Journal of Asian Research
ISSN 2575-1565 (Print) ISSN 2575-1581 (Online)
Vol. 7, No. 2, 2023
www.scholink.org/ojs/index.php/jar

Original Paper

Reflections on the Information Management System for Highway Tunnel Construction

Dong Tianxiong[1], Qi Gaoyuan[2] & Deng Yuewen[1]

[1] China Merchants Chongqing Highway Engineering Testing Center Co., Ltd., Chongqing 400067, China

[2] China Municipal Engineering Central South Design & Research Institute Co., Ltd., Wuhan 430064, China

Received: June 1, 2023 Accepted: June 20, 2023 Online Published: June 26, 2023

doi:10.22158/jar.v7n2p57 URL: http://dx.doi.org/10.22158/jar.v7n2p57

Abstract

In the process of tunnel construction in China, various accidental and unforeseen factors arise, making it a complex and intersecting endeavor involving multiple stakeholders. Safety risks are particularly prominent in tunnel construction due to its inherent nature. With the advancement of information technology, intelligent systems, and the Internet, leveraging advanced internet technologies becomes feasible for comprehensive monitoring of the entire tunnel construction process and dynamic management of all relevant information. This facilitates the intelligent and information of tunnel construction, reduces quality and safety risks, and elevates the level of tunnel construction management. This paper provides a thoughtful design for the information system of tunnel construction, aiming to serve as a reference for the development of information in tunnel engineering.

Keywords

tunnel engineering, safety, information, management system

1. Introduction

China, a mountainous country with over 2/3 of its territory covered by mountains, has witnessed rapid development in its highway construction. Tunnel engineering, due to its ability to overcome topographical obstacles, reduce route distances, and mitigate elevation changes, has been widely adopted and implemented. However, tunnel construction is shrouded in concealment, with only limited visible aspects during the construction process, while the majority of construction work remains concealed. This characteristic gives rise to numerous unexpected circumstances, increasing safety hazards in tunnel construction. Furthermore, tunnel construction sites are subjected to a dynamic environment, where geological and hydrological conditions vary, often leading to unpredictable factors. Consequently, it is imperative to conduct proactive geological forecasting and monitoring throughout the tunnel construction process to facilitate dynamic information updates and design modifications. Considering the challenging tunnel construction environments, characterized by adverse conditions dictated by different surrounding rock formations and burial depths, each stage of tunnel construction necessitates close coordination. Nonetheless, tunnel construction management is a demanding task, involving extensive workloads and multifaceted responsibilities, presenting significant difficulties. As a result, safety and quality risks frequently emerge during tunnel construction (Su, 2021, pp. 93-94).

Numerous engineering case studies have confirmed the existence of substantial safety and quality risks in tunnel construction. Addressing these risks, ensuring precise early warning and assessment of safety conditions throughout the tunnel construction process, as well as promptly implementing effective measures to mitigate construction risks, has emerged as a pressing challenge. Enhancing construction safety in tunnel projects has become an imperative task that demands immediate attention (Ye, 2012, p. 389). In light of China's progress in information technology and intelligent systems, the application of the Internet of Things technology has been widely adopted across various industries. Consequently, tunnel construction has also witnessed advancements in process information management. Leveraging advanced internet technologies enables comprehensive monitoring of the entire tunnel construction process and dynamic management of all tunnel-related information. This facilitates the intelligent and information of tunnel construction, resulting in reduced quality and safety risks, and an elevated level of construction management.

2. Safety Factors in Tunnel Construction Process

The basic characteristic of tunnel construction is the complex geological environment, which requires consideration of various interconnected factors such as geological conditions, excavation methods, construction techniques, manpower resources, mechanized equipment, economic investment, and project schedule. These factors have a significant influence on safety control throughout the tunnel construction process and are essential aspects of tunnel engineering information management.

① Geological Factors: Geological factors encompass topography, lithology, geological structures, regional stress characteristics, hydrogeological conditions, etc. During tunnel construction, serious geological hazards may arise, including sudden water or mud inflows, significant deformation of surrounding rock formations, coal seam gas, fault fracture zones, karst collapse, and rock burst phenomena.

② Excavation Methods: Suitable excavation methods are adopted based on the surrounding rock classification. Common excavation methods include full-section excavation, bench method, excavation with a core soil ring, excavation with adjacent tunnels, excavation with cross tunnels, excavation with side wall pilot tunnels, etc. Different excavation methods have varying construction time, difficulty, and risk levels.

③ Construction Techniques: Construction techniques play a vital role in tunnel excavation. The experience and technical capabilities of construction teams and units have a significant impact on tunnel excavation as they can anticipate potential risk factors in advance.

④ Human Resources: Proper allocation of labor, technical workers, and professionals is crucial during tunnel excavation.

⑤ Mechanized Equipment: Corresponding to different excavation methods, scientific equipment allocation is necessary. The use of automated machinery and equipment in highway tunnel construction in China is becoming increasingly widespread.

⑥ Economic Investment: In the context of independent PPP investment, there is a growing demand for efficient use of funds in tunnel construction. Owners strive to save costs while achieving fast and high-quality tunnel construction.

⑦ Project Schedule: Currently, tunnel construction projects have stringent time requirements. Shortening the construction period and maximizing benefits within a limited time frame is another significant influencing factor in tunnel engineering.

3. Current Development of Tunnel Construction Information

Since the beginning of this century, rapid advancements in computer technology, the internet, and the Internet of Things have facilitated the rapid development of information in tunnel construction. Construction process information refers to the utilization of sensing technology, communication technology, Internet of Things technology, etc., to install sensors, video systems, and monitoring systems inside tunnels. Various construction information, including surrounding rock deformation, harmful gas concentration, temperature and humidity, advanced geological forecasting, and monitoring data, can be collected. Based on this information, the safety status of the tunnel can be analyzed, construction can be guided, and feedback can be provided for design.

Chinese scholars frequently integrate practical examples into their research on construction information. In the 1980s, typical analog analysis methods and complementary BMP software were developed for tunneling projects in China. These initiatives were based on the practical requirements of tunnel engineering, promoting the advancement of information design methods (Ye, 2015).

Yang Fan, Zhao Jian, and Liu Ziming have implemented real-time monitoring technology for structural deformation in the construction of Shenzhen subway tunnels. They have successfully conducted dynamic monitoring of the subway system, enabling information-based construction practices. By utilizing the monitoring results, they have optimized the design and construction processes, thus providing valuable experience for similar projects (Yang, Zhao & Liu et al., 2012).

Xu Nan conducted real-time monitoring of the inner wall displacement of Shanghai subway tunnels. The monitoring was focused on the subway tunnels, and through data processing, achieved graphical representation of the monitoring data and implemented a system alarm function (Xu, 2009).

Xing Weimin, Zhang Min, Cheng Qiangqiang, and others conducted real-time monitoring of tunnel structures by combining static leveling instruments and displacement meters. Through remote real-time dynamic monitoring, they were able to accurately collect deformation data of subway tunnel support structures and timely assess the safety status of the subway tunnel construction process (Xing, Zhang, & Cheng et al., 2011).

In the era of rapid internet technology development, integrating the internet and Internet of Things technology into tunnel information construction has become an inevitable trend. This integration significantly enhances the level of tunnel construction management.

4. Design of Tunnel Construction Safety Management Platform

4.1 Platform Contents

Considering the safety risks associated with tunnel construction, it is essential to monitor the primary influencing factors, conduct real-time analysis and early warnings, and dynamically adjust tunnel construction management. The platform includes the following components: tunnel access control system, tunnel personnel positioning system, visual monitoring of work areas, monitoring of toxic and hazardous gases, construction progress tracking, monitoring measurements, advanced geological forecasting, quality testing, tunnel imaging, team safety management, data analysis, and visualization.

4.2 Tunnel Access Control System

The tunnel access control system is specifically designed for tunnel entrances and exits. It facilitates the control of vehicle and personnel entry, identification, and monitoring, thereby assisting in the effective management and control of tunnel personnel and vehicles. The system consists of various components and devices, for example, the equipment for the tunnel access control system includes access terminal devices, management platforms, and access controllers. The software components consist of system software and user software. The sensors incorporated in the system encompass license plate recognition sensors, facial recognition sensors, and sound recognition sensors. Additionally, other devices such as traffic lights, electronic lighting controllers, surveillance cameras, and automatic doors are also included.

4.3 Tunnel Personnel and Equipment Management System

The tunnel personnel and equipment management system enables the upload and correlation of location information, attendance records, training data, and violations of operations to a server, effectively mapping and managing the following aspects related to personnel and equipment attendance:

①Personnel dynamic display function

②Setting of alarm zones in advance

③Prohibition of entry into the tunnel for personnel engaged in violations

④Prohibition of entry into the tunnel for personnel with inadequate safety training

⑤Real-name attendance management for labor service personnel

4.4 Visual Monitoring

The video surveillance system is integrated into a wireless network platform, providing real-time monitoring of the construction site through strategically placed fixed or mobile cameras, as well as track vehicle-leading cameras. The onboard intelligent system employs speed detectors, positioning devices, and mainframes to facilitate voice alerts, dispatch commands, locomotive inspections, and virtual safety protections for cross-construction. Cameras are deployed at various work areas, including tunnel faces, invert arches, secondary linings, and tunnel entrances, as well as hazardous work zones, allowing for video monitoring of construction personnel and activities. In the event of emergencies, the visual monitoring system provides a comprehensive understanding of the on-site situation, enabling

management personnel to promptly respond with appropriate measures.

4.5 Toxic and Hazardous Gas Monitoring

Toxic and hazardous gases in tunnels, such as methane, carbon monoxide, carbon dioxide, hydrogen sulfide, nitrogen, varying levels of hydrocarbons, and trace amounts of rare gases, pose significant safety risks if not handled properly. To address this, gas monitoring devices utilizing various gas sensor detection technologies are employed during tunnel construction. These devices collect real-time data on the concentrations of toxic and harmful gases, including hydrogen sulfide, carbon dioxide, carbon monoxide, and gases, in critical sections of the tunnel, as well as wind speed and pressure. Continuous monitoring ensures that hazardous gas levels remain within permissible limits, safeguarding the well-being of personnel and the progress of construction. The system triggers audible and visual alarms when gas density exceeds specified thresholds, enabling prompt response measures to be taken during subsequent construction phases. Additionally, the platform provides real-time visualization of toxic and hazardous gas data, empowering management personnel with up-to-date information on the tunnel construction environment and supporting proactive measures for occupational disease prevention.

4.6 Construction Progress

Based on construction site records and inspections conducted by supervisory units, progress data for excavation, invert arches, and secondary linings under different excavation methods are collected and presented in graphical form on designated display screens for easy reference and assessment.

4.7 Monitoring and Measurement

Monitoring and measurement are crucial for evaluating the stability and convergence of tunnel excavation. The system is designed to automatically import daily monitoring and measurement data into a computerized system, facilitating automated calculations to identify any instances of exceeding thresholds or triggering necessary warnings.

4.8 Quality Inspection

The quality inspection of tunnel engineering includes the use of radar detection for initial support, secondary lining, and anchor pull-out. It also involves measuring the clearance of tunnel sections, testing the strength of concrete in the secondary lining, detecting debris in the vault, measuring the thickness of the vault, and examining the dissolution at the base of the vault. These inspections aim to monitor the quality of tunnel construction and propose measures for improvement.

4.9 Image Data of Tunnel Hidden Engineering

In accordance with relevant requirements, the process control of hidden works in tunnels can be achieved by uploading various photos and videos from different stages of the hidden works. This allows for traceability and quality control of the hidden works.

4.10 Safety Positioning Measures for Construction Teams

Real-time updates and inquiries can be achieved regarding the number of personnel entering the tunnel, their entry time, and their positions after entry. The system also facilitates voice communication to

ensure the safety of personnel during tunnel construction.

4.11 Data Analysis and Visualization

Through the monitoring module, various monitoring data results are collected and processed in the background. They are then summarized and displayed on a unified interface. This includes displaying relevant warning situations and conducting comprehensive analysis of the safety conditions inside the tunnel. The system evaluates the current level of safety within the tunnel.

5. Conclusion

Safety risks in tunnel construction are a primary concern for all parties involved. Tunnels are characterized by their hidden nature and complex construction processes, posing challenges in safety and quality management. Information-based monitoring systems utilize remote monitoring and network technologies to enhance the understanding of construction activities within the tunnel, effectively improving the safety of tunnel projects.

Furthermore, the essence of information-based tunnel construction lies in the comprehensive analysis of a large amount of multidimensional information. By harnessing this information, it can serve the construction and operation phases of tunnel projects, providing robust support throughout the entire life cycle of engineering construction. This leverages the transformation power of information-based production management and enables the development of tunnel projects in an information-based and intelligent manner.

References

Su, Q. R. (2021). Application of Information Technology in Tunnel Construction Management. *Journal of Building Materials Development (Part II)*, *19*(4), 93-94.

Xing, W. M., Zhang, M., & Cheng, Q. Q. et al. (2011). Remote Real-time Monitoring and Data Processing Technology for Structural Displacement of Subway Tunnels. *Modern Urban Rail Transit*, *6*(3).

Xu, N. (2009). *Real-time Monitoring System for Displacement of Subway Tunnel Lining*. Ocean University of China.

Yang, F., Zhao, J., & Liu, Z. M. et al. (2012). Application and Analysis of Automation Real-time Monitoring in Subway Tunnels. *Chinese Journal of Geotechnical Engineering*, *2012(S1)*(5).

Ye, Y. (2012). *Tunnel Construction Information Early Warning* (p. 389). Beijing: People's Communications Publishing House.

Ye, Y. (2015). *Tunnel Construction Information Early Warning*. People's Communications Publishing House Co., Ltd.