Detection of Internal Defects in Concrete Structures by Analyzing Elastic Wave Propagation *

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Abstract

Though the impact echo method is commonly used for thickness measurement of plate concrete structures, the method to detect the internal defects in concrete structures is still not clearly established. Basically the impact echo technology is used to obtain the resonant frequency of flutter echo between the measuring surface and the opposite surface of a concrete plate.

The thickness can be calculated by dividing the elastic wave speed of the concrete by twice the measured dominant frequency. By this method, if the thickness of the plate is known, the wave speed of the flutter echo can be calculated.

We found out that the travel path condition of the wave affect the wave speed. The wave speed is almost always reduced if there is defected area on the path. In case the cross section of defect is circular, higher harmonic frequencies are generated near the direct top surface of the defected areas.

From these observations, distribution of the flutter echo's wave speed on the measuring plane shows the location of the projection area of the defect. The results of the experiments using concrete plate with voids show that the location of the voids are indicated by the area where the wave speeds of the flutter echo are slower than the areas with no voids. Also the method and the results for location detection and degree of filling of the actual PC bridge sheaths are shown in this paper.

Key words: Impact echo, NDT, Sheath, Filling rate

1. Introduction

The Impact Echo Method is commonly used for internal defect detection with a resonant frequency caused by the multiple reflections between measuring surface and the internal defect.

From the results of experiments using the concrete plate specimens with sheaths of filling rate variation from 0% to 100%, it is found that the wave speed while passing through the defected part was reduced in accordance with the size of the defect. That is, if the areas where the wave speed reduction of the multiple reflections are detected, shapes of the internal defects reflected on the measuring surface are obtained. From the results of a field test on an actual PC bridge, the point where the wave speed decreased shows the location of the sheath. And if the shape of the internal defect is circular in shape, harmonics are observed near point of the defect. This report shows the method to detect the internal defects by using the variance in the wave speed of the multiple reflections in a concrete plate.

2. Theory of Impact Echo Method of us

The theory of the impact echo method is based on the frequency analysis elastic wave, when applied on the measuring surface of the concrete plate, propagates between the measuring surface and opposite surface, and then the thickness related resonant frequency is established. Figure 1 shows the schematic illustration of the measuring method of the impact echo method of the authors. As shown this figure, the elastic wave is generated by steel ball blow and the response of the concrete plate is measured by a high sensitivity accelerometer placed near the blow point. The thickness related resonant frequency is generated by the multiple reflections between the two surfaces. It is the flutter echo phenomena of acoustic engineering. Equation 1 shows the relationship between the period of the vibration measured on the concrete surface (T), the thickness of the plate (D) and the elastic wave speed in the concrete (V_p).

$$D = \frac{1}{2} V_p T \tag{1}$$

The thickness of the plate is obtained by measuring the period(T). If the wave form of the vibration which contains the resonant frequency is like sinusoidal wave, the thickness of the plate is determined by the peak frequency (f_0) obtained by the using frequency analysis.

$$D = \frac{1}{2} \frac{V_p}{f_0} \tag{2}$$

The frequency range used for the impact echo is usually lower than about 25 kHz; even if it is affected by mass of the steel ball and stiffness of the concrete surface.

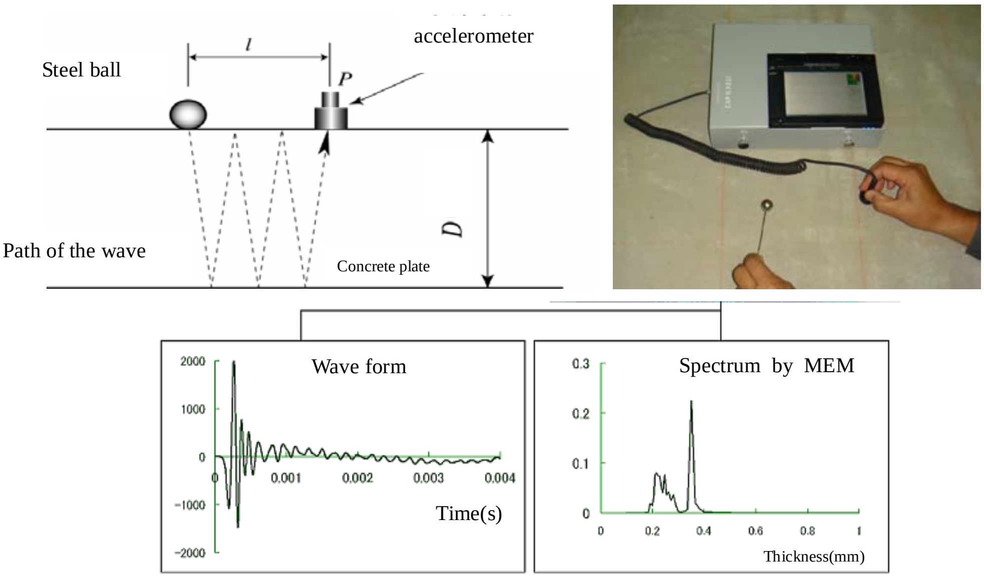

Fig1 Schematic illustration of the Impact echo method of us

3. Numerical Simulation for internal defect detection

The elastic stress wave in the concrete propagates with a minute volume change and thus resulting in the multiple reflections between the two parallel planes. The numerical simulations of the wave propagation in a one dimensional bar, which has mechanical impedance changes in the middle part, are performed to clarify the relationship between the wave speed and the ratio of sectional area loss (defect). Figure 2 shows a result of the numerical simulation as the relationship between the length of the defect and resonant frequency reduction. In this figure, it is found that the wider the defect, the more reduction in resonant frequency, and the both are in linear relationship. The longer the defect, the more frequency components are observed. It considered that these frequencies are due to the multiple reflections between both ends of the bar and the defect, and both ends of the defect.

In this numerical simulation, it was found that if there were some defects or non homogeneous part on the elastic wave propagation paths, it caused resonant frequency reduction. And if the wave velocity value was not changed in the thickness analysis, the thickness of defect position was observed thicker than the actual thickness. That is, the location of the defect is detected as the thicker portions by examining the spatial distribution of the analyzed thickness.

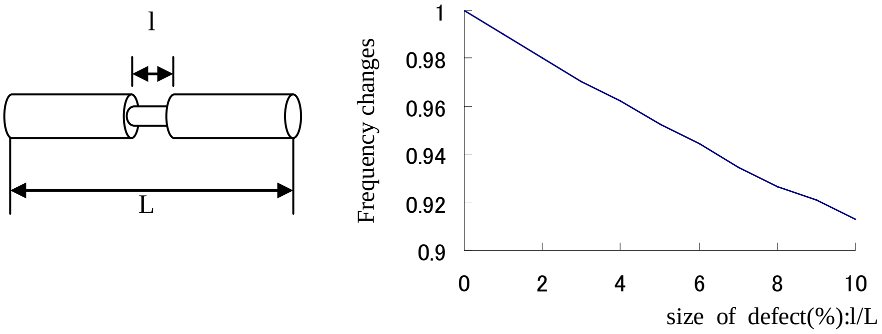

Fig.2 Frequency changes due to size of defect

4. Laboratory experiment using specimen with void

4.1 Specimen

The specimen used for the experiment is 350mm in thickness, 1000mm in width and 2500mm in length with 93mm in diameter plastic sheathes with filling rate variation from 0 to 100% and buried 200mm deep as shown figure 3. There are no reinforced bars in the specimen.

4.2 Methods for Impact and measurement

The authors used the iTECS (our impact echo method instrument). Three lines of measurement are employed that is 250, 500mm away from the front side of the specimen. Measuring points were 50mm apart on each measuring line and 30mm diameter steel ball was used as the impactor. The thickness was calculated using Eq.(2) and the wave speed of the specimen was measured prior to the experiment.

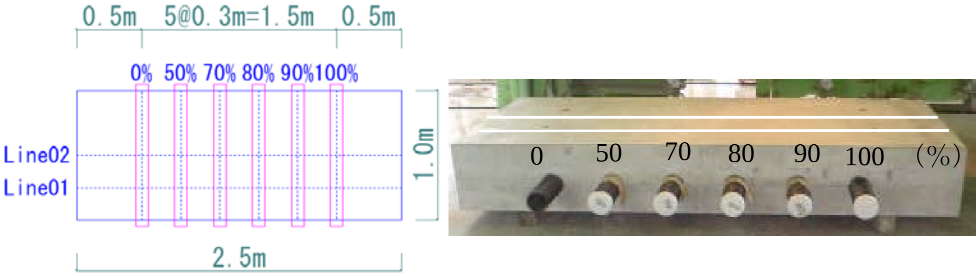

Fig.3 Specimen

5. Results of the experiment

5.1 Location of the sheath

The results of the frequency analysis at the points directly above the sheaths (Filling Rate 0,50 and 100%) are shown in Figure 4. The maximum entropy method (MEM) was used for frequency analysis. Figure 4 shows the averaged power spectrum analyzed as running spectrum of 8 ms, and the thickness was calculated using Eq.(2) keeping the wave speed constant. The thicknesses of the points directly above the sheaths resulted thicker than the actual thickness of the specimen plate regardless of a filling rate. In additions the harmonic frequencies were also observed near the sheath position. Figure 5 shows the contour map indication of the frequencies on the plane comprised of distance and depth. The color in Fig.5 indicates the intensity of power spectrum, the red color shows the strongest and the navy color the weakest power. The locations of the sheaths are indicated as the white circles and the number on each circle show the filling rate of each sheath. The depth of each sheath observed is deeper than the thickness of the plate. The wave speed used for thickness analysis was 4,200m/s and this value was not changed. The reason why the depth of the sheaths were observed deeper than the plate thickness was that the apparent wave speed of the sheath position is slower than the actual wave speed of the plate specimen. And it is shown that there are no resonant frequencies of the multiple reflections between the measuring surface and the top of the sheath.

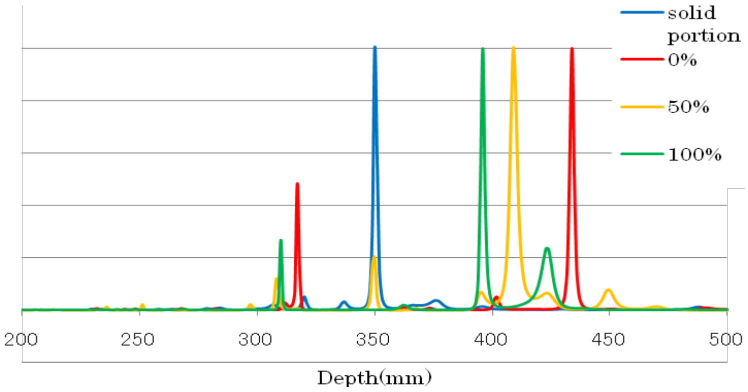

Fig.4 Results of frequency analysis

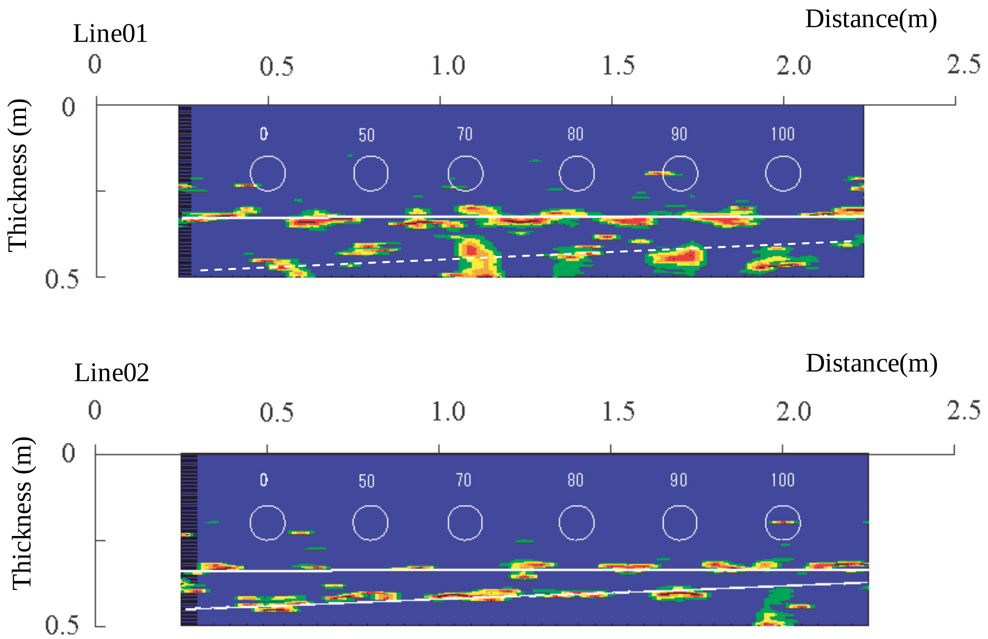

Fig.5　Results of analysis　（MEM averaged running spectrum）

Figure 6 shows the relationship between the filling rate of the sheath and the apparent wave speed. This figure shows apparent wave speed is affected by the filling rate of the sheath.

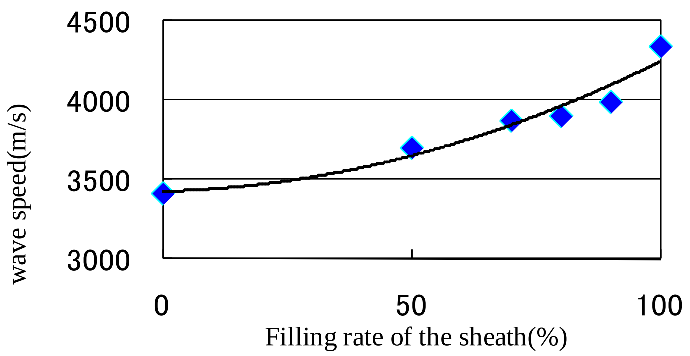

Fig.6　Filling rate and wave speed

6. Field experiment using Actual PC Bridge

6.1 Bridge description

The bridge tested is a road bridge and the age is almost 40years and there are many exfoliations due to frost damage and crack repair lines along the embedded sheath. The bridge beam is simple support and the sheath is a steel-made.

6.2 Bridge measurement

The measuring area and photo are shown in figure 7. The examined area is 800mm in height and 2200mm in width. and this area is divided into 50mm×50mm mesh. At each cross points of the mesh, we measured the vibration response of the bridge beam plate to the impact force. A steel ball of 15mm diameter and 14gm in weight was used as the impactor. The sheaths used for this bridge were made from steel. The measurements were taken for two beams (Beam 1 and 3) as shown Fig.7.

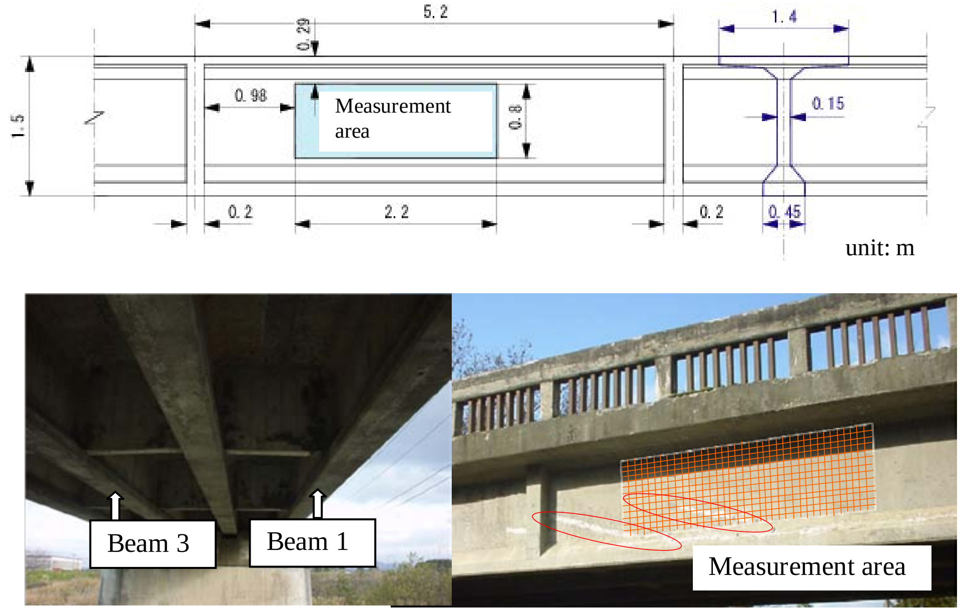

Fig.7 Bridge, beams and measuring mesh

6.3 Detection of the sheath location

After analyzing the frequency spectrum, the contour maps where the apparent thicknesses were 20% thicker than actual thickness of the bridge beam were made. Figure 8 shows the contours of the accumulated power spectrum intensity where apparent thicknesses are larger than 180mm. The thin lines or dashed lines indicate the location of the sheaths. The location of the lower frequency observation and the sheath location are almost the same. The location of the sheaths were detected clearly.

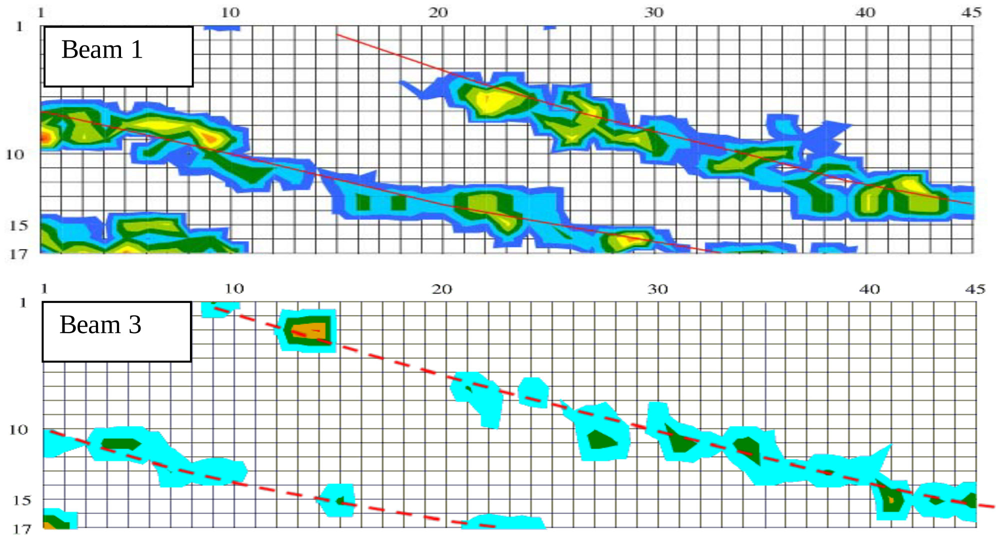

Fig.8 Distribution of the power spectrum intensity depth more than 180mm

7. Conclusions

The apparent speed of the elastic wave is reduced if there were defect(s) on its path. Therefore, it is possible to detect the location of any defect or embedded structure like a sheath on the measuring plane if the contour of apparent wave speed is obtained. And it is found that there are no multiple reflections on the circular like embedments such as a sheath and harmonic frequency is observed near such embedment or defect.

The filling rate of the sheath is estimated by the reducing rate of the apparent wave speed. If 100% filled, the apparent wave speed is almost the same as the wave speed of the solid and if the sheath is not filled, the apparent wave speed is reduced by 20%.

The harmonic frequency of the basic resonant frequency of the plate thickness were observed near the location of the void sheaths. This fact shows that the distribution of the harmonic frequency indicates the location and filling rate of the sheath.

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