Research on Combined Support Technology of High Convex Strip-bolting for Deep Soft Rock Roadway

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特　　集

Research on Combined Support Technology of High Convex Strip-bolting for Deep Soft Rock Roadway

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Based on the systematic analysis of mechanical characteristics for deep roadway excavated in soft strata, the high convex strip-bolting support technology was put forward, and a numerical analysis was carried out by FLAC^{3D}. The process of general bolting support and high convex strip-bolting support of deep soft rock roadway were simulated. The results indicate that the convex bed of strip-band can adapt to large deformation of high pre-stressed bolting, and the high strength and high rigidity of strip can bear large axial force and moment of flexion. In addition, bolting and anchoring combined support can control the deformation of rock masses by transferring the strength of deep strata, and bolt-grouting can form stress-relief region in deep and generates high strength invert arch at shallow which can afford some support resistances. A case study is also presented and the results of field measurement show that the new support system is suitable for roadways excavated in weak rocks.

Keywords: Deep engineering, Soft rock roadway, High convex strip, Numerical simulation

1 INTRODUCTION

With the shallow coal resources decreasing, many collieries have been shifted to deep mining in China, where the relevant problems have been increasingly serious in soft rock roadway, such as large deformation, high ground pressure and supporting hard[1,2]. The driving workload of state-owned key coal mine is 7464.6km in 2005 and the roadway excavated in deep soft rocks has high share, about 30 percent[3]. Recently, with the problems of engineering soft rock roadway in deep becoming prominent, extensive researching work has been conducted by many domestic experts and scholars. According to the statistics of main journals about late 30 years in China, more and more researchers pay attention to soft rock bolting combined support technology related to coal-mining, moreover, there are also deficiencies at studies of surface protecting components for bolting support technology, especially studies of the strip[4]. In fact, the reinforcement effect of bolt supporting relies heavily on the mechanical characteristics of strip. The rock anisotropy is the key reason for inharmonic deformation of surrounding rock. The deformation incompatibility of strip-bolting combined support has two reasons, one is the strength and rigidity of strip which can't bear the high stress of surrounding rock so that it would be torn or pulled off, the other is the proximity degree between rock and strip which can't release the harmful deformation from the roadway periphery. Therefore, it is the most effective method of studying a strip-bolting technology which can accommodate the non-linear deformation and high ground pressure to enhancing and controlling the deformation stability of deep shafts.

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2 THEORETICAL BASIS OF HIGH CONVEX STRIP-BOLTING SUPPORT TECHNOLOGY

The shape of roadway course section with straight wall and half closed arch is widely used in rock driven at depth, for rock gangway service time is usually very long, in addition, long-term stability and less maintenance need to be assured during the service. The numerical simulation results show that the upper wall and lower wall of roadway are the key position for supporting[5]. Bolt-grouting support is used to reinforce lower wall, because cohesion and internal friction angle of surrounding rock will be improved by grouting, and Young's modulus will be strengthened by bolting. At the same time, bolt-grouting can form stress-relief region in deep and generate high-strength invert arch at shallow which can afford some support resistances to the lower wall. Pre-stressed bolting and anchoring combined support is used to reinforce the upper wall, whose bottleneck problem is strip vulnerable to damage at present.

The strength and stiffness of high convex strip are higher than that of general strip. The yielding strength of general strip is less than 340MPa in China, and the high convex strip is up to 400-600MPa, so it can play an important role in high pre-stressed bolting and anchoring combined support. In the complicated mechanical environment at depth，soft rock enters into the non-linear plastic large deformation stage. The boss of new strip reserves some deformation space, about 8-12mm, in order to adapt to harmful deformation of surrounding rock. At the same time, two sides of the new strip cling to the surface of surrounding rock, in order to control the roof deformation. The structure of high convex strip is shown in Fig. 1.

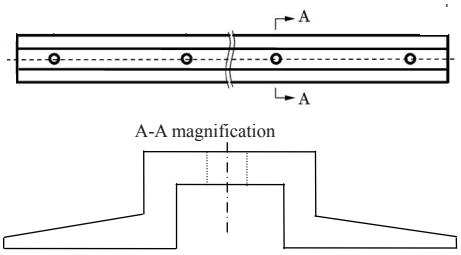


Fig.1 The structure of high convex strip

3 NUMERICAL SIMULATION OF HIGH CONVEX STRIP-BOLTING SUPPORT TECHNOLOGY

3.1 Numerical modeling

The finite difference method is used to predict deformation and stress in roadway at depth. The numerical model constructed by FLAC^{3D} is presented in Fig.2. The length, width and height of the model are 30m, 5m, 30m respectively. Cubic elements are used for simulating construction, and the model is meshed into 7576 elements. A straight wall and half closed arch of roadway (5m×4m) is placed in the center of the model, and the height of the arch and straight wall are 2.5m, 1.5m respectively. All sides of the model are fixed. The Mohor-Coulomb criterion is used for simulating the linear broken surface. The major principal stress of the model is 25.2MPa, the minor principal stress 14.6MPa and the vertical stress 21MPa. The mechanical properties of the model material are shown in Table 1. In order to investigate the supporting effect of high convex strip-bolting technology on the stress redistribution around the roadway, the general bolting support and high convex strip-bolting support conditions are considered in our present study.

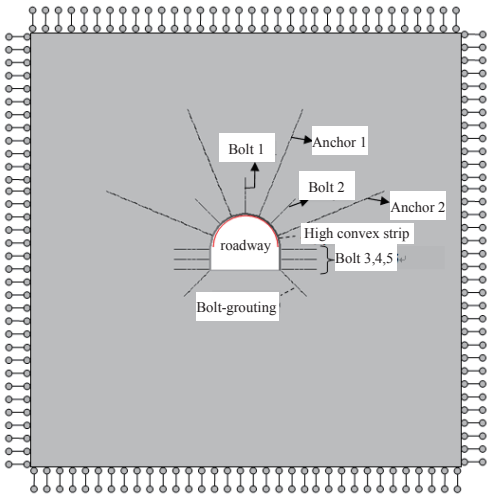


Fig.2 Numerical calculation model

Table 1 mechanical properties of materials used in the numerical model

	Young's modulus (GPa)	Poisson's ratio	Cohesion (MPa)	Internal friction angle (°)	Density (kN/m^3)	Dilation angle (°)
Surrounding rock	1.3	0.35	0.2	27	22.5	10

3.2 Deformation of deep roadway

Displacement and its rate of roadway for general bolting support are shown in Fig.3a. The floor heave of roadway is 189.3mm. The displacements of roof and side are 118.1 mm, 108.9mm, respectively. The floor heave was basically stable, but the roof displacement has exceeded anchorage support's permissible value (anchorage support's permissible value generally doesn't exceed 80~100mm in China[7]). However, under the condition of the high convex strip-bolting support, the roof displacement is 50.5mm and the

maximum displacement rate is only 8.64mm after every 200 steps (Fig.3b). It can be seen that the deformation of the surrounding rock is satisfactorily controlled by the high convex strip-bolting support.

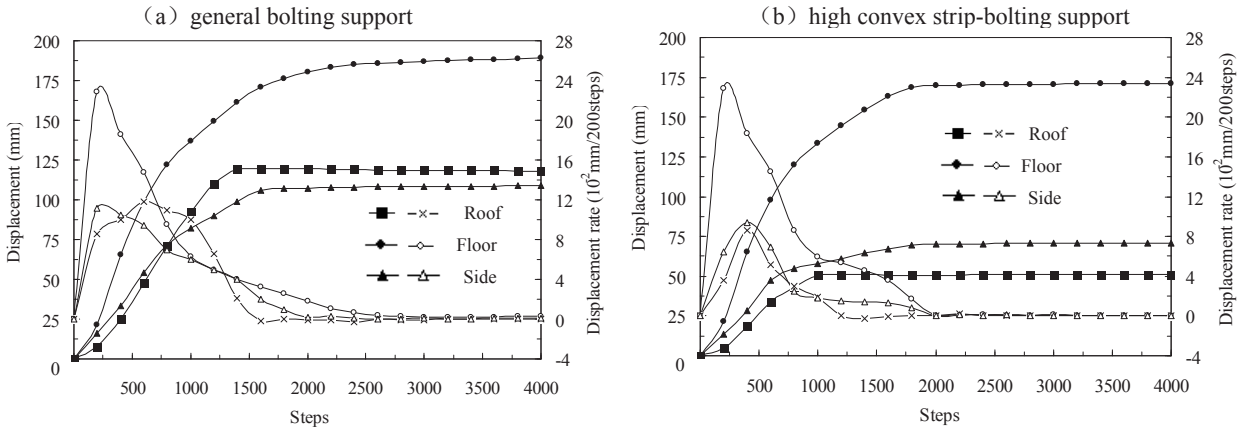


Fig.3 Behavior of different forms of support employed in soft rock roadway at depth

The displacement distributions for general bolting support and high convex strip-bolting support are shown in Fig.4. Displacement in most part of roof is beyond 50mm for general bolting support, but less than 40mm for high convex strip-bolting support. It will be seen that the supporting effect of high convex strip-bolting is better than that of general bolting support.

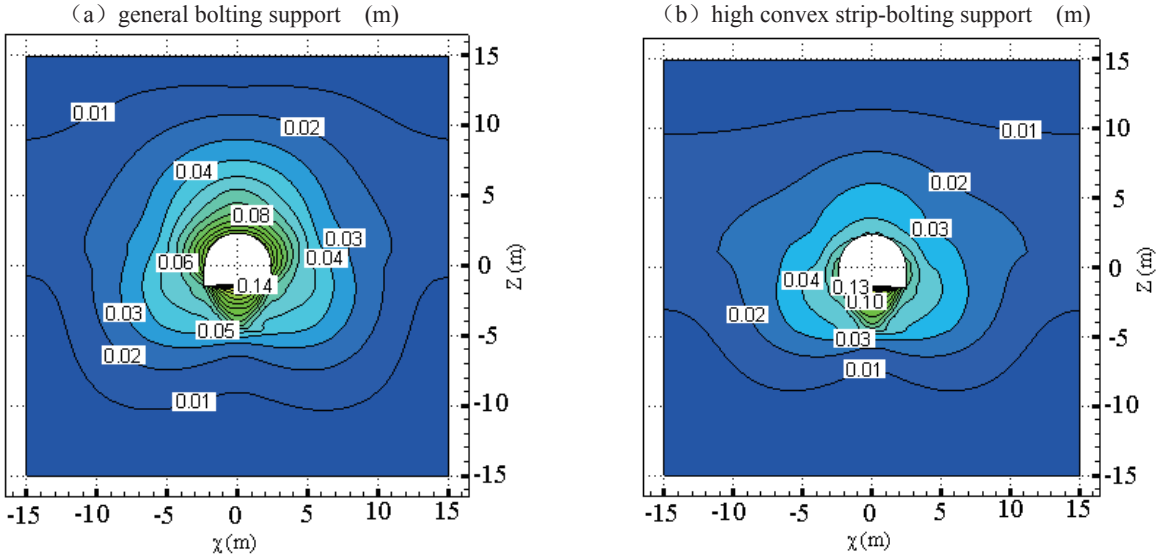


Fig.4 The displacement distribution for deep soft rock roadway

3.3 Strip-bolt coupling effect

Axial force of bolt and anchor for general bolting support is shown in Fig.5(a). Most of the axial forces are more than 200kN and the highest is up to 257.1kN, which is beyond the broken load of high strength bolt (the majority of high strength bolt's broken load is 200-300kN[7]), but Bolt 5 is only 90.3kN. However, under the condition of the high convex strip-bolting support, the axial stresses for bolt and anchor are less than 160kN (Fig.5b). At the same time, axial stresses for Bolt 1, 2, 3 reduce gradually at the early supporting, which shows that the high-convex strip has played a coordination role in the effect of the adjacent bolt or anchor and the stress distribution of bolt and anchor is reasonable.

The stress distribution of high convex strip is shown in Fig.6. The existent of bolt and anchor which take on uneven tension coordinates the inhomogeneous deformations of surrounding rock to the deep and shallow part. As a result, the high convex strip which takes on uniform axial stress and large moment in roof and two sides, will release the harmful deformation caused by bolting or anchoring.

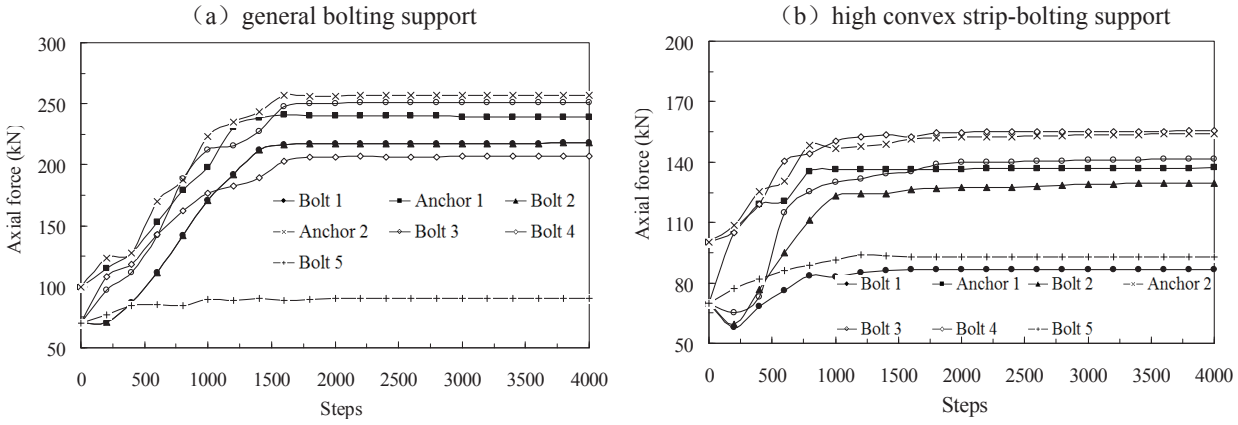
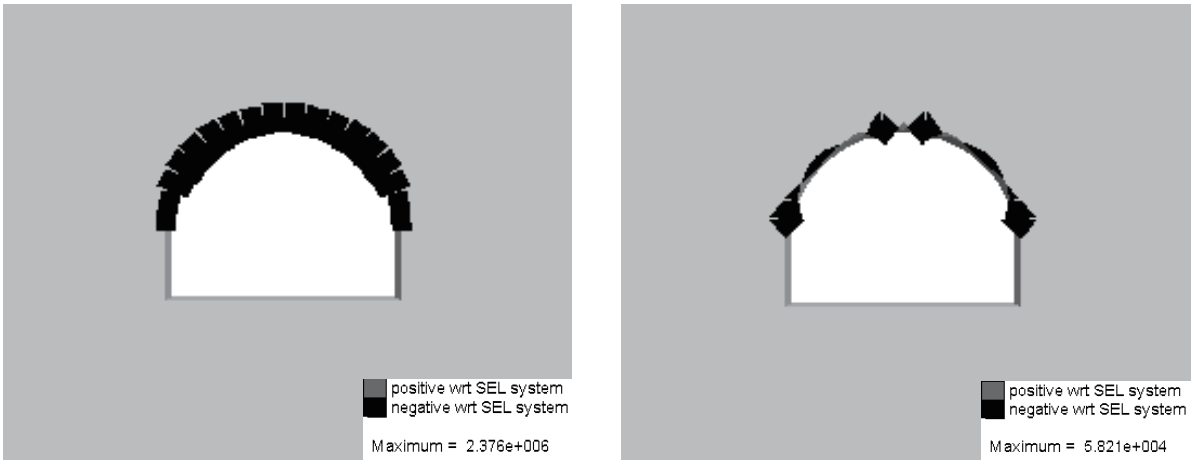


Fig.5 Bolt behavior of different forms of bolting support employed in deep soft rock roadway



（a）axial stress(Pa)　　（b）moment(N·m)

Fig.6 Influence of high stress accumulation on the strip character within high convex strip-boling support

4 CASE HISTORY

4.1 General engineering situation

In order to overcome the roof supporting problems of the deep high-stressed permanent soft rock roadway at Hebi Coal Mining Administration in China, a haulage roadway at -420 level (depth of 640m) in Hebi No.9 Coal Mine was selected to conduct on-site experimental support study. The exposed surrounding rock mainly consists of charcoal gray sandstone and black flaggy sandy mudstone with auxetic jointed cracks. The rock would collapse after being immersed into water. According to the Chinese National Standards for Engineering Rock Mass Classification[(6)], the surround- ing rock of the roadway was classified as soft rock.

4.2 Design of support project

The high convex strip-bolting support projects including smooth blasting, high strength and high stiffness strip-bolting support, delayed anchoring and delayed bolt-grouting will be used according to soft rock properties and deformation conditions of the roadway:

1. Smooth blasting. Design width and height of the roadway are 4.8m and 3.9m, respectively. Dig width and height of the roadway are 5m and 4m, respectively, and the reserved deformation is 100mm.
2. High pre-stressed and high stiffness bolting support and web-forming are used for the roof and two sides of roadway. High convex strip is used immediately after bolting. Left rotation whorl-strip resin bolts with *L* 2500mm, *φ*22mm, spacing of 700×700mm, pre-stress of exceeding 80kN, a diamond pattern arrangement and end anchored are installed with resin anchoring coagulant of label K2335. The label of high convex strip is *GDT30/140×20×2000-Q/YZK034-2003*. The high convex strip tray of label *30/140×20×40* is used in roof, but ordinary dish iron tray on two sides.
3. Anchoring and grouted bolt are installed behind the excavating face 10-25m. Seamless-tube grouted bolt with *L* 2500mm, *φ*32mm is installed at the angle of 45º to the floor, and grouting pressure is 2-3MPa. It must take more than 20min for grouting in a single-hole. Strand anchor with *L* 8m, *φ*18.9mm, spacing of 1400mm×2100mm, resin anchoring coagulant of *CK2335* and *K23350* is used. The label of the high

convex strip is *GDT30/140×20×2000-Q/YZK034-2003*, and *30/140×20×40* for tray.

It will take about 30 days to finish the whole procedure from blasting to support.

4.3 Support effect

Four surface displacement observational stations including roof, floor, and two sides were set every 15m. Observation period is more than one year. The monitoring results show that deformation of soft rock roadway is divided into two phases: at the start of the excavation, high pre-stressed and high stiffness bolting support was applied, and the surrounding rock deformed at a closure rate of almost 3mm/d at the first five days after its excavation, then gradually stabilized; after the delayed anchoring and delayed bolt-grouting support was employed 20 days, the deformation of surrounding rock was stable gradually. The total wall-to-wall closure and roof-to-floor convergences are respectively less than 120mm and 90mm after over 650 days from excavation on. Obviously, high convex strip-bolting support is suitable for the roadway excavated in such soft rock.

5 CONCLUSIONS

According to our studies, the technical characteristics of high convex strip-bolting combined support technology are summarized as follows:

1. High convex strip greatly releases the rocky harmful deformation and play a coordinative effect of bolting or anchoring.
2. Bolting and anchoring combined support can control the deformation of surrounding rock by transferring the deep rock strength, which will turn waiting for stability negatively to promoting stability actively.
3. Bolt-grouting can form stress-relief region in deep and generates high strength invert arch at shallow which can afford some support resistances.
4. The roadway deformation for high convex strip-bolting support is more reasonable than that of general bolting support, so it can achieves an optimal combination of rock mass and support structure.

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REFERENCES

（1）He M. C., Zou Z. S., Zou Y. F., Introduction of roadway engineering in soft rock (in Chinese), China Mine University Press,(1993).
（2）Sun X. M., He M. C., Zhang G. F., Cai F., Study on failure mechanism and support countermeasure of deep high stressed soft rock roadway in Hebi No.5 Coal Mine (in Chinese), Journal of Liaoning Technical University (Natural Science), Vol.28, No.3, (2009), p393-396.
（3）Zhao X. S., Present status and development tendency of high efficient roadway driving technology in coal mine (in Chinese), Coal science and technology, Vol.35, No.4, (2007), p1-10.
（4）LI Z. P., LUO P. P., ZOU Z. S., Research outlines of coal roadway supporting in china based on statistical analysis of the periodical literature (in Chinese), Coal mine machinery, Vol.30, No.9,(2009),p7-9
（5）Sun X. M., Cai F., Yang J., Cao W. F., Numerical simulation of the effect of coupling support of bolt-mesh-anchor in deep tunnel, Mining Science and Technology, Vol.19, No.3,(2009),p352-357
（6）The National Standards Combination Group of People's Republic of China, GB 50218-94 Specifications for engineering classification of rock masses (in Chinese), China Planning Press, (1995).
（7）Chen Y. G., Lu S. L., Strata control around coal mine roadway in China (in Chinese), China Mine University Press, (1994).

深部軟岩坑道用ハイコンベックス・ストリップボルトを用いた複合支保技術に関する研究

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概要

深部軟岩中に掘削された坑道の力学的特性を系統的に解析し，ハイコンベックス・ストリップを用いたボルト支保技術の開発を行った。また，FLAC3D による数値解析も行った。一般的なロックボルト支保とハイコンベックス・ストリップを用いたボルト支保の深部軟岩坑道への適用シミュレーションを実施した。その結果，ストリップ・バンドの凸部はプレストレスド・ボルティングの大きな締め付け力による変形にも耐え，ストリップの高い剛性と強度は大きな軸力やたわみモーメントにも耐えることがわかった。加えて，アンカー型のボルト支保においては，深部の岩盤強度を利用して岩盤変位を制御でき，グラウトタイプのボルト支保では深部に応力解法領域を形成できるため坑壁近傍に高強度のアーチ作用が働き支保抵抗を緩和できることがわかった。また，現場計測により新支保システムは軟弱岩盤の坑道掘削にも適用できることがわかった。その事例についても本文で紹介する。

Keywords: Deep engineering, Soft rock roadway, High convex strip, Numerical simulation

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