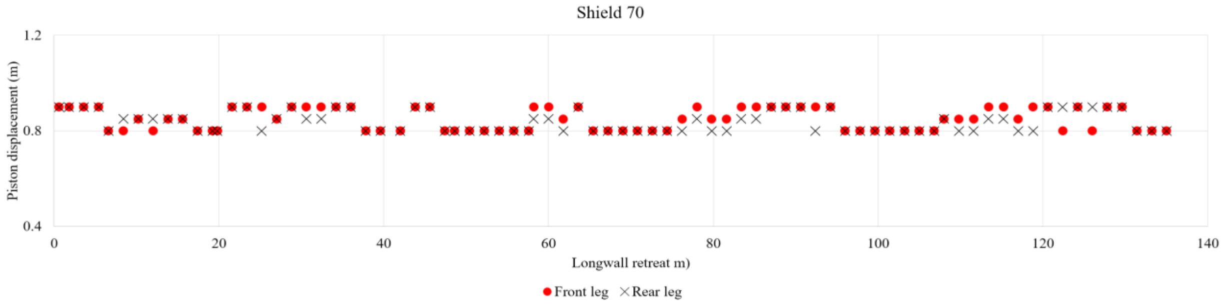


*Figure 9. Piston displacement of Shield 70, mechanised longwall, Seam 7, Vang Danh coal mine.*

The displacement of leg piston in the first 140 m of longwall retreat is shown in Figure 9. The displacement is associated with the pressure shown in Figure 8. Figure 9 shows that the leg piston ranges between two values of 0.8 and 0.9 m. Since the shield is commonly set at maximum piston displacement of 0.9 m, the shield convergence therefore ranges from 0 to 0.1 m, and no extension of leg is recorded. This shield behaviour means that the ground pressure at T-junction is stable, and no significant movement of roof strata is detected. Another evidence for the roof stability is that the piston displacement of front leg is mostly equal and greater than that of rear leg. The roof behaves properly as cantilever beam.

The change of piston displacement in the first 54 m of retreat seems more frequent than that in the last 86 m. The shorter caving span of top coal and immediate roof in the first 54 m and the longer caving span of main roof in the last 86 m are the main cause. In comparison with shield pressure (Figure 8), the shield convergence does not change much when a high pressure is reached. A possible reason for this is that the maximum support resistance (38.2 MPa, equivalent to maximum force of 4.8 MN) is much greater than the ground pressure (less than 25 MPa). It is the high shield capacity that the change in shield behaviour (both pressure and convergence) at T-junction is less severe than that at the mid-panel shield (Le et al., 2025). The ground pressure near gateroads under competent strata condition is well managed at Seam 7 Vang Danh coal mine. It should be highlighted that although the field data indicates stable roof at T-junction, the risk of roof weighting must be assessed where roof strata become more competent and closer to coal seam. An analytical analysis from Pham (2022) did confirm this risk.

## 4. Solution to improving shield support capability

For Vietnam coal industry, modern mechanised longwall systems have been invested mostly for favourable ground control condition. The mining under unfavourable conditions such as competent roof has not been equipped with capable face support. In the case of Seam 7 Vang Danh coal mine, initial design ranked the ground control to be favourable. However, practice shows that competent roof can occur locally that adversely impacts shield support. Based on the similarity in geo-mining conditions between Vietnam and China and the affordable investment cost, the shield support for mining in China coal industry is proposed to use for Vietnam coal industry. The support has two improvements. First, the maximum support force can be increased to 15 MN for cutting height up to 5.2 m or 18 MN for cutting height up to 7.0 m. Second, the face guard now has two levels or three levels.

## 5. Conclusions

This paper presents an analysis of Vietnam coal mining pressure under competent roof strata. Using classical ground pressure theories, the pressure law around longwall mining from setup entry to first strata caving and cyclic strata caving is strongly confirmed to follow pressure arch, voussoir beam and cantilever beam theories, respectively. Through analysis of shield pressure and shield convergence from a typical longwall mining under competent roof strata in Vietnam, the study clearly demonstrates the pressure law caused by progressive mining. The pressure change is proved to have a close relationship with roof strata movement and classical pressure theories. The pressure magnitude increases significantly and decreases rapidly when competent roof strata rupture. The difference in pressure and piston displacement between front leg and rear leg can indicate the stability of coal face and roof. The shield behaviours at T-junction are found to be less severe than those at the mid-panel width. The current study also proposes solutions to improving shield capability by increasing maximum support force and using multi-level face guard. Despite the limited field data, the results from this study assist mining engineers in Vietnam in better understanding ground pressure on coal face and properly designing face support. The sustainable mining under unfavourable conditions such as competent strata can be better achieved for the national coal industry.

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**Contributions of authors**

Nhan Thanh Thi Dinh - funding acquisition, literature review, Writing - Original Draft; Dung Tien Le - project administration & Writing, Review & Editing; Dung Tien Thai Vu - formal analysis; Anh Tuan Nguyen - data collection & validation.

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