The research results of this article can provide experience for similar frozen rock tunnel construction Research on Drilling and Blasting at the Entrance Section of a Frozen Rock Tunnel and Its Vibration Effects

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Abstract. China ranks as the third-largest country in terms of the distribution area of perennial frozen rock in the world. Perennial frozen rock poses a significant constraint on ground transportation extending to high-altitude or high-latitude frigid regions. This paper takes the blasting construction at the entrance section of a tunnel in a high-altitude cold region as the engineering context. According to the grade of surrounding rock and the size and shape of the tunnel section, reasonable blast hole layout and blasting parameters are designed. Surface measurement points are arranged near the tunnel entrance section to collect and analyze blasting vibration monitoring data, studying the propagation patterns of blasting vibrations. The results indicate that a total explosive amount of 157.5kg is required for a single blasting at the tunnel entrance section. The empirical formula for the propagation and attenuation of blasting vibration velocity in the entrance section of a frozen rock tunnel is: $V=157.2\times(Q^{1/3}/R)^{1.54}$. The research results of this article can provide experience for similar frozen rock tunnel construction.

Keywords: Frozen rock; Tunnel; Blasting; Vibration

1 Introduction

China is the world's third-largest country in terms of the distribution area of perennial frozen rock, which refers to various types of rocks with temperatures consistently below 0°C and containing ice[1, 2]. Perennial frozen rock poses a significant constraint on ground transportation extending to high-altitude or high-latitude frigid regions. Nowadays, the excavation methods for frozen rock are generally divided into crushing method and melting method. The melting method has high costs, huge energy consumption, and is prone to causing an increase in the temperature of the surrounding frozen soil, affecting the environment. There are three types of crushing methods:

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manual excavation, mechanical excavation, and blasting excavation. The blasting method is the most commonly used.

Recent research has seen scholars delve into the excavation and blasting methods for tunnels in cold regions. Liang et al.[3] introduced a novel explosive loading structure known as Composite Non-Coupling Explosive Loading Structure (comprising water or saline water and non-coupled air). They conducted comparative cooling experiments with different loading structures in blasting chambers and studied the damage parameters of specimens under different test conditions. Du et al.[4] addressed the safety and stability concerns in frozen soil construction in high-altitude areas. They achieved this through research on drilling machinery and discussions on the selection of blasting equipment under varying climatic conditions, thus summarizing principles for blasting construction in frozen soil regions.Huang et al.[5] a perspective rooted in tunnel insulation and frost prevention technology. Using finite element software, they analyzed the temperature field in tunnels with four different insulation layer layouts, varying insulation layer thicknesses, and different insulation materials, both in steady-state and transient analyses.Yan et al.[6] focused on studying the freezing expansion force in fractured frozen rock tunnels in cold regions. They established a rational calculation model, utilizing Queshui Mountain Tunnel of Sichuan-Tibet Highway as their project foundation. In-situ tests involving hydraulic pressure gauges, soil pressure boxes, and multi-point platinum resistance temperature sensors were conducted to compare and analyze the results with calculated values.

While there has been significant research both domestically and internationally on related topics, there is still a considerable gap in the study of excavation blasting and its vibration effects at tunnel entrances.

This paper is set against the backdrop of excavation blasting construction at the entrance section of a cold region tunnel in high-altitude terrain. Surface measurement points have been strategically placed near the tunnel entrance to collect and analyze blasting vibration monitoring data. The aim is to investigate the propagation patterns of blasting vibrations and propose sound blasting control techniques.

2 Project overview

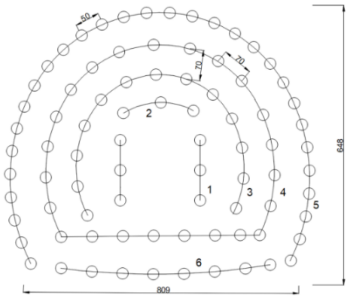
The tunnel in question is situated at an altitude of 4350 m and features a terrain that slopes from south to north. The lowest recorded temperature can plummet to -40°C, and the area experiences seasonal frozen soil conditions. The region is characterized by steep slopes, high altitudes, and low stability, with the tunnel having a cross-sectional area of 43 m^2. The entrance terrain exhibits significant undulations and is generally characterized by a terraced distribution, with slopes ranging from 235° to 255° and an approximate slope angle of 30°. Surface investigations reveal that K0-K0+075 range of the entrance segment is covered by a certain thickness of Quaternary impact gravel and slope accumulative gravel, typically less than 2 m in thickness. The bedrock primarily consists of Jurassic highly weathered and moderately weathered argillaceous conglomerate, which exhibits poor rock mass stability. Taking these factors into account, the rock mass classification for the entrance segment from K0 to K0+045 is determined as Class V, while the range from K0+045 to K0+185 is determined as Class IV. The tunnel entrance is depicted in Fig. 1.

Fig. 1. Tunnel entrance

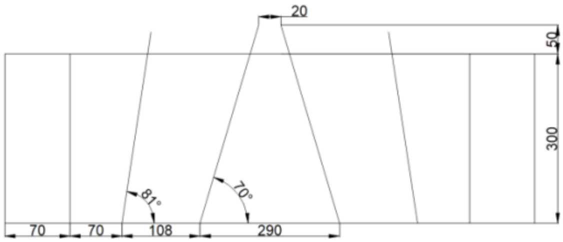
3 Design of excavation blasting for the entrance section of frozen rock tunnel

3.1 Tunnel blasting construction plan and blast hole layout

In the design of excavation and blasting for the tunnel entrance section in frozen rock, several factors are considered, including the classification of surrounding rock into different Classs (II, III, IV, V) based on rock characteristics. The excavation method chosen for the blasting sections within the vibration monitoring range is the full-section method, which is determined in accordance with the specific conditions at the construction site. This method involves a daily advance rate of 3 m, utilizing blast holes with a diam of 42 mm, spaced 50 cm apart, and auxiliary holes spaced at 70 cm intervals. Additionally, undercutting holes are excavated to a depth of 3.5 m to ensure the desired advance rate. An essential aspect of this approach is the precise control of explosive quantities to maintain the integrity of the internal contour surface, thus preventing issues like over-excavation or under-excavation. Fig. 2 shows the arrangement of blast holes.



(a) Working face view



(b)Plan view

Fig. 2. Blast hole arranement diagram (unit: cm)

3.2 Tunnel blasting parameters

In the process of excavating the tunnel working face, a series of precise blasting parameters are implemented to ensure the safety and efficiency of the operation. Initially, manual pneumatic rock drills are used to create blast holes in the rock. Once these holes are prepared, explosive charges are carefully placed within them. To initiate the blasting sequence, digital electronic detonators are employed, allowing for precise control of the detonation process. One key aspect of the blasting approach involves introducing millisecond-delayed detonations. This technique effectively disperses the energy generated during the blast, thereby minimizing the impact of shock waves on the surrounding rock mass. This strategic use of delayed detonations serves to enhance the inherent load-bearing capacity of the surrounding rock. These blasting parameters are illustrated in Table 1.

Table 1. Smooth blasting parameters of tunnel entrance section

Blast hole type	Hole depth (m)	Number of holes	Single hole explosive quantity(Kg)	Total explosive quantity(kg)	Delay time(MS)
Cutting hole	3.5	6	2.1	12.6	0
Auxiliary hole	3.25	3	1.8	5.4	25
	3.25	16	1.8	28.8	50
	3.25	26	1.8	46.8	75
Smooth blasting hole	3	34	1.5	46.8	100
Bottom plate hole	3	9	1.8	16.2	125
Total		94		157.5	

4 Monitoring and analysis of blasting vibration

4.1 Layout of monitoring points

TC-4850 vibration m was selected as the monitoring instrument of choice. To guarantee the accuracy and reliability of the monitoring process, a series of preliminary tests were carried out before the commencement of actual monitoring activities. Additionally, all vibration m underwent a calibration process to ensure their precision and consistency. The positioning of blast vibration monitoring points was done with great care. These monitoring points were strategically located directly above the central axis of the inclined shaft, spanning from the surface coordinates of K0+045 to K0+065. The layout of monitoring points is shown in Fig. 3.

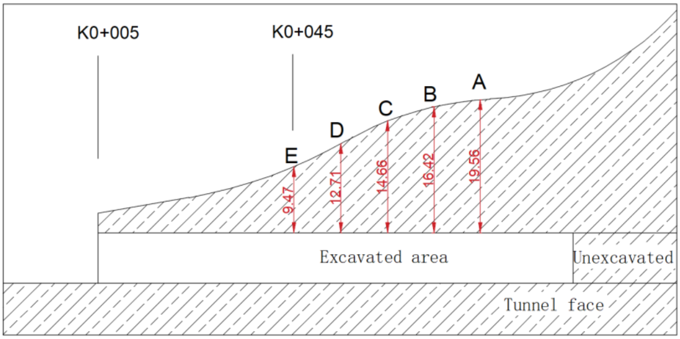


Fig. 3. Schematic diagram of monitoring point layout

4.2 Analysis of monitoring results

Regarding the arrangement of monitoring directions, the X-axis was specifically aligned with the longitudinal axis of the main tunnel, the Y-axis corresponded to the transverse cross-section of the inclined shaft, and the Z-axis represented the vertical direction. Following the collection of vibration data from each of these distinct directions, a vector synthesis approach was employed to consolidate and compute the composite peak vibration data, as documented in Table 2.

Table 2. Blasting vibration velocity record

Monitoring point	Dosage per segment(kg)	Horizontal distance(m)	Vertical distance(m)	Explosive source slant distance(m)	Peak vibration velocity (cm/s)
A	46.8	9	19.56	21.53	11.4
B	46.8	14	16.42	21.58	10.2
C	46.8	19	14.66	24.00	8.5
D	46.8	24	12.71	27.16	8.1
E	46.8	29	9.47	30.51	4.9

In practical engineering endeavors, it is common practice to make use of real-world data obtained directly from the field. These empirical data are subsequently subjected to regression analysis, applying Sadiq Safdari's empirical equation. This analytical process yields essential parameters (*k* and *a*)[7, 8], which then form the basis for the development of related blasting designs and the optimization of blasting parameters. In the context of this paper, the data collected from the aforementioned monitoring points underwent rigorous regression analysis. The outcome of this fitting process is presented in Fig. 4.

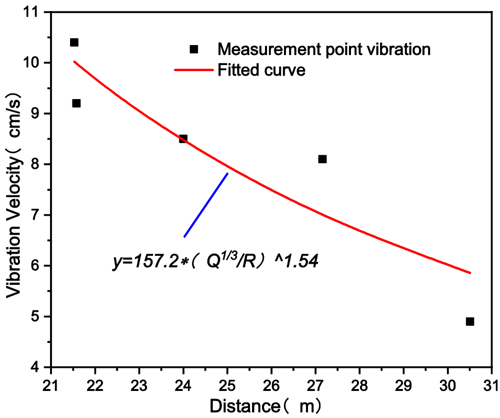


Fig. 4. Fitting process results

The empirical equation for the propagation and attenuation pattern of blasting-induced vibration velocity in the entrance section of a frozen rock tunnel is as follows:

$$V=157.2\times(Q^{1/3}/R)^{1.54} \tag{1}$$

where V is the peak vibration velocity of the particle, in cm/s; Q is the maximum dosage, in kg; and R represents the distance between explosive sources, in m.

5 Discussion

In this article, We take the blasting construction of a tunnel entrance section in a cold region of the plateau as the engineering background，and designed the arrangement of blast holes and blasting parameters. At the same time, we obtained the empirical formula for the propagation and attenuation of blasting vibration velocity in the entrance section of a frozen rock tunnel, which is: $V=157.2\times(Q^{1/3}/R)^{1.54}$ At present, we have rarely seen research on the propagation law of blasting vibration in frozen rock tunnels, and the research direction of this article is very representative[9, 10]. The research results of this article can provide experience for similar frozen rock tunnel construction.

6 Conclusion

(1) It is imperative to give special consideration to the surface vibrations directly above the working face when conducting blasting excavation at the tunnel entrance section. This consideration becomes even more crucial when dealing with steep and varied terrains. Therefore, exercising caution and precision during blasting operations is of paramount importance to prevent potential destabilization issues on the upslope side of the working face.

(2) The initiation of undercutting holes introduces the most intense surface vibrations due to the pronounced confinement effect exerted by the surrounding rock on both sides. Consequently, effective management and control of these vibrations at this stage emerge as critical factors in achieving successful vibration control.

(3) Throughout the blasting and excavation process, the adoption of well-thought-out undercutting structure designs, meticulous control over advance rates and explosive quantities, and the application of millisecond-delayed blasting techniques collectively contribute to a substantial reduction in the impact of blast-induced vibrations and a consequent decrease in the associated risks.

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Reference

1. Zhang Xinhe, Jia Shijie, Zhao Guoqiang. Analysis of Mechanism and Experimental Study on Mechanical Properties of Frozen Rock Blasting in High Cold Regions [J]. Modern Mining, 2022,38 (07): 72-76
2. Sinclair S A, Pham N, Amos R T, et al. Influence of freeze-thaw dynamics on internal geochemical evolution of low sulfide waste rock[J]. applied geochemistry, 2015,61: 160-174.
3. Liang Weimin, Huang Xiaoguang, Chu Huaibao, et al. Experimental Study on Composite Uncoupled Charge Structure of Frozen Soil Tunnel [J] Journal of Railway, 2008 (01): 113-116.
4. Du Haili, Liu Ning, Lin Yamin. Blasting excavation technology in frozen soil [J] Road Construction Machinery and Construction Mechanization, 2015,32 (10): 82-84.
5. Huang Wenhu Analysis and Research on Thermal Insulation Technology of Tunnel in Cold Regions and Its Factors Affecting Frost Heave Force [D] Anhui University of Science and Technology, 2022.
6. Yan Jian, He Chuan, Zhou Zihan, etc. In situ testing of rock water ice forces and frost heave force model for fractured frozen rock tunnels in cold regions [J] Journal of Civil Engineering, 2020,53 (S1): 300-305.
7. Zhang Jitao, Xiao Bing, Wu Shaokang, et al. Experimental Study on the Propagation Law of Tunnel Blasting Vibration [J]. Mining Technology, 2023,23 (05): 99-103.

8. Feng Jukai, Gao Wenwen, Shi Liansong, et al. Research on Excavation Blasting and Vibration Effects of Tunnel Portal Section: 2018 Academic Seminar on Underground Engineering Drilling and Blasting Technology and Safety Management [C], Nanjing, Jiangsu, China, 2018.
9. Paronuzzi P, Bolla A. In-depth field survey of a rockslide detachment surface to recognise the occurrence of gravity-induced cracking[J]. engineering geology, 2022,302.
10. Obenaus-emler R, Falah M, Illikainen M. Assessment of mine tailings as precursors for alkali-activated materials for on-site applications[J]. construction and building materials, 2020,246.