Abstract

With the development of engineering construction in China, there are more and more tunnel projects built or planned in western China. Due to the complex geological conditions in these areas, and the deepening depth of those tunnels, the high geostress in deep tunnels usually leads to various degrees of rock bursts, resulting in personal casualties, equipment losses, delays in construction periods, or various economic risks. Many scholars at home and abroad have conducted a lot of researches on rock bursts caused by high geostress, and also put forward some preventive measures. However, since the occurrences of those rock bursts have such characteristics as uncertainty, abruptness and concealment, there still exist many disputes in the mechanism, systematic monitoring, early warning devices and preventive measures of rock bursts. In particular, there is no effective countermeasure in the engineering field to control serious high-intensity rock bursts. Thus this book studies the deformation mechanism of those high-intensity rock bursts and puts forwards a pre-release de-stress blasting method, i. e. by combining with a series of reasonable drilling and blasting parameters, an artificially controlled blasting method can be used to weaken the intensity of rock bursts, and to provide solutions to the rock bursts in high-stress tunnels and underground projects.

Based on the study of the mechanism of the pre-release de-stress blasting for those high-intensity rock bursts, combined with numerical simulations, some reasonable de-stress blasting parameters are selected, including the diameter of the borehole, the spacing between boreholes, the depth of the borehole, the angle of the borehole, and so on. Some on-site tests were also held to verify the validity of this method and the rationality of the parameters. The book has obtained the following research results:

①Through the numerical simulations of the physical and mechanical properties of surrounding rocks, and of the excavation conditions, it is found that such characteristics as compressive strength and Poisson's ratio have more obvious influence on the rock burst acitivity, while other factors as excavation size, excavation way and supporting structure have less influence. Meanwhile, through the analysis of and comparison with those prevention measures, it is confirmed that for those high-intensity rock bursts, pre-relief de-stress blasting is feasible, since it can distrub the surrounding rocks in blasting vibration, shock waves, or other huge energy, guiding redistribution of the stress in surrounding rocks, or partially releasing the stress, thereby reducing

the rock burst intensity.

②Appling some related theories, such as the exponential decay theory of stess waves, we can derive a calculation formula of residual stress after de-stress blasting, which is used to find the distribution rules of the stress in the tunnel wall. The theoretical analysis and the on-site test results are in consistency.

③The numerical simulation software ANSYS/LS-DYNA and FLAC 3D were used to simulate the stress relief blasting in surrounding rocks under high-geostress conditions. According to the actual situation of de-stress blasting in high-geostress area, the numerical parameters of de-stress blasting are determined, which mainly include the diameter of the blast hole, the length of the blast hole, the spacing between the blast holes, the non-coupling coefficient of the blast hole, the order of initiation, and the included angles between the blast hole and the tunnel axis in the X direction and the Y direction, respectively. Then based on the orthogonal experiment method, an optimum blasting scheme under multi-parameter interaction conditions was determined, as well as the optimum blasting scheme under single factor variation, and the simulation analysis of de-stress blasting was also carried out.

④Based on the theoretical analysis and numerical simulation results, applied with the optimum parameters, an on-site stress relief blasting test was carried out at K186+94.020 at Sangzhuling Tunnel of Lin-la Railway. The test results show that the stress reduction rate reaches 63% (the maximum principal stress before blasting is 30.7 MPa, while the maximum principal stress after blasting is 11.5 MPa), which verifies that the de-stress blasting method has great effect on reducing the maximum principal stress. According to the rock burst grading system proposed by Tao Zhenyu, the surrounding rocks before blasting are prone to have a medium rock burst, while after blasting, the surrounding rocks have lower rockburst or even no rock burst activity. After calculating the stress in the surrounding rocks by the derived formula of residual stress after explosion, and then comparing with the on-site test results, we find the stress values in all directions are very close (with minor errors having no effect on the judging of rockbust grades), which verifies that the derived formula of residual stress after explosion in this book is scientific and reasonable.

Keywords: High-intensity rock burst; Geotress; De-stress blasting; Stress relief; Sangzhuling tunnel

Contents

Chapter 1 Introduction

1.1 Background and Significance

At the "2015 China (Shanghai) Technical Seminar on Underground Tunnel Engineering", according to the survey by the Tunnel and Underground Works Branch of Civil Engineering Society of China (CESC), China has become the country with the largest scale and the fastest speed in underground tunnel construction in the world. By the end of 2016, there had been nearly 13,000 road tunnels with a total length of 12,831 km in China. It is expected that there will have been a total number of 17,000 railway tunnels put into operation in China and the total length will have exceeded 20,000 km by the end of 2020. The extension of large-scale infrastructures to the west has increased not only the number of railways, highways and hydropower tunnels, but also the number of tunnels, which are longer than 10 km and demonstrate the characteristics of being "longer, larger, deeper and clustering". Some deep engineering dangers occur frequently due to the complexity of the geological conditions, including high geostress, high water head, high ground temperature and engineering disturbance. Take Sichuan-Tibet railway as an example, according to the plan, there will be 198 tunnels along the whole railway, with a total length of 1, 223.451 km, which accounts for 70.2% of the total length of the line; and there are 46 extra-long tunnels with a length of 724.441 km. Among them, there will be the longest (69 km) and the second longest (59 km) tunnels in the world. In those long and large tunnels, there might appear many high geostress problems, even rock burst threats. Some relevant data show that in our country, there are an increasing number of tunnels with a depth of hundreds of meters or even over kilometers, and there also emerges some long and large tunnels crossing those deeply-buried high-geostress zones. The increase in tunnel length will inevitably lead to the rise of buried depth. Table 1.1 shows the length and buried depth of some tunnels in China.

Table 1.1 Statistics of tunnel length and buried depth in China

Name	Site	Length/m	Maximum buried depth/m
Tongyu tunnel	Kaixian, Chongqing	4,279	1,030
Qinling tunnel	Qinling, Shaanxi	(line Ⅰ) 18,460 (line Ⅱ) 18,456	1,700
The extra-long Erlangshan tunnel	Luding, Sichuan	4,176	748
Secondary tunnel of Jinping Hydropower Station	Liangshan, Sichuan	18,700	2,525
Zhegushan tunnel of National Highway 317	Aba, Sichuan	4,400	1,400
Qinling Zhongnanshan Extra Long tunnel	Qinling, Shaanxi	18,020	1,600
Ba Yu tunnel	Shannan, Tibet	13,073	2,080
Sangzhuling tunnel	Shannan, Tibet	16,449	1,347
Duoxiongla tunnel	Milin, Tibet	4,784	820

Most of these tunnels are built in complex geological conditions, and the exceeding length and corresponding buried depth make those high geostress phenomena most frequent. In recent years, furthermore, as the development of hydropower resources intensifies, the underground water power generation system has gradually developed towards the direction of super tunnel length, large house span, deep buried depth and so on, which inevitably bring more high geostress phenomena. According to some incomplete figures, by 2013 various hydraulic tunnels with total lenghth of 10,000 km had been built, over 1,000 km of headrace tunnels are under construction, and over 2,000 km of headrace tunnels have been planned. At present, some super long water diversion tunnels under construction include the Qinling Super Long Water Diversion Tunnel (98.3 km in length), the Taohe river water diversion tunnel (96.35 km in length), the Dajihuang water diversion tunnel (24.17 km in length), the Northwest Liaoning water supply tunnel (230 km in length), and the Songhuajing water supply Tunnel in Central Jilin (134.631 km in length, 6.6 m in diameter, in TBM Construction) (Kairong Hong, 2015). Moreover, there are countless large-scale, complexly structured underground cavern groups, built for various uses, crossing each other in the limited space.

Due to the reduction and even depletion of shallow resources, deep well mining has become imperative and a vital technology in mining industry throughout the world. In China, the coal reserves buried in less than 1,000 meters only account for 53% of the total coal resources. At present, the depth of coal mine is increasing at a rate of 8 to 12 m every year, and the mining depth in eastern China is even developing at a rate of 100 to 250 m every 10 years. It is even expected that many coal mines will enter the depth of 1,000 to 1,500 m in the next 20 years. In recent years, some metal mines in China have entered deep mining layers, such as the mining depth of Huize Pb-Zn Mine in Yunnan Province has exceeded 1,000 m, the Dongguashan Copper Mine in Tongling has reached 1100 m, and the Hongtoushan Copper Mine in Fushun has reached 900-1,100 m. Over seas, there are nearly 100 metal mines with a mining depth of over 1,000 m, among which the gold mine of AngloGold company in western Africa has reached 3,700 m; in Kolar gold mining area of India, there are 3 mines with a depth of over 2,400 m, with one even reaching 3,260 m; in Krivolog iron mining area of Russia, the mining depth is up to 1,570 m. In addition, the mining depth of some metal mines in Canada, the United States and Australia has also exceeded 1,000 m.

While China is vigorously developing the western region and promoting the economy of the western area, we need to pay special attention to the inevitable deep engineering problems, i. e., high geostress, uneven distribution, complexity and difficulty of construction procedures. In a condition of high geostress, the excavation of underground tunnel often produces severe rock bursts, which directly threatens the safety of construction personnel and equipment, and affects the progress of the project, so it is urgent to put forward a proper solution to avoid those geological disasters.

Based on incomplete statistics, at least 2,000 coal bursts or rock bursts have occurred in many coal mines in China. In some severe rock bursts, tons of rock blocks, rock slices or rock plates have been thrown out, causing huge damages. Rock bursts also occur frequently in some hydropower projects, such as in the underground works of Ertan, Taipingyi, Jinping, Tianshengqiao and other hydropower stations. According to some document retrieval, at least 18 countries or regions in the world have large-scale rock bursts. Thus the stability of the surrounding rocks in high-geostress tunnels has become an urgent problem to be solved in the excavation of underground tunnels. Numerous engineering projects show that the greater the buried depth, the more intensive the tectonic movement, and the higher the geostress level, the higher the possibility of deep engineering threats, such as high-intensity rock bursts, continuous deformation and even large-scale collapses. These dangers have seriously restricted the development of hydraulic and hydroelectric projects, transportation, national defense, and deep basic physics in China, and even affected the safety of mining in China. In order to reduce or avoid the rock bursts, and minimize the economic losses and casualties, it is urgent to conduct in-depth researches on the mechanism, forecast, and preventing techniques of those high-intensity rock bursts.

In underground engineering, the fundamental reason for the instability of the surrounding rocks is that the excavation causes the concentrated stress to exceed the strength of the surrounding rocks, which makes them break and even destroyed, thus forming a broken zone. Therefore, in order to keep the stability of the surrounding rocks, some control measures need to be taken to prevent the forming of a broken zone, or to restrain the developing of the broken zone. On the contrary, if the concentrated stress is less than the strength of surrounding rocks, they will not be damaged, causing no broken zone, and the tunnel will be in natural stability without any treatment. Specifically, two measures can be taken: one is the strengthening method, i.e., to strengthen the surrounding rocks to improve their intensity; the other is the geostress control method, i.e., to control the geostress distribution in the surrounding rocks, so that the peak geostress is transferred to the deeper rocks far away from the tunnel face, to avoid high-geostress concentration or tensile zone around the tunnel, keeping the tunnel in low-stress area. According to Xiangshen Guo (2010), the strengthening method is suitable for ordinary tunnels, while for the deep-buried, high-stress tunnels, the method is not so ideal as it may cost more labor force, more materials and more financial resources, usually with high supporting costs.

So far, for high-intensity rock bursts, scholars have made many in-depth research and lots of scientific achievements, most of which, however, just focus on forecast and evaluation. The control measures are fewer, even the existing ones, to some degree, have certain limitations, without the control of solving the problem of high-intensity rock burst. Furthermore, researchers today investigate rockbursts mainly through field investigation and laboratory test, combined with mechanism analysis of existing physical properties and mathematical methods. Take 3 methods as examples: ①The high-pressure water injection method. According to Xianneng Wang (1998), this method is to make advancing boreholes in rocks and then inject water into rock mass with high pressure and even flow. This method can release strain energy and transfer the maximum tangent stress to deeper surrounding rocks, which might generate some new tension cracks and make the original cracks expanding to weaken the intensity of rock mass, thus reducing the capacity of the rock mass to store strain energy. However, as is shown in the case of the Krishna Gold mine in Kolar India, for those hard rock mass with high geostress, water injection might bring new problems by triggering some rock bursts around the internal cracks, so the method has certain limitations. ②The staged excavation method. Many scholars recommend the staged excavation method to reduce rock bursts. However, this method, according to the numerical analysis of the Tianshengqiao Ⅱ Hydropower Station, is not necessarily beneficial because the more excavations, the higher chances of rock bursts. ③The reinforcement method. In high-intensity rock burst sections, we can take such measures as deepening and densifying system anchor bolts, adding base plates, hanging a whole network, spraying and mixing cement. However, as shown in a series of engineering practices, when anchor bolts are used in areas with severe rock bursts, it is prone to cause accidents such as collapse. All in all, the above methods have no obvious effect on reducing those high-intensity and severe rock bursts.

To sum up, there is no effective solution to the high-intensity rock bursts under the high-geostress condition, so it is necessary to explore new forecast and control measures. The author of this book holds that to control blasting by pre-releasing geostress can effectively weaken, and even prevent those high-intensity rock bursts since it can reduce the stress accumulation in surrounding rocks before large-scale excavation. Therefore, it is of vital importance to study the control method on pre-relief de-stress blasting for high-intensity rockbursts. In some areas with a high proneness of rockbursts, before unloading excavation, we can release the geostress of surrounding rocks by applying the control de-stress blasting technique to reduce the energy concentration and to wipe out rock bursts from the root. This study might also provide some theoretical support for the treatment of high-intensity rock bursts in deep engineering projects.

1.2 Foreign and Domestic Researches

China is experiencing a rapid development of infrastructure construction. So the research on the evolution, forecast and prevention of deep engineering dangers is an important topic for the safety construction and operation of hydraulic and hydroelectric projects, transportation, national defense projects, as well as for the safety and efficiency of metal mining industry. All these deep engineering projects, involving the fields of mining, transportation, water conservancy and hydropower, national defense and others, are directly related to the sustainable development of national economy. Rock burst is a moving geological threat occuring in hard rock tunnels in high-geostress areas. There are usually a large number of blocks exploding in the excavation space when rock burst occurs, which often cause huge damage to personnel and equipment and affect the progress of the project. Therefore, rock burst, as a typical threat in high-geostress area, has always been a hot topic in the field of geotechnical engineering. Scholars at home and abroad have done a lot of researches in this field.

1.2.1 Current research of rock bursts

The earliest record of rock burst in the world can be traced back to the 1830s, when a rock burst occurred in the Leipzig Coal Mine in UK. Since then, rock bursts of various sizes have occurred in underground projects around the world. We made rough statistics as follows: in Norway, a strong rock burst took place in Sima underground power station; in Sweden a rock fragment ejection with sounds also took place in Forsmark nuclear power station; in South Africa, some rock bursts even triggered earthquakes in mine pillars, mining zones, fault zones; Canada also experienced two large rock bursts, which triggered fault sliding, collapses, earthquakes and casualties, and finally the mines were shut down; in Japan rock bursts also occurred in the Guanyue Tunnel with a total length of 10.9 km, of which 1.1 km was the rock burst area, where most rock bursts occurred in quartz diorite instead of hornfels, and in place without water gushing, not in place with water gushing; in Guizsasso Road Tunnel in Italy a rock burst occurred suddenly on the right side of the tunnel face, and the top arch collapsed, with a burst volume of hundreds of cubic meters.

Because of its suddenness in time, randomness in space, burst ejection in form, and harm in result, rockburst has attracted worldwide attention. In particular, South Africa, as one of the most advanced countries in rock burst research in the world, has accumulated rich experience in theoretical research, forecast, prevention and other control measures of rock bursts, and has established a fairly complete theoretical system. In China, the research history of rock burst is relatively short, with the earliest record of a rock burst in Shengli Coal Mine, Fushun, in 1933. Since the late 1970s, rock burst research has entered a new stage both at home and abroad. Many international academic conferences on rock bursts have been held for exchanging and accumulating valuable data and practical achievements on the forecast, control and prevention of rock bursts. In recent years, the main domestic research of rock bursts include the follows: Tong Jiang et al. (1998) summarized the main rock burst theories, discussed their advantages and disadvantages, and forecasted the future developing trend; Shaohui Tang (2003), Linsheng Xu et al. (2001; 2002; 2004) introduced some actual rock bursts and field researching results; Yuanhan Wang et al. (1998) put forward some methods to judge the occurrence and intensity of rock bursts; Tianbin Li et al. (2011) introduced some research results in field simulation tests; In combination with actual engineering practices, Guoqing Chen et al. (2013), Xiangdong Xu (2008), Peng Yan et al. (2008), Gong Fengqiang et al. (2007), Wang Bo et al. (2007), Guan Jianji et al. (2006), ManChao He et al. (2006), Yongmou Xie et al. (2004), Zemin Xu et al. (2004; 2003), Yun Jiang (2002), and Jianglin Wan et al. (1994) also disscussed the mechanism, forecast methods and prevention measures of rock burst from different aspects, and obtained lots of beneficial results. Through literature review, we can summarize the main achievements as follows:

(1) Classification of rock bursts The classification of rock bursts is mainly based on the storage and release of elastic strain energy in rock mass or the patterns of geostress effects. At present, there exist some disputes among scholars. Zhuoyuan Zhang et al. (1994) divided rock bursts into three types according to the site and the amount of energy released, namely the rock burst caused by sudden rupture of the surface rock on the cave wall, the rock burst caused by

sudden failure of ore pillar or of large range of surrounding rock, and the rock burst caused by fault movement. Based on the intrinsic factors, Wenzhi Zuo et al. (1995) classified rock bursts into three types: the horizontal tectonic geostress type, the vertical pressure type and the comprehensive type. The research group of Tianshengqiao Ⅱ Hydropower Station proposed two standards for classification. Firstly, according to the degree of rupture, rock bursts can be divided into two categories: the fracture relaxation type and the rupture detachment type. Secondly, based on the scale, rock bursts can be divided into three categories: the sporadic rockbursts (0.5-10 m long), the monolithic rockbursts (10-20 m long) and the continuous rockbursts (larger than 20 m). Zhi Guo (1996), based on the failure modes, classified rock bursts into three types: the ejecting type, the flaking type and the collapsing type. Up to now, the most influential classification comes from Dr. Tan Yi'an: according to the origin of high geostress and the direction of maximum principal stress, he firstly divided rock bursts into three categories, namely the horizontal geostress type, the vertical geostress type and the mixed geostress type; secondly, according to the specific conditions of geostress and features of rock bursts, he divided rock bursts into six sub-categories.

(2) Intensity of rock bursts Nowadays there also exist different opinions on the intensity of rock bursts. In 1981, according to the scale of damage to the project, German Bukhoino divided rock burst intensity into three levels: the minor damage, the moderate damage and the severe damage. In 1974, while studying steep slope tunnels in Norway, Norwegian Russeness B. F. defined four grades from 0 to 3, according to the sound features and the failure characteristics of surrounding rocks. In 1988, Dr. Tan Yian divided rock burst intensity into four levels: weak, medium, strong and extremely strong, according to the damage level, the mechanical and acoustic characteristics and the damage pattern. In 1996, in the *Technical Consultation Report on High Geostress in Erlang Mountain Tunnel* issued by China Railway No. 2 Research Institute, rock burst intensity was divided into three levels: minor, moderate and severe, according to the criterion of σ_θ/R_b. In 1996, based on the sound features, the deformation fracture of rocks, the σ_θ/R_B ratio and the maximum horizontal principal stress $\sigma_{H\max}$, $\sigma_{H\max}/\sigma_V$, the First Highway Design Institute of Ministry of Communications of China divided rock burst intensity into three levels: minor, moderate and severe. Based on previous classifications, the research group on High Geostress and Rock Stability of Erlangshan Tunnel on Sichuan Tibet Highway, headed by Professor Lansheng Wang, defined four levels: slight, medium, strong and severe, based on the damage scale, the sound, movement, form characteristics, the position, the aging feature, the depth and the σ_θ/R_b ratio, etc.. Based on those previous research and combined with domestic engineering experience, Jingjian Zhang and Bingjun Fu (2008) pointed out that no rock burst will occur when $\sigma_c/\sigma_1>14.5$ and a rock burst might occur when $\sigma_c/\sigma_1 \leqslant 14.5$, and they also divided rock burst

intensity into four levels.

(3) Mechanism of rock bursts At present, many scholars at home and abroad have applied various theories to analyze mechanism of rock burst from the aspects of strength, stiffness, stability, energy, fracture, damage and mutation theory, etc. They have also put forward many hypotheses, as well as formed different theoretical criteria, which have had a certain degree of agreement with some practical projects. E. Hoek et al. believed that rockburst was the result of shear failure of the surrounding rocks in high-geostress area. When explaining the cause of borehole collapse, Professor Zoback also believed that the hole wall collapse, which was similar to "rockburst", was just a kind of shear failure. However, Mastin (1984) and Haimson (1972), after conducting a unidirectional compressed physical simulation test on a sandstone slab with a circular hole and reproducing the collapse phenomenon of the hole wall in the laboratory, believed that this phenomenon was caused by the partial failure of the stress concentrated part of the hole wall and was the product of tensile fracture. Professor Shuqing Yang et al., at the diversion tunnel of Tianshengqiao Ⅱ hydropower station, after making physical simulation experiments on some similar materials, summed up two mechanisms for rock fracture and shear, and pointed out that they were the products of two kinds of stress: the fracturing damage belongs to the brittle fracture, and the shear failure is the destruction in the peak strength of geostress. Yi'an Tan (1992) thought that rock burst is an asymptotic failure process, and its formation process follows three stages: splitting into plates, shearing into blocks and ejecting into pieces. "The Research Group on High Geostress and Rock Stability of Erlangshan Tunnel on Sichuan Tibet Highway", led by Professor Lansheng Wang, compared the rock burst effects with the whole process of rock deformation and failure under the condition of three-direction geostress, and concluded that the mechanical mechanism of rock burst can be summarized into three basic forms, namely, the compressive tensile crack, the compressive shear tensile crack and the bending and folding, which can appear in combined forms.

(4) Forecast of rock bursts While lots of researches have been done in the forecast of rock bursts at home and abroad with huge achievements, there still exists some limitations in research and methods, due to the complexity of forecast. The forecast methods of rock bursts in the world can be roughly divided into the theoretical analysis method and the field test method (Li Guo, 2003). The theoretical analysis method has advantages in the developing trend forecast, since it costs low and it can apply the existing data to get a rapid evaluation of the rock burst trend. The field test method is to use necessary instruments to directly monitor or test the rock mass to determine the possibility of a rock burst, or to indicate the approximate time of the rock burst, so as to pull out staff and equipment in time and to ensure safety. The field test methods includes various direct contacts and those geophysical patterns.

(5) Prevention and control of rock bursts In terms of prevention and control of rock bursts, various studies have been conducted at home and abroad. In the past the main measures were as follows: ①to reduce disturbance to surrounding rocks and concentration of geostress. In the section with a high proneness of rock bursts, a short footage driving method shall be adopted as far as possible, since it can lower the explosive amount used for primary blasting, and reduce the disturbance to the surrounding rocks; at the same time, a smooth surface blasting should be applied to smooth the excavation contour and to avoid geostress concentration caused by uneven surface. ②to spay water. To spray water to the new excavation face after blasting, so as to reduce the capacity of rock mass to store strain energy; ③to make immediate support. In order to lessen the geostress of surrounding rocks, immediate and effective support should be provided to the section where rock burst occured or may occur. ④to make advance borehole. In order to release high geostress beforehand, some advance boreholes are drilled in the tunnel face.

In conclusion, although huge achievements have been made in the study of rockburst at home and abroad, there are still some problems yet to be solved, due to the complexity of rockbursts and the diversity of geological environment. These problems include:

Both at home and abroad, the intensity classification of rock burst is usually based on one single or a few indexes, not on comprehensive factors. There are gaps between theory and its applications. For example, in the grading scheme of rock burst intensity, on the rock burst sites, insufficient attention is paid to the macroscopic signs or phenomena which are easy to identify, thus making it difficult for theoretical researchers and on-site technicians (engineering designers, construction and supervision personnel, etc.) to reach consensus in a timely manner, so their views are often neglected on the site. There are also different views about the mechanism of rock bursts, without classical and unified theory consented by all academic communities. Most rock burst theories or criteria do not consider the geostress concentration caused by excavation of caverns (the loosening and fracture of surrounding rocks), or they only take one factor into consideration, thus the results are not systematic and comprehensive, and some assumptions are even lack of theoretical and experimental evidence. The measures for controlling rock bursts, such as injecting water or drilling, do have certain effects to reduce rock burst intensity, especially for those medium and minor rock bursts. However, in high-intensity rockburst areas, due to the intactness of the surrounding rocks, the underdevelopment of cracks, the poor splitting effect of water injection, and the limited release capacity of empty holes and channels, etc., the above-mentioned methods are insufficient to meet engineering needs, so it is urgent to explore more scientific and effective methods.

1.2.2 Current research of geostress pre-relief controlled blasting

For avoiding intensive unloading after excavation, to pre-release the geostress in surrounding rocks before excavation is a better choice. Geostress pre-relief technique is adaptable to various geological conditions, especially suitable to hard rock tunnels and deep buried tunnels. In 1950, this technique was applied in a gold mine in South Africa, and successfully reduced rock bursts, by improving the geostress in rocks of hanging walls. This technique was also applied in lead-zinc mines in India. The research on geostress pre-relief technique in China started at the end of 1980s: Zhaofang Xing introduced it into the field of outburst prevention and put forward an anti-outburst measure of controlling stress-relief blasting in deep holes. Bole et al. (1993a, 1993b) analyzed many successful cases of rock burst prevention by blasting, and established a preliminary mathematical model, but the model had some limitations. Based on Livingston's energy balance theory, Shoufeng Chen et al. (2001) put forward a designing plan of stress-relief controlled blasting in surrounding rocks under high geostress. Shudong Feng (2007), Jianfeng Li et al. (2008) examined the control effect of loose blasting on percussive rock bursts, expounded on the blasting mechanism, and introduced the blasting technique and the parameters of loose stress pre-release. Based on the features of tunnel rock bursts, Jiande Cai et al. (2008) put forward a method of stress-relief blasting, and they, according to numerical simulations, also optimized the stress-relief blasting plan for extended auxiliary shallow holes.

Mazaira, Konicek, etc. found that in the excavation of deep tunnels, when the lithology of the surrounding rock is hard, it is easy to produce high stress concentration in the surrounding rocks of the excavation boundary. As shown by the solid line in Figure 1.1, the hard surrounding rock, which has high strength and complete shape, will accumulate a large amount of elastic strain energy under high geostress. In excavation, it is easy to have dynamic instability (brittle failure), so the rock burst risk is high. After the surrounding rock is loosened by blasting, certain crushing area or fracture area will be produced, where a large number of cracks will replace the original intact rock, thus degrading the mechanical force of the surrounding rock, reducing its modulus, and causing plastic failure. Meanwhile within the range of the blasting, the stress in the surrounding rock is greatly reduced, and the peak geostress is transferred to those deep elastic zones, and large amount of elastic strain energy accumulated in the surrounding rock is released, as is shown by the dotted line in Figure 1.1, and thus the risk of rock bursts is reduced.

In conclusion, some achievements have been made in the research of controlled blasting technique for de-stressing surrounding rocks, but a series of problems still need to be solved:

①The geostress pre-relief technique is now mainly applied in some small section

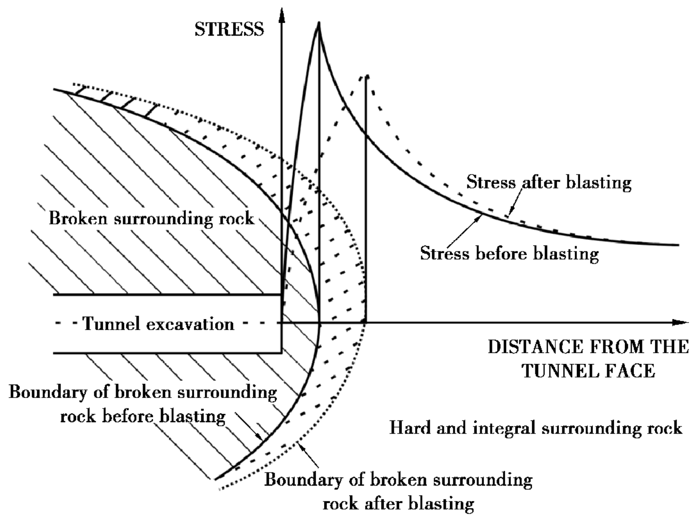

Figure 1.1 The mechanism to control rock burst using de-stress blast

tunnels. However, due to high frequency of rock bursts, it is seldom applied in those deep-buried large-section tunnels with higher geostress and more obvious unloading effect in large scale excavation.

②The interacting mechanism between the advance de-stress blasting and the geostress in surrounding rocks is not clear;

③The related parameters of de-stress controlled blasting, including diameter of charge, distance between holes, etc., need to be verified by field tests to achieve refinement and standardization.

④There is a lack of a more direct, accurate and convenient evaluation mode for the effects of de-stress blasting, owing to the difficulty in testing geostress change in deep surrounding rocks of underground projects. The quantification of geostress change is a main reference for evaluating the rationality of blasting parameters and for the feedback of the controlled pre-release de-stress blasting.

Therefore, it is of great significance to make research on the control method of pre-release de-stress blasting for high-intensity rockburst, including the research on the interacting mechanism of the on-site geosress and the controlled pre-release de-stress blasting, the research on the scope of loose zones, and the research on the criterion of blasting parameters, all of which are carried out to meet the major needs of national construction, to provide solutions to rock burst threats faced by many deep buried tunnels and underground projects.

1. 2. 3 Current research on numerical simulation of the stability of surrounding rocks

To study the stability of tunnel surrounding rocks, researchers mainly apply the experimental research, the theoretical research and the numerical simulation research, among which the numerical simulation research, owing to its convenience and low cost, has been widely used. This research includes the finite element method, the finite difference method, the discrete element method, and so on.

The finite element method, as a method of deep theoretical basis and wide application, can solve the problems that can not be solved by analytical methods in the past. It is also very effective to solve those complex problems with irregular boundary and various structures. Jun Xu et al. (2003) deduced the calculation iteration formula of the elastoplastic random finite element incremental initial stress method. Combining the reliability theory, they proposed a reliable analysis method to test the stability of surrounding rocks, and also pointed out the geostress values of the surrounding rocks and the anchor and shotcrete support structure. Huabing Zhang et al. (2004) used the viscoelastic plastic model to make finite element analysis of the surrounding rocks in loess tunnel, and found that the simulation results are basically consistent with the deformation and failure process in real tunnels. Wenqing Hu et al. (2004) took the construction of the weak surrounding rock section of the Muzhaling Tunnel as an example, and carried out a finite element numerical analysis of the plane elastoplastic surface. Gang Liu et al. (2003) used ANSYS software to calculate the loose zone of surrounding rocks in rectangular tunnels, and obtained the qualitative and quantitative relationship between the loose zone and its influencing factors. Dehai Li et al. (2005) used the corresponding principle of viscoelastic theory to get the theoretical solution to the displacement field of the viscoelastic model in the axisymmetric circular roadways. By way of numerical simulation analysis in ANSYS, he also made comparative analysis between the theoretical analytical solution and the numerical simulation solution.

The finite difference method is mainly used to solve large deformation problems which can not be solved by the finite element method. Based on the principle of finite difference method, FLAC (Fast Lagrangation Analysis of Continuum) numerical analysis method is proposed. Some scholars used the hoek-brown empirical criterion, based on the GSI method, and the strength reduction method of fast Lagrange difference method and others to determine the strength parameters and deformation parameters of the excavated tunnel. This method is most suitable for the discontinuity and large deformation of rocks and soil mass, and the solution speed is faster, but the disadvantages are that it is not easy to solve the boundary problem and the mesh division is more arbitrary. The FLAC 3D uses the program of three-dimensional explicit finite difference, which can simulate the mechanical behaviors of geotechnical materials. In the calculation, the Lagrange algorithm does not form a stiffness matrix and does not need to iteratively satisfy the elastoplastic constitutive relationship. Instead, it only needs to calculate geostress through strain, which greatly saves memory and time, compared with the ordinary implicit solution method. The explicit time approximation method of FLAC 3D general equation of motion is more suitable for progressive failure and instability of rocks and soil, as well as large deformation analysis. ANSYS/ LS-DYNA is a specialized blasting simulation software, which can dynamically simulate the instant mechanical changes in tunnel blasting and other issues, and has been approved by many designers and researching institutions. Therefore, in the study of de-stress blasting, we plan to use ANSYS/ LS-DYNA software to carry out dynamic simulation of controlled de-stress blasting in the hope to explore more clearly and vividly the influence of parameters on the de-stress effect, and to play a guiding role in the simulation analysis of high-intensity de-stress controlled blasting. FLAC 3D can well solve the stress problem of surrounding rocks under the static state. For the design of the tunnel stress-relief scheme, there are few assumptions about the numerical simulation analysis, so it is close to the actual deformation and boundary conditions of the surrounding rocks. Therefore, in this project, ANSYS/ LS-DYNA is used to simulate the instantaneous action of blasting, and then the FLAC 3D software is used to simulate the change process of geostress field under the static action. The technical means of combining the two software data is used to study the application effects of de-stress blasting scheme in high-geostress tunnels.

1.3 Main Research Contents and Technical Route

1.3.1 Research contents

Based on the mechanism of pre-release de-stress controlled blasting for high-intensity rock bursts, combined with field tests, selecting reasonable blasting parameters, including the charge diameters, the distances between holes, etc., the authors of this book apply the numerical simulation method to compare the data before and after blasting, with an aim to analyze the effectiveness of pre-relief de-stress controlled blasting and to verify the rationality of those blasting parameters. The main research contents in this book are as follows:

1) Study on the mechanism of pre-relief de-stress controlled blasting for high-intensity rockbursts

The research of the mechanism of de-stress controlled blasting for high-intensity rockbursts is the premise to determine the drilling and blasting parameters. Through deducing the theoretical