NONDESTRUCTIVE EVALUATION BY ANALYSIS FOR DENSITY OF CRACK IN TUNNEL & UNDERGROUND STRUCTURES WITH TUNNEL SCANNER

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Abstract: This study has focused on the method of state-estimation in tunnel and underground structures by analyzing density of cracks. Reliability on this technique is decided by exact measurement and analysis of cracks. The tunnel scanner, one of the nondestructive technologies, is used by high resolution CCD(charge-coupled device) camera because accurate data could not be acquired by the conventional visual inspection method. This method can get reliable image data through detailed shooting on the surface of the target structures and analyze accurate information (width, length, location etc.) of cracks by image processing. The crack density was analyzed by considering section type of structures, length of span and expansion-joint and by using numerical location and distance of cracks like width and length. Cracked area, which is a basis of crack density analysis, was calculated 0.25 m width per crack length. We can specially manage a zone to be concentrically generated through a distribution chart of crack density to be analyzed over all structures. The analyzed data, which were detected by nondestructive tunnel scanner, proffered information for reasonable judgment in evaluating conditions of tunnel and underground structures, and further, they are used as reliable information to determine safety diagnosis, precise safety diagnosis or priority of repair and reinforcement works.

Keywords: Tunnel structures, Crack density, Crack width, Scanner, Image processing

1. Introduction

In the precise safety diagnosis for tunnels that is carried out for maintenance and management, the times, method and priority of repair and reinforcement works are decided by a chief engineer's subjective judgment, and the party in charge of facility maintenance and management does the repair or reinforcement works based on the decision. Under this circumstance, inefficient and uneconomical managements are often taken. That is, insufficient managements are taken for the sections that really need repair or reinforce-ment while excessively sufficient managements are given to the sections for which it is okay to postpone the works later.

This paper has described the method of analyzing and evaluating the crack density in order to determine how to do repair and reinforcement works. For this, it has analyzed the degradation phenomenon such as crack, water leakage, exfoliation, separation, etc. found in the whole section of box culvert and NATM(New Austrian Tunneling Method) tunnel lining in Seoul Subway. For this, it has investigated the external crack, using a tunnel scanner that is generally used in the advanced foreign countries and also is developed and applied in Korea. Based on the results, it has analyzed the crack density of tunnels by span, distance and location. Through this analysis, it has not only chosen reasonable ways of repair and reinforcement, but also determined priority in systematic repair and reinforcement works.

Compared with the conventional investigation by naked eyes, tunnel scanner has the following advantages and disadvantages:

1) Job site investigation is carried out at night in consideration of the site conditions of tunnels.
2) The height of the structures under investigation is mostly over 5 m so investigators should hold back their head all through the investigation, which can cause industrial disasters.
3) It has problems like omission or error in recording or error in CAD works.
4) Investigators subjectively record and determine the investigation results

2. Measurement of external cracks

Measurement of external crack is one of the most important investigation items in safety check and precise safety diagnosis. A tunnel scanner that is generally used in advanced foreign countries and also is developed and applied in Korea [1], has been used for the investigation, and the results have been reconfirmed.

2.1. Development of tunnel scanner for external cracks

Tunnel scanner is a high-tech equipment that checks the status of damage promptly and accurately, using laser and optics. The conventional method of investigation checked cracks or water leakage on a structure by naked eyes and then, sketched. The tunnel scanner automatically draws diagrams of appearance investigation and totals the details of damage, and it also uses objective and accurate information to analyze any progress in the degradation phenolmenon such as crack, water leakage, exfoliation, etc. That is, the conventional investigation by naked eyes was performed at night in consideration of the site conditions of tunnels so it had some problems such as omission or error in recording, error in CAD works, etc. Because of these problems, use of the data was not active and it was impossible to grasp any progress in damage. In addition, in determining the works of repair and reinforcement based on the judgment and the results of investigation of cracks, water leakage and exfoliation, engineers made different and subjective decisions so it was difficult to secure objective and accurate data.

Therefore, the tunnel scanner, developed in Korea, used for this study has included the followings:

1) Name of equipment: Detecting system for cracks on concrete structures
2) Image filming machine: 8 sets of digital video camera
3) Device for the field: Light, digital recorder, screen divider, power generator
4) Scanning velocity: 4km/hr ~ 10km/hr
5) Analyzer and S/W: Image processing board, image processor, image processing software

2.2. Outline of the facility to be investigated

The facility in question is Seoul Subway, and the section for precise safety diagnosis is about 3 km from Sta.2k806 to Sta.5k760[3]. At the time of carrying out the construction work, the tunnel corresponds to no. 2, 3 and 4 section, and among these sections, no. 2 section is up to Sta.4k486 (1-lane box culvert from the start to 4.0 m, which is connected to 2-lane box culvert and then, passes through the stop). And no. 3 section is from 2-lane box structure to multi-lane tunnel: from the 2-lane box, it is connected to multi-lane tunnel; in the middle of the multi-lane tunnel, there are 2-lane box culvert sections to construct a structure for ventilation; and the section of stop is passed. No. 4 section is composed of 2-lane box and multi-lane box of the last 2m, which is the terminal for the precise safety diagnosis. In addition, the tunnel is composed of about 2,400 m box section and about 600 m NATM tunnel. The box section is a reinforced concrete structure and NATM tunnel is mixed with reinforced concrete and unreinforced concrete. The tunnel is horseshoe-shaped and through the lower part of both walls, water is drained out.

2.3. Analysis processing by tunnel scanner

The work of analysis processing by tunnel scanner is different by each scanner system. And it has some restrictions in analyzing this feature accurately, but mostly the work goes through the followings:

1) Getting image data: Each system has different ways to get data, but most of tunnel scanners get data of external conditions of tunnels on site, using their equipment. In order to operate this system using CCD digital video camera, optical system, scanning system and dust-proving system are necessary.

2) Saving image data: Video tape, hard disk or CD is used to save data.

3) Interpretation of image data: In order to make diagrams of appearance investigation including the degradation phenomenon like cracks, water leakage, exfoliation, etc., it creates visible and quantitative data which users can easily operate.
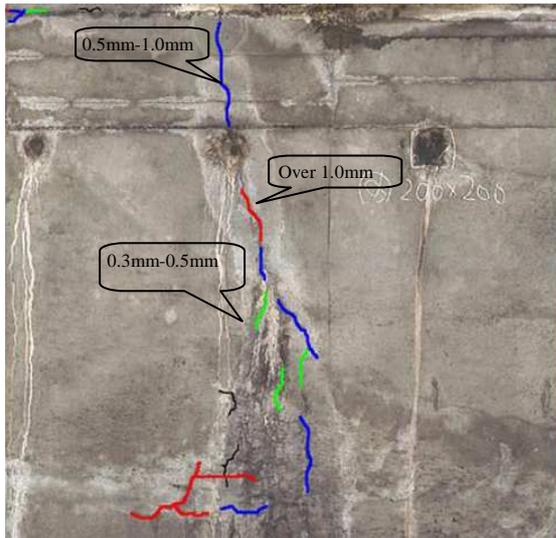
The appearance investigation in the above secures and analyzes image data of an actual tunnel as like Fig.1, and further, gets to have diagrams of appearance investigation as like Fig.3.

(a) Scanning using developed tunnel scanner

(b) Real image of tunnel surface

(c) Analyzed image of tunnel surface

Fig. 1. Actual status and result of tunnel scanning

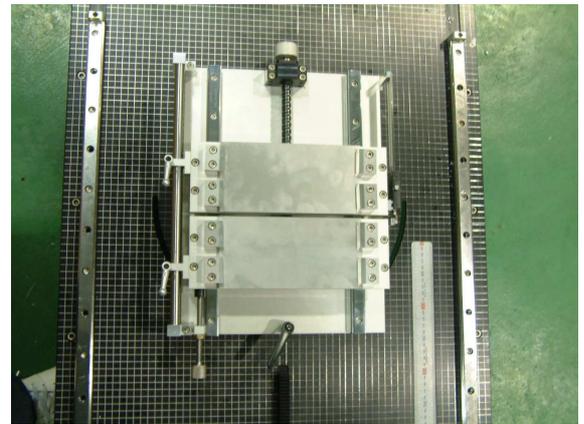## 3. Verification of Crack Analysis Algorithm

Reliability of the developed crack detecting algorithm is verified by a special designed system, as shown in Fig.2. Verification system consists of a CCD camera installation, a specimen fixture, a reference base plate, and an external illumination. CCD camera installation is compatible with various kinds of cameras and supplies adjustable distance and angle between camera and specimen. A specimen fixture controls crack location, the direction of crack and the width of crack, which can be adjusted with the resolution of 0.01 mm. Reference base plate supplies information for measuring the distortion of image, viewing angle, and inspection area. External illumination is adjustable to illumination intensity, angle between source and reference base plate. According to the change of influence factors such as viewing distance and angle between specimen and camera, illumination conditions, crack width, crack position, and the direction, an artificial crack in these conditions is measured by crack detecting algorithm and compared.

(a) Verification System
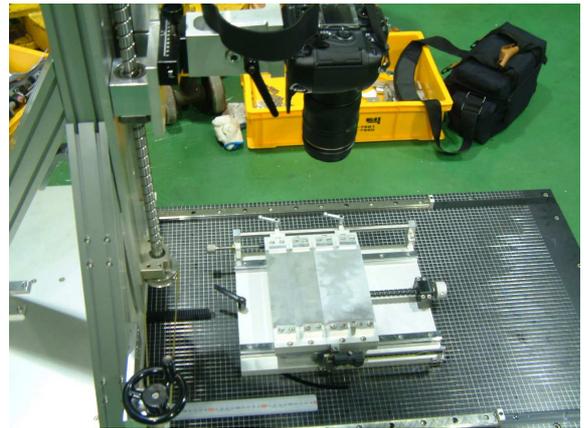
(b) Camera and specimen

(c) Crack width control

Fig. 2. Verification system of crack analysis algorithm

4. Crack density Analysis

Investigation of external crack is one of the most important investigation items in safety check and precise safety diagnosis. A tunnel scanner that is generally used in advanced foreign countries and also is developed and applied in Korea, has been used for the investigation, and the results have been reconfirmed. Appearance investigation result obtained from the tunnel scanner is accurate more than that by the naked eye observation, and can be important data to determine the progressive possibility of the existing a crack as shown in Fig.3. However, there is no quantitative analysis in crack density analysis using the appearance investigation result obtained from the tunnel scanner. In this study, analysis is focused on the appearance investigation of cracks because other defects are minor in analysis of appearance investigation result.

Assumptions adopted in the crack density analysis are as follows;

1) It is assumed that crack area is 0.25 m in width per crack unit length according to the specification for inspection and detailed diagnostication. The crack area is where crack occurs on the concrete lining

2) The investigation area for the crack density analysis is classified into a section of works, subway station, box culvert section, and tunnel section. In the specification for inspection and detailed diagnosis,

the investigation area for the crack density analysis is divided into the reinforced concrete lining section and the cement concrete lining section, and the length of lining section is between 5 m and 50 m. However, span length in box culvert section is 30 m, and that of tunnel section is between span joints.

3) In the crack analysis, the determination of the repair and reinforcement method is dependent on 0.3 mm, which is a limitation for repair method in tunnel.
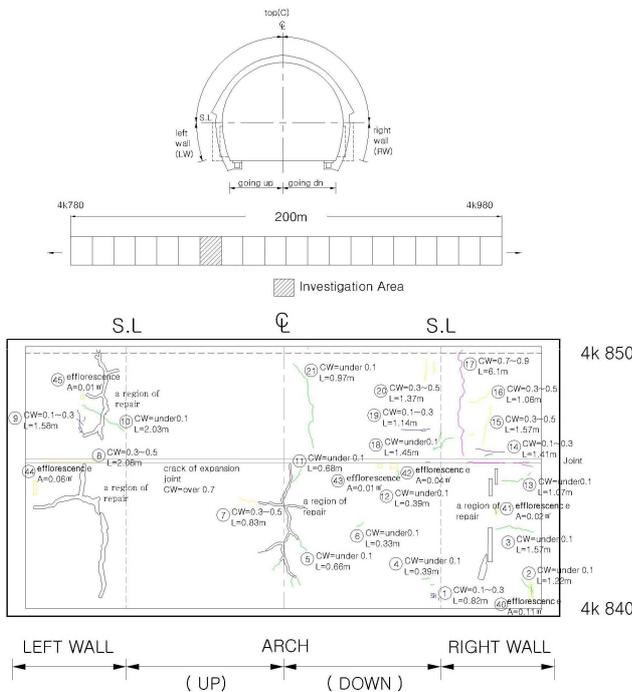

Fig.3. Diagrams of external crack of tunnel

5. Results of crack density analysis

Fig.4. shows the result of the crack density analysis

1) The crack density of section 2 is relatively higher than that of sections 3 and 4 reinforced

2) In classification of structure, the crack density of box culvert section is high, that of subway station section is middle, and that of tunnel section is low.
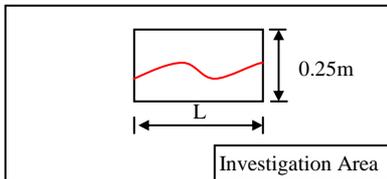
$$\frac{\text{Crack Area}}{\text{Investigation Area}} \times 100(\%) = \frac{\text{Crack Length(L)} \times 0.25}{\text{Investigation Area}} \times 100(\%) \ [2]$$

3) The crack density of the box culvert in section 2 nearby subway station is the highest, and that of two-lane tunnel in section 3 is the lowest.

4) If the crack density is greater than 0.06 m^2/m^2, the section may need the concentrated maintenance, and first of all, repair in the maintenance.

5) The cracks with over 0.3 mm in width were found in the concentrated maintenance section more than the other sections. There is no special section with characteristics of direction of crack.
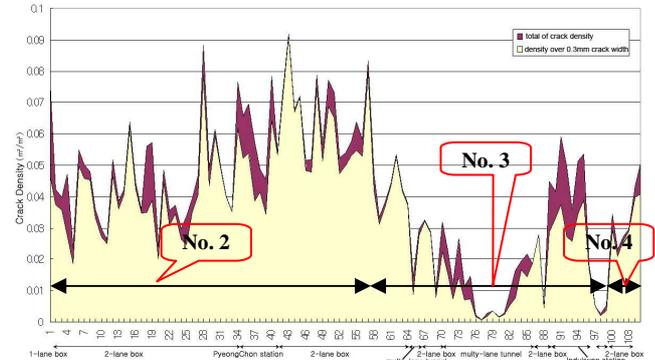

Fig. 4. Crack density analysis in the measured section

Table 1. The concentrated of maintenance section.

Section.	Station No.(Sheet No.)	Length (m)	A reason of selection
	The sum total	364	
2-lane box of no. 2 section	2k980~988(7)	8	-A lot of exfoliation occurred after repairing the side wall
	3k174(14)	1	-Construction joint omitted
	3k200~230(15)	30	-Crack density is over 0.06m²/m²
	3k590~620(28)	30	-Crack density is over 0.06m²/m²
The station of no. 2 section	3k745~770(34)	25	-Crack density is over 0.06m²/m² -Diagonal crack occurred at 3k745~748(RS)
2-lane box of no. 2 section	3k920~4k100(40~45)	180	-Crack density is over 0.06m²/m²
	4k220~280(50~51)	60	-Crack density is over 0.06m²/m²
	4k430~460(57)	30	-Crack density is over 0.06m²/m² -Construction joint is omitted at 4k445

6. Advantages of the tunnel scanner

1) Improvement in investigating environment.

2) Increase in precision to obtain higher measurement quality.

3) Appearance investigation within a short time (investigation speed: 4 km/hr ~ 10 km/hr).

4) Reliable correlation between evaluation of the conditions and repair/reinforcement

5) Construction of objective database (so it is possible to check any progress in damage)

6) Unification of information management through connection with IT (Information Technology)

7. Conclusions

In general, in the precise safety diagnosis for tunnels, the determination of repair and reinforcement methods and its

priority order in maintenance is largely dependant on the chief engineer's subjective opinion.

Appearance investigation using the tunnel scanner in the box culvert and tunnel sections for the subway was conducted to determine the repair and reinforcement methods systematically and objectively. The crack density analysis was performed on each span, each distance, and each location.

This is reasonably to determine repair and reinforcement methods and its priority order in maintenance.

1) It is assumed that crack area is 0.25 m in width per crack unit length according to the specification for safety diagnosis and precise safety diagnosis.

2) The crack density analysis was conducted on each section of works, each facility, cement concrete lining section, and reinforced concrete lining section. The determination of the repair and reinforcement method is dependant on 0.3 mm, which is a limitation in repair method in tunnel.

3) From the result of the crack density analysis, the crack density of box culvert section is high, and that of tunnel section is low. The section with high crack density should need the concentrated maintenance, and, first of all, repair.

4) The priority order for repair and reinforcement can be systematically managed by means of the analysis of appearance investigation result obtained from tunnel scanner.

In this study, it is suggested that the crack density analysis should be used for analyzing the result obtained from tunnel scanner.

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