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and
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Deformation-failure characteristics and control strategy of mining roadway roof in argillaceous rock

Aimed at the large amount of mining roadway roof subsidence in argillaceous rock, as well as frequently happened roof caving accidents, the mining roadway from Baode coal mine was taken as the research background. By the integrated use of field measurement, numerical simulation, and the theoretical analysis, the deformation-failure characteristics and engineering controllability of mining roadway roof in argillaceous rock was studied. The results indicate that: During the mining influence. This kind of roadway suffers serious roof deformation and failure and has little to do with the increase of the support strength. The roof subsidence is far out of the endurance of the anchor cable. The roof breakage depth is around 4.0m. With the existing technology, it is not available to limit the roof subsidence by high-strength bolting, and it is a must to adopt the supporting method with good extension property, which gives priority to roof caving control. Accordingly, the control strategy which gives priority to long-extension bolt appeared. The engineering testing results indicate that this technology can coordinate with the roof deformation, thus effectively prevent the roof caving.

Keywords: *Argillaceous rock; mining roadway; large deformation; long-extension bolt.*

1. Introduction

With the continuously increase of mining depth and intensity of Chinese coal mine, the mining conditions become more and more complex. Because of the mining disturbance, the mine ground pressure appears particularly acute. Especially in argillaceous rock roadway, the surrounding rock is generally broken and has high deformation value, which seriously affects the roadway safety and normal service [1~3]. For a long time, many scholars and filed researchers centered on continuously increasing supporting strength about this kind of argillaceous rock roadway, and attempting to control or decrease the roadway deformation by high supporting resistance [3~7]. Taking the Baode coal mine of China Shendong coal company as an example, its main supporting measure is increasing the number of cable in large quantity and increasing the diameter of anchor cable, so that the number of roadway roof anchor cable increased to 5-7 per meter, and the cable's diameter increased from the 15.24mm at first to 21.6mm, which increases the support cost and reduces the roadway formation speed. This high-strength support, which costs a lot, has some positive effect on deformation of argillaceous roadway surrounding rock, but the effect is not ideal, and many cable fracture failures still exist, roof caving accidents happen from time to time. On the other hand, for the requirement of safety, high production, high efficiency of large modern coal mine, and the increase of mining roadway section square and roadway length [8~10]. Thus, the mining roadway cannot adapt the high-strength, multi-level support methods as the permanent roadways. In this article, the large deformation-failure characters of Baode mining roadways was studied by field tests, and the relation between support strength and roof subsidence in Baode mine was analyzed during simulation experiment and theoretical calculation, and the counter measures gives priority to long extension bolt was put forward, which was put into field test and has achieved a good result. This technology can be used as reference to the support of large deformation roadways.

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2. Roof structure and characteristics of deformation and failure

2. 1 Roof structure and characteristics of deformation

No.8 coal seam is the main mining seam of Baode coal mine, whose depth is around 400m. The roof is mainly mudstone and sandy mudstone, partly kern stone. There is 2.0~3.0 meter-deep in the roof, which includes 0.2 meter-deep gangue. Above the top-coal, the mudstone and sandy mudstone is around 4.0~7.0m. Fig.1 shows the roof drilling results of mining roadway, and as it is shown in the multiple sets of drilling video, the roof rock strata changes with large scope, and the thickness of unstable strata is large. Also, endogenic fractures develop in roof, and the roof is unstable.

For the theoretical outcome of the two airways after the first mining influence, the adopted drift support parameter could satisfy the supporting requirement well so that the sinkage of the roof was minor; however, during the mining

lithology	columnar	thickness (m)	tired of thick (m)	description
kern stone		1.0	8.0	bright white , existence of gravel
mud stone		1.6	7.0	dark gray mudstone, gray cut, partially broken
sandy mud stone		1.7	5.4	white, black region on the top and lower boundary
mud stone		1.4	3.7	dark gray mudstone, hard, gray cut, lumpish, fissure development
coal		1.6	2.3	grance coal, pitchy luster, bedding and linear structure, fissure development
parting		0.2		
coal		0.5		

Kern stone

Mud stone

Sandy mud stone

Fig.1 Roadway roof drilling video results of 8 # coal seam

exploitation period, the mine pressure within the drift appeared to be intense, which led to large deformation of the roof, severe floor heave of the bottom plate, destruction of the support; along with multiple roof falling and roof leaking incidents. The earliest method that had been adopted was enhancing the strength of the supports so that their high intensity could prevent the roof deformation; the two drifts that served under the mine influence went through multiple (2~3) systematic cable enhancement, eventually a high support density had been reached. However, the outcome was still not ideal, incidents such as severe roof sinkage, anchor cable breakage and roof falling still occurred, which significantly affected the production efficiency of the mine. The mining gateway of the mine, which lied 300m behind the coal face, presented to be significantly asymmetrical. The roof sinkage was greater than both sides', the holistic deformation of the coal pillar side is greater than the cutting coalside; the roof sinkage was greater near the coal pillar side and the floor heave was greater near the cutting coal side; the deformation bottom of the cutting coal side is greater than its top and the coal pillar side is exactly opposite. Fig.2 shows the cross-section of the Baode mine's mining gateway.

2.2 Testing for the depth of roof rupture

According to traditional theory, the deformation of the drift's surrounding rock consists of elastic deformation at the elastic zone and the deformation at the plastic zone. But the elastic deformation only occupies a very small portion. Since the drift's sinkage at Baode coal mine was severe during the exploitation period, it is necessary to understand the depth of the drift's rupture and its rupture structure.

As shown in Fig.3, pick a cross-section around 30.0m ahead of the coal face, uniformly develop 6 10-meter-deep drillholes, monitor and record these drillholes with multiple logger recorder; the rock surrounding at this position cannot be considered stable until no more breakage or fracture appears in these drillholes. As it is demonstrated in Fig.3, the depth of roof rupture reaches 3040mm, 3900mm, 3850mm, 3700mm, 2750mm and 2000mm. The largest rupture occurs at the middle of the roof, the extent decreases as it expands to the sides; the boundary contour of the rupture is in a shape of caving arc, the roof condition at this position is very unstable and can cause roof falling incidents easily.

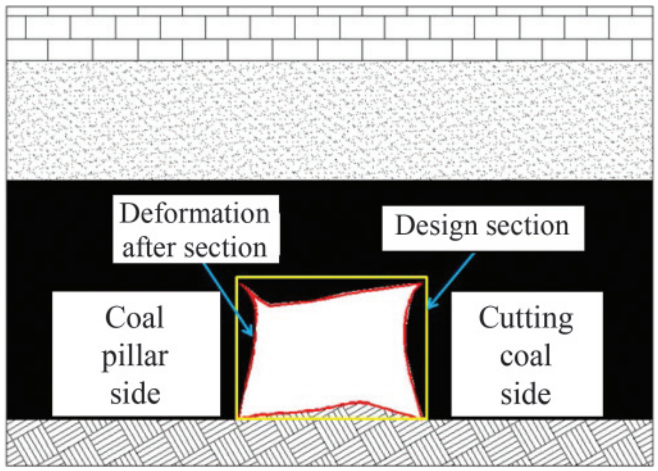

Fig.2 Comparison of Baode mine mining roadway deformationsection before and after

3. Analysis of controllable roof deformation breakage

At present, it is still not feasible to find the relationship between the rectangular drift supporting strength and the deformation breakage of the rock surrounding by doing quantitative calculation, which is mainly based on theoretical analysis. However, the calculation results used for circular drift with similar dimension can be used as a reference. The mechanical model is shown in Fig.4. Assume the circular drift generates an identical perpendicular side-pressure P_o at the spot infinitively far away, the radius of the drift's plastic zone is:

$$R = r\left(\frac{2}{K+1}\cdot\frac{\sigma_c + (K-1)P_0}{\sigma_c + (K-1)P_i}\right)^{\frac{1}{K-1}}$$

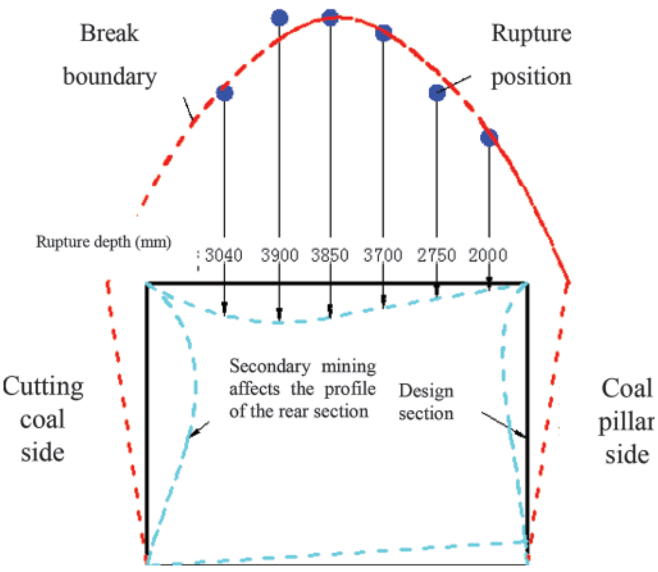

Fig.3 Measured results of rupture depth in the roof of Baode mining roadway

$$K = \frac{1+\sin\varphi}{1-\sin\varphi} \quad \text{... (1)}$$

Where: P_o – in-situ stress; P_t – support resistance; r –drift radius; φ – internal friction angle of the rock surrounding; C – cohesion of the rock surrounding; μ – Poisson's ratio; E – elastic modulus; σ_c – uniaxial compressive strength.

When doing the calculation for the deformation of the rock surrounding, it is inappropriate to assume a constant rock size in the plastic zone; and the capacity expansion dues to rock breakage must be considered. Assume the displacement of plastic zone expansion as u^p, rock expansion gradient as η, then the relationship of rock expansion and rock surrounding strain can be simplified to a linear relationship:

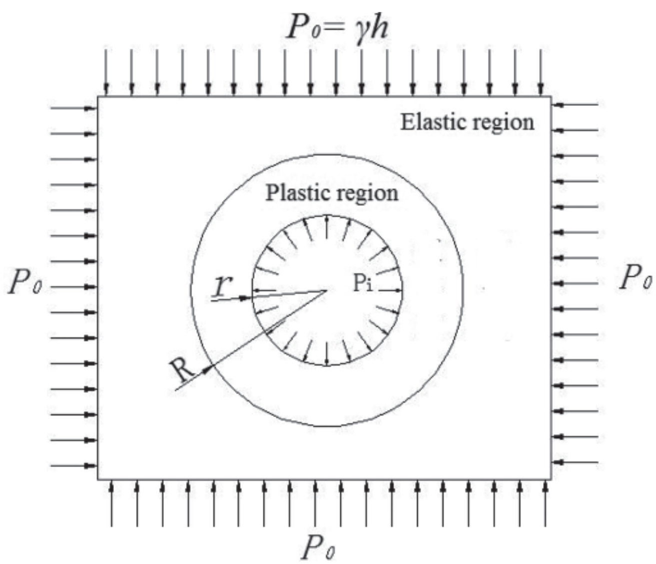

Fig.4 Deformation and failure mechanics model of roadway surrounding rock

$$\frac{u^P}{r} + \frac{du^P}{dr} = -\eta\frac{u^P}{r} \quad \text{... (2)}$$

The radial stress σ_R at the junction of the elastic and plastic zone of the rock surrounding:

$$\sigma_R = \frac{2P-\sigma_c}{1+K} \quad \text{... (3)}$$

Under the plain strain condition, radial displacement caused by drift excavation:

$$u = \frac{1+\mu}{E}\cdot\frac{R^2}{r}\left(P_0-\sigma_R\right) \quad \text{... (4)}$$

Since the radial displacement at the elastic/plastic junction is continuous, when $r = R$, equation (2) is equivalent to equation (4) with $u = u_p$, then:

$$u^P = \frac{(1+\mu)(P-\sigma_R)}{E} - R\left(\frac{R}{r}\right)^{1+\eta} \quad (5)$$

Plug equation (3) to equation (5):

$$u^P = \frac{(1+\mu)\left[(K-1)P+\sigma_c\right]}{(K+1)E}R\left(\frac{R}{r_0}\right)^{(1+\eta)} \quad (6)$$

According to equation (1) and (6), the relationship between supporting strength and rock surrounding rupture under various stress environment and rock surrounding conditions can be obtained. As demonstrated in Fig.5, for the control of drift rock surrounding with muddy rock type, supporting resistance is one of the factors that influence the extent of rock surrounding deformation. However, it has a very small impact on the project, under the current technological condition, raising the supporting strength from 0.2 MPa to 0.8 MPa can only reduce the deformation by 5%~15%, which is a very small amount for this project. Thus, the alteration of the in-situ stress has a great influence on the extent of rock surrounding's deformation; while the drift's coffer mechanics and the stress environment remains constant, the reduction in rock surrounding deformation generated by the enhancement in supporting strength is very ting, and this calculation result agrees with the test result that mentioned earlier in this paper. It also proves that, the deformation of rock surrounding caused by its plastic failure is uncontrollable. Under the current engineering technological condition, it is nearly impossible to control the rock surrounding deformation by trying to use the primary supporting, and it is not economically feasible, either.

(a) The relationship between the strength of support and the depth of plastic damage

(b) The relationship between supporting strength and surrounding rock deformation

$r = 2.5$m; $E = 4000MPa$; $\sigma_c = 40MPa$; $\mu = 0.15$; $c = 4.0MPa$; $\varphi = 25^o$; $\eta = 2$

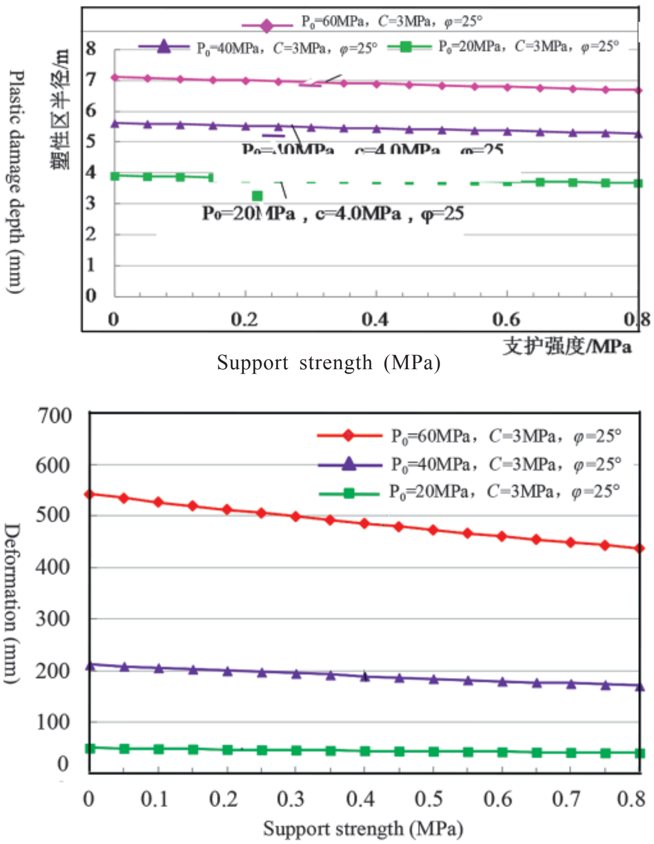

Fig.5 Curves of roadway deformation vs. support capacity

4. Drift's rock surrounding control strategy

For the control of the mining gateway roof with such a large scale, preventing roof sinkage with high strength support is extremely costly and it is undesirable for this project; another type of supporting form, which is mainly used to control roof falling should be adopted. More specifically, a supporting material that can deform compatibly, provide continuous resistance force, keep validity when rock deformation occurs and have enough anchorage range, should be adopted.

The rod body of long-extension bolt can be divided into two or more sections; the end of each section has connector with internal thread, and the two sections connect with each other through a connecting bolt with external threads, as it is shown in Fig.6. The connecting head and connecting bolts are specially heat-treated to match the strength of the rod body. When installing, use the torque of the bolt drilling machine to connect the sections together naturally. The installation process is almost the same as the ordinary bolt. The length of the long-extension bolt can be selected arbitrarily, and it is not limited by the roadway section in the installation.

The bearing capacity and elongation rate of supporting materials are two important indexes for the performance of anchor cables. Based on the measured results of the rupture depth of the roof of Baode mining roadway, as shown in Fig.3,

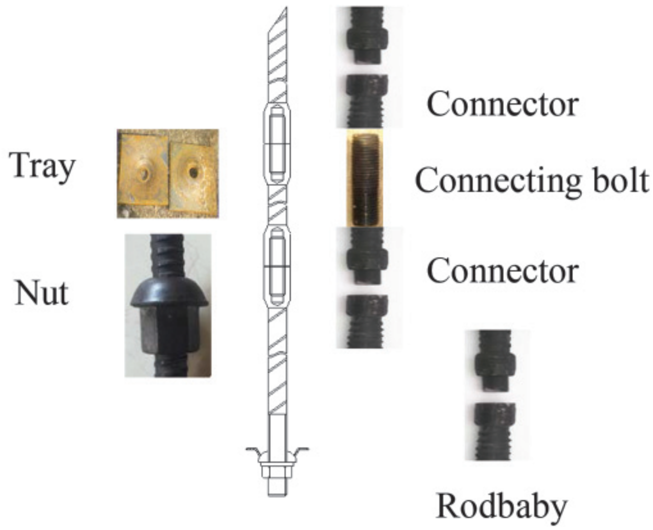

Fig.6 Structure of long-extension bolt

the maximum roof rupture depth is about 3.9m, therefore, the length of the supporting material is designed to be 5.0m, and the long-extension bolt is designed to be two sections, each is 2.5m in length and 20mm in diameter. At the same time, the anchor cable with the length of 5m and the diameter of 17.8mm was selected as a comparison to do the tensile test of the laboratory and underground roadway.

Fig.7 (a) shows the laboratory tensile test results of Φ20 × 5000mm long-extension bolts and Φ17.8 × 5000 mm cable bolts, and the results indicate that, the maximum extension

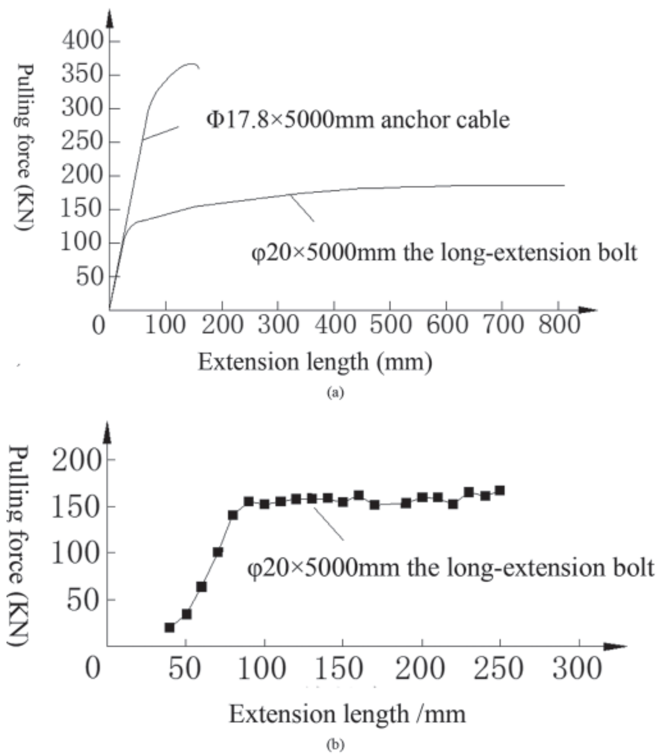

Fig.7 Tensile test curve of the anchor cable and the long-extension bolt

length of 5000mm Φ17.8 cable is 162 mm, and the extension rate is 3.24%; the maximum extension length of 5000mm Φ20 long-extension bolt is 807mm, and the extension rate is 16.14%; the elongation of the long-extension bolt is 4.98 times of the anchor cable's, and its pulling force is stable at over 167KN after stretching over 300mm.

Fig.7(b) shows the underground tensile test results of the Φ20×5000mm long-extension bolts, and the tensile test was carried out by using the large-range bolt drawing machine, and make a record of it every 10mm, and the results indicate that, when the stretching length reaches 40mm, the drawing force is 22KN; then, as the stretching length increases, the drawing force increases almost linearly; drawing force changes little the when stretching length is over 90mm. Between 151KN~165KN, due to the limit of the length of the anchor rod drawing machine, the long-extension bolt is not pulled to break, but within the 250mm stretching length, the bolt drawing force is stable and is basically the same as that in the lab. It can be inferred that the long-extension bolt can be adapted to the deformation of the surrounding rock well during the sinking of the roof.

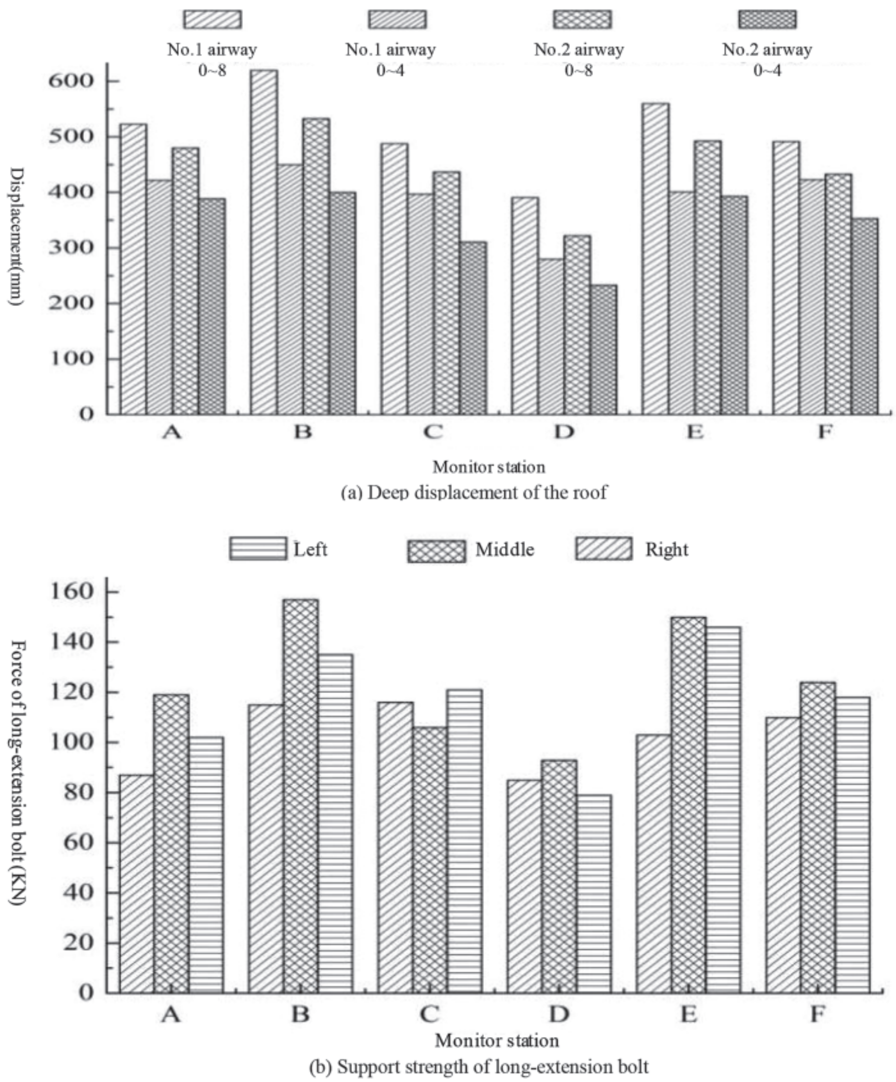

Fig.8 Roof deep displacement and supporting strength of airways for 81306 coal face

5. Engineering application

According to the recent production status of Baode coal mine, the 400m-long industrial tests were respectively carried out in the No.1 airway and No.2 airway, which is about 1000m in advance of 81306 coal face. The original supporting parameters for roofs of the two airways are 2Φ 17.8×6500 mm anchor cables and 4Φ 20×2200mm long-extension bolts, and the parameter for the secondary reinforcing support is installing 4Φ 20×5000mm long-extension bolts for the roadway roof per meter. At the same time, the control effect of the surrounding rock and supporting force of long-extension bolt was monitored by the 6 evenly-distributed monitor stations (A、B、C、D、E、F) in the two airways. Each monitor station of No.1 airway consists of a roof deep displacement monitor station and three monitoring points of long-extension bolt support strength, and each monitor station of No.2 airway includes a roof deep displacement monitor station. Fig.8 shows the monitoring statistics results of the deep displacement and long-extension bolts' strength of the two airways' roof of 81306 coal face.

The statistical results of the deep displacement monitoring in Fig.8 (a) show that, during the mining influence, the roof deformation of No.1 airway from 0 to 8m is 390~620mm and the roof deformation of 0~4m is 280~ 450mm. The roof deformation of No.2 airway from 0~8m is 322~530mm, and the roof deformation of 0~4m is 230~402mm. The roof deformation of the range of 0~4m (anchor range of long-extension bolts) accounts for 71%~85% of the deformation of roof from 0~8m range, and the long-extension bolts bear most of the surrounding rock deformation. The results of the monitoring statistics of long-extension bolt, shown in Fig.8(b), shows that the support stability of the long-extension bolt is stable at 79~159KN, and its working condition is good, and the bolt breaking phenomenon is rare. The monitoring results show that the large extension performance of lone-extension bolts can not only adapt to the large deformation of roadway surrounding rock, but can provide continuous high working resistance. It can ensure the surrounding rock unbroken during the deformation and ensure the reliability and safety of the supporting system.

(a) Deep displacement of the roof

(b) Support strength of long-extension bolt

6. Conclusion

(1) The roof of Baode mining roadway is sinking violently, the roof rapture reaches nearly 4m. Under existing technical conditions, increasing the support strength has limited control effect on the deformation and failure of roof. It is necessary to adopt flexible supporting mode which can adapt to the deformation of surrounding rock, have sufficient anchorage length, and provide continuous high supporting force to control the roof caving primarily.

(2) The long-extension bolt has more reasonable stretching characters than the anchor cable. So it works well in the extension process. The engineering test results show that, the long-extension bolt technique can coordinate the deformation with the surrounding rock, and guarantee support resistance effectively and prevent the roof caving of the roadway.

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Conclusions

Innovative developments, such as new detection methods, automation, advanced exploration techniques and new leaching technologies, besides others, would mitigate many of the challenges faced by the mining sector, including deepening underground mining operations, lower grades, higher labour costs, fewer mature orebodies and increasing environmental impacts.

Any mineral reach needed to be at the "cutting-edge of technology" and embrace innovation in an environment that supported economic growth.

There is a need to develop solutions, "do things better", innovate more and adapt to and understand nation's constant changing "realities", which also applied to how the country would position itself in an ever-changing global context to remain competitive. R&D could be used as a catalyst for value-adding and added that global tax regimes have proved to be successful in stimulating investments.

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