A Non-Destructive Inspection Method for Concrete Elements in Tunnel Linings Using Remote Laser Sensing

Masahiro SHINODA
Assistant Senior Researcher, Foundation & Geotechnical Engineering, Structures Technology Division

1. Introduction

To ensure that trains run safely, the performance of railway civil engineering structures is checked by periodic inspections. Table 1 shows a summary of different general inspection methods for tunnel linings, such as impact acoustics, infrared and ultrasonic methods. Each method has merits and demerits, but none of them offers the combination of high accuracy and quick inspection.

In an effort to resolve this problem, the Institute for Laser Technology, the Tokyo Institute of Technology, the Railway Technical Research Institute and West Japan Railway Company jointly developed a remote laser sensing system as an alternative to the impact acoustics method for detecting defective concrete elements in tunnel linings. This report describes the principle of the proposed method, an algorithm to detect faulty concrete elements and a verification test with the proposed method.

2. Development of laser remote sensing

(1) Principle of remote laser sensing

Figure 1 shows the principle of the proposed remote laser sensing system. This system has two lasers, one to apply an impact to the concrete surface and the other to measure the vibration of the concrete generated by the impact laser. The impact laser is a high-energy pulse laser that induces vibration in the concrete. The detection laser has a signal beam and a reference beam. The signal beam reflects on the concrete surface and goes into the dynamic hologram crystal. The reference beam diffracts in the dynamic hologram and enters the detection sensor with the signal beam. The vibration of the concrete surface can be measured to detect the movement of an interference pattern.

(2) Prototype of remote laser sensing system

A prototype of the remote laser sensing system was developed. This uses the principle shown in Fig. 1, and the device is illustrated in Photo 1. The system is equipped so that it can stabilise an interference pattern, and this allows it to reduce the amount of movement in the interference pattern generated by a small external vibration between the detector and the surface of the concrete.

3. Development of a detection algorithm to show concrete defects

In this research, the time history of acceleration on the surface of the concrete after application of an impact force by hammering is adopted as the relevant data for the impact acoustics inspection. Figure 2 and 3 show representative Fourier spectrums measured from concrete specimens without and with defects, respectively. The performance of the concrete can be evaluated by using the ratio of the area of the Fourier spectrum that is lower than a given frequency tolerance to the whole area of the Fourier spectrum. The index of the above ratio can be calculated from the following formula.

$$R_S = A_1/(A_1 + A_2) \qquad (1)$$

where A_1 is the area of the Fourier spectrum lower than the frequency tolerance, A_2 is the area of the Fourier spectrum higher than the frequency tolerance and RS is the ratio of the Fourier spectrum area. This ratio is referred to as a spectrum score in this paper.

The proposed detection algorithm was verified against the result obtained from the impact acoustics inspection. Figure 4 shows the result obtained using the proposed detection algorithm. The evaluation by the detection algorithm agrees well with the result of the impact acoustics method using the tolerance of 2000 Hz and a spectrum score of 0.1.

4. Verification field test with an actual bridge

The proposed laser remote sensing system and the detection algorithm were verified with the help of field tests conducted at a bridge and in a tunnel on the Shinkansen. Photo 2 shows the tunnel used for the field tests. An impact test using hammering was applied to obtain the accurate response acceleration on the surface of the concrete before application of the proposed method. In both tests, the result obtained from the proposed method agreed well with that obtained from the impact test by hammering. Consequently, it is verified that the proposed method can be used as an alternative to the standard impact acoustics method.

5. Conclusions

The paper describes the proposed remote laser sensing system including the detection algorithm using an impact laser to induce vibration on the surface of the concrete and a detection laser to measure the vibration on the surface of the concrete. The following conclusions can be drawn and a proposal for future investigation put forward:

1. A prototype of the remote laser sensing system to detect defects in concrete elements was developed.
2. Verification of the proposed system was conducted using field tests.
3. It is possible to measure the performance of concrete by the proposed method.
4. To make the proposed method suitable for practical use, it will be necessary to develop a vibration canceling system on the maintenance vehicle and to increase the intensity of the detection and impact lasers.

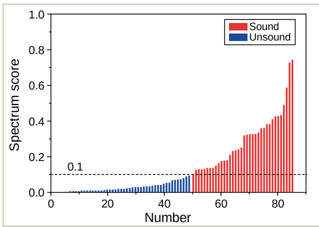


Fig. 4 Inspection result by spectrum score

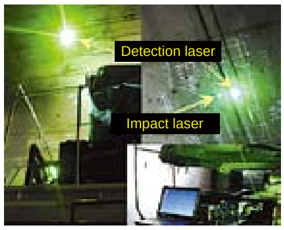


Photo 2 Field test of a tunnel lining

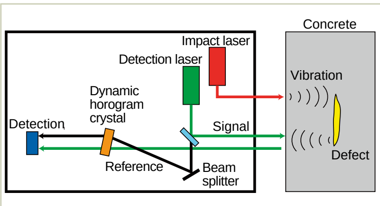


Fig. 1 Principle of the remote laser sensing system

Photo 1 Prototype of the remote laser sensing system

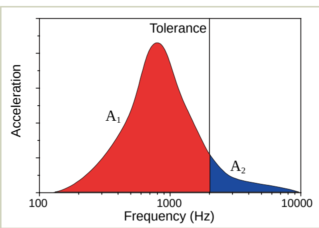


Fig. 2 Representative Fourier spectrum measured from the concrete specimen without defects

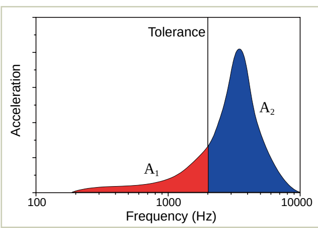
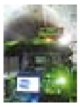
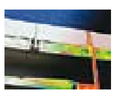
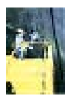


Fig. 3 Representative Fourier spectrum measured from the concrete specimen with defects

Table 1 Comparison of the proposed method with different general non-destructive inspection test methods for concrete elements in tunnel linings

	Proposed method	General methods		
	Laser ultrasonic method	Impact acoustics method	Infrared method	Ultrasonic method
Situation				
Advantage	• Non-contact • Quick detection • High accuracy • Can be used on curved surfaces	• Many previous records • Simple to use • Unsound concrete can be removed with a hammer	• Non-contact and remote sensing • Detection of damaged area	• Small apparatus • High accuracy
Disadvantage	• Decrease of accuracy due to external disturbance • Large apparatus	• Long inspection time in total • Need for many engineers • Elevated working position	• Low accuracy • Need to heat the concrete surface	• Long inspection time in total • Cannot be used on curved surfaces • Elevated working position