Journal of Rock Mechanics and Geotechnical Engineering 7 (2015) 483–492

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full length article

Longwall mining "cutting cantilever beam theory" and 110 mining method in China—The third mining science innovation

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ARTICLE INFO

Article history:
Received 28 April 2015
Received in revised form
14 July 2015
Accepted 17 July 2015
Available online 6 August 2015

Keywords:
Mining innovation
121 mining method
Cutting cantilever beam theory (CCBT)
Non-pillar mining
110 mining method

ABSTRACT

With the third innovation in science and technology worldwide, China has also experienced this marvelous progress. Concerning the longwall mining in China, the "masonry beam theory" (MBT) was first proposed in the 1960s, illustrating that the transmission and equilibrium method of overburden pressure using reserved coal pillar in mined-out areas can be realized. This forms the so-called "121 mining method", which lays a solid foundation for development of mining science and technology in China. The "transfer rock beam theory" (TRBT) proposed in the 1980s gives a further understanding for the transmission path of stope overburden pressure and pressure distribution in high-stress areas. In this regard, the advanced 121 mining method was proposed with smaller coal pillar for excavation design, making significant contributions to improvement of the coal recovery rate in that era. In the 21st century, the traditional mining technologies faced great challenges and, under the theoretical developments pioneered by Profs. Minggao Qian and Zhenqi Song, the "cutting cantilever beam theory" (CCBT) was proposed in 2008. After that the 110 mining method is formulated subsequently, namely one stope face, after the first mining cycle, needs one advanced gateway excavation, while the other one is automatically formed during the last mining cycle without coal pillars left in the mining area. This method can be implemented using the CCBT by incorporating the key technologies, including the directional pre-splitting roof cutting, constant resistance and large deformation (CRLD) bolt/anchor supporting system with negative Poisson's ratio (NPR) effect material, and remote real-time monitoring technology. The CCBT and 110 mining method will provide the theoretical and technical basis for the development of mining industry in China.

1. Introduction

In the 1960s, Prof. Minggao Qian proposed the "masonry beam theory" (MBT) (Qian, 1981, 1982) for the first time in China, and presented a full discussion on the transmission and equilibrium method of overburden pressure in mined-out areas by using reserved coal pillar. On this basis, the "121 mining method" was established, namely one stoping face needs two advanced excavation tunnels and one reserved coal pillar before the next mining cycle. The MBT and mining system based on the 121 mining method laid a sound foundation for the development of mining science in China. The second mining innovation started in the 1980s, which was characterized by the "transfer rock beam theory" (TRBT) (Song, 1979, 1982) proposed by Prof. Zhenqi Song. This illustrated a further transmission path of stope overburden pressure and the pressure distribution in high-stress areas. Then the advanced "121 mining method" was raised with smaller coal pillar in terms of field excavation design, making important contributions to development of the coal recovery rate in that era.

At the beginning of the 21st century, large deformation failure problems in coal mines became more challenging with increasing mining depth, and the accidents in risk-prone gateway and deep gob-side gateway accounted for 80%–90% of total accidents in working face gateways (He, 2004, 2005; He et al., 2005). It is basically considered that the traditional 121 mining method was not suitable for the deep mining purpose (Zhai and Zhou, 1999; Li, 2000; Liu and Shi, 2007; Fei, 2008). In 2008, the theory of "cutting cantilever beam theory" (CCBT) was first put forward. In this theory, it can be noted that the ground pressure was used for the purpose of advanced roof caving by precutting to form a cantilever beam above the gob-side gateway. When the precutting was performed

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Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.
1674-7755
http://dx.doi.org/10.1016/j.jrmge.2015.07.002

on the roof of gateway, the transmission of overburden pressure was cut off, which mitigated the periodic pressure when using the 121 mining method, and part of roof rock mass was driven down, forming one side of the gateway for the next stope mining cycle. The CCBT provides a new basis for the non-pillar mining, under which the 110 mining method was developed (He et al., 2007; Zhang et al., 2011; Song and Xie, 2012; Wang and Wang, 2012; Liu and Zhang, 2013; Sun et al., 2014), namely one stope face, after the first mining cycle, only needs one advanced gateway excavation; while the other one is automatically formed during the last mining cycle without coal pillars left in the mining area by using this mining technology. The core idea of the 110 mining method is that, first, the natural ground pressure is used to make part of the roof fall down, instead of fully reinforcing it by artificial supporting system and coal pillar; second, the gob roof rock is used to form one side wall of the gob-side gateway; and third, the expansion characteristic of broken gob roof rock is used to reduce the surface subsidence. This mining method will reduce 50% of gateway excavation workload in the stope and fulfill 100% coal pillar recovery, which achieves a significant reduction in mining costs and more importantly, will reduce the accidents in the stope. It may be used to fulfill the "N00 mining method" in the future, which is the optimization and innovation of the 110 mining method. The symbol "N00" means no matter how many mining cycles and working faces are in the district, all the gateways would be formed automatically with CCBT, suggesting no need for gateways to be excavated when using traditional methods. In this paper, China's three innovations in longwall mining will be reviewed and discussed, including the related theories and the 121 mining method, the CCBT and the 110 mining method, and the key technologies involved. The CCBT and 110 mining method will be considered to be the basis for China's next-generation mining industry development, from mining giants to mining powers.

2. The MBT, TRBT and 121 mining method

For the development of coal mines in China, the mining science and technology was characterized by the MBT proposed by Prof. Minggao Qian, which formed the traditional 121 mining system (i.e. the 121 mining method), and then by the TRBT proposed by Prof. Zhenqi Song, which further improved the awareness of the 121 mining method, as shown in Fig. 1. This method is currently the most widely used system in longwall mining in China, which makes an important contribution to the development of China's mining science and technology.

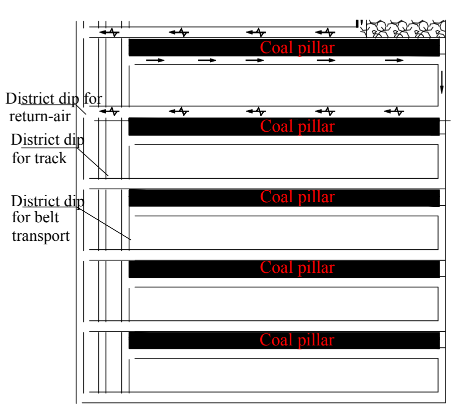


Fig. 1. Layout of the 121 mining method.

2.1. The MBT and 121 mining method – the first mining science innovation

Prof. Minggao Qian first introduced the concept of the "movement mechanics of stope overlying rock strata" in 1962, which has been verified by the field tests in Datun mining area and Kongzhuang coal mine. The MBT was proposed in 1981 and then was recognized after the First Conference of Coal Mine Stope Pressure Theory and Practice on 21 August 1981 in China. In 1982, the MBT was promoted internationally after the topic, *Stope overburden rock mass structure model and its application to strata control*, was presented at the International Conference of Rock Mechanics in the University of Newcastle, UK. The MBT points out that: *Periodic breaks of the roof rock beam occurred during stoping, which formed the rotary extrusion of broken rocks, and the masonry beam structure was formed due to the horizontal force and friction in the gob area*. The structural and mechanical models of MBT are shown in Figs. 2 and 3, respectively. Based on the proposed models, the calculation formulae of support strength and roof subsidence were proposed. It is the first time to present the detailed discussion on the transmission and equilibrium method of overburden pressure in mined-out areas. In this instance, the "large coal pillar-artificial support-gangue" supporting method is established consequently, i.e. the next mining cycle and two gateways are far from the gob, which forms the 121 mining method as shown in Fig. 4.

The supporting strength (Qian and Li, 1982) for longwall mining can be written as

$$P = \gamma R \sum h + nL_c(\gamma h_c + q) + \left[2 - \frac{L_0 \tan(\varphi - \theta)}{2(h - s_0)}\right] Q_0 \tag{1}$$

where P is the supporting strength (kN/m); $\sum h$ is the total thickness of immediate roof (m); R is the face width (m); n is a constant coefficient; q is the uniformly distributed load of overburden (kN/m^2); L_0, h_c, s_0 and Q_0 are the breaking length (m), thickness (m), subsidence (m) and weight (kN/m) of cantilever rocks, respectively; L_c is the roof length supported by caving rock; φ is the friction angle of rock (°); θ is the angel between fracture plane and vertical plane; γ is the volume weight of rock layer (kN/m^3).

The roof subsidence (Qian and Li, 1982) can then be expressed as

$$\Delta s_R = \frac{2}{3}\frac{R}{L_R}\left[m - \sum h(K_P - 1)\right] \tag{2}$$

where Δs_R is the roof subsidence (m), L_R is the length of cantilever rocks on the immediate roof (m), m is the mining height (m), and K_P is the loose coefficient of broken rocks.

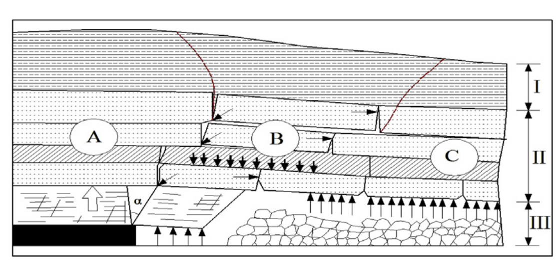


Fig. 2. Structural model of the masonry beam theory (MBT): A is the coal seam support affected zone; B is the abscission zone and support affected zone; C is the gob zone, supported by broken caving rock; I, II and III are the overlying strata (Qian, 1982).

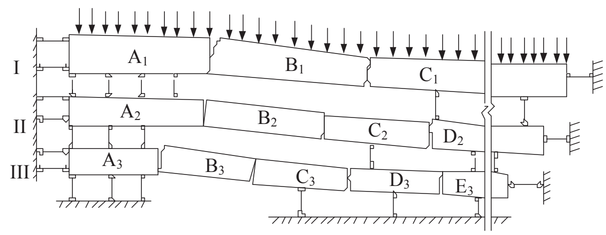


Fig. 3. Mechanical model of the masonry beam theory (MBT). The subscripts 1, 2, and 3 are the blocks in different overlying strata (Qian, 1982).

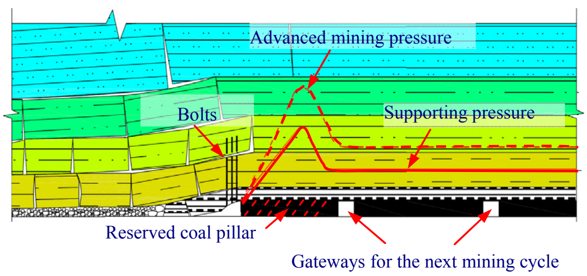


Fig. 4. Scheme of roof strata movement of the 121 mining method (He, 2014).

2.2. The TRBM and improved 121 miming method – the second mining science innovation

The TRBM was first proposed by Prof. Zhenqi Song in 1979, according to the drilling observational data in Zhaogezhuang mine, Kailuan, China. In 1981, the theory was presented in the First International Conference on Ground Control in Mining in Morgantown, USA. Then it was generally acknowledged at the First Conference of Coal Mine Stope Pressure Theory and Practice on 21 August 1981. The official proposition of the TRBM was given in the scientific paper entitled "Rules for the stope bearing pressure and its application" (Song, 1982).

The TRBM states: "*With underground stoping, periodic fracture occurred in the main roof, and then the rock beam structure was formed which was supported one side by the coal seam in front of working face, and the other side by the gangue.*" The force was always kept in the direction of advance mining, namely the force was transferred from the roof to the advanced coal and gangue in the goaf. This structure is called "transfer rock beam" (TRB), and its structural and mechanical models are shown in Figs. 5 and 6, respectively.

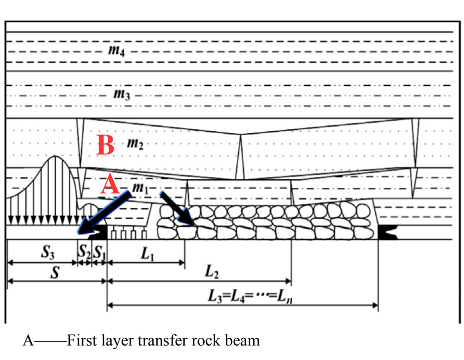


Fig. 5. The structural model of transfer rock beam (TRB).

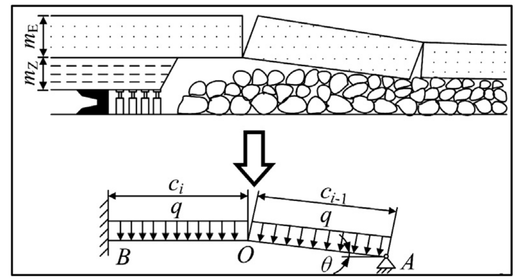


Fig. 6. The mechanical model of transfer rock beam (TRB) theory.

The TRBM emphasizes the effect of roof movement state on the required supporting strength, and the effect of deformation on coal stress distribution and stope supporting structure. It further explains the transfer path of overburden pressure, and the high-stress region should be divided into internal and external stress fields. It also points out that the excavation of gateway could be in the low internal stress field and only small coal pillar is needed for supporting, as shown in Fig. 7. Thus the gateway pressure can be reduced when excavating in the internal stress field by the improved 121 mining method. The roof control design and method show that determination of roof support strength can be calculated by Eq. (3). The TRBM is formulated on the basis of a large number of engineering practices, which helps to improve the coal recovery rate in China.

Similar to the MBT, the supporting strength of the TRBM (He, 2014) can be written as

$$P_{\mathrm{T}} = P_{\mathrm{A}} + \frac{m_{\mathrm{E}}\gamma_{\mathrm{E}}c}{K_{\mathrm{T}}L_{\mathrm{T}}}\frac{\Delta h_{\mathrm{A}}}{\Delta h_i} \tag{3}$$

where P_{T} is the supporting strength (kN/m^2), P_{A} is the force acting on the immediate roof (kN/m^2), Δh_{A} is the maximum roof subsidence of the face (m), Δh_i is the designed roof subsidence (m), K_{T} is the rock redistribution coefficient, m_{E} is the thickness of rock beam (m), γ_{E} is the volume weight of rock beam (kN/m^3), c is the interval of periodic weighting (m), and L_{T} is the face width with stope support (m).

3. The CCBT and 110 mining method – the third mining science innovation

At the beginning of the 21st century, the disasters and accidents caused by large deformation of surrounding rocks of tunnels were frequently reported with the increase of mining depth. According to the incomplete statistics, accidents in deep gateway accounted for 80%–90% of total accidents, among which 80%–90% of the gateway accidents occurred in the gob-side gateway and the

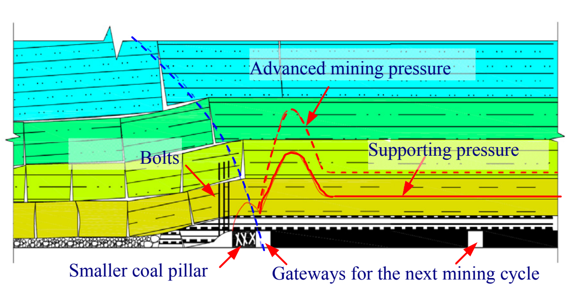


Fig. 7. Scheme of roof strata movement of the improved 121 mining method (He, 2014).

accident-prone gateway. Accidents were mainly induced due to coal pillar burst and support failures under large ground pressure at great depth and periodic pressure caused by main roof breaking. Thus, the traditional 121 mining method in terms of reserved coal pillar was facing great challenges.

For the limits of the traditional 121 mining method, the CCBT and 110 mining method were proposed in order to address the problems encountered in longwall mining. The CCBT was verified in field by using advanced roof caving in 2008, and was first applied to working face No. 2442 in Baijiao coal mine, Sichuan Province, in 2010. In this project, non-pillar mining technique was used in the gateway near the goaf formed automatically by advanced pressure relief and roof caving (Zhang et al., 2011). The CCBT was established on the basis of interactions of stress fields, supports, and surrounding rocks during the process of advanced pressure release and roof caving. One of the key technologies is the orientation cutting in the goaf side roof, which cuts off the transfer of overburden pressure to other parts on the roof, falls part of roof rock mass down, and forms a new excavation roadway for stoping subsequently. Besides, many other key technologies were involved to achieve CCBT. For instance, a new supporting material, the bolt or anchor with constant resistance and large deformation (CRLD), was employed in the gob-side roadway roof supporting to keep the gateway roof stable during the advanced roof caving.

Along the working face direction, the mechanical model of CCBT is shown in Fig. 8. In this figure, G is the gravity of the immediate roof (kN), F_h is the horizontal force in the rock strata (MPa), L is the length of working face (m), L_0' is the length of gateway, H_c is the depth of roof precutting (m), α is the angle of advanced roof cutting (°), T is the shear force on the precutting plane, and N is the normal force on the plane.

Then the horizontal and normal forces imposed on the precutting surface can be respectively obtained:

$$N = F_h \cos\alpha - G \sin\alpha \tag{4}$$

$$T = G \cos\alpha - F_h \sin\alpha \tag{5}$$

The frictional resistant force (or resistance) can be written as

$$F_\varphi = (G \cos\alpha - F_h \sin\alpha)\tan\varphi + cA \tag{6}$$

where F_φ is the frictional resistance, c is the cohesion of the sliding surface, and A is the area of the precutting plane, following the equilibrium equation on this plane. Then we have

$$T = \sum \gamma_i H_i (\cos\alpha - \lambda \sin\alpha)\tan\varphi + cA \tag{7}$$

The depth of the precutting into the roof is first determined by the height of the gateway because one side of the gateway needs to be automatically formed after roof caving, which is the minimum depth (H_{min}) of roof cutting. The volume of rock increases after rock breakage, thus the roof caving depth is designed to make the broken rock be filled in the mined-out area, in order to keep the main roof stable along its trend. This would weaken or mitigate the negative periodical impact and increase the stability of the roadway. Based on this, the maximum caving depth and the range of the roof cutting depth can be obtained.

(1) Minimum cutting depth

The minimum cutting depth is

$$H_{min} = H_G + 1.5 \tag{8}$$

where H_{min} is the lower bound of the critical value (m), and H_G is the height of the gateway (m).

(2) Maximum cutting depth

The maximum cutting depth is

$$H_{max} = H_s + H_p \tag{9}$$

where H_s is the height of the caving rock after breaking, and H_p is the maximum bending subsidence.

(3) Cutting depth design

The cutting depth is then written as

$$H_c = (H_G - \Delta H_1 - \Delta H_2)/(k-1) \tag{10}$$

where ΔH_1 is the main roof bending subsidence, ΔH_2 is the height of floor heave, and k is the bulking coefficient of rock (see Fig. 9).

Based on the CCBT, the 110 mining method with respect to the reserved gob-side gateway and non-pillar mining is established. The layout of the 110 mining method is shown in Fig. 10. The "110" means for one stope face of the whole mining district, only one advanced gateway excavation is needed after the first mining cycle, because the other one, i.e. the gob-side gateway in the traditional 121 mining system, is automatically formed during the last mining cycle without coal pillars left in the mining area by using this mining technology. Fig. 11 shows the movement of overlying strata in the 110 mining method and its effect on ground pressure distribution. The force transmission in overlying strata is changed by the directional precutting, forming a short cantilever beam structure (Song and Jiang, 1986). The transfer of ground pressure is cut off and the pressure is used to fall part of gob roof rock down, instead of completely reinforcing it by artificial supporting system and preserved coal pillar. The roof rock is used to form one side of the gateway wall, and the gob-side gateway is reserved for the next

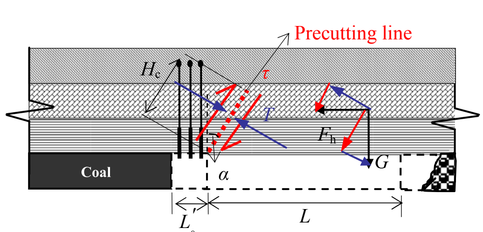


Fig. 8. Mechanical model of CCBT.

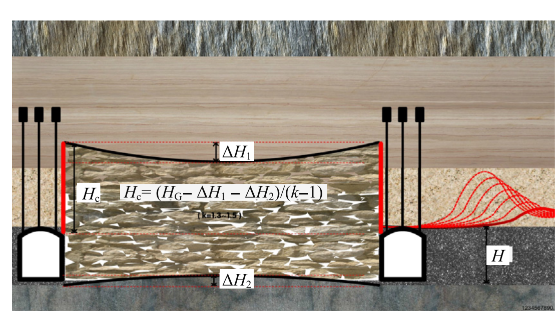


Fig. 9. Design for pre-splitting hole depth (H_c).

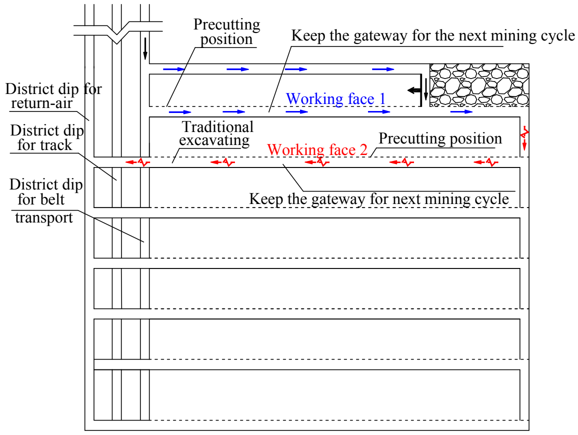


Fig. 10. Layout of the 110 mining method.

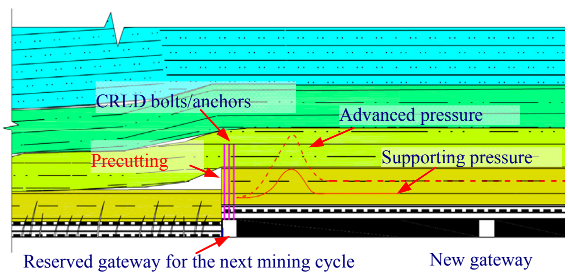


Fig. 11. Scheme of roof strata movement of the 110 mining method (He, 2014).

mining cycle, reducing the cost and risks for gob-side gateway excavating. Extension of broken gob roof rock is calculated and used for the purpose of gobbing-up the mined-out area. Thus surface subsidence can be significantly reduced.

4. Key technologies of the 110 mining method

For the fulfillment of 110 mining method, several key technologies are used, including directional roof precutting, CRLD supporting system, and remote real-time monitoring technology. In addition, the characteristics of different projects in different mines are also considered in this new method. Thus, the 110 mining system with non-pillar mining and automatic formation of gob-side gateway for the next mining cycle by precutting and advanced roof caving is established.

4.1. Directional pre-splitting roof cutting technology

The characteristics of high rock compressive strength and low tensile strength are comprehensively considered, and a blasting device is developed to achieve the two-directional blasting to form a cohesive energy flow and thus to produce concentrated tensile stress. The blasting device is employed with normal explosives, and the depth of boreholes is determined by the coal seam depth, gateway height and other conditions in the field, from 1.5 m to 5 m or more. The explosive charge follows the general blasting design, normally from 2 to 8 packages of explosives with directional blasting device for different engineering conditions, and it should be performed on relatively hard rock layers. The top plate is set in accordance with the direction of the formation of pre-splitting tensile fracture surfaces (Fig. 12). Field application results (Fig. 13) show that this technology can achieve good directional roof pre-splitting according to the design at exact

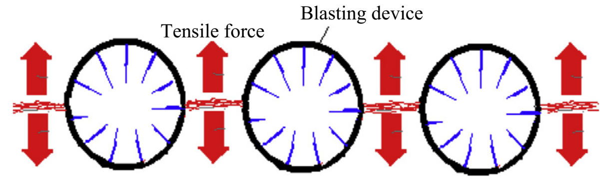
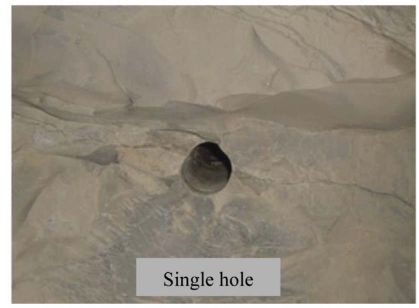
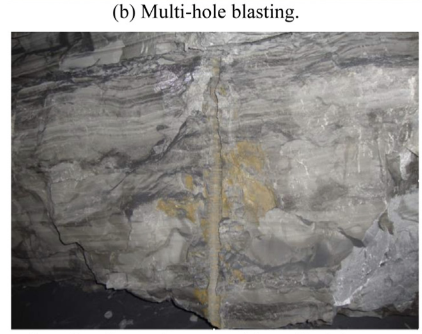


Fig. 12. Mechanism of directional roof cutting technology.



(a) Pre-splitting hole.

(b) Multi-hole blasting.



(c) Manual roof caving to form one side wall of the gateway.

Fig. 13. Photographs for field application.

positions, and reach the designed depth along the roof with actively advanced pre-splitting roof cutting but will not destroy the roof.

4.2. CRLD supporting system

The problems of mining pressure transfer are one of the key issues during advanced pre-splitting cutting and roof caving. In practice, part of the roof in existing gateway needs to be reserved. The traditional support system, in a combination of mesh, bolts, and anchors, can be easily broken when surrounding rocks have large deformations. In this case, the manual roof caving will produce large tensile force to the gateway roof, although the precutting has been performed to reduce the force

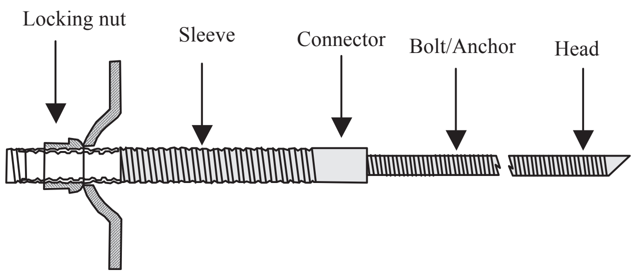


Fig. 14. The CRLD bolt/anchor.

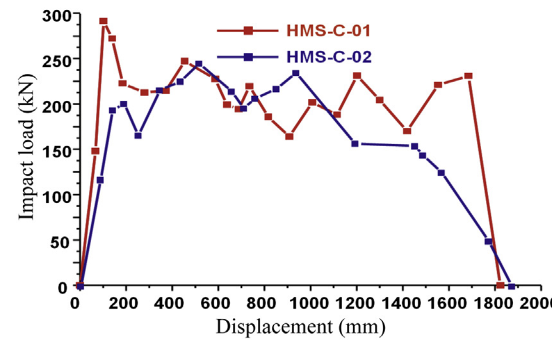


Fig. 16. Impact features of the CRLD support material.

transition. For this reason, a new supporting material, the CRLD bolt, is used to control the gateway deformation and reserve the roof and one side wall of the gateway, as shown in Figs. 14 and 15. A large number of tests have been conducted on this material and testing results show that its mechanical properties are quite unique and can keep the designed constant resistance during elongation. As shown in Fig. 16, the CRLD bolt is able to adapt to the dynamic pressures generated by the roadway roof caving and effectively control part of the reserved roof. The CRLD bolt can also withstand various dynamic impacts, and the high impact energy absorbing abilities are observed in both laboratory and field tests. Therefore, the CRLD bolt can achieve high impact resistance and deformation energy released during roof caving, which can effectively guarantee the overall stability of roadway safety (He et al., 2014).

Fig. 17. Remote monitoring system in the gateway.

4.3. Remote real-time monitoring technology

In order to analyze the CRLD stress and associated potential risks encountered during roof caving, remote real-time monitoring technology is introduced. The forces in CRLD bolts/anchors are continuously recorded and transmitted to indoor computers automatically for feedback monitoring (Figs. 17 and 18). It shows that the force of CRLD increases during the mining and manual roof caving process, and the roof subsidence and gateway stability are effectively controlled under the periodic roof pressure impacts.

During mining activities, the pressure on mining shields is also monitored in field. The measured data show that the stress on advanced roof cutting and caving was reduced by about 30% of

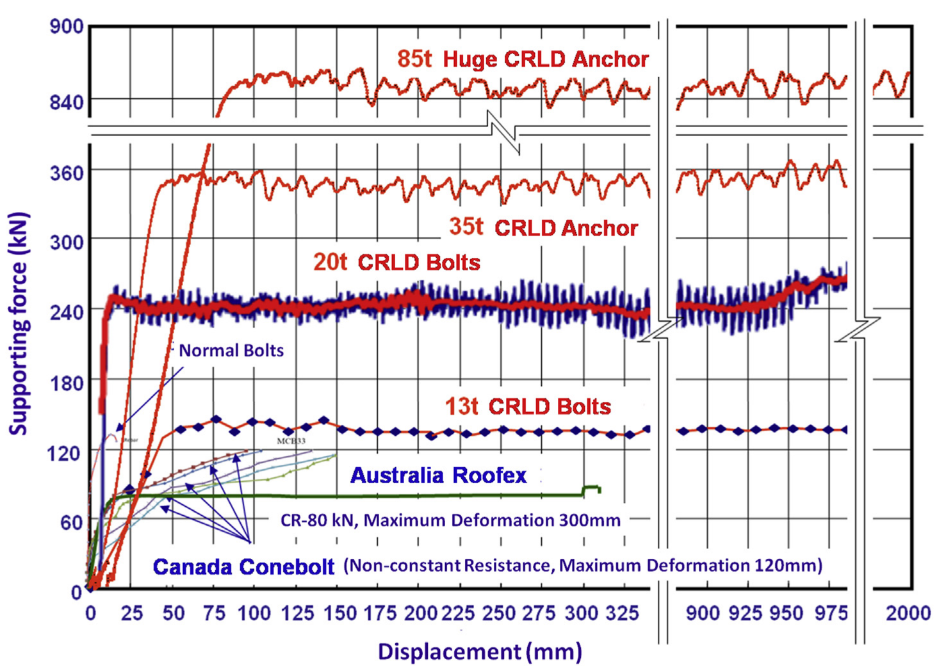


Fig. 15. Curves of different materials' mechanical properties of CRLD bolts.

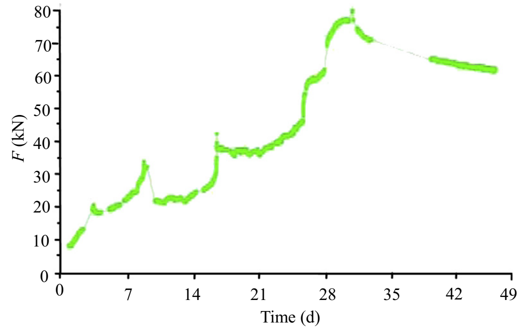


Fig. 18. The monitored force in a CRLD anchor in field.

the previous maximum periodic pressure in the mining area, i.e., from 40 MPa to 27.5 MPa (see Figs. 19 and 20), in conjunction with the calculated height of the cutting depth with Eqs. (6) and (7). As the stoping face advanced, the variation range of roof pressure was significantly reduced, i.e., from 23–40 MPa to 21–27.5 MPa. It is proved that this mining method can effectively reduce the periodic roof pressure imposed on brace and greatly improve the stability of the roof, which also facilitates the selection of support measures.

5. Case studies using 110 mining method

5.1. Case I: normal coal seam in Baijiao coal mine

Baijiao coal mine (Zhang et al., 2011) is located in Furong mining area, Sichuan Province, China. This mine is the first site used with the 110 mining method. The working face No. 2422 of this mine is characterized by normal thickness coal seam of 2.1 m, and the height of gateway was 2.5 m. Fig. 21 shows the composite columnar section of working face No. 2422. The first layer of immediate roof is hard limestone with an average thickness of 1.5 m. The mining depth is 482 m, the width of working face is 165 m, and the length of gateways is 465 m.

Before application of the CCBT and 110 mining method, there were various accidents reported every year for worker injuries and property losses caused by rockburst and support failures in gateways. In 2009, we introduced the CCBT and 110 mining method to working face No. 2422. Fig. 21 shows the support system and precutting design. The directional pre-splitting roof cutting was performed at the dashed line position and the blasting hole was calculated to be 5 m in depth. The CRLD bolts and anchors were used in the support design. The design depth of CRLD anchors is 8 m to keep the gateway stable during the manual roof caving. The prestress of CRLD anchors was larger

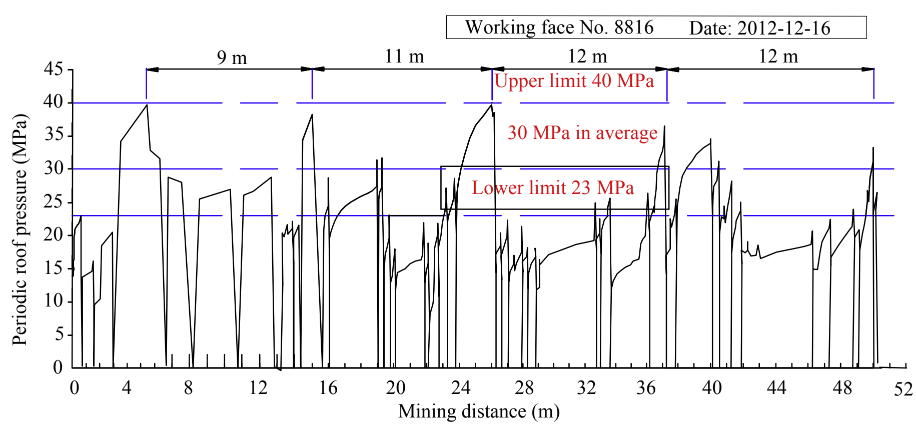


Fig. 19. Mining impacts recorded by 121 mining method in Tangshangou mine, China.

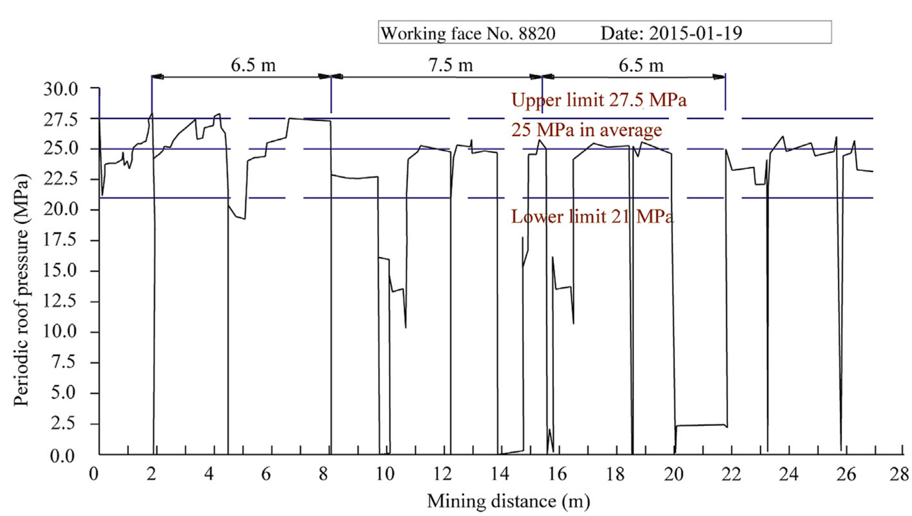


Fig. 20. Mining impacts recorded by 110 mining method in Tangshangou mine, China.

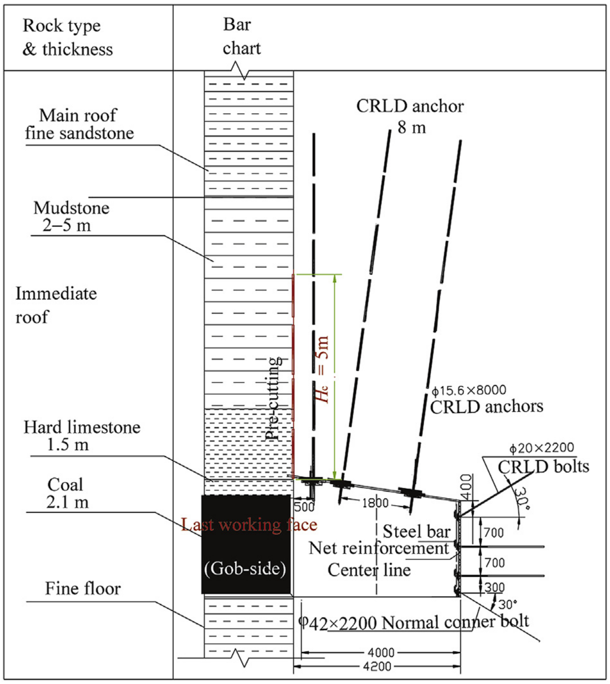


Fig. 21. Support system and precutting design for working face No. 2422 in Baijiao mine using the CCBT and 110 mining method.

than 12 kN and the force in anchors was monitored during the production by 110 mining method (Fig. 22). When the stoping distance of 350 m was used in the field experiment, 330 m gob-side roadway for the next mining cycle was automatically formed. The average deformation between roof and floor is 15 cm and the monitored stress curve (Fig. 22) shows that the advanced stoping had impact on the CRLD support system, but the peak force in CRLD anchor was only increased to 106 kN, and then kept stable at 84 kN. The maximum of anchor force was 110 kN during the precut roof caving far from the design constant resistance of CRLD support material.

Fig. 23 shows the reserved gateway in field by 110 mining method, allowing for the next mining cycle. In Baijiao mine field test, the length of gob-side roadway is 460 m, and the excavation cost is RMB 465.78 per meter, compared to RMB 3075 per meter in the original design, thus RMB 1.2 million was saved. One gob-side roadway excavation was reduced and the relevant waste rock transportation fee accounting for another RMB 1.82 million was saved consequently. The recovery of 10 m wide coal pillar made a profit of RMB 4.416 million at that time; and burst prevention drillings in coal pillar of RMB 3.1 million was also saved. In other words, the CCBT and the 110 mining method

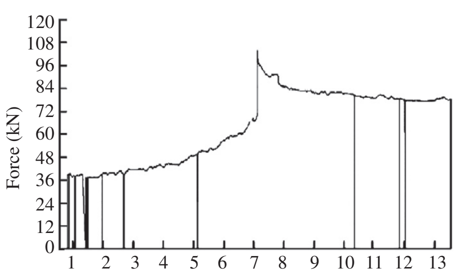


Fig. 22. Monitored CRLD anchor force curves in Baijiao mine.

Fig. 23. Reserved gob-side gateway by 110 mining method.

projects at the working face No. 2422 saved RMB 11 million in terms of safe production.

5.2. Case II: thin coal seam in Jiayang coal mine

Normal thick coal seam can always allow for enough space for roof caving in the gob after pre-splitting cutting. However, the space in thin seam mined-out area is limited, and the bend and sinking of roof will interference the advanced roof caving. To fulfill the CCBT and the 110 mining method, the key parameters of gob-side entry retaining technique in thin coal seam are obtained by the successful case at working face No. 3118 in Jiayang coal mine, Sichuan, China.

Working face No. 3118 is 850 m in length and 157 m in width, the average thickness of coal seam is 0.91 m, and the dip angle is 3°. The height of gateway is 2.9 m and the width is 3 m. The composite columnar section and gob-side gateway support design and precutting design are shown in Fig. 24.

The advanced roof caving mainly relies on the gravity of immediate roof and shearing force by overburden pressure. The precutting angle, α, is employed as a major factor to avoid larger frictional resistance at the interface during formation of cutting cantilever beam. It can be determined by the field condition of working face No. 3118 in Jiayang coal mine, the internal friction angle of immediate roof is about 55°–60°, and the final precutting angle α' is about 28°–33°. The precutting depth can be calculated by Eq. (10), and the precutting depth is 4 m.

Field application of the 110 mining method proves to be successful in thin coal seam mining (see Figs. 25 and 26), which lays a good basis to similar mining projects.

6. Conclusions

The paper presents three major technological changes in China's mining science and technology in terms of three representative theories. The 121 mining method and 110 mining method are introduced based on the theoretical basis. The main conclusions are drawn as follows:

(1) The traditional 121 mining method has made important contributions to the development of China's mining science and technology. The MBT developed by Prof. Minggao Qian has led to the first mining innovation in China, which focuses on the transmission and equilibrium method of overburden pressure in the mined-out areas by using reserved coal pillar. The TRBT proposed by Prof. Zhenqi Song gives a further explanation to the transmission path of stope overburden pressure and pressure distribution in high-stress area, an important contribution to the advanced 121 mining method with smaller coal pillar.

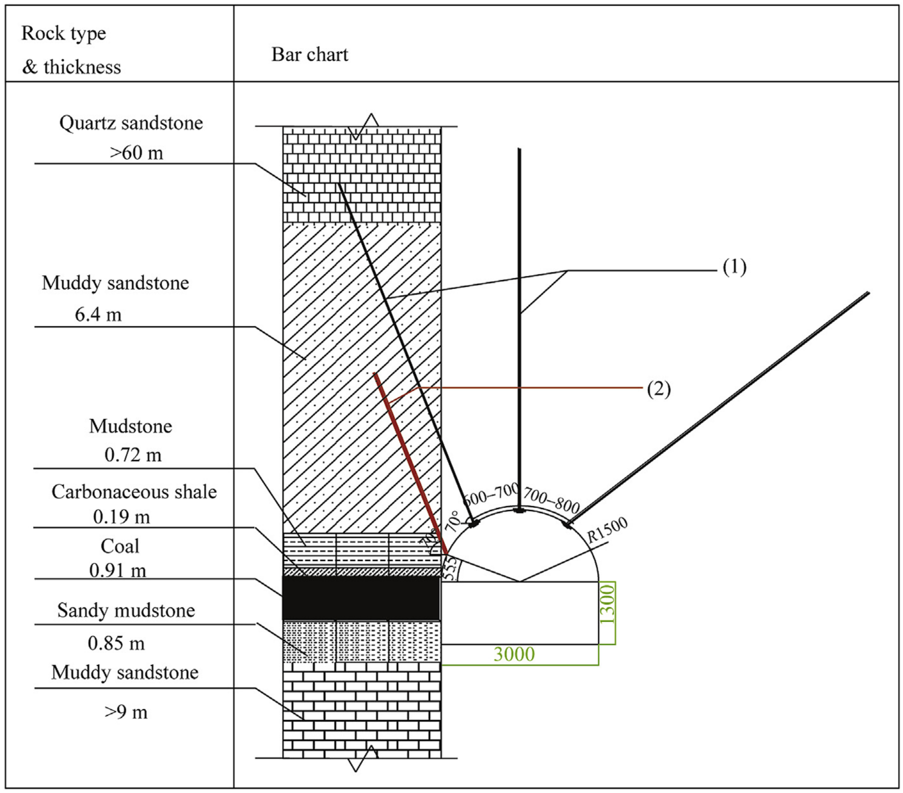


Fig. 24. Support system and precutting design for working face No. 3118 in Jiayang coal mine by the CCBT and 110 mining method. (1) CRLD anchors, constant resistance: 200 kN, length: 7.5 m, spacing: 800 mm × 1000 mm; (2) Pre-splitting hole, diameter: 50 mm, depth: 4 m, spacing: 800 mm.

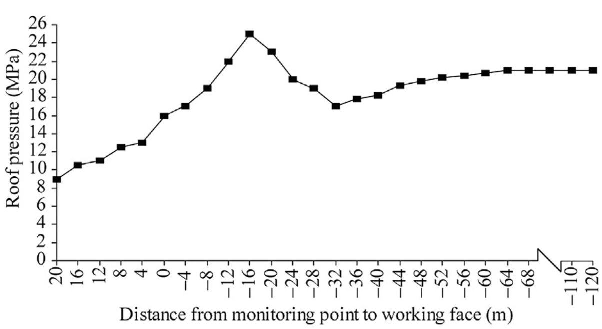
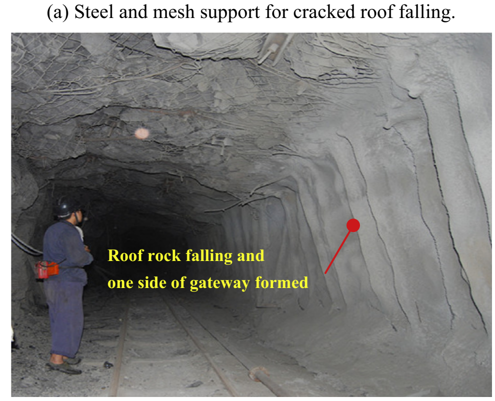


Fig. 25. Measured roof pressure curve in field.

(a) Steel and mesh support for cracked roof falling.



(b) Spraying concrete surface treatment.

Fig. 26. Photographs of the reserved gateway for the next mining cycle.

(2) With increasing mining depth, large deformation of surrounding rocks in deep tunnel becomes a challenging issue, thus the CCBT using advanced roof caving is put forward. With the use of directional pre-splitting roof cutting, the periodic pressures can be reduced or eliminated. The CCBT provides a basis for non-pillar mining and automatic tunneling technology, under which the 110 mining method is established.
(3) The 110 mining method mainly includes directional pre-splitting roof cutting, CRLD supporting system and remote real-time monitoring technology. In addition, the site-specific geological conditions are also considered, forming the technology of pre-splitting and roof caving for the purposes of pressure release and automatic gateway formation. The CCBT

and 110 mining method will provide theoretical and technological basis in China for the purpose of major mining powers.

(4) Two cases using the 110 mining method in different mining conditions are introduced, and field applications prove that the new theory and mining method is practicable, economic and effective. More importantly, the safety is ensured in the daily mining production.

Conflict of interest

The authors wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Acknowledgements

It is gratefully noted that the work is supported by the National Natural Science Foundation of China (No. 51404278) and the State Key Program of National Natural Science Foundation of China (No. 51134005).

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