Research on the Selection and Matching Technology of Mechanized Construction Equipment for Plateau Tunnel Drilling and Blasting Method

Chendi Wang [1,a], Xiaoyue Kang [2,b], Kai Xu[2,3,c] *, Youliang Liu [1,d], Xiaolong Ma[1,e], Dongxing Liu [2,f]

[1]Qinghai Communications Construction Management Co.,Ltd., Xining 810008, China
[2]China Merchants Chongqing Communications Technology Research & Design Institute Co., Ltd., Chongqing 400067, China
[3]State Key Laboratory of Hydraulic and Mountain River Engineering Sichuan University, Sichuan Chengdu 610065, China

[a]wangchendi223@163.com, [b]kangxiaoyue@cmhk.com, [c]xukai7@cmhk.com, [d]liuyouliang233@163.com, [e]maxiaolong212@163.com, [f]liudongxing@cmhk.com
*Corresponding author

Abstract. Taking the Shangmajia Plateau Highway Tunnel Project as an example, based on the mechanized supporting construction plan, the research focused on the mechanized supporting advanced geological prediction, excavation, initial support, concrete lining and other processes of the tunnel. Through the comparative analysis of traditional construction technology, it is concluded that the proposed mechanized construction equipment supporting technology has better applicability to the plateau region, the construction efficiency has been greatly improved, which promotes the overall improvement of the level of mechanization of plateau tunnel construction, ensures the construction safety of the operators and the construction environment, and alleviates the tense human resources of plateau tunnel construction. The optimal mechanical supporting plan suitable for the drilling and blasting construction of plateau highway tunnels has been formed, and the construction goals of mechanization, less manpower and intelligence of plateau tunnel construction have been achieved.

Keywords: Tunnel engineering; Mechanized Construction; High-altitude Tunnel

1 Introduction

With the continuous promotion of China's transportation strategy and the start of construction of Sichuan-Tibet Railway[1], China's plateau railroad tunnel construction projects are increasing. Plateau region due to the harsh natural environment, poor geological conditions, short construction period and labor costs and so on, the construction of plateau tunnels will inevitably move towards the direction of mechanization, less

W. Nie et al. (eds.), *Proceedings of the 2024 6th International Conference on Hydraulic, Civil and Construction Engineering (HCCE 2024)*, Atlantis Highlights in Engineering 37,
https://doi.org/10.2991/978-94-6463-726-7_79

manned, intelligent development. To improve the efficiency of tunnel operations, it has become an inevitable trend to propose a targeted mechanized equipment selection and matching plan based on the characteristics of plateau tunnels.

Many domestic and foreign scholars [2-4] have conducted research on this issue. Li et al. [5] proposed a rapid construction method for high-altitude tunnel inclined shafts, which improved tunnel construction efficiency and project quality. Wang [6] proposed a mechanization package for high-altitude, low-oxygen, low-pressure environments and corresponding quality assurance measures. Fu et al [7] analyzed the Gan-Qing tunnel under various complex geological environments and proposed tunnel design schemes and mechanized construction schemes applicable to high-altitude areas. Zhao et al [8] put forward corresponding countermeasure suggestions for the mechanization support and rapid construction problems in the tunnel construction of Sichuan-Tibet Railway. Hao [9], Zhang [10] proposed for the Sichuan-Tibet Railway drilling and blasting method of construction mechanization equipment package. Wang et al [11] combined with the domestic tunnel mechanization supporting construction cases, put forward a set of suitable for the construction of the Sichuan-Tibet Railway tunnel mechanization supporting program.

At present, there have been many studies on the mechanized supporting schemes for plateau tunnel construction. However, most of the studies are still focused on the comparative analysis of the applicability of mechanical supporting schemes, and there are few studies on the supporting equipment for highly mechanized, less-manned, and intelligent construction of plateau tunnels. Therefore, this paper takes the Shangmajia Tunnel in the Qinghai-Tibet Plateau as the engineering background to study the selection and supporting technology of mechanized construction equipment for plateau tunnel drilling and blasting.

2 Project Overview

Shangmajia Tunnel is in the transition zone of Qinghai-Tibet Plateau and Loess Plateau in the east of Qinghai, the east end of Qilian Mountain tributary Laji Mountain, the topography and geomorphology of the skeleton is mainly controlled by the north-west tectonics. The altitude is more than 3km, the tunnel inlet is located in the east side of the foothill slope of Shangmajia Village, and the outlet is in the left bank of the Yellow River in the middle and lower part of the slope side. The length of the left and right tunnel is 2062m and 2074m respectively, the longitudinal plane is single slope, the inlet adopts the end-wall type door, and the outlet adopts the end-wall type door. Inside the tunnel, there are 2 vehicular cross passages and 6 pedestrian cross passages.

3 Tunnel Mechanization Supporting Scheme

3.1 Mechanical Matching Principles

(1) The principle of advancement and applicability. Conventional environment of tunnel drilling and blasting construction mechanization supporting research and applica-

tion has matured. However, for high-altitude environment mechanization of construction still has problems, should be combined with mature experience to adopt a strong applicability of mechanized equipment

(2) Selection of machinery with a high degree of synergy. Ensure that the construction process is carried out in an orderly manner to improve construction efficiency, to achieve the goal of "fast construction, machine for man".

3.2 "9+N" Tunnel Drilling and Blasting Mechanized Construction Technology

According to the setup principle of plateau tunnel mechanization supporting construction plan, at the same time for the special plateau environment of pressure, low temperature and lack of oxygen in Shangmajia Tunnel, drawing on the experience of selecting mechanization equipment for plain tunnel. Since traditional diesel will produce a lot of exhaust gas, which is not conducive to tunnel operation, the "9+N" tunnel drilling and blasting electric mechanization equipment construction technology is adopted for Shangmajia tunnel, and the whole process is fully mechanized construction for tunnel excavation. The specific mechanization scheme is shown in Table 1, and some of the mechanical equipment is shown in Fig. 1.

Table 1. Tunnel drilling and blasting method of mechanization equipment and its function

Assignment name	Device name	Key features	Quantities
Advanced geological forecast	Multi-function geological drilling rig	Determination of the level and stability of the surrounding rock at the palm face, intelligent forecasting analysis	1 unit
Excavation operation	Computerized three-arm rock drill	3D profile scanning, intelligent positioning, automatic drilling, anchor construction, automatic generation of rock drilling logs	2unit
	Excavator		2 unit
	Loader	Slag removal, slag transport	1 unit
	Dump truck		1 unit
	Tunnel dusting machine	Dust reduction and auxiliary maintenance in the tunnel	1 unit
Support operation	Arch anchor installation trolley	Arch installation, anchor rod and anchor net installation	1 unit
	Multifunctional flat lift trolley	Auxiliary charging, auxiliary measurement, vault quality inspection	1 unit
	Concrete wet spray truck	Initial support and palm face closure and other wet spraying concrete work, remote control spraying	2 unit

Concrete lining operations	Self-propelled hydraulic inverted arch trestle	Inverted arch formwork, automatic material distribution, automatic vibration leveling, water stop fixture	1 unit
	Waterproofing board laying trolley	Automatic walking, automatic welding, electromagnetic welding machine, steel bar installation, hot melt gasket, laser positioning device	1 unit
	Secondary lining trolley	Automatic filling system, information integration transmission system, soft lap technology	1 unit
	Automatic spray maintenance trolley	High-pressure automatic spraying, automatic reverse travel	1 unit
	Tunnel milling machine	Chiseling of joint surface	1 unit
	Cable trench trolley	Closed box structure, cart positioning and fixing	1 unit

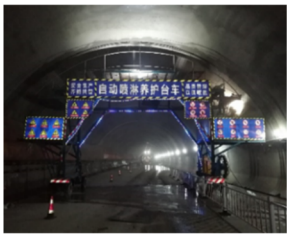
(a)Multi-function geological drilling rig

(b) Computerized three-arm rock drill

(c) Concrete wet spray truck

(d) Multifunctional flat lift trolley

(e)Self-propelled hydraulic inverted arch trestle



(f)Automatic spray maintenance trolley

Fig. 1. Part of the equipment diagram

3.3 Mechanical Suitability Analysis

Throughout the tunnel boring process, the main mechanical equipment involves rock drilling cart, wet spraying cart, arch anchor installation cart and automatic spraying

maintenance cart. Due to the altitude, oxygen concentration and air pressure affecting the internal combustion engine, heat dissipation performance and air pressure of mechanical equipment, the heat dissipation system of wet spraying carts and rock drilling carts traditionally used in plateau tunnels will be affected. The suitability of the current commonly used mechanized equipment is evaluated.

Evaluation of the Suitability of Rock Drilling Dollies. The excavation operation line is a mechanically configured operation line represented by rock drills and pneumatic rock drills. Combined with the current use of machinery and equipment, pneumatic rock drill is mainly based on YT28 wind gun, through the simple excavation platform and external air compressor with the construction work, in the high-altitude areas of operational inefficiency. Computerized rock drill dolly drive system adopts electric power system, which is not affected by the altitude, the mechanical automation degree of the excavation operation is higher, and at the same time, the computerized control improves the precision of the excavation, reduces the amount of explosives, and at the same time, well controls the overrun of the excavation.The comparison between the fully computerized rock drilling rig and the hydraulic rock drilling rig is shown in Table 2.

Table 2. Comparison of fully computerized rock drills and hydraulic rock drills

Comparison project	Drill control	Control of over- and under-cutting
Hydraulic rock drill dolly	Manual measurement, manual point placement, manual operation of the trolley to the point to find holes	Manual operation of the drill arm to the hole, over and under excavation control is difficult
Computerized rock drill dolly	The excavation section layout plan including the position and angle of each hole, the number of holes drilled by each arm, the sequence and direction of movement are all carried out automatically by the on-board computer in accordance with the pre-optimized plan of the office; the positioning and opening of all holes and the entire drilling cycle of the drilling wells are completely automated by the computer.	Optimized drilling design and precise fast drilling can effectively control over-under-excavation, reduce concrete lining and secondary excavation, while the flat section shape reduces the consumption of explosives and spray-anchor support, which is ultimately reflected in the shortening of the construction period and the reduction of overall costs

Applicability Evaluation of Wet Spray Truck for Concrete. The traditional wet spraying machine has a small operation radius and needs to move frequently during the process of spraying, which is more difficult for the construction environment with low oxygen in high altitude areas. Concrete wet spraying cart is more flexible than the traditional spraying machinery and covers a large area, suitable for spraying height of 17.5m, width of 31.4m range of large tunnels; Meanwhile, as shown in Table 3, the

operation time of the concrete wet spraying truck is one-third of that of manual spraying of concrete; reduces the loss of sprayed concrete materials, more material saving.

Table 3. Wet blast truck ergonomics schedule

Process name	Conventional wet spraying consumption time(min)	Consumption time of integrated wet spraying cart (min)	Consumption time of 2 integrated wet spraying dollies (min)
work preparation	50	25	35
Normal operation	366	120	60
Platform transfer	30		
Total	446	145	95

Evaluation of the Applicability of the Arch Frame Anchor Installation Cart. As shown in Table 4, The use of arch anchor trolleys for arch installation solves the problem of the traditional manual arch installation process, where workers move the arch to the designed position by carrying it on their shoulders, with a low chance of one-time success, low quality, long installation time, and low efficiency. In addition, workers perform heavy physical labor in a high-altitude, low-oxygen environment, which is prone to safety accidents. The use of arch trolleys for installation and adjustment is extremely convenient and quick, and only 2 people are required to operate the platform. On the premise of reducing the number of personnel, the labor intensity of workers is greatly reduced, and the speed is fast, the efficiency is high, the safety is high, and the installation is accurate.

Table 4. Comparison between arch anchor installation trolley and manual operation

Operating method	Number of people	Time	Security	Remark
Arch anchor installation trolley	8	3h	Good	4 arch frames
Manual work	10	2.5h	poor	

4 Application Effect Analysis

In the construction process, the mechanized supporting construction of personnel, equipment, safety, quality, environmental protection, economy, applicability and other aspects of the process of recording, comparative analysis of highly mechanized supporting construction and ordinary drilling and blasting construction in the construction efficiency, construction quality, construction safety and environmental protection differences.

4.1 Construction Efficiency Analysis

After the adoption of highly mechanized construction, the construction effi-ciency has been greatly improved. As can be seen from the comparison in Fig 2, due to the use of two three-arm drilling RIGS to work together, the operation time is reduced by 21% compared to manual work. The use of arch bolt mounting trolley and multi-functional flat lifting trolley in the arch frame installation not only ensures the construction safety of the operators, but also increases the construction efficiency by 29%. On the other hand, from the data in Table 5, especially in the case of shotcrete, the highly mechanized equipment is better coordinated, reducing the construction time by 56%. Compared with manual drilling and blasting construction, the total time of single cycle construction is reduced by 225min.

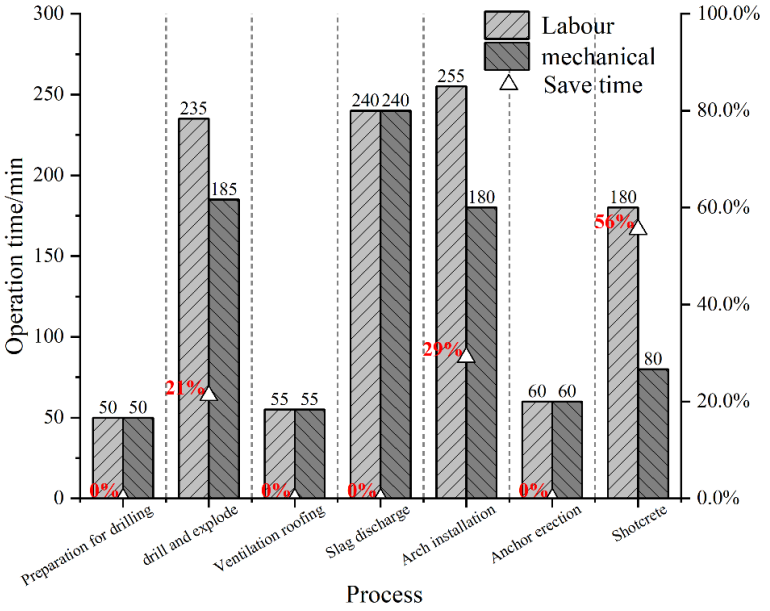


Fig. 2. Comparison of single-cycle operation time between manual drilling and blasting method and mechanical drilling and blasting method.

Table 5. Comparison of single cycle operation time of different projects.

Construction technology	Single cycle time of each project/h			
	Current project	Literature 12	Literature 13	Literature 14
Fully mechanized	14.16	9.83	9.68	7.25
Traditional crafts	17	10.58	11.77	10.75

Through this plateau tunnel project and literature[12], literature[13], literature[14] in the plains tunnel blasting method of single-cycle operation comparison can be seen: plateau tunnel in the use of mechanized construction, compared with the plains tunnel mecha-

nized time-consuming there is still a large gap. This also reflects that due to the influence of the construction environment such as low pressure, low temperature, and low oxygen in the plateau area, the efficiency of mechanized construction has declined. At the same time through the traditional process in the plateau region and the plains of the comparison can be seen, the applicability of traditional technology in the plateau region is poor, after the implementation of a high degree of mechanization compared to the traditional process efficiency increased by 16.7%, reflecting the implementation of the necessity of mechanization of construction in the plateau region.

As shown in Fig 3, In terms of personnel allocation comparison, manual drilling and blasting method consumes a lot of human resources in blasting, bolting and concrete spraying. After the adoption of mechanized supporting technology, the use of three-arm drilling platform(As shown in Fig 4), arch anchor installation platform, concrete spray protection platform and other mechanical construction, the personnel allocation has been greatly reduced, especially in the excavation and shotcrete links decreased by 45% and 75% respectively. It saves a lot of human resources and realizes the mechanization and less human construction of plateau tunnel.

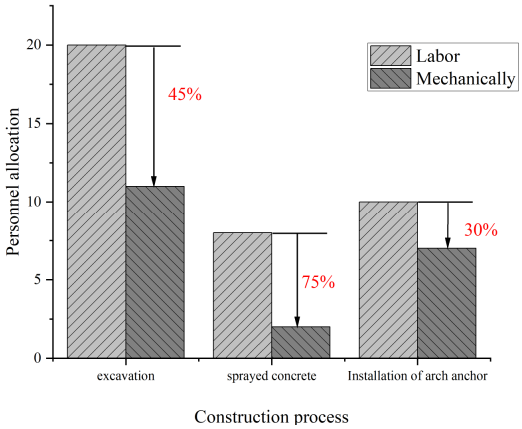


Fig. 3. Comparison of manual vs. mechanized staffing.

Fig. 4. Simultaneous drilling by two three-arm rock drills.

4.2 Construction Quality Analysis

Plateau tunnels have high requirements for construction quality due to their geographical location and the particularity of the construction environment. Compared with traditional construction methods, mechanized supporting construction can more effectively control construction technical specifications and quality standards and reduce human factors. The fully computerized three-arm rock drilling trolley used in the excavation stage can effectively control the tunnel excavation profile through computer control, reduce over-excavation and under-excavation, and have higher construction accuracy, which provides a guarantee for the subsequent initial support and secondary lining construction. At the same time, it avoids the deviation of the steel arch installation due to under-excavation, which greatly improves the construction quality; the wet spraying manipulator can better avoid the occurrence of primary support voids and ensure the safety of primary lining construction; the chute-type material distribution system equipped with the secondary lining trolley realizes the visualization and intelligent window-by-window layered pouring of the lining. At the same time, the automatic spraying maintenance trolley performs intelligent maintenance on it, avoiding problems such as concrete segregation, aggregate accumulation, herringbone slope cold joints, insufficient thickness and voiding of the tunnel arch lining, and improving the construction quality.

4.3 Security Analysis

Adopting mechanized supporting technology for construction improves the degree of mechanization and reduces the safety problems caused by the lack of oxygen and the geological environment of the tunnel. When the rock drilling cart is used for the construction work, the operator is in the hole section far away from the palm face, which effectively avoids the safety hazards such as rockfalls and landslides that occur when the surrounding rock of the palm face is unstable. At the same time, the wet spraying cart is used, and the concrete is transported by tanker trucks after centralized mixing in the mixing station, and sprayed by wet spraying machine. This method reduces the dust content, significantly improves the construction environment of plateau tunnels, greatly improves the working efficiency, reduces the working time of workers in the tunnel, and thus reduces the occurrence of occupational diseases and plateau reaction of workers. Tunnel boring the whole process of mechanical operation than the traditional manual operation, personnel ratio reduced by 47%, construction efficiency increased by 19%. The improvement of mech-anization greatly reduces the staffing, which is of great significance for the improvement of unmanned level for the special construction environment in high altitude area.

4.4 Analysis of Environmental Benefits

In the artificial drilling and blasting drilling, due to the number of artificial air drills, will produce a lot of noise and discharge many wet foggy water vapors, combined with the tunnel smoke and dust, inhaled by the human body, long-term in the environment

of the high-intensity work, the construction workers caused serious harm to the body. After adopting mechanized construction, rock drilling cart combined with tunnel dust removal equipment, the noise generated is smaller than manual drilling and blasting, and the wastewater generated can be recycled after treatment in the sedimentation tank, which improves the utilization rate of water resources. It protects the ecological environment and realizes the coordinated development of engineering construction and environmental protection.

5 Optimization Suggestions for Key Process Equipment Configuration

Throughout the whole process of tunnel boring, by its time-consuming in the excavation drilling and blasting is the largest, the construction staff configuration is the largest, so in the mechanical selection should be considered. A high degree of mechanization, intelligent construction processes should be used to improve construction efficiency, reduce staff ratios, and alleviate the problem of tight human resources in plateau tunnel construction. At the same time, to ensure the safety risks brought to operators by the decrease in oxygen content in the tunnel in plateau areas during tunneling, more electric drives should be used instead of traditional internal combustion engine-driven machinery to reduce oxygen consumption, strengthen ventilation in the tunnel and intelligent monitoring of oxygen content to ensure the safety of operators.

At the same time, in view of the harsh construction environment of low pressure, low temperature, and low oxygen in plateau areas, the coordination of mechanical equipment should be improved, and the research on intelligent construction equipment should be strengthened. For example, high-performance fans and large-diameter air ducts with low air leakage rate should be used to ensure ventilation quality, and the research and development and applicability tests of advanced horizontal drilling rigs, mixed explosive machines, dust removal and dust reduction equipment, container slag discharge systems, and main tunnel belt transportation systems should be strengthened, and the research and development of intelligent construction equipment and technology for "unmanned and less-manned" tunnels should be strengthened.

6 Conclusions

Based on the Shangmajia Plateau Tunnel Project, this paper studies the selection and matching technology of mechanized construction equipment for tunnel drilling and blasting in view of the low oxygen, high altitude construction environment and complex engineering geology faced by plateau tunnel construction, and draws the following conclusions:

(1) Based on the traditional empirical selection method, the "9+N" tunnel drilling and blasting method full-process electric mechanized equipment construction technology suitable for plateau tunnels is proposed, and the applicability of its mechanical equipment in plateau areas is discussed and analyzed.

(2) Compared with traditional construction methods, the full-process mechanized construction supporting technology proposed in this paper is discussed and analyzed from the aspects of construction efficiency, construction quality, safety, etc. This technology can achieve better application effects in plateau tunnel construction. At the same time, it improves the efficiency and mechanization degree of mechanical equipment in plateau areas, and realizes the construction goals of mechanization, less manpower and intelligence of plateau tunnel construction.

Acknowledgment

Qinghai provincial science and technology plan project (2023-SF-127), Transportation science and technology project of Zhejiang Provincial Department (2023002), major transportation construction engineering research project of Zhejiang Provincial Transportation Department (2023-GCKY-08) and Guangdong provincial science and technology plan project (2021B1111610002).

References

1. Tian Y X, Zhang X Y,(2018)2500 billion yuan to fully start the planning and construction of the Si-chuan-Tibet Railway [J]. Tunnel Construction, 38(10):1611-1611. https://qikan.cqvip.com/Qikan/Article/Detail?id=7000878192.
2. Liu C Y. (2012)Study of Rapid Construction Technique for Long and Large Tunnel in Plateau[D]. Beijing. Beijing Jiaotong University, https://cdmd.cnki.com.cn/Article/CDMD-10004-1012318755.htm.
3. Xing B, Feng H H. (2021)Suggestions and considerations on equipment selection for constructing Sichuan-Tibet railway tunnels at high altitudes[J]. Tunnel Construction, 41(10): 1644-1653. htpp://doi.org/10.3973/j.issn.2096-4498.2021.10.003.
4. Li R F, Zhang X S, Yang X C, et al. (2023) Full-process Mechanized Con-struction Technology and Comprehensive Evaluation Analysis of Long and Large Tunnels[J]. Engineering and Technological Research, 8(2):213-215. htpp://doi.org/10.19537/j.cnki.2096-2789.2023.02. 068.
5. Li Z J, Yu J B, Wang J G, et al. (2024)Mechanized matching and fast con-struction technology for inclined shafts in high-altitude railway tun-nels[J]. Tunnel Construction, 44(3): 576. htpp://doi.org/10. 3973 /j.issn. 2096-4498. 2024. 03. 015.
6. Wang L X. (2023)Study on the Construction Equipment Configuration Scheme for Tunnelling under High Altitude, Low Oxy- gen Content and Low Atmospheric Pressure Conditions[J].Modern Tunnelling Technology, 60(3):259-265. htpp://doi.org/10.13807/j.cnki.mtt.2023.03.028.
7. Fu Y P, He Y W ,Yang M G, et al.(2021) Design and Engineering Countermeasure of Ganqing Tunnel on Xi'ning-Chengdu Railway. [J].Railway Standard Design, 67(02):109-117.htpp://doi.org/10.13238/j.issn.1004-2954.202110180005.
8. Zhao Y, Shi S S , Tian S M, et al.(2021) Technical difficulties and countermeasure suggestions in tunnel construction of Ya'an-Linzhi section of Si-chuan-Tibet railway[J]. Tunnel Construction, 41(7): 1079-1090. htpp://doi.org/10. 3973 /j.issn. 2096-4498. 2021. 07. 001.

9. Zhang X D. (2019)Preliminary Study on Selection of Mechanized Equipment for Drilling and Blasting Construction of Sichuan-Tibet Railway Tunnel [J]. Tunnel Construction,39(S1):420-432. htpp://doi.org/10. 3973 /j. issn. 2096-4498. 2019. S1. 057.
10. Hao J M. (2020)Research on Mechanized Supporting Rapid Construction by Drilling and Blasting method in New-built Sichuan-Tibet Railway Tunnel [J]. Railway Construction Technology, (03):26-30+48. htpp://doi.org/10.3969/j.issn.1009-5439.2020.03.006.
11. Wang F Y, Zhou K G, Zhou L J. (2020)Study on Adaptability of Mechanized Matching Construction of Sichuan-Tibet Railway Tunnel[J]. Modern Tunnelling Technology, 57(S1):57-62. htpp://doi.org/10.13807/j.cnki.mtt.2020.S1.008.
12. Li Z, Liu K, Shan Z Y. (2023)Analysis of mechanized supporting construction technology for all processes of highway tunnels[J]. Hunan Communication Science and Technology, 49(02): 146-150. htpp://doi.org/10.3969/j.issn.1008-844X.2023.02.027.
13. Liu Y J.(2022) Study on mechanized supporting technology for rapid construction of long highway tunnel [D]. Anhui University of Science and Technology, htpp://doi.org/10.26918/d.cnki.ghngc.2022.000166.
14. Li W L, Jiang Z Q. (2021)Research on Machinery Matching Design and Process Standardization Control in Tunnelling by Drilling and Blasting Method [J]. Modern Tunnelling Technology, 58(06): 210-217. htpp://doi.org/10.13807/j.cnki.mtt.2021.06.025.