MINISTRY OF EDUCATION AND TRAINING
HANOI UNIVERSITY OF MINING AND GEOLOGY

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RESEARCH AND APPLYING CONSTRUCTION TECHNOLOGY OF ARTIFICIAL PILLAR TO REPLACE THE COAL PILLAR PROTECTING THE PREPARATION ROADWAY DURING THE MINING PROCESS IN UNDERGROUND COAL MINES IN QUANG NINH REGION

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SUMMARY OF PhD THESIS

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1. URGENTITY OF THE THESIS

The reserve in coal pillars protecting the preparation roadway at large underground coal mines in Quang Ninh region is estimated at about 93 million tonnes, accounting for over 10% of the total coal reserves. These are all available reserves, which were be prepared to exploit by roadways of the longwall, but are currently considered as natural losses in the mining projects.

The coal loss rate according to the mining technology by the underground method is now common at over 20%, mainly concentrated in the coal pillars protecting roadways of the longwall (equal to 12 ÷ 15% of the total coal reserves of the longwall). This rate is relatively high, significantly affecting the efficiency of mine construction investment and wasting non-renewable resources.

In many countries around the world (Russia, China, Poland, ...) have successfully applied the technological solution of using artificial pillars to replace coal pillars protecting the preparation roadway. Accordingly, in order to simultaneously exploit coal in the protective pillar and maintain the transportation roadway as a ventilation road for next longwall, the coal pillar will be replaced by artificial pillars. The materials used to construct the pillar can be clustered column, wooden/metal crib, stone crib, brick/rock blocks or crib using chemical materials... Besides reducing the rate of resource loss, the solution of using artificial pillars also allows to reduce the cost of preparing roadways (reducing 01 roadway) and mining cost.

The research works to reduce coal loss in the pillar have been carried out in Vietnam in recent years, mainly in the direction of reducing the size of the protection pillar, or driving a new ventilation road according to the area that has been exploited. Take advantage of the protection pillars at the same time as the mining process of the longwall. Recently, the program of mining technology that does not leave coal protection pillars has also been studied and proposed, but has not been implemented in practice. Therefore, the thesis **"Research and applying construction technology of artificial pillar to replace the coal pillar protecting the preparation roadway during the mining process in underground coal mines in Quang Ninh region"** is new and very necessary for underground coal mines to consider and develop a plan to apply technology in order to maximize resource exploitation and improve production efficiency.

2. RESEARCH OBJECTIVE OF THE THESIS

Proposing technological solutions to use artificial pillar to replace coal pillars protecting the transport roadway of longwall during the mining process at underground coal mines in Quang Ninh area in order to reduce resource loss and improve production efficiency.

3. TARGET AND SCOPE OF RESEARCH

- ***Research target**:* Coal reserves are located in the pillar protecting transport roadway of longwalls in underground coal mines in Quang Ninh region.

- ***Research scope**:* underground coal mines in Quang Ninh region.

4. RESEARCH CONTENTS

- Overview of experience in applying the technology of using artificial pillar to replace coal pillars protecting the preparation roadways of the longwall and to evaluate the total coal reserves in the protection coal pillars in underground mines of Quang Ninh coalfield.

- Studying the rules of mine pressure acting on the artificial pillar protecting the preperation roadway and determining some optimal parameters of the artificial pillar.

- Research & propose, develop instructions for calculation, construction process of technology using artificial pillars to replace coal pillars protecting the roadway of longwall, suitable to the conditions of underground coal mines in Quang Ninh region.

- Design, implement and evaluate the results of experimental application of technological solutions using artificial pillars to replace coal pillars protecting transport roadway, proposed specific conditions for underground coal mines in Quang Ninh region.

5. RESEARCH METHODS

The thesis uses synthetic research methods, including:

- Methods of analysis, evaluation and synthesis.
- Theoretical research methods.
- Experimental research methods.
- Statistical method
- Numerical modeling method.

6. SCIENTIFIC MEANING AND PRACTICAL VALUE

- Scientific significance: Technological solutions have been proposed to use artificial pillars to replace coal pillars protecting transport roadway, develop calculation instructions and determine some optimal parameters of the technology in the conditions of underground coal mines in Quang Ninh region.

- ***Practical significance:*** The research results of the thesis will contribute to the orientation for underground coal mines in Quang Ninh area, companies and individuals working as consultants, scientists consider and choose to deploy the solution. Appropriate technology solutions to be applied in practice, thereby contributing to the maximum exploitation of the coal reserve expected to be left as a pillar to protect the transport roadway, in order to reduce the loss of resources, the cost of metering of roadway, improve the efficiency of investment capital in mine construction and production&business.

7. NEW POINT OF THE THESIS

7.1. This is the first work to fully study the theory and practice in the application of artificial pillars with wooden crib structure combined with steel beams to replace coal pillars protecting the preparation roadways in the conditions of underground coal mines in Quang Ninh region.

7.2. Determining the relationship between the width and required compressive strength of the artificial pillar with geological factors (thickness of seam, dip coal seam, mining depth), which will guide the selection select materials used for artificial pillars and suitable construction means in the conditions of underground coal mines in Quang Ninh region.

7.3. Selecting technological solutions to use artificial pillars to replace coal pillars protecting the roadways are prepared to suit the conditions of underground coal mines in Quang Ninh region (including: artificial pillars made of stone crib; wooden/metal crib, artificial pillars form continuous strips of materials with high compressive strength).

8. PROTECTION ARTICLES

8.1. The width of the artificial pillar protecting the roadways and the dip angle of the seam have a relationship that follows a first-order linear function.

8.2. Using artificial pillars to replace protective coal pillars will reduce resource loss and improve production and mining efficiency.

9. STRUCTURE OF THE THESIS

The thesis is structured including: introduction, 4 chapters and a recommendation conclusion. The content of the thesis is presented in 126 pages typed in A4 size with 31 tables, 107 drawings and 67 references.

CHƯƠNG 1: OVERVIEW OF EXPERIENCE APPLICATION OF

ARTIFICIAL PROTECTION PILLAR TO REPLACE COAL PILLAR PROTECTING PREPARATION ROADWAY AND SUMMARY ASSESSMENT OF COAL RESERVE IN THE PILLAR AT UNDERGROUND COAL MINES IN QUANG NINH REGION

1.1. Experience in research and application of artificial pillars to replace coal pillars protecting preparation roadway in the world

The technology of using artificial pillars to replace coal pillars protecting the preparatory roadway has been researched and applied quite popularly in the world. Materials used to construct pillar can be clustered column, wooden/metal crib, stone crib, brick/rock blocks or crib using chemical materials. Details of experience in applying classification according to pillar materials are as follows:

- ***Artificial pillar made of stone crib:*** applied when exploiting coal seams of not great thickness (usually less than 1.5m) according to the mining system with a longwall, mining along the strike of coal seam, prepared roadway according to the diagram. The longwall is enlarged, in order to avoid/reduce the need to transport the stone obtained from the dug-out face of roadway and the longwall to the outside. This type of artificial pillar was formerly used quite commonly in the former Soviet Union. For example, Centralnaya-Bokovskaya mine exploits coal seam number 51 Nadbokovskiy with a thickness of 1.0m, Volodarskiy mine exploits coal seam h8 Maydannovskiy with a thickness of 1.1 ÷ 1.15m, and some other mines such as Voroshilo-ugol, Stalino-ugol, Rutchenko-ugol. The common disadvantage of these diagrams is that the operations between the longwall face and the preparation roadway face affect each other. The stone crib has a large shrinkage, so the area used for the prepared roadway is drastically reduced after construction.

- ***Artificial pillar in the form of wooden cribs: clusters of columns and support pillars:*** applied in coal seams with larger thickness. Pillars are constructed right inside the roadway or in the space where the tail of the longwall is adjacent to the roadway to be protected. For wooden crib, the crib can be either an empty crib or filled with various materials such as waste rock, sandbags, or high strength mineralized material to increase the crib's compression resistance. For artificial pillar with supporting pillar, the pillars are constructed of concrete right inside the roadway towards the gob area. This form is applied in a number of coal mines in Poland such as: Bogdanka mine uses a wooden crib with a width of 1.2m, filled with mineralized material with compressive strength of 40 MPa, and protects the along seam transport roadway, in the coal seam has a thickness of 1.3 ÷ 3.4m, a dip angle of 2 ÷ 20°; Ziemowit mine uses concrete pillars (diameter 400÷500mm) to protect the roadway in coal seam with thickness of 4.5m and dip angle of 4°. Because the gob area and the roadway are not well isolated, the problem that has not been solved is the problem of wind leakage and the flow of gas, heat and water from the mined area into the adjacent longwall below. Along with this disadvantage, in the condition that the coal seam has the ability to self-ignite, the solution will be limited in application.

- Artificial pillars in the form of continuous strips: To overcome the disadvantages of artificial protective pillar structures with clusters of columns, cribs or concrete pillars (high wood cost, low isolation capacity, potential fire hazard, etc.) endogenous, wind leakage, gas, heat, water from the mined area, ...), some underground coal mines in the world have built artificial pillars forming continuous strips at the side of the prepared roadway need to be protected, thereby ensuring tightness and good isolation of the exploited area. Depending on the condition of the dip angle, artificial pillars can be built: (1) entirely of materials brought in from the outside (when the dip angle of the seam/longwall is small) or (2) a combination of stone has been mined used fills the width of the side armor of the roadway, which is expected to serve as a protective pillar, and then injects binder to stabilize and increase the compressive capacity of the seam to form an artificial pillar protecting the roadway (when the dip angle of the seam /longwall is increased). Conditions for applying this form of artificial pillars are quite wide in terms of thickness (up to 6.1m) as well as seam dip angle (up to 37°). Because the construction material of the pillar has high compressive strength, the basic width of the artificial pillar is in the range of 1.6 - 2.0m, so the volume of materials transported and constructed is not large, the pillar has the ability to load capacity and high reliability.

This form is widely applied in China, for example, Tan Nguyen mine (Shandong province) uses an artificial pillar with a width of 2.0m, a height of 2.8m with a material with a compressive strength of 20 MPa to protect transporting roadway in the coal seam has a thickness of 2.8m, a dip angle of 4°; Changcun mine uses an artificial pillar with a width of 1.6m, a height of 3.5m made of materials with compressive strength of 30 MPa to protect transport roadway in the coal seam with a thickness of 6.1m, dip angle 4°; Dai Bao Dinh mine in China applies a pillar made of a combination of stone mined and adhesive material with a width of 2.0m to protect roadway in the coal seam with a thickness of 2.54 ÷ 2.88, average 2.71m, seam dip angle from 31 ÷ 37º.

1.2. Status of research, application of artificial pillars and exploitation of coal pillars protecting preparation roadway in underground coal mines in Quang Ninh region

The form of using artificial pillar to replace coal pillar protecting the roadway in underground coal mines in Quang Ninh has not been mentioned. The research works to reduce coal loss in the coal pillar post mainly go in the direction of reducing the size of the coal pillar, driving a new ventilation roadway along the exploited area or fully exploiting the protection pillar at the same time with longwall mining process. Recently, the diagram of mining technology that does not leave protection pillar has also been studied and proposed, but has not been implemented in practice.

1.3. General evaluation of coal reserves in the preparation roadways at underground coal mines in Quang Ninh region

- The scope of evaluation: The thesis limits the subjects to 12 large underground coal mines belonging to Vinacomin, including Mao Khe, Nam Mau, Uong Bi, Vang Danh, Ha Lam, Nui Beo, Duong Huy, Quang Hanh, Thong Nhat, Ha Long (Khe Cham II-IV), Khe Cham (Khe Cham III) and Mong Duong.

- Materials used for evaluating: Geological exploration reports and 13 construction investment projects for underground coal mines mentioned above by the Industrial and Mining Investment Consulting Joint Stock Company - Vinacomin and the Institute of Mining Science and Technology – Vinacomin established.

- Evaluation results: The total geological reserve mobilized in 13 underground mining projects is 924,169 thousand tonnes. In which, the reserve left in the protection coal pillars is 93,460 thousand tonnes, accounting for 10.11% of the total mobilized reserves. By factor of thickness and dip angle of seam, this reserve is concentrated mainly in the range of medium thickness to thick, gentle to inclined (68,824,000 tonnes, accounting for 73.64%). This is the extent of the seam being exploited by a longwall , which will be convenient for applying the research results of the thesis into practice to replace the coal pillar protecting the preparation roadway with an artificial pillar one to reduce resource loss, see Table 1.7 for details.

Bảng 1.7. Classification of coal reserves in the protection coal pillars for preparation roadway in underground coal mines in Quang Ninh region

Seam's dip angle (degrees)		Seam's thickness (m)			
		0,7 ÷ 1,2	*1,21 ÷ 3,5*	*> 3,5*	*Total*
1	≤15°	28	5.849	10.217	16.095
	Percentage	*0,03%*	*6,26%*	*10,93%*	*17,22%*
2	15 ÷ 35°	748	21.468	31.290	53.505
	Percentage	*0,80%*	*22,97%*	*33,48%*	*57,25%*
3	35 ÷ 55°	520	10.826	7.949	19.295
	Percentage	*0,56%*	*11,58%*	*8,51%*	*20,65%*
4	>55°	280	2.228	2.056	4.564
	Tỷ lệ	*0,30%*	*2,38%*	*2,20%*	*4,88%*
5	***Total***	***1.576***	***40.370***	***51.513***	***93.460***
	Ratio	***1,69%***	***43,20%***	***55,12%***	***100,00%***

CHƯƠNG 2: RESEARCH ON THE RULES OF COMPREHENSIVE PRESSURE IMPACT ON ARTIFICIAL PROTECTION PILLAR PROTECTING ROADWAY OF LONGWALL AND MAIN PARAMETER OF THE PILLAR

2.1. Studying the rules and theory of determining the load acting on the artificial pillars protecting the roadway of longwall

2.1.1. Status of stress distribution in the coal pillar adjacent to the mining area of the longwall

The mining process will disrupt the equilibrium and increase the stress in the raw coal block adjacent to the mining area. The affected coal cylinders will form four zones with stress greater than the primary stress in the direction from fire failure to the whole block of coal: Loose zone (I); Discrete region (II); Plastic region (III); High range of elastic region stress (IV). The vertical stress of coal pillar σy is distributed as curve 1. The value of σy develops in a negative exponential curve depending on the distance between the width of the spring-limited equilibrium area to the edge of the mining area. Zone V is the primary stress zone that is not affected by the mining of longwall. The stress distribution characteristics on the coal pillar under the influence of supporting pressure are shown in Figure 2.1.

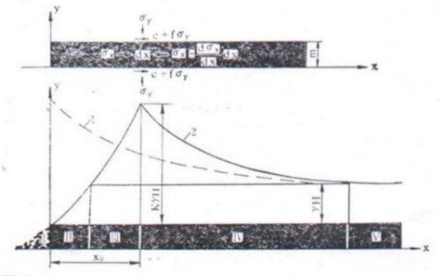


Figure 2.1. Vertical stress distribution and elastic-plastic deformation zone in coal pillar

1 - Elastic stress; 2 - Elastic - plastic stress

The limited equilibrium region, whose dimensions are equal to the sum of the widths of regions II and III, is determined by the formula:

$$x_o = \frac{m}{2f\xi} ln \frac{K\gamma H + Cctg\phi}{\xi Cctg\phi}, (m) \qquad (2.1)$$

In there:

x_o – Width of the limit balance zone, m; m - Thickness of mined coal seam, m; C - Coal cohesive force, kN/m^2; ϕ - Coal internal friction angle, degrees ; ξ - Limit equilibrium coefficient; f - Coefficient of friction between the contact surface of the wall and the coal seam pillar and the rock; K – Stress concentration coefficient; γ - Volumetric weight of the soil and rock layers above the coal seam, kN/m^3; H - The depth of the roadway arrangement compared to the topographic surface, m;

When using the form of protection by coal pillars, the roadway must be located outside/or in the area less affected by the mining of the longwall. That is, it is arranged in zone IV and zone V. If it is arranged in zone V, then the longwall will be completely outside the affected area of pressure like the bazar, however, then the width of coal pillar will be large, which increases the loss rate.

2.1.2. Theoretical study of calculating the load acting on the artificial pillar protecting the roadway of the longwall

During the routine collapse, the basal rock will fracture at certain apertures, as shown in figure 2.1, consisting of rock blocks A and B above the coal block, rock block C has fractured and collapsed within gob are. The retained roadway is under rock block B, so the load of block B affects the stress environment and has a decisive effect on the stability of the surrounding soil and rock of the retained roadway. A simple model depicting the rock structure around the artificial pillar area is shown in Figure 2.3.

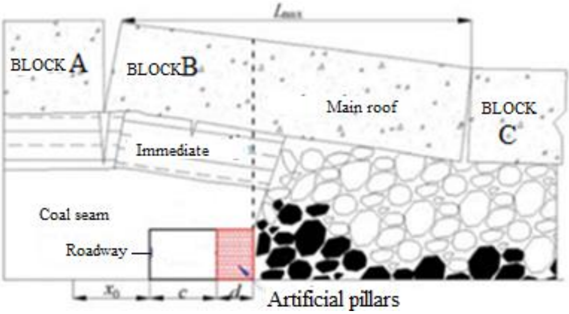


Figure 2.3. Structure of soil and stone around the roadway and artificial pillars

Artificial pillars protecting the roadway are arranged on the side of the roadway adjacent to the gob area, ie located in the fractured area. At that time, the load acting on the artificial pillar is the load caused by the fracture of the rock slabs of the seams. The load acting on the artificial pillar is then determined by the following formula:

$$P_f = [h_b\gamma_b L_{max} + h_a\gamma_a (x_o + c + d)]/2, \text{ kN/m}; \quad (2.2)$$

In there:

h_a – Thickness of immediate roof, m; h_b – Thickness of main roof, m; γ_a - Volumetric weight of direct wall rock, kN/m^3; γ_b - Volumetric weight of basic wall rock, kN/m^3; c – Width of furnace line, m; d - Width of artificial protection post, m; L_{max} – Periodic fracture step of the main roof, m;

In the design of artificial pillar, the relationship between the mine load acting on the artificial pillar (P_f) and the destructive load of the artificial pillar (P_{ph}) is closely related. In order for the pillar to meet the requirements of holding support, the destructive load of the artificial pillar must be not less than the mine load acting on it and is determined by the following formula:

$$P_{ph} = \sigma_{vl}. d(\frac{d}{2}: h), \text{ kN/m}; \qquad (2.3)$$

Trong đó:

σ_{vl} - Compressive strength of pillar construction materials, kN/m^2;

h – Height of artificial pillars, m;

The relationship between the mine load acting on the artificial pillar (P_f) and the destructive load on the artificial pillar (P_{ph}) is expressed through the pillar's strength coefficient (or safety factor) k as follows:

$$k = \frac{P_{ph}}{P_o} \qquad (2.4)$$

In there:

P_o - Load acting on one meter of artificial pillar strip;

$$P_o=P_{fd}, \text{ kN/m}; (2.5)$$

k - strength coefficient of the pillar, m; for the design of stabilizing the guard post in coal mining, the value of the pillar durability is in the range from 1.5 ÷ 2.0. However, in practice, depending on the importance, function, and lifetime of the longwall to be protected, the designer can decide that the force selects the factor k greater than 2).

The value of the load acting on the artificial pillar calculated according to the above theory is usually very large. Accordingly, the materials used to construct artificial pillars in China and Poland are currently mostly materials with high compressive strength (from 10 40 MPa, commonly from 20 30 MPa), which are construction in a continuous strip right inside or in the gob space adjacent to the side of the roadway to be protected. Therefore, when using construction materials of artificial pillars made of materials with low strength and high shrinkage such as wooden cribs, wooden columns, stone cribs, etc., it will not be suitable, because the crib cannot create strength. against hold by calculation.

In fact, the current underground coal mines in Quang Ninh region, in terms of application orientation, in parallel with prioritizing the application of artificial pillars made of materials with high compressive strength, the form of artificial pillars of various types. Existing, inexpensive models such as wooden cribs, wooden poles, etc. will also be applied. However, these materials have low strength, high degree of shrinkage and deformation, and the working mechanism will be like an anti-flexible, so the theoretical use of formulas from (2.1) ÷ (2.5) will give results that are inconsistent with reality and not feasible to implement the technology. With this form of artificial pier, the load acting on the pillar can be determined equivalent to the mine load acting on the roof of the prepared longwall under the influence of mining and is determined according to the degree of displacement of the pillar. soil and rock at the edge of the longwall according to the following formulas:

- For single longwall:

$$U_{kp} = U_{okp} + U_1 . k_{kp} . k_{st} . k_k \qquad (2.6)$$

- For two longwall operating in parallel, the second longwall is not less than 20m away from the first longwall:

$$U_{kp} = U_{okp} + 1{,}3 . U_1 . k_{kp} . k_{st} . k_k \qquad (2.7)$$

In there:

U_{okp} – Displacement of soil and rock at the top of the roadway in the horizontal and inclined roadway before the influence of mining work, is calculated according to the following formulas:

$$U_{okp} = U_{tkp} k_\alpha k_s k_B k_t \qquad (2.8)$$

Here: U_{tkp} – Soil displacement is determined according to Figure 2.4, depending on the compressive strength value of the top soil and rock and the construction depth.

The values of U_1, k_{kp}, k_{st}, k_k, k_α, k_s, k_B, k_t are looked up from pre-built city and tables, thereby determining the load acting on the artificial pillar. The calculated load according to this theory gives results consistent with the load-carrying capacity of pillar structures made of materials with low strength, high degree of shrinkage and deformation.

2.2. Studying the mine pressure acting on the artificial pillar protecting the roadway and the main parameters of the artificial pillar by numerical analysis model

2.2.1. Selection of input factors and parameters to build a numerical model to determine the main parameters of the artificial pillar

2.2.1.1. Selection of numerical software and input parameters for model building

The thesis selects Phase 2 digital software. Within the scope of the thesis, it is limited and the typical input factors that have a great influence on the working ability of artificial pillars are: (1) seam thickness; (2) pavement dip angle; (3) mining depth; (4) geological conditions of the roadway area. In there:

- Regarding the factor of seam thickness: select two typical cases of medium thickness seam (thickness of 2.2m) and thick seam (thickness of 5.0m).
- Regarding dip angle factor: limit the dip angle range to 35° degrees (the range is exploited by longwall), in ranges of 10°, 20° and 35°.
- About mining depth: choose two depth values: 350m (currently popular mining strata of mines) and 500m (mining depth of maintenance layer).
- Regarding geological conditions: including coal seams and other types of cliffs, pillars and rocks common in stratigraphy in Quang Ninh region.

2.2.1.2. Selecting the main parameters of the artificial pillar to be determined

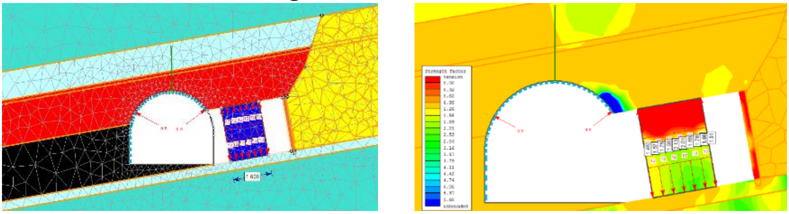
The thesis delves into the research, analysis and determination of the optimal parameters of **the artificial pillar using materials with high compressive strength**. The basic parameters of the artificial pillar to be determined are: (1) the size of the pillar width and (2) the compressive strength of the pillar.

2.2.3. Building and exploiting models to determine the parameters of artificial pillars in the condition of medium thickness seams

2.2.3.1. Determining the optimal compressive strength of artificial pillars

According to the results of the overview study, the width of the artificial pillar is controlled and oriented in the range (0.5-1.1) and the height of the longwall mirror. Corresponding to the height of the face 2.2m, the thesis determines the width of the artificial pillar as 1.6m and 2.4m, from which to determine the appropriate compressive strength of the artificial pillar in the corner conditions. Seam dips of 10°, 20° and 35°. Mining depth in the model is 350m.

Due to the complex geological conditions of underground coal mines in Quang Ninh region, the thesis chooses a durability coefficient of 2 to determine the optimal compressive strength of artificial pillars in the numerical model. Accordingly, in the thesis models change the assumed compressive strength value of the pillar, until the durability coefficient of the pillar reaches the value ≥ 2, that is, the pillar meets the requirement of holding resistance. Research results for the case of dip angle of 10°, width of artificial pillar 1.6m shows that, with compressive strength of artificial pillar of 12 MPa, then the durability coefficient of pillar reaches >2. Thus, the optimal compressive strength of the artificial pillar for this case is 12 MPa, see Figures 2.14, 2.15 for details.



a) B = 1,6m và $\alpha = 10^0$ b) Durability factor in the protection pillar

Figure 2.14. Strength of compressive resistance and durability coefficient of protective pillar (B = 1,6m, α = 10⁰)

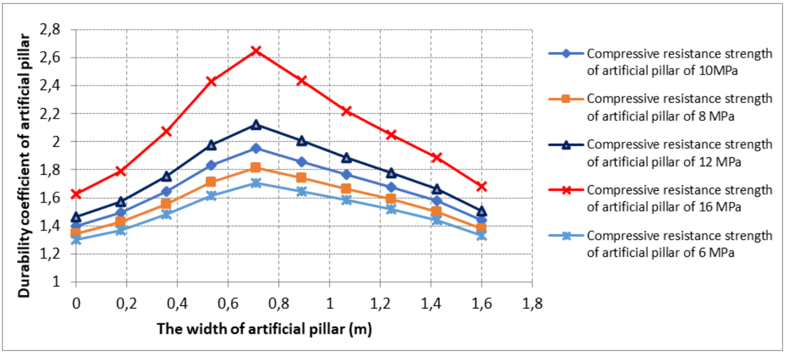


Figure 2.15. Durability coefficient in the protection pillar (B = 1,6m, α = 10⁰)

Performing the same steps in the models for the cases of dip angle and the remaining width of artificial pillars, the thesis obtained the results shown in Table 2.9.

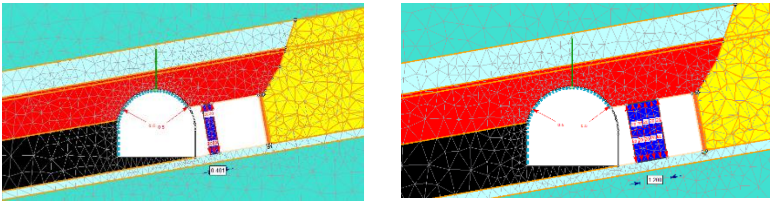
Table 2.9. Research results on the optimal compressive strength of artificial pillars in the condition of medium thickness seams

The width of pillar	Seam's dip angle		
	10°	20°	35°
1,6m	12 MPa	28 MPa	17 MPa
2,4m	8 MPa	18 MPa	16 MPa

From the results shown in Table 2.9, compared with the conditions of the coal seams in Quang Ninh (most of them are inclined seams, sloping from over 15 ÷ 35°) and the results of research on the experience of using artificial pillars in the world (pillar construction materials have a common compressive strength of 20 40 MPa), **the thesis chooses the optimal compressive strength of the pillar at 20 MPa and 30 MPa** to study and determine the optimal width of the artificial pillar in the next content.

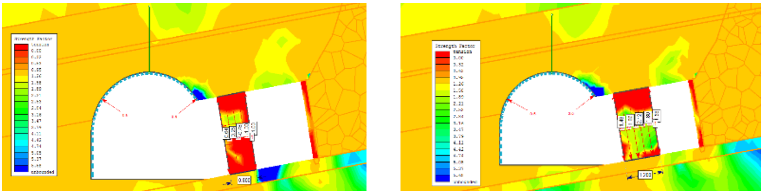
2.2.3.2. Determining the optimal width of the artificial pillar

With a given compressive strength of the artificial pillar of 20 MPa and 30 MPa, the numerical model is studied to determine the optimal width of the artificial pillar for different cases of seam thickness (medium-thick seam, thick seam, etc.), seam dip angle (up to 35, at ranges of 10°, 20°, 35°), mining depth of 350m and 500m is accomplished by varying the width of artificial pillar in the models, until The durability coefficient of the pillar reaches the value ≥2. Then the width of the pillar meets the requirement of anti-retaining to protect the roadway. Research results determine the optimal width of artificial pillars for the case of medium thickness seams, compressive strength of artificial pillars 20 MPa, mining depth of 350m shown in Figure 2.24, 2.25. The summary of research results to determine the optimal artificial width of pillar is shown in Tables 2.10 and 2.13.



a) B = 0,4m b) B = 1,2m

Figure 2.24. The model determines the optimal width of pillar with average thickness, P=20 MPa, α = 10°, H = 350m



a) B = 0,8m b) B = 1,2m

Figure 2.25. The coefficient of strength in the protection pillar in case of medium thickness seams, P=20 MPa, α = 10°, H = 350m

Table 2.10. Summary of research results on the optimal width of protection pillar, when mining medium thickness seam

Seam's dip angle	**Value of optimum protection pillar width, m**					
	α = 10°		α = 20°		α = 35°	
H = 350m	B=1,2	B=1,0	B=2,0	B= 1,6	B = 2,4	B = 2,2
H = 500m	B=1,6	B=1,4	B=2,8	B = 1,8	B = 3,0	B = 2,8
The compressive strength of the pillar, MPa	P=20	P=30	P=20	P = 30	P = 20	P = 30

Table 2.13. Summary of research results on the optimal width of protection pillar ,when exploiting thick seams

Seam's dip angle	**Value of optimum protection pillar width, m**					
	α = 10°		α = 20°		α = 35°	
H = 350m	B=1,2	B = 0,8	B = 1,8	B=1,4	B = 2,2	B = 1,6
H =-500m	B=1,8	B = 1,4	B = 2,0	B=2,2	B = 2,0	B = 2,4
The compressive strength of the pillar, MPa	P=20	P = 30	P = 20	P = 30	P = 20	P = 30

Using the statistical software SPSS, version 25 of IBM to study the relationship between the parameters shown in Tables 2.10, 2.13 shows that there is a high correlation between the pillar width parameter and the seam's dip angle of the reservoir, that is, There is a functional relationship between them. Specifically, the relationship between the width of the artificial pillar and the dip angle of the pavement follows a first-order linear function, where:

- In case of medium thickness seam:

$$y = 0,0508x + 0,8829 \qquad (2.12)$$

Variance $R^2 = 0,9591$

- In case of thick seam:

$$y = 0,0287x + 1,1118 \qquad (2.13)$$

Variance $R^2 = 0,8637$

In there:

y – Width of artificial pillar, m;

x - Seam dip angle, degrees;

CHƯƠNG 3: RESEARCH AND PROPOSED TECHNOLOGY TO USE ARTIFICIAL PILLAR TO REPLACE PROTECTION COAL PILLAR FOR PREPARATION ROADWAY PREPARATELY FOR THE CONDITIONS AT UNDEGROUND COAL MINES IN QUANG NINH REGION

3.1. Analysis and selection of artificial pillar technology suitable for the conditions of underground coal mines in Quang Ninh region

On the basis of the above analysis, in accordance with the conditions of underground coal mines in Quang Ninh region, the thesis selects and proposes 03 types of artificial pillar to apply:

- (1) Artificial pillar made of stone cribs: applied to thin seam conditions in order to avoid/reduce the need to transport waste rock from excavated or mined mirrors outside the site. The main disadvantages are the large amount of manual work, the high degree of material shrinkage, and the limited ability to protect the roadway.

- (2) Artificial pillars made of crib structure: applicable to the condition of the seam from thin to thick. The advantage is using available materials, low cost, simple construction. The disadvantage is that the load capacity is not high, the shrinkage is large, the level of manual work is still high.

- (3) Pillars formed in continuous strip form made of materials with high compressive strength: applicable to the condition of the seam from thin to thick. Advantages are compressive strength, high reliability, good isolation, simple construction, can be mechanized. This artificial pillar is an advancement, allowing to completely overcome the existence of the aforementioned types of artificial pillar. In the allowable conditions, this type of artificial pillar should be preferred.

3.2. Develop instructions and construction process for technology using artificial pillars to replace coal pillars to protect the preparation roadway

3.2.1. Technology using artificial pillars with stone cribs.

3.2.2. Technology using artificial pillars with crib structure.

3.2.3. The technology uses artificial pillar in the form of continuous strips.

For each technology, the thesis has developed calculation instructions, construction process, as a basis for calculation application for specific application area conditions. At the same time, some types of construction materials and equipment are proposed to be suitable for the conditions of underground coal mines in Quang Ninh region.

3.3. Research on the possibility of reducing resource loss when applying artificial pillar to replace coal pillar protecting the roadway

Using the traditional form of protecting the roadway with coal pillars, when the mining depth increases, the width of the pillars also increases. Depending on the solidity of the coal, wall rock, pillar rock, at a depth of 350 ÷ 700m, the width of the protective coal pillar is from 13.2 ÷ 40.1m, corresponding to that, the loss rate changes. from 14.06 to 39.21%. When using the form of protection by artificial pillars, the width of the pillars is controlled not to be larger than the width of the foot of the longwall (<3.0m), the loss rate is only from 5.0 to 19.31 %. Thus, using artificial pillar allows to reduce from 9.06 ÷ 17.57% the rate of resource loss.

CHƯƠNG 4: RESEARCH AND TEST APPLICATION OF TECHNOLOGY TO USE ARTIFICIAL PILLAR TO REPLACE PREPARATION PROTECTION COAL PILLAR IN KHE CHAM COAL MINE III OF KHE CHAM COMPANY – VINACOMIN

4.1. Characteristics of geological and technical conditions of the mine in the design area

The selected design location is the longwall 14-5-19, level -170/-150 seam 14-5 of Khe Cham III coal mine of Khe Cham Coal Company - VINACOMIN. The object of application of the solution of using artificial pillars to replace protective coal pillars is the roadway of the longwall. The excavator is anchored and completely located in the seam 14-5, arch-shaped cross section, height 3.24m, width 4.03m, excavation area 11.2m2, usable area 8.5m2, support with construction Structure because of flexible steel 05 SVP27 steel sections, 0.5m/steel arch support step.

The characteristics of geological and technical conditions of the mine in the design area are as follows: the thickness of the reservoir is from 3.85 ÷ 9.0m, with an average of 5.6m; dip angle 12°; coal solidity f = 1÷2; the immediate roof is mainly siltstone, the main roof is basically sandstone and cobblestone sets; direct pillar is siltstone; the area belongs to class I in terms of methane, coal in the seam is not self-combustible, less affected by water; in mining depth 350m.

The total mobilized reserve in the design area of longwall is 81 thousand tonnes, in the area of the longwall is 57 thousand tonnes, in the protection pillar along the transport seam is 24 thousand tons. The coal output expected to be exploited from the longwall according to the plan of Khe Cham Coal Company is 47,500 tonnes, equivalent to a loss rate of 39.0%. The cost of the preparation roadway meter is 8.26 m/1000 tonnes of coal.

4.2. Choosing the type of artificial pillar to replace the protective coal pillar

The along seam transportation roadway of longwall 14-5-19 is built within the thick coal seam (average 5.6m), so the artificial pillar solutions made of stone cribs are not suitable for application. Accordingly, in this case, artificial pillars with continuous strip construction and crib construction are applicable.

At the time of implementation of the research results, the along seam transport roadway of longwall 14-5- 19 has been completed and must be put into operation soon. Comparing the current status of technical conditions, the ability to supply materials for reinforcement, production progress, the thesis chooses the solution of artificial pillars using the crib structure, because the materials can be used, which are available and do not require specialized construction equipment.

4.3. Design the proposed solution using artificial pillars

The artificial pillar constructed at the tail-inspection area of the longwall are designed as follows:

- Structure of a crib includes 04 flexible SVP-27 steel columns (each column assembled from 02 bars, linked by M24 shackles) and horizontal wooden bars. The density of cribs is calculated as 0.284 cribs/m^2.

- Schemat to hold selected artificial pillars: width of artificial pillar of 2.4m; number of cribs 02 cribs; the distance between the cribs is 1.6m in dip and 1.6m in the direction of the seam. Actual density of cribs in the examination: 0.52

cribs/m^2.

The density of cribs arranged in the artificial pillars is 1.83 times larger than calculated. Thus, the schemat holds the foot examination with the proposed crib structure (artificial pillar) to ensure the requirements (see Figure 4.4).

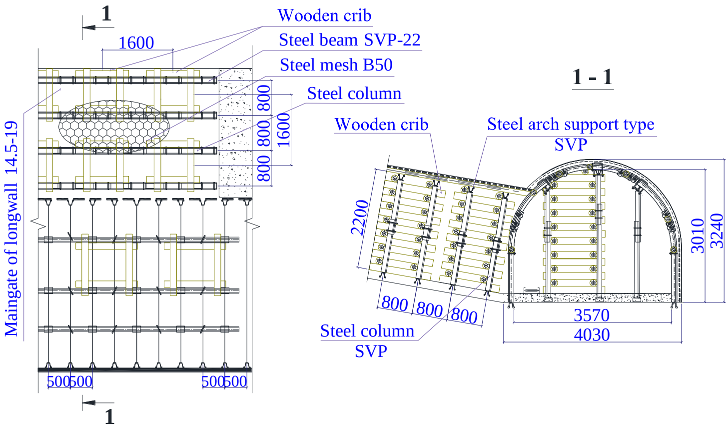


Figure 4.4. Schemat of artificial pillar protecting the transportation roadway of longwall 14.5-19

4.4. Evaluation of the results of applying the technology of using artificial pillars to replace coal pillars protecting the transportation roadway 14-5-19

4.4.1. Evaluation of technical efficiency

4.4.1.1. About the economic and technical indicators

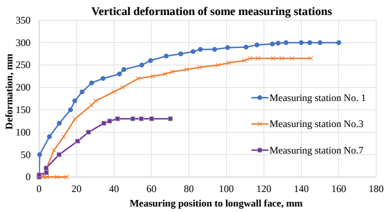
- When applying the technological solution of using artificial pillars to replace the coal pillars of the longwall 14-5-9 , an additional 19,951 tonnes of coal can be exploited in the coal pillar protecting the preparation roadway, increasing the total mining output of the designed area to 67,451 tonnes:

- Loss rate decreased to 14%, nearly 3 times lower than expected (39%).

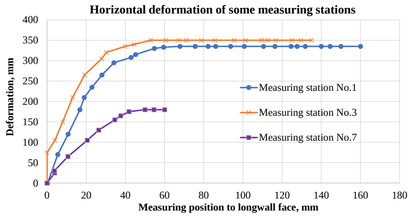
- The cost of the preparation roadway is 6.3 m/1000 tonnes of coal, down nearly 1.9 m/1000 tonnes (equivalent to 23.8% decrease) compared to the plan (8.19 m/1000 tonnes of coal).

4.4.1.2. About the effectiveness of roadway protection

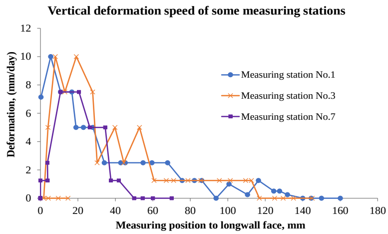
The total deformation value of the roadway during the monitoring period reaches the maximum 300mm (measurement station No. 1) in the vertical direction, 350mm in the horizontal direction (measurement station No. 3), corresponding to a reduction in the cross-sectional area of about 9.8 ÷ 9.97%, ensuring the size according to safety regulations to serve ventilation and production of the longwall 14-5-20. For details see the charts in Figure 4.10.



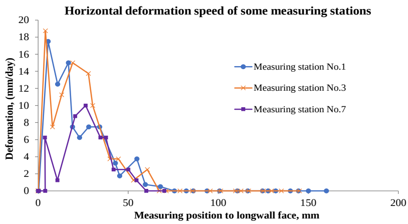
a. Degree of vertical deformation



b. Degree of horizontal deformation



c. Vertical strain rate



d. Horizontal strain rate

Figure 4.10. Result of deformation monitoring roadway of longwall 14-5-19

4.4.2. Economic efficiency assessment

The production cost in the form of using coal pillars protecting the roadway as planned by Khe Cham Coal Company is VND 1,617,844/tonne. The production cost when using artificial pillar to replace coal poles to protect the furnace line according to the research of the thesis is 1,583,929 VND/tonne.

Thus, applying artificial pillars has reduced VND 33,915/tonne of coal mined from the longwall. Corresponds to the total output of 67.45 thousand tonnes of commercial coal, the beneficial value brought to Khe Cham Coal Company in only one area of 14.5-19 longwall is 2,287,610,000 VND (actual efficiency is 2,410,033,517 VND).

CONCLUSIONS AND RECOMMENDATIONS

I. CONCLUSION

1. Experiential research in the world shows that the technology of using artificial pillars to replace coal pillar protecting the roadway has been and is being applied relatively popularly, allowing to reduce resource loss and bring about economic efficiency. According to the assessment results, the coal reserve left in the pillar protecting prepared roadways in the underground coal mines of Quang Ninh coalfield is relatively large, accounting for about 10.11% of the total mobilized reserves. In order to fully exploit this reserve, applying artificial pillars to replace coal pillars protecting the roadway is a suitable and feasible direction.

2. In the condition of underground coal mines in Quang Ninh region, when applying the form of artificial pillars made of high compressive resistance materials, the appropriate compressive strength of artificial pillars is from 20 ÷ 30 MPa. At the same time, the research results have shown that the width of the artificial protection pillar is proportional to the mining depth and the dip angle of the coal seam, but inversely proportional to the compressive strength of the pillar. In which, between the width of the artificial protection pillar and the dip angle of the seam, there is a relationship that follows a first-order linear function, with the average thickness of the seam $y = 0.0508x + 0.8829$, with the thickness of the seam $y = 0.0287x + 1.1118$.

3. The thesis has selected and proposed technologies to use artificial pillar to replace coal pillar protecting the preparation roadway suitable to conditions for underground coal mines in Quang Ninh region, along with a number of types. materials and equipment for the construction of pillar, including: (1) technology of using artificial pillars made of stone cribs; (2) technology of using artificial pillars with crib structure; (3) the technology of using artificial pillars in the form of continuous strips made of materials with high compressive strength. For each technology, the thesis has developed calculation instructions, construction process, as a basis for calculation application for specific application area conditions. At the same time, from the proposed technologies, the thesis has researched and

determined that when applying artificial pillars to replace coal pillars protecting the roadway, the coal loss rate is only 5.0 ÷ 19.41%, through That allows to reduce the loss from 9.06 ÷ 17.57% compared to the traditional form of protection of the roadway by coal pillars.

4. Based on the research results, the thesis has selected and calculated the design, implementation, monitoring and evaluation of the results of applying the solution of using artificial pillars with a crib structure to replace the coal pillar protecting the roadway of longwall 14-5-19 of Khe Cham III undergroud coal mine. Result of successful application, in the along transport seam 14-5-19 has the following deformation size to meet the technical and safety requirements to serve ventilation for the next longwall, which is 14-5-20. Besides, the successful application of the solution has allowed to reduce the loss rate by 25.0%, the cost metr of the preparation roadway by 23.08%, benefiting for Khe Cham Coal Company over 2.4 billion VND.

II. RECOMMENDATIONS

On the basis of the results of the thesis, it is recommended that management units and underground coal companies in Quang Ninh region consider, choose and apply technological solutions using artificial pillars to replace coal pillars protecting the preparatory roadways, in order to exploit the most of the reserve in the mining project, thereby reducing losses, investment unit costs, cost meter of preparation roadway and improving production efficiency for enterprises.

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