



Ground Pressure and Methods to Enhance Roof Stability in Mechanized Coal Mining

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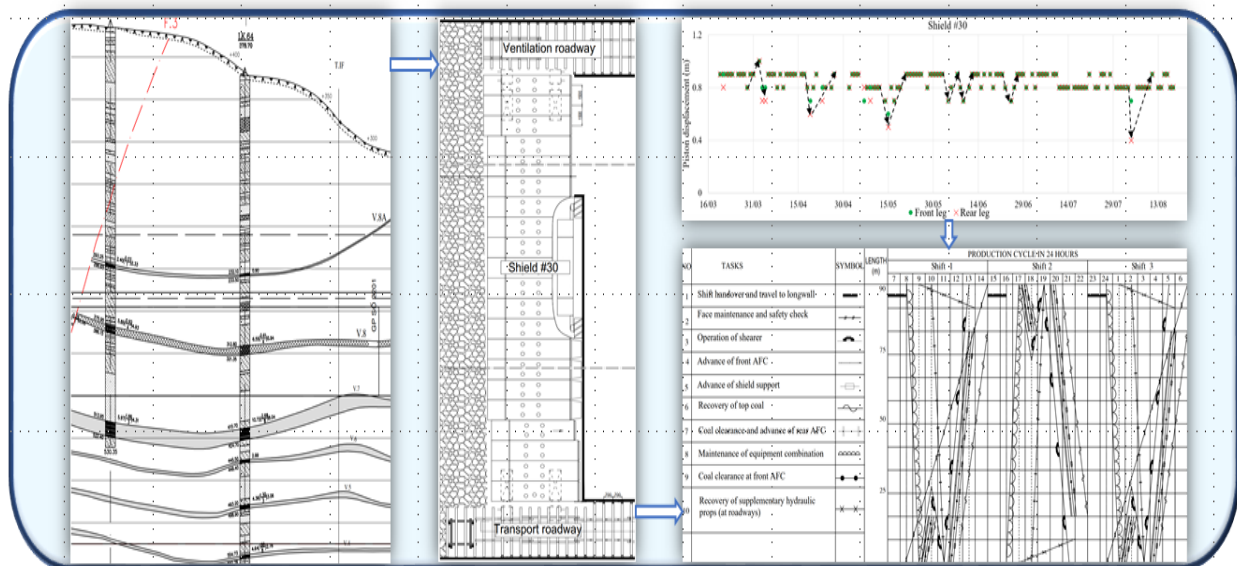
Rock Mass Stability

ABSTRACT

This paper presents an investigation on the manifestation of ground pressure and rock mass in underground coal mining. By using theoretical analysis, field observation of rock mass stability and field measurement of shield support in a mechanized longwall panel in Vietnam. The study reveals that during normal longwall mining cycles, the ground pressure on shield support increases and decreases cyclically within a period of 4–12 days, equivalent to a face advance of 7.56–22.68 m. Within a ground pressure change cycle, its duration and magnitude vary as the caving span of immediate roof varies. An increase in phase commonly lasts longer than the decrease phase. The coal wall instability is found to strongly relate to the abnormal displacement of shield leg piston. A greater piston displacement than the initially set value may indicate a roof cavity. A greater piston displacement at rear leg than that at front leg may also denote coal wall instability. The short drillhole blasting can be effectively used to some extent in mechanized longwall where coal/rock does not readily cave after shield advance. The findings of the study provide geotechnical engineers with better understanding of ground pressure and rock mass behaviour associated with underground coal mining. More effective controls for safe and productive longwall mining can be accordingly developed.

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Graphical Abstract



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1. INTRODUCTION

Underground mining methods produce a major production in coal industries (1, 2); where, the surface topography has hill or mountain shape, and/or the seams are at great depth (3, 4). Mining, unfortunately, creates voids in underground space that ultimately change the in-situ ground pressure and rock mass stability (5-7). For most coal mines, different ground control measures from traditional coal/rock pillar to modern shield support and backfilling have been used. However, since the redistributed ground pressure can be great in places; it may cause significant rock mass instability, threat to the safety of worker, damage of equipment, and ruin of land and water environment. A thorough understanding of the manifestation of ground pressure and rock mass is therefore of critical importance to minimize their impacts on underground mining operation (8, 9).

There have been three main approaches in studying ground pressure redistribution in underground mining. The first approach is to use empirical methods through experience, field measurement and observation. A typical example of this has been reported by Whittaker (10) which the developed stress profile around a longwall mining. One major advantage of the empirical methods is that it is based on actual happening and can hardly lead to totally wrong answer when it is judiciously used. However, extrapolation of the results outside the original data is always fraught with risk. The second approach is to use equivalent material model or physical modelling. This method provides detailed insights into the process of micro-mechanisms, which are commonly not well understood in empirical studies. Physical modelling, however, has the main disadvantages of building cost and time consume. The third approach is to use numerical modelling methods. The method can study detailed mechanisms of ground pressure and rock mass with low cost within project time. The representative of inputs, experience of user and procedure of modelling are key factors to the success of numerical methods.

Vietnam coal industry produces more than 40 million tons each year in the past 10 years. The proportion from underground mining method in the total national production increased from 50% in 2013 to more than 70% in 2024 (11-14). Following such increasing trend, the favorable coal reserves for underground mining become depleted (15-17). Many coal mines started exploiting coal in unfavorable conditions such as hard-to-cave roof strata and at depth. In such conditions, the ground pressure can manifest itself strongly through the hanging and breaking of roof strata that finally cause coal wall instability and shield damage. Historical mining in Vietnam shows that the roof hanging and sudden breakage has occurred mostly in Uong Bi - Dong Trieu coal region, where occupies about 40% of total in Quang Ninh coal field reserves. Since many past studies focus

on the favorable mining conditions, the understanding of ground pressure in the region remained limited. The lack of field measurement instrumentation (ground pressure, real-time support pressure), which can be attributed to the national technological level and budget, is another reason for the limited understanding above (18-20).

This paper presents a detailed study of ground pressure manifestation and associated rock mass stability. A typical mechanized longwall mining in Vietnam coal industry has been selected for the analysis. The theoretical and field measurement methods are used to jointly investigate stress distribution in association with coal wall and shield support behaviours. The findings of the study provide geotechnical engineers with fundamental science to better control safety and productivity of underground coal mining.

2. MATERIALS AND METHODS

Vang Danh coal mine is one of the largest underground mines and located in Uong Bi - Dong Trieu coal region, Quang Ninh province, northeast of Vietnam (see Figure 1). The mine was established in 1964 and produces more than three million tons per year recently. Back to the years of 2008–2013, Vang Danh coal mine was the first coal operator that used fully mechanized longwall mining in Vietnam. The equipment combination was provided by the joint venture between Czech Republic and Vietnam. The shield support was the 2-leg type with a coal recovery window located within roof canopy. In this period, the mechanized longwall line produced 145,673 tons per year, equivalent to 32% of the total production by design. One main geological reason for the low production rate was the relatively competent roof strata that did not cave readily after shield advance. The hanging roof alleviated the ground pressure acting on top coal section during normal mining cycles, consequently delaying the top coal caving and reducing coal recovery rate. The hanging roof, on the other hand, caused great loading on shield and coal wall at periodic distances. Since the shield support capacity was low (2287 kN), the hanging roof resulted in coal wall instability events in this mechanized longwall.

Since 2018, a new mechanized longwall line in which 4-leg shield type with resistance capacity up to 4800 kN from China has been used (Figure 2) (21-24). The mechanization line has been planned to be installed at Seams 8, 7, 6 and 4 at Vang Danh zone, Vang Danh coal mine. A typical geological cross section of the zone is shown in Figure 3. The surface is at an elevation ranging from +435 to +235 m. The coal seams are distributed relatively parallel to each other, at an elevation ranging from +150 to -200 m. Due to sedimentary formation, the overburden strata of coal seams mostly consist of claystone, siltstone, sandstone, and gritstone. Claystone



Figure 1. Location of Vang Danh coal mine in Quang Ninh province (red dotted boundary), Vietnam

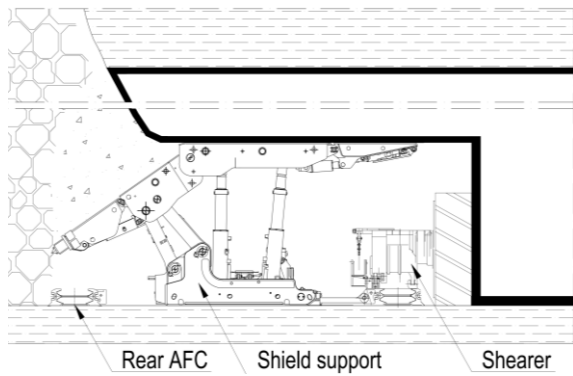


Figure 2. Mechanized longwall line since 2018 at Vang Danh coal mine

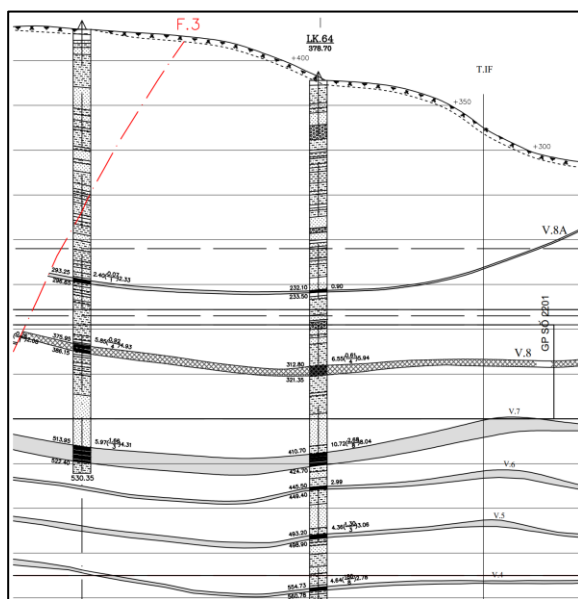


Figure 3. Geological cross section at Vang Danh zone, Vang Danh coal mine (7)

has a thickness of 0.2–2.0 m with thin layers. Siltstone has a thickness of 0.3–20 m with layered structure. Its average Uniaxial Compressive Strength (UCS) is 46.8 MPa. Sandstone has a thickness of 0.5–15 m with thick layers and an average UCS of 71.4 MPa. For Seam 8 where the new mechanization line was installed for the first time, the longwall panel dimension in the strike and dip direction was 390 and 93 m, respectively. The seam floor was at elevation ranging from +0 to -20 m. Seam 8 has an average thickness of 5.54 m and dip angle of 11 degrees. The coal industrial reserves were 279.6 thousand tons.

The new mechanized longwall line at Seam 8 was installed at the end of 2017. There were five shield supports ZFG4800/20/32 near gateroads and 55 shield supports ZF4400/17/28 at working face along panel width (Figure 4) (25-28). Detailed specifications of the shields are summarized in Table 1. Each shield has two pressure gauges mounted on front and rear legs. The monitoring pressure range was from zero to 80 MPa. The initial force (setting force) was set at less than 80% of the yield force. Due to limited budget, there has not been real-time monitoring of shield pressure and roof convergence in most Vietnam coal mines, including Vang Danh. At the study site, the shield pressure was monitored by reading the gauge value. At the same time, the piston displacement of the shield leg was measured by handheld tape measure. Since one production cycle was designed to complete in one working day of 24 hours (Figure 5), the shield pressure and displacement were measured at the beginning of each working day that did not affect the scheduled production. For a representative profile of ground pressure at the longwall, the pressure and displacement of Shield 30, which was at the mid-panel width, was monitored (Figure 6). The monitoring was performed from March (which was two months after panel commencement) to August 2018 (which was two

months before panel end). The data were, however, not representative of each production cycle due to different algorithms of using data. The displacement data has not been published before.

3. RESULTS

The pressure of front leg and rear leg of Shield 30 in the mechanized longwall is presented in Figure 7. In general, the pressure fluctuated within the range of 20–26 MPa. This actual working pressure was 63.5–82.5% the designed working pressure (31.5 MPa) and 57.1–74.29% the yield pressure (35 MPa). During normal

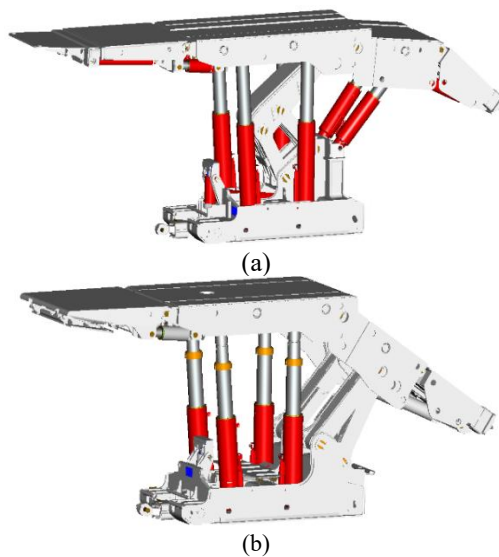


Figure 4. Shield support (a) ZFG4800/20/32 and (b) ZF4400/17/28

TABLE 1. Specifications of the shields

Parameters	Unit	ZF4400/17/28	ZFG4800/20/32
Height	mm	1700–2800	2000–3200
Width	mm	1430–1600	1430–1600
Advance interval	mm	600	600
Working force	kN	4400	4800
Support intensity	MPa	0.75	0.72
Pumping pressure	MPa	31.5	31.5
Maximum working angle in panel strike	Degree	15	15
Maximum working angle in dip direction	Degree	35	35

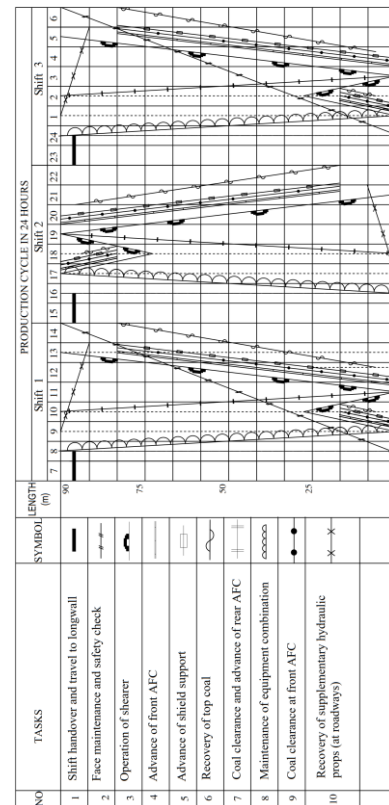


Figure 5. Production organization chart of mechanized longwall

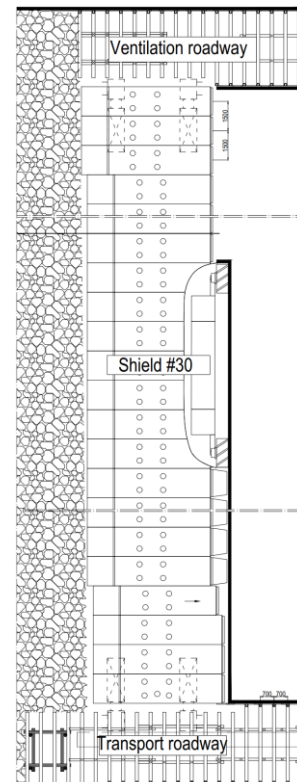


Figure 6. Location of Shield 30 at mid-panel width in mechanized longwall

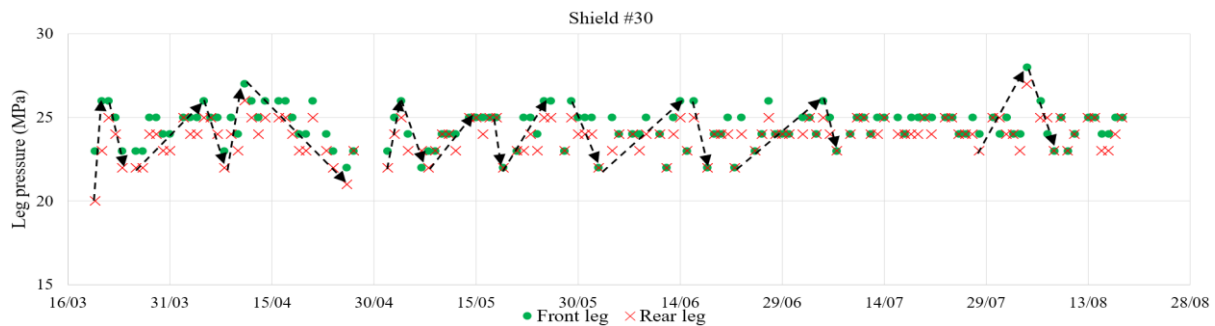


Figure 7. Leg pressure of Shield 30 at mid-panel width, Seam 8, Vang Danh coal mine

production cycles, the leg pressure increased and decreased cyclically. For example, from the start of field measurement, the leg pressure increased from a low value of 20 MPa to a peak value of 26 MPa after two working days. The pressure then decreased to a low value of 22 MPa in next two days. The first cycle of leg pressure change (leg pressure cycle) was completed in four working days, equivalent to 7.56 m of face advance. After the first cycle, the leg pressure increased to next peak of 26 MPa in nine days and decreased to a low value of 22 MPa in three days. The second pressure cycle lasted in 12 days or 22.68 m of face advance. As the mining progressed further, the leg pressure continued to increase and decrease cyclically. The low and peak values were mostly 22 and 26 MPa, respectively, although the peak value could reach 27–28 MPa, as seen in April and August. The period of leg pressure cycle typically ranged from four days to 12 days, which was similar to that in the first two cycles. The above pressure cycles clearly indicate that the ground pressure was relatively stable in the area.

The pressure cycles associated with progressive mining can be attributed to the cyclic caving of immediate roof strata at the field. It is widely accepted that in longwall mining, the immediate roof acts as a cantilever beam that causes load concentration on shield support and coal wall. Once the beam breaks, the load on shield and wall can be relieved and transferred to surrounding area. At Seam 8 Vang Danh coal mine, the engineer reported that the top coal and lower part of immediate roof commonly caved after each shield advance. This caving should result in periodic change in leg pressure, as can be seen in Figure 7. As the mining progressed further, the upper part of immediate roof, which was up to 14.5 m above seam roof caved. This caving resulted in the significant deviation in leg pressure, which was mainly 4 MPa. Because in practice the thickness of seam and immediate roof varied by a deviation of 13%, the caving span of immediate roof varied that resulted in different durations and magnitudes between pressure cycles. Figure 7 also shows that within each pressure cycle, the increase phase commonly lasted longer than the decrease phase. This was because that the

upper part of immediate roof hung up over some face advances and increased the load on shield. Once the brittle immediate roof broke, the load on shield was quickly relieved, and the leg pressure was rapidly decreased.

The ground pressure not only broke roof strata and exerted load on shield support but also caused coal wall instability. The shield leg pressure (Figure 7), leg piston displacement (Figure 8) and field observation of coal wall were jointly analysed to understand the ground pressure. Figure 8 shows that during the monitoring period, the piston displacement of shield leg fluctuated in the range of 0.6–0.9 m. Since the piston displacement was initially set at 0.8–0.9 m, it was then reduced during operation. The reduced displacement was due to the increase in roof strata convergence. During normal production cycles, the piston displacement steadily varied between 0.8 and 0.9 m. This was associated with the cyclic hanging and breaking of roof cantilever beam. The cyclic caving of roof strata resulted in stable coal wall in most production cycles.

The field observation reported minor coal wall instabilities at the mid-panel width. Such an observation was strongly related to the abnormal piston displacement events in Figure 8. For example, in early April, the piston displacement increased to a peak value of 1.0 m. This means that the coal wall and its roof were deteriorated or caved that lead to roof cavity and increase of piston displacement. A likely reason for this event was the significant hanging of the cantilever top coal and/or roof strata. Due to the cantilever bending about the wall (which acted as clamped end or fulcrum), the compressive stress was generated and resulted in top coal/roof failure between wall and shield. The failure mode was buckling and led to the guttering mode of roof cavity. For the other abnormal events, the piston displacement was, however, reduced to 0.7 or even 0.4 m. This means that the roof converged to floor without severe deterioration of its contact with shield support. The high value of roof convergence (or small value of piston displacement) was due to the increase in length of cantilever roof beam.

coal does not cave readily after shield advance, drillholes are drilled from the roof canopy into top coal section. The holes are of 2-m length and at an angle of 75 degrees to the horizontal plane. The distance between the holes is 1.5 m in panel width direction. Within each drillhole, at least one fourth of the hole is charged by stemming. For each blasting round, only five holes are blasted. After blasting, the top coal is broken and afterwards easily recovered at rear canopy.

The solution of short drillhole blasting shows efficiency in breaking top coal/roof strata when the coal/rock does not readily cave after shield advance. The solution has one major advantage of flexibility because it does not require uninstallation of shield and is applicable to any location in panel. Furthermore, the solution uses the available equipment and materials at field and therefore requires low cost. However, the solution clearly has some limitations. Firstly, as the blasting is not initially designed and embedded in production cycle, the normal production is interrupted. The production output is significantly reduced. Secondly, the use of blasting may seriously impact worker safety, damage expensive equipment, and ruin coal wall stability. Lastly, if the hanging top coal/roof becomes thicker, the solution may become inappropriate due to limited effective range of short drill hole blasting. To minimise the above limitations, it is suggested that technical measures must be developed and strictly obeyed to ensure safety regarding worker and equipment. For long-term operation, an advanced roof cutting technique by using large borehole combining with hydro fracturing can be considered as long as economically feasible.

4. CONCLUSIONS

This paper presents a study of ground pressure manifestation above an underground longwall mining and associated rock mass instability. By using theoretical analysis, field observation of coal wall and rock mass stability, and field measurement of shield support at a mechanized longwall where real-time monitoring has not been performed, the following conclusions were drawn from the study. Firstly, during normal longwall mining cycles, the ground pressure on shield support increases and decreases cyclically within a period of 4–12 days, equivalent to a face advance of 7.56–22.68 m. Secondly, within a ground pressure change cycle, its duration and magnitude vary as the caving span of immediate roof varies. The increase phase commonly lasts longer than the decrease phase. Thirdly, coal wall instability is strongly related to the abnormal displacement of shield leg piston. A greater piston displacement than the initially set value may indicate a roof cavity. A greater piston displacement at rear leg than that at front leg may also denote coal wall instability. Lastly, the short

drillhole blasting can be effectively used to some extent in mechanized longwall where coal/rock does not readily cave after shield advance. The conclusions of the study provide geotechnical engineers with better understanding of ground pressure and rock mass behaviour associated with underground mining. More effective controls for safe and productive longwall mining can be accordingly developed.

5. FUNDING

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Persian Abstract

چکیده

این مقاله تحقیقی در مورد چگونگی بروز فشار زمین و توده سنگ در استخراج زغال سنگ زیرزمینی ارائه می‌دهد. با استفاده از تحلیل نظری، مشاهده میدانی پایداری توده سنگ و اندازه‌گیری میدانی تکیه‌گاه سپر در یک پتل جبهه کار بلند مکانیزه در ویتنام. این مطالعه نشان می‌دهد که در طول چرخه‌های معمول استخراج جبهه کار بلند، فشار زمین بر روی تکیه‌گاه سپر به صورت چرخه‌ای در یک دوره ۴ تا ۱۲ روزه افزایش و کاهش می‌یابد، که معادل پیشروی جبهه کار ۷.۵۶ تا ۲۲.۶۸ متر است. در یک چرخه تغییر فشار زمین، مدت و بزرگی آن با تغییر دهانه فرو ریختن سقف فوری تغییر می‌کند. افزایش فاز معمولاً بیشتر از فاز کاهش طول می‌کشد. مشخص شده است که ناپایداری دیواره زغال سنگ به شدت به جابجایی غیرطبیعی پیستون پایه سپر مربوط می‌شود. جابجایی پیستون بیشتر از مقدار اولیه تعیین شده ممکن است نشان‌دهنده حفره سقف باشد. جابجایی پیستون بیشتر در پایه عقب نسبت به پایه جلو نیز ممکن است نشان‌دهنده ناپایداری دیواره زغال سنگ باشد. انفجار چاه کوتاه می‌تواند تا حدی در جبهه کار بلند مکانیزه که زغال سنگ/سنگ پس از پیشروی سپر به راحتی فرو نمی‌ریزد، به طور مؤثر مورد استفاده قرار گیرد. یافته‌های این مطالعه درک بهتری از فشار زمین و رفتار توده سنگ مرتبط با استخراج زغال سنگ زیرزمینی را در اختیار مهندسان ژئوتکنیک قرار می‌دهد. بر این اساس، می‌توان کنترل‌های مؤثرتری برای استخراج ایمن و پربازده از طریق جبهه کار طولانی ایجاد کرد.