ГИАБ. Горный информационно-аналитический бюллетень /
MIAB. Mining Informational and Analytical Bulletin, 2026;(7):49-67
ОРИГИНАЛЬНАЯ СТАТЬЯ / ORIGINAL PAPER

УДК 622.272 DOI: 10.25018/0236_1493_2026_7_0_49

ИССЛЕДОВАНИЕ ПРОЦЕССА РАЗРАБОТКИ ТЕХНОЛОГИЧЕСКОЙ СХЕМЫ ОТРАБОТКИ ПРЕДОХРАНИТЕЛЬНЫХ ЦЕЛИКОВ В ВЫРАБОТАННЫХ ПРОСТРАНСТВАХ УГОЛЬНЫХ ШАХТ

Хоанг Хунг Тханг[1], **В.И. Голик**[2]

[1] Куангниньский промышленный университет, Куангнинь, Вьетнам,
e-mail: hoanghungthang@qui.edu.vn
[2] Московский политехнический университет, Москва, Россия

Аннотация: При подземной разработке угольных месторождений в провинции Куангнинь оставление угольных целиков приводит к значительным потерям ресурсов. Повторная отработка этих запасов позволит не только увеличить коэффициент извлечения, но и продлить срок службы шахт. Целью данного исследования является разработка технологических решений, обеспечивающих высокую производительность при повторной отработке остаточных угольных целиков в выработанных пространствах. Основная задача заключается в оптимизации набора технических параметров и определении безопасных, технически реализуемых процессов, которые могут в дальнейшем применяться в широких масштабах для повышения эффективности угледобычи. На основе геологических изысканий, проведенных на шахте Нам Мау, было предложено технологическое решение, включающее следующие этапы: геологическое доизучение; проектирование подготовительных выработок; выемка короткими забоями или системами обходных выработок; управление состоянием массива и эффективное проветривание. В ходе исследования был разработан безопасный и эффективный метод извлечения, адаптированный к натурным условиям по результатам испытаний. Новая технологическая схема признана высокоэффективной: она обеспечивает рост коэффициента извлечения угля на 10–15% и снижение затрат на проведение выработок на 8–12% по сравнению с традиционными методами. Данный метод может найти широкое применение на подземных рудниках Куангниня и других месторождениях со схожими горно-геологическими условиями.

Ключевые слова: угольный целик, извлечение угольных ресурсов, отработка остаточных запасов угля, выработанные пространства угольных шахт, шахта Нам Мау.

Для цитирования: *Хоанг Хунг Тханг, Голик В. И.* Исследование процесса разработки технологической схемы отработки предохранительных целиков в выработанных пространствах угольных шахт // Горный информационно-аналитический бюллетень. – 2026. – № 7. – С. 49–67. DOI: 10.25018/0236_1493_2026_7_0_49.

Study on developing a technological process for recovering protective coal pillars in depleted underground mining areas

Hoang Hung Thang[1], **V.I. Golik**[2]
[1] Quang Ninh University of Industry, Quang Ninh, Vietnam, e-mail: hoanghungthang@qui.edu.vn
[2] Moscow Polytechnic University, Moscow, Russia

Abstract: In underground coal mining operations in Quang Ninh, leaving the coal pillars as protection for the roadways and underground works has caused great losses. Re-mining of these leftover coal reserves will not only maximize the recovery rate but also prolong the life span of mines through improving the overall socio-economic efficiency of mining enterprises. The purpose of this research is to provide a practical combination of technological and engineering solutions that will ensure high productivity for residual coal pillar re-mining from exhausted underground mining areas. The end purpose here is to determine an optimized technical parameter set guided by safe, feasible mining processes that can serve as a base for further large-scale applications, plus improved efficiency in recovering more coal. A geological survey was carried out at Nam Mau mine, based on which a technological solution was proposed, including the following steps: geological investigation; design of access roadways; mining using shortwall or surrounding roadway systems; strata control; and effective ventilation. Also, a secure and handy extraction method fine-tuned by real-world tests was set up. The fresh tech route got rated as very doable, bringing big money gains with a 10–15% boost in coal get back rate plus an 8–12% drop in road making costs against old ways. This method can see broad use in under-the-surface pits in Quang Ninh, along with other pits having similar geo-tech setups.

Key words: Coal pillar, Coal resource recovery/Recovery of remaining coal, Depleted Underground Mining Areas, Nam Mau mine.

For citation: Hoang Hung Thang, Golik V. I. Study on developing a technological process for recovering protective coal pillars in depleted underground mining areas. *MIAB. Mining Inf. Anal. Bull.* 2026;(7):49-67. DOI: 10.25018/0236_1493_2026_7_0_49.

Introduction

Underground coal mining in the Quang Ninh area is an important sector to ensure national energy security. When mining underground coal, to protect tunnels and underground structures, protective coal pillars are often left on the roof, floor or walls of the tunnel [1]. After decades, a large amount of coal still remains in the form of protective coal pillars supporting structures and tunnels in the mine. In Quang Ninh, underground coal mining plays a crucial role in ensuring national energy security. To protect tunnels and underground structures, protective coal supports are often placed on the roof, floor, or walls of underground coal mines [2]. After a long period of mining, a large amount of coal remains in the form of protective coal pillars, supporting structures and tunnels within the mine. These tunnel support pillars reveal a large volume of coal, often left behind after mining operations are completed to ensure safety underground [3]. To maximize coal extraction rates and extend the operating life of mines, as well as increase production [4], revenue, and socio-economic efficiency for mining enterprises, it is necessary to extract this remaining coal. However, conducting mining operations in mines often faces many challenges, so it is necessary to carefully determine and control detailed technical parameters such as safe design of mining tunnel networks [5], specific roof support options, optimized blasting models, and especially the organization of production cycles and allocation of labor force to balance productivity and safety. Therefore, building standard technological processes and optimizing technical parameters based on experimental data is a strategic and necessary requirement [6, 7].

The restoration of protective coal pillars is always difficult in terms of safety and engineering due to the complex conditions of abandoned mining areas [8]. Old mine tunnels are often deformed and damaged, and roof and pillar rocks in these areas are affected by accumulated secondary stresses, leading to a high risk of roof collapse and tunnel deformation [9, 10]. In addition, old mining areas may accumulate methane gas (CH_4), with old or clogged ventilation systems, leading to a significantly increased risk of fire and explosion [11—13]. Furthermore, the possibility of water infiltration from flooded areas above remains a hazard to safe restoration operations [14].

Research on coal mining in areas with complex geological conditions, particularly mining from guard piles, has long been a concern in underground mining. Numerous publications have investigated this issue both theoretically and practically. While [15] has conducted a practical survey of retaining coal piles in deep mine tunnels, [16] has demonstrated the sustainable redevelopment of an old coal mine through the mining of pile-blocked coal mines, [17] has used the top coal collapse method along the length simulating the mining of remaining coal piles above during super-close bottom slab mining, and [18] has proposed a method to estimate the optimal width of guard coal piles by considering the main roof collapse mechanisms. Also related to coal pillar mining, [19] the use of cement-based filler material, [20] has optimized the top coal collapse rate in large-slope residual coal seams. In addition, the development of deformation pipeline systems for efficient pillar recovery [21], studies of fracturing processes and depressurization control in thick, rigid roofs [22] and the deployment of depressurization tunnels combined with combined support technology to minimize long-term failures in deep mining areas [23] have also been addressed in numerous studies on coal pillar mining. Although these studies have focused on specific geological or engineering conditions, studies on pillar recovery in complex hydrological environments remain limited. Therefore, further research on safe and efficient recovery methods in water-bearing areas is necessary.

In Vietnam, coal mining in complex geological conditions in Quang Ninh has achieved some significant progress. Regarding coal pile protection, [24] a comprehensive evaluation of international methods for calculating the size of coal piles used in countries with advanced coal industries has been conducted, and proposals have been made to select methods suitable for the specific geological and mining conditions of underground mines operated by Vinacomin (TKV) in Vietnam. In addition, [25, 26] a study on the application of artificial coal piles to protect tunnels during mining at Khe Cham III mine has been carried out. The results of the study have demonstrated the feasibility and effectiveness of using artificial piles in complex mining conditions. However, most existing studies focus on the stability and design of the piles, with little mention of coal recovery from remaining or abandoned piles in areas with complex conditions such as depressions or fault structures. This gap highlights the need for integrated engineering solutions to ensure safety, improve resource recovery, and adapt to the challenging hydrogeological conditions of underground coal mines in Vietnam.

Research Area

The study area is the central experimental production field of Quang Ninh University of Industry, located within the Than Thung area under the management of Nam Mau Coal Company. The terrain of the research area is characterized by high hills and mountains, with a protected for-

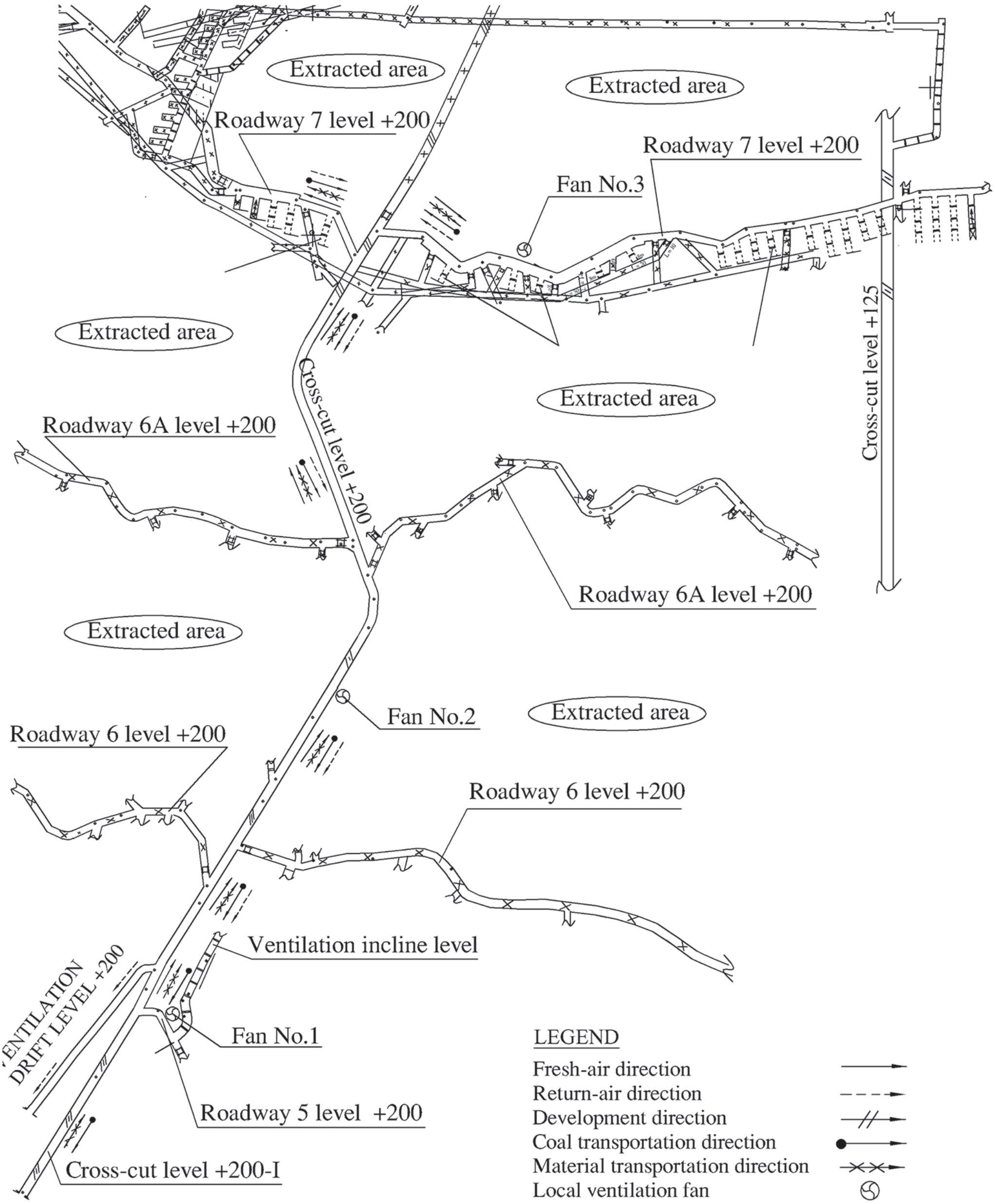


Fig. 1. Roadway network layout in the protective coal pillar recovery area, strike roadway levels +200/+215, seam 6 (8)

Рис. 1. Схема расположения сети горных выработок на участке отработки предохранительных угольных целиков, штреки на горизонтах +200/+215, пласт 6 est in the western region. Mountain slopes are generally steep and have an average elevation of approximately 450 meters. The terrain gradually descends from North to South. The surface is highly dissected by many streams that cut across the coal-bearing strata and flow primarily from North to South, emptying into the larger Trung Luong stream. The coal-bearing stratum in the mine area combines Triassic-Late Norian to Early Jurassic (T3n—J1) coal-bearing sediments, overlain by Quaternary sediments on the surface.

This geological layer consists of dark-colored rocks, mostly mudstone, sandstone, and some layers of claystone and coal seams. The coal-bearing layer is divided into three main units, with the most valuable coal seams concentrated in the second unit. Quaternary sediments form a discontinuous cover over the bedrock units. This cover material is a mixture of gravel, crushed stone, sand, and quartz mixed with clay in the valleys, with a thickness of 5 to 10 meters. Structurally, from East to West, the Nam Mau coal mine area exhibits a series of folds (anticlines and synclines) as follows:

Anticline L1 is situated between sections T.I and T.IA, and is clearly observable on maps and cross-sections. Its axis is oriented Southeast-Northwest.

Syncline L2 is located to the west of section T.IA and is clearly observed on maps and cross-sections. Its axis is oriented Southeast-Northwest.

Anticline L3 is not clearly visible on maps. On cross-sections T.II and T.IIA, the anticline axis dips toward the North.

Syncline L4 is located in the T.III area, clearly visible on maps and cross-sections. Its axis is oriented Northwest-Southeast and dips toward the Southeast.

Syncline H.6 in the Northwest T.VI area has an axis oriented Northeast-Southwest.

Anticline B.7 has an axis that nearly coincides with the F50 fault, trending Southwest-Northeast.

In addition to the main anticlines and synclines mentioned above, the mine area also contains several smaller synclines that locally alter the strike of the coal seams but do not significantly affect the coal reserves.

The area designated for the recovery of the protective coal pillar for the strike roadway in Seam 6 (at level +200 to the Outcrop) has a thickness ranging from 6.0 to 7.0 meters, with an average dip angle of 25° to 27°. The coal seam contains one to three rock partings (intercalations), with parting thicknesses varying from 0.04 to 0.6 meters, averaging 0.25 meters. Generally, these rock partings often appear close to the coal pillars.

The current layout of the mine network in the application area includes: the crosscut at level +200, the strike roadway at level +200 located in Seam 6, the strike roadway in Seam 5 at level +200, and the ventilation raise from level +125 to +200 in Seam 5, all of which are illustrated in Fig. 1.

Methodology

The technology process for the complete recovery of the protective coal pillar includes key technological steps (driving upper raises for pillar recovery, rock drilling and blasting for pillar recovery, coal extraction, haulage, and roof control) and auxiliary technological steps (restoring the strike roadway system, haulage technology, ventilation technology, and dewatering technology). This process is generally divided into the following main stages:

Stage of Roadway Rehabilitation and Support Installation

Technological Procedure for Slashing and Support

The technological procedure for slashing and roadway rehabilitation is strictly implemented in sequence, beginning with the consolidation and temporary packing of the roadway roof and ribs in the area designated for slashing (within a 10-meter range). This step involves inspecting and replacing damaged gaskets/covers and tightening the arches or steel components for preliminary reinforcement. Then, workers use a digging tool to expand the tunnel roof to the design size, pushing the console beam forward and installing new roof gaskets. In this step, specialized connectors are used to position and link the new gaskets to the old ones (if the coal face in front of the expansion area is unstable, temporary support with wood or filler material is required for safety). Next, the two tunnel sides are expanded, foundation pits are dug, and new support columns are erected. Connecting bars are installed between the support columns and gaskets; the roof and sides are sealed with concrete blocks. Finally, dismantle the old support system in sequence: remove the washers first, then the columns (using a winch to pull the columns out), simultaneously excavate the earth and rocks to lower the mine floor, adjust and complete the new support system and rails, and dig temporary drainage trenches to fully restore the cross-section and technical condition of the mine tunnel.

Technological process for tunneling and supporting underground mine roadways

The technological process of tunneling and supporting mine roadways is carried out in a strict sequence, consisting of two main stages: establishing the roadway outline and executing the work within a driving cycle. roadway outline establishment begins with determining the location, installing temporary props, and reinforcing the old supports using timber frames or steel rails. Subsequently, the face is excavated either manually (with soft coal/rock) or by drilling and blasting (with competent coal/rock) to open the roadway and erect the new support set at the roadway margin. The subsequent steps are carried out in the roadway driving cycle:

- Check and Consolidate: Ventilation, system checks, reinforcement of the old supports, and scaling/removal of all loose coal and crushed rock surrounding the face.
- Drilling and Blasting: Perform exploratory drilling, followed by drilling and blasting according to the established procedure.
- Face Dressing: Ventilate for a minimum of 30 minutes, check the quality of the blasting, and partially remove coal/rock to create working space.
- Support erection: Excavate column foundation pits, erect support columns, install roof washers, align and adjust the support frame, drive wedges and wedge the roof, wedge the sides (prioritize wedges behind the columns before installing washers, and wedge the roof first, then wedge the sides), and finally install temporary bracing. (Note: for raises/inclined roadways, the support must be installed with an inclination of 3–5°).
- Haulage/Mucking Out: Manual or mechanical excavation, using conveyor belts/scrapers to transport coal and rock after blasting.
- Completion and cleaning: Perform auxiliary tasks such as installing additional supports for wooden supports, extending ventilation ducts, installing rails/scraper chutes/sliding chutes, constructing steps and retaining walls for the upper mine; then proceed with industrial cleaning and shift handover.

The entire process must strictly adhere to the Technical and Safety Regulations in Underground Mining, which clearly stipulate that at the face, there must be workers of level 4 or higher; loading and blasting must only be carried out by specialized blasters; and all activities must comply with the approved bracing and blasting permits.

Stage of protective coal pillar recovery

Installation of hydraulic supports in the longwall face

The technological procedure for installing mobile hydraulic supports in the longwall face for the recovery of the protective coal pillar is carried out through a series of steps to ensure safety and proper technique. First, the starting raise area must be thoroughly prepared: firmly reinforced and the roadway floor cleaned, while simultaneously installing the emulsion fluid supply system (pumping station, pipelines, valves, and charging guns). Next, the hydraulic supports are disassembled into two main parts (the roof beam and four hydraulic legs) for transportation to the installation position in the mine tunnel using mine carts, winches, or manual labor. After inspecting and reinforcing the surrounding tunnel section, workers use hoists and crowbars to lift the roof beam into the correct position, placing it perpendicular to the upper tunnel and temporarily securing it. A crucial step is to temporarily support and suspend the hoist-pulley system to raise the roof beam to the installation height, then lay steel mesh on top as a bracing/holding layer for the roof. Finally, a single hydraulic prop is used to press the canopy tightly against the roof. The four main hydraulic legs are then installed (linked by cable clamps, installing anti-slip bases), the support is pre-loaded (chất tải) to ensure an initial pressure greater than 7.0 MPa, and the newly erected supports are linked to the old ones using steel wire and bracing. This process is repeated for subsequent supports and concludes with the installation of connecting tie-rods between the supports along with the chute to complete the preparation for extraction.

Executing the work within a longwall extraction cycle

The longwall extraction cycle in the face is carried out through a strict, multi-step procedure, starting with drilling and blasting the longwall face down the dip. This is followed by explosive loading after checking the Methane concentration (<1) to ensure blasting safety. Concurrently, working face reinforcement is performed frequently, especially before and after blasting, to check the hydraulic prop pressure and adjust the support canopy/beam. After blasting and ventilation, the work proceeds to face dressing and temporary support installation, which includes roof scaling, connecting wire mesh as lagging/blocking, and pumping emulsion fluid into the temporary beam push mechanism for face advance. Next is coal loading and floor leveling from the working area onto the chute, taking care to maintain a level floor. After loading, miners proceed to advance the main hydraulic supports at the working face (progress of 0.8) from bottom to top, ensuring the initial support pressure is greater than 7.0 MPa. Finally, after every two extraction cycles (1.6 m), the scraper conveyor bridge is cut at the level gate road, followed by roof coal recovery, which includes drilling and blasting the roof (in cases where the coal does not collapse naturally) and creating coal release ports to fully extract the roof coal.

Stage of disassembly and recovery of hydraulic supports after extraction

The procedure for the disassembly and recovery (withdrawal) of the mobile hydraulic supports after the completion of extraction is carried out systematically, prioritizing the retrieval of supports from top to bottom in the working face, followed by the two supports located in the gate road. The process begins by preparing the face condition: tightly setting the canopy close to the face, and retracting the face advance beam, while simultaneously removing the relocation valves. Next, substitute timber supports (supplementary supports), consisting of a 2.3 m cap and two posts, are erected in the gap between the hydraulic support units to secure the roof. A special precaution is required: if the mesh/netting above the canopy to be recovered is no longer effective, chocks/props must be installed to secure the roof coal before the canopy is lowered.

This is followed by the step of deloading the support legs. First, two safety ropes are attached to secure the support. Then, the four legs are gradually deloaded (prioritizing the two legs on the caving side first, followed by the two legs on the working face side) to the required distance to attach the pulley-hoist system. Careful observation is crucial at this point to prevent the canopy from tilting completely to one side, and the safety rope securing the canopy must be tightly fastened. Next, temporary props (2.5 meters long, supported by a single hydraulic prop) are installed along the dip, and the pulley-hoist system is attached to pre-load and secure the canopy. Once firmly secured, the four support legs are retrieved by dumping the load, removing the cable connectors at the top of the legs, and removing the safety ropes. Finally, the roof canopy is lowered to the floor level using the pulley-hoist system. During this lowering process, a safety observer must ensure safety while simultaneously rotating the canopy so that the face advance beam end turns downwards along the dip of the roadway. Simultaneously, the installation of additional support structures (consisting of a 2.5 m long, ∅160 diameter wooden beam and three support columns) is carried out along the mine face, positioned close to the replacement wooden supports. Subsequent supports are recovered using a similar procedure. Finally, the support structures are moved out of the mining face area using a winch or safety rope, then lowered down the seam tunnel to the collection point.

During transportation, workers must be positioned to use crowbars to control the direction of movement and ensure safety.

Stage of drilling and blasting

The drilling and blasting procedure play a role as the core technical step in the production cycle for breaking up the coal mass of the protective pillar and supporting strata control (especially roof caving) in areas where mining has been completed. The research focused on building and optimizing the blasting parameters to maximize extraction efficiency and ensure technical safety. The procedure aims to break up the coal pillar at the working face with the highest efficiency while controlling strata pressure and actively inducing roof caving to safely and completely recover the roof coal. The procedure includes determining and practically testing crucial parameters such as:

(1) Drill Hole Layout Scheme: Establishing a rational density and position of drill holes (including the number, diameter, and depth of the holes) on the face to achieve the optimal breaking coefficient.

(2) Blasting Charge Parameters: Determining the necessary explosive charge and appropriate detonation method to ensure the coal is thoroughly broken up, minimizing coal remnant, while limiting negative impacts on the support structure. The drilling and blasting process must be strictly implemented based on an optimized blasting plan. Adjustments to the drilling and blasting scheme must demonstrate effectiveness in improving the stability of the mine face and slopes, and increasing the coal recovery factor, thereby improving the overall productivity of the guardrail mining face. The established drilling and blasting process is a crucial foundation for the successful implementation of the entire mining technology, ensuring feasibility and safety under the complex geological conditions of the mining area.

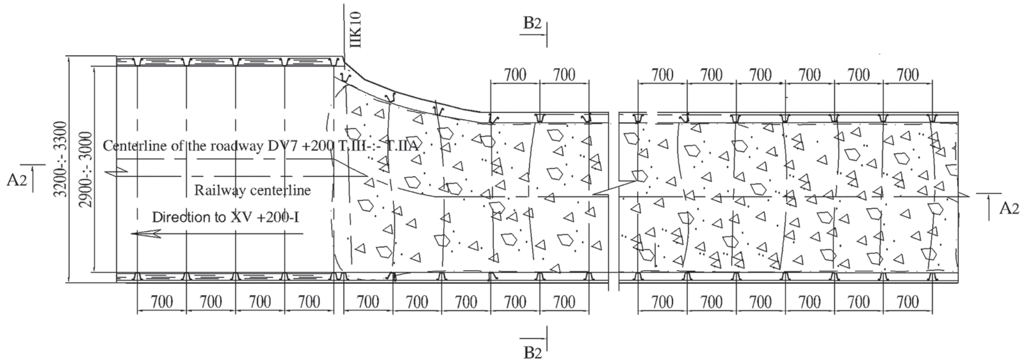


Fig. 2. Existing plan view of the strike roadway at level +200, seam 6, before slashing and restoration (8)
Рис. 2. План штрека на горизонте +200, пласт 6, до начала работ по расширению и восстановлению

Results and discussion

The achieved results in this research focus on finalizing the technological procedure, optimizing the technical parameters, and evaluating the socio-economic effectiveness of recovering the protective coal pillars in underground mines, specifically as follows:

Roadway restoration and driving for preparatory recovery of reserves within the protective pillar

To safely and economically proceed with the pillar extraction and ensure continuous production, it is mandatory to restore the roadway network system in the area, particularly the strike roadway at the level designated for recovery. This is because this roadway system (especially the main haulage strike roadway) has existed in the mined-out area for a relatively long time without regular maintenance. Consequently, the support structure has deteriorated, and the roadway cross-section has been narrowed. The current state layout of the strike roadway before being slashed and rehabilitated is shown in Fig. 2.

Based on the survey of the current roadway status, the original design documentation for the +200 level haulage strike roadway, and the existing material and equipment inventory at the experimental production unit, the authors selected steel

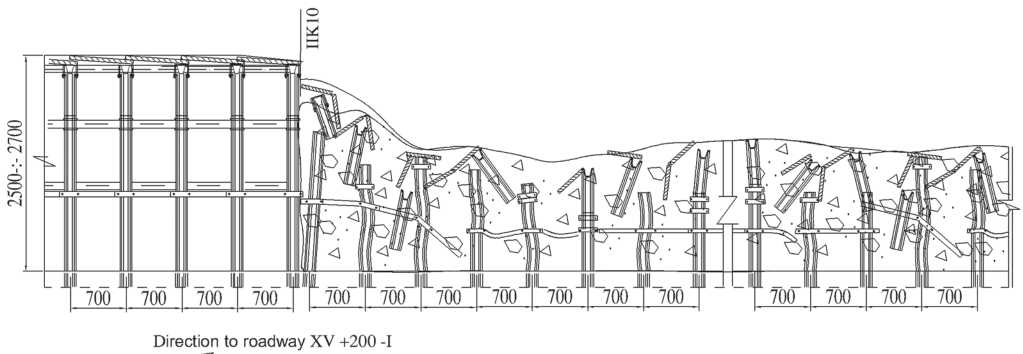


Fig. 3. Current state longitudinal cross-section of the strike roadway at level +200, seam 6, before slashing and restoration (8)

Рис. 3. Продольный разрез штрека на горизонте +200, пласт 6, в текущем состоянии до начала работ по расширению и восстановлению

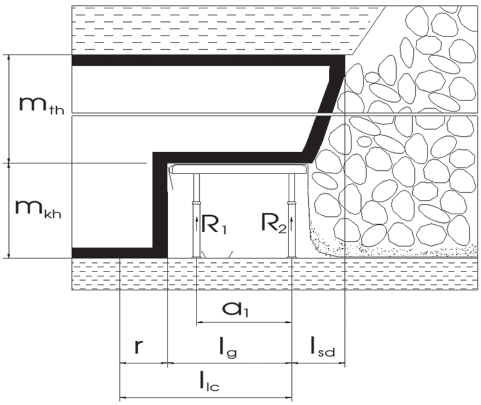


Fig. 4. Schematic diagram of the working principle of the mobile hydraulic support in the longwall face (8)

Рис. 4. Принципиальная схема работы передвижной гидравлической крепи trong очистном забое (лаве)

arch supports (SV2) to reinforce the strike roadway during rehabilitation. The roadway cross-sectional area (Ssd) after slashing is 8.4 m^2, with a support spacing of 0.7 meters per set (Fig. 3)

The preparatory roadways for the longwall face extracting the protective pillar have the following technical parameters:

Ventilation rib road at level +212 is driven with a timber-supported trapezoidal cross-section, a driving area of 6.4 m^2, a usable area of 4.0 m^2, and a support spacing of 0.7 meters per set. Starting Raise at levels +200 to +212 is driven with a timber-supported trapezoidal cross-section, a driving area of 6.4 m^2, a usable area of 4.0 m^2, and a support spacing of 0.7 meters per set.

Coal Extraction for Protective Pillar Recovery

Based on the proposed extraction schemes and considering the geological conditions of the protective pillar reserves in Seam 6 at level +200, the study selected the following extraction solution: The reserves within the protective pillar at level +200, Seam 6, in the Than Thung area will be exploited using a longwall panel mining system along the strike, a caving longwall face with roof coal, full caving for strata control, support provided by mobile hydraulic supports, and coal extraction performed by drilling and blasting

Selection of the technology for protective coal pillar complete recovery

Based on the technical conditions of the area designated for the trial application, the authors selected the following support technology for the extraction face using the caving longwall with roof coal method: the use of XDY-1T2/LY mobile hydraulic supports and single hydraulic props as supplementary supports for the haulage strike roadway and the ventilation strike roadway.

Calculation and Preparation of the Support Plan for the Protective Pillar Longwall Face

To calculate the strata pressure and determine the support density of the longwall face, the working principle diagram of the hydraulic support in the longwall face Fig. 4 is considered. The procedure for calculating and preparing the support plan for the protective pillar longwall face focuses on three main contents. Firstly, the calculation of the strata pressure q_{lc} acting on the support is performed based on the working principle diagram of the hydraulic support and the geological parameters (such as the unit weight of coal γ_t = 1.64 T/m^3, the unit weight of roof rock $\gamma_đ$ = 2.66 T/m^3, the thickness of the recovered coal layer m_{th} = 4.3 m, and the longwall face dip angle α = 26°). The results indicate that the load acting on the working face area is q_{lc} = 16.33 (T/m^2), which leads to the maximum load acting on the support unit being:

$$R_{max} = \frac{16.33 * \left(2.86 + 0.8\right)^2 * 1.0}{2 * 2.86} + $$
$$+ 6.0 = 44.24 \text{ (T)}$$

Furthermore, the possibility of the support posts sinking into the roadway floor is checked. With the floor bearing capacity $\sigma_{KL} = 0.58^* \sigma_n = 203$ (Kg/cm^2) and considering the maximum load, the necessary post base area is 54.5 cm^2. Since the actual post base area of the hydraulic support (250 – 300 cm^2) is greater than the necessary minimum, the supports are confirmed not to be prone to sinking. Additionally, the density of the hydraulic supports is determined to be 0.38 supports/meter, and based on calculations and practical experience, the spacing between supports is chosen to be 1 meter. For a 16-meter-long longwall face, the total amount of support includes 16 sets of mobile hydraulic supports, 3 single props for support relocation, 14 steel/box beams, and 42 single hydraulic props for the reinforcement of the longwall face ends.

Calculation and preparation of the blasting plan

The preparation of the Blasting Plan/Passport is performed based on the careful selection of drilling equipment, explosives, and detonation devices, followed by detailed calculation of the drilling and blasting parameters to ensure efficiency and safety. The drilling equipment used is the SPR-19M Drilling Machine (power 1.2 kW, voltage 127 V, rotation speed 2750 rpm, weight 15 kg), combined with a spiral auger drill rod and specialized coal drill bits. The explosive material is AH1 explosive, manufactured by Quang Ninh Mining Chemical Company, with a detonation velocity of 3 km/s and high work capacity (250 – 260 cm^3). The detonation devices include instantaneous detonators (intensity No. 8, copper casing, minimum firing current 1.2 A) and the BMK-1/100 Exploder (hand-cranked, capable of simultaneously firing a maximum of 100 detonators).

a. Blasting plan for standard face excavation

This plan is applied to the standard horizontal excavation of the longwall face, serving as the calculation foundation for the entire area. The technical parameters are as follows:

- This plan/passport determines that the advance per blasting cycle is r = 0.8 m (which corresponds to the drill hole depth of 0.8 m in the floor row and 0.7 m in the roof row).
- The technical calculations indicate that the necessary specific explosive charge is approximately 0.263 kg/m^3, which results in a total explosive charge required for one slashing cycle (longwall face length 16 m, cutting height 2.2 m being 7.5 kg.
- The drill hole layout is established with 30 holes (2 rows: the roof row and the floor row), with drill hole lengths of 0.8 m (floor row) and 0.7 m (roof row), along with an inclination angle of 70º.
- The specific explosive charge is: 0.3 kg of explosive per hole (for the floor row) and 0.2 kg of explosive per hole (for the roof row), using one instantaneous detonator for each hole.

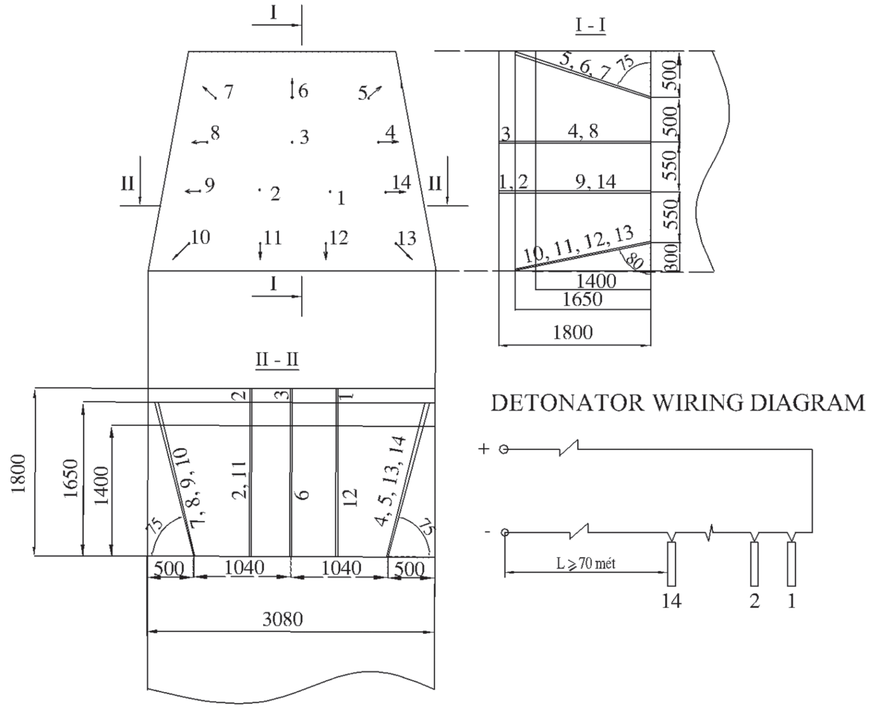
b. Drilling and blasting for preparatory roadway driving (raise)

This blasting plan is established for the driving of the recovery raises with a cross-sectional area S = 6.4 m^2 (timber supported), which is a mandatory preparatory step for accessing the coal pillar (Fig. 5). The equipment used is a handheld electric drill (or SPR-19M). The plan is designed to ensure efficient roadway driving progress:

- Advance per cycle (r): 1.4 m.
- Drill hole depth (Llk): Approximately 1.65 m (with a drilling utilization coefficient of 0.85).
- Specific explosive charge (q): 0.647 kg/m^3.
- Total explosive charge (Q): Approximately 5.8 kg (for a 6.4 m^2 cross-section).

c. Drilling and blasting for roof/pillar coal extraction (core of recovery)

This is the most crucial blasting plan/passport, representing the technical solu-



BLASTING RECORD

No	Name	Hole depth	Inclination (degree)		Explosive (kg)		Detonator VSAT		Tamping		Blasting sequence	devices
			HC: I - I	HC: II - II	Type	Amount (kg/h)	Type	Quantity (/hole)	length (m)	Type		
1	1-:-3	1,80	90	90	NTLT	0,6	MS1	01	>0.7	Clay-sand mixture	Instantan-eous blasting	Blasting machine
2	4, 8-:-14	1,65	75-:-90	75-:-90		0,4	MS3	01				
3	5, 7	1,65	75	75-:-90		0,3	MS5	01				
4	6	1,65	75	75-:-90		0,2	MS5	01				
Tổng	14 lỗ	23.55				5,8kg		14				

Fig. 5. Blasting plan/passport for driving the raise for protective pillar recovery (8)

Рис. 5. Паспорт буровзрывных работ (БВР) tai проведение восстающей выработки для отработки предохранительного целика

tion for breaking up thick roof/pillar coal (thickness approximately 6.5 m) by blasting in the calculated segment length (L = = 3.5 m). The purpose of this stage is to break up the coal mass over a single extraction segment to ensure complete recovery and support strata control.

The specific parameters are:

• Length of Simultaneous Extraction Segment (L): 3.5 m (determined using the formula for the critical bending strength of the roof rock).

• Drill Hole Layout: Fan-shaped pattern around the roadway with 16 blast holes (comprising 02 rings, each ring having 08 holes).

• Explosive Charge Quantity: Total explosive required: 16 kg (1.0 kg /hole) and detonators required: 16 units (1 detonator/hole).

Detailed calculations of drilling and blasting parameters for standard face-cutting blasting passports are presented in Tables 1 and 2. Specific technical parameters

Table 1

Blast Hole Log of Longwall face

Журнал (параметры) буровзрывных работ в очистном забое (лаве)

No.	Hole name	Length (m)		Inclination angle (degree)	Explosive charge quantity (kg)	Number of deto-nators	Type of explosive	Blasting machine	Detonator type
		total	cut						
1	Floor Row	1	0.8	70	0.3	1	AH1	BMK 1/100	Instanta-neous
2	Roof Row	1	0.7	70	0.2	1			

Table 2

Table of drilling and blasting parameters

Параметры буровзрывных работ

No.	Parameters	Unit	Quantity
1	Total number of meters drilled per cycle	m	30
2	Total number of holes drilled per cycle	hole	30
3	Specific Explosive Charge	kg/m^3	0.263
4	Total Explosive Charge for One Cycle	kg	7.5
5	Total Number of Detonators for One Cycle	piece	30

for preparatory tunnel excavation and roof coal mining are compiled and applied separately, illustrated in Fig. 6, demonstrating the flexibility and optimality of the overall coal pillar recovery technology process.

Roof rock conditions

The strata control procedure in the protective coal pillar recovery operation is divided into two main stages to mitigate strata pressure and ensure complete roof caving:

a. Initial Roof Caving

To bring the longwall face recovering the protective pillar into regular extraction, it is essential to perform initial caving to alleviate strata pressure. Although the immediate roof rock is assessed as having medium stability, because the face is located in a mined-out area with numerous faults and fractures, the roof rock here tends to be more prone to caving. For this reason, the author team selected the solu-

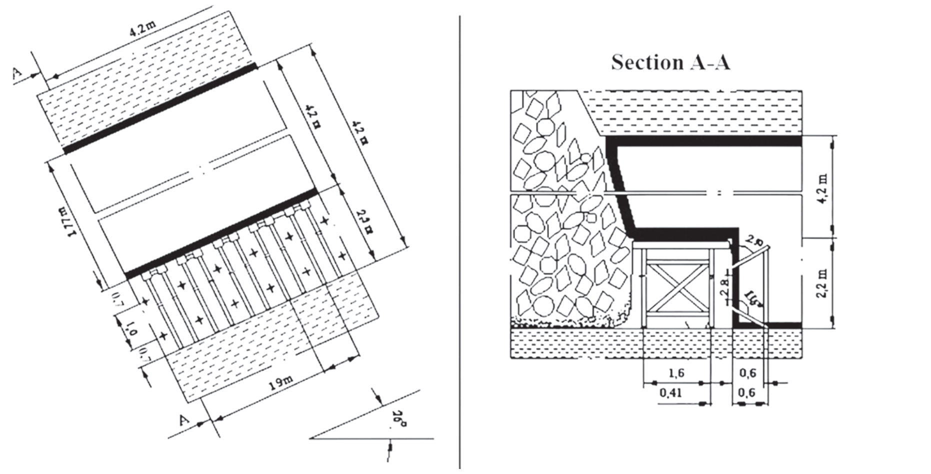


Fig. 6. Drilling pattern layout on the longwall face (8)

Рис. 6. Схема расположения шпуров в очистном забое (лаве) tion of performing initial caving during the rounds of driving the starting raise, where the hydraulic supports are installed, using a blasting plan/passport similar to that of the lower-level longwall face. Once the initial caving is completed, the roof rock is ensured to collapse completely, creating conditions for the safe and stable regular extraction and support of the longwall face.

b. Routine caving work

Routine Caving Work in the protective pillar longwall section is performed similarly to that previously applied in the lower-level longwall face. However, the research team notes that when geological conditions change, particularly when encountering harder roof rock, it may lead to caving with a larger breakage span. In this case, close monitoring of the longwall face condition is necessary to promptly implement appropriate supplementary support solutions when approaching the roof's breaking step, thereby ensuring the safety and stability of continuous production.

Production organization work

The production organization works in the longwall section for the recovery of the protective strike pillar at level +200 is implemented according to the current regime of the Vietnam National Coal – Mineral Industries Group, which entails 3 shifts per 24-hour day, with each shift lasting 8 hours. In the protective pillar longwall section, two shifts are assigned to complete one extraction cycle. The main tasks in one cycle include:

- Extraction of one longwall face cut with an advance of 0.8 m.
- Relocation of all hydraulic supports after each cutting and support cycle.
- Roof coal recovery with a caving step of 0.8 m, timbering with square sets/chocks to maintain the +200 level strike roadway, and transferring the coal to the chute.

Auxiliary Work

Haulage work

The coal recovered from the protective strike pillar in Seam 6, level +200, Than Thung area, Nam Mau Coal Mine, can be transported out of the mine mouth using independent transport methods. Considering that the volume of coal to be transported during the pillar recovery process is only about 54 tons/ shift, the transportation is carried out by manual mine cars. Therefore, the designed haulage solution for the protective pillar longwall section is as follows:

The recovered coal from the protective pillar is transported by chute down to the longwall face bottom and is then manually loaded onto 3-ton mine cars at the +200$ level strike roadway. The mine cars are subsequently towed by an electric locomotive through the +200 level rock crosscut to the +200 level surface area

Due to the relatively small volume of materials required during production, equipment and materials are loaded onto mine cars or specialized skips/containers at the surface area and then transported into the +200 level, Seam 6 strike roadway. From here, the equipment and materials are towed by the electric locomotive through the rock crosscut and the +200 level strike roadway to supply the protective pillar longwall face.

Ventilation and dewatering work

a. Ventilation work

Ventilation for the protective pillar recovery longwall section at level +200, Seam 6, is carried out according to an independent ventilation scheme using local auxiliary fans following the forcing ventilation method.

Fresh air is drawn from the surface area, passes through the +200-I crosscut, enters the haulage strike roadway at level +200, Seam 6, and is then channeled up to ventilate the protective pillar longwall section at levels +200 / +212. The exhaust air from the longwall face then follows the ventilation rib road at level +212, Seam 6, passes through the +212 level strike roadway to the Seam 6 ventilation raise between levels +200 and +252, and finally exits to the outside.

b. Dewatering work

Since the protective coal pillar recovery area is located above the natural drainage level of the area, the dewatering method used for this section is gravity drainage.

Water from the longwall face and the mining area is collected in the drainage ditch in the +200 level, Seam 6 strike roadway. From here, the water flows via the drainage ditch into the +200 level, Seam 6 crosscut, and is directed out to the surface area, where it flows into the area's surface drainage system.

Discussion

The development of the technological procedure for the complete recovery of the protective coal pillar represents an essential and effective technical solution aimed at resolving the issue of significant resource loss (estimated at 15 — 25% of reserves) due to the necessity of leaving behind protective coal pillars in mined-out underground sections. The procedure successfully converted the abandoned coal pillar into a source of an economically valuable product. The feasibility of this procedure is demonstrated through the detailed design of complex preparatory works, such as the restoration of the strike roadways using SV2 steel supports and the driving of raises using timber supports, thereby ensuring that the access roadway system is safe and stable within a mining environment characterized by numerous faults and fractures and complex strata pressure conditions.

The established technological procedure successfully determined a set of optimal technical parameters, ensuring safety and efficiency objectives under difficult mining conditions (steep seam, faulted area, and complex strata pressure). Crucially, the establishment of three separate blasting plans for standard face extraction (r = 0.8 m), preparatory roadway driving (r = 1.4 m), and roof coal extraction (L = 3.5 m) serves as the basis for accurately controlling the blasting energy. Specifically, the roof coal extraction segment L = 3.5 m was calculated based on the critical bending strength of the roof rock to break up the thick roof coal mass. Simultaneously, the initial and routine caving solutions were incorporated into the procedure to ensure complete roof caving, mitigating common incidents (such as support instability/tilting and face collapses) often encountered with other roof coal recovery methods.

From a production organization perspective, the proposed technological process involves applying a longwall length of 30–40 m and changing the method of roof coal recovery by exploiting the entire longwall section in segments, from bottom to top. This method essentially solves the problem of coal accumulation on the transport tunnel along the seam, thereby contributing to increased face advance speed and labor productivity. These parameters have been proven optimal through superior economic and technical indicators such as a 10–15% increase in coal recovery coefficient, while tunnel excavation costs per meter are reduced by 8–12% compared to the traditional seam mining process in the same area.

Although the proposed technological process is highly feasible, further monitoring and refinement are needed during practical application. The proposed parameters need to be evaluated for stability and sustainability when deployed in areas with varying geological conditions, such as when encountering harder rock layers which may cause collapse with greater failure steps, thus requiring the addition of appropriate support solutions. The direction for future research should focus on the mechanization or automation of certain optimized steps within the production cycle (such as the roof coal haulage/transport) to reduce labor intensity and further enhance overall efficiency, while simultaneously mitigating occupational safety risks. Furthermore, the development of AI-based longwall deformation prediction models, utilizing parameters from this technological process, is considered a promising research direction for proactively improving the accuracy of mine safety control.

Conclusion

The study established and optimized a technological process for the complete recovery of protective pillars in the mined space, creating a technical basis for addressing the problem of coal resource loss. A comprehensive approach, combining theory, detailed engineering design, and field testing, was applied to the research. This combination ensured the feasibility and accuracy of the proposed parameters. Furthermore, the study successfully established an optimal set of technical parameters, including optimizing the length of the longwall face (30—40 m), determining a specialized blasting passport for mining the coal seam roof (L = 3.5 m), and organizing the production cycle to ensure recovery of each section from bottom to top. These results helped increase the coal recovery factor by 10—15% and improved the technical safety of the longwall face. To improve efficiency and safety, future research directions should focus on evaluating the sustainability of parameters under varying geological conditions (e.g., encountering harder rock walls) to develop additional support solutions.

Furthermore, research should be conducted on mechanizing or automating production steps (especially roof coal transportation) to reduce labor intensity and safety risks. In addition, plans should be made to develop an AI-based model for predicting longwall face deformation to achieve more proactive and accurate mine safety control.

СПИСОК ЛИТЕРАТУРЫ

1. *Djanetey G. E., Yakin Z.* Ground control systems for deep underground mining: Advancing safety and resource recovery in high-stress mining environments // World Journal of Advanced Research and Reviews. 2025, vol. 27, no. 1, pp. 2134—2142. DOI: 10.30574/wjarr.2025.27.1.2751

2. *Фам Дик Тханг*, *Абрамкин Н. И.*, *Нгуен Нгок Минь* Рациональное определение параметров подзавальных целиков при применении камерно-столбовой системы для разработки наклонных угольных пластов средней мощности: пример исследования Куангниньского угольного бассейна, Вьетнам // Горный информационно-аналитический бюллетень. — 2026. — № 3. — С. 49—61. DOI: 10.25018/0236_1493_2026_3_0_49.

3. *Ullah M. F., Alamri A. M., Mehmood K., Akram M. S., Rehman F., Rehman S. U., Riaz O.* Coal mining trends, approaches, and safety hazards: a brief review // Arabian Journal of Geosciences. 2018, vol. 11, no. 21, article 651. DOI: 10.1007/s12517-018-3977-5

4. *Кубрин С. С.*, *Закоршменный И. М.*, *Решетняк С. Н.*, *Максименко Ю. М.* Повышение эффективности функционирования горных машин угольных шахт // Уголь. — 2024. — № 4. — С. 83—87. DOI: 10.18796/0041-5790-2024-4-83-87.

5. *Баловцев С. В.*, *Скопинцева О. В.*, *Куликова Е. Ю.*, *Рыбичев А. А.* Алгоритмы принятия решений по снижению аэрологических рисков в угольных шахтах // Устойчивое развитие горных территорий. — 2025. — Т. 17. — № 2. — С. 688—700. DOI: 10.21177/1998-4502-2025-17-2-688-700.

6. *Закоршменный И. М.*, *Грабский А. А.*, *Блохин Д. И.*, *Кобылкин А. С.* Использование термохимических технологий для отработки оставленных запасов угля // Устойчивое развитие горных территорий. — 2023. — Т. 15. — № 4. — С. 966—974. DOI: 10.21177/1998-4502-2023-15-4-966-974.

7. *Федоткин И. О.* Ключевые факторы угледобычи в ведущих странах мира // Горный информационно-аналитический бюллетень. — 2025. — № 3. — С. 153—167. DOI: 10.25018/0236_1493_2025_3_0_153.

8. *Ngwenyama P. L., De Graaf W. W., Preis E. P.* Factors and challenges affecting coal recovery by opencast pillar mining in the Witbank coalfield // Journal of the Southern African Institute of Mining and Metallurgy. 2017, vol. 117, no. 3, pp. 215—222. DOI: 10.17159/2411-9717/2017/v117n3a2.

9. *Wang H., Xue S., Jiang Y., Deng D., Shi S., Zhang D.* Field investigation of a roof fall accident and large roadway deformation under geologically complex conditions in an underground coal mine // Rock Mechanics and Rock Engineering. 2018, vol. 51, no. 6, pp. 1863—1883. DOI: 10.1007/s00603-018-1425-1.

10. *Скопинцева О. В., Баловцев С. В.* Оценка влияния аэродинамического старения выработок на аэрологические риски на угольных шахтах // Горный информационно-аналитический бюллетень. — 2020. — № 6-1. — С. 74—83. DOI: 10.25018/0236-1493-2020-61-0-74-83.

11. *Tutak M., Brodny J., Szurgacz D., Sobik L., Zhironkin S.* The impact of the ventilation system on the methane release hazard and spontaneous combustion of coal in the area of exploitation — A case study // Energies. 2020, vol. 13, no. 18, article 4891. DOI: 10.3390/en13184891.

12. *Забурдяев В. С., Подображин С. Н.* Метановая опасность старых выработанных пространств // Безопасность труда в промышленности. — 2019. — № 8. — С. 7—12. DOI: 10.24000/0409-2961-2019-8-7-12.

13. *Босиков И. И., Клюев Р. В., Майер А. В., Стась Г. В.* Разработка метода анализа и оценки оптимального состояния аэрогазодинамических процессов на угольных шахтах // Устойчивое развитие горных территорий. — 2022. — Т. 14. — № 1. — С. 97—106. DOI: 10.21177/1998-4502-2022-14-1-97-106.

14. *Zhang Y., Xue B., Liu X., Wei J., Li Y., Zhang L., Zhang H., Jia Z.* Research on the impact of water inrush on the stability of coal pillar in a mining face based on the three-field coupling method // Energy Exploration & Exploitation. 2025, vol. 43, no. 4. DOI: 10.1177/01445987241309036.

15. *Wang L., Liu G., Ma P., Duan B., Wang F., Zhu Y.* Practical research on coal pillar retention in deep mining roadways // Scientific Reports. 2024, vol. 14, no. 1, article 27570. DOI: 10.1038/s41598-024-78385-4.

16. *Gao H., An B., Han Z., Guo Y., Ruan Z., Li W., Zayzay Jr. S.* The sustainable development of aged coal mine achieved by recovering pillar-blocked coal resources // Energies. 2020, vol. 13, no. 15, article 3912. DOI: 10.3390/en13153912.

17. *Feng G., Wang P.* Simulation of recovery of upper remnant coal pillar while mining the ultra-close lower panel using longwall top coal caving // International Journal of Mining Science and Technology. 2020, vol. 30, no. 1, pp. 55—61. DOI: 10.1016/j.ijmst.2019.12.017.

18. *Wang B., Dang F., Gu S., Huang R., Miao Y., Chao W.* Method for determining the width of protective coal pillar in the pre-driven longwall recovery room considering main roof failure form // International Journal of Rock Mechanics and Mining Sciences. 2020, vol. 130, article 104340. DOI: 10.1016/j.ijrmms.2020.104340.

19. *Sun Q., Zhang J., Zhou N.* Study and discussion of short-strip coal pillar recovery with cemented paste backfill // International Journal of Rock Mechanics and Mining Sciences. 2018, vol. 104, pp. 147—155. DOI: 10.1016/j.ijrmms.2018.01.031.

20. *Yang W, Lai X, Shan P, Cui F, Yang Y.* Study on the characteristics of top-coal caving and optimization of recovery ratio in steeply inclined residual high sectional coal pillar // Geofluids. 2020, vol. 2020, no. 1, article 8883784. DOI: 10.1155/2020/8883784.

21. *Ren J., Zhao Y., Zhang X., Sun Z.* Design of a deformable pipeline for efficient recovery of protective coal pillars // Rock Mechanics and Rock Engineering. 2025, pp. 1—29. DOI: 10.1007/s00603-025-04811-2.

22. *Wu Y., Ma X., Chen D., Gao Y., Xie S., Meng Y.* Research on the fracture mechanism and pressure relief control technology of the thick and hard roof in a coal pillar recovery working face // International Journal of Geomechanics. 2025, vol. 25, no. 5, article 04025063. DOI: 10.1061/IJGNAI.GMENG-1062.

23. *Wu Y., Liang D., Li H., Xie S., Wang Y., Liu C.* A sustained failure mitigation method for roadways in coal pillar recovery working faces of deep mines: excavated pressure-relieving roadways and combined support technology // Rock Mechanics Bulletin. 2025, article 100268. DOI: 10.1016/j.rockmb.2025.100268.

24. *Hai D. D., Giang N. N., Khanh N. N.* Overview study of the coal pillar size calculating methods in preparation tunnels // Mining Industry Journal. 2022, p. 3. [In Vietnamese].

25. *Hoi V. V., Duong P. T.* Research proposes a method to calculate and determine the size of coal pillars to protect the longitudinal seams of the longwalls at underground mines belonging to the Vietnam National Coal and Mineral Industries Group // Mining Industry Journal. 2023, p. 5. [In Vietnamese].

26. *Pham N., Hoang H.* Research and proposal of a technology process for recovering guarding coal pillars in underground mining phases where mining has ceased. Basic-level research project at Quang Ninh University of Industry. 2014. [In Vietnamese]. ГИАБ

REFERENCES

1. Djanetey G. E., Yakin Z. Ground control systems for deep underground mining: Advancing safety and resource recovery in high-stress mining environments. *World Journal of Advanced Research and Reviews*. 2025, vol. 27, no. 1, pp. 2134—2142. DOI: 10.30574/wjarr.2025.27.1.2751

2. Pham Duc Thang, Abramkin N. I., Nguyen Ngoc Minh Efficient determination of gob-side pillar parameters in room-and-pillar mining of medium-thick and inclined coal beds: A case-study of the Quang Ninh Coal Basin, Vietnam. *MIAB. Mining Inf. Anal. Bull.* 2026, no. 3, pp. 49—61. [In Russ]. DOI: 10.25018/0236_1493_2026_3_0_49.

3. Ullah M. F., Alamri A. M., Mehmood K., Akram M. S., Rehman F., Rehman S. U., Riaz O. Coal mining trends, approaches, and safety hazards: a brief review. *Arabian Journal of Geosciences*. 2018, vol. 11, no. 21, article 651. DOI: 10.1007/s12517-018-3977-5

4. Kubrin S. S., Zakorshmenny I. M., Reshetnyak S. N., Maksimenko Yu. M. Increasing operational efficiency of mining machines in coal mines. *Ugol'*. 2024, no. 4, pp. 83—87. [In Russ]. DOI: 10.18796/0041-5790-2024-4-83-87.

5. Balovtsev S. V., Skopintseva O. V., Kulikova E. Yu., Rybichev A. A. Decision-making algorithms for reducing aerological risks in coal mines. *Sustainable Development of Mountain Territories*. 2025, vol. 17, no. 2, pp. 688—700. [In Russ]. DOI: 10.21177/1998-4502-2025-17-2-688-700.

6. Zakorshmennyi I. M., Grabsky A. A., Blokhin D. I., Kobylkin A. S. The use of thermochemical technologies for mining abandoned coal reserves. *Sustainable Development of Mountain Territories*. 2023, vol. 15, no. 4, pp. 966—974. [In Russ]. DOI: 10.21177/1998-4502-2023-15-4-966-974.

7. Fedotkin I. O. Key factors of coal mining in world's leading countries. *MIAB. Mining Inf. Anal. Bull.* 2025, no. 3, pp. 153—167. [In Russ]. DOI: 10.25018/0236_1493_2025_3_0_153.

8. Ngwenyama P. L., De Graaf W. W., Preis E. P. Factors and challenges affecting coal recovery by opencast pillar mining in the Witbank coalfield. *Journal of the Southern African Institute of Mining and Metallurgy*. 2017, vol. 117, no. 3, pp. 215—222. DOI: 10.17159/2411-9717/2017/v117n3a2.

9. Wang H., Xue S., Jiang Y., Deng D., Shi S., Zhang D. Field investigation of a roof fall accident and large roadway deformation under geologically complex conditions in an underground coal mine. *Rock Mechanics and Rock Engineering*. 2018, vol. 51, no. 6, pp. 1863—1883. DOI: 10.1007/s00603-018-1425-1.

10. Skopintseva O. V., Balovtsev S. V. Evaluation of the influence of aerodynamic aging of production on aerological risks on coal mines. *MIAB. Mining Inf. Anal. Bull.* 2020, no. 6-1, pp. 74—83. [In Russ]. DOI: 10.25018/0236-1493-2020-61-0-74-83.

11. Tutak M., Brodny J., Szurgacz D., Sobik L., Zhironkin S. The impact of the ventilation system on the methane release hazard and spontaneous combustion of coal in the area of exploitation — A case study. *Energies*. 2020, vol. 13, no. 18, article 4891. DOI: 10.3390/en13184891.

12. Zaburdayev V. S., Podobrazhin S. N. Methane hazard of old mined-out spaces. *Occupational Safety in Industry*. 2019, no. 8, pp. 7—12. [In Russ]. DOI: 10.24000/0409-2961-2019-8-7-12.

13. Bosikov I. I., Klyuev R. V., Mayer A. V., Stas G. V. Development of a method for analyzing and evaluating the optimal state of aerogasodynamic processes in coal mines. *Sustainable Development of Mountain Territories*. 2022, vol. 14, no. 1, pp. 97—106. [In Russ]. DOI: 10.21177/1998-4502-2022-14-1-97-106.

14. Zhang Y., Xue B., Liu X., Wei J., Li Y., Zhang L., Zhang H., Jia Z. Research on the impact of water inrush on the stability of coal pillar in a mining face based on the three-field coupling method. *Energy Exploration & Exploitation*. 2025, vol. 43, no. 4. DOI: 10.1177/01445987241309036.

15. Wang L., Liu G., Ma P., Duan B., Wang F., Zhu Y. Practical research on coal pillar retention in deep mining roadways. *Scientific Reports*. 2024, vol. 14, no. 1, article 27570. DOI: 10.1038/s41598-024-78385-4.

16. Gao H., An B., Han Z., Guo Y., Ruan Z., Li W., Zayzay Jr. S. The sustainable development of aged coal mine achieved by recovering pillar-blocked coal resources. *Energies*. 2020, vol. 13, no. 15, article 3912. DOI: 10.3390/en13153912.

17. Feng G., Wang P. Simulation of recovery of upper remnant coal pillar while mining the ultra-close lower panel using longwall top coal caving. *International Journal of Mining Science and Technology*. 2020, vol. 30, no. 1, pp. 55—61. DOI: 10.1016/j.ijmst.2019.12.017.

18. Wang B., Dang F., Gu S., Huang R., Miao Y., Chao W. Method for determining the width of protective coal pillar in the pre-driven longwall recovery room considering main roof failure form. *International Journal of Rock Mechanics and Mining Sciences*. 2020, vol. 130, article 104340. DOI: 10.1016/j.ijrmms.2020.104340.

19. Sun Q., Zhang J., Zhou N. Study and discussion of short-strip coal pillar recovery with cemented paste backfill. *International Journal of Rock Mechanics and Mining Sciences*. 2018, vol. 104, pp. 147—155. DOI: 10.1016/j.ijrmms.2018.01.031.

20. Yang W, Lai X, Shan P, Cui F, Yang Y. Study on the characteristics of top-coal caving and optimization of recovery ratio in steeply inclined residual high sectional coal pillar. *Geofluids*. 2020, vol. 2020, no. 1, article 8883784. DOI: 10.1155/2020/8883784.

21. Ren J., Zhao Y., Zhang X., Sun Z. Design of a deformable pipeline for efficient recovery of protective coal pillars. *Rock Mechanics and Rock Engineering*. 2025, pp. 1—29. DOI: 10.1007/s00603-025-04811-2.

22. Wu Y., Ma X., Chen D., Gao Y., Xie S., Meng Y. Research on the fracture mechanism and pressure relief control technology of the thick and hard roof in a coal pillar recovery working face. *International Journal of Geomechanics*. 2025, vol. 25, no. 5, article 04025063. DOI: 10.1061/IJGNAI.GMENG-1062.

23. Wu Y., Liang D., Li H., Xie S., Wang Y., Liu C. A sustained failure mitigation method for roadways in coal pillar recovery working faces of deep mines: excavated pressure-relieving roadways and combined support technology. *Rock Mechanics Bulletin*. 2025, article 100268. DOI: 10.1016/j.rockmb.2025.100268.

24. Hai D. D., Giang N. N., Khanh N. N. Overview study of the coal pillar size calculating methods in preparation tunnels. *Mining Industry Journal*. 2022, p. 3. [In Vietnamese].

25. Hoi V. V., Duong P. T. Research proposes a method to calculate and determine the size of coal pillars to protect the longitudinal seams of the longwalls at underground mines belonging to the Vietnam National Coal and Mineral Industries Group. *Mining Industry Journal*. 2023, p. 5. [In Vietnamese].

26. Pham N., Hoang H. *Research and proposal of a technology process for recovering guarding coal pillars in underground mining phases where mining has ceased*. Basic-level research project at Quang Ninh University of Industry. 2014. [In Vietnamese].

ИНФОРМАЦИЯ ОБ АВТОРАХ

Хоанг Хунг Тханг — доктор горного дела, ректор,
Куангниньский промышленный университет, Мао Кхе, Куангнинь, Вьетнам,
e-mail: hoanghungthang@qui.edu.vn, Scopus ID 57225075880,
ORCID ID: 0009-0003-4031-977X,
Голик Владимир Иванович — д-р техн. наук, профессор,
профессор, Московский политехнический университет,
e-mail: v.i.golik@mail.ru, ORCID ID: 0000-0002-1181-8452.
Для контактов: Хоанг Хунг Тханг, e-mail: hoanghungthang@qui.edu.vn.

INFORMATION ABOUT THE AUTHORS

Dr. Hoang Hung Thang, Rector of Quang Ninh University of Industry,
Quang Ninh province, Vietnam, e-mail: hoanghungthang@qui.edu.vn,
Scopus ID 57225075880, ORCID ID: 0009-0003-4031-977X,
V.I. Golik, Dr. Sci. (Eng.), Professor, Professor, Moscow Polytechnic University,
107023, Moscow, Russia, e-mail: v.i.golik@mail.ru, ORCID ID: 0000-0002-1181-8452.
Corresponding author: Hoang Hung Thang, e-mail: hoanghungthang@qui.edu.vn,

Получена редакцией 26.02.2026; получена после рецензии 02.04.2026; принята к печати 10.06.2026.
Received by the editors 26.02.2026; received after the review 02.04.2026; accepted for printing 10.06.2026.