충격탄성파법을 이용한 PC형교의 쉬이스 내부 그라우트 미충전부 탐사

Probe of Unfilled Sheath of Prestressed-Concrete Girder Bridge Using Impact-Echo Method

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Abstract

Sheaths are arranged in the web and lower part of prestressed-concrete girder bridges, and prestressing wires and concrete are indirectly bonded together by filling interior parts of the sheaths. However, when the filling is not sufficient, water can penetrate the interior parts of the sheaths and, thereby, prestressing wires can be corroded or transverse cracks would occur around sheaths by the freezing and thawing action of the penetrated water. Therefore, it is an important element in maintenance management of structures to find out the sheaths unfilled with grout early after construction. In this paper, in order not to damage bridge members, the impact-echo method with a new approach in application is used to probe sheaths unfilled with grout for real structures. The location of sheaths is first estimated with reinforcing bar probing instrument of radar type and the measurement locations of sheaths are determined. By sending elastic wave to the side of girders and receiving the response, the location of the unfilled part of a sheath was estimated from the difference between high frequency peak and twice the resonance frequency indicating thickness. To verify the location of void estimated by the impact-echo method, pictures were taken by an industrial fiber scope after drilling a hole.

Keywords : Impact-echo method, Prestressed-concrete girder bridge, Unfilled grout, Resonance frequency

1. Introduction

Currently, in Japan, the number of new large scale constructions is decreasing, and especially the structures like bridges are at times of maintenance management. Therefore the demand for repair and rehabilitation is increasing. For an efficient repair and rehabilitation, it is utmost important accurately to find out the current condition of the structures such as the safety or remaining life expectancy of existing structures.

In general, in prestressed-concrete (PC) girder bridges of mid-size, the prestressing wires are inserted into sheaths arranged in the girders. Prestressing wires and concrete surrounding the sheaths are indirectly bonded together by filling out

the sheaths with grout. Grouting can prevent water penetration into sheaths, the corrosion and breaking of prestressing wires, and the concrete cracking caused by the freezing and thawing action of the penetrated water. It is not an easy job to perform grouting because there is not much space between sheaths and prestressing wires. In addition, it is not easy to judge the effectiveness of grouting during construction because the inside of sheaths cannot be seen. Therefore, it is an important element in maintenance management of structures to find out the sheaths unfilled with grout early after construction.

In probing the unfilled sheaths with grout, because it is desirable not to damage bridge members of prestressed-concrete girder bridges,

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the impact-echo method, one of the nondestructive testing methods, would be effective. For the measurement of the degree of filling using the impact-echo method, two methods have been studied : 1) directly sending elastic wave to prestressing bars and measuring the degree of filling from the response(Tomita et. al, 2000), and 2) sending elastic wave to the sides of girders and finding the void due to unfilling(Gokudan et al, 2002). Even though it can estimate the overall filling percentage, the first method can neither find the location of unfilled sheaths, nor is easy to apply when the prestressing wires are arranged in a curve. In addition, the second method remains in just theoretical and experimental level.

In this study, the impact-echo method with a new approach in application is used to probe the unfilled location of sheaths with grout for the girders of prestressed-concrete girder bridges in use. The location of sheaths is first estimated with reinforcing bar probing instrument of radar type and the measurement locations of sheaths are determined. By sending elastic wave to the side of girders and receiving the response, the location of unfilled sheath and the degree of filling are qualitatively estimated. The accuracy of the estimated location for unfilled sheath was verified by drilling the side of girder.

2. Impact-Echo Method and Analysis Method

2.1 Impact-Echo Method and Test Technique

In the impact-echo method, an elastic wave caused by impacting concrete surface with a steel ball is measured by an accelerometer installed near the impact point. The elastic wave has enough energy to be transmitted without scattering even in inhomogeneous material such as concrete, and is multiply reflected at discontinuous surface such as boundary of members, void, or crack. This

Fig. 1 Impact-echo method

characteristics can be used to measure length, thickness of members or the distance to the discontinuous surface. Fig. 1 shows the measurement diagram of the impact-echo method. The following equation can be obtained, where the distance from the surface to the void inside member, D , the velocity of p-wave, V_p , the resonance frequency of elastic wave measured from the accelerometer, f .

$$D = \frac{V_p}{2f} \quad (1)$$

This equation assumes the travel path of the p-wave is twice the depth and is therefore valid for spectra obtained from waveform recorded close to the impact point.

It should be considered in using the impact-echo method that impacts with short contact times generate higher frequency components than with long contact times. It is apparent from Eq.(1) that high frequency component is necessary when measuring short dimension like thin object. In addition, it is found that the contact time depends on the size and mass of an impactor (Sansalone and Carino, 1989). The authors verified the relationship between the size of impactor (steel ball) and the dimension of object by an experiment (Kurosawa et. al, 2010) as shown in Fig. 2. The graph shows that a ball of a one-thirteenth diameter of the object dimension is necessary.

Fig. 2 Relationship between diameter of impactor and thickness of object

2.2 Analysis Method

Explained here is the method to find void in the cross section. When a sectional dimension is measured using the impact-echo method, a number of the integer multiples of the fundamental frequency are obtained in addition to the fundamental resonance frequency corresponding to the measurement dimension. However, in the case of concrete, most of high frequency content of the elastic wave is absorbed, and only the fundamental resonance frequency and twice its frequency are obtained generally.

For example, when a frequency measurement is done for the thickness T of a PC girder, the fundamental resonance frequency f_1 and twice its frequency f_2 are obtained as shown in the Fig. 3. On the other hand, when a frequency measurement is done for the part with a void, resonance frequency f_3 corresponding to the depth D of the void is obtained. Shape of the frequency f_1 and f_2 (part surrounded in a circle of the broken line), representing thickness T , depends on the magnitude of void width W . In other words, if the magnitude of width W is large, f_1 and f_2 disappear, and if W is small, f_1 and f_2 become prominent. Therefore, when the sheath of prestressed-concrete girder bridge is measured, f_3 has a prominent value if void

Fig. 3 Measured dimension and resonance frequency

Photo 1 Measured prestressed-concrete bridge

magnitude is large to some degree. As a result, f_3 would also have different value from f_2 . This is because the sheath is arranged at the center of the section, and D is smaller than $T/2$ (or f_3 is larger than f_2) considering the diameter of the sheath. In addition, the difference becomes larger as the unfilled degree becomes higher.

In this research, the difference between f_3 and f_2 is used to find unfilled sheath and its degree in the prestressed-concrete girder bridge.

3. Measurement

3.1 Measured Bridge

The bridge for the measurement is a prestressed-concrete girder bridge of 366m in length and 12.5m in width, located in Kami-gun, Miyagi, Japan (Photo 1). Fig. 4 shows the side view

Fig. 4 Side view and cross-section of prestressed-concrete girder

Fig. 5 Detailed cross-section

and cross-section of the girder of the measured prestressed-concrete bridge. In the girder, there are 13 sheaths (outside diameter 48 mm) arranged in disperse and there are 12 prestressing wires of $\phi 5\text{mm}$ in each sheath (Fig. 5).

Measurement probing for the location of sheath and void (unfilled part of sheath) was performed around the longitudinal cracks (Photo 2, presumably occurred along the sheath) observed in some girders of the studied bridge.

3.2 Measurement Method

Prior to the measurement of the impact-echo

Photo 2 Measured locations

Fig. 6 Surveyed cross-section diagrams at measurement location LC

Fig. 7 Location of re-bars and sheaths at measurement location LC

method, the location of reinforcing bars and sheaths was surveyed for the side of web of the girder using reinforcing bar probing instrument of radar type. Fig. 6 shows the cross-section diagrams surveyed around the measurement location LC. The location arrangement of reinforcing bars and sheaths at the same place is shown in Fig. 7. While the location of reinforcing bars is fixed, the location of sheaths arranged with slope varies.

Part to probe was determined to be 3 locations as shown in Fig. 4 and the measurement was performed at 5 cm grid for each location. The measurement location was identified as LA (5 points in lengthX 3 points in width= total 15 points), LB (6 points in lengthX 3 points in width) and LC (5 points in lengthX 3 points in width) from the left. Photo 2 shows the distribution of measurement points at each measurement location LA, LB and LC.

The measurement system used in this research is shown in Photo 3. The waveform measured

by an accelerometer is digitized by a dynamic strain meter. The data is analyzed by a program in a PC. The sampling time is 1 micro-second and the bandwidth of accelerometer is 1~25,000Hz.

When there are contaminants attached to the concrete surface, they are removed with a steel brush before measurement. In addition, the location of the crack should be avoided in measurement to reduce the error of estimation of the position. The impactor of 8mm diameter was used for measurement.

Photo 3 Measurement system

Fig. 8 Fourier spectrum for calibration

4. Measurement result

Prior to the probing measurement of unfilled sheaths, measurement for calibration was performed at the location of no sheath to determine the propagation velocity near the measurement point. Frequency characteristics obtained from the impact-echo method were similar for 3 measurement points (Fig. 8). The mean propagation velocity using Eq.(1) was 3,000m/s.

Among total 3 measurement points shown in Fig. 4, the results of LB and LC measurement point are summarized in this paper. The reason is that verification by drilling was not performed under on-site condition for measurement point LA. Figs. 9 and 10 show the Fourier spectrum obtained for LB (18 points) and LC (15 points) measurement points using impact-echo method, respectively.

Fig. 9 Fourier spectrum for each measurement point at LB

Fig. 10 Fourier spectrum for each measurement point at LC

Fig. 11 Estimated void location and drilling point at LB and LC

Because a relatively small steel ball was used in measurement as an impactor, the component of high frequency is large. However, there is also a peak in the frequency (around 8 kHz for propagation velocity of 3000m/s) corresponding to the 18 cm of web thickness of the girder. This shows that the size of void is not so large even if there is void because when there is a big void at cross-section, there are only resonance frequency and integer times the frequency in measured spectrum identifying the distance between surface and void.

A peak around 16 kHz (2 times 8 kHz) in high frequency components means no void. However, at spectrum in Figs. 9 and 10, there are many other peaks (other than 16 Hz) around the center of measured points. To show the degree visually, for each measurement point, Fig. 11 shows a contour line of the difference between high frequency peak and twice the resonance frequency indicating thickness. The difference is large around center for both case of LB and LC. This confirms that there is a sheath and void at center. Formal data were not obtained at three parts of red circle at LB due to the influence of surface condition of the concrete.

5. Verification by Drilling

To verify the location of void estimated by the impact-echo method, pictures were taken by an industrial fiber scope after drilling a hole. The locations of drilling are near the 14th measurement point for LB and 11th measurement point for LC

Photo 4 Inside picture of a drilled hole at LB and LC

(identified as a circle in Fig. 11) and the sheath was actually found at a depth of about 60 mm. Photo 4 shows the inside picture of the sheath taken by the industrial fiber scope. Prestressing wire and sheath are clearly shown and the gray part marked by the elliptical circle is the unfilled part of the sheath. Because no signs of corrosion of prestressing wire or water penetration into the sheath were found, it was found that the unfilled part of sheath is not continuous.

6. Conclusion

In probing measurement of the unfilled part of a

sheath of a prestressed-concrete girder using the impact-echo method, the location of a sheath was estimated using the reinforcing bar probing instrument of radar type to save time. The location of the unfilled part of a sheath was estimated from the difference between high frequency peak and twice the resonance frequency indicating thickness, and was verified by drilling a hole.

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Reference

1. Gokudan, K. and Sakae, T., "Measurement of the Grout Filling Degree in Sheath of the PC Bridge by the Impact-Echo Method", Proceedings of JCI, Vol. 24, No. 1, 2002, pp.1557-1562. (in Japanese)
2. Kurosawa, N., Sagara, Y., Lee, S. H. and Endo, T., "Influence of Magnitude of Impactor to the Accuracy of Measurement to Detect the Internal Defect of Concrete by Impact-Echo Method", Proceedings of the Annual Conference of Tohoku Branch of JSCE, 2010, paper no. V-16. (in Japanese)
3. Sansalone, M. and Carino, N. J., "Detecting Delaminations in Concrete Slabs with and without Overlays Using the Impact-Echo Method", ACI Materials Journal, Vol. 86, No. 2, March-April 1989, pp.175-184.
4. Tomita, Y., Iwanami, M. and Otsuki, N., "Nondestructive Evaluation of Fresh Grouting Performance in Prestressed Concrete Members by Impact Echo", Journal of JSCE, No. 648, V-47, 2000, pp.127-135(in Japanese)

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요 지

PC형교에서는 거더의 복부와 하부에 PC강선을 수용하는 쉬이스가 배치되어 있으며, 그 내부에 그라우트를 충전함으로써 PC강선과 콘크리트를 간접적으로 부착시킨다. 그러나 이 충전이 불충분하면, 쉬이스 내부에 물이 침투하여 PC강선이 부식하거나, 동결융해 작용에 의한 쉬이스 배치 위치에서의 횡방향 균열이 발생한다. 그 때문에 시공 후 조기에 미충전부를 파악하는 것이 구조물의 유지관리상 중요한 요소가 된다. 본 연구에서는, 교량 부재에 손상을 입히지 않게 하기 위해 충격탄성파법을 이용하여 실구조물에 대한 그라우트 미충전부 탐사측정을 실시하였다. 우선 레이더형 철근 탐사기로 철근과 쉬이스의 위치를 추정하고 그 위치를 기준으로 쉬이스에서의 측정부위를 정하였다. 거더 측면에 탄성파를 입력하고 그 응답으로부터, 고주파수 피크와 두께를 나타내는 공진주파수의 2배수 주파수와의 차로서 미충전부의 위치와 충전정도를 정성적으로 추정하였다. 추정 부위에 대한 확인을 위해 거더의 측면을 천공하고 공업용 내시경에 의한 촬영을 실시하였다.

핵심 용어 : 충격탄성파법, PC형교, 그라우트 미충전, 공진 주파수