MINGZHOU ZHAO
RENSHU YANG
and
JUAN FANG

Application of hollow grouted anchor cable in coal roadway of compound roof

With the increasing scale of coal mining, the deterioration of engineering geology condition brings great difficulty to roadway support. Main return way 5104 is coal roadway of the loose and cracked compound roof in Zhaozhuang coal mine, the compound roof is difficult to control by using traditional support measures which increase the walls shrink and the floor heave and greatly affect the normal excavation and safe production, or even initiated roof fall accident. Through methods of laboratory tests and field observation, based on the analysis of mineral composition, physical mechanics parameters and development degree of joint fissures, comprehensive analysed the mechanism of the road deformation and failure; expounded the supporting mechanism of the coal roadway with compound roof by means of numerical simulation and theoretical analysis, and proposed the design scheme of combined support of anchor net beam and hollow grouting anchor cable. The industrial test showed that, it achieved the integration of anchor injection by hollow grouting anchor cable, compared to the original support, roof convergence of the roadway is reduced by 76.3%, floor heave value of the roadway is reduced by 45.5%, two nearer quantity of the roadway is reduced by 79.2%, and achieved good results.

Keywords: *Compound roof, coal roadway, hollow grouted anchor cable,combined arch, bolt-grouting.*

1. Introduction

With the widening of coal mining scale, growth of the mining depth is significantly speed up, engineering geological conditions become more complex, compound roof roadway appears more and more[1-2]. Because the compound roof is a common rock occurrence state in coal strata, as a result, the compound roof of roadway are widely distributed in the coal mine[3-4]. Composite roof made up of rock multilayer thickness smaller, bedding, joint and fracture development, low strength of soft coal strata, the cohesion between different rock weak even without cohesion, the total thickness of the composite roof is usually more than bolt length, compound rock strata easy to abscission layer and sinking or even destruction under the stress of surrounding rock, compound roof difficult to form effective bearing structure and even roof caving, the support of composite roof is one of the problems of roadway support at home and abroad[5-9].

Many scholars at home and abroad for deformation and failure mechanism of the composite roof rock and support technology do a lot of research, compound roof of roadway support has experienced from the tent retaining to the transition of the bolt support, but in many cases, improper form of support or unreasonable support parameters lead to bolt support also failed to achieve good supporting effect, even if using secondary supporting measures of ripping or erecting shed, not only the large amount of repair works, high cost, the effect is not ideal[10]. Research on compound roof coal roadway supporting technology is necessary. In order to guarantee the stability of surrounding rock of roadway, reduces costs, and improves the economic benefit. This paper takes the return airway of Zhaozhuang coal mine as the engineering background, by means of field engineering geological survey, laboratory test and numerical simulation, the support mechanism of compound roof roadway is analysed, the new support scheme is proposed and the support effect test is carried out, this study has important theoretical and engineering significance.

2. Engineering background

2.1 The engineering geological conditions

5104 roadway is the main return way of 5 panel in Zhaozhuang coal mine. design engineering quantity of main return way is 2650.5m, comprehensive mechanized drivage along coal seam roof, coal seam dip angle of 0 to 8 degrees, an average of 6 degrees, coal thickness of 4.60-5.00m, the average thickness of 4.79m, the design section shape of the roadway is straightwall arches(rise-span ratio of 0.3), sectional area of the roadway is about 22.15m^2. Tunnel buried depth of about 520m, the geological structure that affects the driving and supporting is the collapse column DX170 (long

Messrs. Mingzhou Zhao, Faculty of Resources & Safety Engineering, China University of Mining & Technology (Beijing), Beijing 100 083 and also with College of Mining Engineering, Guizhou University of Engineering Science, Bijie 551 700, Renshu Yang, School of Mechanics & Civil Engineering, China University of Mining & Technology (Beijing), Beijing 100 083 and Juan Fang, School of Civil Engineering, Guizhou University of Engineering Science, Bijie 551 700, China. E-mail: 785895722@qq.com

TABLE 1: CHARACTERISTICS OF ROOF AND FLOOR OF ROADWAY

The name of the top and floor	The name of the rock	Thickness (m)	Lithological characteristics
Main roof	No solid main roof	/	Composite roof, easy to fall off layer
Immediate roof	Sandy mudstone	2.0-4.8	Dark gray, clip thin coal seam, containing plant fossils.
False roof	Shale	0.0-0.3	Gray-black, more broken, the local existence
Immediate bottom	Siltstone	8.03	Darkgrey~colored, local with thin coal seam, lower part (no.4 coal seam) sometimes become siltstone, containing plant fossils.
Hard floor	Fine-sandstone	2.10	Gray, feldspar quartz sandstone, local phase into siltstone.

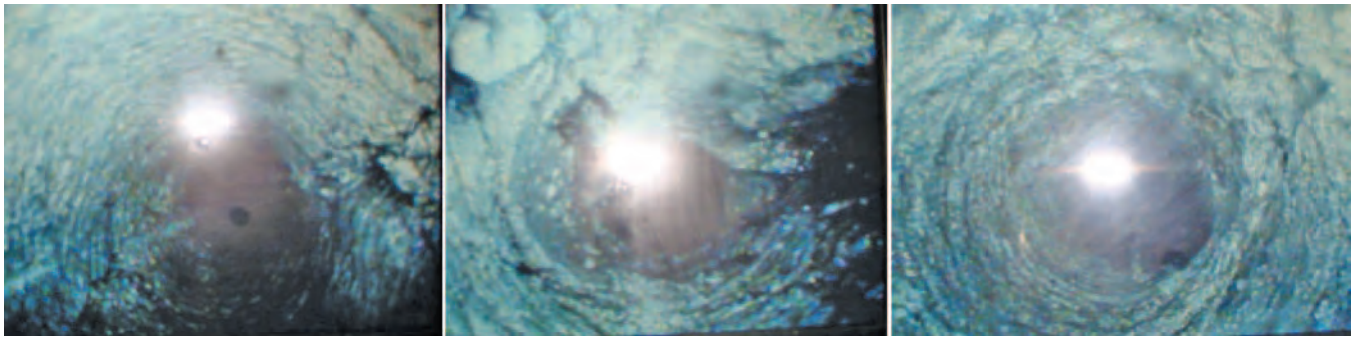

Fig.1 Video capture of drilling cracks

axis: 100-105m, short axis: 50-55m) and concealed small fault. Due to the complex hydrogeological conditions in the field, the roadway may appear water spraying or water inflow in the process of tunnelling, the maximum inflow of water is expected to 15m^3/h, the normal inflow of water is 8m^3/h.

2.2 ENGINEERING ROCK MASS CHARACTERISTICS

Characteristics of roof and floor of roadway are shown in Table 1. Table 1 shows that the roof of the roadway is a composite roof, local existence false roof of shale and thin coal which has a great influence on roadway driving and support.

The main mineral content of different rock group by X ray diffraction experiment are shown in Table 2. It can be seen from Table 2 main mineral composition content difference is very big, surrounding rock containing the dilatability of illite and smectite mixed layer, swelling rock; swelling after mineral water, produces bigger expansion stress, leading to large deformation of roadway. The macrostructure of the surrounding rock is mostly jointed and the fractures are more developed, which is very unfavourable to the support, as shown in Fig.1.

The physical and mechanical properties of different lithologies are shown in Table 3. As can be seen from Table 3, low strength, high content of expansive mineral composition and composite roof structure of the roadway rock and other factors to increase the difficulty of the roof support.

3. Analysis of deformation failure mechanism

3.1 DEFORMATION AND FAILURE CHARACTERISTICS

The original support of roadway is combined support with anchor mesh and beam-rope, support the basic parameters: roof of roadway used φ15.24mm×6400mm of high strength and low relaxation of steel cable anchor to support, spacing and

TABLE 2: THE MAIN MINERAL COMPOSITION OF DIFFERENT LITHOLOGY

Lithology	Main mineral content%		
	Quartz	Clay mineral	Illite and smectite mixed layer
Coal	0.6	12.3	19
Sandy mudstone	28.1	54.8	35
Siltstone	53.5	23.5	45
Fine-sandstone	51.2	25.3	42

TABLE 3: PHYSICAL AND MECHANICAL PARAMETERS OF SURROUNDING ROCK OF ROADWAY

Lithology	Density /kg.m^{-3}	Bulk modulus /GPa	Shear modulus /GPa	Cohesion /MPa	Internal friction angle/°	Tensile strength /MPa
Siltstone	2600	5.0	2.5	2.0	25	1.8
Fine-sandstone	2580	4.5	2.2	1.8	24	1.7
Sandy mudstone	2540	2.4	1.3	1.5	20	1.3
Coal	1380	1.1	0.9	1.2	17	1.0

and pitch was 1200mm×1200mm. Two sides of roadway used anchor and bolt support, anchor cable used φ 15.24mm×5400mm of high strength and low relaxation of steel strand, spacing and pitch was 950mm×1200mm; bolt used φ 22mm×2400mm left-handed without longitudinal reinforcement rebar anchor, spacing and pitch was 950mm×1200mm. Roadway deformation and destruction obviously in the process of drivage, characteristics are mainly the following:

(1) The deformation of surrounding rock

Support by using the above form, within 80 days observation time, two nearer the quantity of the roadway up to 760mm and the average nearer rate is 9.5mm/d; roof convergence of the roadway up to 760mm and the subsidence rate is 9mm/d; floor heave value of the roadway upto 380mm and bottom drum up rate is 4.75mm/d, far more than allow the deformation.

(2) The support body damage is serious

The original anchorage parameters of the roadway within the anchor bolt multiple fracture, diamond mesh has become the "net" and torn, serious damage of the support body resulted in serious damage to support performance.

3.2 Analysis of deformation damage

From the above analysis, factors that lead to deformation and destruction of roadway include objective and subjective factors. Its dilatability of surrounding rock is stronger, the intensity is low and joints fracture development belong to the objective factors, subjective factors embodied in improper support during the process of roadway drivage. So it must fully consider the objective factors and change or adjust the subjective factors can realize the effective control of the roadway, to ensure that the roadway during the excavation of the safe and normal use.

4. Countermeasure of surrounding rock control

4.1 Analysis of supporting mechanism

Bolting and shotcrete supporting mainly include bolt, anchor cable and beam, mesh and other member and the surrounding rock grouting is the formation of a set of joint support system in order to effectively control the effect of the surrounding rock, supporting the principle as is shown in Fig.2.

Composite roof becomes the compression arch stability of the structure by bolt along the roadway around the rupture area layout, to improve the overall strength of composite roof and bending stiffness and to prevent the rock alienation or rupture; reinforced roadway two sides to build a solid skewback for combined arch.The work resistance and the prestressing force of bolt spread by beam installed, the beam acts to balance the force of the anchor rod and improves the overall support. The net can prevent the gravel from falling

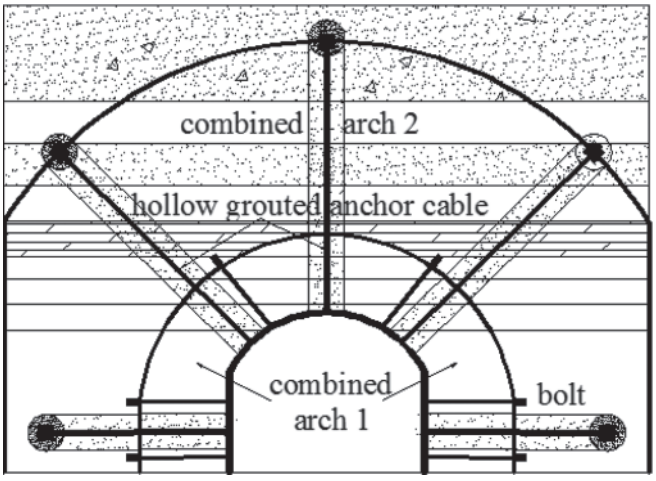

Fig.2 Supporting principle diagram

off and improve the stress state of the rock on the surface of the roof, the net plays a connecting role to the overall support system formed by bolt simultaneously. In order to compensate for the anchor cannot reach the deep stability rock of the defects for larger thickness of composite roof, avoiding abscission layer that causes overall sink of the roof even fall accident outside the scope of the bolt anchoring by hollow grouting anchor cable reinforcement, control of early sinking deformation of composite roof by high preloading force of anchor, caving hidden dangers composite roof in anchoring range is suspended in the stability of the main roof using high destroy-force of anchor to restrain the roof convergence and deep separation in turn enhances the stability of the support system.

To restrain the roof convergence and deep separation in turn enhance the stability of the support system. Composite roof with high dilatability mineral composition content and joint fissure development is to be supported by bolting with wire mesh, at the same time through the surrounding rock grouting to change the mechanical parameters of surrounding rock, closed water and air channel. Bolt and hollow grouting anchor cable control respectively shallow and deep surrounding rock, and to achieve anchor integration, the roadway around the formation of self-supporting structure of the two compression arches (compression arch 1 and compression arch 2) work in order to achieve the overall stability of the surrounding rock[11-12].

4.2 Design of supporting scheme

(1) Using hollow grouting anchor cable

High intensity hollow grouting anchor cable has the following characteristics: the diameter is 22 mm and length is 7300mm, the yield strength and breaking strength respectively are 1500MPa and 1760MPa, and elongation of hollow grouting anchor cable up to 5% anchorage section of hollow grouting anchor cable have three "bird's nest" structure as shown in Fig.3. The grouting anchor cable has the following

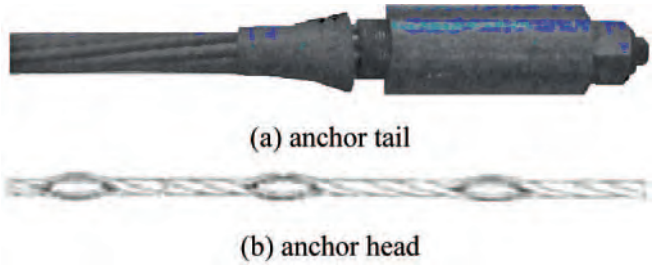

Fig.3 Hollow grouting anchor cable

advantages[13]: (a) own core pipe of grouting anchor cable which can realize the integrity of the bolting and grouting, the reverse grouting method not only eliminates the possibility of cavitation, ensures that the anchor slurry is filled with drilling holes, but also eliminates the special joint of the exhaust pipe and the grouting pipe (directly using the thread locking mechanism as the grouting pipe joint), construction procedure was greatly simplified. (b) the anchor head of the anchor cable is end anchoring-grouting using stir resin drug roll and anchor tail is tightened by threads, an anchor can be carried immediately after installation, anchor cable to sync with bolt rod bearing supporting role to form a whole to achieve the overall support effect. (c) grouting and tunneling can achieve parallel operation to improve the efficiency of tunneling. (d) anchor tail locking high reliability and does not appear the spark in the lock, exposed length small of anchor tail will not affect the effective height of roadway.

(2) Supporting parameters

Roof is supported by bolt and anchor: The anchor used φ22mm×7300mm of high intensity hollow grouting anchor and spacing and pitch is 2700mm×2000mm. The bolt used φ22mm×2400mm of strong rebar anchor with levorotatory and no longitudinal reinforcement, spacing and pitch is 900mm×1000mm.

Roadway's sides are supported by bolt and anchor: The bolt uded φ22mm×2400mm of such as strong rebar anchor with Levorotatory and no longitudinal reinforcement, spacing and pitch is 1000mm×1000mm. The anchor used φ22mm×5400mm of high intensity hollow grouting anchor and spacing and pitch is 1200mm×2000mm.

Anchor with three anchoring agent, one of the specifications for the MSK2335, two specifications for the MSZ2360 (MSK2335 anchoring agent after installation MSZ2360 anchoring agent). Bolt with two anchoring agents, a specification for MSK2335, another specification for MSZ2360. Bolt plate is arch-type high-strength tray and the specifications of the pallet is 150×150 ×10mm. Anchor plate is butterfly tray and the specifications of the pallet is 300×300 ×16mm.Top wire is steel mesh welded by Ø6mm steel reinforcement with mesh is 50mm.Working slope network is high-strength plastic net. Beam is reinforced beam welded by φ16mm steel reinforcement and full-section use, new supporting design layout as shown in Fig.4.

Fig.5 shows the plastic zone distribution of roadway by new design, numerical simulation shows that the new design compared to the original design scheme can well control the deformation of the surrounding rock, so as to realize the stability of roadway.

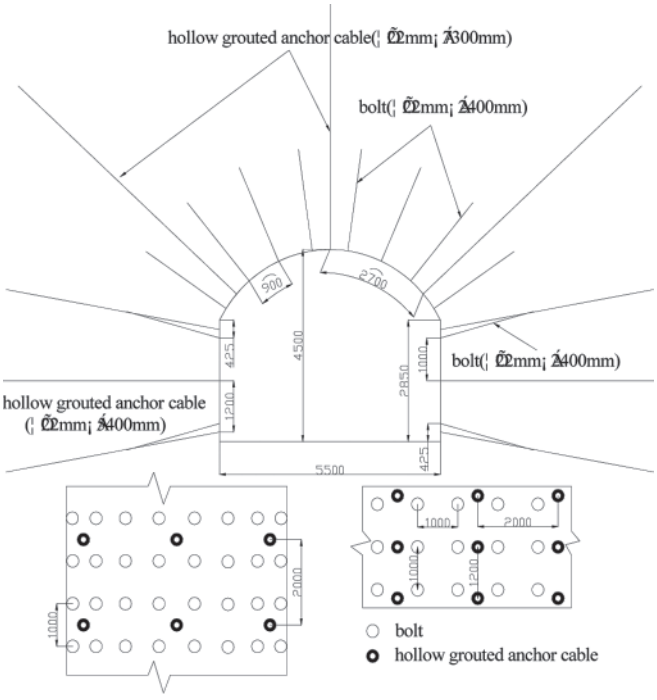

Fig.4 New supporting design layout

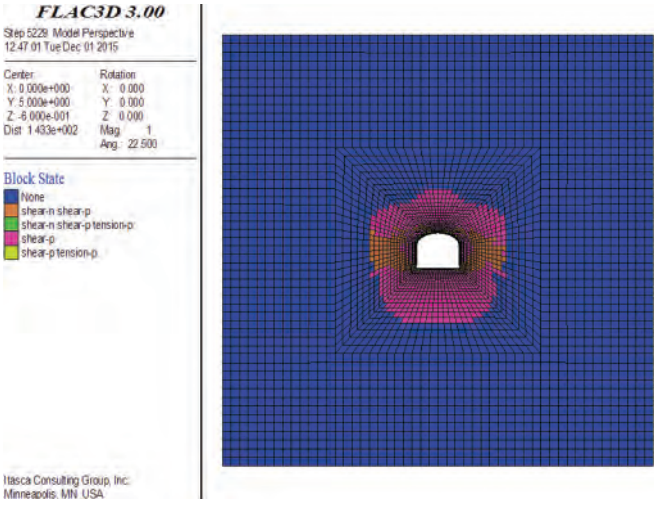

Fig.5 The plastic zone distribution of roadway in new design

4.3 The construction process

Drivage speed of roadway and its supporting effect is closely related to the supporting construction process, reasonable construction process is conducive to improve the speed of tunnelling and ensures the quality of support, so must pay attention to the design of the construction process,

this design adopts the construction process as follows:

(1) The first stage: Install anchor net cable

Roadway excavation → temporary support → suspended net → drilling roof bolt and anchor → install the roof anchor and bolt → drilling wall of roadway bolt and anchor → install the wall of roadway anchor and bolt, pre-tightening force of anchor not less than 250kN and pre-tightening force of bolt not less than 150kN.

(2) The second stage: grouting

Holesealing → proportioning (→ connection pipe → grouting. Portland cement and ACZ-□ cement grouting additive as the main material, slurry water cement ratio of 2: 1 and grouting pressure of 3 ~ 5MPa, grouting work lag in 15m and parallel to the tunnelling working operations, the grouting and its technological process is shown in Fig.6.

5. Supporting effect

Length of the road supported by new support scheme is 203m at the scene, roadway molding well and no obvious the phenomenon of obvious of abscission layer and net pocket, the deformation of surrounding rock is small and support body work in good condition. Roadway layout of three mine pressure observation stations and cumulative observations of 80 days, the deformation of surrounding rock is shown in Fig.7. The results of mine pressure observations results show, roof convergence of the roadway up to 171mm and the subsidence rate is 2.14mm/d, floor heave value of the roadway up to 207mm and bottom drum up rate is 2.59mm/d, two nearer the quantity of the roadway up to 158mm and the average nearer rate is 1.98mm/d, the deformation rate tends

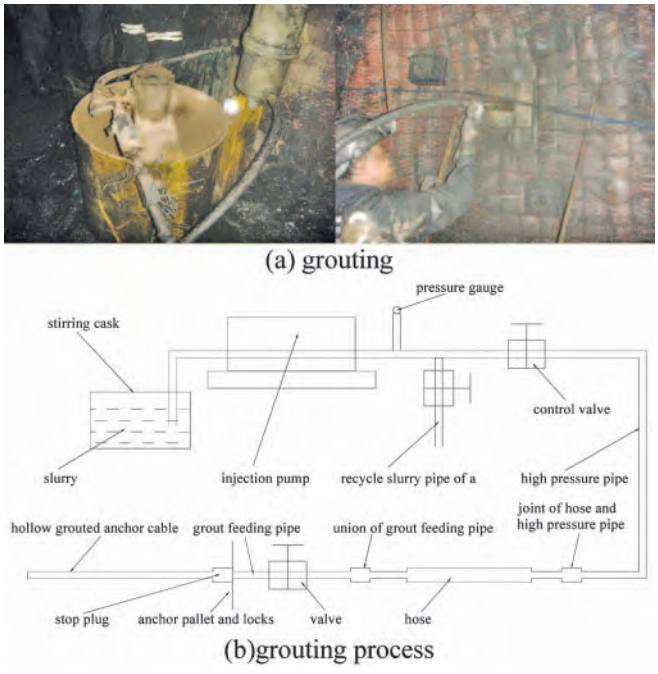

Fig.6 Grouting and technological process

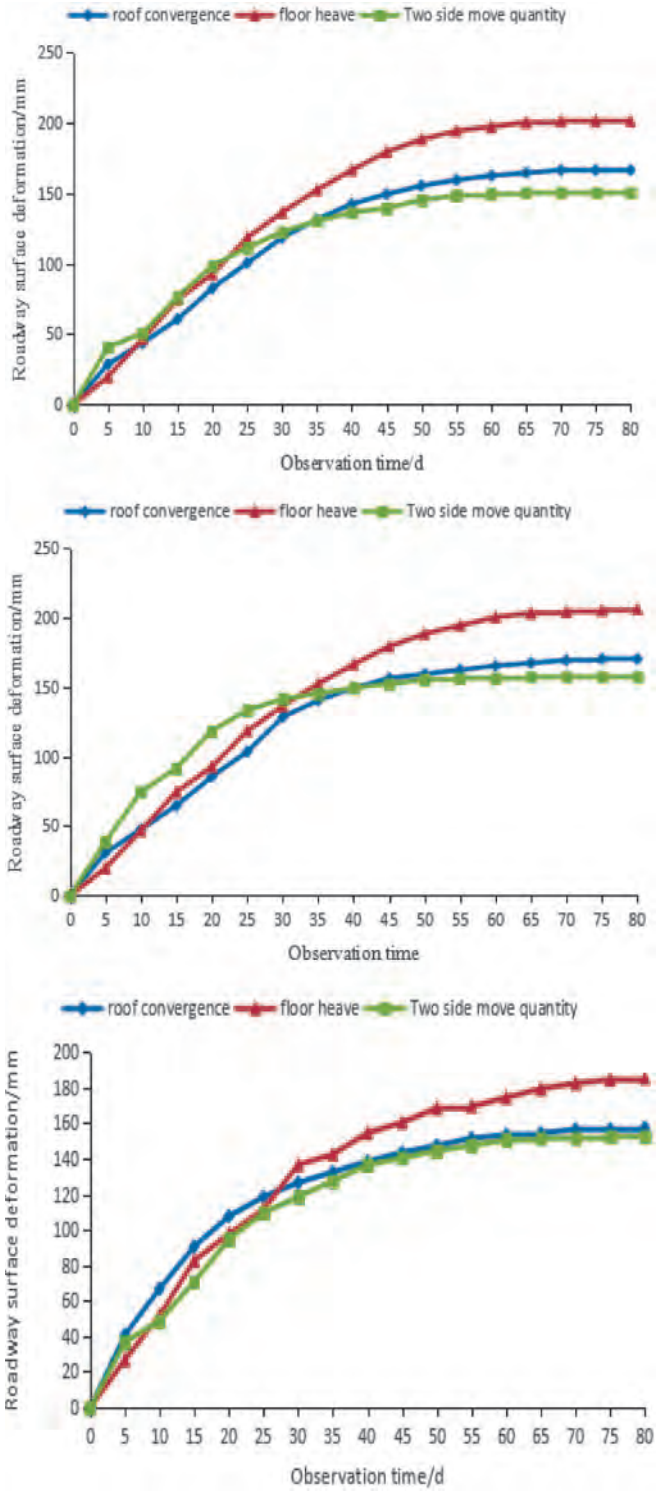

Fig.7 Deformation of roadway surrounding rock

to decline and the deformation of surrounding rock becomes stable. Compared to the original support, roof convergence of the roadway is reduced by 76.3%, floor heave value of the roadway is reduced by 45.5%, two nearer the quantity of the roadway is reduced by 79.2%, it can be seen that the new design scheme has achieved remarkable supporting effect.

6. Conclusion

Based on engineering geological conditions and deformation failure mechanism analysis of main return way 5104 in Zhaozhuang coal mine, from the improvement of the surrounding rock's own strength and the environment, optimize roadway cross section shape, select the appropriate support body, optimize the support parameters and other aspects, combined support plan of the compound roof with bolt mesh and beam and hollow grouting anchor cable was designed and constructed, successfully solved the support technical problems of compound roof coal roadway in Zhaozhuang coal mine.

Successful support experience shows that: Beam metal net combined support can play maximum ability of support body, to mobilize the strength of the deep surrounding rock and to utilize the bearing capacity of the surrounding rock, so that the surrounding rock and supporting components to optimize combination, to achieve load equalization and support integration, hollow grouting anchor cable not only plays the role of steel cable anchor, but also to achieve integration of anchor injection. Combined support technology by bolt mesh and beam and hollow grouting anchor cable is a scientific and reasonable and effective technique for the stability control of compound roof roadway, the technology can provide a reference for the similar roadway supporting.

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