Development of Concrete Peel-off Detection Device using Laser


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1. Introduction (Background of development)

For the concrete structures that constitute the foundation of today's society, concerns about fall-off of concrete due to deterioration are growing. The concrete fall-off in a tunnel in Sanyo Shinkansen[1] in 1999 especially reminded us of the importance of inspection on concrete structures.

The railway tunnel lining inspection using the impact acoustics method, which is a current major inspection method, is associated with some limitation, e.g., inspection cannot be conducted during the period when the railway is operated, it is required to operate the tower wagon that can run on the railroad to carry it to the site for the works, and also the feeding for the railway operation is required to be cut off. In addition, the actual work time is limited to approximately 1 to 3 hours. Therefore the burden on the inspection engineers becomes large and a significantly long time is required to conduct the inspection. Against the background, a concrete peel-off detection device using a laser-based non-contact measurement technology (hereinafter referred to as "this Technology") that allows to inspect concrete from the distance of 10 m (hereinafter referred to as "this Device") is developed to reduce the necessity of work in high places and the feeding cut off, and to allow to detect the disorder before the concrete falls off from the structure.

2. Overview of the technology

2.1 Principle of laser-based non-contact measurement technology

The hammering method and this Technology are based on the same principle because both of them set up vibrations on the surface of concrete to analyze the vibrations on the surface (Figure 1). In the hammering method, the surface of concrete vibrates when it is hit by hammer, and the vibration is transferred in the air to be heard as sound. The integrity of the concrete surface is determined based on sound. On the other hand, this Technology uses a vibration laser to vibrate the concrete surface and detect the condition of the vibration generated by using laser.

Figure 2 shows the detection principle of this Technology.[2] When a high output vibration laser is radiated on the concrete surface, the solid material on the surface (e.g. cement) is gasified and emitted into the air. The shock wave is generated as a reaction to the emission and transferred into the inside of the concreted to trigger the vibration on the surface. The vibration on the surface is measured by laser interferometric detection using a continuous wave laser for measurement. The measurement laser is split into the signal light and the reference light by a beam splitter. The signal light reflects on the concrete surface, enters into the diffraction grating with the information regarding the surface form of the concrete surface, and then interferes with the reference light. This principle enables measurement with high detection sensitivity.

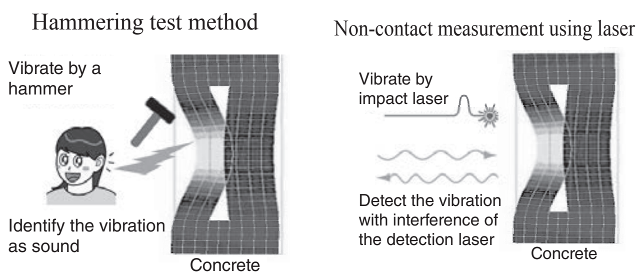

Fig. 1 Comparison between hammering test method and this Technology

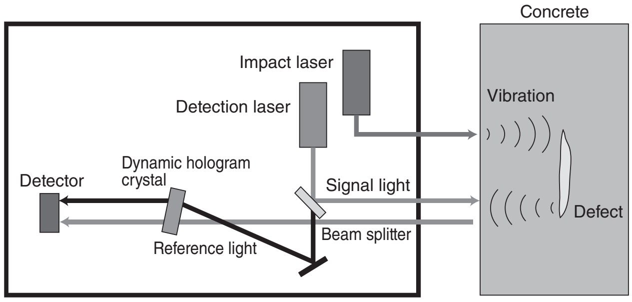

Fig. 2 Principle of this Technology

2.2 Development of defect detection algorithm for concrete peel-off

When using this Technology for actual cases, the determination of the level of the integrity will be an important factor. In the impact acoustics method that is currently used, the inspection engineer judges the integrity level such as α (dangerous), β (required to be monitored), γ (safe), and healthy for the targeted area based on the frequency of the sound which is heard when he/she hits the concrete. The characteristics of the frequency of the sound (spectrum) are converted into numerical form to develop an algorithm to allow to objectively judge the integrity of the targeted area.[3) 4)]

Figure 3 and 4 show an overview of the vibration spectra (vibration on the concrete surface) that are obtained by the hammering test for a healthy part and a part with defect. Components of relatively high frequency dominate for the healthy part. However, components of low frequency dominate for the un-healthy part. Based on these characteristics, the algorithm is developed by using the ratio of the areas of the low frequency side A_1 and high frequency side A_2 while setting the threshold at 2 kHz to detect defects. The calculation formula is expressed in Equation (1):

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

Figure 5 shows the relation between the values of Rs and the judgment by the inspection engineer. For more than 400 inspection locations, Rs values and judgment of the integrity (α, β, and γ) by the inspection engineer were compared. α and β represent the location with defects and γ represents the healthy area.

As a result, because the matching rate becomes 85.2% when the threshold and the spectrum score are set at 2 kHz and 0.09 respectively, it was found that the location with defects can be identified within the healthy area.[5]

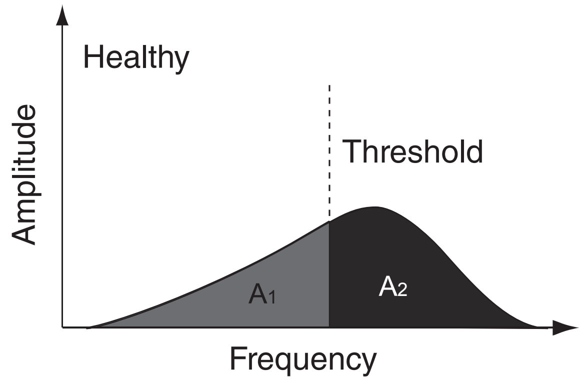

Fig. 3 Vibration spectrum for healthy area

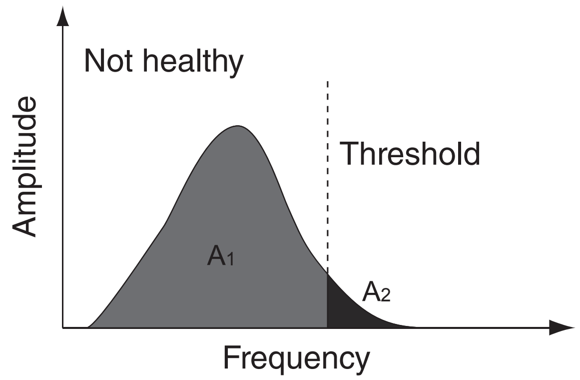

Fig. 4 Vibration spectrum for location with defects

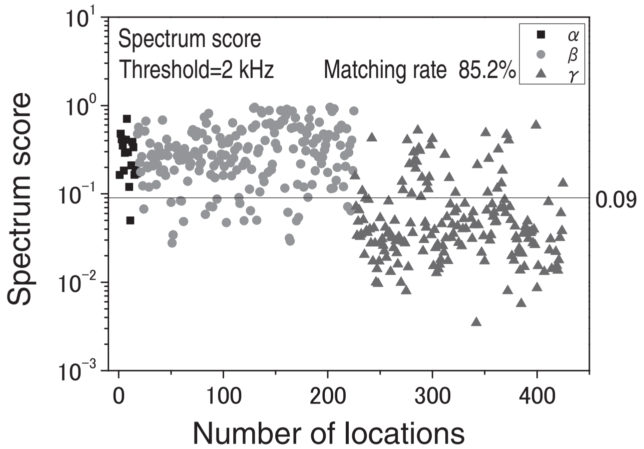

Fig. 5 Matching rate between Rs value and judgment by inspection engineer

3. Verification test in a tunnel for the Sanyo Shinkansen

The verification test was conducted in a tunnel for a Shinkansen using the prototype of the testing device. It has become evident that the vibration spectrum obtained by the impact acoustics method corresponds with that obtained by the accelerometer that is adhered to the concrete.[6) 7)] Therefore an accelerometer was used to measure the acceleration of vibration generated by hammering on the concrete surface at the point on which the measurement using laser was conducted (Figure 6), and then the results of the laser measurement and those of the surface vibration test using the hammering method were compared. Figure 7 shows an example of the comparison. The dominant frequency for the location with defects is approximately 2,5 kHz in the surface vibration test. Also in the laser measurement, the dominant frequency is around 2,5 kHz. As described above, the spectra obtained by this Technology and the impact acoustics method match well.

Fig. 6 Surface vibration test

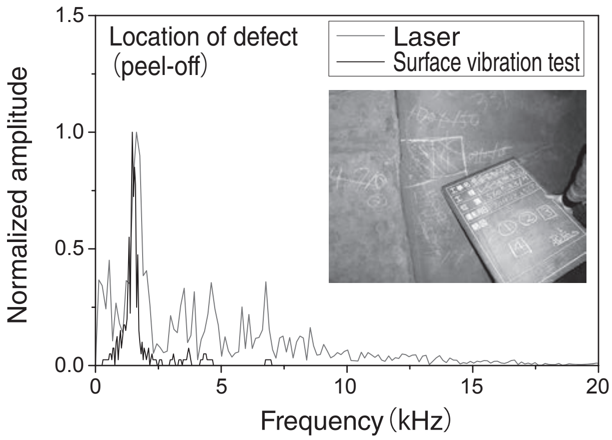

Fig. 7 Result of test in tunnel for the Shinkansen

4. Development of the practical device

According to the result of the verification test conducted in a tunnel for the Shinkansen using the prototype device, it is confirmed that this Technology allows to reduce the vibration and noise caused by the maintenance vehicle, and that the measurement technique using this prototype device is established. However, there is concern about the limitation on the working time for the prototype device that is structured to be drawn by the maintenance vehicle because the distance between the maintenance bases and the work site is long and it is required to depart the maintenance base after working hours have started. Therefore the prototype was improved to enable it to run on the inspection aisle provided in the center of the tunnel for the Shinkansen to reduce the loss caused by the transfer using the maintenance vehicle and to extend and allow to effectively use the limited working hours in the night. Furthermore, it was downsized to allow to run on the central aisle of the tunnel for the Shinkansen while maintaining the functionality of the prototype device. The laser is irradiated to the concrete through the irradiation window that is provided on the device as shown in Figure 8. The distance between the device and the concrete surface is measured with the laser. The device is controlled to always focus the laser on the concrete surface. This distance measurement also aims to confirm that the laser is not irradiated to objects other than the concrete such as the accessories for the overhead contact line. The power source car is equipped with a battery and inverter to operate the laser and measurement devices. As a result, it is allowed to significantly extend the time that can be used for inspection compared to the method using the maintenance vehicle. It is expected that it is allowed to save labor for the inspection for which significant manpower and time are required by making the device ready for practical use.

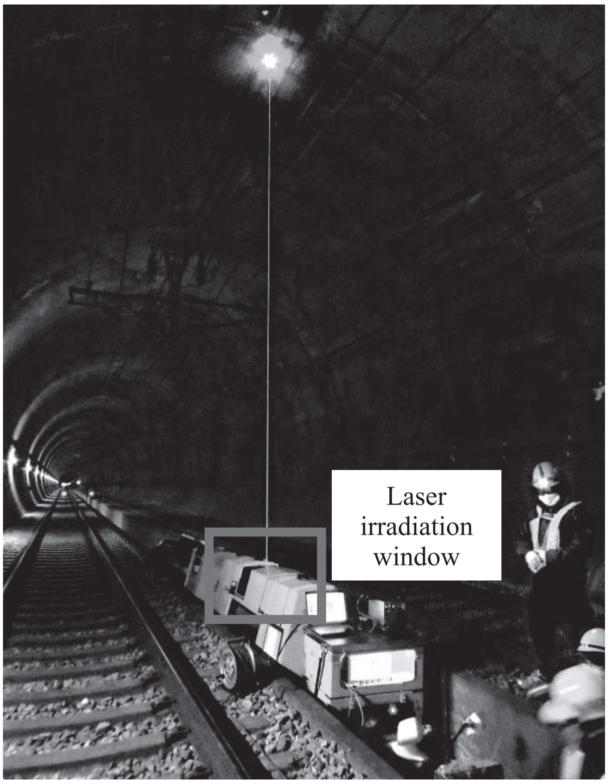

Fig. 8 Laser measurement for tunnel lining

5. Conclusion

In this study, the concrete peel-off detection device using the non-contact measurement technique with laser and the defect determination algorithm are established and developed in a system as an alternative to the impact acoustics method. The results are as follows:

① The prototype of the concrete peel-off detection device was developed by providing it with a vibration isolation base and soundproof room to accommodate use under the conditions regarding vibration and noise in the site. It was confirmed that the device can be used to conduct laser measurement in the site.

② The defect determination algorithm to determine the location of concrete peel-off was proposed.

③ The laser measurement device that can run on the central aisle in a tunnel for the Shinkansen was developed.

For this study, I received great cooperation from the concerned parties. I would like to express my gratitude to them.

Reference

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NEWS

○Running test on commercial line using superconducting feeding cable

On March 27, Railway Technical Research Institute (RTRI) conducted a running test by installing a superconducting feeding cable in the section between Takyo and Shuzenji stations of the Sunzu Line of Izuhakone Railway to supply power to the feeder to carry out a round-trip operation in the section.

Because its electric resistance is zero, the superconducting feeding cable is expected to contribute toward energy saving in direct current electric railways due to reduction of regeneration cancellation and feeding loss, and toward the load leveling between the substations. Therefore RTRI is dedicating its effort for its development. RTRI has conducted running tests in the test track on RTRI's premises by installing the superconducting feeding cable with a length of 31 m and 310 m in 2013 and 2014 respectively, and confirmed that it is possible to use for direct current electric railways.

The running test this time mainly aims to verify the validity of basic technology for commercialization such as the connection of the superconducting feeding cable to the facilities actually used for commercial operation, and checks on operation of the system. The running test was conducted before the dawn of May 27 after installing the superconducting feeding cable of the length of 6 m with a current capacity of 2080A in the substation of the Sunzu Line to integrate with the feeding circuit. The cable was electrified after cooling it to approx. 70K with liquid nitrogen, and then the test train (3-electric car train of the Izuhakone Railway 3000 series) was operated to conduct a round-trip operation with the same pattern as that for commercial operation.

RTRI will advance the development of the superconducting feeding cable while conducting test runs in a commercial line with the aim of introducing the technology to the lines of the JR group and private railways.

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