Detection of internal defects of concrete structures by analyzing wave speed scattering

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ABSTRACT

The method to detect internal flaws by analyzing the scattering of the elastic wave speed in the direction of multiple reflections between both ends of the plate like concrete structures is discussed in this paper.

The theory of detection of the internal flaws, the impact echo and its related technologies were applied by using the frequency of the flutter echo between the measuring surface and the internal flaws.

However, if the size of the flaw is small or if the surface shape of the flaw is not clear, careful examination is necessary whether the flutter echo continues long enough to analyze the characteristic frequency by the normal FFT.

The limitation of the internal flaw detection by the impact echo method technologies is discussed by using the results of the theoretical examination of the wave propagation in the plate with a small void. Then with the results of the laboratory experiments using concrete plate with voids, the fact that the wave speed becomes slower if there is a void just under measuring point is shown. And finally from the results of a field examination of the actual PC bridge, the method to detect the exact locations of the void sheaths by using the scatter diagrams of the wave speed was confirmed.

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.

THEORY TO DETERMINE THE WAVE SPEED OF THE PLATES OF KNOWN THICKNESS

When a semi-infinite elastic solid plate was hit by a small steel sphere, stress waves can be generated and propagated.

Then on the conditions whose measuring plane and reflective surfaces are free ends (for example, concrete / air interface), the waves propagate between the both ends, and then the thickness related resonant frequency is established.

Furthermore, the standing wave’s wavelength at this time serves as half of the thickness, as shown in the equation (2).

$$\lambda = 2D \tag{1}$$

where λ is wave length of standing wage, D is the thickness.

Since all stress waves obey the fundamental relation of equation(2)

$$V = f\lambda \tag{2}$$

where V is the wave speed, f is the resonant frequency and λ is the wave length of the standing wave. Thus wave speed can be determined from the equations (1) and (2).

Figure 1 shows the schematic illustration of the measuring method of the authors.

As shown in this figure, the elastic wave is generated by steel ball hit and the response of the concrete plate is measured by a high sensitivity accelerometer placed near the hit point.

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

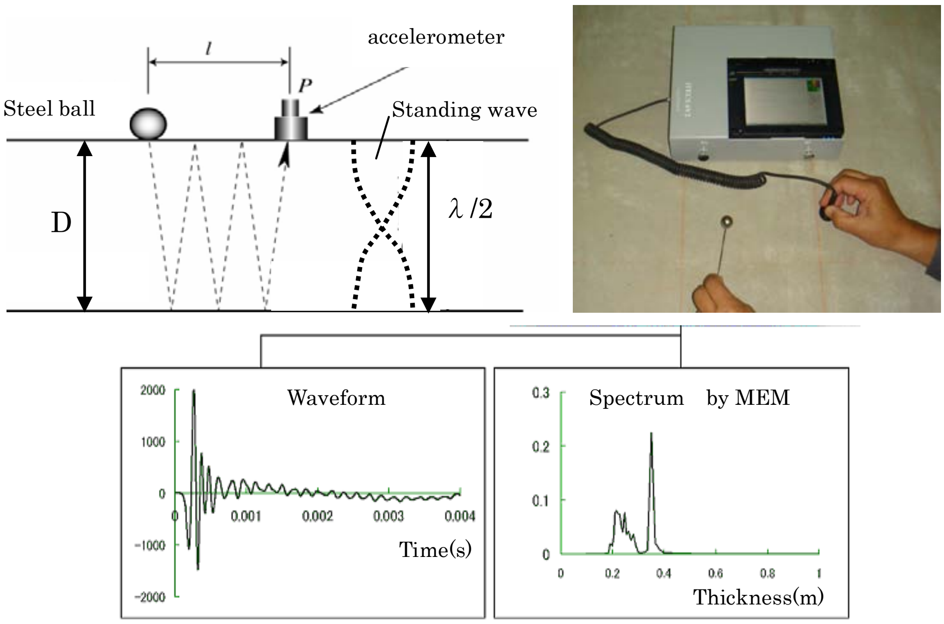

Fig1 Schematic illustration of the method for thickness determination

NUMERICALSIMULATION FOR INTERNAL DEFECT DETECTION

2-D Simulation of wave propagation

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.

Fig 2 shows a comparison of the wave propagation at various times after the impact for the normal model and model with a void. (Results of the two-dimensional simulation)

From this result we can find that it takes longer time to reach to the opposite surface for the model with a void. To know more precisely, we did numerical simulation by using one-dimensional model.

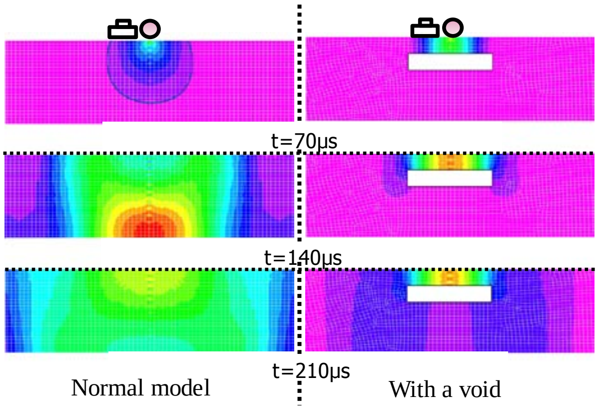

Fig.2 Results of the 2-D simulation (Obase et al,2005)

1-D Simulation of wave propagation

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 3 shows the result of the numerical simulation as the relationship between the size of the defect and apparent wave speed changes from resonant frequency changes. In this figure, it is found that the wider the defect, the more reduction in apparent wave speed, and the both are in linear relationship.

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 apparent wave speed 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 slower portions by examining the spatial distribution of the wave speed.

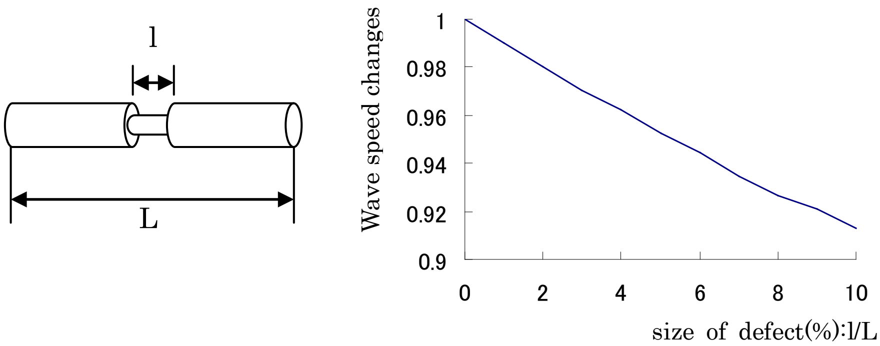

Fig.3 Frequency changes due to size of defect

LABORATORY EXPERIMENT USING SPECIMEN WITH VOID

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 4. There are no reinforced bars in the specimen.

Measurement

The authors used the iTECS (our impact echo method instrument). Two 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.(3) and the wave speed of the specimen was measured prior to the experiment.

$$D = V / 2f \tag{3}$$

where D is the thickness, f is the resonant frequency , and V is the wave speed

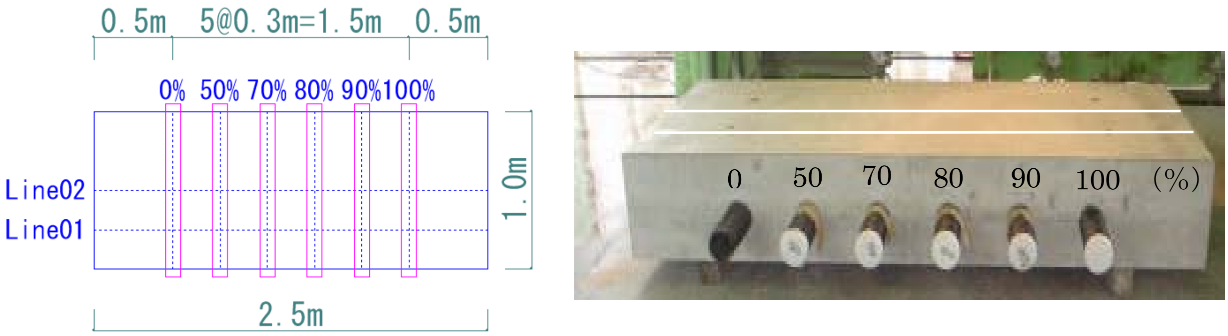

Fig.4 Specimen

RESULTS OF THE EXPERIMENT

Location of the sheath

The results of the frequency analysis at the points directly above the sheaths (Filling Rate 0, 50 and 100%) and no sheath portion are shown in Figure 5. The maximum entropy method (MEM) was used for frequency analysis. Figure 5 shows the averaged power spectrum analyzed as running spectrum of 8 ms, and the thickness was calculated using Eq.(3) keeping the wave speed constant. The thicknesses at 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 6 shows the contour map indication of the frequencies on the plane comprised of distance and depth. The color in Fig.6 indicates the intensity of power spectrum, the red color shows the strongest and the navy blue 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 calculated thickness of the specimen is thicker than the actual thickness where sheaths are embedded. 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 at 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 around the sheath.

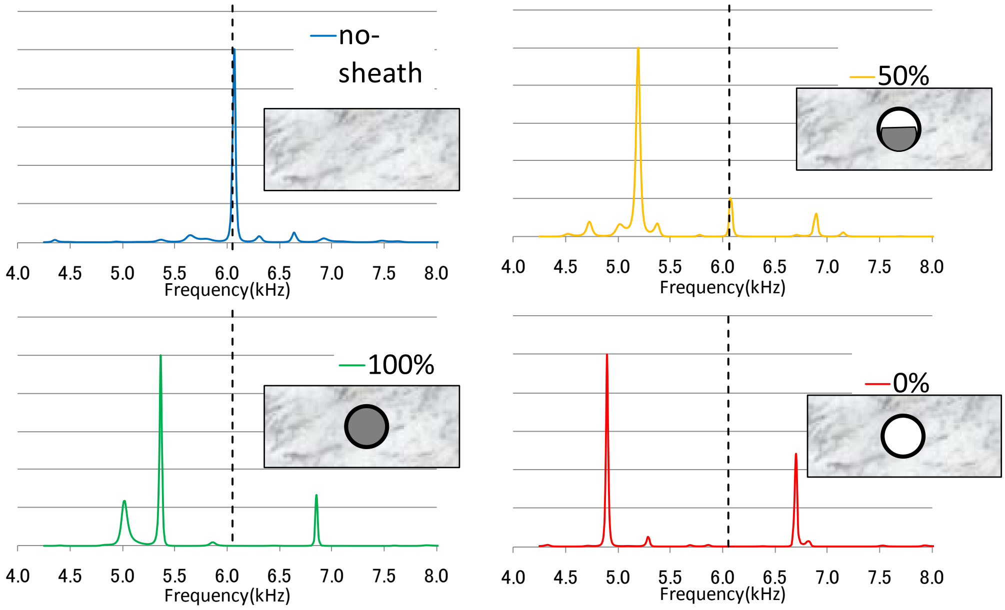

Fig.5 Results of frequency analysis

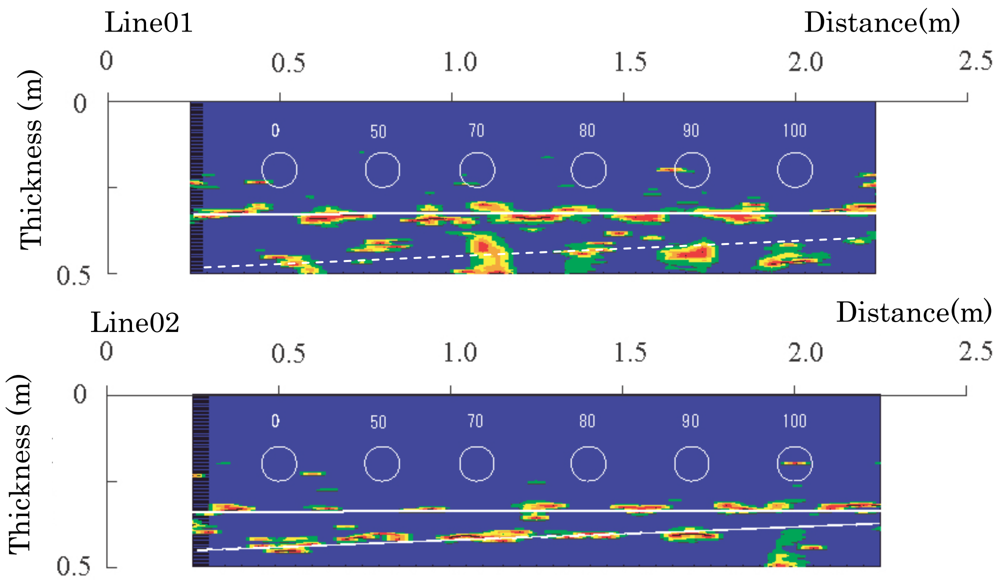

Fig.6 Results of analysis （MEM averaged running spectrum）

Figure 7 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.

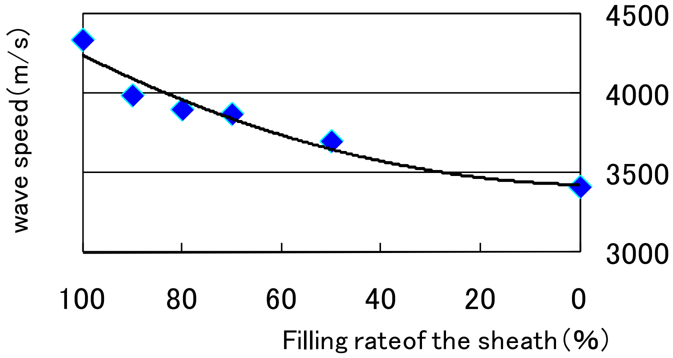

Fig.7 Filling rate and wave speed

FIELD EXPERIMENT USING ACTUAL PC BRIDGE

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.

Bridge measurement

The measuring area and photo are shown in figure 8. 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.8.

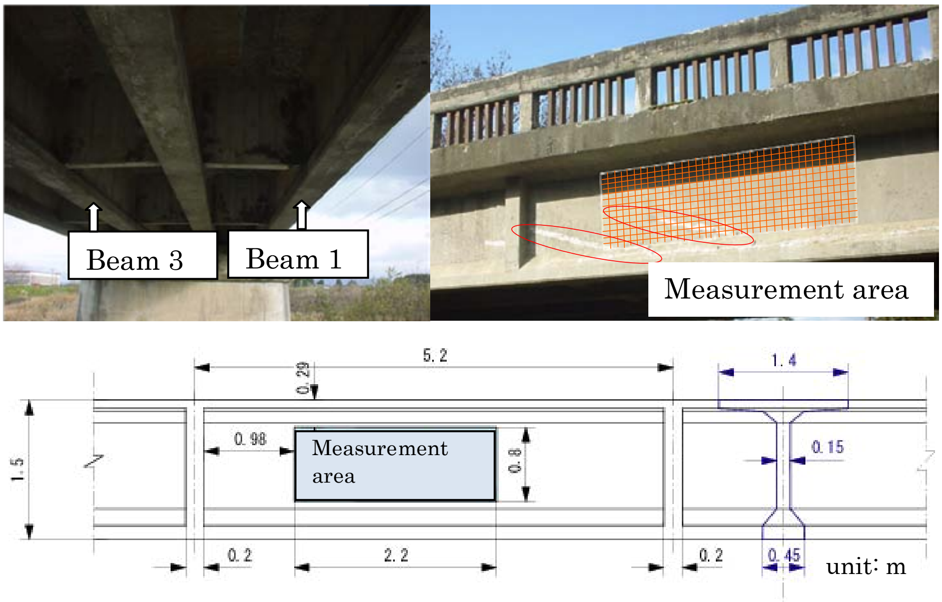

Fig.8　Bridge, beams and measuring mesh

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 9 shows the contours of the accumulated power spectrum intensity where apparent wave speed is reduced by 20%. The thin lines or dashed lines indicate the location of the sheaths. The locations of the slower wave speed observation and the embedded sheath locations are almost coinciding.

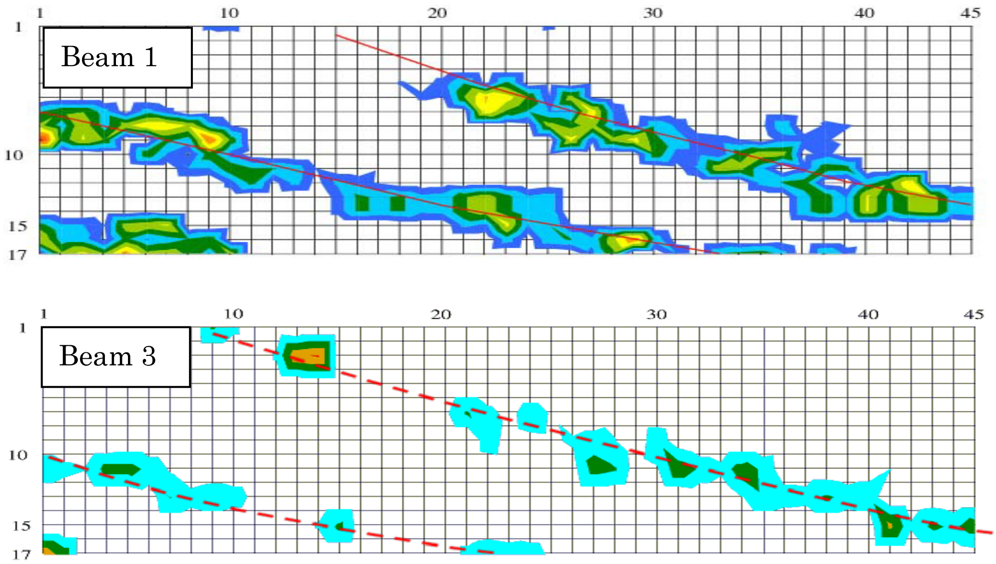

Fig.9 Distribution of the apparent wave speed reduced by 20%

CONCLUSIONS

The apparent wave 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 embedment 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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