

Exploration on Defect Prevention and Maintenance Methods of Highway Tunnel Structure

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Abstract: Highway tunnel traffic safety is an important part of traffic safety. With the aging of tunnels, increase in traffic flow, changes in the operating environment and traffic accidents, the many problems started to occur in tunnels, affecting the operational and structural safety. In this paper, we summarize and analyze the types and causes of defects found in the process of tunnel maintenance at home and abroad, and propose corresponding suggestions for the current maintenance of the main structure of highway tunnels.

Keywords: Highway; Tunnel structure; Safety maintenance

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1. Introduction

In the construction of highway projects, tunnels occupy an important position in road transportation. In recent years, China's highways have been developing rapidly, and their mileage and density are among the highest in the world. Highway traffic is a complex system, with the passage of time, the needs of economic and social development, and the improvement of highway construction standards and technical level as well as the growth of traffic volume, the requirements for highway traffic safety also increases. Highway tunnel structure is generally in the form of single and double holes, and in the domestic highway, the longest The longest road tunnel is more than 20km, and the shortest is about 0.036km. Besides, the design and construction quality of tunnels are also improving. According to the number of lanes, the highway tunnel can be divided into two lanes, three lanes, or four lanes. The traffic speed in the tunnel is stipulated according to the design speed of 80km/h, 100km/h, and 120km/h. In terms of technical standards of highway engineering, the safety of the main structure of highway tunnels is crucial to highway maintenance [1].

2. Overview of tunnel disease and maintenance technology

2.1. Tunnel diseases

According to literature, there are four main forms of maintenance for highway tunnels in China. The first one is the inspection of apparent problems at the tunnel entrance and inside the tunnel; secondly, management of external and internal structural diseases of the tunnel; thirdly, maintenance and replacement of internal tunnel facilities (e.g., electromechanical equipment); and fourthly, routine minor maintenance

of the tunnel structure. From domestic and international research, the common defects in road tunnels are mainly as follows: (1) potholes ; (2) deformation defects such as poor water seepage through the cave wall and sinking of the vault; (3) water seepage from the cave wall (water seepage inside the cave); (4) sinking of the tunnel roof or sinking of the arch shoulder cracking, falling blocks, and many more; (5) settlement breakage and cracks (such as crack expansion, crack misalignment, and so on) occur at the cave entrance or roof; (6) deformation and seal failure of the cave door. (7) cracking (or deformation and breakage and falling off) of the vault; (8) cave roof collapse, arch shoulder collapse or cracking, and so on ^[2].

2.2. Domestic and international tunnel maintenance technology development

Tunnel maintenance technology started early, with Germany standardizing tunnel maintenance work in the 1970s and Japan starting in the 1990s. In the early days, tunnel maintenance was mainly maintenance-oriented, and the service life of tunnels was improved through various maintenance measures. Germany's highway maintenance program is divided into two phases, the first phase is mainly for regular inspection and repair of vehicles in operation, and the second phase is mainly for daily inspection and maintenance of tunnel structures. In mainland China, before 2000, China did not have a specialized highway tunnel maintenance agency, the only road and bridge management agencies were the ones established by the local government. Since 2000, with the continuous increase of highway length and traffic volume, the highway traffic environment has become increasingly complex. In order to ensure road operation safety, improve management level, and standardize road maintenance and management behaviors, special road maintenance management organizations have been gradually established, and an effective communication mechanism has been formed between highway operating units. In recent years, China has begun to pay attention to the problem of frequent accidents in highways and has strengthened the research on highway defects and management. The early research and development of tunnel maintenance technology has been documented in China and has achieved good results, including the one-year highway tunnel maintenance comprehensive pilot research project (SJTC01) conducted by Professor Shibao Zhang's team at Lishui, Zhejiang, and the cloud-based highway tunnel disaster management and safety monitoring system ^[3-4].

3. Solution for defects and maintenance measures of highway tunnel main structure

3.1. Analysis of disease causes and treatment methods

3.1.1. Analysis of disease causes

One of the causes of tunnel defects is the poor design of tunnel structure and substandard construction quality; secondly, poor maintenance management may also be an indirect cause of tunnel defects. The generation of tunnel defects is related to environmental factors, such as temperature changes, vehicle overload, and many more. In addition, there are external causes, such as damage to components and structural damage caused by traffic accidents. The current maintenance management model used on China's highways is mostly an after-the-fact maintenance phase, which is a reactive maintenance approach. Only passive maintenance or reinforcement treatment can be carried out after the occurrence of tunnel defects, which is not as good as to implementing preventive maintenance based on the structure of the tunnel and the surrounding environmental conditions (such as ventilation, lighting, temperature, and so on) ^[5].

3.1.2. Treatment methods

(1) Prevention and strengthening of insufficient lining thickness

During the construction process, the type of surrounding rock and geological conditions should be taken into account to reasonably determine the spacing between the blasthole, reasonably determine the various process conditions of blasting, effectively control the effect of light surface blasting on the excavation surface, and minimize the over-under-digging that occurs in the construction of the tunnel

section; at the same time, a reasonable detection method should be used to ensure sufficient space before the construction of the secondary lining. If insufficient space is found, the initial support must be treated in advance. Tunnels that are in use should be demolished and replaced or reinforced with steel strip to avoid engineering safety accidents caused by non-compliance with design requirements ^[6-7]. In case of demolition and replacement, when the old lining is removed, the lining that meets the design requirements outside the demolition and replacement area must be protected in order to avoid secondary damage. In the construction of the new lining, the joint part of the old and new construction must be planted with reinforcement and the contact surface should be chiseled to ensure the old and new concrete is properly joined.

(2) Treatment of the cavity behind the lining.

Presence of a cavity behind the tunnel lining poses a great threat to its safety. Therefore, it is necessary to prevent and control the formation cavities behind the tunnel lining. When there is a cavity behind the secondary lining, it is usually drilled and grouted to make it dense. When grouting, the shrinkage rate of concrete should be monitored, and should be regulated by reducing the amount of cement by adding water-reducing agent and extracting liquid, and the shrinkage rate of concrete should be regulated by appropriate amount of expansion. It is also necessary to leave venting holes in the grouting position, and when there is mud flowing out of the venting holes, the grouting should be stopped and plugged immediately to give enough pressure to the cement slurry. If the cavity behind the lining is too large, the treatment effect and construction safety should be fully considered during the treatment, and the corresponding range of lining should be dismantled and rebuilt if necessary ^[8-9].

(3) Reinforcement of the surrounding rock behind the lining.

During the use of the tunnel, the stability of the tunnel's surrounding rock is affected due to stress changes, the action of groundwater, and so on. Therefore, the stability of the surrounding rock can be achieved by grouting reinforcement; with good rock conditions, the stability of the surrounding rock body can be improved by anchor cable reinforcement support. Conduit is driven into the surrounding rock and slurry is injected to change the adhesion between the surrounding rock, thus forming a support arch on the rock body and ensuring the stability of the rock body. If the rock layer is loose, additional radial anchor reinforcement can be installed at the same time to prevent the displacement of the rock layer and ensure its stability. By grouting the rock layer, a reinforcement ring can be generated in the outer surrounding rock of the tunnel to enhance the stability of the rock layer and improve the stability of the surrounding rock.

(4) Treatment of leaking lining

If leakage is caused by a gap between the liner and the rock, it can be treated by grouting for reinforcement, which not only improves its strength and corrosion resistance, but also enables segmental water repulsion; on the lining surface, leakage due to concrete cracking, especially in single-layer concrete, can be treated by riding joints, diagonal joints grouting, and surface sealing for seepage control.

3.2. Tunnel maintenance recommendations

In recent years, with the rapid development of China's economy and society, the role of highways in the national comprehensive transportation system has become increasingly prominent, and the scale of highway tunnels has become larger and larger. The treatment and treatment of civil structure defects of expressway tunnel is an important task in the daily management of expressway, which is very important to ensure the safe operation of highway tunnel and improve the road traffic capacity. At present, China has built many highway tunnels with many defects, these defects not only bring serious impact on the normal use of the tunnel, but also brings a major risk to the people's lives and property. Therefore, tunnel structure protection should be taken seriously and take effective measures to solve existing issues as soon as possible. At present,

although China's highway tunnel maintenance technology and methods have been greatly enhanced, there are still many problems in maintenance management, such as (1) maintenance construction technology is relatively backward, (2) insufficient maintenance funds, (3) maintenance engineering quality control to be strengthened. Therefore, the maintenance management level of the main structure of the tunnel should be strengthened, and new technologies should be used continuously to improve the quality of maintenance works [10-11]. Combined with the current situation of domestic highway construction and operation maintenance and disease characteristics, the following recommendations are made.

3.2.1. Focus on training high-level technical and management personnel

In the construction of highway bridges and tunnels in China, the most important thing is to strengthen the training of construction personnel. The construction and operation of highway bridges and tunnels fully reflect the role of technical personnel. The publicity and investment in the project need to be increased, relevant technical personnel needs to be actively introduced, and the training of practitioners needs to be improved, so that they have a comprehensive understanding of the work, lay a solid foundation for the maintenance work they carry out, as well as play a role in mentoring and training more professional and technical talents.

3.2.2. Strengthen the coordination of production linkage

To improve the maintenance and management technology of highway tunnels, it is necessary to strengthen the coordination and cooperation among material production, machinery manufacturing, scientific research, and maintenance enterprises to improve the level of tunnel maintenance.

3.2.3. Use new technologies, techniques, and equipment

Highway tunnel operation must not only meet the safety and comfort requirements, but also use more advanced technology. For example, ultrasonic detection technology, automatic monitoring technology, and many more. In the past few years of development, there has been a series of new equipment that are more comprehensive, innovative technology, with high efficiency, high reliability, and other advantages, which can greatly improve the quality of tunnel maintenance. With the rapid development of 5G, BeiDou navigation, and artificial intelligence in recent years, automated inspection and monitoring systems can be developed to conduct regular or irregular inspections of bridges and tunnels at a certain frequency, and collect monitoring data automatically and transmit them to the terminal database for early warning of structural cracks, displacements, water seepage, and other problems, which can then be verified and solved by experts. Compared to conventional methods, the quality and efficiency of maintenance work will be significantly improved, so the promotion of automation and intelligent development of relevant maintenance equipment has a very significant role in enhancing the effectiveness of the management of highway tunnel maintenance.

4. Conclusion

China's highways have been rapidly developing, and the safety and maintenance management level of tunnel main structure is directly related to the overall quality of structural facilities and operational efficiency, which is an important factor to ensure traffic safety. In this paper, we analyze the causes of the main structure of highway tunnels and propose solutions and maintenance management measures for the problems in the daily maintenance of highway tunnels, which can provide some technical references for future research on the safety and maintenance of the main structure of highway tunnels. In the future, it is necessary to increase the investment in the structural safety and maintenance management of highway tunnels to provide a guarantee for safe tunnel operation. The daily maintenance and construction

management of highway tunnels should be strengthened, the emergency rescue plan measures and system of highway tunnels should be improved, and the supervision and inspection efforts should be increased. We should strengthen the technical research work of highway tunnels, to provide a scientific basis for traffic maintenance and management through the introduction of advanced detection means to diagnose and analyze various diseases. Besides, the monitoring of traffic conditions on expressways should be strengthened and promptly deal with problems to ensure highway traffic safety. The protection of road facilities should also be improved to prevent the damage of construction and passage of highway facilities and pollution.

Disclosure statement

The authors declare no conflict of interest.

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