콘크리트 구조물의 결함탐사에 대한 새로운 가시화 수법

A new approach of imaging defects in concrete structures

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Abstract

Image created by stack imaging spectral amplitudes based on the impact-echo (SIBIE) method is largely one-dimensional because a single frequency domain spectrum for wave reflected below a single point of impact is used to create the image. The method has limitations for representing defects in a cross section of a concrete structural element using two-dimensional coordinates. This study focused on defect detection and visualization in a concrete structural element using multiple impacts and accumulated SIBIE. An impactor was used to induce energy at multiple points at positioned at prescribed intervals along the structural element. A modified SIBIE method was applied to the collected data of each point and the modified SIBIE images were accumulated to generate one image (an accumulated SIBIE image).

1. Introduction

The impact-echo method, one nondestructive testing method available for evaluating in situ concrete component condition, has been widely applied by numerous engineers and researchers. It has been used to: estimate concrete strength and thickness; detect internal defects; detect voids in grout used in prestressed concrete tendon ducts; estimate of crack depths. The accuracy of data produced using this method is, however, easily affected by a number of items, such as: the concrete structural component's surface condition, shape and cross sectional dimensions; and the material or the size of the impactor. In addition to these items affecting data accuracy, depending on the concrete structural component being investigated (e.g., slab) and the corresponding critical dimension (e.g., slab thickness), the frequency component that may need to be detected may not be the highest amplitude peak. This is a significant problem inherent to the impact-echo method. Ohtsu et al. proposed the SIBIE method for imaging the concrete specimen cross section using frequency spectra from waves detected using impact-echo [2]. Images created using SIBIE are, however, basically one-dimensional although they appear two-dimensional. The method uses a single frequency domain spectrum for reflected waves normal to the plane of impact that are then captured at one or two points near this single impact point (Fig. 1).

In this study, defects in a concrete structural component, a beam, were detected using impact-echo with multiple impacts and results were visualized using a modified and accumulated SIBIE approach. Impacts were applied at multiple points at prescribed intervals along the beam. Resulting SIBIE images were then modified by smoothing the data and making corrections to the incident angle to obtain continuous images. Resulting images for each impact point were then accumulated and reimaged in an attempt to represent impact-echo results in the concrete beam cross section as two-dimensional images.

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2. Analysis plan and method

2.1 Modifications to SIBIE

The SIBIE method (Fig. 2) was developed to image a specimen cross section using the frequency spectrum of a wave using impact-echo measurements. The images created by the SIBIE method are basically one-dimensional because: (1) a single frequency spectrum is used (the peak indicates the predominant frequency for waves causing multiple reflections normal to the plane of impact); and (2) data that are collected are for impact at one point (waveforms may be collected at one or two points). To create adequate two- or three-dimensional SIBIE images, a large number of input and output data is considered necessary.

To modify and improve the SIBIE method so that true two-dimensional images are obtained, measurements were taken in this study using multi-point inputs in a row. Data obtained using each multi-point input row was changed into image data for each impactor input using the SIBIE method in conjunction with algorithms that smoothed and corrected the results for the wave incident angle as described below.

2.1.1 Smoothing procedure

An example of the smoothing procedure used with the modified SIBIE image for a concrete element having an internal void is shown in Fig. 3. Fig. 3 a) has the coarsest mesh and, in the figure, contours that represent discontinuous planes such as voids are semicircular around the point of impact and largely discontinuous. The semicircle indicates that the data is a function of the distance relative to the point of impact, or is one-dimensional, and each discontinuity between the contour clusters, which should represent a peak, shows that the mesh size is too large and, subsequently, no frequency spectrum peak is uniformly captured. Reducing the mesh size eliminates this discontinuity (Fig. 3 b)) and smoothing using Parzen's lag window [3] solves the problem without needing to considerably reduce the mesh size (Fig. 3 c)).

2.1.2 Consideration of incident angle

The impact-echo method generally uses unidirectional accelerometers that mainly measure vibrations normal to the contact surface. Corrections should therefore be made to the reflected waves that are not normal to the contact surface and, subsequently, have an incident angle (θ) with respect to the surface (see Fig. 2). Corrections are generally made by obtaining a vertical component of the wave through multiplication of the amplitude by its direction cosine. In this study, amplitude is multiplied by the square of direction cosine so that multiple reflections are considered. Corrections were made to the smoothed image shown in Fig. 3 c) based on the incident angle and the resulting image is shown in Fig. 4.

2.2 Multi-point input and accumulated SIBIE images

The nine items shown in Fig. 5 are SIBIE images at a certain input point (indicated by the black point in the figure) obtained after smoothing and correction for incident angle. The right figure shows an image obtained by accumulating corrected SIBIE images collected at respective input points at intervals of 1 cm across the top of the beam cross section. Unlike individual SIBIE images, it is evident in the figure that defect positions are shown as two-dimensional data from right to left and top and bottom in the figure. A specific application for this procedure to detect defects is outlined in the sections that follow.

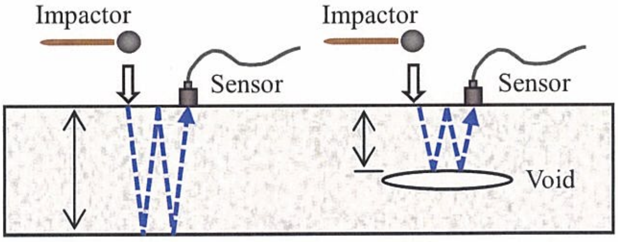


Fig. 1 Impact-echo on a concrete structure

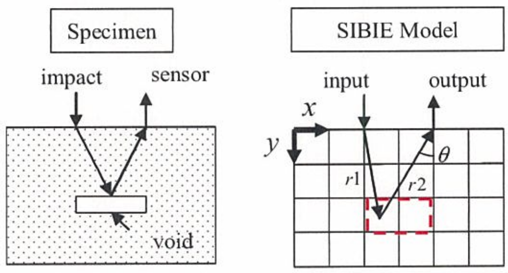
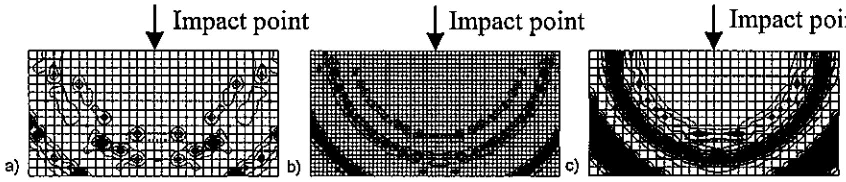


Fig. 2 Specimen and SIBIE Model



a) 10mm mesh size b) 5mm mesh size c) 10mm mesh size, after smoothing

Fig. 3 Effect of mesh size and smoothing

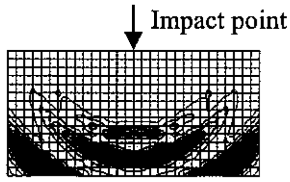


Fig. 4 Considering incident angle

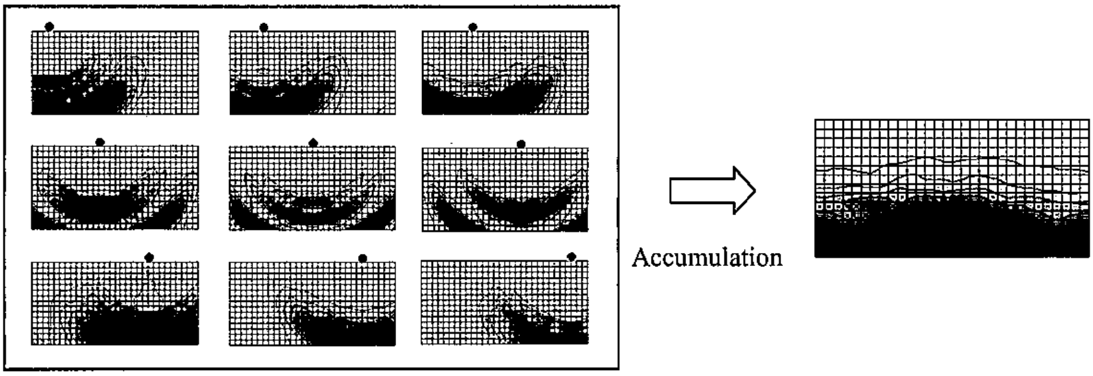


Fig. 5 Modified SIBIE images of each impact point and Accumulated SIBIE image

3. Analysis result and discussion

3.1 Measurement system and items

The measurement system used for this study was comprised of impactors of varying diameters (steel balls with a bar), impact-echo sensors and a data acquisition system (dynamic strain meter). The sensors were unidirectional accelerometers having a measurement bandwidth of 1 through 25,000 Hz. The sampling period for the dynamic strain meter was set at 1 μsec. Measurements were made on a concrete beam having three known internal defects constructed using wood plates embedded at different depths in the cross section. Fig. 6 details the relevant dimensions and contains a photograph of the specimen. Impacts were applied on the top surface of the specimen at longitudinal intervals of 1 cm. Modified SIBIE images were created using measurements from each point of impact.

3.2 Results of measurement represented by accumulated SIBIE images

Fig. 7 shows contours based on accumulated SIBIE images that detail measurement results for the beam specimen. Results were obtained by applying impacts using 7-, 10- and 15-mm-diameter impactors. In all three cases longitudinal (horizontal in the images) positions for defects were well defined despite the difference in degree of precision. Vertical defect positions were not well identified, however, it was verified that locations of contours representing the defects varied according to the distance to the defect. Contour variation based on the distance to the defect was also verified based on whether the contour was highlighted (using red) or not. It was evident that contour shape changed according to the size of the impactor. As impactor size increased, the highlighted area was farther from the point of impact. Defects at depths of 12 and 15 cm were highlighted when a 7-mm-diamter impactor was used while defects at a depth of 15 cm were highlighted when at 10-mm-diameter impactor was used. When a 15-mm-diameter impactor was adopted, the bottom surface, at a depth of 20 cm, was highlighted rather than the defects. It was therefore shown that results were affected by the size of the impactor and varied according to the distance to the boundary (defect or component surface) from the impact point.

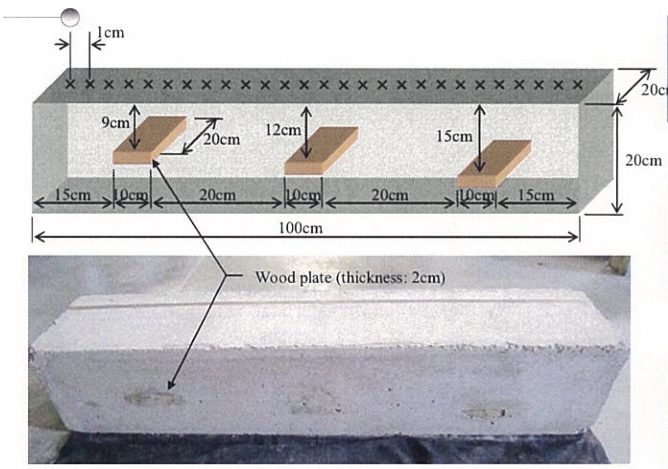
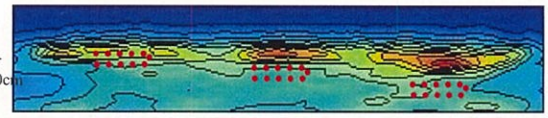
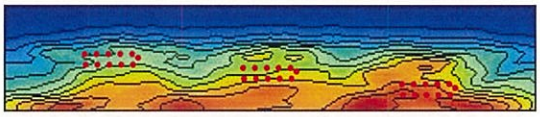


Fig. 6 Dimension of the specimen having three artificial defects (wood plates)



a) impactor size: φ7mm

b) impactor size: φ10mm



c) impactor size: φ15mm

Fig. 7 Accumulated SIBIE images of each impactor size

4. Conclusion

This study assessed a method for visualizing the results of measurement of a concrete specimen with internal voids using the impact-echo method with a modified and accumulated SIBIE approach. The proposed method involved the application of impacts at multiple points at specified intervals within in the measurement area on the tested concrete structural element. It then utilized modified SIBIE that incorporates smoothing of the results and correction for measured incident angles incorporating multiple SIBIE images at each input point. Finally, the method developed an accumulated SIBIE image that merged all input point images. The method was applied to actual test measurements of a concrete structural element containing defects to assess its effectiveness for defect detection. As a result of these studies, the following conclusions were reached.

1) The method enabled the measurement of horizontal positions of defects regardless of the impactor. Vertical positions could also be estimated based on the shape of the contour by considering the size of the impactor.
2) It was verified that accumulated SIBIE images clearly indicated the horizontal and vertical positions of defects although individual images could not show the positions of defects as the highest amplitude peak.
3) The accumulated SIBIE method appears to improve upon existing methods to detect voids or other defects in concrete.

Reference

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