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“Technical Research and Development for Road Policy Quality Improvement”
Study Summary

No.	Title	Principal Researcher
No.2021-5	Research and development of diagnostic technology based on quantitative data of flaking and spalling of road structures such as bridges and tunnels using a laser hammering system	Nagoya University Prof. Hikaru Nakamura

Laser hammering system, that is progress in social implementation for tunnel inspections, can remotely measure and quantify the displacement (movement) of the concrete surface instead of using sound waves. By quantify "state of flaking and spalling", the inspection will evolve from detection and recording to diagnostic technology. It led to expand the application to road structures such as bridges and improve quality and efficiency of inspections.

1. Backgrounds and Objects

To expand the application of laser hammering system to road structures such as bridges and tunnels and social implementation, it is necessary to address the following issues; 1) High efficiency of inspection such as improvement of operability and shortening of preparation of laser hammering system and work time, 2) Laser irradiation technology that enables detection of defect from a farther position, 3) Improvement of detection accuracy for flaking and spalling of concrete, 4) Provision of quantitative information required for diagnosis. The purpose of this research was to solve these four problems, and to make greatly progress in the social implementation of the laser hammering system.

2. Activities in Research Period

[Theme 1] "Development of high-speed measurement method for laser hammering system"
In previous, the time for laser hammering inspection was about 4.2 times longer than the conventional hammering test. By developing a new control system combined with the result of AI extraction such as obstacles and cracks, we reduced the measurement points by shortening the irradiation position setting time and optimizing the irradiation area and succeeded in shortening the inspection time about 2.2 times compared with conventional hammering test.
[Theme 2] "Improvement of laser hammering system for inspection of bridge structures"
We have developed a portable long-distance laser hammering system. In the defect detection test of the actual bridge structure, under the condition of 30m distance and incident angle of 45 degrees, we succeeded in detecting defects that inspector judged to be level II.
[Theme 3] "Adding the ability to detect flaking and spalling in various states to a laser hammering system"
We devised new method to create concrete specimen simulating various damage conditions of flaking and spalling in a short period of time and confirmed that level I to III flaking and spalling can be detected from tests of many damaged specimens. In addition, we succeeded in detecting the region judged to be level II by inspection engineers in actual structures such as road bridges and road tunnels.
[Theme 4] "Construction of recording formats useful for continuous observation and measures, and thresholds and evaluation methods that support diagnosis"
As a new evaluation method to distinguish level II and III defects, we proposed an "evaluation method from attenuation waveform" using a "normalized waveform integrated energy curve" that focuses on the decay process of the decay waveform.

3. Study Results

[Theme 1] For the development of AI extraction of obstacles, it was confirmed that obstacles in MIMM-acquired images can be automatically extracted with an extraction rate of more than 90% through deep learning with approximately 50,000 obstacle images as a base. For the development of AI extraction of dense cracks region, we constructed a processing logic to calculate a risk score that leads to spalling based on the density and number of intersections in the AI-extracted dense crack region. In the demonstration test of the tunnel structures, as shown in Figure-1, we have succeeded in improvement of inspection speed by narrowing the region of inspection to the joints with dense cracks, setting appropriate inspection pitches and instructing the coordinates to the laser hammering system.

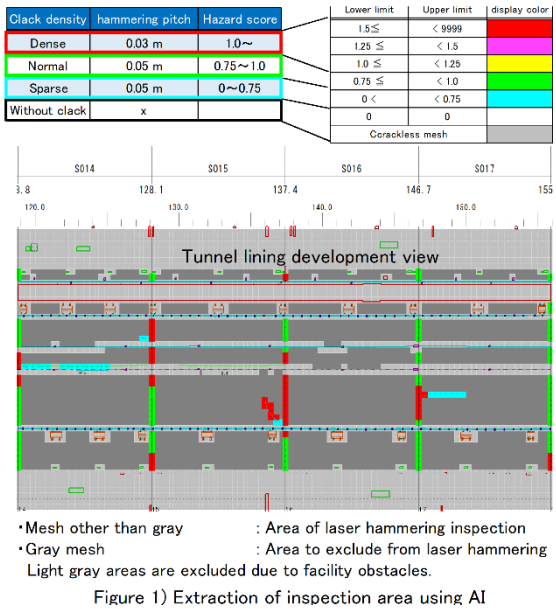

Figure 1) Extraction of inspection area using AI

[Theme 2] We have developed a technology for long-range laser hammering method. In a performance test using a concrete specimen at a distance of 40m, we have succeeded in detecting a 10 mm-deep defect at an angle of incidence of 60 degrees and a 30 mm-deep defect at an angle of incidence of 45 degree. In addition, a portable long-range laser hammering system was developed, and in a defect detection test at an actual bridge structure under the conditions of 30 m distance and an angle of incidence of 45 degree, as shown in Figure-2, it succeeded in detecting a defect that an active inspector judged to be Level II.

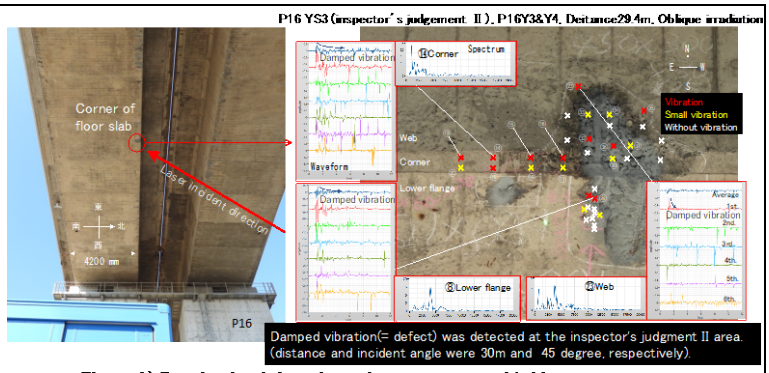

Figure 2) Result of a defect detection test at actual bridge structure

[Theme 3] New method was developed to create specimens simulating various damage states of flaking and spalling in a short period of time by applying internal expansion pressure with non-explosive demolish agent. 28 specimens created by this method was tested by (1) laser hammering, (2) hammering test by active inspector, (3) hammering test by AI hammering checker, (4) hammering test by steel ball drop, (5) knocking off and (6) cutting. It was confirmed that detection of level I-III flaking and spalling were possible. Applicability was also confirmed for actual structures such as road bridges and road tunnels.

[Theme 4] As a new evaluation method to distinguish level II and III defects, we proposed the "evaluation method from attenuation waveform" focusing on the attenuation process. In addition, an evaluation method as areal defect was also developed to evaluate the results of point measurement, assuming the case that the measurement pitch would become wider due to faster laser hammering inspection. This method enables to display as contour map of the inspection results. As shown in Figure-3, we have succeeded in obtaining consistent result of the region determined as Level II and III, hammering test and cut surface of concrete specimens.

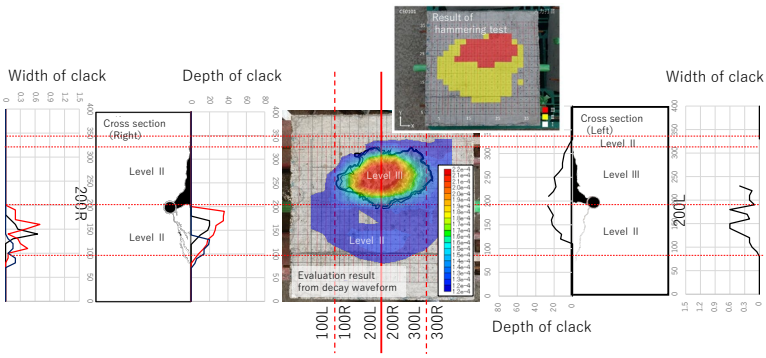

Figure 3) Comparison between hammering test and evaluation result from decay waveform of surface vibration

4. Papers for Presentation

・S. Tomoto, N. Hasegawa, H. Okada, S. Kondo, T. Kitamura, M. Nishikino and **H. Nakamura**: Study on advancement of diagnostic support technology for tunnel lining concrete by performing raster scan measurement using laser hammering system, Journal of Structural Engineering, Vol.68A, pp.671-684 (2022).

・**H. Nakamura**, S. Tomoto, H. Matsunaga, F. Sugiyama, T. Miura: Proposal of a method for generating artificial corrosion cracks using non-explosive demolish agent with arbitrary crack patterns and damage level, Journal of Structural Engineering, Vol.69A, pp.718-733 (2023).

・N. Hasegawa, M. Nishikino, H. Okada, S. Kondo, K. Sakamoto, S. Kogure, M. Abe, S. Tomoto and **H. Nakamura**: Advanced inspection method of infrastructure using Joule class pulse laser -Laser Hammering System-, The Review of Laser Engineering, Vol.51, No.9 (2023) in press.

5. Study Development and Future Issues

With social implementation of laser hammering system, it will become easier to record the state of flaking and spalling as quantitative data of vibration of concrete surface. This will enable diagnosis using quantitative data, evaluation of the progress of deterioration, and acquisition of accurate location, and is expected to advance the maintenance management cycle. For this technology to be widely used in society as an inspection support technology, it is necessary improvement of inspection speed and decrease of cost to the same or lower than the cost of conventional inspections.

6. Contribution to Road Policy Quality Improvement

If the laser hammering system can be automated a series of processes from setting the laser irradiation area to diagnosis of the defect, even inexperienced inspectors can easily operate. This will enable to support to future shortage of inspectors.

7. References, Websites, etc.

Not in particular.