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Study on Improvement of High Gas Tunnel Control System

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ABSTRACT
Based on an in-depth investigation of a high-gas tunnel project, this paper explores safety, technical, and management challenges in such construction and proposes corresponding countermeasures. Through comprehensive analysis using field inspections, report reviews, expert discussions, literature review, and questionnaire surveys, the study identifies critical issues including lax safety protocols, inadequate technical support, and incomplete management systems in current high-gas tunnel projects. To address these problems, the paper proposes a series of improvement measures: enhancing safety training, optimizing ventilation systems, strengthening explosion-proof management of electromechanical equipment, upgrading gas monitoring systems, and establishing robust management frameworks. The implementation of these measures will effectively improve the safety and quality of high-gas tunnel construction, providing valuable references for China's highway development and tunnel engineering projects.

KEYWORDS
High gas tunnel; Safety management system; Explosion-proof technology; Gas monitoring

1 Introduction

1.1 Research background

With the deepening implementation of the "Transportation Powerhouse" strategy and the ongoing advancement of the Western Development Strategy, tunnel engineering will continue to play an increasingly significant role in transportation infrastructure development. Notably, when tunnel projects inevitably encounter coal-bearing strata or gas-rich zones during construction, they face more complex technical challenges and safety risks[1]. Gas tunnel construction is characterized by its inherent concealment, high-risk nature, and suddenness. Accidents occurring in such environments often result in severe casualties and substantial property losses.

1.2 Research significance

The safety of high-gas tunnel construction has become one of the key bottlenecks constraining China's tunnel engineering development. Enhancing construction technologies and improving management control systems for high-gas tunnels hold significant theoretical and practical importance. Theoretically, this study systematically identifies critical technical nodes and management priorities in high-gas tunnel construction, establishing a more comprehensive safety prevention framework. Practically, the research findings directly guide tunnel construction practices in high-gas environments, reduce accident rates, and provide actionable risk management solutions for tunnels under similar geological conditions.

1.3 Overview of research subjects

This study focuses on a high-gas tunnel in Menyuan County, Qinghai Province. The construction of this tunnel involves crossing multiple geological hazard zones, including coal-bearing strata, fault structures, and water-rich weak surrounding rock. It also faces the dual threat of high-concentration methane and hydrogen sulfide gas, making it one of China's rare ultra-high-risk tunnel projects. Drawing from field engineering practices, this paper systematically analyzes the safety management system and technical countermeasures implemented during the tunnel construction process, aiming to provide replicable risk control solutions for similar geological conditions in tunnel engineering.

1.4 Research methods and framework

This study adopted a combination of various methods to ensure the comprehensiveness and reliability of the results.

Literature research method: systematically review the domestic and foreign high gas tunnel construction technology and safety management related literature, understand the research status and development trend.

Field research method: obtain first-hand data and data through field survey, equipment inspection, gas detection and other methods.

Expert interview method: in-depth communication with project managers, technicians, front-line workers and industry experts to understand practical problems.

Questionnaire survey method: Design a structured questionnaire to quantify the safety awareness and operation specifications of construction personnel.

Case analysis method: combine the typical high gas tunnel engineering cases at home and abroad for comparative analysis and experience reference.

2 Research ideas

This study adopts the research ideas of "problem orientation, system thinking and multi-dimensional analysis", starts from the actual construction of high gas tunnels, finds out problems through comprehensive investigation, deeply analyzes the causes of problems, systematically proposes solutions, and finally forms a replicable and scalable safety control system for high gas tunnel construction

2.1 Evaluation of the soundness of the construction management system

In view of the high risk of high gas tunnel construction, it is very important to establish a sound safety management system [2]. This study evaluates from the following aspects:

(1) Safety management organization: evaluate whether a special gas safety management organization structure has been established, whether full-time safety management personnel are equipped, and whether the responsibilities and authority of each post are clear.

(2) The evaluation found that although the project has set up a safety management department, there is insufficient full-time gas safety management personnel, and some positions have overlapping and ambiguous responsibilities.

(3) Safety management system: Check whether the safety control mechanism covering the whole construction process has been formulated, including special emergency plans, standardized operation procedures and post operation specifications and other technical management documents.

The survey found that the actual number of full-time gas safety managers is only 60% of the demand, and 30% of the personnel are not professionally trained.

2.2 Evaluation of the perfection of the safety production control system

The construction of high gas tunnels requires the establishment of a special safety production control system. This study focuses on the evaluation of:

(1) Establishment of special management agencies: Check whether special management agencies such as gas monitoring group, ventilation management group, cave entry management group, construction blasting management group and emergency rescue group have been established.

The current situation is that some special agencies are missing, the existing agencies are understaffed and the operation efficiency is low.

(2) Implementation of safety technical measures: Assess whether detailed

safety technical measures have been formulated and strictly implemented.

It is found that there is a phenomenon of "emphasizing formulation over implementation" in technical measures, and the on-site implementation rate is only about 65%.

(3) Performance of the supervision unit: Check whether the management personnel and responsibilities of the supervision unit have been implemented, and whether the construction process is monitored.

The supervision unit has the problems of large personnel mobility, low professional quality and insufficient supervision.

2.3 Assessment of sufficient technical support force

The construction of high gas tunnel needs strong technical support. This study evaluates from the following aspects:

(1) Reasonable project organization structure: evaluate whether the project organization structure design is scientific and whether the responsibilities of each position are clear.

The current organizational structure has problems such as overlapping functions and unclear rights and responsibilities, which affect the decision-making efficiency.

(2) Effectiveness of the special gas management team: Check the staffing and professional competence of the special gas management team.

The professional composition of the team is not complete, and there is a lack of key professionals such as geology and ventilation.

Scientific construction organization design: evaluate the scientificity and feasibility of construction organization design and special safety construction plan.

Some schemes are copied, and they are not closely combined with the actual situation on site.

(3) Sufficiency of technical briefing: Check whether the workers have been fully briefed on gas tunnel construction technology and safety.

The handover workflow is formal, the workers' mastery degree is insufficient, and the qualified rate of random inspection is only 58%.

(4) Completeness of equipment: check whether the mechanical equipment, ventilation equipment, blasting equipment, power equipment, labor protection supplies, emergency supplies and monitoring instruments meet the construction requirements.

The equipment allocation rate is about 85%, but the maintenance is not timely, and the integrity rate is only 72%.

Through the above comprehensive evaluation, the main problems in the construction of high gas tunnels are systematically sorted out, and a clear direction for subsequent improvement is provided

3 Analysis of existing problems in high gas tunnel construction

3.1 Safety management issues

3.1.1 Weak safety awareness and management leakage

The investigation found that there are widespread problems of weak safety awareness and insufficient risk prevention on the construction site, which are embodied as follows:

Safety education and training are not in place: the training time is insufficient, the content is not targeted, and the form is single; the training content is more theoretical than practical, and it is not closely combined with the characteristics of high gas tunnel construction; the training form is mainly centralized teaching, and there is no interaction and experience.

The concept of "safety first" has not been firmly established: the questionnaire survey shows that some construction personnel agree with the view that "safety is more important than progress"; about 40% of management personnel tend to protect progress when progress and safety conflict. This ideological deviation directly leads to the discounting of the implementation of safety measures.

The policy of "prevention first" is not implemented effectively [3]: On-site observation found that preventive measures are insufficient and mostly passive. For example, gas detection is mainly based on scheduled detection, without continuous monitoring; ventilation system adjustment lags behind, and cannot be adjusted in real time according to the change of gas concentration.

Safety responsibility attenuation layer by layer: Although the production safety responsibility system has been established, there is a phenomenon of "hot at the top, moderate at the middle and cold at the bottom". The senior management attaches importance to it, but the middle management does not implement it effectively, and the grass-roots level is even perfunctory. The safety pressure has not been effectively transmitted to the operation surface.

3.1.2 The safety production control system is not perfect

The current safety management control system has systematic defects:

Simplification of preventive measures: Existing preventive measures are mostly based on principles such as "prohibition" and "must", without specific operational guidelines and technical standards. For example, gas over-limit treatment only stipulates "stop work and evacuate personnel", but does not specify details such as evacuation route, assembly place and subsequent disposal.

The technical prevention measures are insufficient: excessive reliance on "human defense" and lack of technical prevention and control means. For example, the automatic alarm linkage system for gas concentration is not established, and manual detection is still relied on; the automation degree of ventilation system is low, and the adjustment is not timely.

The "civil defense" organization is loose: the personnel access management is not strict, some special workers are working without certificates; the operation process supervision is not effective, violations of operation occur from time to time; the shift handover system is not strictly implemented, there are gaps in management.

The emergency management system is not perfect: the emergency plan is not operable, and no special disposal plan is formulated for different accident scenarios; the frequency of emergency drills is insufficient and the effect is poor; the emergency supplies are not complete, and some emergency equipment is expired and ineffective.

3.2 Construction technical problems

Construction ventilation system problems.

There are many problems in the operation of ventilation system, which seriously affect gas dilution and discharge:

Poor maintenance of ventilation facilities: the damage rate of wind tubes along the road reaches 15%, and the air leakage is serious; the fan is not running at full power, and the replacement of wind tubes damaged after blasting in the face is not timely, and the average repair time is more than 4 hours.

The system design is not reasonable: the ventilation system is not dynamically adjusted with the construction progress, and there are problems such as sharp bend and compression in the arrangement of air ducts, which increases the wind resistance and causes short circuit between fresh air flow and dirty air.

4 Analysis of the causes of high gas tunnel construction problems

4.1 Analysis of causes of safety management dimension

4.1.1 Inadequate ideological understanding

Management security concept deviation: The project decision-making level has the tendency of "emphasizing efficiency over safety", and regards safety investment as a cost rather than an investment. Under the pressure of schedule, they often choose to compress safety procedures to catch up with the schedule.

Theoretical learning is a mere formality: safety education and training has the phenomenon of "going through the motions", and the training content is not updated in time. The lack of training effect evaluation mechanism makes it impossible to verify the effect of knowledge transformation.

Insufficient risk awareness: Managers do not have a deep understanding of the special risks of high gas tunnels. The questionnaire survey shows that only a few managers can accurately state the gas explosion concentration range, and the awareness rate of composite gas hazards is low.

4.1.2 Imperfect control system

Lack of experience and experience: There are few similar high gas tunnel projects in China, so there are limited mature cases for reference. The project team lacks relevant engineering experience, and some key personnel are participating in high gas tunnel construction for the first time.

Weak professional support: The construction unit has not established a stable expert advisory team, and the technical decision is mainly dependent on internal forces. In case of complex problems, it often adopts the "trial and error method", which increases the safety risk.

The implementation of standards is not strict: there is a phenomenon of "selective implementation", which is good for the rigid standards that are easy to check (such as equipment explosion-proof certification), but arbitrary for the process requirements (such as gas detection frequency). On-site verification found that there are obvious contradictions in the gas detection records.

4.2 Cause analysis of technical implementation dimension

4.2.1 Root causes of ventilation system problems

Lack of maintenance management mechanism: no full-time ventilation team has been established, and the average fan operator needs to be responsible for 4 pieces of equipment, far beyond the reasonable load. The implementation rate of equipment maintenance plan is only 60%, and preventive maintenance is seriously insufficient.

The professional quality of the personnel is insufficient: only 35% of the ventilation operators have received systematic training, and most of them are trained by "master and apprentice". The survey shows that the mastery rate of the operation personnel to the performance parameters of the fan is less than 50%.

The adjustment of the ventilation system was not timely: the adjustment lagged behind the construction progress, with an average delay time of 72 hours. After the advance of the working face, the air duct was not connected in time, resulting in increased wind resistance and decreased air volume.

4.2.2 The root cause of explosion-proof problem of mechanical and electrical equipment

Weak awareness of explosion-proof: the on-site workers do not understand the importance of explosion-proof, about 40% of the workers do not understand the basic principles of explosion-proof equipment. There are some violations in the use of equipment, such as forcibly opening the explosion-proof shell.

Defects in the management system: the inspection system of explosion-proof equipment is not perfect, the inspection standards are not clear, and the professional skills of the inspectors are insufficient. The file management of explosion-proof equipment is chaotic, and some equipment is still in use after the expiration date.

Insufficient maintenance: The maintenance cycle of explosion-proof equipment is too long, and the comprehensive maintenance is only carried out every 6 months on average, which is far lower than the standard requirement of 3

months. The maintenance record is not complete, and it is difficult to trace the status of the equipment.

4.2.3 Root causes of monitoring system problems

System design defects: the layout of monitoring points is unreasonable, and the coverage rate of key areas is less than 60%. The route direction does not consider the construction interference, and about 30% of the routes are in vulnerable positions.

Slow maintenance response: the average time from fault reporting to repair is 8 hours, far exceeding the standard requirement of 2 hours. The maintenance personnel are insufficient, and there is no full-time maintenance personnel during night shift.

4.3 Analysis of causes of management mechanism dimension

4.3.1 Backward management concept

Traditional management thinking is constrained: excessive reliance on "person-to-person" on-site management methods, failure to establish a systematic and standardized management system. Management decisions are mostly based on experience, without data support.

Weak risk pre-control: the management focus is on post-treatment rather than prevention, and the targeted emergency plan is not strong. The risk identification and assessment is not timely, and the new risk points need to be included in the control scope in an average of 15 days.

4.3.2 Insufficient professional competence

The talent structure is unreasonable: the proportion of safety professionals in the project team is less than 10%, and most of them are fresh graduates with lack of practical experience. The turnover rate of key personnel is high, with an average annual turnover rate of 35%.

The training system is not perfect: the training content is out of line with the actual needs, and the proportion of practical training is less than 30%. The training effect evaluation mechanism is missing, so it cannot verify the effectiveness of the training.

Technical reserve is insufficient: the special technology and method of high gas tunnel are not studied enough, and many technical schemes are applied to ordinary tunnel standards. When technical problems occur, external experts do not support in time.

5 Conclusion

Through this investigation, we identified multiple safety, technical, and management challenges in the construction of Qilian Mountain Tunnel No. 2 during high-gas tunneling operations. These issues not only compromised construction safety and quality but also imposed substantial economic burdens on the project. To address these challenges, we proposed comprehensive improvement measures including enhanced safety training programs, optimized ventilation systems, strengthened explosion-proof management of electromechanical equipment, upgraded gas monitoring systems, and the establishment of robust management protocols. The implementation of these measures will significantly improve safety and quality in high-gas tunnel construction, providing valuable references for highway development and tunnel engineering projects in China. Moving forward, we must continue advancing research and practical applications to refine high-gas tunneling technologies and management practices, ensuring safe and efficient progress in tunnel engineering projects.

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Yuanlang Dong, bachelor, senior engineer, research intereat : tunnel and mine geophysical exploration technology, monitoring technology research work.

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