

Study on the possibility of using artificial pillar to replace the protection coal pillar of the preparation roadways during the mining process at underground coal mines in Quang Ninh region, Vietnam

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Abstract: The coal reserves in protection pillar of roadways are expected to be left in the mining process in underground mines in Quangninh coal basin which is relatively large (about 16% of the total reserves). If it can be exploited, it will help to save non-renewable coal resources, reduce the cost of preparing roadway meters, extend the mine life and increase the efficiency of construction investment. In the world, in order to reduce coal loss in protection pillar of roadways, mining technology to exploit and use artificial protection pillars are quite popular. Accordingly, in order to simultaneously exploit coal in the protection pillar and maintain the transport roadway as a ventilation roadway for the longwall in below level, the post-mining coal pillar will be replaced by artificial pillars formed from the stone backfill cribs, columns, metal cribs, chemical materials or low-grade concrete mortar mixes formed from fly ash, bottom ash of thermal power plants, combined crushed waste rock and a cement additive,... This paper will evaluate the possibility and propose a number of mining technological scheme as well as the type of construction materials suitable for artificial columns.

1. Introduction

In the underground coal mines of Quang Ninh region, longwall mining system is widely applied and always contributes most of the coal output. In this mining system, in order to maintain the transportation roadway in the coal seam of the upper stratified as a ventilation roadway for the lower-level longwall mining, the mining process along the axis of coal will leave a coal cribs bordering the transportation roadway as a protection pillar. Depending on the depth of exploitation, the geological characteristics of the area the roadways have to be protected, the coal pillar is in the direction of slope from 15 ÷ 20m, corresponding to the coal reserve of about 13 ÷ 15% of the total coal reserve. Dynamic in the mining space of the longwall mining (length of longwall in the direction of popular slope from 100 ÷ 150m). This is a ready-to-be-delineated reserve of prepared roadways, if it can be exploited, it will allow significant savings of non-renewable coal resources, reducing the risk of endogenous fire in areas with coal spontaneous combustion. At the same time, the coal mining in the protection pillars will make use of the existing constructions, so they do not have to pay for the cost of mining depreciation, contributing to reducing the cost of meters for preparation roadway, thereby allowing reducing production costs, prolonging mine life and increasing construction investment efficiency. To solve this problem, the mining technology scheme of using artificial pillars to replace coal-protection pillars for preparation roadways has been successfully applied in many countries around the world, effectively meeting the requirements.

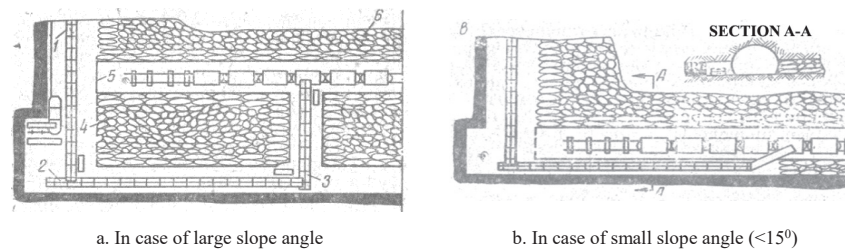
2. Experience of applying artificial pillars to replace coal pillars to hold up the preparation adits in the world

Technology to exploit and use artificial pillars to replace coal pillars to hold up the preparation roadway has been widely applied in the world. In particular, the materials used for the construction of the pillars can be clustered columns, wooden/metal cribs, backfilling brick/stone masonry or chemical materials. Recently, the material is a low-grade concrete mixture composed of ash and ash from thermal power plants, crushed waste rock combined with additives, cement is also applied and becoming more and more popular. The overview is as follows:

2.1. Artificial pillars are made of backfill stone

The artificial protection pillars by backfill stone is applied when exploiting coal seams of small thickness (usually below 2.0m) according to the seamless front exploitation system, driving the preparation roadway in accordance with the enlarged front scheme. In order for the working space to meet the prescribed requirements, the cross section of

longwall, the cross section of ventilation roadway and the cross section of transportation roadway have to be dug by carried forward will have to cut off part of the floor or roof. Stone after cutting will be transported to the scope of construction of artificial protection pillars, which will simultaneously allow maximum exploitation of resources, not transporting stones out of the door and limiting the risk of fire endogenous (Figure 1). This method was previously used quite popularly in the former Soviet Union (Centralnaya-Bokovskaya mine exploited the coal seam No.51 Nadbokovskiy with a thickness of 1.0m; Volodarskiy mine exploited the coal seam H8, Maidannovskiy with thickness of 1.1÷1.15m [2-4]).



1 - scraper conveyor in longwall ; 2, 3 - scraper conveyor for transporting coal; 4,6 - Stone backfill stone from blasting stones at longwall along seam 5; 5 - transportation roadway along seam

Figure 1. Diagram of construction for artificial pillars by stone backfill according to the exploitation system closely face

Construction diagram as shown in Figure 1 has disadvantages of backfill stone with large shrinkage so the area of using preparation roadway is expected to decline sharply after construction. In addition, the lower-floor longwall mining (if any) in the mining process will have to pass through the insertion stone 4 (Figure 1b) of the expanded stage longwall -face or to dig the new ventilation roadway (Figure 1a), so basically only applicable to the final longwall mining in the floor. This disadvantage will be overcome when organizing concurrent excavation of transport roadway (upper-floor longwall), ventilation (lower-floor longwall) by expanding face of longwall. Then, the coal pillars between the two roadways will be exploited to create storage space for waste rock from the longwall mining along the seam during excavation (Figure 2) without having to be transported out; the ventilation work is done by low pressure. General should be simple and cost-effective.

For example, this scheme has been applied in Russia could include Lugansugol coal mine (construction of roadway along the coal seam in a thickness of 1.5 ÷ 1.8m, excavation area of 14.5 m², excavation by blasting drilling) combined with the slitting machine, the excavation speed reaches 501 m/month) and Kalininygol mine in Tula coal region (construction of roadway along the seams in coal seams with a thickness of 1.2 ÷ 1.5 m, excavation area of 8.0 m², using ПК-3 Combain, speed reaches 1,635 m/month). In China, the Ba Yi Coal Mine (Shandong province) also applies this scheme to construct pairs of ventilation roadway and transportation roadway when exploiting the coal seam No.16 with a thickness of 0.8 m; the road is in square shape. Height and the width of the roadway is 2.0 m, the length of the extended face section between the two stone-insulated roadway is 8.0m.

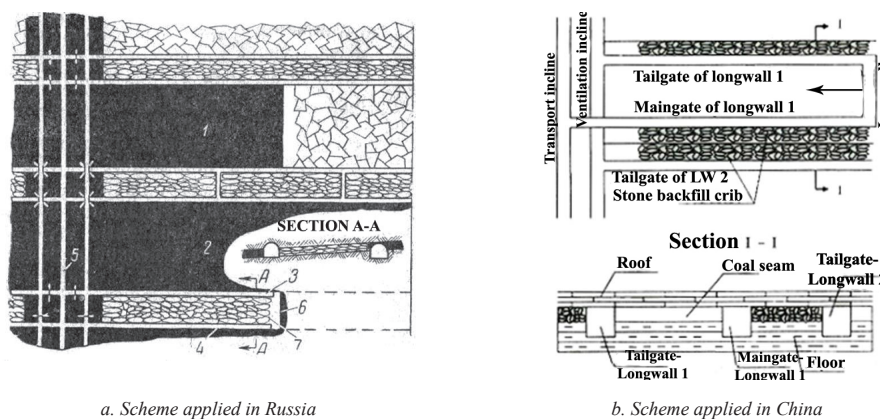


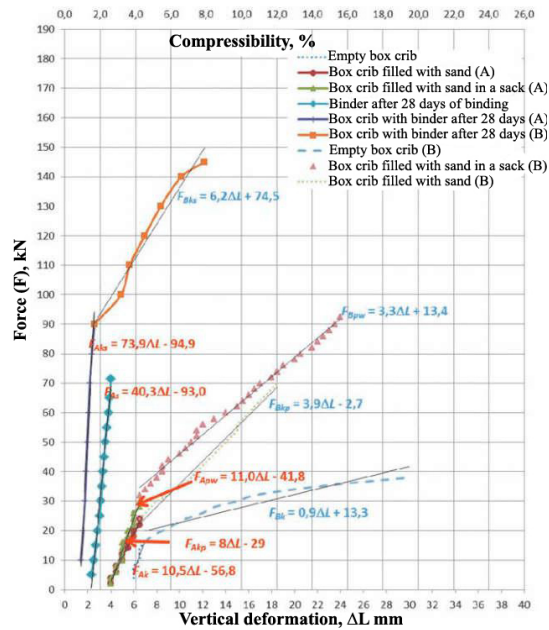
Figure 2. Construction diagram for artificial pillars by backfill stone according to the long-column exploitation system in the direction

2.2. Artificial pillars of crib form, clustered columns and support pillar

Artificial protection pillar made by clustered columns, wooden cribs, or support pillar are applied in larger coal seams. With protection pillar a crib form, to increase load capacity, it can be reinforced by filling the gap between by waste rock, sandbag, cement or mineralized material (chemical). Research by Polish scientists [7] has shown that the maximum compressive strength of wooden cribs is only 44 kN, but when filled with mineralized materials is increased to 166 kN, by sand bags 116 kN, (sand can be replaced with waste rock) 119 kN, details are shown in Figure 3.



a. Crib filled with chemical materials



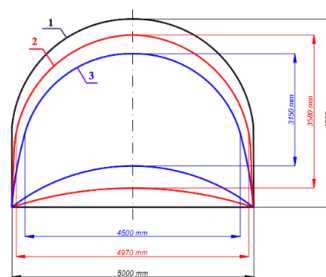
b. The intensity of compressive resistance of the crib according to the fill material

Figure 3. Comparison of compressive resistance strength and deformation level of crib according to fill material [7]

The concrete protection pillar was tested at Ziemowit mine (Poland). The concrete protection pillar with a diameter of 0.6m, is used to protect the roadway along the seam with the height from 4.0÷4.3m, width of 5.0÷5.5m when exploiting the longwall 902 and 904 at the seam No.209 (seam thickness 4.5m, slope angle 4°). The results of successful application, the protected adits ensure the required size as a ventilation adit for the next longwall (903 and 905), reducing 30 ÷ 60% of the cost compared to the new digging (Figure 4). However, this solution will not solve the problem of air leakage and gas, heat, water from the exploited area into the adjacent longwall.



a. concrete protection pillar in adit



b. Results of protection for adit along the seam 062

- 1-Size when digging;
- 2-The size of the scope of the junction longwall ;
- 3-Size at the position of 200m behind the face of the longwall

Figure 4. Results of applying solutions to replace coal pillars to hold up the roadway prepared by concrete pillars at Ziemowit mine (Poland)

2.3. Artificial pillars are continuous stone strip

To overcome the disadvantages of the structure of artificial protection pillars by columns, crib or concrete pillars (high timber costs, potential fire, air leakage, gas, heat, water from the exploited area), some underground mines in the world have built artificial pillars to form continuous stone strips at the edge of the roadway to be protected, thereby ensuring tightness and good isolation of the area exploited. Artificial pillars have the same height as the coal seams exploited, the width depends on the bearing capacity and construction materials, but usually equal to 0.7÷1.1 times the thickness of seams. In Poland, materials used to build protective pillars are usually formed from a mixture of water, cement, fly ash and other solid aggregates to increase the compression resistance of the pillar. The pillar after construction from 6÷7 hours will freeze under pressure, after 28 days the compressive capacity can reach 24 MPa [6].

In China, the replacement of coal pillars with artificial pillars is also quite popular. It can be mentioned that Xin Yuan Mine (Yang Mei Coal Group, Shandong Province) applied this solution to protect the roadway along the seam and supply clean air for the synchronized mechanization longwall mining 3107 at the seam No.3. (thickness of 2.8m, slope angle of 40°). The roadway is anti-anchor reinforced plastic combined with cable anchors, width of 4.0m, and height of 2.8m, length of roadway of 1592m, depth of topographic terrain surface of 500m. The artificial strip pillar is constructed with a mineralized mixture (chemical) of high water content (chemical-water-additive ratio is 1-5-1), pillar's size: height x width is 2.8x2.0 m, pierced through the pillar's body are arranged with additional steel anchors to increase compression resistance. The results of application are good, the size of the road ensures the requirements, and the stable strip pillar is not destroyed, the maximum mine pressure affecting the pillar is 12.75 MPa, details are shown in Figure 4 [13].



a. Location of construction for artificial strip pillar



b. The artificial pillar has been completed

Figure 4. Artificial pillar strip o the preparation roadway at Xin Yuan mine, Yang Mei Coal Group, Shandong Province

Besides the advantages of ease of construction, high bearing capacity, fast execution time, less shrinkage, good isolation of exploited areas, solutions for construction of artificial pillar by chemical materials with disadvantages: The point is high cost. Recently, a number of mines in China such as Duan Tai, Xi Nan, Wo Long Hu, Ping Mei, Da Zhuang, ... have used construction materials for artificial protection pillar of materials including mixed Combine fly ash, bottom ash of thermal power plant; combine a quantity of cement additive. The results of application are as good as chemical materials, while the cost is significantly reduced. At the same time, the use of fly ash and bottom ash also allows the settlement of a large amount of solid waste from thermal power plants in neighboring areas [8-12].

3. Potential of using artificial pillars to replace coal pillars to hold up preparation adits in Vietnamese underground mines

Evaluation results from applied 12 underground coal mines in Quang Ninh area (as Mao Khe, Vang Danh, Nam Mau, etc...) [1] showed that the reserves in the coal protection pillar are expected to be left in the mining process about 150.2 million tonnes, accounting for 16.25% of the total coal reserves (924.2 million tons). These are available reserves, will be zoned by the preparation roadway there its the longwall mining area, the reliability will be certain, if exploited, it will reduce the loss of resources and improve construction investment efficiency for mine, details see figure 6.

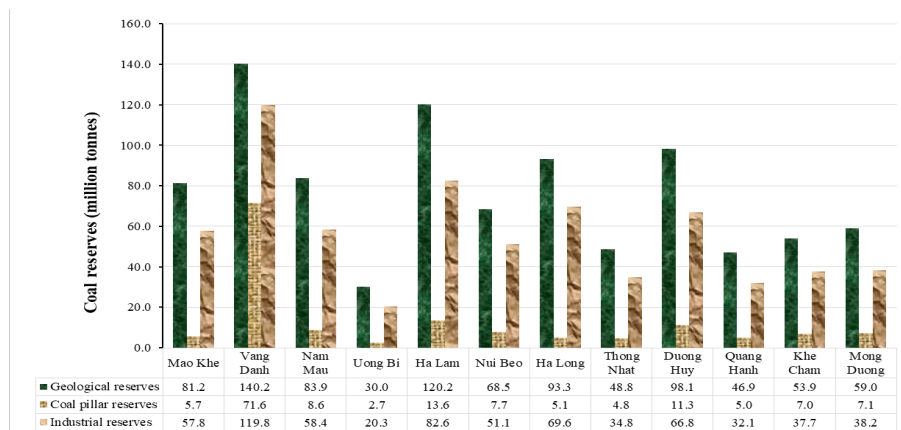


Figure 6. Coal reserves distribution in protection pillars according to mine projects

For the Vietnamese mining industry, the width of the coal pillar protecting the preparation adit is usually determined according to the formulas of Professor Protodiakonov [5] as follows:

$$L_w \geq \frac{\cos \alpha}{5} \times \zeta \times \sqrt{\frac{L_d \times H}{f}}, (m) \quad (1)$$

Where:

L_d - Length of slope direction of the longwall mining, m;

α - Slope angle of coal seam, degree;

H - Average mining depth, m;

f - Solid coefficient of floor rock according to the scale of Protodiakonov;

ζ - Coefficient refers to the strength of coal and roof rock.

From the formula (1) mentioned above, the depth of exploitation factor has a great influence and is proportional to the size of the protection coal pillar. Underground coal mines in Quang Ninh are exploiting the upper floors of the mine's project, the exploitation depth compared to the surface of the terrain is not large; the size of coal pillars protects in the preparation roadways. Has ranged from 15÷20m. According to the plan of the underground coal mines, in the coming time, it will have to dig deeper (550÷750m compared to the terrain surface [1], see Table 1 in detail), then the size of the protection pillar will increase, proportional to with it, coal losses also increase.

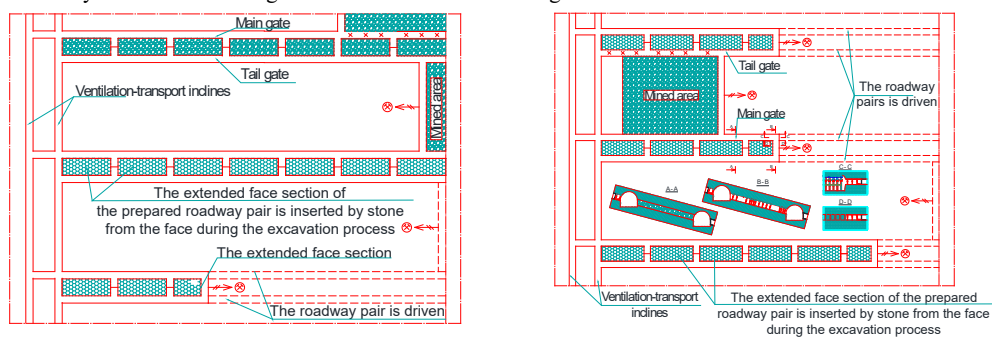
Table 1: Plan to go deep in some underground coal mines in Quang Ninh region

No.	Name of coal mine	Mining level		Average depth, m (calculated for the deepest level)
		Level	Depth (m)	
1	Ha Lam	Level I	-50 ÷ -300	550 ÷ 600
		Level II	-300 ÷ -450	
2	Nam Mau	Level I	+125 ÷ -50	645 ÷ 695
		Level II	-50 ÷ -200	
3	Vang Danh	Level I	±0 ÷ -175	700 ÷ 750
		Level II	-175 ÷ -300	
		Level II	-50 ÷ -150	
4	Duong Huy	Level I	+38 ÷ -100	590 ÷ 640
		Level II	-100 ÷ -250	
		Level III	-250 ÷ -350	
5	Thong Nhat	Level I	-35 ÷ -120	615 ÷ 665
		Level II	-120 ÷ -350	
6	Quang Hanh	Level I	-50 ÷ -175	500 ÷ 550

		Level II	-175 ÷ -300	
7	Mong Duong	Level I	-100 ÷ -250	650 ÷ 700
		Level II	-250 ÷ -400	
		Level III	-400 ÷ -550	
		Level I	-100 ÷ -300	
8	Khe Cham	Level I	-100 ÷ -300	550 ÷ 600
		Level II	-300 ÷ -450	

From the above analysis, combining experience in the world shows that the application of technology to exploit coal and use artificial pillars to replace coal pillars to protect preparation roadways in Vietnamese underground coal mines is very necessary and feasibility. However, due to the specific tropical climate, the annual rainy season is prolonged, the amount of heavy rainfall, meanwhile, at many mines when exploiting the upper layers, collapsing stone walls appears, and shifting the cracking of interconnects. To the surface of the terrain, the problem of surface water infiltrating / flowing into the exploited area, then exporting to the lower exploitation floor is entirely possible. Therefore, the solution use the artificial materials and structures to replace protective coal pillars applied in Vietnamese underground mines must have some adjustments to suit the actual conditions. On that basis, in the conditions of Vietnam, it is possible to apply some solutions to use artificial pillars to replace coal pillars to protect the preparation adits in the process of exploitation as follows:

- (1) **Using artificial protection pillars are stone strips.** To overcome the disadvantages of high shrinkage, wind leakage, it is possible to add a concrete mortar of low-grade concrete (cement or fly ash of thermal power plant) to the stone strip inserted after construction. This solution can be applied to reservoir conditions up to 2.0m thick, the area is less affected by surface water and groundwater. For details see Figure 7.



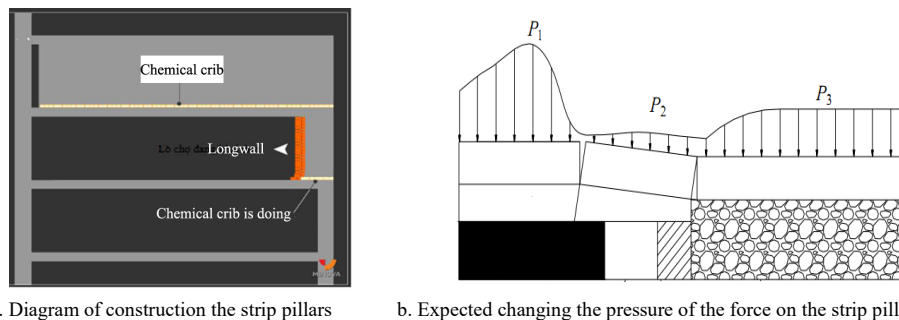
a. Stone strips in mining longwall system along the strike

b. Stone strips in longwall system with simultaneous mining and driving roadway

Figure 7. Artificial pillars formed by stone backfill

- (2) Using artificial protection pillars are in the form of wooden crib structured (inside filled with waste rock, sand bags or mineralized materials) or by concrete pillars: This type of artificial pillar can be applied to seam conditions has large thickness (experience at Ziemowit mine is up to 4.5m). Similar to the solution of using stone inserts, the structure of artificial pillars of this type is also not suitable for application in areas affected by surface water and groundwater. In particular, in the coal seam area with self-burning coal characteristics, this solution will not be applied due to the disadvantages of wind leakage into large mining areas, easily leading to the burning of protection coal pillars in the area.

- (3) Using artificial protection pillars in continuous strips: Materials used to build artificial pillars are chemical materials (chemical mineral) or concrete mixes including fly ash, bottom ash of thermal power plants, combined a quantity of cement additives (Figure 8). This solution will be suitable to use for many conditions of different seam thickness, good isolation ability should be applied to areas affected by surface water, groundwater as well as in coal mining conditions. Capable of self-igniting. Besides, in the conditions of Vietnam, Quang Ninh province is currently the province with the most coal-fired power plants in the country with a total generating capacity of about 5,550 MW, equivalent to the amount of ash discharged annually about 7.5 million tons/year, is a huge challenge for thermal power plants in storage and handling issues to ensure the safety of the living environment of local residents and the regional landscape. If it is possible to use ash to build artificial pillars to protect the preparation adits during coal mining in the underground mines of Quang Ninh, at the same time as reducing coal loss, it will also contribute to reducing the pressure load. Above forces for thermal power plants.



a. Diagram of construction the strip pillars

b. Expected changing the pressure of the force on the strip pillar

Figure 8. Technological diagram of exploitation and use of artificial pillars made of chemicals or concrete mixtures

4. Conclusion

Applying technology to use artificial pillar to replace coal pillars to hold up the preparation roadways during coal mining in Vietnamese underground coal mines is necessary to reduce the loss of non-renewable coal resources and the cost for a meter of preparation adits, production costs and improve the efficiency of mine construction investment. However, the Vietnamese mining industry has not had much experience; there is also no in-depth research on this field. The solutions given by the authors in the basic scope of the report only at the proposed level based on foreign experience. Therefore, in order to meet the requirements of Vietnam's coal industry, it is necessary to study and cooperate with experienced foreign partners (eg Poland) to jointly research and apply the technology testing using artificial pillars to replace protective coal pillars in real conditions at Vietnamese underground coal mines, as a basis for evaluating, improving and replicating technology.

References

1. Investment project for construction of underground coal mines in Quang Ninh, Vietnam.
2. Проведение штреков широким забоем на шахте «Центральная-Боковская», бюллетень ЦИТИ (1957).
3. Разработка угольных пластов без выдачи породы на поверхность, Косович В.Л., 125с, Углетехиздат (1958).
4. Краткий справочник горного инженера угольной шахты, Бойко А.А., 642с, Москва (1963).
5. Задачик по подземной разработке угольных месторождений.
6. Piotr Niełacny, *Praca doktorska: Dobór technologii utrzymywania wyrobisk przyścianowych w jednostronnym otoczeniu zrobów na podstawie pomiarów przemieszczeń górotworu*, Akademia Górniczo-Hutnicza w Krakowie (2009).
7. Waldemar Korzeniowski, Krzysztof Skrzypkowski (2012), Badania porównawcze nośności i charakterystyk obciążeniowo-odkształceniowych kasztów o różnym wypełnieniu, *Przegląd Górniczy*, Nr 4, 36-40, (4/2012).
8. 刘德明, 赵平谦, 晏立森. 平煤股份一矿戊8-22180工作面沿空留巷膏体充填材料的应用研究[J]. 华东科技:学术版, 372-372, (8/2013).
9. 柳成懋, 戚洋. 沿空留巷膏体充填工作面顶板控制技术[C]. 全国采矿学术会议 (2015).
10. 张大虎, 范祥峰. 膏体充填沿空留巷技术在卧龙湖煤矿的应用[J]. 安徽科技, 50-51, (8/2010).
11. 张年有. 膏体充填沿空留巷技术研究[J]. 煤矿现代化, 4-6, (1/2017).
12. 刘国磊, 温朋朋, 贾广辉. 济阳煤矿膏体充填沿空留巷技术[J]. 煤矿安全, 43(12):94-96 (2012)
13. 张自政, 博士学位论文: 沿空留巷充填区域直接顶稳定机理及控制技术研究, 中国矿业 (2015)