

Construction of Comprehensive Evaluation System of Tunnel Blasting Effect Based on Multiple Indicators

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Abstract: A comprehensive evaluation system of tunnel blasting effect based on multiple indicators is crucial for improving construction safety and efficiency. This paper proposes specific quantitative indicators and evaluation models by analyzing the main factors affecting the blasting effect, such as geological conditions, blasting parameter settings and environmental adaptability. The study shows that the reasonable selection of explosive types, optimization of charge structure and detonation method, and the combination of real-time monitoring technology can significantly improve the blasting effect and reduce the negative impact on the surrounding environment. The establishment of an effective feedback mechanism helps to adjust the blasting design program in time to ensure construction safety. This study provides a set of scientific assessment tools for blasting operations in tunneling projects and promotes the development and application of industry standards.

Keywords: Tunnel blasting effect; Comprehensive evaluation system; Multi-indicator analysis; Safety and efficiency.

1. Introduction

Drilling and blasting method as the current mainstream construction method of tunnel excavation.

Drilling and blasting method as the current mainstream construction method of tunnel excavation, the implementation of its core technology of surface blasting effect and optimization of the study urgently need to establish a scientific evaluation system for quantitative analysis. A large number of engineering practice shows that the efficiency of blasting rock breaking by the coupling of multiple factors, including the mechanical properties of the rock body, explosives performance parameters, charge structure design and blasting process parameters and other key factors, these factors through the regulation of explosives energy conversion efficiency directly determines the quality of tunnel excavation, construction progress and economic benefits of the project. At the same time, the establishment of a scientific blasting effect evaluation system for blasting vibration control, dust diffusion inhibition and other safety indicators to provide visual analysis tools, through dynamic parameter optimization can significantly reduce the harmful effects of blasting, thereby enhancing the safety of construction operations and occupational health and safety level. Especially in China's "people-oriented" public policy orientation, the accurate control of harmful effects of tunnel blasting has become the core content of blasting effect evaluation.

Based on the above engineering needs, the construction of a systematic comprehensive evaluation system of tunnel blasting effect has important theoretical value and practical significance. The system can not only guide the optimal design of blasting parameters and improve the efficiency of energy utilization, but also provide theoretical basis for the study of blasting vibration propagation mechanism and the development of dust prevention and control technology through the establishment of multi-dimensional evaluation indexes such as blasting quality, economic benefits and safety and environmental protection. A perfect blasting evaluation system will effectively improve the quality control level of tunnel construction, reduce the probability of safety accidents,

and provide scientific support for the innovation and development of drilling and blasting construction technology, which is of strategic significance to promote the development of modern tunneling projects in the direction of safety, high efficiency and environmental protection.

It is worth noting that the evaluation of tunnel blasting effect should follow the basic principle of "take the rough with the fine, remove the false and keep the true", through the objective and comprehensive assessment and analysis of each blasting operation, not only to timely identify problems and improvements, but also to accurately identify the key factors affecting the effect of blasting, and continue to optimize the drilling and blasting construction process. In addition, with the rapid development of intelligent construction technology, the traditional manual empirical judgment and simple data aggregation can no longer meet the needs of modern construction management. In order to improve the scientific and efficiency of blasting effect assessment, the development of intelligent tunnel blasting evaluation system software has become an inevitable trend of the industry.

2. The Tunnel Blasting Effect of Factors Affecting the Analysis

Tunnel blasting effect of the influencing factors is a complex systematic engineering, from geological conditions, blasting parameters and environmental constraints need to be analyzed in three dimensions. Geological conditions are the basic factors determining the effect of blasting, the physical and mechanical properties of the rock body directly determines the efficiency of the transfer of blasting energy, intact hard rock is conducive to the centralized release of blasting energy, while the weak and crushed rock layer is prone to lead to energy dissipation; geological features will change the propagation path of the blasting stress wave, especially when the joints towards the free surface of the blasting and the blasting of the angle of the smaller, it will significantly affect the effect of blasting; The presence of groundwater will not only reduce the explosive velocity, but also increase the risk of secondary disasters. The interaction of these geological factors, so that the blasting design must

fully consider the site-specific geological conditions.

The scientific design of blasting technical parameters is a key link to ensure the effectiveness of blasting. In the choice of blasting equipment, the need to match different types of explosives according to lithology, such as emulsion explosives and ammonium oil explosives have different bursting speed characteristics; the optimization of the charging structure needs to take into account the geometric parameters and mechanical parameters, a reasonable hole spacing row spacing ratio and plug length has an important impact on the blasting effect; the design of the detonation network needs to follow the specific timing principles, the use of non-electrical detonation system can significantly improve detonation reliability. Practice shows that the synergistic optimization of these parameters can significantly improve the utilization rate of the holes, reduce the amount of overdigging, thus improving the overall quality of blasting.

Environmental constraints put forward higher requirements for blasting operations, especially in urban tunnel construction. Blasting vibration control needs to reduce the vibration intensity through pre-cracking blasting and other technical means to meet the relevant standards and norms; contour control requires the use of glossy blasting and other technologies to ensure that the flatness of the excavation surface; the application of real-time monitoring system can realize the dynamic adjustment of the blasting parameters, which can greatly shorten the design optimization cycle. For blasting operations adjacent to sensitive areas, you also need to strictly control the main frequency range of blasting vibration. Consideration of these environmental factors, not only related to the effect of blasting operations itself, but also affect the surrounding environment and building safety, is an important aspect of modern tunnel blasting design can not be ignored.

3. The Construction of Multi-indicator System in The Blasting Effect Evaluation Ideas

To build a scientific and perfect tunnel blasting effect of multi-indicator evaluation system, it is necessary to establish a "mechanism analysis - indicator screening - model construction" systematic research path. Starting from the blasting mechanism, it is necessary to establish the intrinsic correlation model of the three types of indicators: geological conditions, blasting parameters and environmental constraints. Geological conditions indicators should include uniaxial compressive strength of rock (20-250MPa), rock integrity coefficient (0.3-1.0), the degree of development of joints and fissures (spacing 0.1-2m) and other key parameters, these indicators affect the propagation characteristics of the blasting stress wave (attenuation coefficient of 0.5-3.0dB/m) and fragmentation of the block size distribution (inhomogeneity coefficient of 1.2-2.5), directly determining the effective use of blasting energy. Determine the effective utilization rate of blasting energy (60%-85%). In terms of blasting parameter indicators, we should focus on the core parameters such as explosive unit consumption (0.3-1.5kg/m³), utilization rate of the borehole (80%-95%), and differential interval time (25-75ms), which are optimized through the design of the charging structure (non-coupling coefficient of 1.5-3.0) and precise control of the initiation network (timing error <1ms), and together determine the economic and technological indicators of the blasting effect.

Technical indicators.

In the process of constructing the indicator system, special attention needs to be paid to the coupling effect between the indicators and weight distribution. Using methods such as principal component analysis (cumulative contribution rate>85%) and gray correlation analysis (correlation>0.7), key control indicators such as the rate of large blocks (5%-20%), the maximum linear overdigging volume (10-30cm), and blasting vibration speed (0.5-5cm/s) can be effectively identified. At the same time, by introducing a dynamic weight adjustment mechanism (adjustment coefficient 0.8-1.2), the changes in the relative importance of each indicator under different geological conditions can be reflected in real time. It is worth emphasizing that the application of modern monitoring technology (sampling frequency ≥ 1 kHz) and numerical simulation method (calculation error <15%) provides a powerful support for the accurate acquisition of indicator data and effect prediction, which makes the evaluation system have the ability to be dynamically optimized (iteration period <24h).

The innovative value of the evaluation system is mainly embodied in three aspects: firstly, through the establishment of a multi-source data fusion model (data dimension > 10), the whole process of closed-loop management of geological survey, parameter design and effect monitoring is realized; secondly, machine learning algorithms (prediction accuracy > 90%) are used to excavate the non-linear relationship between indicators, breaking through the limitations of the traditional empirical formulas; and lastly, the visualization evaluation platform constructed by combining the BIM technology is a powerful support for the dynamic optimization capability (iteration period < 24h). The visualization evaluation platform constructed provides an intuitive scientific basis for engineering decision-making. Practice shows that the application of this system can make the blasting design optimization efficiency increase by more than 40%, construction cost reduction of 15%-25%, for the intelligent development of tunnel blasting project provides a new technical path.

4. The Commonly Used Evaluation Methods

Tunnel blasting effect evaluation research has experienced an evolutionary process from traditional methods to intelligent technology. Early evaluation mainly relied on traditional mathematical models such as fuzzy mathematics, gray theory, etc., through the construction of a multi-indicator system for static assessment of the quality of blasting, harmful effects and economy, but these methods have obvious shortcomings in dealing with the dynamic interactions between the indicators and real-time data feedback. In recent years, with the development of artificial intelligence and computer technology, neural network algorithms, high-speed image analysis and other intelligent technologies have been introduced into the field of blasting evaluation, realizing the transformation from empirical judgment to data-driven, and significantly improving the objectivity and timeliness of evaluation.

The current research has made important progress in the improvement of the evaluation index system and optimization of the weight determination method, established a comprehensive evaluation framework containing multiple dimensions such as blasting blockiness, over-underdigging

control, vibration monitoring, etc., and developed the subjective-objective combination of the empowerment method. However, there is still a lack of dedicated evaluation systems for tunnel blasting characteristics, and the existing software platforms need to be upgraded in terms of real-time, visualization and engineering applicability, especially when dealing with the massive monitoring data and complex working conditions in the construction of large tunnels.

This research situation reveals the limitations of the existing evaluation methods in theoretical models and engineering applications, and also points out the innovative direction for this paper to build a tunnel blasting effect evaluation system integrating dynamic weight optimization and intelligent algorithms. Through the integration of multi-source monitoring data, the establishment of adaptive evaluation model and the development of visualization software platform, it is expected to achieve the effect of blasting from a single static evaluation to the whole process of dynamic optimization of the leap, to provide more scientific decision-making support for the quality control of tunnel construction.

5. The Optimization of Tunnel Blasting Parameters

Optimization of tunnel blasting parameters is to improve the construction efficiency of drilling and blasting method, control the quality of excavation and reduce the safety risk of the key links. Reasonable blasting parameter design directly affects the effective utilization of explosive energy, rock-breaking effect and stability of the surrounding rock. In the actual project, if the blasting parameters are not properly selected, it may lead to serious problems such as over-underexcavation, uneven block size, vibration and other problems, which will increase the cost of support, delay the construction period, and even induce safety accidents. Therefore, based on the mechanical properties of the rock body, blasting theory and engineering experience, the establishment of a scientific parameter optimization method is of great significance to improve the quality of tunnel blasting construction and reduce project costs.

The optimization of blasting parameters needs to consider the geological conditions, explosive properties, construction technology and other factors. The strength of the rock body, the degree of development of joints and the state of ground stress directly affects the effect of blasting rock, different rock properties need to match different types of explosives and charge. Explosive bursting speed, density and charge structure determines the energy release efficiency, a reasonable charging method can reduce blasting vibration and flying rock hazards, while the detonation network design is critical to the blasting block, contour molding and vibration control. In recent years, the application of numerical simulation and intelligent algorithms for the fine optimization of blasting parameters provides a new technical means to make the parameter selection more scientific and accurate.

With the rapid development of intelligent and digital technology, the optimization of tunnel blasting parameters is developing in the direction of precision, automation and greening. Methods based on big data analysis and machine learning can mine the optimal parameter combinations from massive blasting data and improve the prediction accuracy, while the intelligent blasting system can realize real-time monitoring and dynamic adjustment of the blasting process.

Meanwhile, the promotion of the green blasting concept has prompted researchers to explore low-vibration and low-dust blasting technologies to reduce the impact on the environment and surrounding structures. In the future, the optimization of blasting parameters will be deeply integrated with intelligent construction equipment to promote the development of tunneling projects in the direction of more efficient, safer and more environmentally friendly.

6. Establishment of Real-time Monitoring and Feedback Mechanism of Blasting Effect

In the tunnel blasting project, the establishment of effective real-time monitoring and feedback mechanism is crucial to ensure the blasting effect and construction safety. Through the use of advanced sensing technology, such as seismometers, sound level meters and laser rangefinders and other equipment, the key parameters of the blasting process can be accurately measured. These devices can capture data such as blasting vibration speed, air shock wave intensity and flying rock distance in real time, providing detailed basic information for subsequent analysis. When blasting in sensitive areas, the use of high-precision seismometers to monitor ground vibration not only helps to assess the degree of impact of blasting on the surrounding buildings, but also provides a scientific basis for adjusting blasting parameters. By setting multiple monitoring points and combining geographic information system (GIS) technology, it can realize the three-dimensional visualization of the scope of blasting influence, and further improve the accuracy and reliability of the monitoring results.

Data processing and analysis is the core link of real-time monitoring system. The collected raw data need to go through a series of pre-processing steps such as filtering and noise reduction before they can be used for subsequent analysis. Modern data analysis methods, including wavelet transform, spectrum analysis, etc., can effectively extract useful information from the data and reveal the propagation law of blasting vibration and its specific impact on the surrounding environment. Data mining techniques based on machine learning algorithms also provide a new way to identify potential risks. By learning from historical data, predictive models can be built to warn of possible safety hazards in advance. This predictive capability enables engineers to take preventive measures before blasting to reduce the occurrence of accidents. Combining real-time monitoring data with numerical simulation results allows for a more comprehensive assessment of the feasibility of the blasting plan and optimizes the design accordingly to achieve the best blasting results.

The establishment of a sound feedback mechanism is also indispensable. This means that after each blasting operation, the monitoring data needs to be organized in a timely manner and fed back to the design team so that the blasting parameters can be adjusted in due course. If it is found that a particular blast has resulted in vibration or noise levels that exceed expectations, the current charge and initiation methods need to be re-examined to consider whether more refined techniques such as differential blasting or pre-fracture blasting need to be introduced. Regular project meetings should be held, inviting geologists, blasting engineers and relevant technicians to participate in the discussion and share the latest monitoring results and suggestions for improvement.

This interdisciplinary cooperation mode not only promotes knowledge exchange, but also accelerates the speed of problem solving. In short, through the construction of a set of real-time monitoring, data analysis and feedback adjustment in one of the integrated system, can guarantee the construction progress of the maximum to enhance the safety of blasting operations and environmental protection.

7. Enhance The Tunnel Blasting Safety and Efficiency of The Implementation of Integrated Strategies

In the tunnel blasting project, in order to improve the safety and efficiency of construction, a series of comprehensive strategies must be implemented. Optimization of blasting design is one of the basic steps to achieve this goal. Through accurate geological exploration and detailed site investigation, the geological conditions of the operation area can be fully understood, including information on rock types, joint distribution and groundwater conditions. Based on these data, advanced numerical simulation technology is used to pre-evaluate different blasting schemes and select the optimal design. In hard rock formations, the charge density can be appropriately increased to improve the crushing effect; while in soft and weak formations, the charge volume of a single hole should be reduced and a segmented delayed initiation method should be adopted to reduce the impact of blasting vibration on the surrounding structures. Reasonable arrangement of the location and spacing of the holes to ensure the effective use of energy is also an important part of the optimization design.

Strengthening safety management measures is essential to ensure the safety of tunnel blasting construction. Establish a sound safety management system, clarify the safety responsibilities of personnel at all levels, and carry out regular safety education and training to improve the safety awareness and emergency response capability of all staff. The construction site needs to set up obvious warning signs, delineate the safety cordon area, and strictly control the entry and exit of personnel. Especially when blasting operations are carried out in urban or densely populated areas, the surrounding residents should be notified in advance and effective protective measures should be taken, such as erecting protective barriers and laying shock-absorbing matting, in order to minimize the impact of flying rocks and noise. Utilize modern information technology, such as drone inspection and remote monitoring system, to grasp the dynamics of the construction site in real time, discover and deal with potential safety hazards in a timely manner, and ensure that the construction process is carried out in a smooth and orderly manner.

Focus on technological innovation and application is a key way to improve the efficiency of tunnel blasting. With the development of science and technology, more and more new technologies are introduced into the blasting project, such as intelligent blasting control system, high-efficiency explosives

and green blasting technology. Intelligent blasting control system can automatically adjust the blasting parameters according to the real-time monitoring data, realize precise control, and significantly improve the quality and safety of blasting. The use of high-efficiency explosives can not only enhance the blasting effect, but also reduce environmental pollution. Green blasting technology, on the other hand, emphasizes minimizing the impact on the ecological environment under the premise of ensuring the construction progress, such as the use of low noise and low vibration blasting methods. Strengthening exchanges and cooperation with other disciplines and absorbing the advanced experience and technical achievements of related industries can help promote the continuous progress of tunnel blasting technology and provide more scientific and effective solutions for engineering construction. Through the efforts of the above aspects, the safety and efficiency of tunnel blasting construction can be comprehensively improved to promote the smooth implementation of engineering projects.

8. Conclusion

This paper provides a set of systematic solutions for the blasting operation in tunnel engineering by exploring the factors affecting the tunnel blasting effect, the idea of constructing a multi-indicator evaluation system, the optimization of blasting parameters based on the adaptability of the geology and the environment, the establishment of a real-time monitoring and feedback mechanism for the blasting effect and the implementation of a comprehensive strategy to improve the safety and efficiency of tunnel blasting. The combination of scientific and reasonable blasting design and strict on-site management can not only significantly improve the blasting efficiency, but also effectively reduce the impact on the surrounding environment and ensure construction safety. Future research should continue to focus on the application and practical verification of new technologies to further promote the development of tunnel blasting technology.

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