NON-DESTRUCTIVE EVALUATION FOR HORIZONTAL CRACKS IN EXISTING RC SLABS BY ANALYSIS-AIDED IMPACT ELASTIC-WAVE METHODS

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In this study, impact elastic-wave method was performed at the bottom surface of RC slab cut from an existing highway bridges to survey the horizontal cracks. Before measurements by impact elastic-wave method, impact response analysis was applied to determine optimal steel ball diameter, distance between impact point and receiving point of elastic-wave. Efficiency of analysis-aided impact elastic-wave method was confirmed by drilling and observing the interior of the RC slab by stick scanner. Evaluation results by this method agreed well with results of visual inspection. Thus, validity of the analysis-aided impact elastic-wave method on detection of horizontal cracks in RC slabs of highway bridges was demonstrated.

Keywords: RC slabs; horizontal cracks; non-destructive testing; impact elastic-wave methods.

1. Introduction

Horizontal cracks have been recently found in cut cross-sections of deteriorated RC slabs of highway bridges in Japan (shown in Fig. 1)¹.

In this study, impact elastic-wave method was performed at the bottom surface of an RC slab cut out from an existing highway bridge to survey horizontal cracks. Before measurements by impact elastic-wave method, impact response analysis was applied to determine elastic-wave input method and elastic-wave detection method.

Fig. 1. Horizontal cracks in cut cross-sections of RC slab.

2. Outline of a Reinforced Concrete Slab Cut from a Highway Bridge

An outline and dimensions of a RC slab cut out from a highway bridge is shown in Fig. 2. The thickness of the RC slab was increased by additionally applying steel fiber reinforced concrete of a thickness of 60 mm and an asphalt pavement of the same thickness. The slab was approximately 2000 mm in width, 6400 mm in length and 320 mm in thickness.

Fig. 2. Outline of a RC slab used in an existing highway bridge.

3. Outline of the Proposed Method

This chapter describes a method for determining an appropriate combination of “I: elastic-wave input method” and “II: elastic-wave detection method” for a RC slab cut from a highway bridge, through 3-dimensional impact elastic analysis. In general, it is not so easy to correctly simulate propagation behavior of elastic wave, especially ultrasonic wave (the wavelength is relatively small) in concrete because concrete is inhomogeneous material that contains aggregates and voids in cement paste matrix. However, when the impact elastic-wave method is applied, as elastic wave of relatively long wavelength is used, reflection of wave at interfaces between aggregates/voids and cement paste matrix would rarely occur. So, in the case of using the impact elastic-wave method, concrete can be thought as homogeneous material. Then we can utilize impact response analysis to simulate elastic behavior in target concrete members. That is why we apply this type of analysis for this study.

3.1. Analysis model

The width and the length of the analysis model were set at 2000 mm based on the results of past studies of the authors² to minimize effects of reflection at side surfaces of the model. The thickness of the slab was set at 320 mm as same as the thickness of the RC

slab cut from a highway bridge. A disk-shaped void portion was set in the model to simulate a horizontal crack. The diameter of the void portion was 200 mm. The depth of the void portion was set at 60 mm that was equivalent to the distance from the bottom surface of the slab to the tensile reinforcement. Solid elements defined by eight nodal points were adopted for the model. One side of an element had a length of approximately 10 mm. The model was supported on four sides 80 mm x 80 mm each on corner of bottom surface (shaded part in Fig. 3). For the boundary condition, displacement at all nodal points in the shaded section (in x, y and z directions) were fixed. An impact force was applied at a nodal point at the center of the bottom surface (shown in Fig. 3). The point of output was 50 mm away from the point of input.

Fig. 3. Analysis model with void portion.

3.2. Selection of elastic-wave input method

It has been known that the characteristics of frequency of elastic-waves produced by tapping a steel ball against the slab surface are affected by the diameter of a steel ball². In order to determine “I: elastic-wave input method”, impact response analysis was conducted by simulating the tapping by steel balls with various diameters. The frequency spectra obtained by impact response analysis are shown in Fig. 4.

A steel ball was selected from among three steel balls that are capable of evaluating both models with and without void. Acceleration waveform was selected as output and maximum entropy method was adopted as the frequency analysis method.

The arrows show the theoretical peak frequency corresponding to the model thickness f_T . The broken lines indicate the theoretical peak frequency corresponding to the crack depth f_d . In the frequency spectrum obtained using a model without a void (shown in Fig. 4. a)), a peak is clearly identified nearly at the position of f_T at all steel balls of diameters. It was considered that slab thickness could be estimated properly in cases where a steel ball of 6.4, 12.8 and 15.7 mm diameter was used for tapping the slab surface.

Discussed next is the frequency area near f_d in the frequency spectrum obtained using a model with void (shown in Fig. 4. b)). Frequency peaked near f_d in 6.4 mm cases except the cases where a steel ball of 12.8 or 15.7 mm diameter was used. It was concluded based on the above discussions that a steel ball of 6.4 mm diameter was the most appropriate for evaluating both slab thickness and void depth.

Fig. 4. Frequency spectra for different steel ball diameters.

3.3. Selection of wave output positions

In this study, optimal distance between impact point and output point of elastic-wave was determined by impact response analysis. An impact force was applied at a nodal point at the center of analysis model (shown in Fig. 3). Frequency spectra obtained by impact response analysis are shown in Fig. 5.

Fig. 5. Frequency spectra for different distance between impact point and output point.

Points of output were set at 20, 50 and 100 mm away from the input point in x-direction. In these frequency spectra obtained using a model without a void, a peak clearly appeared nearly at the position of f_T at all distance. In the cases of distance of 20 and 100 mm, however, peaks also identified at other locations near f_T .

On the other hand, in these frequency spectra obtained using a model with void, a peak is clearly identified near f_d at distance of 20 and 50 mm. Therefore, it was concluded that distance between input point and output point of 50 mm was appropriate for evaluating both slab thickness and void depth.

4. A Case Study of Measurement of a Reinforced Concrete Slab Cut from a Highway Bridge

4.1. Outline of measurement

In order to verify the validity of “I: elastic-wave input method (tapping with a steel ball of 6.4 mm diameter)” and “II: elastic-wave detection method (distance between impact point and output point 50 mm)”, measurements were performed for a RC slab cut from a highway bridge as a case study (shown in Fig. 6).

Fig. 6. Outline of measurement points by impact elastic-wave method.

4.2. Results of measurement and discussions

Examples of characteristic frequencies obtained at several measurement points by impact elastic-wave method are shown in Fig. 7. This figure shows that a peak frequency in the frequency spectrum was identical to f_T at measurement point A2 and A5. It therefore seems that no horizontal cracks existed at the point A2 and A5.

Fig. 7. Examples of frequency spectra obtained in measurement.

In contrast, a single peak appeared in the area of frequency higher than f_T at

measurement points A6 and A10. The peak frequency in the frequency spectrum was 16 kHz at measurement point A6 and 12 kHz at point A10. Thus, there may be a possibility that horizontal cracks existed at depths of 125 and 167 mm from the bottom surface of the slab at measurement points A6 and A10, respectively (where C_p was 4000 m/sec). In order to verify the validity of the results of estimation by non-destructive measurement, holes of 25 mm diameter were drilled at measurement points A5 and A6. After the holes were drilled, rod-shaped scanner was inserted into the holes to film the internal cracks. It was thus clarified that the results of estimation by the analysis-aided impact elastic-wave method were in good agreement with visual inspection results (shown in Fig. 8).

Fig. 8. Panoramic images by rod-shaped scanner.

5. Conclusions

The following conclusions were obtained in this study.

- (1) As a better non-destructive method to detect horizontal cracks in RC slabs, a method was proposed for determining elastic wave input method and elastic wave detection method by impact response analysis before measurements by the impact elastic-wave method.
- (2) The proposed analysis-aided impact elastic-wave method was applied to a RC slab cut from an existing highway bridge as a case study. Obtained results by the method showed good agreement with the depths of horizontal cracks measured directly in boreholes.

References

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