Hindawi
Shock and Vibration
Volume 2022, Article ID 5057665, 13 pages
https://doi.org/10.1155/2022/5057665

Research Article

Research on Rock Burst Control Mechanism of Deep Buried Tunnel Using Surrounding Rock Modification Theory

Yanhua Sun,[1] Xiaohu Zhang,[1] and Hanhua Xu[2,3]

[1]*School of Civil Engineering, Guizhou University of Engineering Science, Bijie 551700, China*
[2]*Kunming Prospecting Design Institute Of China Nonferrous Metals Industry Co., Ltd, Kunming 650051, China*
[3]*Yunnan Key Laboratory of Geotechnical Engineering and Geohazards, Kunming 650051, China*

Correspondence should be addressed to Xiaohu Zhang; zhangxiaohucumtb@163.com

Received 25 May 2022; Revised 10 July 2022; Accepted 15 July 2022; Published 11 August 2022

Academic Editor: He Mingming

In order to solve the rock burst disaster during the excavation of deep buried high stress hard rock tunnel, the method of changing the properties of surrounding rock by blasting is proposed in this paper. This method can effectively change the physical and mechanical properties of surrounding rock, reduce the storage capacity of surrounding rock corresponding to variable energy, and transfer the stress concentration position to the deep layer, which is an effective means to control rock burst. Taking the tunnel with rockburst tendency as an example, the stress distribution characteristics and displacement changes of surrounding rock under different modification depths are studied by using the numerical calculation method and elastic-plastic mechanics theory, and the effect is tested combined with microseismic data. The results show that the thickness of tunnel blasting loosening is closely related to the stress concentration of surrounding rock, and blasting loosening can effectively inhibit the occurrence and prevention of rock burst. With the increase of blasting depth, the maximum stress concentration decreases. The relevant research results can be used to reasonably design the blasting and loose surrounding rock reconstruction of high stress rock burst tunnel and improve the theoretical and practical basis.

1. Introduction

With the rapid development of tunnel engineering and underground engineering, the characteristics of long and deep buried tunnel are becoming more and more obvious. Under the unique high ground stress characteristics of deep and long tunnel, it is often prone to geological disasters such as rock burst. Due to the complexity of rock burst occurrence, many scholars have obtained many different rock burst occurrence mechanisms from different angles. The main viewpoints include energetics, strength theory, deformation instability theory, fracture mechanics theory, damage mechanics theory and microfracture mechanism. For example, He and Dou [1] established the criterion of rockburst caused by interlayer dislocation induced by horizontal stress. The research shows that the stress state, the edge depth of elastic zone, support strength, friction angle, and cohesion between coal seam and roof and floor are sensitive factors. Ma et al. [2] comprehensively elaborated the definition of rockburst and analyzed several main rockburst theories, such as strength theory, energy theory, blasting trigger theory, stiffness theory, and instability theory. The mechanism of rock burst can be most reasonably explained by using the two body interaction theory of Newton's law. The research shows that the development process of rockburst is a static process, and the occurrence process of rockburst belongs to the category of dynamics. Zhang et al. [3] proposed the specific stress field conditions and trigger stress value of rockburst by using the numerical simulation method. Wang et al. [4] analyzed and studied that the occurrence of rock burst depends not only on the strain energy storage characteristics of rock but also on the environment of strain energy accumulation in the mining process. Gong et al. [5, 6] proposed a new rockburst propensity criterion based on the linear energy storage law and residual elastic energy index, considering the energy consumption characteristics of rock materials during the entire loading process, and studied the influence of peak strength strain energy storage index on rockburst. Wen et al. [7] studied and analyzed the influencing factors related to the coal seam thickness and surrounding rock strength and constructed a corresponding rockburst risk assessment method, which reflected the influence of the coal seam thickness on the stress distribution of the surrounding rock of the roadway. He et al. [8] proposed a new concept of stress path, which takes into account static and dynamic stress, and developed a new type of energy-absorbing bolt as an important method to control rockburst. Many other experts have also analyzed the response characteristics of geotechnical engineering under stress from geological survey and theoretical analysis [9, 10].

The main work of rockburst prediction is based on mechanism research, field experience summary, and data fitting analysis methods such as neural network. For example, Pu et al. [11] reviewed various applications of machine learning methods in rockburst prediction and analyzed typical machine learning methods and their main characteristics as prediction tools. Sepehri et al. [12] reviewed current methods for rockburst prediction; then, a method was proposed to assess the mining-induced strain energy and the extent and magnitude of its accumulation in rock mass to predict rockburst potential in underground mines. A combination of traditional and numerical methods was used to estimate the rockburst potential of an actual mine. Wu et al. [13] proposed a new tunnel rockburst prediction probability model based on the analysis of actual rockburst cases based on the qualitative results obtained by traditional rockburst prediction models. Wang et al. [14] conducted a rockburst prediction study on a rockburst database consisting of 102 case histories (i.e., data from 1998–2011) from 14 hard rock mines. Xue et al. [15] effectively predicted the rockburst according to the microseismic activity of the surrounding rock of the tunnel. Experts and scholars have put forward the criteria for the occurrence of rockbursts, such as stress criteria, energy criteria, and lithology criteria. In other geotechnical engineering fields, many experts have also used theoretical analysis, numerical calculation, laboratory experiments, and other methods to carry out research on the risk prediction of geotechnical hazards [16–18].

In terms of safety construction control of high ground stress, the current research results are mainly derived from experience. The previous experience of successful prevention and control of rockburst is summarized. The engineering measures to prevent rockburst mainly include improving the physical and mechanical properties of the surrounding rock, improving the stress conditions of the surrounding rock, and strengthening the surrounding rock [19–21].

2. Engineering Geological Background

The rockburst tendency tunnel is located in Wanyuan City, China, with a total length of 6113 m and a maximum burial depth of about 750 m. The engineering geological profile is shown in Figure 1. Geologically, it belongs to the Eastern Sichuan Indosinian fold belt (southwest along the line) and the South Qinling Indosinian fold belt (northeast). The fold belts are relatively active areas, with relatively developed folds and faults and strong structural compression.

The tunnel mainly passes through slate, siliceous dolomite, limestone, shale, quartz sandstone, and mudstone. The folds that the tunnel passes through include Houzhaigou~Daolingou anticline, Hujia roof ridge~miaoliang anticline, Huajiaoping syncline, Yuantan~Lianhuachi main anticline, Hujiawan syncline, Hujia Wan~Heiyakou anticline, and Zhangjiaping~Dujiwan syncline; the main faults are Lujiahe reverse fault (F1), Bashan reverse fault (F2), Houzhaigou~Miaoliang upper reverse fault (F3), Lujiaping~Lianhuachi reverse fault (F4), Tangwan thrust fault (F5), Yuantan-Taoshuya reverse fault (F6), Dimumiao-Dazhulin reverse fault (F7), etc.

Hydraulic fracturing in situ stress test is one of the stress testing methods recommended by ISRM. It is mainly used to obtain the in situ stress characteristics of rock mass in the field borehole. It is the most important in situ stress test method in the engineering survey period and is widely used in various fields of rock engineering and geodynamics research, such as hydropower, transportation, and mining. The maximum horizontal principal stress near the tunnel line is 19–20 MPa, the minimum horizontal principal stress is about 11–12 MPa, and the estimated vertical principal stress is about 14 MPa. The in situ stress value increases with the depth, and the maximum horizontal principal stress direction is N71E. Within the test depth range, the lateral pressure coefficient of the hole is greater than 1, indicating that the in situ stress in the engineering site is dominated by tectonic stress. At the same time, it shows that the stress field in the field area is dominated by the horizontal stress field.

Many scholars, such as Barton, use the ratio of the uniaxial strength of the rock to the original in situ stress as an important indicator for judging rockburst. The specific evaluation methods are as follows:

$$\begin{aligned} &\sigma_c/\sigma_1 > 5 \text{ (low probability of rock burst)},\\ &\quad 2.5 < \sigma_c/\sigma_1 < 5 \text{ (slight and medium rockburst)},\\ &\sigma_c/\sigma_1 < 2.5 \text{ (severe rock burst)}. \end{aligned} \tag{1}$$

According to the in situ stress of the four boreholes and the lithology of the tunnel crossing position, the ratio of strength to stress is obtained. According to the Barton criterion, the occurrence of rockburst is analyzed, as shown in Table 1.

According to the inversion results of in situ stress and the changes of rock properties along the line, the different rockburst grades along the tunnel are divided. According to Figure 2, the total length of the slight rockburst area is 1360 m. The total length of the medium rock burst area is 805 m. The total length of the severe rock burst area is 2085 m. According to the above analysis, rockburst has become an unavoidable problem in tunnel engineering construction. How to prevent rockburst is the key issue of this paper.

3. The Theory of Surrounding Rock Reconstruction and Its Control Mechanism for Rock Burst

As shown in Figure 3, the radial stress unloading on the surface of the tunnel wall disappears after tunnel excavation. Assuming that the tunnel radius is R_0, and the original rock

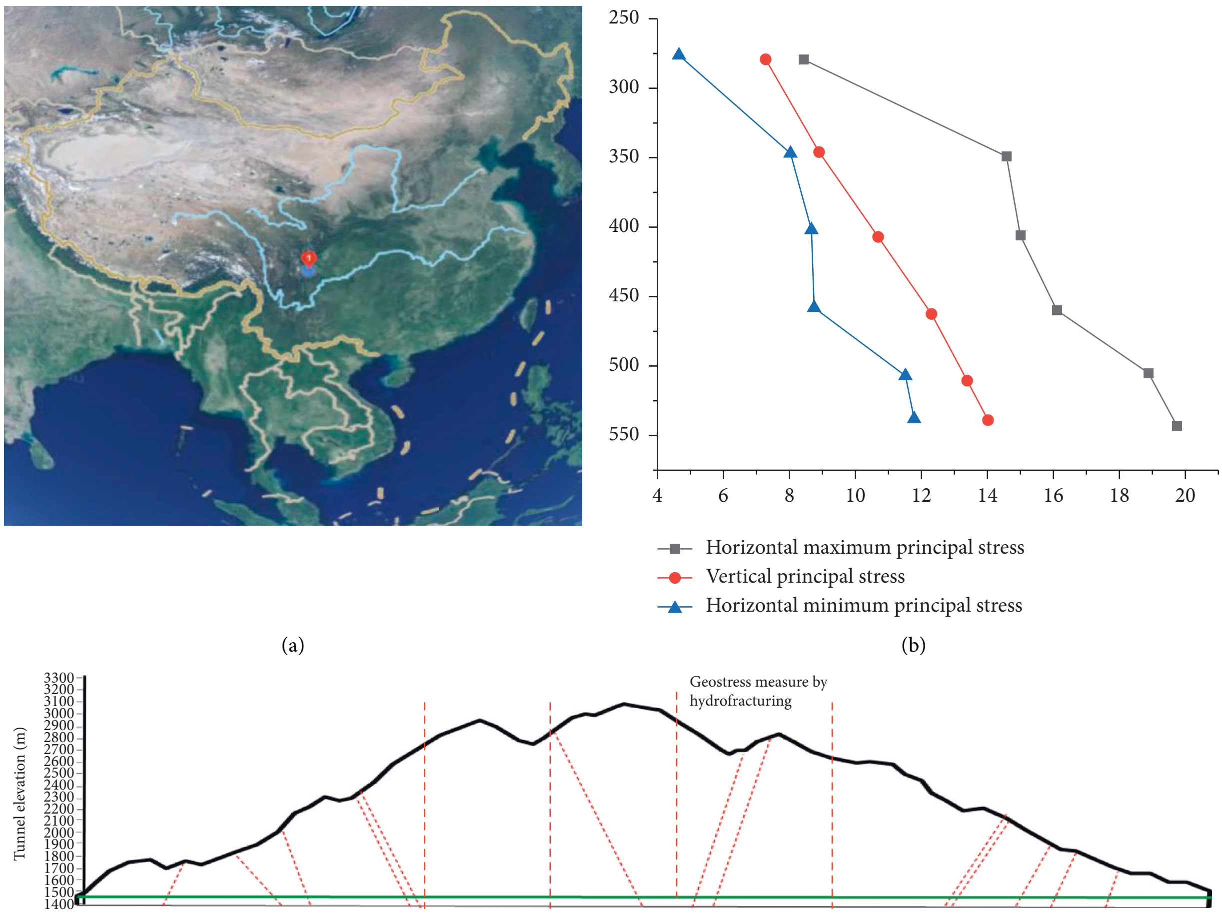


Figure 1: Engineering geological features. (a) Research target location. (b) In situ stress distribution characteristics. (c) Geological section.

Table 1: Characteristics of in situ stress and rock strength.

Borehole no.#	Area	σ_H (MPa)	σ_h (MPa)	σ_v (MPa)	σ_c (MPa)	σ_c/σ_1	Barton criterion
1	Rhyolite in strong structural damage area	20.12	12.83	10.21	30.12	1.49	Severe
2	Andesite in substrong structural damage area	32.45	23.78	33.35	69.51	2.14	Severe
3	Rhyolite in weak structural damage area	33.32	23.45	36.12	122.36	3.67	Medium
4	Rhyolite in weak structural damage area	16.12	13.22	23.12	86.31	3.73	Medium

stress is P_0, according to the axisymmetric plane strain calculation method in elastic mechanics, the hoop shear stress and radial stress at any point of the surrounding rock of the tunnel are obtained:

$$\begin{cases} \sigma_r = P_0\left(1 - \dfrac{R_0^2}{r^2}\right), \\ \sigma_\theta = P_0\left(1 + \dfrac{R_0^2}{r^2}\right), \\ u_r = \dfrac{(1+\nu)P_0}{E} \cdot \dfrac{R_0^2}{r}. \end{cases} \tag{2}$$

In the formula, σ_r is the radial force of the surrounding rock; σ_θ is the tangential stress of the surrounding rock; E is the elastic modulus; ν is the Poisson's ratio of the surrounding rock; and P_0 is the initial stress of the surrounding rock.

According to the stress state of the surrounding rock, the circumferential stress σ_θ at any point in the surrounding rock is the maximum principal stress σ_1, the radial stress σ_r is the minimum principal stress σ_3, and the original rock stress P_0 is the intermediate principal stress. According to the surrounding rock elastic strain energy density formula, as shown in formula (3), the calculation method of surrounding rock strain energy described in formula (4) is obtained.

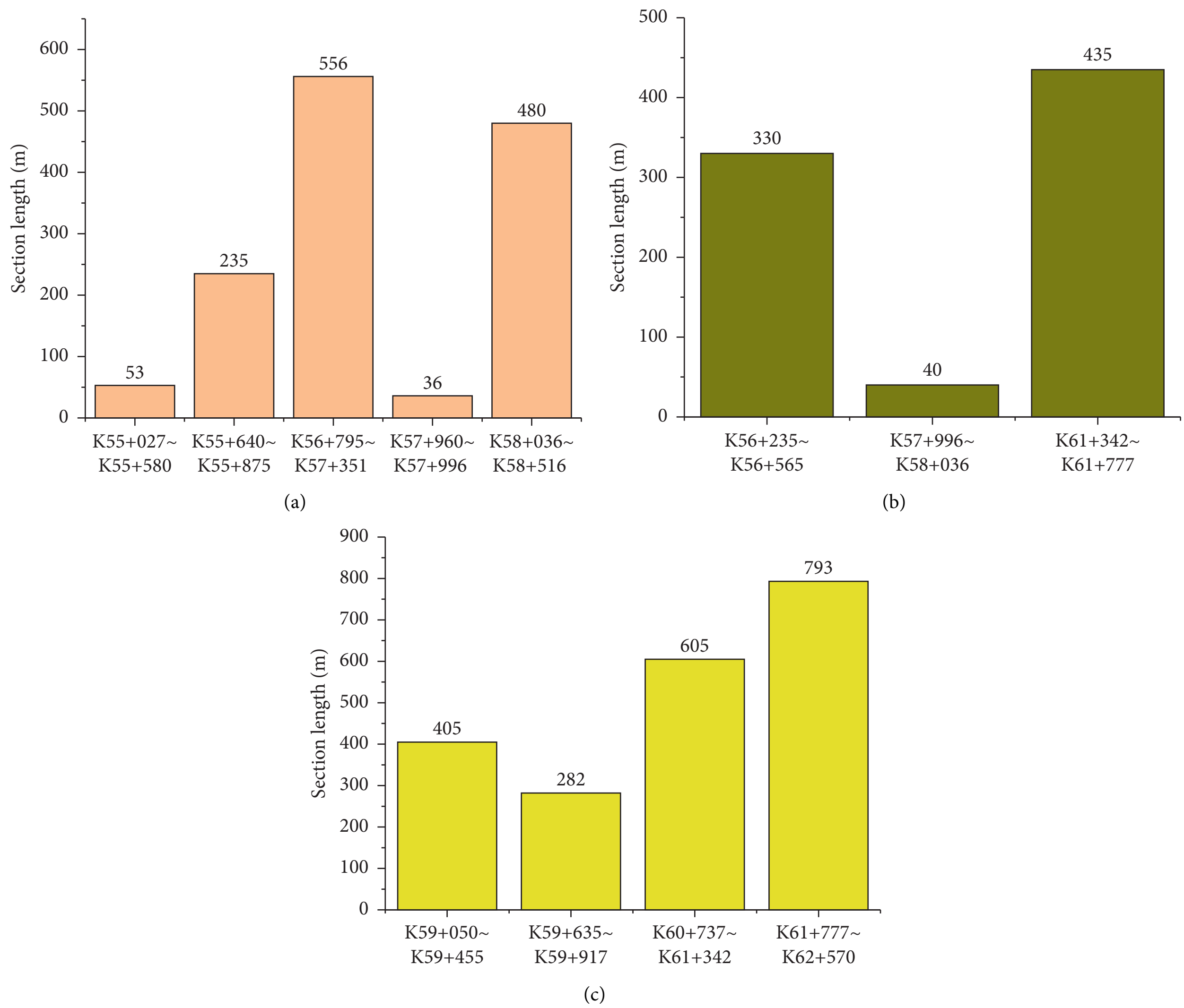


FIGURE 2: Dangerous zone of rockburst occurrence in tunnel. (a) Minor rockburst area. (b) Moderate rockburst area. (c) Severe rockburst area.

$$U = \frac{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\nu\left(\sigma_1\sigma_2 + \sigma_1\sigma_3 + \sigma_2\sigma_3\right)}{2E}, \tag{3}$$

$$U = \frac{\sigma_\theta^2 + P_0^2 + \sigma_r^2 - 2\nu\left(\sigma_\theta P_0 + \sigma_\theta\sigma_r + P_0\sigma_r\right)}{2E}. \tag{4}$$

According to formula (4), it can be obtained that the energy accumulated inside the surrounding rock is related to the eighth power of the depth of the surrounding rock. Therefore, shifting the depth of the stress concentration location in the surrounding rock of the tunnel can greatly reduce the energy accumulation.

After the surrounding rock is blasted, a plastic zone is formed, as shown in Figure 4 [22, 23]. It is assumed that the radius of the plastic zone formed after blasting is r_b, the radius of the tunnel is r_0, and the hydrostatic pressure of the tunnel is P_0. The stress solution at any point in the elastic region is [24–26]

$$\begin{aligned} \sigma_r^e &= -\frac{u_{r_1} E r_b}{(1+\mu) {r_1}^2} + p_0, \\ \sigma_\theta^e &= \frac{u_{r_1} E r_b}{(1+\mu) {r_1}^2} + p_0. \end{aligned} \tag{5}$$

According to (4), it can be seen that, as the radius of the blasting plastic zone increases, the accumulated energy in the elastic zone of the surrounding rock decreases. Therefore, the modification of surrounding rock by blasting can theoretically alleviate the problem of rock burst.

4. Numerical Simulation

4.1. Numerical Modeling. The numerical calculation adopts the three-dimensional discrete element calculation software 3DEC (3-dimension distinct element code). The Coulomb

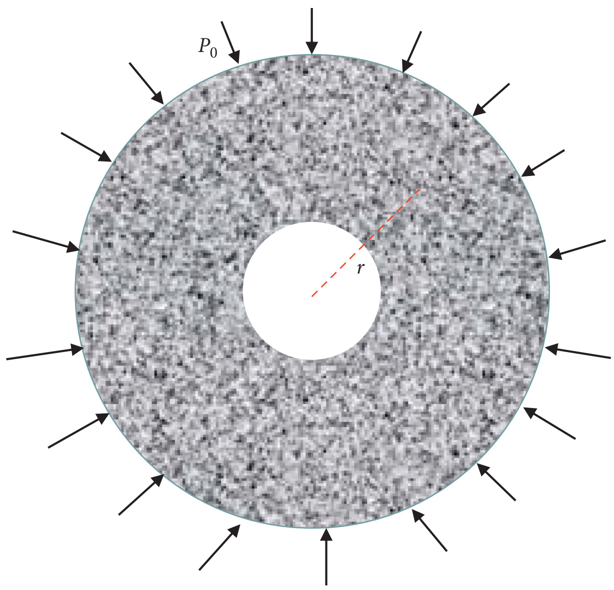


Figure 3: Mechanical model after tunnel excavation.

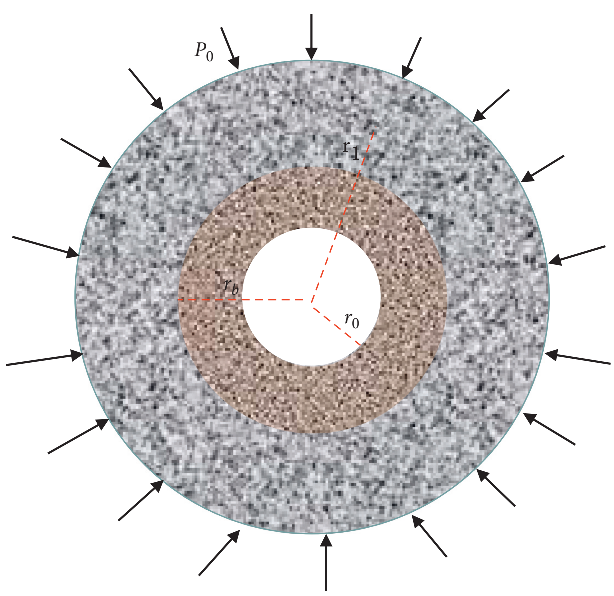


Figure 4: Mechanical model after tunnel blasting surrounding rock modification.

strain model is used in the numerical calculation of joint softening effect. According to the analysis of engineering geological data, the lithology of surrounding rock in the area where rock burst occurs is mainly rhyolite. The selection of numerical calculation parameters is shown in Table 2.

According to the surrounding rock and engineering research area, the numerical calculation model is divided into the tunnel excavation part, the modified part of the surrounding rock after blasting, and the surrounding rock part. The numerical calculation model has a size of $60 * 30 * 45$ m, and a horizontal load is applied to the x direction of the model, with a maximum horizontal principal stress of 20 MPa (Figure 5). The minimum principal stress is applied, and the vertical load is 12 MPa. The intermediate principal stress is applied, and the horizontal load in the y direction is 14 MPa. The numerical calculation is divided into three groups of working conditions. In the first working condition, the surrounding rock is not modified by the surrounding rock loosening blasting, and then the tunnel excavation is carried out. In the second working condition, the modified surrounding rock is loosened by blasting, and the depth of loosening the surrounding rock is 3 m. In the third working condition, the modified surrounding rock is loosened by blasting, and the depth of loosening the surrounding rock is 5 m.

4.2. Analysis of Numerical Results. By comparing the stress distribution of surrounding rock under the above three working conditions, the effect of preventing rockburst after modification of surrounding rock under blasting is evaluated. As shown in Figure 6, the maximum principal stress distribution of surrounding rock under different working conditions is analyzed. It can be seen that, without blasting the surrounding rock modification, the maximum principal stress around the tunnel can reach 37 MPa, and the stress concentration is located on the shallow surface of the surrounding rock of the tunnel. The maximum stress points are located at the tunnel vault and at the footings. There is a greater risk of rockburst.

After using blasting to modify the surrounding rock, when the depth of the modified surrounding rock is 3 m, the maximum principal stress of the tunnel surrounding rock is 32 MPa. Compared with the case without blasting, it is reduced by 5 MPa, but the maximum stress concentration area is shifted to the deep part of the surrounding rock by 3 m. And, the maximum principal stress of the surrounding rock in the shallow part of the tunnel is 9 MPa. The forward concentrated stress of the tunnel is also shifted forward by 3 m, which reduces the probability of rockburst. When the blasting modification depth of surrounding rock is 5 m, the maximum principal stress concentration position continues to shift to the deep. And, the maximum value is 26 MPa, which is 6 MPa lower than that without blasting. At the same time, the maximum principal stress of the surrounding rock in the shallow part of the tunnel is 4 MPa, and the risk of rockburst is further reduced.

As shown in Figure 7, it shows the distribution characteristics of the minimum principal stress of surrounding rock under different degrees of surrounding rock modification. After the blasting surrounding rock is modified, the free face of tunnel surrounding rock changes from compressive stress to tensile stress, which effectively avoids the phenomenon of stress concentration. In terms of circumferential stress of tunnel, after blasting modification, the tensile stress range expands with the increase of blasting loosening range of tunnel. At the same time, a pressure relief zone with a thickness of 5 m is also formed in front of the tunnel.

As shown in Figure 8, it shows the distribution characteristics of the principal stress in the middle of the

Table 2: Rock mechanical parameters.

Material density (kg·m^{-3})	Modulus of elasticity (Pa)	Poisson's ratio	Cohesion (Pa)	Tensile strength (Pa)	Internal friction angle (°)	Dilatancy angle (°)
2550	4.9e10	0.25	2.3e7	1.18e7	54.8	13

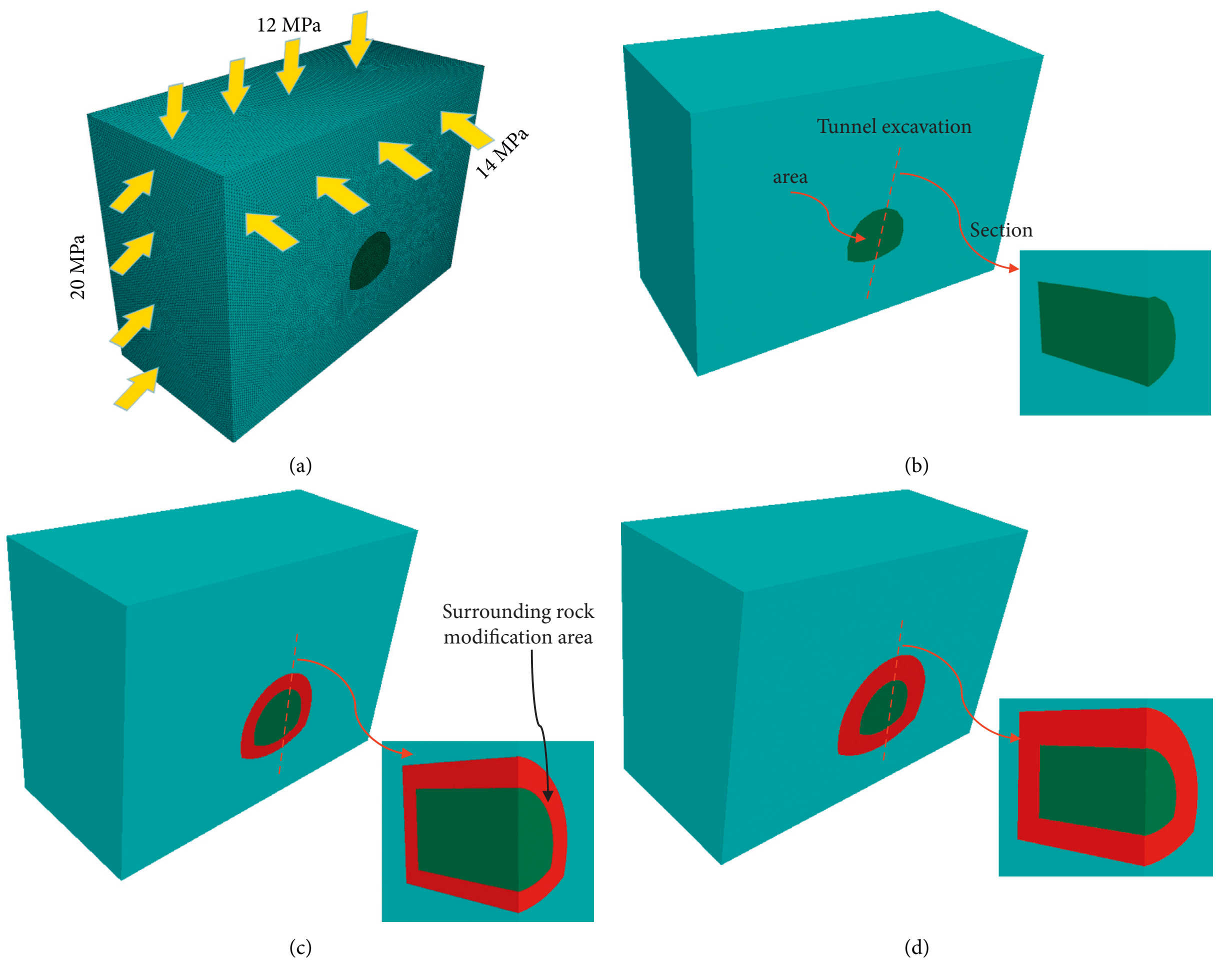


Figure 5: Numerical calculation model. (a) Model stress boundary conditions. (b) Tunnel excavation without surrounding rock modification. (c) The modified depth of surrounding rock during tunnel excavation is 3 m. (d) The modified depth of surrounding rock during tunnel excavation is 5 m.

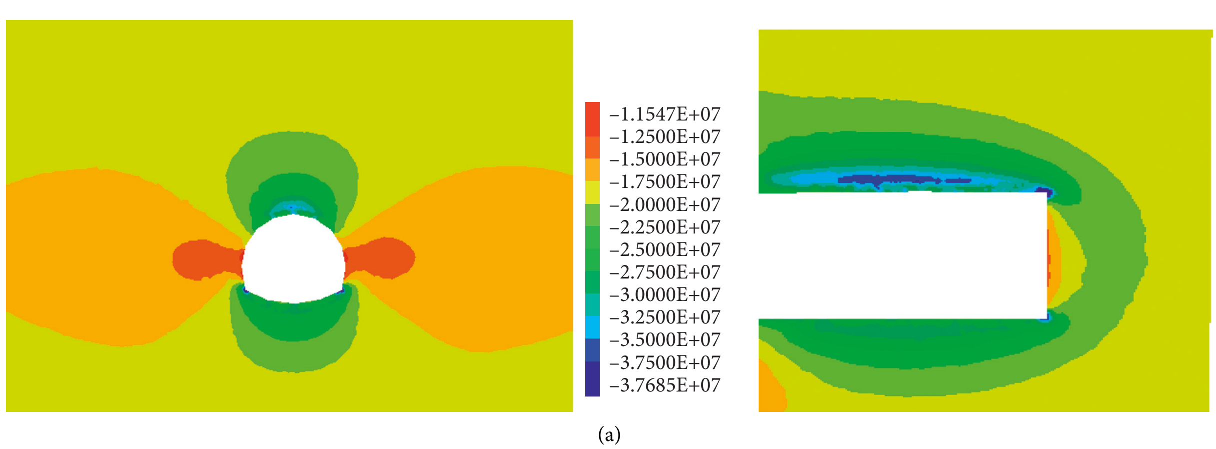
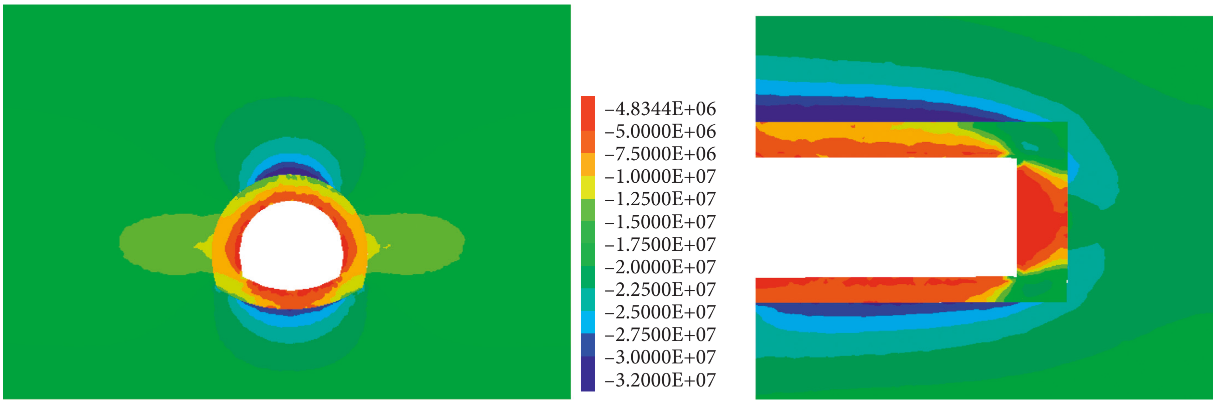
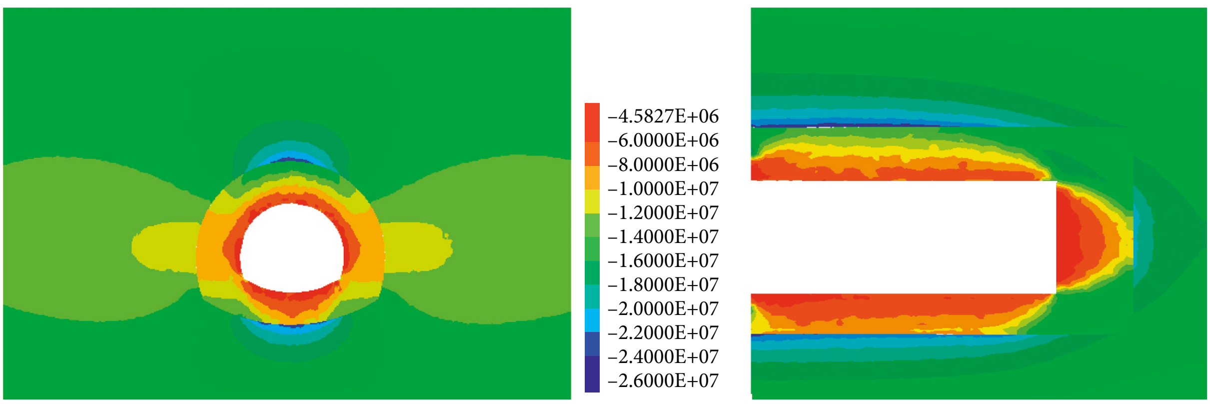


Figure 6: Continued.

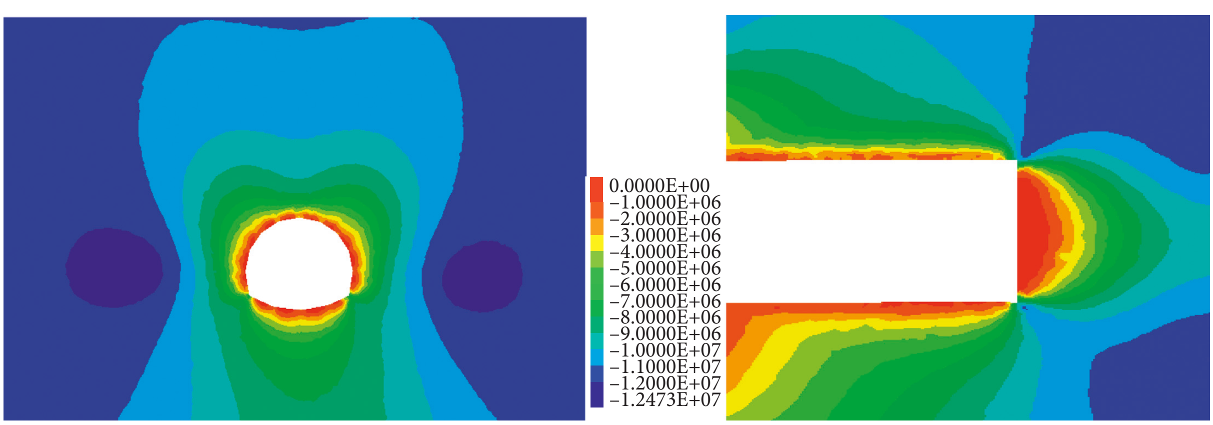


(b)



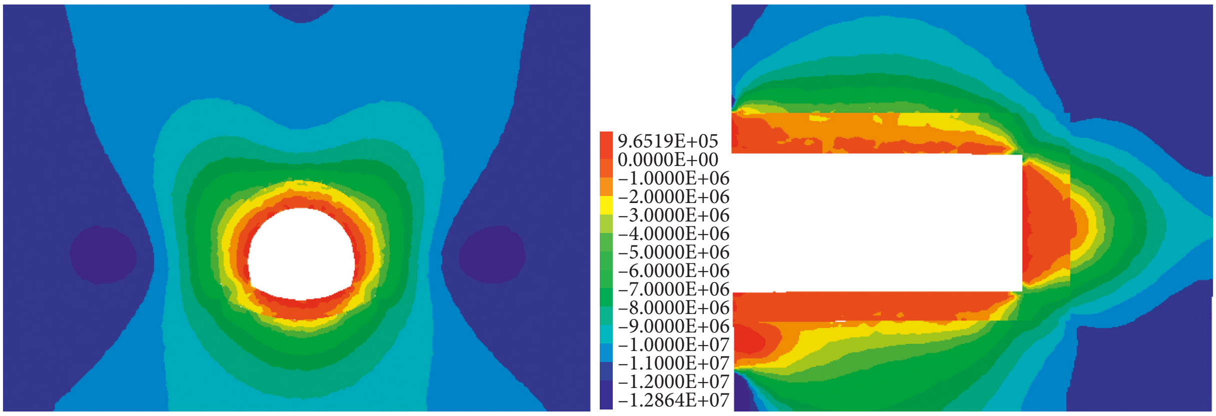
(c)

Figure 6: Distribution characteristics of maximum principal stress of surrounding rock. (a) Tunnel excavation without surrounding rock modification. (b) The modified depth 3 m. (c) The modified depth 5 m.

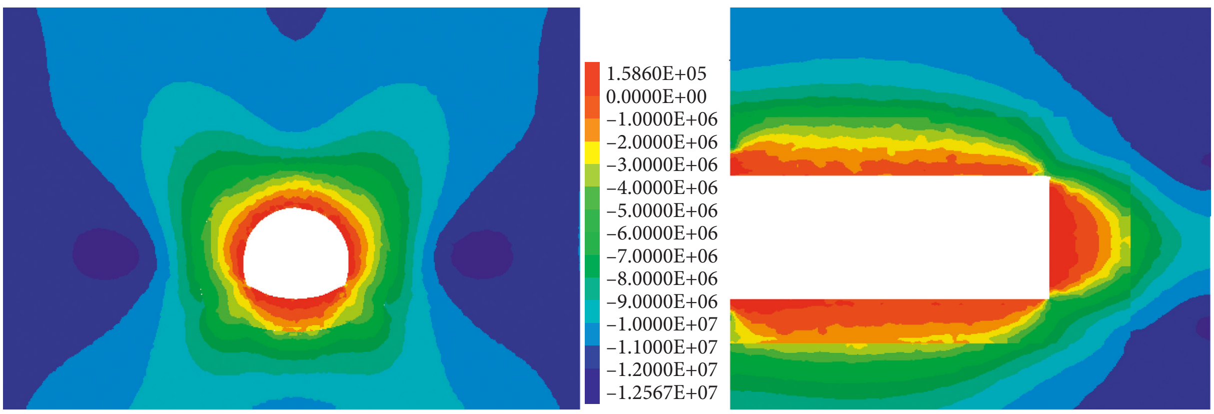


(a)

Figure 7: Continued.

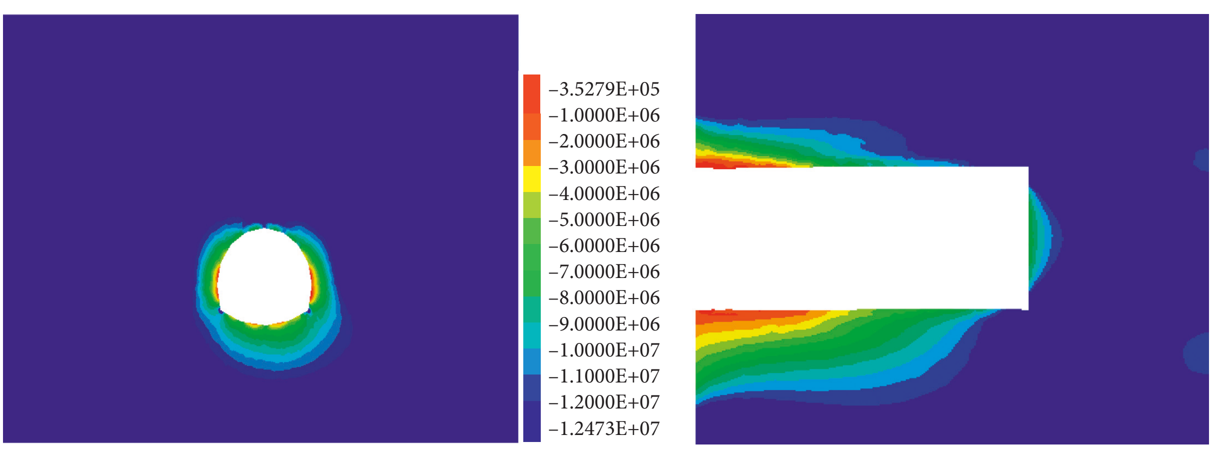


(b)



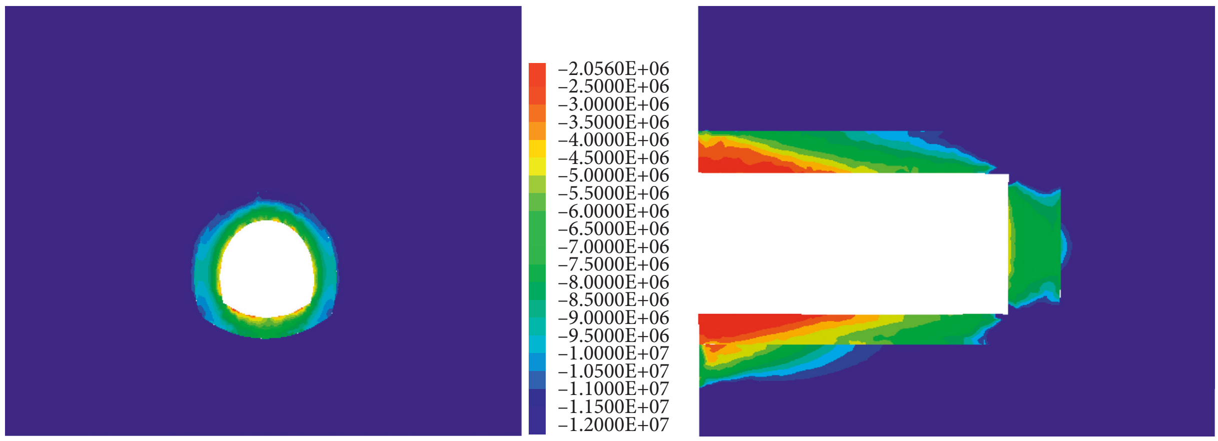
(c)

Figure 7: Distribution characteristics of minimum principal stress of surrounding rock. (a) Tunnel excavation without surrounding rock modification. (b) The modified depth 3 m. (c) The modified depth 5 m.

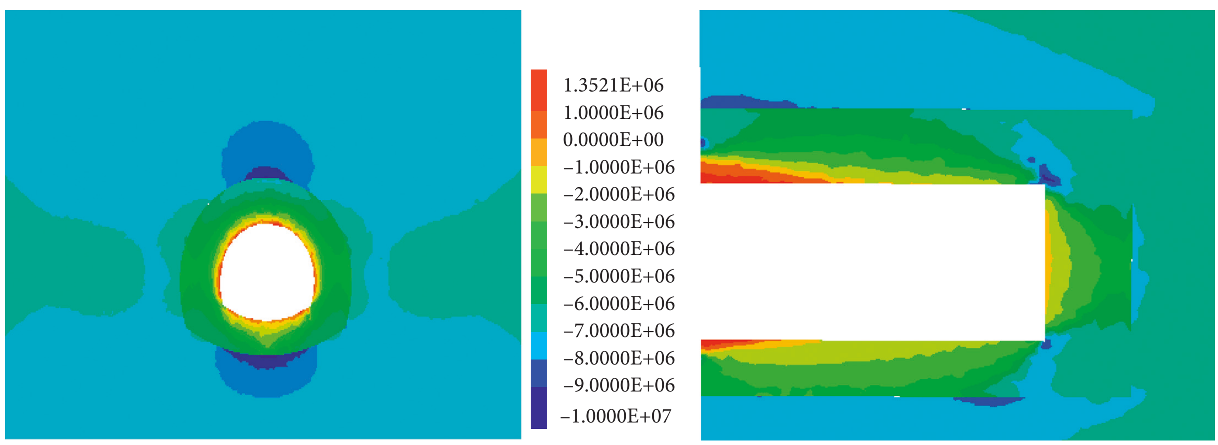


(a)

Figure 8: Continued.



(b)



(c)

Figure 8: Distribution characteristics of principal stress in the middle of surrounding rock. (a) Tunnel excavation without surrounding rock modification. (b) The modified depth 3 m. (c) The modified depth 5 m.

surrounding rock under the modification action. Without blasting, the maximum principal stress in the middle of the shallow surrounding rock of the tunnel is 12 MPa. When the blasting loosening thickness is 3 m, the principal stress in the shallow middle of the surrounding rock is 6 MPa. When the thickness of loose blasting is 5 m, the principal stress in the shallow part of surrounding rock is 2 MPa. After blasting loosening, there is an obvious low stress area in front of the tunnel face.

Figure 9 shows the deformation of the surrounding rock of the tunnel after blasting the modified surrounding rock. Without blasting and loosening, the maximum deformation of surrounding rock is 2 mm. Although the amount of deformation is small, the surrounding rock has accumulated a lot of elastic energy, which is prone to sudden rock bursts. As the modification depth of the surrounding rock of the tunnel increases, the tunnel variable increases slowly. When the modification depth of the surrounding rock is 5 m, the maximum deformation is 2 cm, which does not affect the normal construction of the tunnel, and the elastic energy around the free surface of the tunnel is greatly reduced. Therefore, it is proposed to use blasting to loosen the modified surrounding rock for tunnel rockburst treatment, and the modification depth is 5 m.

5. Engineering Applications

When arranging the modified blasting holes in the surrounding rock, the blasting holes are 10 m deep, and the dobby drill is used to drill holes and extrapolate at 30°. At the 1.4 m, 2.8 m, 4.2 m, 5.6 m, 6.8 m, and 8.2 m positions at the bottom of the hole, 32 mm drug rolls were installed, respectively. Emulsified waterproof explosive is used, and the orifice is sealed with mud to ensure the sealing is tight, as shown in Figure 10.

The tunnel microseismic monitoring adopts the Canadian ESG microseismic monitoring system. The changes in the acoustic emission data received by the microseismic monitoring reflect the implementation effect of the measures to prevent rockbursts (Figure 11). In order to verify the effect of blasting surrounding rock modification on tunnel rockburst control, the modified section was selected and compared with blasting surrounding rock modification. By comparison, it can be seen that, without blasting the modified surrounding rock, the number of microseisms in

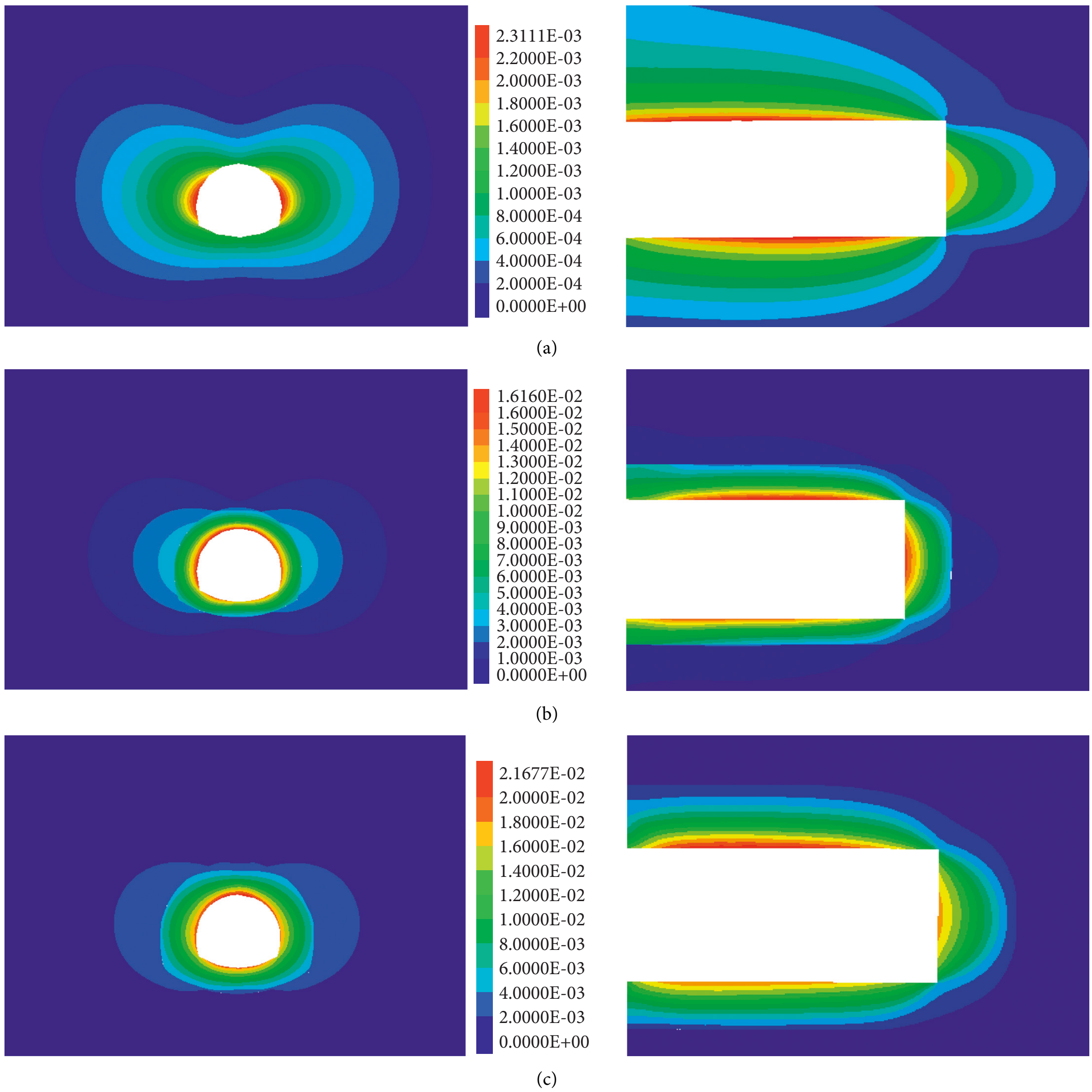


Figure 9: Deformation characteristics of surrounding rock. (a) Tunnel excavation without surrounding rock modification. (b) The modified depth 3 m. (c) The modified depth 5 m.

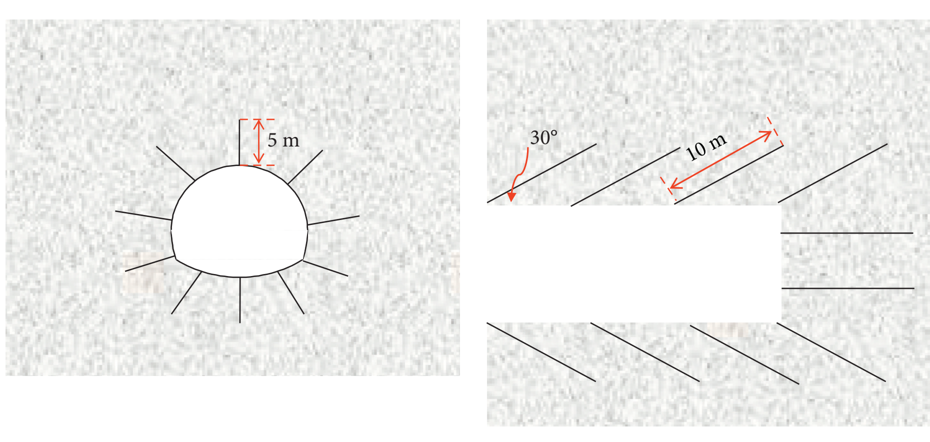


Figure 10: Layout of modified blasting holes in surrounding rock. (a) Front view of drilling and blasting. (b) Side view of borehole blasting.

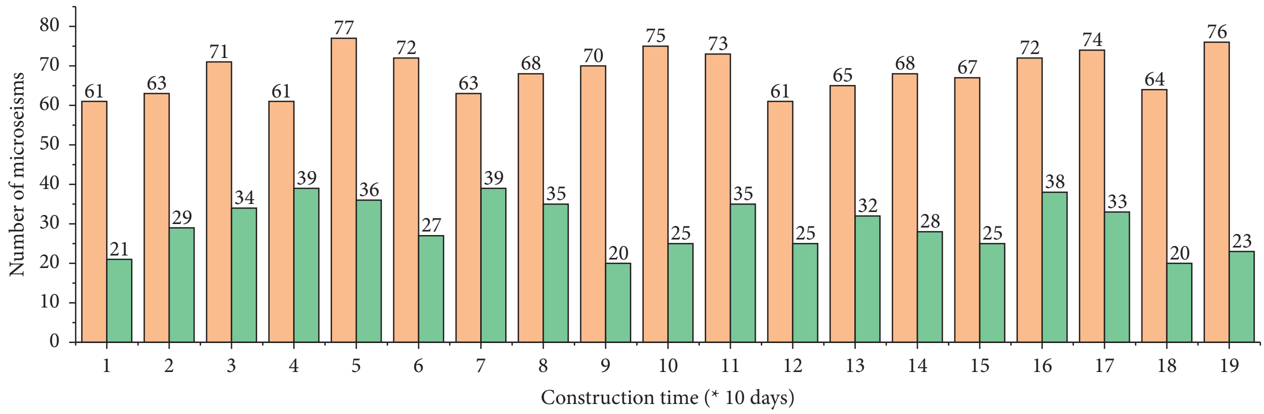


Figure 11: Change of microseismic quantity after blasting loosening modification of surrounding rock.

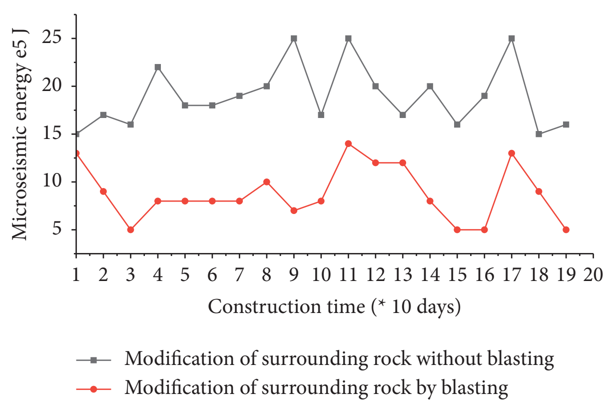


Figure 12: Comparative analysis of microseismic energy.

the tunnel is maintained at 60 to 80 times every 10 days. After the surrounding rock was modified by blasting loosening, the number of microseisms remained at 20 to 40, and the number of microseisms was reduced by 50%.

The surrounding rock was not loosened by blasting, and the microseismic energy fluctuated within 1.5 to 2.5e6J (Figure 12). After the modified surrounding rock is loosened by blasting, the microseismic energy fluctuates within 0.5 to 1.4e6J. To sum up, after blasting to modify the surrounding rock, the number of surrounding rock microseisms and the energy generated by the microseisms are both reduced.

6. Conclusion

The fundamental reason for tunnel rockburst is the accumulation and sudden release of strain energy. Through preblasting, the nature of surrounding rock is changed, so that its energy accumulation capacity is reduced, so as to reduce the risk of rock burst. In this paper, the method of theoretical analysis, numerical simulation, and engineering measurement is used to study the tunnel blasting loosening and the modification of surrounding rock to relieve rockburst. Taking the blasting loosening depth as the only variable, three groups of simulations are carried out; combined with microseismic monitoring, the mechanism of blasting pressure relief and modification of surrounding rock to control rockburst is studied, and the following conclusions are drawn:

(1) It is more reliable to use the ratio of original rock strength to in situ stress to divide the rockburst risk area, and the research target tunnel rockburst risk area is relatively wide. Rockburst control measures should be actively taken to prevent the occurrence of rockburst during construction.

(2) Using advanced blasting to loosen and modify surrounding rock is an effective method to prevent rockburst. The stress wave generated by blasting damages the surrounding rock, reduces the ability of the surrounding rock to accumulate elastic energy, and avoids the sudden large-scale energy release of the surrounding rock in the shallow part of the tunnel during the excavation process.

(3) The control effects of different surrounding rock modification ranges on rockburst were compared and analyzed. After the surrounding rock modification, the maximum principal stress value

decreased, and the stress concentration position increased inward with the increase of the blasting modification depth. Through the comparison of microseismic data, the reliability of advanced blasting modified surrounding rock for rockburst disaster control is determined.

Data Availability

The data used to support the findings of the study are available within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Conceptualization, visualization, original draft preparation, and project administration were performed by Yanhua Sun. Validation and review and editing were performed by Xiaohu Zhang and also provided resources; methodology, resources, and data curation were contributed by Hanhua Xu. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

The authors gratefully acknowledge the funding provided by the Technology Top Talent Support Project of Guizhou Provincial Education Department (item no. [2017]098).

References

[1] J. He and L. m Dou, "Gradient principle of horizontal stress inducing rock burst in coal mine," *Journal of Central South University*, vol. 19, no. 10, pp. 2926–2932, 2012.

[2] T. H. Ma, C. A. Tang, S. B. Tang et al., "Rockburst mechanism and prediction based on microseismic monitoring," *International Journal of Rock Mechanics and Mining Sciences*, vol. 110, pp. 177–188, 2018.

[3] W. Zhang, N. Ma, J. Ma, C. Li, and J. Ren, "Mechanism of rock burst revealed by numerical simulation and energy calculation," *Shock and Vibration*, p. 2020, 2020.

[4] J. A. Wang and H. D. Park, "Comprehensive prediction of rockburst based on analysis of strain energy in rocks," *Tunnelling and Underground Space Technology*, vol. 16, no. 1, pp. 49–57, 2001.

[5] F. Q. Gong, J. Y. Yan, and X. B. Li, "A new criterion of rock burst proneness based on the linear energy storage law and the residual elastic energy index[J]," *Chinese Journal of Rock Mechanics and Engineering*, vol. 37, no. 9, pp. 1993–2014, 2018.

[6] F. Gong, J. Yan, X. Li, and S. Luo, "A peak-strength strain energy storage index for rock burst proneness of rock materials," *International Journal of Rock Mechanics and Mining Sciences*, vol. 117, pp. 76–89, 2019.

[7] J. Wen, H. Li, F. Jiang, Z. Yu, H. Ma, and X Yang, "Rock burst risk evaluation based on equivalent surrounding rock strength," *International Journal of Mining Science and Technology*, vol. 29, no. 4, pp. 571–576, 2019.

[8] M. He, F. Ren, and D. Liu, "Rockburst mechanism research and its control," *International Journal of Mining Science and Technology*, vol. 28, no. 5, pp. 829–837, 2018.

[9] P. Zhang, D. F. Zhang, Y. Yang et al., "A case study on integrated modeling of spatial information of a complex geological body," *Lithosphere*, vol. 2022, no. Special 10, Article ID 2918401, 2022.

[10] Y. Wang, H. N. Yang, J. Q. Han, and C. Zhu, "Effect of rock bridge length on fracture and damage modelling in granite containing hole and fissures under cyclic uniaxial increasing-amplitude decreasing-frequency (CUIADF) loads," *International Journal of Fatigue*, vol. 158, p. 106741, 2022.

[11] Y. Pu, D. B. Apel, V. Liu, and H. Mitri, "Machine learning methods for rockburst prediction-state-of-the-art review," *International Journal of Mining Science and Technology*, vol. 29, no. 4, pp. 565–570, 2019.

[12] M. Sepehri, D. B. Apel, S. Adeeb, P. Leveille, and R. A. Hall, "Evaluation of mining-induced energy and rockburst prediction at a diamond mine in Canada using a full 3D elastoplastic finite element model," *Engineering Geology*, vol. 266, Article ID 105457, 2020.

[13] S. Wu, Z. Wu, and C. Zhang, "Rock burst prediction probability model based on case analysis," *Tunnelling and Underground Space Technology*, vol. 93, p. 103069, 2019.

[14] S. m Wang, J. Zhou, C. q Li, D. J. Armaghani, Xb Li, and H. S. Mitri, "Rockburst prediction in hard rock mines developing bagging and boosting tree-based ensemble techniques," *Journal of Central South University*, vol. 28, no. 2, pp. 527–542, 2021.

[15] R. Xue, Z. Liang, N. Xu, and L Dong, "Rockburst prediction and stability analysis of the access tunnel in the main powerhouse of a hydropower station based on microseismic monitoring," *International Journal of Rock Mechanics and Mining Sciences*, vol. 126, p. 104174, 2020.

[16] Q. Wang, M. C. He, S. C. Li et al., "Comparative study of model tests on automatically formed roadway and gob-side entry driving in deep coal mines," *International Journal of Mining Science and Technology*, vol. 31, no. 4, pp. 591–601, 2021.

[17] Z. Dou, S. X. Tang, X. Y. Zhang et al., "Influence of shear displacement on fluid flow and solute transport in a 3D rough fracture," *Lithosphere*, vol. 2021, no. Special 4, Article ID 1569736, 2021.

[18] D. Chen, H. Chen, W. Zhang et al., "An analytical solution of equivalent elastic modulus considering confining stress and its variables sensitivity analysis for fractured rock masses[J]," *Journal of Rock Mechanics and Geotechnical Engineering*, 2021.

[19] Z. Dou, Y. M. Liu, X. Y. Zhang et al., "Influence of layer transition zone on rainfall-induced instability of Multilayered slope," *Lithosphere*, vol. 2021, no. Special 4, Article ID 2277284, 2021.

[20] G. Li, Y. Hu, S. m Tian, M. weibin, and Hl Huang, "Analysis of deformation control mechanism of prestressed anchor on jointed soft rock in large cross-section tunnel," *Bulletin of Engineering Geology and the Environment*, vol. 80, no. 12, pp. 9089–9103, 2021.

[21] A. Manouchehrian and M. Cai, "Numerical modeling of rockburst near fault zones in deep tunnels," *Tunnelling and Underground Space Technology*, vol. 80, pp. 164–180, 2018.

[22] X. Guo, Z. Zhao, X. Gao, X. Wu, and N Ma, "Analytical solutions for characteristic radii of circular roadway surrounding rock plastic zone and their application,"

International Journal of Mining Science and Technology, vol. 29, no. 2, pp. 263–272, 2019.

[23] X. Guo, Z. Zhao, X. Gao, Z. Ma, and N Ma, "The criteria of underground rock structure failure and its implication on rockburst in roadway: a numerical method," *Shock and Vibration*, pp. 1–12, 2019.

[24] A. R. Kargar, "An analytical solution for circular tunnels excavated in rock masses exhibiting viscous elastic-plastic behavior," *International Journal of Rock Mechanics and Mining Sciences*, vol. 124, Article ID 104128, 2019.

[25] A. Z. Lu, G. s Xu, F. Sun, and W. Q. Sun, "Elasto-plastic analysis of a circular tunnel including the effect of the axial in situ stress," *International Journal of Rock Mechanics and Mining Sciences*, vol. 47, no. 1, pp. 50–59, 2010.

[26] C. C. Torres, "Elasto-plastic solution of tunnel problems using the generalized form of the hoek-brown failure criterion," *International Journal of Rock Mechanics and Mining Sciences*, vol. 41, pp. 629–639, 2004.