Hindawi
Advances in Civil Engineering
Volume 2023, Article ID 7506467, 6 pages
https://doi.org/10.1155/2023/7506467

Research Article

A New Method for Calculating Anchor Mesh Parameters Based on the Energy Absorption Mechanism of Helmet

Xiangdong Niu [1,2,3], Kepeng Hou [1,2], and Huafen Sun [1,2]

[1] *Faculty of Land and Resources Engineering, Kunming University of Science and Technology, Kunming 650093, China*
[2] *Yunnan Key Laboratory of Sino-German Blue Mining and Utilization of Special Underground Space, Kunming 650093, China*
[3] *Yunnan Yarong Mining Technology Co. Ltd., Kunming 650000, China*

Correspondence should be addressed to Kepeng Hou; 2764403681@qq.com

Received 30 January 2023; Revised 12 June 2023; Accepted 16 June 2023; Published 30 June 2023

Academic Editor: Nicola Buratti

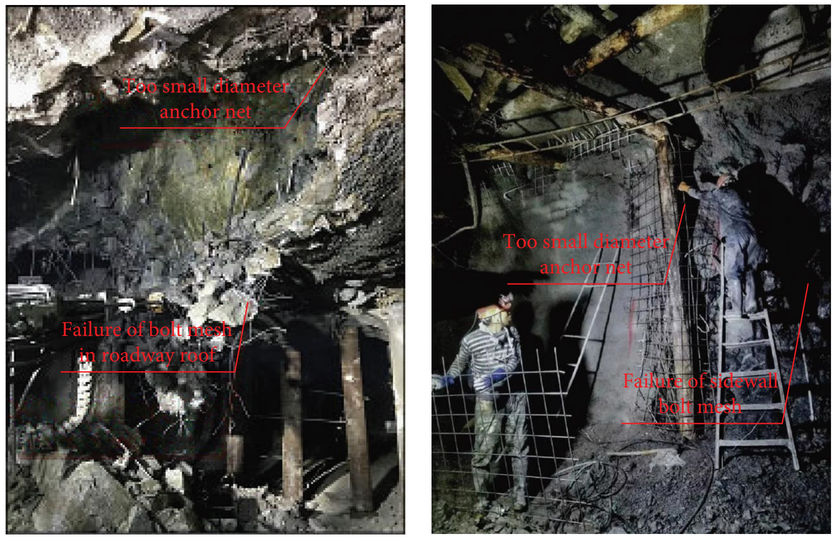
Considering the pressure-bearing mechanism of the safety helmet and as an anchored net is subjected to the surrounding rock mass, researchers should regard the support force as a safety criterion. Thus, a method for calculating the anchored mesh support parameters (mesh width and reinforcement diameter) is proposed in this paper. The method can provide a theoretical basis for selecting the technical parameters of an anchored mesh in active support in underground engineering. Calculation results show that a strong power relationship exists between the mesh width a of the anchor net and the distance h_3 from the anchor net to the top of the worker's safety helmet, that is, $a = 12.891e^{-0.065h_3}$, and the correlation coefficient is $R^2 = 0.947$. Moreover, the mesh width of the anchored mesh decreases with an increase in the distance from the anchored mesh to the top of the worker's safety helmet. The anchored mesh parameters designed and selected by this method ensure that the rocks falling from the anchored mesh pose no safety threat to the workers wearing helmets. The parameters also prevent an excessively large steel wire/steel bar diameter of the anchored mesh, which lowers support costs and makes the selected technical parameters of the anchored mesh economical and safe.

1. Introduction

The support of a roadway and stope is a key factor affecting the safety and efficiency of underground mining [1–4]. As the mining depth of underground mines increases, the surrounding rock pressure of the roadway and stope increases, and the roof stress environment tends to be complex. The surrounding rock seldom remains stable for a long time after excavation, while the surrounding rock of the roadway and roof is difficult to maintain, which seriously hinders safe and efficient underground mining [5–8]. Yu et al. [9] noted that the goaf stability time is 13 days when the rock mass rating is 43 and the safe span of the mine room is 4 m. Liu et al. [10] found that the key to control the stability of roadway surrounding rock is to select the optimal excavation time and coal pillar width.

As an active support form, the anchored mesh support has obvious advantages in preventing surrounding rock deformation, improving surrounding rock stress environment, and reducing support cost [11–14]. However, as underground mines gradually deepen, they contain more large-deformation and high-stress roadways and stopes. Problems also arise in selecting the technical parameters of the anchored mesh support in practical applications. For example, the mesh selection of the anchored mesh might be too large, which may not provide sufficient support for the roof support of the roadway and stope and may cause rock blocks to fall from the mesh and harm on-site staff or damage equipment. Another technical parameter selection problem is an unreasonable diameter selection for the anchored mesh reinforcement (steel wire). If the diameter is too large, the safety redundancy factor would be too large, resulting in excessive support costs. If the diameter is too small, the anchored mesh would break under the action of a large load on the roof, failing to provide sufficient support for the surrounding rock, as shown in Figure 1.

Extensive research has been conducted on the anchored mesh support in underground engineering. Wang and Wang [15] used an anchored mesh cable arch coordinated coupling support as a case study. Through field drilling observations,



(a) (b)

Figure 1: Failure diagram of roadway with insufficiently large bolt net reinforcement diameter: (a) failure of bolt mesh in roadway roof; and (b) failure of side wall bolt mesh.

support parameter calculations, and numerical simulation analyses, they studied the cooperative coupling support technology of the bolt net cable arch for a high-ground-stress soft-rock roadway. The primary and secondary coupling support parameters of a soft-rock roadway with a special high-ground-stress were obtained. The anchored mesh was a steel plastic composite mesh, and the mesh parameters were 900 mm × 2,200 mm; the size parameters of the anchored mesh were not introduced. Zhang et al. [16] studied the optimization of secondary coupling support parameters of a large-deformation soft-rock roadway, the research object being a 500-m-deep soft-rock pedestrian roadway at the west wing of Pengzhuang Coal Mine in Shandong Province. They found that the anchored mesh of the “anchor bolt + anchored mesh + shotcrete” one-time support process used the warp and weft mesh welded with 6.0 mm diameter steel bars. The anchored mesh of the “anchor bolt + anchor cable + anchored mesh + respraying” secondary coupling support adopted the warp and weft mesh welded by the 6# (type of steel bar) reinforcement, and the selected mesh size was 100 mm × 100 mm. However, calculations and research based on the mesh size selection were lacking. Malongdou [17] used a theoretical calculation method to determine the length, diameter, and spacing of the bolt and anchor cable for the 1,207 material roadway support of Nanguan Coal Industry. The technical scheme of the anchored mesh and cable support was designed, but the selection of the anchored mesh parameter was 2,500 mm × 1,000 mm, and the size and calculation of the anchored mesh size parameters were ignored. Wang [18] applied theoretical calculations and engineering analogy methods to determine the technical scheme and support parameters of a full-bolt mesh support for coal mine roadways under different coal thicknesses. Detailed theoretical calculations were performed for the bolt and anchor cable support parameters of the coal mine roadway. However, no specific parameters and calculations of the anchor net were provided.

The research on parameters of the anchor net active support in underground projects has been primarily focused on calculating parameters of the anchor rod and anchor cable support. Little attention has been paid to the parameters of the anchor net support (mesh width and steel bar diameter). The support force should be given as the criterion, considering the pressure-bearing mechanism of the safety helmet and the influence of the surrounding rock mass on the anchor net. When the technical parameters of the anchor net active support are calculated theoretically, the specifications of the anchor net are selected accordingly. Thus, the rocks falling off the anchored mesh would pose no safety threat to workers wearing helmets, and the support costs would be reduced as the steel wire/reinforcement diameter of the anchored mesh would be too large. Therefore, the technical parameters of the anchored mesh selected in this study provide economic and safe anchored mesh active support.

2. Energy Absorption Mechanism of Safety Helmet

A safety helmet is a protective equipment used for protecting the head and is made of steel or similar materials with a shallow dome. The impact mitigation mechanism of the helmet is mainly embodied in the following three aspects [19, 20]: (1) cushioning and shock absorption: a gap of 25–50 mm exists between the cap shell and cap lining. When an object strikes the helmet, the helmet shell deforms under the impact load and absorbs the impact energy of the object, preventing direct impact from the objects falling on top of the head, as shown in Figure 2. (2) Stress dispersion: the cap shell is elliptical or hemispherical, and its surface is smooth. An object that falls on the cap shell slides immediately after impact, and the force borne by the impact point on the cap shell is transmitted to the surrounding areas on the shell. The force reduced by the

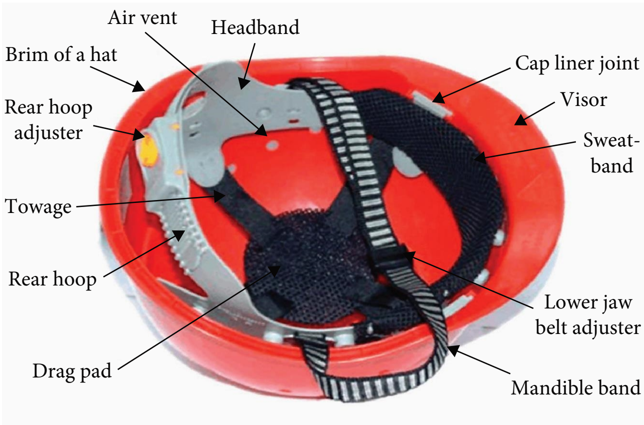


Figure 2: Schematic of each component of a safety helmet.

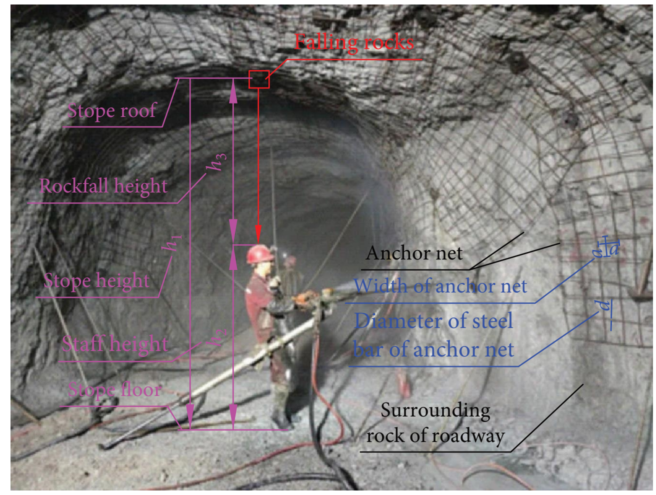


Figure 3: Schematic of mining workers in stope.

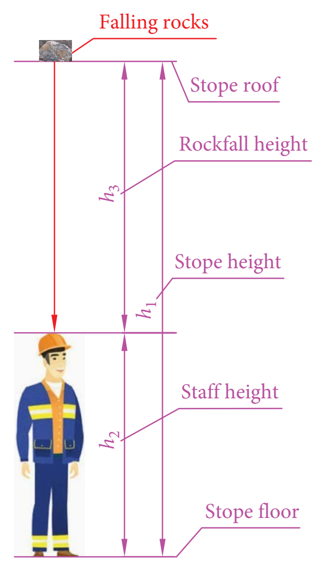


Figure 4: Model of theoretical calculation.

cushion effect of the cap liner can exceed two-thirds of the total force, and the rest of the force is transmitted to the human head through the entire area of the cap liner. In this way, the force point on the cap shell becomes the force surface on the head, thus avoiding the stress concentration caused by the impact force on the head and reducing the force on the head unit area. (3) Biomechanical effect: according to the national standard, the safety helmet must be capable of absorbing a 4,900 N force. The requirement exists because of the maximum limit of the human cervical vertebra under stress in biological tests. If the limit is exceeded, the cervical vertebra would be injured, causing paralysis at the least and endangering lives at the worst.

Therefore, we calculated design parameters (mesh width and steel bar diameter) according to the pressure-bearing principle of the safety helmet with “cushioning and shock absorption” and “dispersing stress,” and according to the 4,900 N absorption capacity limit of the safety helmet stipulated in biomechanical tests.

3. Calculation of Mesh Width of Anchored Mesh

3.1. Calculation of Mesh Width a

3.1.1. Determination of Stope Height h_1. The stope height h_1 is the vertical distance between the stope floor and the stope roof, as shown in Figure 3. Figure 4 is a simplification of Figure 3 into a theoretical calculation model.

Naturally, the thickness of an ore body is in the range of 3–6 m, the average thickness is 5 m, and the dip angle is 6°–9°. In this study, the average thickness of the ore body ($h_1 = 5$ m) was selected for calculations, as shown in Figure 4.

3.1.2. Determination of Height h_2 from STope Floor to Top of Safety Helmet. According to the Chinese adult body size (GB10000-1988) standard, the average static height of men under 1% of the age of 18–25 years in China is below 1,543 mm, that is, $\overline{x}_{\alpha=1\%} = 1543$ mm [21]. According to the standard of General Rules for the Application of Percentiles of Human Body Size in Product Design (GB/T12985-1991), the correction amount of wearing shoes with the human body standing is $\Delta f_1 = 25$ mm. According to the standard of Safety Helmets (GB2811-2007), if there is a gap of 25–50 mm between the helmet shell and the helmet lining, the correction amount for wearing safety helmets in a standing posture is $\Delta f_2 = 25$ mm [22]. Therefore, 1% of Chinese men under the age of 18–25 years old wear shoes and safety helmets to engage in labor operations. The standing height is:

$$\overline{x}_{\alpha=1\%} + \Delta f_1 + \Delta f_2 = 1,543 + 25 + 25 = 1,593 \text{ mm} \quad (1)$$

Thus, the distance from the working floor to the top of the helmet shell $h_2 = 1.593$ m, and the distance between the anchor net supporting position and the top of the safety cap shell is:

$$h_3 = h_1 - h_2 = 5 - 1.593 = 3.407 \text{ m}. \quad (2)$$

3.1.3. Calculation of Anchored Mesh Width a. The width a of the anchor mesh is the spacing of the reinforcing bars in the

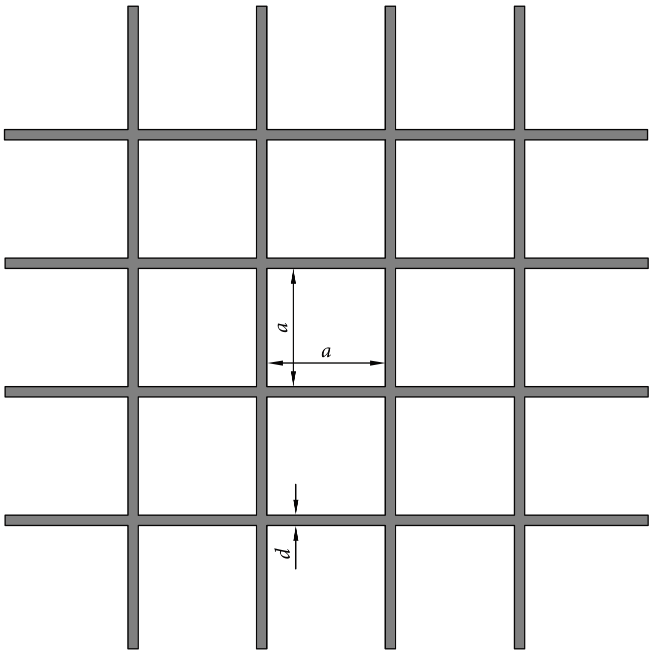


FIGURE 5: Mesh width of anchored mesh and diameter of reinforcement (steel wire).

anchor mesh, as shown in Figure 5. According to the safety helmet impact absorption performance test standard in the Safety Helmet Test Method (GB/T2812-2006), the momentum of a 5 kg steel hammer falling freely from a height of 1 m to the top of the safety helmet shell is:

$$p_1 = m_1 v_1 = m_1\sqrt{2gh_0} = 5\times\sqrt{2\times 9.8\times 1} = 22.135(\mathrm{kg}\cdot\mathrm{m/s}). \quad (3)$$

Suppose a rock mass m falls off from the anchored mesh, the momentum of the falling rock mass dropping freely to the top of the helmet shell is:

$$p_2 = mv_2 = m\sqrt{2gh_3} = m\sqrt{2\times 9.8\times 3.407} = 8.172\,\mathrm{m}(\mathrm{kg}\cdot\mathrm{m/s}). \quad (4)$$

According to the safety helmet impact absorption performance test standard in the Safety Helmet Test Method (GB/T 2812-2006), the criterion for preventing the safety helmet from being damaged by the rock blocks falling from the anchored mesh is as follows: the momentum of the rock blocks falling from the anchored mesh/mesh to the top of the safety helmet must be less than the momentum of the 5 kg steel hammer falling from 1 m to the top of the safety helmet shell, that is:

$$p_2 \le p_1 \text{ or } \sqrt{2gh_3} \le m_1\sqrt{2gh_0}. \quad (5)$$

Hence, when the rock block falling from the anchored mesh freely drops to the top of the helmet, the rock mass that will not damage the helmet is:

$$m \le \frac{m_1\sqrt{2gh_0}}{\sqrt{2gh_3}} = \frac{22.135}{8.172} = 2.709\,\mathrm{kg}. \quad (6)$$

Assuming the density of rock blocks falling off the anchored mesh is $\rho = 2600\,\mathrm{kg/m^2}$, then the volume of rock blocks falling off the anchored mesh is:

$$V \le \frac{m}{\rho} = \frac{2.709}{2,600} = 1.042\times 10^3\,\mathrm{cm}^3. \quad (7)$$

Assuming the anchored mesh is a square, then the rock block falling off the anchored mesh is a cubic rock block; the width of the cubic rock block falling off is:

$$a \le \sqrt[3]{V} = \sqrt[3]{1.042\times 10^3} = 10.138\,\mathrm{cm}. \quad (8)$$

To ensure that the cubic rock block above the anchored mesh support does not fall off from the anchored mesh, the size of the anchored mesh must be less than or equal to the width of the cubic rock block falling off the anchored mesh. Therefore, the size of the anchored mesh should be less than or equal to 10.138 cm; the size of the anchored mesh can be selected as 10 cm.

3.2. Calculation of Diameter d of Anchored Mesh Reinforcement (Steel Wire). The diameter d of the anchor wire (reinforcing bar) is obtained as follows.

Tensile strength of steel wire (reinforcement):

$$\sigma_{\mathrm{tensile}} = \frac{F_{\mathrm{tensile}}}{S} = \frac{m_{\mathrm{tensile}}\,g}{d^2/4}, \quad (9)$$

where

$$d = \sqrt{\frac{4m_{\mathrm{tensile}}\,g}{\sigma_{\mathrm{tensile}}}}, \quad (10)$$

where $\sigma_{\mathrm{tensile}}$ is the tensile strength of the steel wire, MPa; F_{tensile} is the tensile force on the wire (bar), N; S is the cross-sectional area of the steel wire (rebar), m^2; m_{tensile} is the weight of the steel wire (reinforcing bar) subjected to tension, kg; and g is gravitational acceleration, $\mathrm{m/s^2}$.

According to the "Stainless steel wire (GB/T4240-2019)" standard, the expected tensile strength of cold drawn stainless steel wire is 1,000–1,200 MPa [23]. We set $\sigma_{\mathrm{tensile}} = 1{,}000\,\mathrm{MPa}$ and $g = 10\,\mathrm{m/s^2}$ in Equation (10) to obtain:

$$d = \sqrt{\frac{m_{\mathrm{tensile}}}{25}}. \quad (11)$$

If the thickness of the rock stratum requiring anchored mesh support is $H = 10\,\mathrm{m}$, the width of the anchored mesh hole is $a = 10\,\mathrm{cm}$, as shown in Figure 5. The mass of rock mass required to support each mesh of the anchored mesh is $m = \rho V = 2.6\times 10^3\times 0.1^2\times 10 = 260\,\mathrm{kg}$. Therefore, the mass of rock mass shared by each steel bar (steel wire) on the mesh of the anchored mesh is $m_{\text{tensile}} = \frac{1}{4}\,\text{m} = \frac{1}{4} \times 260 = 65\,\text{kg}$; the diameter of the steel bar (steel wire) of the anchored mesh is $d = \sqrt{\frac{m_{\text{tensile}}}{25}} = \sqrt{\frac{65}{25}} = 1.612\,\text{mm}$. Here, the safety factor of the reinforcement (steel wire) is taken as 1.5. The diameter of the reinforcement (steel wire) of the anchored mesh is $d = 1.5 \times 1.612 = 2.418\,\text{mm}$. According to the standard for Stainless Steel Wire (GB/T4240-2009), the diameter of the reinforcement (steel wire) of an anchored mesh is 2.5 mm.

4. Relationship between Mesh Width of Anchor Net and Distance from Anchor Net to Top of Safety Helmet

The relationship between the mesh width of the anchor net and the distance from the anchor net to the worker's safety helmet top is shown. A strong power relationship exists between the mesh width a of the anchor net and the distance h_3 from the anchor net to the top of the worker's safety helmet, that is, $a = 12.891e^{-0.065h_3}$, and its correlation coefficient is $R^2 = 0.947$. In addition, the mesh width a of the anchor net gradually decreases with the increase in the distance h_3 from the anchor net to the top of the worker's safety helmet. This phenomenon occurs because of the following reasons: the greater the distance h_3 is from the anchored mesh to the top of the helmet, the faster the rock falls from the anchored mesh to the helmet, and the greater the momentum and impact force on the helmet are. The maximum momentum that the safety helmet can bear is fixed. Therefore, the smaller the mass of rock blocks that will not damage the safety helmet when falling off from the anchored mesh, the smaller the width of the anchored mesh that is required.

5. Conclusions

This study was based on the pressure-bearing mechanism of the safety helmet and the fact that the anchor net needs to be supported by the surrounding rock mass. A method for calculating anchored mesh support parameters (mesh width and reinforcement diameter) was proposed. The method provides a theoretical basis for selecting the technical parameters of anchored mesh used in active support in underground engineering. The main conclusions of the study are as follows:

(1) According to the specific occurrence conditions of an ore body, a detailed calculation process was validated for the mesh width and reinforcement diameter parameters of the anchored mesh. The method serves as a reference for determining anchored mesh support parameters under other conditions and is more suitable for use among field staff.

(2) A strong power relationship exists between the mesh width a of the anchor net and the distance h_3 from the anchor net to the top of the worker's safety helmet, that is, $a = 12.891e^{-0.065h_3}$, and the correlation coefficient is $R^2 = 0.947$. In addition, the mesh width of the anchor net shows a decreasing trend with the increase in the distance from the anchor net to the top of the worker's safety helmet, and the changing trend is explained in detail.

(3) According to the pressure-bearing mechanism of the safety helmet and the actual support force required by the surrounding rock mass, the calculated parameters of the anchored mesh should be used as the basis for selecting the anchored mesh specifications. Thus, the rocks falling from the anchored mesh would not pose a security threat to the workers wearing helmets, and the high support cost caused by the excessive diameter of the steel wire/reinforcement of the anchored mesh would be reduced, resulting in economic and safe technical parameters of the anchored mesh.

Data Availability

The basic data supporting the research results are all in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] G. F. Wang, L. Zou, C. W. Zhao, Y. Y. Kou, and W. J. Wang, "Research on reasonable supporting parameters of GFRP bolt under the massive backfill in Jinchuan No.2 mining area," *Mining Research and Development*, vol. 42, no. 1, pp. 100–105, 2022.

[2] K. Jiang, "Research on excavation roadway support technology in the filling body in stopes," *Gold*, vol. 43, no. 10, pp. 38–43, 2022.

[3] N. Yasuda, "An analytical model for ground support by bolting," *International Journal for Numerical and Analytical Methods in Geomechanics*, vol. 46, no. 18, pp. 3425–3441, 2022.

[4] I. Azim, J. Yang, M. F. Javed et al., "Prediction model for compressive arch action capacity of RC frame structures under column removal scenario using gene expression programming," *Structures*, vol. 25, pp. 212–228, 2020.

[5] H. X. Liu, *Mechanical Properties and Mining Induced Failure Mechanism of Alterated Rock and Disaster Control Under Deep High Stress Condition*, University of Science and Technology Beijing, Beijing, 2022.

[6] J. F. Zou and P. H. Zhang, "Analytical model of fully grouted bolts in pull-out tests and in situ rock masses," *International Journal of Rock Mechanics and Mining Sciences*, vol. 113, pp. 278–294, 2019.

[7] S.-L. Ren, M.-C. He, W.-J. Lin, T.-W. Zhang, and Z.-G. Tao, "Geomechanics model test and numerical simulation of 2G-NPR bolt support effect in an active fault tunnel," *Journal of Mountain Science*, vol. 19, pp. 2729–2741, 2022.

[8] N. Hu, *Damage Mechanism and Stability Analysis of Stope Surrounding Rock Under Deep High in-situ Stress Condition*, University of Science and Technology Beijing, Beijing, 2021.

[9] S. F. Yu, G. C. Li, Y. T. Sui, and X. X. Jiang, "Study on mine safe span and self-stabilization time in steeply inclined ore body," *Copper Engineering*, no. 4, pp. 49–53, 2014.

[10] Z. H. Liu, Q. Gao, X. Z. Hua, Y. H. Wu, K. L. Fu, and Y. Liu, "Aging characteristics of wall rock control in roadway driving along goaf," *Journal of Mining & Safety Engineering*, vol. 26, no. 4, pp. 465–469, 2009.

[11] Q. Li, "Bolt mesh support technology for large section coal roadway with complex geological conditions," *Mining Equipment*, no. 4, pp. 62-63, 2022.

[12] K. P. Yang, "Practice on combined support technology with bolt-mesh-anchor and shotcreting in roadway under hard roof," *Jiangxi Coal Science & Technology*, no. 1, pp. 76-77, 2022.

[13] C. H. Tan, "Passive bolts reinforcement around a circular opening in strain-softening elastoplastic rock mass," *International Journal of Rock Mechanics and Mining Sciences*, no. 88, pp. 221–234, 2016.

[14] M. Ghadimi, K. Shahriar, and H. Jalalifar, "A new analytical solution for the displacement of fully grouted rock bolt in rock joints and experimental and numerical verifications," *Tunnelling and Underground Space Technology*, vol. 50, pp. 143–151, 2015.

[15] B. Wang and X. Y. Wang, "Dang linhang study on bolt-mesh-cable-shed coupling support technology in soft rock roadway with high ground stress," *Nonferrous Metals(Mining Section)*, vol. 73, no. 1, pp. 5–10, 2021.

[16] H. J. Zhang, S. C. Li, H. Y. Li, J. W. Bai, and H. W. Li, "Secondary coupling support parameter optimization and research on the large deformation of soft rock roadways," *Journal of Central South University(Science and Technology)*, vol. 47, no. 4, pp. 1262–1271, 2016.

[17] L. D. Ma, "Design and application of anchor mesh and cable support parameters of 1207 material roadway," *Jiangxi Coal Science & Technology*, no. 3, pp. 105–107, 2021.

[18] J. D. Wang, "Theoretical calculation method of bolt-mesh support parameters for coal roadway," *Shanxi Coal*, no. 4, pp. 55–58, 2018.

[19] National Standard of the People's Republic of China, *GBT 2812-2006 Helmet Test Method*, China National Standards Administration Commission issued, Beijing, 2006.

[20] National Standard of the People's Republic of China, *GBT 2811-2007 Hard Hat*, China National Standards Administration Commission Issued, Beijing, 2007.

[21] China Institute of Standardization and Information Classification and Coding, *GB/T 10000-1988 Body Size of Chinese Adults*, General Administration of Quality Supervision, Inspection and Quarantine, Beijing, 1988.

[22] China National Administration of Standards, *GB/T 12985-1991 General Rules of using Percentiles of the Body Dimensions for Products Design*, General Administration of Quality Supervision, Inspection and Quarantine, Beijing, 1991.

[23] China Iron and Steel Industry Association, *GB/T4240-2019 Stainless Steel Wires*, China National Standards Administration Commission issued, Beijing, 2019.