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Special Issue

AE and Related NDT for Damage Evaluation of Civil Structures

Damage evaluation of an internal concrete in steel-plate bonded slabs with anchor-bolts

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ABSTRACT

Re-deterioration is currently found in reinforced concrete (RC) slabs of highways, which were retrofitted with steel-plates. However, the presence of asphalt pavement and steel-plates covering the top and bottom surfaces of the slabs makes it extremely difficult to determine internal damage of concrete. The damage could significantly affect the load carrying capacity and the durability of the whole structure. In this study, a novel technique for proper inspection and evaluation is proposed, by applying the temporary anchors left on the steel-plates bonded as sensing probes. An impact is driven by hammering the head of anchor bolt, which is employed as a sensing probe to detect elastic waves through RC slabs. By focusing on the characteristic frequency band of the Rayleigh waves, the arrival time and the associated velocity are to be evaluated. An inspection was carried out on an existing bridge in service for the verification of the sensing technique. It is found that the anchor-bolt sensing technique proposed is applicable to evaluation of internal damage of concrete slabs retrofitted with steel-plates.

1. Introduction

There exist many road bridges in highways constructed up to the old design standards in Japan. These RC slabs are, however, known to be normally thinner, and leading to the lower load carrying capacity and durability than those of today. In order to sustain the service and to improve the load carrying capacity and durability, many of the RC slabs often have been re-strengthened by bonding steel-plates to the bottom surfaces, as shown in Figs. 1 and 2. On the Hanshin Expressway in Japan, an expressway network important in the Kyoto-Osaka-Kobe area consists of about 70,000 panels of RC slabs (around 2–3 m on each side per panel). At the present stage, almost of all panels have been retrofitted with the steel-plate bonding method. However, steel-plate bonded RC slabs have been already in service over 30 years since they were retrofitted. As a result, such deterioration as debonding of the steel plates and water leakage are found in some panels. Although so far no serious damage which requires immediate repair-actions is reported, careful monitoring is definitely necessary for maintenance to prognosticate further evolution of the damage in the RC slabs. In the case of monitoring these RC slabs, the steel plates covering the bottom surfaces do not allow visual observation of internal concrete damaged. Although the presence and area of debonding might be estimated by hammer-tapping tests, no methods are readily available to inspect the damage of internal concrete [1].

In this paper, a novel technique for inspection and damage evaluation of internal concrete in existing steel-plate bonded RC slabs in service is developed on the basis of the elastic-wave method using temporary anchor-bolts as sensing probes.

2. Anchor bolt sensing for internal concrete

2.1. Outline of sensing

According to the previous study [2], it is found that the debonding of steel-plates does not necessarily lead to the reduction in load-carrying capacity. Therefore, the damage evaluation of steel-plate bonded RC slabs could be associated with the soundness of concrete in the slabs. Since the majority of repair work should be done on site of an existing bridge, it is preferable to reduce the

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Fig. 1. RC slab bonded with steel-plates.

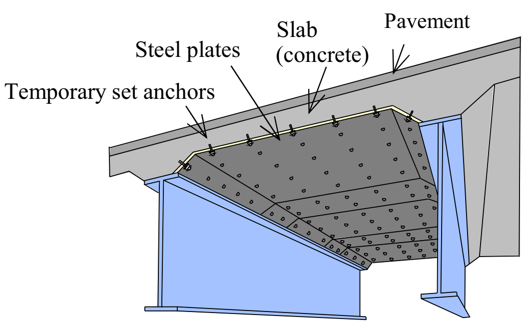

Fig. 2. Schematic illustration of steel-plate bonding method.

impact to the public as much as possible. Accordingly, a core sampling has been limitedly applied as a destructive test, which inevitably requires traffic restrictions.

In this regards, a non-destructive technique (NDT) is to be developed, which could evaluate the damage of concrete through the plate-covered bottom surfaces of the slabs, without causing any impact to the traffic and any damage to the structure. A proposed technique is an NDT technique based on the elastic-wave method, applying temporary anchor bolts installed in the steel-plate bonding as sensor probes. Here-in-after, the damage detection system using the anchor bolts is referred to as the anchor bolt sensing technique.

Fig. 3 shows the outline of the proposed anchor bolt sensing technique. An impact is driven by hammering the anchor-head with a steel ball of 15 mm diameter, and thus elastic waves are generated and propagate in concrete. The anchor-bolt is embedded about 20 mm in depth from the surface of the steel-plate. After elastic waves propagate from the impacted anchor, they are detected and analyzed to evaluate the damage of internal concrete inside the RC slab. The sensor for detection is installed at the head of the anchor-bolt in the receiving side. To determine the excitation time, another sensor is installed on the surface of the steel-plate right next to the impact-side anchor bolt as shown in the figure.

Acoustic emission (AE) sensors (resonant frequency of 140 kHz) were used in the test for the measurement in both the impact and the receiving sides. At least, impacts were driven three times per one measurement, and a representative waveform was selected. Waveforms were recorded by the waveform recorder at a sampling rate of 0.2 μs with the number of samplings of 25,000.

2.2. Procedure proposed for waveform analysis

In the ultrasonic test, the use of P wave velocity of first-arrival is normally recommended [3]. In the present research, it is found that the evaluation of internal damage of concrete in steel-plate bonded slabs is not an easy task [4]. This is likely because P-waves, which constitute the majority of the first-arriving waves, could travel faster through the steel plates than the internal concrete, as irrespective of the damage degree in concrete. Consequently, the evaluation of the damage in internal concrete is attempted, by applying information of propagation of the Rayleigh waves excited at the anchor bolt due to the impact of the steel ball. The wavelet transform reference was applied to the waveforms obtained by the anchor bolt sensing technique to analyze the magnitude of energy of the Rayleigh waves.

In a preliminary test, two reinforced concrete specimens shown in Fig. 4 were prepared for the measurement by the anchor bolt sensing technique. The dimensions were 210 mm × 210 mm × 2200 mm. One was a control specimen representing unaffected condition, and the other was a defective specimen representing concrete with internal damage. The defect specimen was made of poor quality concrete up to the depth of 20 mm from the interface with the steel plate. Mechanical properties of the concrete are given in Table 1.

Fig. 5 shows results of the two models for Measurement pair 5–2, which implies that the impact was driven at location 5 and the wave was detected at location 2 in Fig. 4. In the wavelet analysis, the horizontal axis presents a running time, while the intensity of the spectrum is given along the frequency at the vertical axis. The contour colors represent the spectral intensity. The closer the color reaches to red, the higher the spectral intensity represents. High spectral intensities are found at the time from around 500 μs elapsed to 2000 μs in both the control and defective models, where the peak frequency is found at around 10 kHz. A zone of the high spectral intensities after 500 μs elapsed and at around 10 kHz in the contour graphs reasonably correspond to arrivals of the P-, S- and Rayleigh waves, in this order in accordance with their propagation velocities. Multiple reflection could occur in the

Fig. 3. Schematic diagram of measurement.