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Application of impact response method for detecting the defects of concrete structures

Kentaro YAMASHITA[1], Tomoaki SAKAI[2*] Kunio GOKUDAN[3]

[1] *Toyo Research and Measurement.inc., JAPAN*

[2] *Applied Research Inc., JAPAN*

[3] *iTECS Association, JAPAN*

[1] *1-6-6 Tokodai Tsukuba 300-2635 Japan, kentaro@tkres.co.jp*

[2] *1-6-6 Tokodai Tsukuba 300-2635 Japan, sakai@applied.co.jp*

[3] *1-6-6 Tokodai Tsukuba 300-2635 Japan, info@itecs.jp*

ABSTRACT

In this paper the results of the examination on the applicability of the measurements and analysis methods for detecting internal defects of the concrete structures by using impact elastic wave propagation are presented. The authors used the impact response method to detect internal defects in the concrete structure by focusing on the changes in the elastic wave speed which were obtained from the frequency of the flutter echo in the concrete structure. In this paper, we focused on the methods to evaluate the structural whole body integrity, usages and applicability of the methods to measure scatterings of the wave speed which propagates long distances in the structures and SONAR mode measurement and analysis of structural responses. As a conclusion, a method was finalized from the existing measurement techniques. This method is equally reliable to use on structures with rectangular cross-sections.

Keywords. Impact echo method, NDT, Wave speed, Multiple reflections,

INTRODUCTION

Since the development of the impact-echo method, the integrity test techniques which applied the elastic wave were widely used as the method for detecting internal defects and thickness measurement of concrete structures. In Japan, in 1990s, the iTECS technology has been developed as the advanced impact-echo method (Gokudan K. 1999). Similar to the Impact-Echo method, the iTECS method is commonly used that can detect the thickness of the concrete plate, location and distribution of the internal defects and/or the degree of filling rate of the sheaths of the PC bridges.

The high accuracy means that this method gives the precise information of just only the point where measurement is executed. Therefore if we apply this or similar method to check the integrity of the actual concrete structures, the cost becomes expensive and measuring procedure becomes hard to apply, as a lot of measuring points are required. This fact is a big problem to make this method popular as the method to evaluate the overall integrity of the actual structures.

So from the engineering point of view, the procedure to apply the impact response method as the rational method to check the integrity of the actual structures is proposed. And also the reliability and applicability of the impact response method are examined.

DETECTION OF THE INTERNAL DEFECTS DUE TO A CHANGE IN THE WAVE SPEED FROM MULTIPLE REFLECTIONS.

Figure 1 shows the test specimen used for the applicability examination of the impact response method. The specimen is 350 mm in thickness, 1,000 mm in width and 2,500 mm in length with 93 mm diameter plastic sheathes embedded at 200 mm depth. These plastic sheaths have a filling rate variation from 0 to 100%. There are no reinforced bars in the specimen.

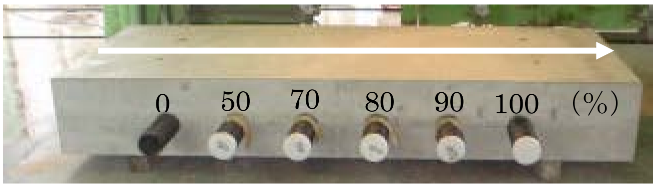

Figure 1. Specimen

The SONAR mode measurement is employed in the middle of the specimen as shown by white arrow line in Figure 1. On this line, the measuring points were 50mm apart in line. A 15 mm diameter steel ball was used as an impactor to generate the stress wave in the concrete specimen. For the thickness calculation, Equation (1) is used with the condition that the wave speed remains a constant value. This wave speed of the specimen was measured prior to the experiment.

$$D = V / 2f \quad (1)$$

Where D, f, V are the estimated thickness, the analyzed frequency and the wave speed respectively.

Figure 2 shows the results of the SONAR mode analysis as the contour map of the frequency power spectrums on the plane comprised of horizontal distance and calculated depth by using Equation (1). The colors in Figure 2 indicate the intensity of power spectrums; the red color shows the strongest and the navy blue color the weakest power. The locations of the sheaths are indicated by the white circles and the number on each circle shows the filling rate of each sheath. The wave speed used for thickness analysis was 4,200 m/s and this value was kept constant. We observed that the presence of the sheaths affects the obtained thickness of the specimen and shows it thicker than the actual thickness.

In other words, the measured wave speed at the sheath position is slower than the actual one. And also the dotted line in the Figure 2 shows, the measured wave speed is affected by the filling rate of the sheath. Figure 3 shows the relationship between the filling rate of the sheath and the measured wave speed. This figure shows the measured wave speed is affected by the filling rate of the sheath. Here, we can replace the filling rate of the sheath, as the degree of internal defects. The iTECS method focuses on the changes in the measured wave speed.

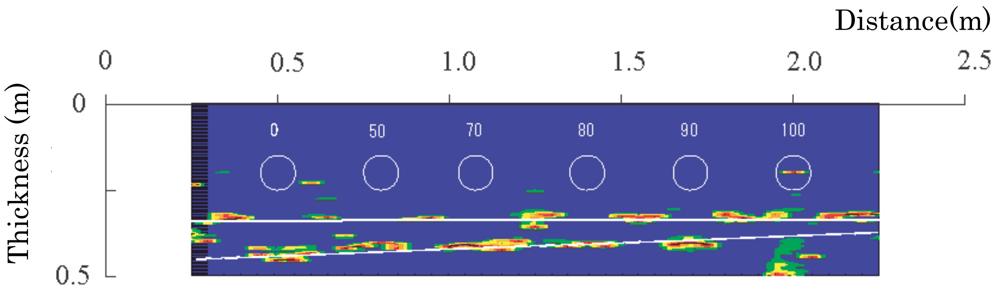

Figure 2. Results of SONAR mode analysis（MEM averaged running spectrum）

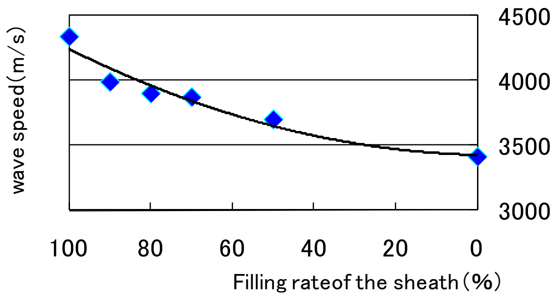

Figure 3. Filling rate and wave speed

PROPOSAL OF THE INTEGRITY ASSESMENT OF THE WHOLE STRUCTURE

iTECS method is used as a detailed investigation method which focuses on the change of the measured wave speed by spatial measurements. Consider the case if iTECS method is applied on the investigation of the internal defects of an actual bridge beam of 20.0 m long span and 1.0 m high dimensions. If we apply spatial measurements with 50 mm by 50 mm mesh for keeping the same accuracy of the experimental test, the total number of measurements becomes over 8,000 points. If we can achieve this detailed measurement, the information is quite credible, but it is not practical as it requires a huge cost and a long time, to complete this task.

Therefore, a method to select the area(s) for possible defect is necessary, and this is the 'screening' method. In Japan, this screening process so far depended much on old fashioned hammering tests and/or on visual inspections. However it also demands a lot of effort, cost, and the skills of workers. Therefore, we propose the rational procedure to apply the iTECS like technology for the integrity test of the actual concrete structures from the point of view of the examination cost.

STEP 1: Measurement of the wave speed which propagate Long-distance.

The wave speed which propagates in the concrete is defined by Equation (2)

$$Vp = \sqrt{\frac{E}{\rho}\frac{(1-\nu)}{(1+\nu)(1-2\nu)}} \qquad (2)$$

Where V_p , E , ρ , ν are the wave speed, the young's modulus, the density and the poisson's ratio of the material respectively. Here, we think that the overall stiffness of the structures will be reduced due to the existence of the internal defects, cracks, or stiffness weaker parts, and then the elastic wave speed which propagates in such abnormal area(s) will be observed lower than the wave speed in the normal area(s). We applied this method to the actual bridge beams. As shown in Figure 4, the wave speed which propagated across the bridge beams was measured. Then, we evaluated the condition of the each beam. The bridge tested was the post-tensioned PC bridge which has two spans(span A, span B) and each span has three beams (the length of each span is about 25.0 m). Both spans have damage due to excessive load, and the central part shows the maximum distortion. We can also see a lot of cracks in each beam.

The wave speed was measured by using two accelerometers as shown in Figure 4. The arrival time difference from the wave forms (Figure 5) was obtained and, the wave speed from the sensor distance was calculated. Figure 6 shows the result of the measurement.

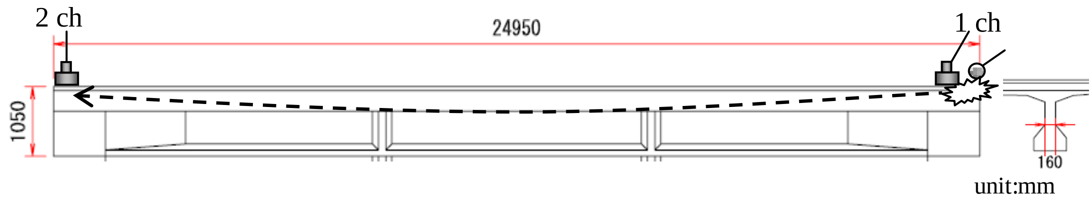

Figure 4. Measurement of long-distance wave speed on actual bridge beam

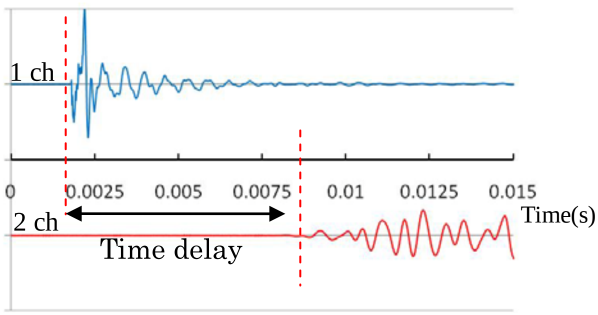

Figure 5. Observed wave form

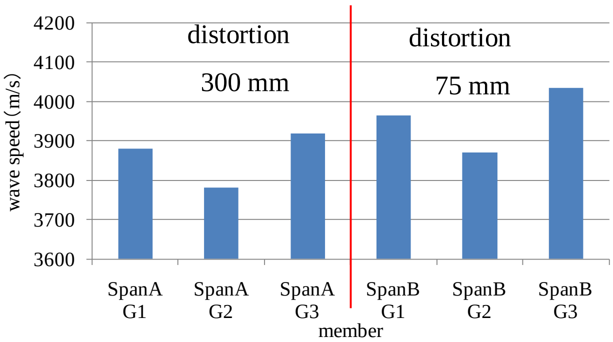

Figure 6. Result of the wave speed measurement

The residual distortion of the span A and span B is about 300 mm and 75 mm at the centre of each span respectively. From the results of previous visual inspection, the number of cracks is in the order of G1, G2, and G3 for each beam. The residual distortion of the span A was larger than it was for the span B and the decrease in the rate of the wave speed for the span A was greater than Span B. And in addition, the fastest wave speed was observed in G3 beam where least number of cracks was observed by visual inspection.

Unfortunately, the wave speed of normal part of the bridge is unknown. However, it was found that relative damage status of the beams was checked by comparing the long distance propagated wave speed of each beam. The more useful information will be obtained if the same measurements were performed on the sides or the bottom of the beam.

STEP 2: The measurement of the wave speed from multiple reflections by the SONAR mode measurement.

If possible defects or problem areas are detected in the bridge beam, then it is required to find out these areas where the further investigation is needed. The wave speed in the concrete structure is obtained by analyzing frequency components of the multiple reflections as shown in Figure 2. The thickness or the wave speed of the plate like structure is obtained by frequency component established by the multiple reflections between the measuring surface and its opposite surface. But in the structure which has rectangular cross-section, the multiple reflections are not only for thickness direction but also for many of the closing path directions. The wave is propagated through the path such as around the beams sectional area as shown on the right side of Figure 7. In this case, instead of the thickness related simple spectrum, the multiple spectrums are observed. If measured at a position which has the same cross section shape, the pattern of the spectrum should be equal. In addition, the pattern of the spectrum will be changed by the presence of any internal defect because of the changes in the actual wave speed or the wave paths. This is the same as the model of plate-like structure. So, this method is applicable even if the beam has a rectangular cross section. Since the wave propagated pass through the whole of the cross-section if the shape of the cross-section is rectangular, the information of the condition of the cross-section is obtained even if a single point measurement for each section is executed.

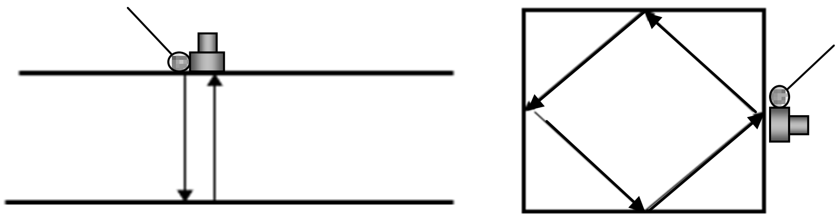

Figure 7. Schematic illustration of the wave path of multiple reflections

Then we introduce the example in which this idea was applied to the actual bridge beam of rectangular cross section. Two different bridges were tested. The cross-section of the each beam is shown in Figure 8, and measurements were performed on the side surface of each beam. The measuring points were 250 mm apart from each other on the measurement line which was set on the almost horizontal center of the side surface. Applying this on 20.0 m span length beam, there are only about 80 measuring points as compared to 8000points as mentioned previously. Results of the frequency analysis are shown in Figure 9. The vertical axis of the Figure 9 is the calculated thickness and the horizontal axis is the position of the measurement points. In Figure 9, we can see that the spectrum pattern of the beam 1 is stable, where as the spectrum pattern of the beam 2 looks random. Thus indicating the possibility that there is some abnormality.

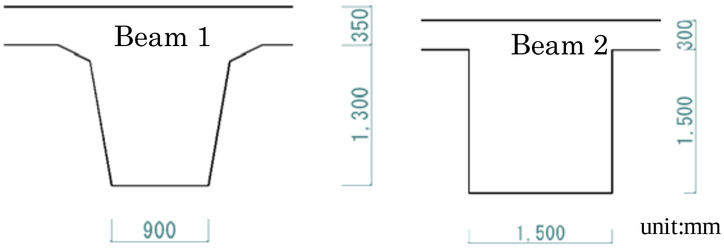

Figure 8. Cross-section of the actual structure

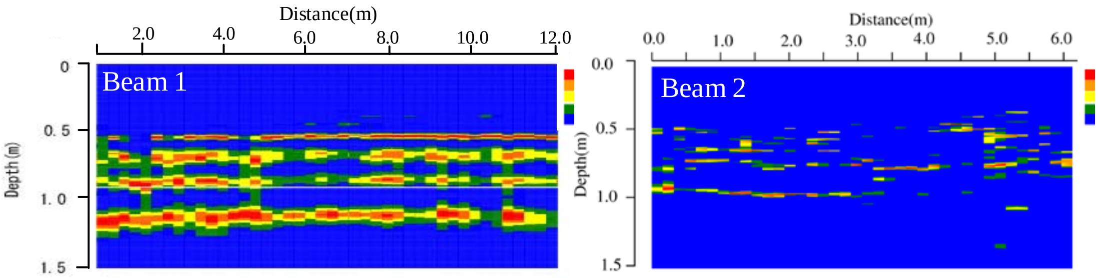

Figure 9. Spectrum patterns from the frequency analysis

STEP 3: Spatial distribution of the wave speed.

Now, we'll try to detect the abnormal area by a conventional spatial measurement method. The area and shape of the beam of the actual PC road bridge are shown in Figure 10. The tested area was divided into the 50 mm mesh (2.2 m × 0.8 m), and the thickness measurements were performed at every mesh points. Figure 11 shows the contours of the accumulated power spectrum intensity where measured wave speed is reduced by 20 %. The thin lines indicate the actual location of the sheaths. If any internal defect was present, instead of the sheaths, this defected area will be detected.

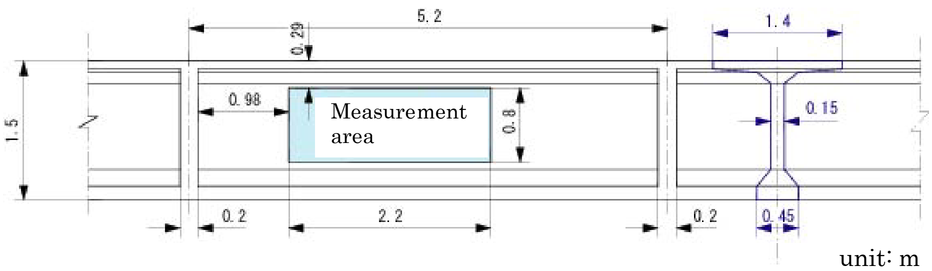

Figure 10. Measurement area on the actual road bridge

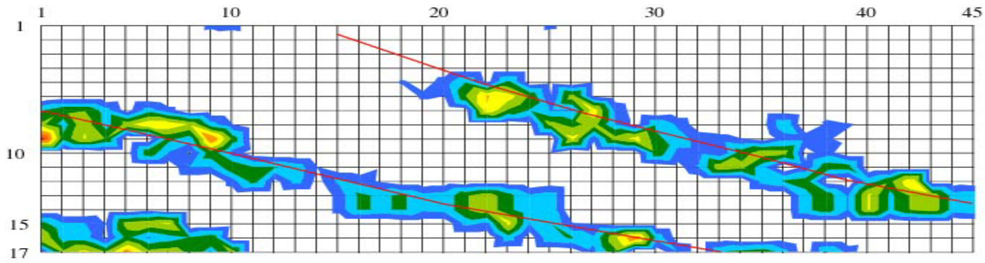

Figure 11. Distribution of the measured wave speed reduced by 20 %

In addition, if we want to know more precisely about the position(s) or the volume of internal defects, it is possible by using the wave speed tomography method.

CONCLUSION

Recently, many NDT methods for the structural integrity inspection are being researched and developed. And some of the techniques are established as the detecting method for the localized defect(s) with relatively high accuracy.

More convenient and low-cost methods are required to detect the integrity condition of actual structures for the country like Japan that is facing the urgent needs of infra structures maintenance.

In this paper we propose the applicable procedure in a wide scene from the screening stage to the detailed investigation by combining the measurement and analysis methods of impact elastic wave investigation.

In the future, we aim to establish a highly reliable and low cost measurement method by combining the other NDT methods such as resonant frequency measurement of the bridge, applying a radar wave, and micro destructive testing.

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