Study on Concrete Carrier Replacing Chain Pillar Between Two Working-faces of the Mining

Li-min LIU*, Jin-peng ZHANG, Chen GAO, Yang LI

ABSTRACT
In order to solve the problem of wasting and poor stability of coal pillar in gob-side entry driving, this paper put forward the concrete carrier replacing chain pillar to achieve the true pillar less mining. The concrete carrier replacing chain pillar is to set aside along concrete carrier driving roadway rather than along the chain pillar. The gangue in the underground mining is directly crushed to produce prefabricated block, then the prefabricated block is connected with the top of roadway to form a concrete carrier which can support the top plate and isolate the goaf and the next section ventilation roadway. The key block theory, FLAC3D numerical simulation and engineering application were used to analyze the stability, feasibility and economy of concrete carrier replacing chain pillar. The results revealed that: The deformation of roadway of concrete carrier is far less than that of coal pillar; The concrete carrier of 1200 meter can gain revenue of 8.325 million Yuan. So it has a significant economic benefit.

INTRODUCTION
At present, the most mines in China still adopt the traditional gob-side entry driving, that is setting the 4–6m width of small coal pillar between the two working surfaces. Some scholars have studied the stress distribution and the width of coal pillar of gob-side entry driving. The theoretical calculation and numerical simulation method are used to study the rational design of small coal pillar of gob-side entry driving1. According to the specific geological conditions, Zhang Q designed solid, dense backfill advanced mining technology with two pre-driving entries2. Huili Lin researched on walling-up with concrete block technology of gob-side entry retaining based on fully mechanized face in medium-thickness coal seam3. WANG Xiang Qian studied on reasonable filling width of gob-side entry retaining4. Zhang Wei etc put forward the surrounding rock deformation control measures5. Meng Chao etc studied the bolt parameters
according to Geological conditions, and obtained that the engineering practice should ensure the preload of the bolt to meet the demand.

The small coal pillar along the gob can isolate the mined-out area and play a certain role in the prevention of air leakage and spontaneous combustion in the short term. However, it causes the waste of coal resources. Because of the Lateral bracing pressure and the advanced abutment pressure of the working face, the plastic zone in coal pillar is developed and the stability of coal pillar is poor. Some scholars have studied the stability of coal pillar and the width of coal pillar. Yang Jiping studied the failure laws of narrow pillar and asymmetric control technique of gob-side entry driving in island coal face7.. Zhao Ming investigated the reasonable width of narrow coal pillar of gob-side entry driving in large mining height8. Sun Qiang researched and applied the schemes for constructing concrete pillars in large section finishing cut in backfill coal mining9. Yuan Zhang studied the stability of coal pillar in gob-side entry driving under unstable overlying strata and its coupling support control technique10. Li Huamin investigated the trial of small gateroad pillar in top coal caving longwall mining of large mining height11.

If the high strength concrete carrier replaced chain pillar, the roadway support will be relatively easy owing to the high compressive strength of the concrete carrier. In addition, replacing chain pillar by the concrete carrier can improve the pillar recovery rate and really realize the non-pillar mining. For the replacing chain pillar by the concrete carrier, no scholars and experts studied it.

So, this paper put forward the technology of concrete carrier replacing the chain pillar. Firstly, the production process and the roofing technology of the concrete carrier are explained in detail. Then the key block theory is used to analyze the stability of concrete carrier of roadway under overlying rock mass fracture structure. The feasibility of concrete carrier replacing the chain pillar is determined. Taking the practical application of a certain mine as an example, the superiority of concrete carrier replacing the chain pillar is studied systematically.

BRIEF INTRODUCTION OF CONCRETE CARRIER

The concrete carrier replacing chain pillar is to set aside along concrete carrier driving roadway rather than along the chain pillar. During the excavation of the roadway in the upper section of the working face, the roadway with large section is directly excavated and bolted in time. When the roadway is excavated for a certain distance, in the area near the working face of the next section. When the overlying strata movement of the overlying strata after the end of mining was stabilized, the tailgate in the lower section has been excavated along the concrete carrier. So, the original section pillar was replaced by the concrete carrier to achieve the coal face without pillar mining.

Prefabricated block making

Gangue concrete prefabricated block making is very simple, the coal mine underground mining gangue is directly crushed into 5cm3 below the granular stone in the underground mining chamber. Then add 425# ordinary portland cement and river sand, and the weight distribution ratio is 6:2.5:1.5. After adding water, using the briquetting machine to press the prefabricated block into the size of 40cm×30cm×30cm. Prefabricate block dry molding and use the mine car transport it to the roadway construction. In order to ensure the support effect
of the carrier, the compressive strength of the block must reach 30MPa. Table 1 shows the construction materials of gangue concrete wall.

Table 1. The construction materials of gangue concrete wall.

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Material name</th>
<th>specification</th>
<th>Use or effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>cement</td>
<td>42.5R</td>
<td>Prefabricated blocks from the cementation</td>
</tr>
<tr>
<td>2</td>
<td>water</td>
<td>freshwater</td>
<td>Used for mixing</td>
</tr>
<tr>
<td>3</td>
<td>sand</td>
<td>Medium sand</td>
<td>Prefabricated blocks play a skeleton role</td>
</tr>
<tr>
<td>4</td>
<td>Stone</td>
<td>Gravel, 5-16 continuous gradation</td>
<td>Prefabricated blocks play a skeleton role</td>
</tr>
<tr>
<td>5</td>
<td>additive</td>
<td>Pumping agents and so on</td>
<td>To obtain a suitable setting time</td>
</tr>
</tbody>
</table>

Support the body to the top process

After the excavation of the haulage roadway (under-floor driving), the roof and the upper gang of the roadway should be supported in time. It should be pointed out that the roadway roof should be supported by the anchor cable and the prestressed anchor bar, then operate the masonry bearing carrier. Firstly, the floor rock should be polished before masonry carrier, so that the floor is flat; then laying cement mortar, constructing the first layer of prefabricated blocks and constructing a layer of masonry-type prefabricated block in accordance with the cycle. After carrying the body is about to top, continuing to pre-block at this time is very difficult, because the top of the wall and roof space is small. So, we add a layer of the partition in the side of the wall as the boundary of the partition. Then pouring concrete into the small space of the carrier roof for the full access to the top that the concrete strength must meet the C35 standard. After 5 to 7 days, when the concrete is shaped, the partitions are picked off. Finally, brush a layer of cement slurry in the outside wall to prevent air leakage. Concrete carrier to connect the top of the method shown in Fig. 1.

Figure 1. The measures of concrete carrier touching wall.

STABILITY OF THE OVERLYING ROCK MASS UNDER THE CONCRETE CARRIER

Rock breaking structure

The upper concrete carrier is the section haulageway. In order to prevent the influence of upper section mining, excavate the next section tail entry after the end of the mining area. In the process of working face mining in the upper section, the roof stratum gradually collapsed and formed the "O-X" structure finally. In the process of the periodic pressure, formed the
structure of voussoir beam at the roof rock stratum along the working face and the arc triangular rock mass at the end position of the masonry beam. The arc triangular rock mass is rotated and sunk along with the advancing of the working surface, and reached to a stable state. The roadway is located under the arc triangle block and is directly affected by the shape of the arc triangle, as shown in Fig. 2.

When the upper section of the working face is mined, the caving characteristics and the occurrence of the falling behind of the overlying rock depend to the basic roof to certain degree. Therefore, the fracture of the overlying rock under the load carrier has the following processes:

1. After the upper section of the working face bracket pushed, the collapse of the roof strata, which is separated from the base rock. The level of coal seams in the middle and both ends of the working face is different, and the direct roof caving degree is also different. At both ends of the working face coal seam is not fully mined, the direct roof of the regular collapsed, as shown in Fig. 2 of B; the central working face is fully mined out, the direct roof of the irregular collapse, as shown in Fig. 2 of C.

2. After the direct roof caving, the basic roof rock is broken, which causes the formation of the rock stratum to bend and sink or rotation, and finally form a hinge structure composed of a multi rock mass. Rock block A, B, C, as shown in Fig. 2. The stability of the hinged structure is determined by the fracture parameters of the basic roof strata and the full extent of the mined out area.

3. With the collapse of the basic roof strata, the overlying strata movement. Grouping the caving movement of the overlying rock under the load carrier, The first group is with the mining of the coal seam, the immediate roof caving, the second group is the basic top layer and the overlying strata fall behind to form a balanced and stable structure. In Fig. 2, the rock block A represents the basic top rock strata above the working face, and the B of the rock block represents the arc triangular block of the working face, and the C represents the caving rock in the goaf, a represents the next bleeder entry. Roadway A is located at the bottom of the rock block B, and the rock block B plays a key role in the stability of the overlying rock mass structure on the roadway, which is called the key block.

Figure 2. Model of the roadway next to the carrier.

**Stability analysis of the rock breaking structure in the roadway under the concrete carrier**

The stability change process of the basic roof key block B structure is overburden caving in goaf formed the key block B structure after mining the upper section working face, the disturbance of the key blocks B structure in the roadway under the load carrying capacity, the influence of lead bearing pressure on the key blocks B structure in the face mining under
the working face of the lower section, its stability is a disturbance to the working face during the process of mining from the stable state to the front of the roadway. The stability condition can be divided into three stages: before and after the roadway, the mining effect of the working face.

(1) Stability analysis of overlying rock mass structure in front of the roadwaying

Mining the upper face over a period of times, the B key block structure rotary carrier position of the upper part of the lower roadway sinking stable, the effects of T3, T2 and T1 are provided by the adjacent rock block A and rock mass C. the role of Q3, Q2 and Q1 in vertical upward friction shear. the function of F1 and F2 on the vertical support of the coal gangue and the side carrier and coal body in the upper section. and the role of P in the vertical downward pressure of the overlying strata. The specific stress of the key block B is shown in Fig. 3.

Under the condition of given settlement, the gangue and the empty side carrier and the coal body in the lower part of the key block B will form a strong supporting function to it. at the same time, the key block B will be subject to the rock block A and rock block C, the key block B is in a stable state. The stability of key block B analysis indicated that in the carrier under section excavation tail entry, overlying rock structure of the upper part of the roadway position is stable.

![Figure 3. The force situation of the key blocks B.](image)

(2) Analysis on the stability of the overlying rock mass structure after the roadway roadwaying

Excavate roadway under the overlying rock structure. The immediate roof above the roadway is in the larger thickness, better integrity. The roadway and overlying rock structure has a certain vertical distance. The driving position of the roadway is in the low stress zone with a relatively small bearing pressure. Therefore, the impact of roadway excavation on the overlying coal and rock strata is little, the deformation and stress characteristics of the key block B are basically unchanged, and the overlying rock mass structure remains stable.

From the above analysis, during roadway excavation, the rock deformation of roadway can be controlled in a small range, the deformation of surrounding rock can be reduced, and the deformation caused by the creep of surrounding rock can be reduced. The key to enhance the stability roadway is: reasonable supporting scheme, reasonable supporting time and high strength prestressed anchor bolt. Using high strength prestressed anchor bolt to slow down the roof sinking of the roadway on both sides of the carrier and make full contact with the carrier.
Analysis on the stability of overlying rock mass structure during the working face mining

① When the next working face is mined, the basic roof rock strata above the mined out area is broken. Due to the roadway is located in front of the working face under the carrier, this break will not occur in the lower carrier above the roadway, only in the mined area. The upper part of the mined out area is connected with the newly generated rock block A and the original rock block B.

② The rock block A is turning to the working face in the direction of the gob and the rock block B after the basic roof breaking. The rock block A after sinking exerts horizontal thrust and vertical friction force on broken basic roof rock in front of the work face. This breaks the stable state of the overlying strata structure in front of the work, and the direct result is: there will be formed a higher lead support pressure in the front side of the working face.

③ Because of the low strength of the solid coal near the roadway, the roadway under the load carrying capacity will produce large deformation under the stress of the surrounding rock. It should be noted that, due to the redistribution of the surrounding rock stress is not balanced, the rock mass property of the roadway roof and surrounding are different, which makes the deformation difference between the roadway roof and surrounding.

The carrier of roadway from beginning to be ahead of the working face support pressure to the working face in a vertical section, the overlying strata structure of the load has been increasing, but the support condition of rock mass has not changed essentially. Therefore, the structure of the overlying strata in the roadway could still be in a stable state. That is to say, as long as the roadway supporting is effective and reliable, the working face passes during the period before the service is to maintain a good stability, and can ensure the normal use of roadway in service period.

OVERVIEW AND DESIGN OF PROJECT

Engineering geological conditions

A mining area adopted the way of vertical shafts. The mine is currently mining Shanxi group 3 coal seam. The average thickness of the coal seam is 2.85m, the average angle is 5.75°, the immediate roof is sandy mudstone that thickness is 3.97m; the basic roof is coarse sandstone that thickness is 17.65m; the immediate floor is sandy mudstone that thickness is 3.56m; the basic floor is fine sandstone that thickness is 13.8m.

213 tailgate was located in the 3 coal seam -400m level. In accordance with the original program, before 213 face mining, in 211 face along the roadway driving on the 213 back to the tailgate with concrete bearing pillar instead of the original roadway pillars width of 4m.

Numerical simulation

The simulation study on the concrete carrier replacing chain pillars under the above engineering geological conditions is carried out by using FLAC3D software. The scheme 1 has compared with the scheme 2.

(1) Scheme 1 (coal pillar with the width of 4m)

Select the original scheme of chain pillar along the roadway leaving the pillars width with the of 4m. The driving section of ventilation roadway 213 is 3mx3m (widthxheight). Roadway
anchor bolts are high-strength prestressed anchor. The specific layout parameters as follows: the anchor specifications in roof of Φ20mm×2200mm, the row spacing between the anchor of 800mm×900mm; the anchor specifications in roadway sides of Φ18mm×1800mm, the row spacing of 800mm×900mm. Arrange three rows of cables in roadway roof by "2-1-2 way", specifications of Φ17.8mm×6000mm and spacing of 1600mm×900mm.

(2) Scheme 2 (carrier with the width of 2m)

The concrete carrier of 2m to replace the roadway pillars. Only support the roof and the right side of roadway on the 213 tailgate with cross section of 3m×3m. The anchor bolts are high-strength prestressed anchor. The specific layout parameters are: the anchor specifications in roof of Φ20mm×2200mm, the row spacing between the anchor of 800mm×900mm; the anchor specifications in 213 tailgate Φ18mm×1800mm; three rows of anchor cables are arranged in the roof of the roadway. Arrange three rows of cables in roadway roof by "2-1-2 way", specifications of Φ17.8mm×6000mm and the row spacing is 1600mm×900mm.

(3) The deformation of ventilation roadway

① The displacement of top and bottom plate

Fig.4 displayed that the displacement of roof and floor in scheme 1 leaving the coal pillar of 4m was 420mm; the displacement of roof and floor in scheme 2 leaving the concrete carrier of 2m was 330mm. Compared with the scheme 1, the displacement of roof and floor of scheme 2 dropped 90mm, and decreasing significantly.

(a)Program 1   (b) Program 2

Figure 4. The displacement of the roadway roof and floor cloud.  Figure 5. The two sections of the roadway displacement diagram.

② The displacement of the roadway sides

Fig.4 displayed that the coal pillars of 4m are reserved in the scheme 1. The displacement of right side is 300mm. the displacement of left side is 479mm. The displacement of right side in the scheme 2 leaving concrete carrier of 2m is 50mm .The displacement of left side is 280mm. Compared with the scheme 1, the displacement of roadway sides of scheme 2 has decreased obviously, especially for the displacement of right side.

The next section of deformation of ventilation roadway

The application of the concrete carrier replacing chain pillar is carried out according to scheme 2. Then observed the deformation of roadway surrounding rock and selected two stations named station 1 and station 2. The deformation curve of the surrounding rock of the station 1 is shown in Fig.6. The deformation curve of the surrounding rock of the station 2 is shown in Fig.7.
Fig. 6 shows: with the continuous improvement of the working face, the deformation of the surrounding rock of station 1 roadway had a big difference. The closer the working face is to the station, the larger deformation of surrounding rock is. The deformation of the roof and floor and the two strata of the roadway are obviously aggravated, attaching to 342 mm. The deformation is much larger than that of the upper section. The maximum amount of the carrier side was 40 mm and the maximum amount of the pillar side was 310 mm.

Fig. 7 shows: with the continuous advancement of the working face, the deformation of the surrounding rock of station 2 roadway has a big difference and the roadway changes in the law and the station 2 is similar to the curve. The closer the working face is to the station, the larger the deformation of surrounding rock is, the faster the deformation is. When the face is advanced to the front of the station about 45 m, the deformation of the roof and floor and the two strata of the roadway are obviously aggravated and the deformation is obviously larger than that of the upper section. The maximum displacement of the roof and floor is 349 mm. The maximum bulging amount of the carrier is 45 mm. The largest drum up the amount of the pillar is 330 mm.

**Analysis of economic and social benefits**

Masonry concrete carrier to replace the roadway pillar input costs are mainly used to buy cement, sand, additives and other materials and grinding graded gravel and depreciation of mechanical wear and tear, support work and so on. The cost of materials used is shown in Table 2 below.

<table>
<thead>
<tr>
<th>Material name</th>
<th>unit price</th>
<th>Per meter to the length of the carrier (2m wide×3m high) usage</th>
<th>Per meter length to the carrier (2m wide×3m high) corresponds to the cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>425 # cement</td>
<td>500 yuan/t</td>
<td>2 t</td>
<td>1000yuan</td>
</tr>
<tr>
<td>Sand</td>
<td>80 yuan/m³</td>
<td>2.5 m³</td>
<td>200yuan</td>
</tr>
<tr>
<td>Fly ash and other active materials</td>
<td>180 yuan/m³</td>
<td>0.5 m³</td>
<td>90yuan</td>
</tr>
<tr>
<td>additive</td>
<td>15 yuan/kg</td>
<td>5 kg</td>
<td>75yuan</td>
</tr>
<tr>
<td>Graded stones</td>
<td>80 yuan/m³</td>
<td>4 m³</td>
<td>320yuan</td>
</tr>
<tr>
<td>Mechanical costs</td>
<td>50 yuan/m</td>
<td>50yuan</td>
<td></td>
</tr>
<tr>
<td>Other wages</td>
<td>80/m</td>
<td>80yuan</td>
<td></td>
</tr>
<tr>
<td>Total cost per meter to length of carrier</td>
<td></td>
<td>1815yuan</td>
<td></td>
</tr>
</tbody>
</table>
As can be seen from Table 2, the cost of 1 m concrete carrier is about 1,800 yuan. 1m carrier can replace the original coal pillars (5m ×3m). The length of the 211 haulage roadway is 1000m. Set the ex-factory price of 500 yuan/t. The average density of coal is 1.35t/m3. Then, the income of masonry the 1200m concrete carrier to replace the roadway pillars:

\[ S = 1000 \times (500 \times 1.35 \times 5 \times 3 - 1800) = 8,325,000 \text{ yuan}. \]

As the application of anchor bolt in the original scheme is cancelled, the economic benefits of the concrete carrier replacing chain pillar will further increase. So, bring about obvious economic and social benefits.

CONCLUSION

(1) The concrete carrier replacing chain pillar is to set aside along concrete carrier driving roadway rather than along the chain pillar. Prefabricated block are directly made of the rock refuse of underground mining in the mining area and then carrying the body connected to the top. The concrete carrier can support the roof and isolated from the mined-out area and lower section of ventilation roadway.

(2) The critical block theory is used to analyze broken structure of overburden strata in under-roadway. It is known that the roadway is supported by the high-strength prestressed bolt, the structure of overburden rock can remain stable.

(3) The application of the concrete carrier replacing the chain pillar decreased the deformation of the roadway obviously. The concrete carrier of 1200 meter can gain revenue of 8.325 million yuan. So it has a significant economic benefits.

REFERENCES


10. Yuan Zhang; Zhijun Wan; Fuchen Li; Changbing Zhou; Bo Zhang; Feng Guo; Chengtan Zhu. Stability of coal pillar in gob-side entry driving under unstable overlying strata and its coupling support control technique. International Journal of Mining Science and Technology. 2013, 23(2):193-199.

11. Huamin Lia; Peng Sydb; Huigui Lia; Yongxiang Xua; Ruifu Yuana; Shuaishuai Yuea; Kun Lia. Trial of small gateroad pillar in top coal caving longwall mining of large mining height. International Journal of Mining Science and Technology. 2016, 26(1):139-147.