

Tunnel Detection Equipment and Recognition Method Discussion and Prospects

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Abstract: Traffic construction has always been an important prerequisite to achieve China's economic development and social progress. In a country with rich landforms, mountains and hills account for about 67% of the land area, tunnels play a positive role in improving transportation efficiency and alleviating urban traffic pressure, and the diagnosis and treatment of lining diseases is the primary task to ensure the safe operation of tunnels. In this paper, the development status of lining disease identification criteria, identification technology and identification integrated equipment are elaborated and analyzed in detail, and the treatment of lining disease is briefly discussed. The main conclusions of this paper are as follows: 1. All countries have relevant provisions on the judgment and management of tunnel safety, and the safety classification of tunnels has been basically defined. 2. In view of different disease characteristics of tunnels, the integration of multiple detection technologies is the mainstream trend at present. 3. The development of lining disease detection technology and methods has been relatively perfect, and major countries have mature commercial products for tunnel safety hidden danger detection.

Keywords: Tunnel engineering; Lining disease; Tunnel detection equipment; Summarize.

1. Introduction

Since entering the 21st century, China's tunnel construction has made great progress, and its railway and highway tunnel mileage has steadily increased year by year. By the end of 2022, China's railway operation mileage reached 155,000 km, among which, 17,873 railway tunnels were put into operation, with a total length of 21,978 km, 3,025 tunnels were under construction, with a length of 7,704 km, and 5,376 railway tunnels were planned, with a total length of 13,221 km^[1]. By the end of 2022, China had 24,850 highway tunnels, with a total length of 26,784,300 km, an increase of 1,582 tunnels, with a total length of 2,085,400 km, including 1,752 extra-long tunnels, with a total length of 7,951,100 km, and 6,715 long tunnels, with a total length of 11,728,200 km^[2]. The rapid development of tunnel traffic has made China the country with the largest number of tunnels in the world^[3].

However, as an engineering building built in underground geotechnical medium, tunnel support and lining are perennially affected by the complex impacts of surrounding rock pressure, groundwater erosion, temperature change, including the vibration of vehicles and trains passing through^[4]. Moreover, different tunnels are built in different years, and their construction is often limited by the survey and design technologies and construction technology at that time. Under the influence of the complex differences in meteorological and hydrological conditions and geographical environment, after years of operation, many tunnels have different degrees of disease problems, affecting the safety of tunnel driving. Among them, wall cracks, lining spalling, water leakage, structural deformation and other diseases are the main diseases that threaten the safety of tunnels.

Today, with the gradual formation of the national transportation network and the gradual improvement of transportation infrastructure, how to conduct rapid, perfect and scientific detection and maintenance of tunnels is an important task of relevant departments. Therefore, the identification and management of lining diseases is an

important direction of China's tunnel engineering. The discussion of related standards, detection technology and integrated equipment of lining diseases is also a hot topic. In order to form a systematic understanding of the above aspects, this paper sorts out and discusses the above three aspects.

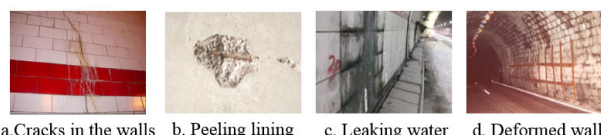


Figure 1. Common disease map

2. Lining Disease Evaluation Criteria

2.1. Foreign evaluation criteria

For the detection standards of tunnel cracks, there are their own standards at home and abroad. In the American "Highway and rail transit tunnel inspection manual"^[5], the tunnel detection of American railways and highways includes seven abnormal types, such as lack of concrete mortar, spalling, surface shallow pits and cracks, which are classified according to mild, moderate and severe grades. The requirement for cracks is that the width is less than 0.8mm is slight, the width is moderate between 0.8mm and 3.2mm, and the width is greater than 3.2mm is serious.

The tunnel evaluation in Germany is carried out according to "Eisenbahntunnel planen, bauen und instandhalten"^[6]. First, the defects of the tunnel are classified, that is, the slight damage of grade an is to the serious defect that will endanger the stability of the tunnel, and then the tunnel state is graded. The tunnel of class A has no defects or only class a damage, while the tunnel of class D has at least one class d damage, which is often unable to deal with the corresponding damage in time. The tunnel will be temporarily closed or slowed down.

Japan is regulated according to the maintenance Management Standard and interpretation of Railway structures, which uses the concept of "Maintenance management standard and explanation of railway structures

"^[7]. In this standard, the soundness is divided into four categories A (AA, A1, A2), B, C and S, among which S is the lowest, has no impact on tunnel operation and public safety, An is the highest, and its disposal measures are from low to high. A2 should take measures if necessary. A1 take measures as soon as possible and AA take immediate measures. we assume that the corresponding authors grant us the copyright to use.

2.2. Some domestic evaluation standards

China's current standards include "Highway tunnel maintenance Technical Code JTG H12-2015"^[8], "Urban rail transit tunnel structure maintenance technical standard CJJT-289"^[9] and "Railway bridge and tunnel building deterioration assessment Part 2: Tunnels"^[10] and so on.

Table 1. Standard for evaluating the health of the tunnel structure during initial inspection

Excavation mode		Evaluation standard			
		Health level 2	Health level 3	Health level 4	Health level 5
Open cut method	Damaged crack	Slight cracking, a small amount of circumferential cracks	The cracks are mainly circumferential cracks, and there are a few longitudinal cracks	Local longitudinal and oblique cracks	There are dense cracks and falling blocks
	Construction joint, deformation joint	Slight collapse of seam position and wrong platform	The distribution of crushing and wrong stations is sparse	Many seams are crushed and wrong	Seriously crushed and wrong platform
Shield method	Segment damage	Slight cracking, a small amount of circumferential cracks	Circumferential cracks are dominant, with a few longitudinal and oblique cracks	Local longitudinal and oblique cracks	There are dense cracks and falling blocks
	Segment seam	Slightly crushed, wrong platform	The distribution of crushing and wrong stations is sparse	Many crushes and wrong stations	Seriously crushed and wrong platform

3. Lining Disease Identification Technology

Tunnel lining diseases can be divided into internal diseases and apparent diseases from the form of expression. Internal diseases are caused by mistakes and other reasons in the construction process, which may lead to insufficient lining thickness, emptying and other bad conditions. At present, the internal diseases of the lining need to be detected by ground penetrating radar approaching the lining. Apparent diseases are diseases shown on the surface of the lining, such as cracks, water seepage, tunnel deformation and so on. For different disease characteristics, different detection technologies have different performances, which can be divided into image measurement technology and three-dimensional measurement technology. That is, visual characteristics such as cracks and spalling can be identified by images, and deformation characteristics such as tunnel convergence deformation can be judged by three-dimensional space distance^[11].

3.1. Image measurement technique

Lining cracks, water leakage, spalling and other diseases have typical visual texture characteristics. Using optical imaging equipment such as CCD camera, infrared thermal imager and multispectral imager can collect tunnel lining images, and recognize various lining apparent diseases through image processing^[12].

Visible light imaging equipment such as CCD camera can quickly obtain gray or color images of tunnel lining surface with the aid of LED light source. Thermal imager converts the invisible infrared energy emitted by the object into visible thermal image. Different colors on the thermal image represent different temperatures of the measured object. The temperature of the tunnel surface will change due to the influence of holes, water leakage and tunnel sidewall materials. For example, the temperature of the lining leakage

water location and wet area is lower than that of the surrounding area. Infrared thermal imager can convert the temperature distribution of the tunnel lining surface into visual images to identify abnormal locations, but it is easy to be interfered by the residual heat emitted by vehicle wakes or other pipelines^[13]. Multispectral imaging is similar to infrared imaging technology. By introducing filter filters to filter part of the spectrum, it can highlight the spectral changes of tunnel lining surface that are difficult to be felt by the naked eye, and then identify the lining diseases. However, because each shooting position needs to be shot many times, and the photos of different spectra need to be superimposed and analyzed after shooting, the detection efficiency is low, and the analysis difficulty is relatively large.

At present, the main imaging equipment for tunnel disease detection is CCD camera. For tunnels with large cross-sectional engineering structures, the imaging field of view of a single camera is limited. In this regard, the practice is to form a linear array or arc array of multiple CCD cameras, so as to obtain a wider field of view, and the image data of half or the whole lining section can be collected at a time. Because of the poor lighting conditions in the tunnel, the light source lighting system must be used to make the array camera clear imaging. The imaging system composed of CCD array camera and lighting light source is installed on a mobile platform to realize the measurement and acquisition of image data and disease detection of tunnel lining cross-section^[14].

3.2. Three-dimensional measurement technology

After the tunnel is excavated, lining will be built on the tunnel wall to provide support for the tunnel. As the lining bears great pressure from rock and soil, the tunnel may have a variety of deformation, including the overall deformation of the tunnel, road surface arch and subsidence, etc., the operating tunnel needs to carry out regular tunnel deformation detection. In the aspect of engineering detection, total station,

laser scanner and other equipment are mainly used to measure the tunnel deformation.

The total station is a non-contact tunnel deformation measurement technology using three-dimensional observation method, which observes the direction and distance of several known points from any station, and calculates the coordinates of the instrument center of the station and the new coordinates of other points through coordinate changes. The total station usually uses the diaphragm recovery reflector as the measuring point target, which is used to measure the clearance displacement of tunnel and underground space. Laser scanner, in the way of laser ranging, can quickly obtain the three-dimensional coordinates and reflection intensity information of a large number of measuring points on the lining surface without light source, and judge the tunnel structure state through the tunnel three-dimensional modeling algorithm, such as tunnel section size, structure deformation and so on^[15].

According to the working mode, laser scanners can be divided into Terrestrial Laser Scanning(TLS) and Mobile Laser Scanning(MLS)^[11]. TLS can obtain the high-resolution point cloud of the tunnel in a short time, but the tunnel is a long column, and the point cloud density will decrease sharply in the distance due to the angular image, so the ground laser scanning needs to set up several stations along the tunnel axis in order to complete the scanning of the whole tunnel, and the laser point clouds scanned for many times are

registered and spliced.

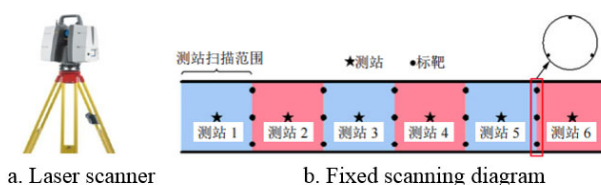


Figure 2. Ground scan diagram

In recent years, the rotating two-dimensional laser scanner is loaded on the mobile platform, and the laser scanning plane is perpendicular to the driving direction to form the mobile laser scanner MLS. The laser emitted by MLS scans the tunnel surface in a helical way, and the laser point cloud information of the tunnel lining surface can be obtained, and the three-dimensional model of the tunnel can be constructed^[16]. Compared with the previous acquisition mode, the speed of obtaining data is faster, and the measurement of the whole tunnel can be completed at one time in a dynamic way, eliminating the later splicing process, but the accuracy is relatively low, and high-precision positioning and attitude information is needed.

3.3. Evaluation of detection methods

Table 2. Three Scheme comparing

Detection method		Detection object	Advantages and disadvantages
Image measurement technology	Industrial camera	Cracks, water leakage	Low cost, dependent on light source, and tedious data processing
	Infrared thermal imaging	Water leakage, lining cracks	High precision, the effect depends on the temperature difference.
	Spectral imager	Water leakage, lining cracks	Accurate discrimination and low efficiency
Three-dimensional measurement technology	Laser scanner	Lining deformation and water leakage	Good acquisition rate and large data redundancy
Internal disease detection	Ground penetrating radar	Lining thickness, voids, steel bar positioning and corrosion	High resolution, acquisition block, short detection distance
	Ultrasonic wave	Voids and cracks in lining	The penetration is strong and the cost is low. Step by step detection, low efficiency

4. Currently Available Equipment

4.1. Some foreign equipment

Ukai et al., Japan, developed a prototype of tunnel scanning system based on array camera in 2007^[17]. The system is equipped with linear array camera and lighting unit on the left, top and right side, and is loaded on the tram. The detection speed is about 10km/h, and the crack disease can be identified with an accuracy of about 0.8mm. Swiss Terra company developed the crack detection equipment tCrack. The equipment is composed of 10 high-definition cameras, which can be installed on the rail car or road car. At the speed of 2.5km/h, the crack with a width greater than 0.3mm can be detected. Spanish Euroconsult company developed tunnel detection equipment Tunnelings. The equipment is composed of 6 sets of high-speed cameras and linear laser generators, which are erected on the mechanical frame. It can collect data of half a tunnel section at 30km/h. The image detection accuracy is 1mm in the tunnel with a width of 12 meters. It

can also obtain three-dimensional data of the tunnel for tunnel lining disease analysis. The equipment can be erected on the car and rail power lathe.

The company of Japan Metrology and Inspection Co., Ltd. designed an automatic tunnel detection system, which is named MIS&MMS tunnel detection system^[18]. The system takes the vehicle as the bearing platform, and there are two detection systems on the platform, namely, the mobile image acquisition system (MIS) and the mobile map construction system (MMS). The MIS system is equipped with 16 CCD cameras and 24 LED light sources. The MMS system consists of 3 GPS, 1 IMU systems, 1 odometer and 3 laser scanning radars. For the tunnel images collected by the camera, the optical resolution can reach 0.2mm, and the detection of tunnel leakage and cracks above 0.2mm can be completed. In normal detection, the detection speed is from 5km/h to 50km/h.

Germany's SPACETEC company designed the TS3 three-dimensional laser infrared vehicle detection system, which can identify cracks above 0.2mm, and can compare the

development of the disease through multiple collection at regular points^[19]. In a single inspection process, the TS3 system can perform multiple tasks at the same time, such as photographing the tunnel surface, thermal imaging and three-dimensional measurement work, and its detection speed is 5km/h. By using laser and infrared, TS3 system can carry out non-contact non-destructive detection of some tunnel diseases, such as deformation, lining cracking, leaking water, falling blocks, etc., and use tunnel surface images to detect lining cracks. The tunnel section size can be obtained by using the test results, which can be used to judge whether the structure in the tunnel exceeds the limit and ensure the driving safety.

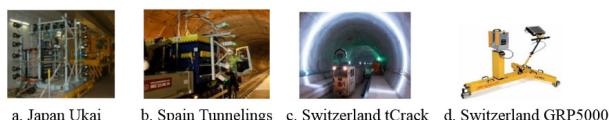


Figure 3. Some tunnel testing instruments abroad

4.2. Some domestic instruments

In China, Tongji University and Shanghai Tongrui Sike Company developed the MTI-100 tunnel detection vehicle^[20]. The detection vehicle sets a variety of sensor equipment. The image acquisition system composed of 6 CCD cameras can continuously obtain lining images. It is suitable for subway tunnels with a diameter of 5.5m. The detection speed range is 3 to 5km/h, and the accuracy is 0.3mm. It can be used for the detection of urban rail tunnels. The equipment is not based on vehicles as the platform, with small volume and light weight. When the detection is carried out by manual propulsion, it can be used to identify cracks, water leakage, block dropping and peeling and other diseases, and can record the location of the disease.

Shanghai Tongyan Civil Engineering Technology Co., Ltd. has developed the highway tunnel intelligent detection system TDV-H2000^[21]. The system uses medium-sized vehicles as the bearing platform and is equipped with a variety of high-precision measuring devices, which can use measuring equipment to collect various diseases and tunnel profile information, and can provide regular inspection services for tunnel maintenance. TDV-H2000 can detect the lining cracks of 0.2mm, and can detect regional diseases, such as lining spalling and lining seepage, the detection speed is up to 80km/h, the distance error measured by lidar to the lining is less than 0.1mm, and the profile measurement error is within ± 1 cm.

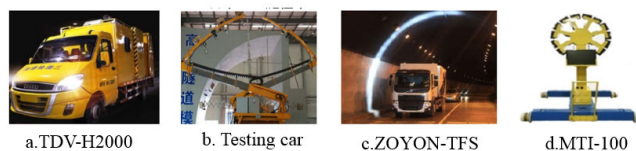


Figure 4. Some tunnel testing instruments in China

Wuhan Wuda Outstanding Science and Technology Co., Ltd. has developed the ZOYON-TFS tunnel rapid measurement system^[22], which takes the medium truck as the vehicle platform and installs several precision sensors on the platform. It consists of four systems: crack detection, main control, infrared detection and deformation monitoring. Among them, the crack detection system includes 34 LED

lighting systems and 32 high-speed area array cameras to achieve full coverage detection of tunnels and cross sections. The main control subsystem includes a GPS, an IMU and an odometer, the infrared subsystem includes three infrared array cameras, and the deformation subsystem includes two laser scanning radars. After one pass, the comprehensive data collection of all the tunnels can be completed. The positioning accuracy is less than 1m, the crack detection accuracy is 0.2mm, and the deformation detection accuracy is 0.2mm.

5. Conclusion

As mentioned in the beginning, at present, the tunnel judgment and evaluation system of major countries in the world has been formed, and the disposal measures of tunnel safety problems have their own provisions. In view of the different characteristics of tunnel diseases, the current trend is to integrate multiple detection techniques for detection. Japan, Germany and China all have mature products in tunnel disease detection, and the accuracy reaches the tunnel detection standard.

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