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A successful case study on the reuse of gob side entry retaining by non-coal pillar mining in Gaohe mine

Based on the engineering background of gob side entry retaining in W1319 working face of Gaohe mine of Lu'an Group, this paper adopts the methods of field investigation, theoretical analysis and physical experiment to tackle the key technical problems of surrounding rock stability control during the effect of secondary mining and successfully retain roadway on site. The main research results are as follows: Firstly, the deformation and failure characteristics of surrounding rock of W1319 intake entry are investigated, the main factors affecting the stability of surrounding rock of gob-side entry retaining are determined, the key points to control the stability of surrounding rock of the gob-side entry are obtained, and the stability of top coal, coal wall and shoulder coal is determined as the starting point to control the stability of surrounding rock. Secondly, according to the stress distribution law of W1319 intake entry and the deformation and failure characteristics of surrounding rock, the reinforcement scheme of "high strength grouting + reinforcement anchor cable" combined support before secondary mining is put forward, and the concrete support parameters are obtained by theoretical analysis combined with site conditions. Industrial experiment and field mine pressure monitoring data show that the reinforcement support technology proposed can effectively control the deformation of surrounding rock, and verify the correctness of the reinforcement scheme proposed in this paper. As the first successful case of gob-side entry retaining reuse in non-pillar mining of Gaohe mine, it has a popularization significance.

Keywords: *Fully-mechanized caving face; gob-side entry retaining; plastic zone; stress distribution; control of surrounding rock.*

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1. Introduction

With the deepening of coal mining depth, the development of roadway retaining technology plays an increasingly important role. According to previous literatures,the technique of controlling the stability of the roadway along the goaf is studied at the angle of the stress, deformation law of surrounding rock,, filling parameters, coal pillar width, material and strength of original supporting system, movement law of overlying strata and breaking position of key blocks[1-6]. At the same time, many important conclusions are drawn, and the development of the stability control technology for the gob side entry retaining has made great contribution.

Gaohe mine has a design production capacity of 7.5 Mt/a, which is a large-scale production mine. The mine production requires a high connection between mining and excavation. In recent years, the technology of gob side entry retaining, represented by flexible formwork support, has been applied in many working faces in Gaohe coal nine. It not only improves the coal recovery rate, but also eases the tension of mining and excavation replacement and achieves good economic benefits. Due to the particularity of gob-side entry retaining technology, stress concentration inevitably occurs in the overlying strata behind the gob-side entry retaining, and the occurrence of disasters such as coal wall slab and roof fall, which has brought a serious threat to coal mine safety production. After adopting flexible formwork support to retain roadway along goaf in W1319 intake entry (W1318 goaf-side entry retaining) of Gaohe mine, the deformation and damage of some areas are serious after the influence of the first mining in the working face. A large number of bolts and cables are broken in the coal pillar side. The roof problems of some sections are prominent, and the flexible formwork filling body is fractured in many places, which will lead to the difficulty of controlling the surrounding rock of the roadway during secondary mining (W1319 working face mining) [7-9]. In order to ensure the safety of W1319 working face, it is urgent to study the surrounding rock movement law and its control technology before the secondary mining of the working face.

Whether the W1319 intake entry is reused successfully or not is related to the sustainability, efficiency and safety of the working face production. Successful reuse of gob-side entry retaining improves coal recovery rate, meets the demand of safe production, and reduces the comprehensive cost of the mine. The research results can provide important basis for safe mining of the working face along the gob side entry retaining under similar conditions.

2. Engineering summary

2.1 Engineering geological conditions of W1319 intake entry

2.1.1 An overview of the location relationship

The specific location of the roadway is shown in Fig.1. The total length of the roadway is 1087m. The design reinforcement length of the roadway is 780 m from the position of W1318 working face stopping line to the cut of W1319 working face. The W1319 intake entry is located in the 3# coal seam, which is the roadway driving along the floor.

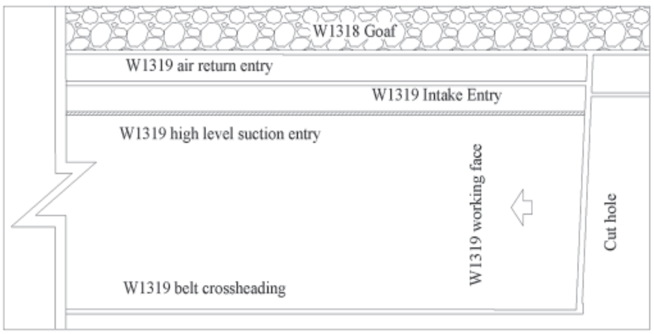


Fig.1 Layout of W1319 working face and entry

Because of the large deformation of roadway surrounding rock in the gob-side entry retaining of other working faces in Gaohe mine, it is difficult and costly to reinforce and support the roadway in the later period, and the possibility of the roadway being abandoned. Therefore, considering comprehensively, Gaohe mine proposed a breakthrough ventilation mode of “W-type + high pumping”. Specifically, a new coal roadway is excavated 35m away from the W1319 intake entry. First, it is used as a return air roadway in mining to meet the ventilation requirements of high gas mine. Second, if the W1319 intake entry is found to be seriously damaged and unable to be retained during the mining period, the 35m coal pillar between the two roadways will not be mined to ensure that the W1319 working face can continue to complete the mining operation as planned.

2.1.2 Coal seam and roof and floor conditions

Coal and rock samples are taken from W1319 intake entry 100 meters away from the cut hole to carry out rock mechanics parameters experiments. The experimental results are shown in Table 1.

2.2 Supporting overview of W1319 intake entry

2.2.1 Characteristics of roadway support

The section of W1319 intake entry is rectangular section, and the supporting form is cable anchor + ladder beam support form. The anchor rod is made of left-handed and non-longitudinal ribbed steel bolt, the anchoring form is end anchoring. the model is Φ22×2400mm, and the anchor tray is 170×170×12mm curved high-strength pallet. The roadway adopts high-strength and low-relaxation steel strand anchor cable. The diameter of steel strand anchor cable is Φ18.96 mm, the length is 8300 mm and 4500 mm, and the specification of anchor cable tray is 300×300×16mm. The metal mesh is made of 10# lead wire, and the mesh is 50×50mm. The ladder beam is made of Φ14mm round steel. The roadway support section is shown in Fig.2 and the roadway support parameters are shown in Table 2.

According to the need of production connection, the W1319 intake entry is reinforced by shed type supporting in December 2016. At the same time, the bottom heave of the roadway is stretched, the broken mesh is connected, and the broken bolt and cable is repaired. The shed type supporting area is from the stop line position of W1318 working face to the cut-off point of W1319 working face and the penetration point of W1319 intake entry to 60m east. The total length of shed reinforcement is about 840m. In the W1319 intake entry, the shed type supporting is “one beam and two columns” shed with single column and Pi-shaped beam. The length of Pi-shaped beam is 3.2m, the spacing is 0.9m, the initial support force of single column is 11.5MPa. The section of shed type supporting is shown in Fig.3.

2.2.2 Brief introduction of flexible formwork support

1. Brief introduction of flexible formwork support technology in gob side entry retaining

The flexible formwork support technology in gob side

Table 1: Mechanics parameters table of rock

Name	Type	Compressive strength (MPa)	Tensile strength (MPa)	Cohesion (MPa)	Internal friction angle (MPa)	Modulus of elasticity (GPa)	Poisson ratio
Main roof	Packsand	46.63	4.96	7.76	36	28.85	0.20
Direct roof	Sandy mudstone	23.44	3.85	4.68	33	3.69	0.27
3# coal	3# coal	9.49	1.12	2.12	30	1.53	0.27
Direct floor	Siltstone	28.51	3.71	5.98	35	24.49	0.17

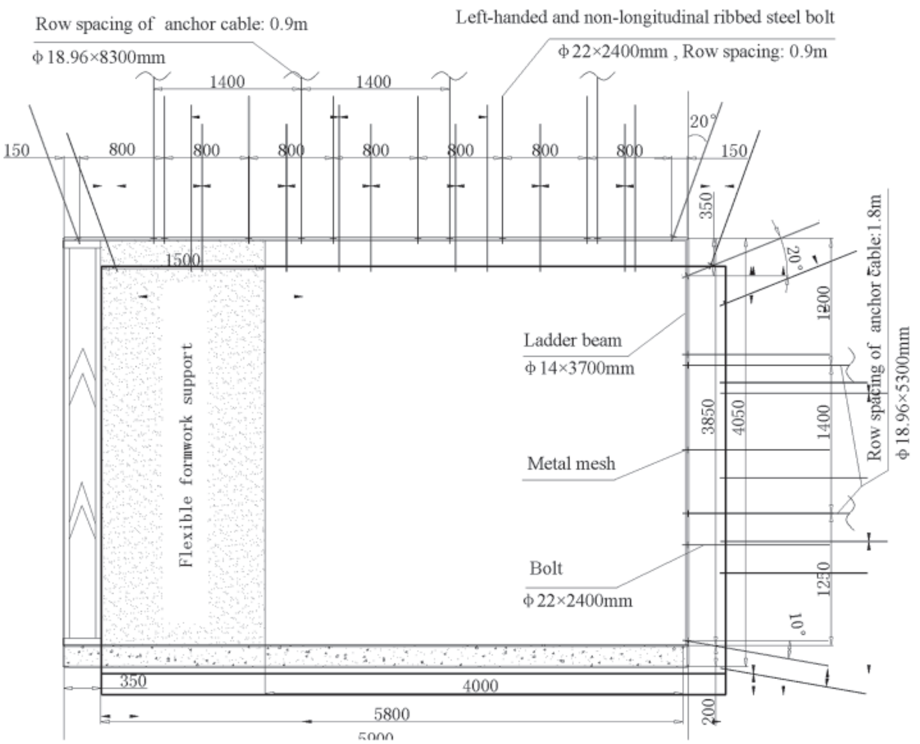


Fig.2 Supporting profile of entry

TABLE 2: SUPPORTING PARAMETER TABLE OF ENTRY

The name of roadway		W1319 intake entry
The gross section	Digging width (mm)	5900
	Digging height (mm)	4050
	Excavating area (m^2)	23.90
The net section	Net width (mm)	4000
	Net height (mm)	3850
	Net area (m^2)	15.40
The row and line space between roof bolts (mm)		800×900
The row and line space between floor bolts (mm)		900×900
Layout of roof anchor cable		Four or four layout
The row and line space between anchor cables (mm)		1400×900
Layout of floor anchor cable		Two or two layout
The row and line space between anchor cables (mm)		1400×1800
Layout of ladder beam	Side (single reinforcement)	Φ14×3700
	Roof (double reinforcement)	Φ14×5000
Layout of mesh (mm)	Side	4200×950
	Roof	5300×950

entry retaining is to lay a continuous closed high strength concrete wall between the W1319 intake entry and the W1318 goaf under the joint support of the end support in working face and the single column in the entry, and to maintain the stability of roadway surrounding rock with the original support system.The safe and smooth recovery of the W1319 working face and the isolation of toxic and harmful gases from the W1318 goaf into the roadway will be guaranteed.

2. The strength of flexible formwork support in W1319 intake entry

C30 concrete is applied to the flexible formwork wall of W1319 intake entry, and its concrete parameters are shown in Table 3.

(1) C30 concrete mix ratio

Technical standards for quality of concrete substrates:

Cement: 42.5R ordinary portland cement;

Sand: medium sand in the second district, washed sand, mud or stone powder content less than 3%;

Stone: 5 ~ 20mm continuous graded crushed stone containing less than 1% mud and less than 0.5% stone powder content.

(2) Strength of flexible formwork support: After 4 hours of initial setting, the concrete strength reaches 4-5 MPa, 10-15 MPa after 1 day, 20-25 MPa after 7 days and 35 MPa after 30 days.

3. Flexible formwork support process

(1) Roof management in pouring area

Before the coal is cut at the working face, a double-layer 1m×8m metal mesh is laid on the coal wall in front of the tailing hydraulic support. After the coal is cut off from the working face, the tailing hydraulic support is pulled out in time, and the single column should be set in time on the side of the gob area. Then, a round wooden column is placed beside the single column, and the spacing between the single column and the round wooden column is 500 mm, and 5.5 mm away from the outer coal wall.

(2) Hanging formwork: Flexible formwork specifications: length × height × width is 3m × 4.2m × 1.5m. A pair of anchor bolt holes with row spacing of 750mm × 800mm is reserved on the flexible formwork.

(3) Pumping concrete: When the flexible formwork is installed, the concrete wall is organized to be pumped

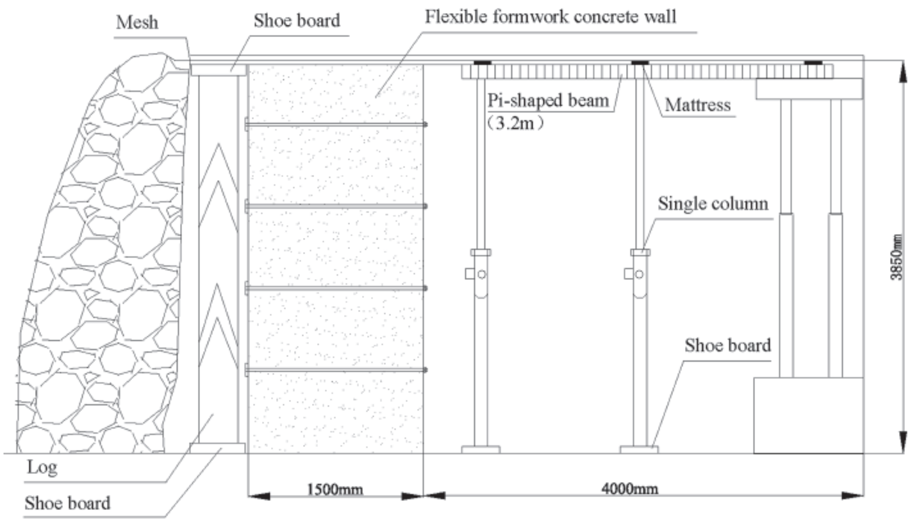


Fig.3 Shelf supporting profile of W1319 intake entry

TABLE 3: PRELIMINARY MIX TABLE OF C30 PUMP INJECTION CONCRETE

Concrete components	Cementitious material	water	Aggregate		Admixture
Name of concrete base material	Cement	Water	Stone	Sand	Admixture
1 m^3 concrete base material quality	550 kg	220 kg	800 kg	765 kg	1 kg

on (about 16 m^3, 3 hours, 2 flexible formwork per day, 6 cycles per day). After 4 hours of initial setting, the concrete strength reaches 4-5 MPa, and 10-15 MPa in one day.

3. Design of reinforcement scheme

3.1 CONTROLLING IDEAS AND METHOD OF SURROUNDING ROCK OF W1319 INTAKE ENTRY

By investigating the deformation and failure characteristics of the surrounding rock of W1319 intake entry, the main factors affecting the stability of the surrounding rock of the gob side entry retaining are determined, and the key points to control the stability of the surrounding rock of the gob side entry retaining are obtained. and the stability of top coal, coal wall and shoulder coal is determined as the starting point to control the stability of surrounding rock of W1319 intake entry. The roof breaking form and the position of key block breaking line in fully mechanized caving face are studied. The evolution process of stress, displacement and plasticity zone of surrounding rock in W1319 intake entry under the influence of driving and primary mining is analyzed comprehensively. It is determined that the main roof breaking line of W1319 intake entry is about 6m inside the coal seam [10-13].

Due to the complexity and seriousness of roadway damage, it is difficult to control the surrounding rock of roadway during the influence of secondary mining. A single technical means cannot solve the problem fundamentally. This paper analyzes and designs a variety of technical ways to ensure the safety of gob side entry retaining and the mining of W1319 working face [14].

Based on the analysis of deformation and failure characteristics and causes of surrounding rock and original supporting system in roadway, the paper puts forward a complete set of “strong coal side and roof control” supporting technology combined with active and passive supporting, i.e. namely, the active combined supporting technology of “high strength grouting + reinforcing anchor cable” in roadway and the original passive combined supporting technology of “high strength flexible formwork wall + dense column” beside roadway.

3.2 HIGH STRENGTH OVERALL GROUTING REINFORCEMENT SCHEME OF SURROUNDING ROCK OF W1319 INTAKE ENTRY

Even if the roof and coal side in the roadway have the original bolt-mesh-cable support and single column reinforcement support, the surrounding rock of the roadway will be irresistibly affected by the high stress of the mine and the mining stress superposition of the working face, inevitably breakage, joint cracks increase and move to the roadway. Although the surrounding rock of W1319 intake entry also undergoes large deformation, the surrounding rock-bolt bearing system can retain most of the supporting capacity, which provides the basic conditions for grouting, bolting and other reinforcement support. As the supporting stress of surrounding rock decreases gradually, if no effective remedial measures are adopted, the damage of surrounding rock-anchor supporting structure will continue to weaken and the plastic zone of surrounding rock will expand to the depth. With the increasing deformation of roadway and the influence of secondary mining later in W1319 working face, the deformation control of W1319 intake entry will be more difficult., so timely and reasonable reinforcement measures

TABLE 4: SELECTION TABLE OF GROUTING PARAMETERS

Related indicators	Parameters
Grouting material	Jinan reinforcement I
Grouting form	Deep and shallow hole grouting
Grouting hole layout	Three-two layout
Grouting pressure	0.7MPa (shallow hole), 2MPa (deep hole)
Grouting time per hole	600s

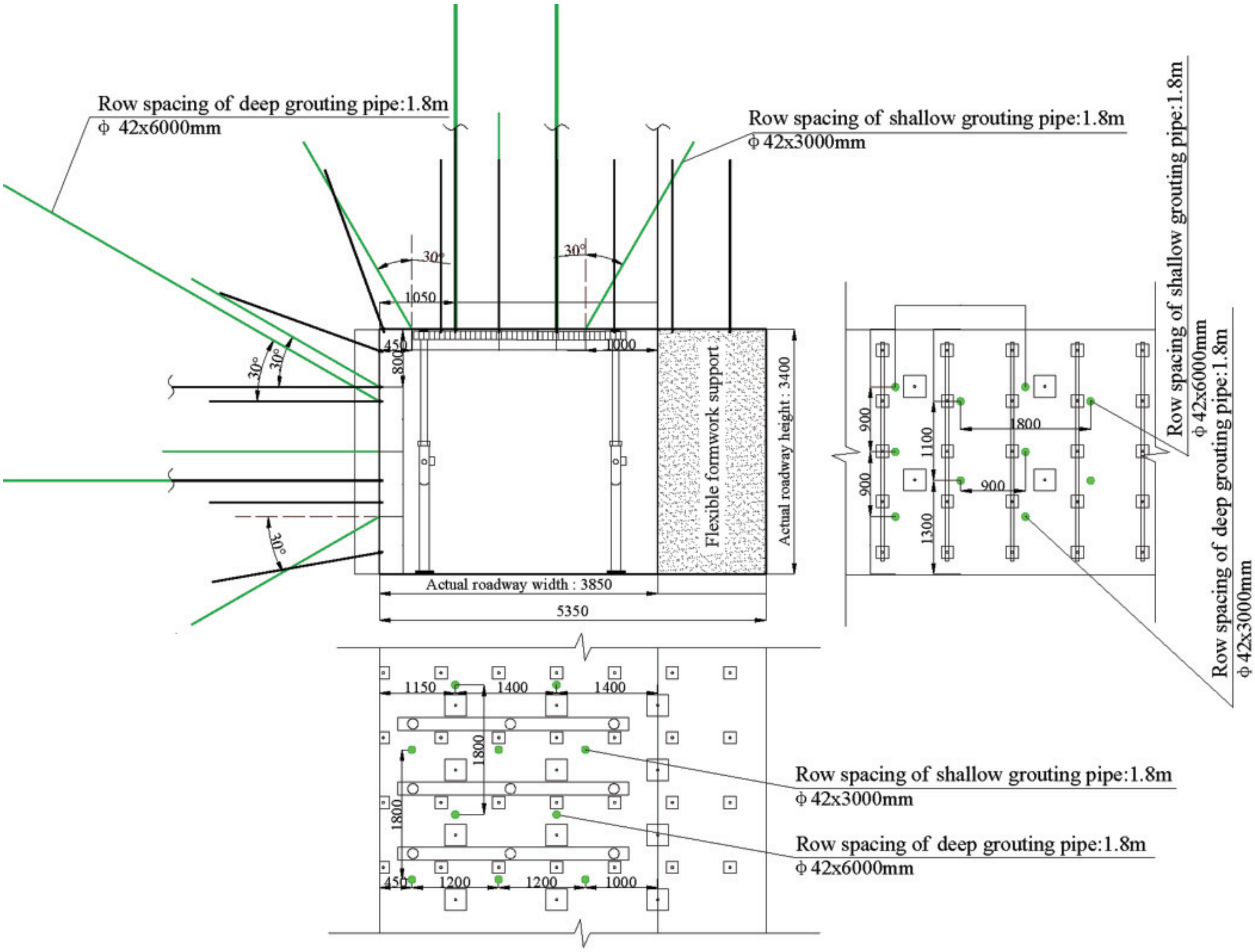


Fig.4 Layout of grouting hole

must be adopted in advance [15-18]. Based on this situation, an overall grouting reinforcement scheme for the W1319 intake entry lane is adopted.

The overall grouting scheme parameters and layout are shown in Table 4 and Fig.4.

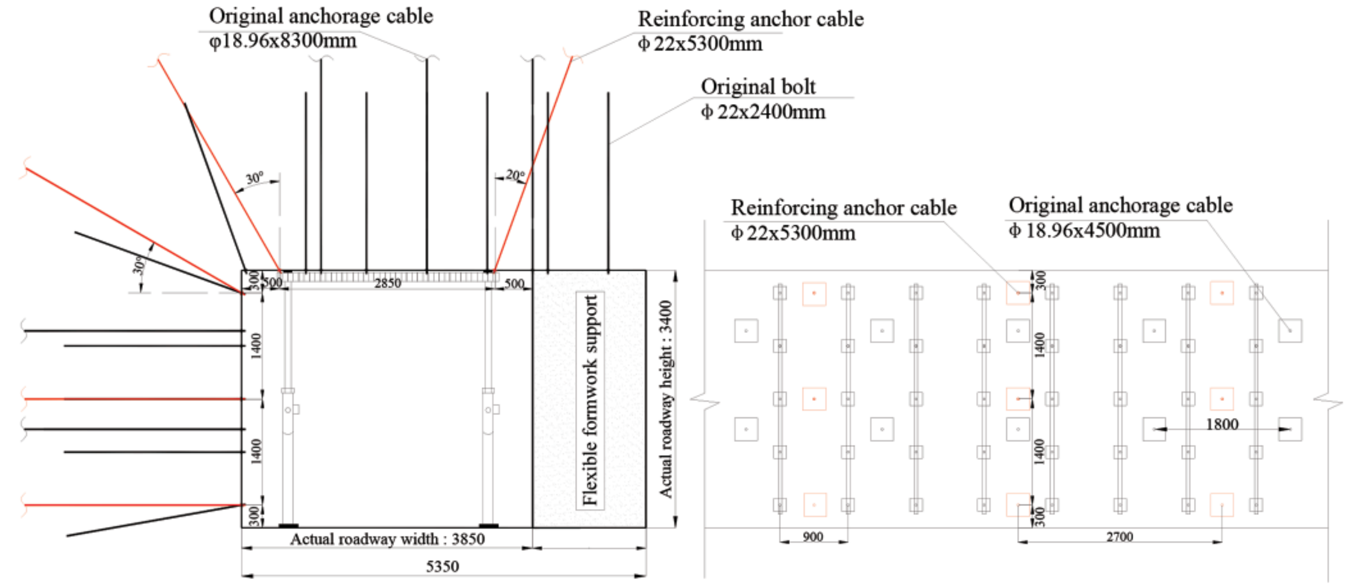
3.3 Anchor cable reinforcement scheme of W1319 intake entry

The surrounding rock of W1319 intake entry has a complex stress environment. After the impact of many mining activities, the stress field of the surrounding rock of roadway is changed by disturbance, and the stress field changes from the original whole area to local area, especially concentrated in the deep of roadway coal side and the top of flexible formwork wall. The change of stress distribution law leads to the deformation of the surrounding rock. When the deformation of surrounding rock reaches a certain amount, cracks and separation will occur in the surrounding rock, and the supporting capacity will decline, and the bonding force with surrounding rock mass will rapidly decrease [19-22].

According to the current deformation and damage of W1319 intakr entry, it is necessary to strengthen the support strength of the bearing area of the coal side, control the coal body at the shoulder corner of the roadway to squeeze and fall into the roadway, and take measures to make the roof and the coal side of the roadway as a whole as far as possible,

Table 5: Parameter table of cable reinforcement

Name	Relevant parameters
Anchor cable specification	Φ18.96×5300 mm
Pretightening force	Φ163.3 kN
Anchorage length	1657 mm
Resin explosive roll	K2335 (1), Z2360 (2)
Row and line space	Coal side: 1400 mm×3600 mm, Roof: 1700×2700
Number	Coal side:3/row? Roof:2/row
Tray specification	300mm×300mm×16mm
Mesh reinforcement	Φ6 steel bar,100mm× 100mmmesh (repair mesh only at failure point)



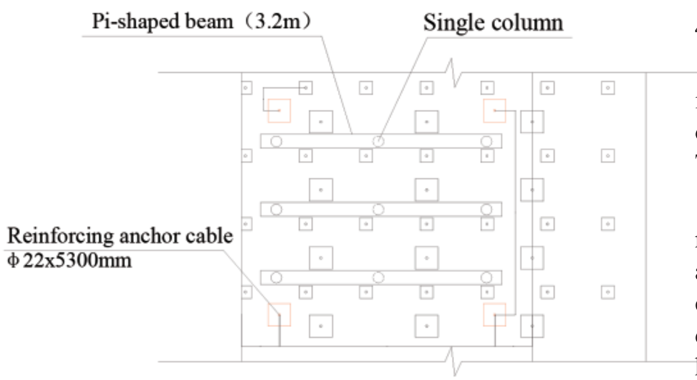


Fig.5 Schematic diagram of cable reinforce of W1319 intake entry

and jointly support and promote the formation or strengthening of the overall bearing structure of the supporting surrounding rock. In order to realize the active and passive interaction between the support and the surrounding rock, the original support and the later grouting of W1319 intake entry are adopted to reinforce the anchor cable scheme and multi-level combined support. The anchor cable reinforcement scheme of W1319 intake entry is shown in Table 5 and Fig.5.

4. Industrial test

In the mining of W1319 working face in Gaohe mine, the scheme proposed in this paper is applied to the reinforcement of W1319 intake entry. In order to check the effect of the design scheme, considering the initial weighting and periodic weighting length of the working face, a data observation station is arranged at 120m away from the cutting hole in W1319 intake entry, mainly collecting the surface displacement of the roadway and the deep displacement of roof and coal side. Where, the observation of the surface displacement is arranged on two sides, and the side faces are 0.9m apart. The location and layout of the data observation station is shown in Fig.6.

4.1 Surface displacement data analysis

The surface displacement data collected by the W1319 intake entry station is processed, and the deformation diagram of the roof and floor and coal side are in Figs.7 to 10 and Tables 6 and 7:

According to Figs.7 to 10 and Tables 6 and 7, the maximum cumulative displacement of roof and floor is 436 mm and the maximum deformation speed is 78 mm/d, the maximum cumulative displacement of roof is 336 mm and the maximum deformation speed is 57 mm/d, the cumulative maximum floor heave is 116 mm and the maximum deformation speed is 22 mm/d. The maximum displacement of the two sides is 388 mm, the maximum deformation speed is 56 mm/d; the maximum displacement of the coal side is 284 mm/d, and the maximum deformation speed is 47 mm/d; the maximum displacement of the flexible formwork side is 104 mm, and the maximum deformation speed is 16 mm/d.

The obvious deformation period of roof and floor and two sides of W1319 intake entry is within the range of 40m away from the working face, so the advance influence range is within the range of 40m ahead of the working face; the area outside 40m away from the working face is less affected by the advance influence of the working face, but there is still

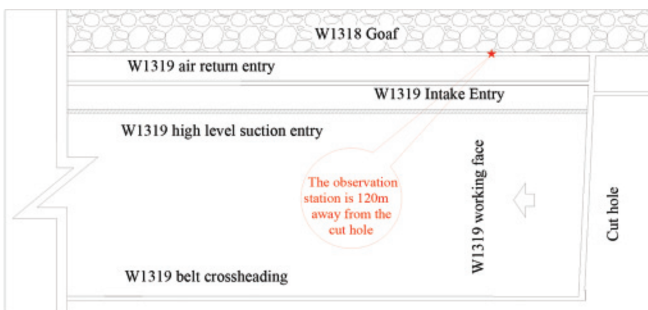


Fig.6 Location schematic diagram of station layout

continuous deformation, indicating that the W1319 intake entry has not reached the complete stress balance state after the W1318 working face has been mined. The new stress distribution system still causes the surrounding rock of the roadway to continue to undergo deformation and damage.

The roof and floor deformation of W1319 intake entry is mainly reflected in the subsidence of the roof. The analysis is because the roof of the roadway is coal seam and mudstone, the rock mechanics parameters are low, soft and easy to deformation, while the floor is sandstone. The rock mechanics parameters are large, rigidity is large, and the anti-deformation ability is strong. It needs to bear high stress, resulting in large deformation of roof. The deformation of the two sides is mainly reflected in the deformation of the coal side. The deformation of the flexible formwork side is small but splitting and tilting occurs. The reason is that the coal seam is soft and easy to deform, while the flexible formwork wall is rigid and allowable deformation is small. Under high stress, the roof sinks sharply, and the flexible formwork wall is subjected to more and more stress in the case of small deformation, which eventually causes shear damage. In short, although the W1319 intake entry has been deformed, the overall deformation is not large, and the roadway is subject to waste, and the deformation is within the allowable and controllable range, which will not endanger the stability of the roadway and the safe production of the working face. In a word, the reinforcement scheme proposed in this paper can effectively control the large deformation of W1319 intake entry under the influence of two mining, and the proposed scheme is reasonable.

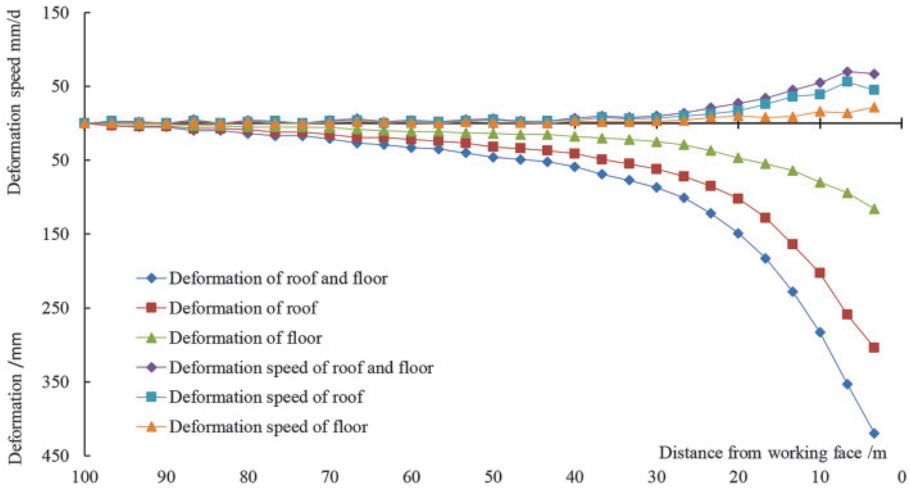


Fig.7 Deformation diagram of roof and floor of the I test surface

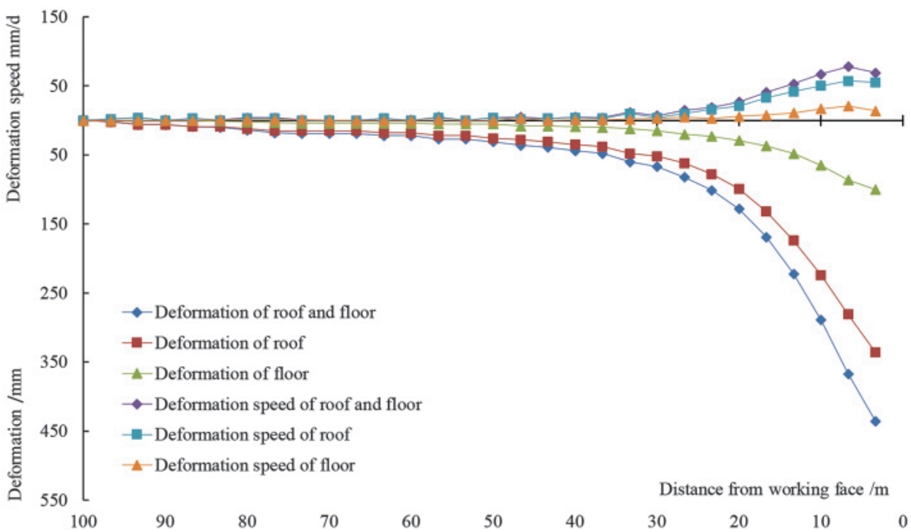


Fig.8 Deformation diagram of roof and floor of the II test surface

TABLE 6: SUMMARY TABLE OF DEFORMATION OF ROOF AND FLOOR

Test surface	Deformation of roof and floor /mm	Maximum deformation speed mm/d	Deformation of roof/mm	Maximum deformation speed mm/d	Deformation of floor/mm	Maximum deformation speed mm/d
I	420	70	304	56	116	22
II	436	78	336	57	100	21

TABLE 7 SUMMARY TABLE OF DEFORMATION OF TWO SIDES

Test surface	Deformation of two sides/mm	Maximum deformation speed mm/d	Deformation of coal side/mm	Maximum deformation speed mm/d	Deformation of flexible formwork side/mm	Maximum deformation speed mm/d
I	388	56	284	47	104	16
II	335	50	254	36	81	15

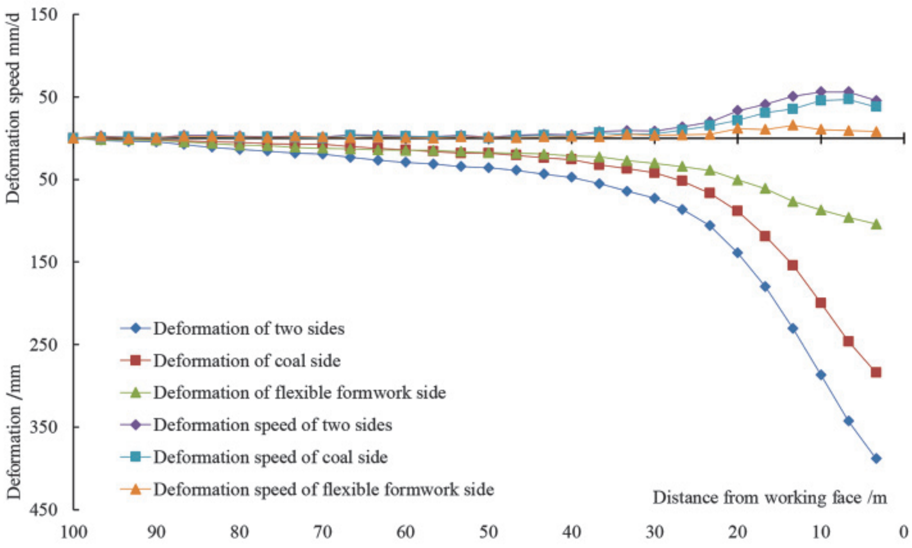


Fig.9 Deformation diagram of two sides of the I test surface

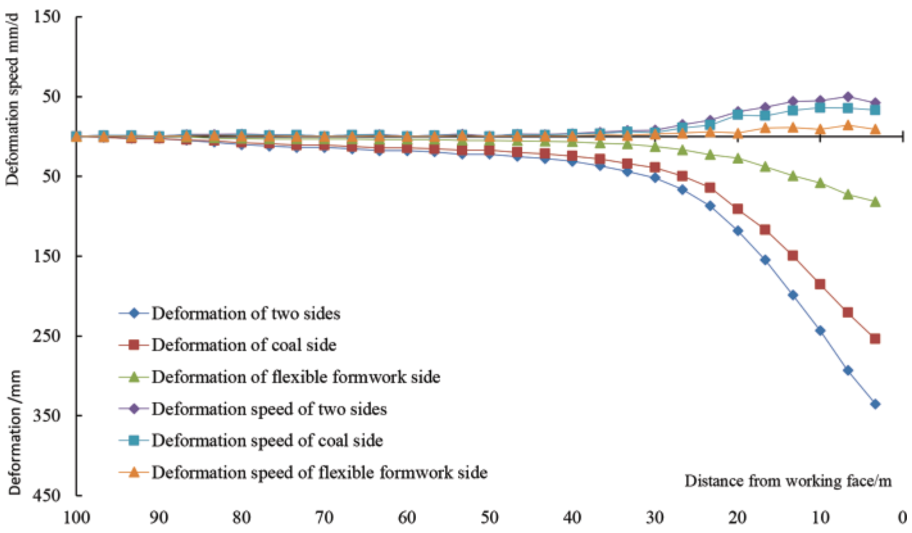


Fig.10 Deformation diagram of two sides of the II test surface

4.2 Deep displacement data analysis

The deep displacement data collected by the W1319 intake entry station is processed, and the deformation diagram of the roof and floor and coal side are drawn in Figs.11 and 12 and Table 8 and 9:

According to Figs.11 and 12 and Tables 8 and 9, the displacement of the roof W1319 intake entry at 1m, 2m, 3m, 4m, 5m and 6m is 227mm, 170mm, 129mm, 104mm, 83mm and 66mm respectively during the mining of the W1319 working face; the displacement of the coal side at 1m, 2m, 3m, 4m, 5m and 6m are 212mm, 157mm, 114mm, 83mm, 58mm and 38mm respectively.

When the data observation station is 40 meters away from the working face, the deep displacement is very small, which indicates that the development of the plastic zone and the separation phenomenon of the surrounding rock in the W1319 intake entry are little affected by the advancing of the W1319 working face; when the distance from the working face is about 40m, the deep displacement begins to change significantly and increases rapidly. It shows that the plastic zone of the roadway begins to evolve slowly within 40m from the working face. The phenomenon of separation layer begins to appear and the displacement of the deep part increases.

From the slope of Fig.12, it can be seen that the deformation of the surrounding rock of the roof and the coal side is gradually decreasing with the increase of the depth. The deformation at 1m is the largest, indicating that the coal seam at 1m is in a loose state, and it is easy to produce separation and displacement. It is judged that the fractures in this region are fully developed and the coal body integrity is low. No matter the roof or the coal side, the deep displacement of the surrounding rock within 6 m does not reach the size of surface displacement, indicating that the rock stratum outside 6m still has a certain amount of deep displacement. Ccompared to surface displacement, it is not so obvious.

The displacement of shallow surrounding rock of W1319 intake entry increases to a certain extent, but during the service period of roadway, the surrounding rock can be maintained basically intact, and the development of cracks has been controlled to a certain extent, which indicates that the reinforcing anchor cable and grouting are helpful to the integrity of deep surrounding rock.

Table 8: General table of deep displacement of roof

Depth	1m	2m	3m	4m	5m	6m
Displacement/mm	227	170	129	104	83	66

Table 9: General table of deep displacement of the coal side

Depth	1m	2m	3m	4m	5m	6m
Displacement/mm	212	157	114	83	58	38

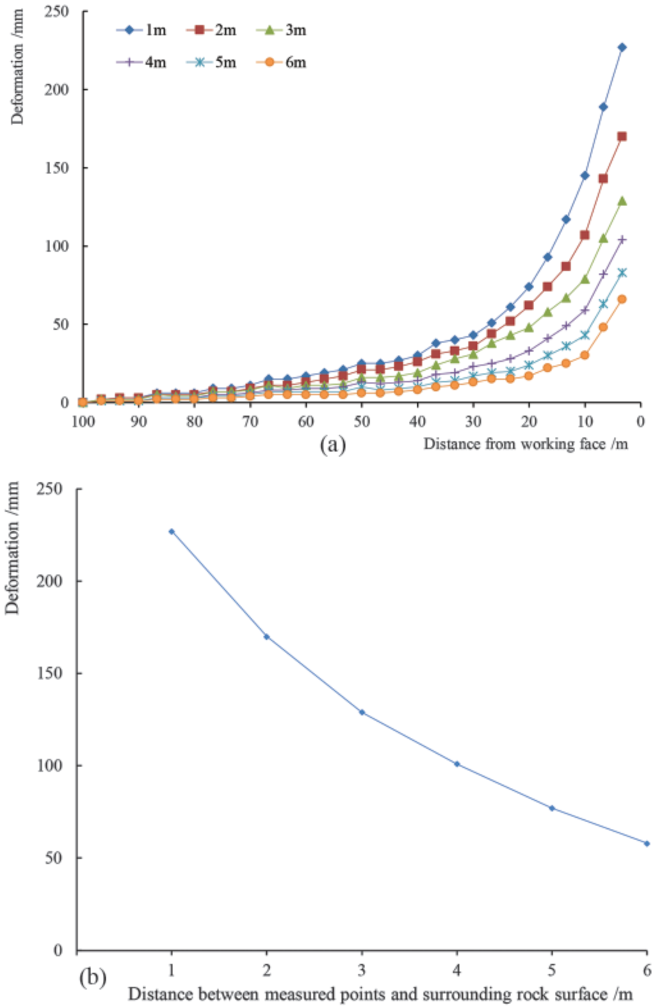


Fig.11 Deep displacement diagram of the roof

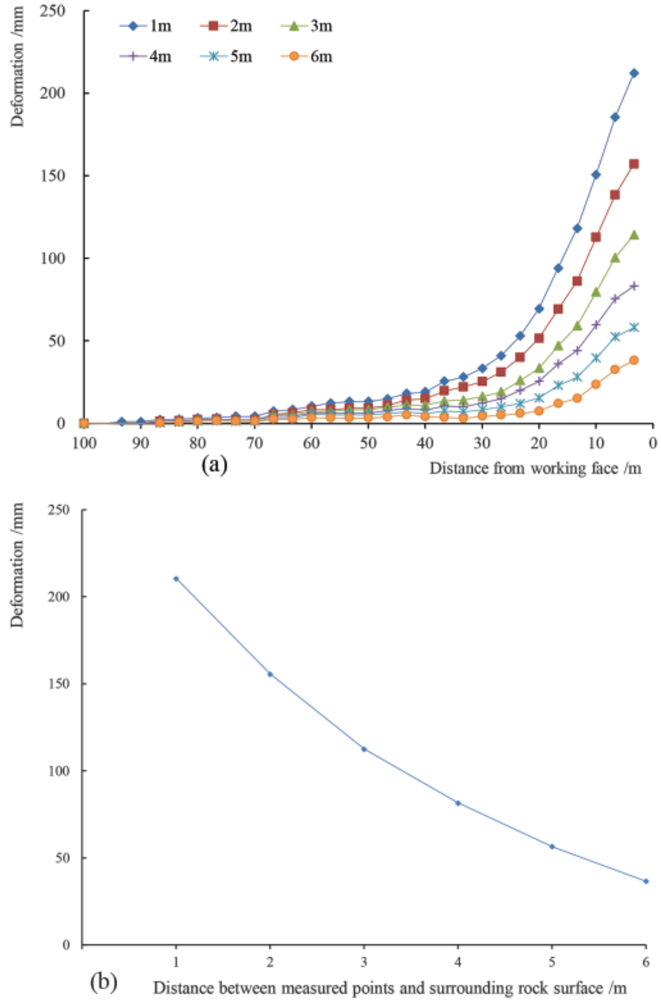


Fig.12 Deep displacement diagram of the coal side

5. Conclusion and significance

In this paper, the surrounding rock control of W1319 intake entry before secondary mining in Gaohe mine of Lu'an Group is taken as the research background. Aiming at the complexity of surrounding rock control of gob side entry retaining by non-coal pillar mining, the methods of field investigation, laboratory physical experiment and theoretical analysis and other methods are used comprehensively to verify the industrial test in this paper. The deformation of surrounding rock is effectively controlled during the influence period, which provides a theoretical basis for the control technology of gob side entry retaining by non-coal pillar mining under similar conditions.

Conflicts of interest

The authors declare no conflicts of interest.

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