Journal of Civil Engineering and Urban Planning (2024) DOI: 10.23977/jceup.2024.060111
Clausius Scientific Press, Canada ISSN 2616-3969 Vol. 6 Num. 1

# *Application of Roof Cutting Gob-side Entry Retaining Technology in Soft Coal Seam with Large Mining Height in Liangbei Mine*

**Ruize Xu[1,*], Ranghe Zhu[2], Qiang Ma[2]**

[1]*College of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo, Henan, 454001, China*
[2]*Henan Xuchang Xinlong Mining Co., Ltd., Yuzhou, Henan, 461670, China*
[*]*Corresponding author*

***Keywords:*** Soft and Weak Thick Coal Seam, High Cutting, Roof Cutting Gob-Side Entry Retaining, Flexible Concrete Infilled Wall, Roadside Support

***Abstract:*** Aiming at the problems of strong dynamic pressure, severe roadway deformation and difficult implementation of Roof cutting Gob-side entry retaining technique in the application of weak and thick coal seam conditions, combined with the 21051 working face of Liangbei Mine, proposed the surrounding rock deformation control idea of concrete flexible membrane + dense anchor cable beam + single hydraulic prop cooperative support. The theoretical calculation verifies the load capacity of the flexible concrete infill wall. Simulation and analysis of the deformation pattern of large mining height and soft coal seam conditions were carried out using FALC 3D numerical software. The numerical calculation showed that the flexible concrete formwork can prevent the rotation of the short arm beam in the roof structure of the gob-side entry retaining wall to a certain extent and decrease the deformation in the roof structure in the deck. The support parameters of gob-side entry retaining were designed, and conducted field trials. The field application results indicate that under the active support, single hydraulic prop and flexible formwork support, the roof of gob-side entry retaining is complete, the degree of distortion of the enclosing rocks is within manageable limits, and the field application effect is good, that can meet the demands of the next mining face.

## 1. Introduction

Compared with the traditional coal mining engineering, gob-side entry retaining does not require coal pillar protection, which can ease the strain of replacing mined material and reduce wasted coal resource. At present, the most widely used gob-side entry retention technique is roof cutting and roadside filling techniques. In terms of gob-side entry retaining by roof cutting, He Manchao proposed the technique of the self-forming roadway with no coal pillars by cutting the roof [1].Through the energy-gathering blasting roof cutting, The goaf's roof is cut off along the cutting surface after mining, and the the roadway roof forms a short cantilever beam, which can limit the impact of mining pressure on gob-side entry retention. However, after cutting the roof of the working face at a large working height in a thick seam of coal, the broken and swollen roof gangue cannot completely fill the goaf, and cannot prevent the rotation and lowering of the key block of the overlying base roof, resulting in strong mine pressure in the retaining roadway. Under the condition of soft and thick coal seam, there will be problems such as easy spalling of the side and roof caving of the rof. [2]. Roadside filling gob-side entry retention technique has also developed rapidly. At present, a variety of filling materials and filling methods suitable for different geological conditions have been developed [3,4]. It is mainly divided into two kinds of concrete pouring wall and precast block assembly wall [5,6]. It balances the activity of overlying strata with high strength roadside support, and has certain shrinkage. The flexible concrete filled wall makes up for the lack of the side due to mining, And with the former support of the roadway to form a whole, to withstand the mining pressure, to keep the stabilisation of the roadway, in order to normal use in the next working face [7,8].

With regard to the retention of the gob-side entry in a thick coal seam, hrough theoretical analysis and numerical simulation. FENG et al [9] found the stress distribution law of the filler adjacent to the roadway and believed that the stress distribution was related to the deformation characteristics of the first weighting and periodic weighting of the working face. According to the geological characteristics of weak and thick coal seam. ZHANG et al [10] proposed the Gob-side entry retention technique of roadway excavation along the coal seam roof and mining along the coal seam floor. By the addition of wooden cribs at the top of the carriageway with a high level of support, the amount of coal mining was improved, and the stability of the gob-side entry retainer has been assured. Wang [11] proposed a collaborative control scheme for stabilizing the surrounding rock of gob-side entry retaining through the utilization of hydraulic fracturing roof cutting and concrete roadside filling technique, which was successfully applied in the mining face of high gas thick coal deposit. GUO et al [12] proposed a way of gob-side entry retaining through the use of reinforced support and flexible concrete filled wall technology, the effect of gob-side entry retaining is good.

The roadside support offlexible concrete filled wall has the characteristics of large initial support force and appropriate shrinkage in the beginning phase of flexible concrete filled wall, and inherits the rigidity of concrete support in the later stage, which is the first flexible and then rigid roadside support in the gob-side entry restraint[13,14]. Supporting the side of the roadway after roof cutting can control the rotation deformation of the short arm beam of the roadway roof.

In summary, this paper takes the 21051 machine roadway of Liangbei Coal Mine as the background. In the context of directional blasting roof cutting in a soft and thick coal seam at a large mining height mining face, it is proposed to adopt the cooperative control scheme of 'concrete flexible formwork wall plus anchor net cable active support and single hydraulic prop' for the stabilization of the surrounding rock in the gob-side entry. The deformation characteristics of the roadway are analyzed, and the feasibility of its application at a large mining height in a thick coal deposit is studied.

## 2. General Situation of Mining Face

The average coal thickness of 21051 machine roadway is 5.3m, with the coal seam exceeding a thickness of over 8 m. The $II_1$ coal is black, powder and granular, semi-bright, no dirt band, and the solid coefficient of coal body is 0.15-0.33.It is a very soft coal seam. The coal simple seam has a structure, and its stability is relatively consistent. The 21051 working face is buried at a depth of 506 m, with a strike length of 1235 m, an inclination length of 230 m, and full mining height all at once. The arrangement of the working face is depicted in Figure 1. The immediate roof consists of a 3.0 m layer of sandy mudstone, which is low in strength and relatively broken, and has exceeded the scope of bolt support. The basic roof comprises 11.5 m of hard sandstone, along with an average coal thickness of 5.3 m and an average dip angle of 7°. Given the significant depth at which the roadway is buried and the weak nature of the surrounding rock, the roadway experiences substantial deformation, characterized by rapid speed, the deformation on both sides and the roof is exacerbated, the loosening range is expanded, the mine pressure is obvious, and the deformation is more severe during mining.

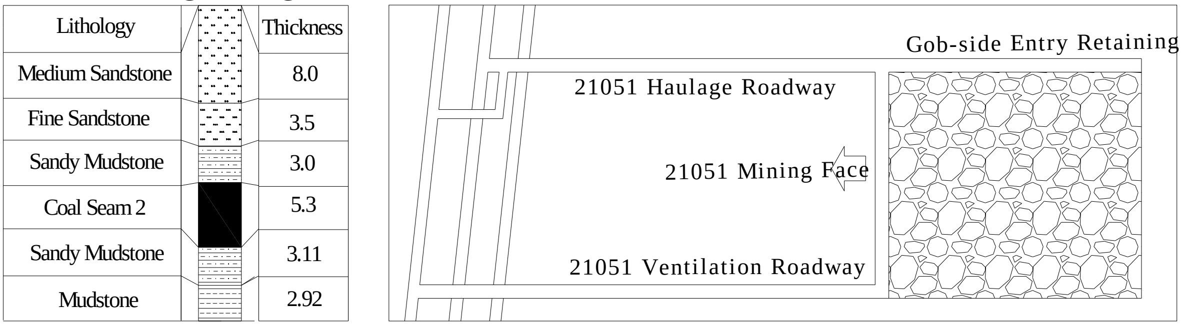


Figure 1: Comprehensive columnar and layout of mining face.

The 21051 deep hole pre-splitting blasting method is used to cut the top, and the specific specifications of the explosive are installed in two energy-gathering devices with energy-gathering effect oriented accordingly. Taking advantage of the rock's low tensile strength and compressive resistance characteristics, the blasting object is tensioned and fractured in the set direction. This method can prevent the stress transfer between the roof of the retaining roadway and the overlying strata of the goaf. This method can reduce the pressure of surrounding rock on the roadway, reduce the deformation of surrounding rock, and maintain the stability of surrounding rock structure along the goaf. The specific roof cutting pressure relief parameters are shown in Table 1:

Table 1: Parameter table of roof cutting drilling

| Drilling Content | Parameter |
|---|---|
| Location *S* | 100mm |
| Angle *β* | 15° |
| Depth *H* | 15m |
| Diameter *d* | 42mm |
| Spacing *L* | 350mm |

## 3. Roadside Support Technology of Gob-Side Entry Retaining in Large Mining Height Working Face of Soft Coal Seam

Following the extraction of the high mining height working face, the broken rock produced by the roof caving cannot completely fill the goaf, resulting in the rotation of the key rock blocks above the roadway, leading to significant deformation of the roadway's ceiling. Following the cutting of the roof and relieving pressure, it was decided to use flexible concrete filling wall for roadside support. Based on the geology and mining conditions of the 32021 mining face, and referring to the engineering experience of 21011 working face previously mined in Liangbei Coal Mine, the flexible concrete-filled wall for the roadside support of the 32021 working face measures 1000 mm in width, and the concrete strength is C30. In order to control the transverse deformation of flexible formwork concrete, anchor bolts are preset in the flexible concrete fulled wall.

## 3.1 Bearing Capacity Checking of Flexible Concrete Filled Wall

Flexible concrete infilled wall is a kind of prestressed composite structure reinforced by fiber. Its bearing capacity is composed of confined reinforcement and core concrete.,The actual bearing capacity is higher than the strength of the general concrete axial compressive member. The theoretical calculation of its bearing capacity is carried out, and its bearing performance is theoretically verified. The calculation formula of flexible concrete flexible formwork wall N is [12]:

$$N = \varphi( f_c + 4\sigma_r )A \tag{1}$$

In the formula, $N$ is the load capacity of the support; $\varphi$ is the coefficient of stability of the component, and $\varphi$ = 1 can be seen from the 'Code for Design of Concrete Structures'; $f_c$ is the design value of axial compressive strength of concrete, N/mm$^2$, and the design value of axial compressive strength of C30 concrete is 15 N/mm$^2$. $A$ is the cross-sectional area.

The calculation formula of anchor bolt binding force is:

$$\sigma_r = \frac{\sigma_b \pi d^2}{4a_1a_2} \tag{2}$$

Substituting the above parameters into the above formula, the 1.0m-thick flexible concrete infilled wall is calculated to have a bearing capacity of $N$= 16440kN/m.

## 3.2 Roadside Support Load Calculation

The 'separated rock block method' is employed to calculate the load on the roadside filling mass [12]. The theory holds that the rock mass with a certain height $H$ above the roadway produces a separation layer after roof cutting, forming a separated rock mass, and the load borne by the roadside support body is the mass of the separated rock. The load mechanics model of the roadside support structure can be seen in Figure 2.

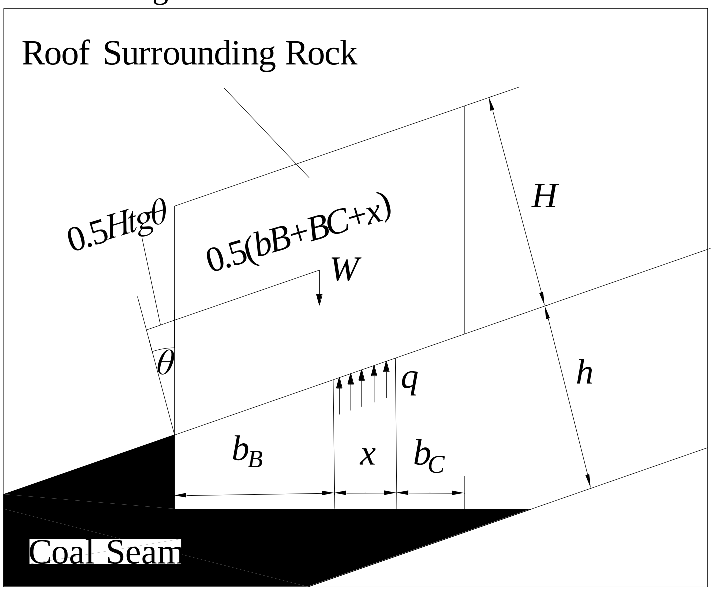


Figure 2: Load calculation model of roadside support in gob-side entry retaining

Lane support load calculation formula $q$ is as follows:

$$q = \frac{8htg\theta + 2(b_B + x + b_C)}{x} \times \frac{h(b_B + x + b_C)\gamma_s \times \cos\alpha}{b_B + 0.5x} \tag{3}$$

In the formula, $q$ is the load of the support; $b_B$ is the dimension from the inside of the support to the coal side, 4.6m; $x$ is represents the width of the supporting body, 1.0 m; $b_C$ is the suspension distance of the Outside of support, and the distance is 0.3m; $\gamma$ is the weight of rock mass, which is calculated according to the average weight of overlying rock mass of 24kN/$m^3$. $h$ is the mining height, taking 4.5 m; $\theta$ is the shear angle, which is selected as 26° according to experience. $\alpha$ represents the dip angle of the coal seam, taking 7°; h is the caving height, according to the experience, 4h is selected, which is 22 m.

According to the calculation of the above formula, given that the width of the retaining roadway is 5.6 m. and the support thickness is 1.0m, the load on the support is as follows:

$$q = 3321.1\text{kN/m} \tag{4}$$

Considering the influence coefficient of 3 times of the dynamic mining face pressure, the maximum support load of the roof on the flexible concrete filled wall is q in the gob-side entry retention scenario $q$ =9963.3kN/m.

The bearing capacity of the flexible concrete infilled wall, which is $N$ = 16440kN/m, exceeds $q$ = 9963.3kN/m. and the abutment pressure of roadway side will be further reduced after roof cutting and pressure relief. Therefore, the C30 flexible concrete infilled wall with a thickness of 1000 mm can meet the requirements of bearing capacity of roadway side.

### 3.3 Numerical Analysis

The mining of the 21051 large mining height working face in Liangbei Coal Mine is simulated using FLAC3D numerical simulation software, and law of deformation of surrounding rock of gob-side entry to maintain is obtained. The vertical stress in the study area changes approximately linearly along the depth of the underground strata. The roadway burial depth is 500m, and the mean bulk rock density is 2500 kg/$m^3$, so the stress applied vertically above the model is 12.5 MPa. The lateral pressure coefficient is 1.0. The horizontal displacement in the model is restricted by the two vertical boundaries, while both horizontal and vertical displacements are constrained by the bottom edge. The data in Table 2 outlines the key physical and mechanical parameters of the model. The mechanical constraints of the calculation model are depicted in Figure 3.

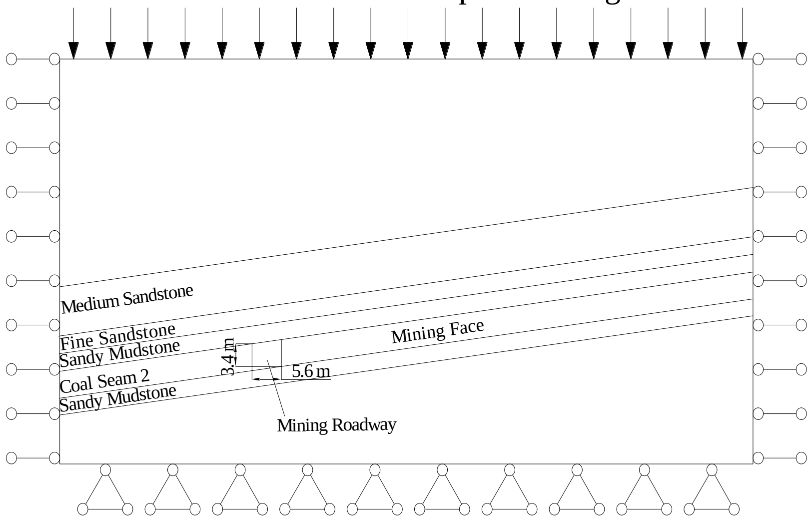


Figure 3: Mechanical boundary conditions

Table 2: The correction values of main physical and mechanical parameters of the model

| Rock Formation | Thickness/m | Density /(kg·m$^{-3}$) | Bulk Modulus /GPa | shear modulus /GPa | Cohesion /MPa | internal friction angle/(°) |
|---|---|---|---|---|---|---|
| Medium Sandstone | 8 | 2750 | 6.3 | 3.5 | 2.6 | 24 |
| Fine Sandstone | 3.5 | 2350 | 5.5 | 2.5 | 3.5 | 28 |
| Sandy Sandstone | 3 | 1800 | 5.5 | 2.3 | 2.3 | 23 |
| Coal Seam 2 | 5.3 | 1400 | 4.5 | 1.7 | 1.8 | 25 |
| Sandy Mudstone | 3 | 1750 | 5.5 | 1.9 | 2.5 | 25 |

Figure 4 and Figure 5 illustrate the vertical displacement cloud diagram of rock before and after the roof cutting operation in the area adjacent to the gob-side entry retaining. The numerical calculations demonstrate a maximum deformation of 541 mm in the roadway roof prior to the process of roof cutting and pressure relief. The roof of roadway is affected by the collapse of goaf, and the rotation deformation occurs in the direction of goaf as a whole. The effectiveness of goaf caving is inadequate, leading to a considerable extent of suspended roof area. The process of roof cutting and pressure relief proves to be an effective method to disconnect the roof of the goaf from the roadway roof. Following the implementation of roof cutting, a significant improvement is observed in the caving effect of the roof, the roof cutting operation results in a reduction of the maximum deformation of the roof to 166 mm, and the roof caving effect of the goaf is good, which indicates that the effect of the retaining roadway after roof cutting is well.

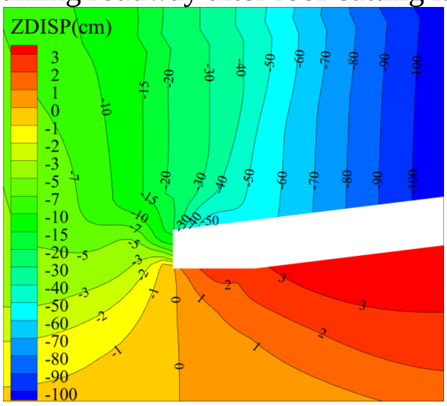


Figure 4: Displacement cloud diagram of surrounding rocks gob-side entry retaining in front of roof cutting in large mining height working face

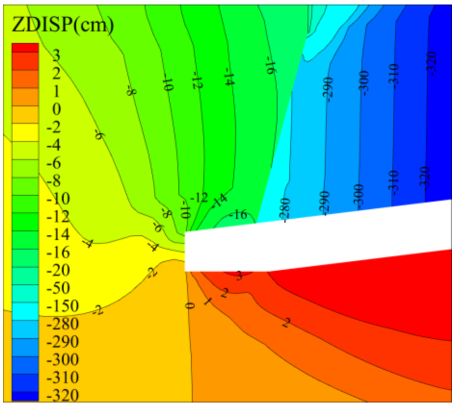


Figure 5: Displacement cloud diagram of surrounding rocks gob-side entry retaining after roof cutting in large mining height working face

### 3.4 Validation of the Effectiveness of Flexible Concrete Infilled Walls

To examine and explore the impact of a flexible concrete infilled wall on the roof of the roadway, a concrete wall with a width of 1 m was added to the side of the roadway following mining. Representative position of the gob-side entry retaining section in the calculation results was taken to extract the displacement cloud map as shown in Figure 6. Following the implementation of a flexible concrete infilled wall in the roadway, the location experiencing the greatest deformation in the roof shifted towards the left side of the passage, and the maximum deformation was 143 mm, which was reduced by 23 mm. After adopting the flexible concrete infilled wall, the caving effect of the goaf is better, which is similar to that when it is not adopted.

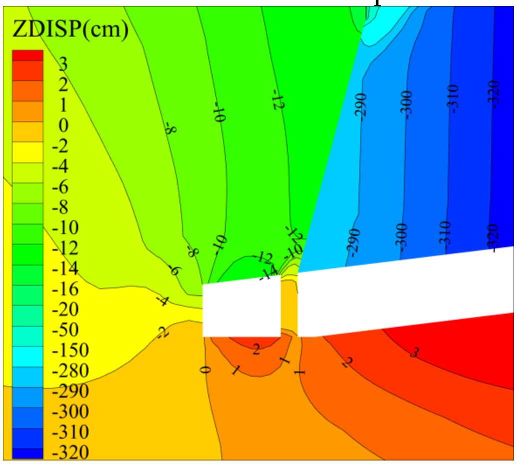


Figure 6: Displacement cloud diagram of surrounding rock of flexible concrete infilled wall roadside support roadway

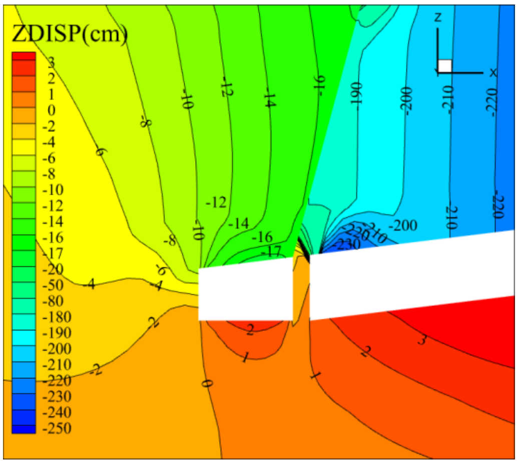


Figure 7: Displacement cloud diagram of roadway surrounding rock when flexible concrete infilled wall is on the right side of cutting seam

During the implementation of gob-side entry retaining in the upper working face of Liangbei Mine, the flexible concrete infilled wall is placed on the right side of the slit. In view of this situation, numerical simulation verification is carried out. The displacement cloud diagram of the calculation results is depicted in Figure 7. Currently, the flexible concrete infilled wall is not placed in the roadway, which continues to serve as a support structure at the roadside, effectively retaining gangue and sealing off the goaf, but loses the roof support of the gob-side entry bracket. Not only is there no reduction in the deformation of the roof, but also prevents the roof from falling in the goaf, which is not conducive to the surrounding rock control of gob-side entry retaining.

## 4. Supporting Scheme Design of Gob-Side Entry Retaining

The gob-side entry support differs from the conventional design of coal faces. It needs to experience the recovery of two working faces, so it needs to undergo two times of dynamic pressure. Generally speaking, the deformation is large, and it needs to be supported with high strength. In terms of active support, following the principle of maximizing the inherent support capacity of the surrounding rock, the gob-side entry support approach is implemented [15]. The collaborative support method is adopted. The W-shaped steel belt and anchor cable beam are combined with a densely distributed anchor cable system, along with the integration of high-density bolt support methodology, to effectively control the stability of both the roof and the surrounding rock. At the same time, the flexible concrete infilled wall is used for roadside support. During the influence of the dynamic pressure of the retaining roadway, three rows of single hydraulic props are set up in the middle of the roadway to jointly control the deformation of the surrounding rock of the gob-side retaining roadway.

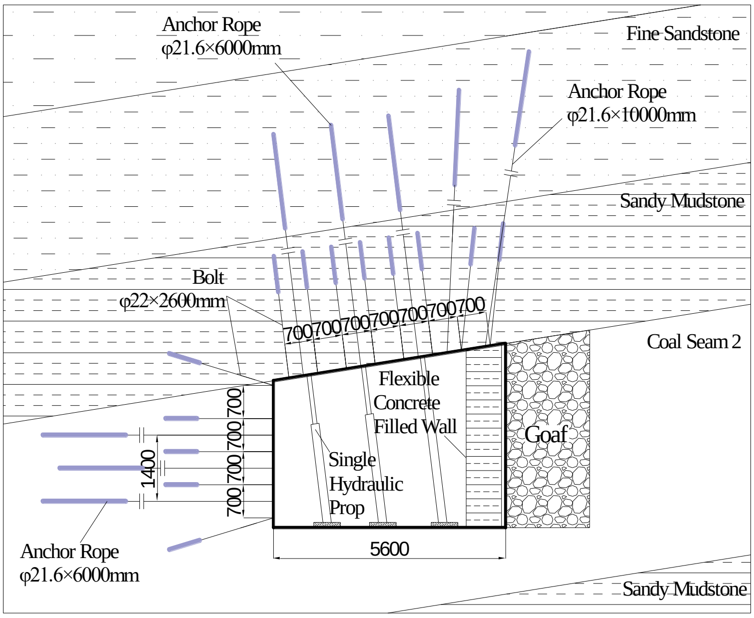


Figure 8: Gob-side entry retaining support parameter diagram

The roof is reinforced using 7 rows of anchor rods measuring 22 mm in diameter and 2600 mm in length, with a row spacing of 700 mm x 700 mm. Additionally, 4 rows of short anchor cables measuring 21.6 mm in diameter and 6000 mm in length are also employed, 1050 mm×1400 mm in row spacing. Each pair of anchor cables is combined with an I-steel joist, spanning a length of 1750 mm, to form a sturdy anchor cable beam structure, moreover, an additional row of anchor cables measuring 21.6 mm in diameter and 10000 mm in length is incorporated, positioned 500 mm below the upper side of the roof.. The top-cut anchor cable beam, the row spacing is 1050 mm, the anchor cables are set at an angle of 75 ° relative to the horizontal line. On the left side of the roadway, a reinforcement approach using 7 rows of 22 mm diameter bolts, each measuring 2600 mm in length, is applied. The bolts are aligned with a row spacing of 700 mm x 700 mm, 2 rows of anchor cables with a diameter of 21.6 mm and a length of 6000 mm, and the row spacing is 1050 mm×1400 mm. The flexible concrete infilled wall has the characteristics of large initial support force and appropriate shrinkage in the early stage, this reinforcement technique compensates for the excavation-induced loss of support on the roadway side, forming a cohesive structure with the existing support system to collectively withstand the mining pressure. The strengthening support method of the retained roadway is the single column with the Π-shaped beam. Within a proximity of 200 m from the trailing edge of the working face, two rows of single columns are set to adopt the arrangement of one beam and three columns, and the beam spacing is 800 mm. The 1 m wide flexible concrete infilled wall support is used, and the flexible concrete infilled wall is placed on the left side of the roof cutting borehole at 200 mm from the upper side. The supporting parameters are shown in Figure 8.

## 5. Field Application Effect Analysis

The roadway surface displacement monitoring was carried out on the 21051 advance section, as shown in Figure 9. Gob-side entry support deformation is rapid in the range 0-80m behind the mining face. In the case described, the roadway roof undergoes a maximum deformation of 151.2 mm, the floor experiences a maximum deformation of 32.4 mm, and both sides exhibit a maximum displacement of 77.8 mm. The maximum displacement observed in the walls, roof, and floor of the roadway is well within the manageable range. The field application effect is shown in Figure 10. In the field application, under the support of the concrete flexible formwork filling wall, the roof cutting effect of the roadway is good, and the roof of the goaf collapses along the cutting surface. The roof of the roadway is kept intact, and a good effect of retaining roadway is achieved, which can meet the requirements of the next working face.

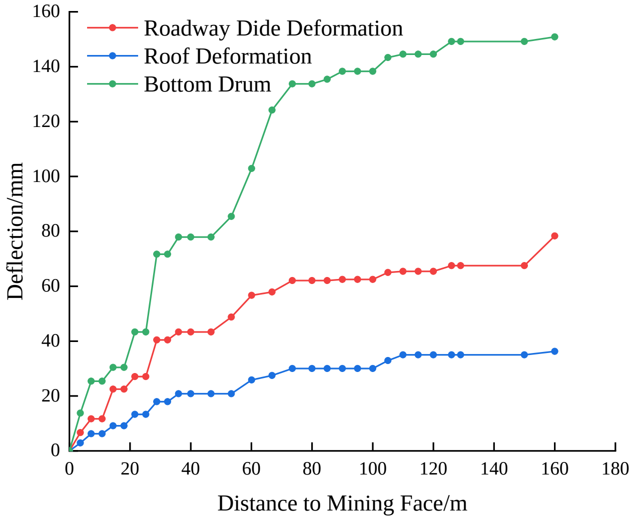


Figure 9: Surrounding rock deformation monitoring

Figure 10: Field application effect

## 6. Conclusion

(1) Combined with the technical conditions of gob-side entry retaining in 21051 thick coal seam of Liangbei Coal Mine, the control idea of " concrete flexible formwork wall + active support + single hydraulic prop support " is put forward, and the corresponding support parameters are designed for gob-side entry retaining in thick coal seam.

(2) Combined with the geological conditions of 21051 working face, the strength of concrete flexible formwork with a width of 1 m is verified by theoretical calculation, which can meet the requirements of roadside bearing capacity. The numerical simulation model of gob-side entry retaining is established. The results show that the 1 m wide concrete flexible formwork has a good control effect on the roof of gob-side entry retaining.

(3) The field application was carried out. The monitoring data of surrounding rock showed that during the period of retaining roadway, under the support of concrete flexible formwork filling wall, the roof cutting effect of roadway was good, the roof of roadway was kept intact, and the better effect of retaining roadway was obtained, which could meet the next mining face requirements.

## References


*[1] He Manchao, Wang Yajun, Yang Jun, et al. Comparative analysis on stress field distributions in roof cutting non-pillar mining method and conventional mining method. Journal of China Coal Society, 2018,43( 3) : 626-637. DOI: 10. 13225/j. cnki. jccs. 2017. 0969.*

*[2] Wang Kai, Yang Baogui, Wang Pengyu, et, al. Deformation and failure characteristics of gob-side entry retaining in soft and thick coal seam and the control technology . Rock and Soil Mechanics. 2022, 43(07): 1913-1924.*

*[3] Shi Guoyue. Gateway Retained Along Goaf Technology with Pier Pillar Backfilled with High Water Material in High Gassy Mine. Coal Science and Technology. 2014(7): 30-32, 60.(in Chinese)*

*[4] Yang Junzhe. Analysis and application of rapid mechanization gob-side entry retaining technology with flexible-formwork in thick seam. Coal Science and Technology. 2015(s2): 1-5.*

*[5] Hua Xinzhu, Li Chen, Liu Xiao, et al. Current situation of gob-side entry retaining and suggestions for its improvement in China. Coal Science and Technology. 2023, 51(1): 128-145.(in Chinese)*

*[6] Kang Hongpu. Seventy years development and prospects of strata control technologies for coal mine roadwaysin China. Chinese Journal of Rock Mechanics and Engineering. 2021, 40(01): 1-30.*

*[7] Wang Ping, Zeng Zilong, Sun Guangjing, et al. Principle and technology of surrounding rock control for gob-side entry retaining in deep mine gangue backfilling face. Coal Science and Technology. 2022, 50(6): 68-76.(in Chinese)*

*[8] Kang Hongpu, Zhang Xiao, Wang Dongpan, et al. Strata control technology and applications of non-pillar coal mining. Journal of China Coal Society. 2022, 47(1): 16-44.(in Chinese)*

*[9] Feng Guorui, Ren Yuqi, Wang Pengfei1, et al. Stress distribution and deformation characteristics of roadside backfill body for gob-side entry of fully-mechanized caving in thick coal seam. 2019, 36(06): 1109-1119.*

*[10] Zhang Sheng, Zhao Wenfeng, Wang Xiaoliang, et al. Research on technology of excavating under roof then mining along bottom in soft and thick coal seam. Coal Science and Technology. 2019, 47(1): 79-84.(in Chinese)*

*[11] Wang Dongpan, Yang Hongzhi, Yuan Weiming, et al. A "support and pressure relief" ground control technology for double-used roadway with fully-mechanized caving method in thick coal seam. Journal of Mining and Strata Control Engineering, 2022,4(4):043014.*

*[12] Guo Haijun, Du Huailong. Research and application of flexible formwork concrete gob-side entry retaining technology in thick coal seam. Coal Science and Technology, 2022,50(S2):105−112.*

*[13] Chen D, Wang X, Wu S, et al. Study on stability mechanism and control techniques of surrounding rock in gob-side entry retaining with flexible formwork concrete wall. Journal of Central South University. 2023, 30(9): 2966-2982.*

*[14] Yang Juncai, Wang Wen, Zhang Guangjie, et al. Study on surrounding rock deformation law and control technology of flexible formwork concrete wall retaining roadway along goaf. . Coal Science and Technology. 2022, 50(S1): 89-99.*

*[15] Long Jingkui. Study and Application of Synergetic Bolting for Deep Heavily Stressed Soft-rock Roadway. Coal Engineering. 2015, 47(4): 41-43, 46. (in Chinese)*