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Time domain and frequency domain interpretation of safety diagnosis for concrete structure

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Abstract: The traditional and still most widely used, test methods for concrete structures are destructive method, such as coring, drilling or otherwise removing part of the structure to permit visual inspection of the interior. While these methods are highly reliable, they are also time consuming and expensive, and the defects they leave behind often become focal point for deterioration. In this study, tomography by theoretical inversion method in case of elastic wave using impact-echo method among concrete non-destruction test method was made. Taken model experiments are theoretical inversion method and time domain and frequency domain test on pier test model at laboratory level. Also experiment concerning frequency domain on 3 kinds of tunnel model with 1-dimension form was carried out.

1. Introduction

As history of concrete application on civil structure gets longer, deterioration of existing structures is becoming a serious problem all over the world including Korea. For example, recent breakdowns of newly building large structures shows the necessity of civil structure safety diagnosis and evaluation. Due to inevitably brought deficiency in some parts of the structures caused by construction of large structures in a short time and deterioration of various concrete structures, safety management through effective repair and reinforcement has become a important matter.

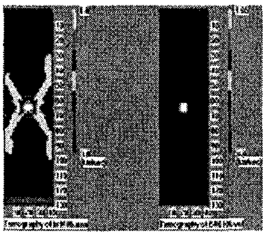
In this study, tomography by theoretical inversion method in case of elastic wave using impact-echo method among concrete non-destruction test method was made.
Taken model experiments are theoretical inversion method and time domain and frequency domain test on pier test model at laboratory level. Also experiment concerning frequency domain on 3 kinds of tunnel model with 1-dimension form was carried out.

2. Experiment on pier Model

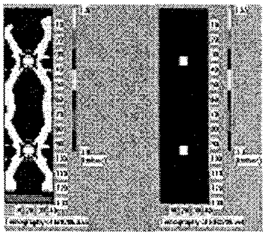
2.1 Time Domain Experiment

(1) Cavity Model

As the cavity, size of 6x6 cm, has water and other, the velocity of the cavity was assumed 1.5km/sec, a second in the velocity of elastic wave of concrete that is 3.0km/sec. On the left side of pier 40 wave-sources were installed and 40 detectors were installed on the right side of it. The calculation result using ART inverse calculation method is shown in Fig.1-(a),(b). The picture on the right side indicates theoretical model.



(a) one cavity (b) model
Fig.1. (a), (b) The tomography of threoretical calculation result of 6cm×6cm size cavity model used ART inversion method.



(a) two cavity (b) model

Fig. 2. (a), (b) The tomography of threoretical calculation result of two 6cm×6cm size cavity model used ART inversion method.

Tomogram by ART inversion calculation method in case of 2 cavity existence is shown in Fig.2, and the location of cavity is very clear. In this case, Fig.2-(a) is a inversion calculation result, and Fig.2 - (b) indicates theoretical model. [7]

(2) Laboratory pier Model Experiment

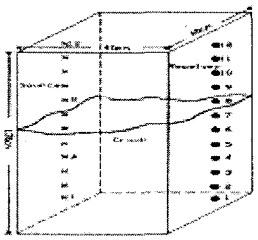
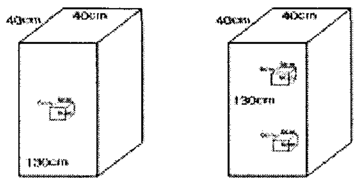


Fig. 3. Experimental model.



(a) (b)

Fig. 4. Various experimental models.

Concrete pier model of 40x40x130 cm was made Fig.3. In bridge structure, there's artificial crack and cavity. Model (a) of Fig.4 has a 6x6x6 cm, and (b) has 2 6x6x6 cm cavities.

(3) Supersonic experiment and Inversion Calculation

Supersonic survey was taken on above model Fig.4. The survey used 2 frequencies: 37kHz and 54kHz. Transmission sensor was located on the left and 12 receive sensors were located on the right with 10cm apart from each other to be measured. Then transmission sensor was moved 10cm, and in the same way, 12 receive sensors, 10cm apart from each other, were measured.

In the case of one cavity is located in a pier model, the calculation results of LSQR inversion method for each measured data that was acquired with ultrasonic sensors of 37 kHz and 54 kHz are shown in Fig. 5 and Fig. 6. In this case the distance between 13 transmission sensors and 13 receive sensors were set 5cm apart from each other to be measured. As in the pictures, the location of cavity is precisely detected in the inverse calculation of model experiment data. [9]

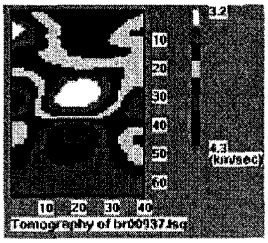


Fig. 5. The tomography of experimental data result used LSQR inversion method when one cavity is located in concrete model (37kHz)

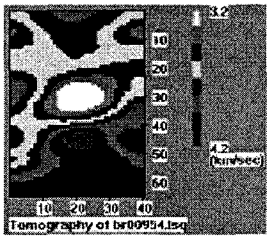
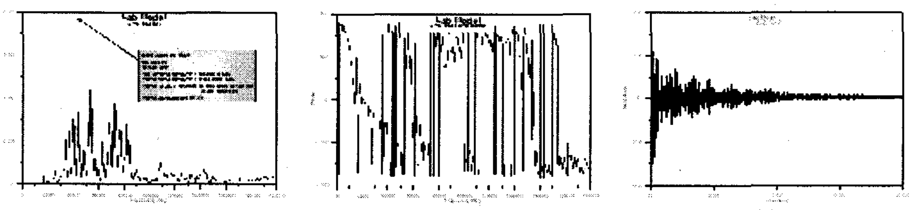


Fig. 6. The tomography of experimental data result used LSQR inversion method when one cavity is located in concrete model (54kHz)

2.1 Frequency Domain Experiment

The pier model at the laboratory level is a scale-down of the actual pier form. The measurement result of primary wave on homogeneous surface using impact-echo method and supersonic detection method was Cp=3200m/sec, and it was set as a standard velocity. Fig. 7 is a graph containing (a) frequency response function, (b) transformation of phase angle, (c) time domain of measured result of concrete part without back cavity. The measured resonance frequency is 4000Hz and calculated depth is 40cm according to the equation $T'=Cp/2f'$ to conform the actual pier length of 40cm. Also, periodic change from -180° to 180° of phase angle is shown. It indicates the side reflected from the opposite side with sensing point is a obvious free surface. Fig. 8 shows the measured result of A-C7 point on the surface having 6x6x6 cm cavity inside. Occurrence of several peak point caused by diffraction phenomenon in cavity parts on incidence impact stress wave is shown on the spectrum surface. The measured resonance frequency is 5150Hz, and measured depth is 31.068 cm. The detection of cavity was impossible. However, the results of measurement on surface without cavity and on reflected resonance frequency are different. It suggest the existence of cavity, but interpretation is difficult without information about inside defection of actual pier.



(a) (b) (c)

Fig. 7. Spectrum from impact-echo test at A-S1 on a solid pier of the Lab Model ; 40cm thick.

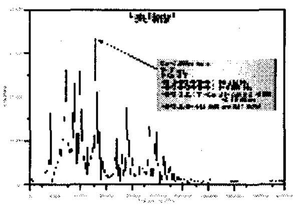


Fig. 8. Spectrum from impact-echo test at A-C7 on a pier with cavity of the Lab Model ; 17cm thick.

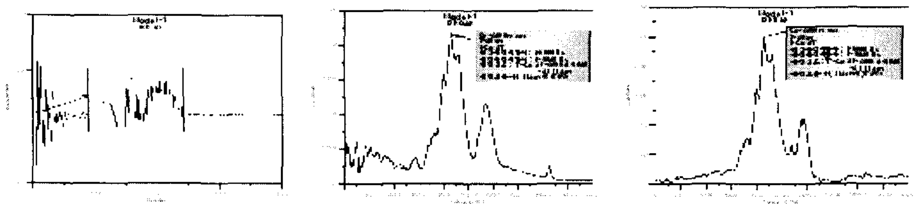
The reason it's difficult to detect the location of cavity on pier model is stress wave cannot bring multiple-reflection phenomenon and this stress wave pass through the cavity due to small size of cavity compared to the reflection distance where cavity takes place.
The reason is that the vibration mode occurs largely in the FFT processing because the object such as bridge structure has more free surface than tunnel lining in the processing of multiple reflection of the impact-stress wave, and so the noise occurs.

3. Experiments on Tunnel Model

Defection detection on tunnel lining form was on thickness measurement of the model, cavity detection in the model and actual tunnel lining form.

3.1 Thickness Measurement of Model(Model-1)

Concrete support of model 1 is considered a homogeneous structure, and Primary wave velocity of concrete was set to 3600m/sec.
Fig. 9 shows the result of (a)time waveform, (b)power spectrum, (c)frequency response function in impact-echo method measured on 20cm thick concrete form.



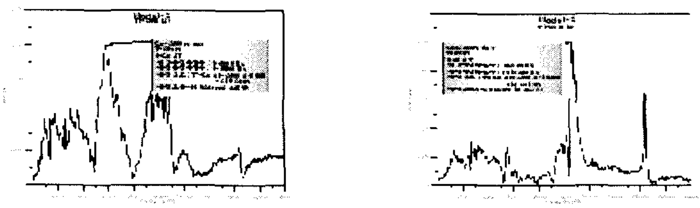
(a) (b) (c)
Fig. 9. Waveform (X2) from impact-echo test on a plate of the Model 1; 20cm thick.

(a) shows the result of time-domain that surface displacement in reciver caused by multiple-reflected impact-echo which is caused on apparent wave source. In this case main period section on FFT Analyzer is converted Fourier as the first resonance mode, it's measured as f'=8525Hz like (b) and (c). With Primary wave velocity of 3600m/sec, depth T' is 21.115 cm which means it has approximately 1cm error compared to actual thickness of 20cm by equation T=Cp/2f'. Almost exact thickness of the model was inferred.
With comparatively shallow depth such as of 20cm, interpretation through (c)frequency response function rather than (b)power spectrum is desirable. It is because regularization of amplitude on whole frequency extent simplifies interpretation of signals in the high frequency band.

3.2 Location detection of cavity in Model(Model-2)

Model 2 has a cavity which is interpreted as heterogeneity medium layer or discontinuity layer inside the concrete structure. Except for the cavity are homogeneous concrete, and Primary wave velocity is set 3600m/sec.
Fig. 10(a) is the measured resonance frequency f'=5800Hz, the measured result on the 30cm thick homogeneous concrete without 3600m/sec, and by using equation T'=Cp/2f', the measured 31.034cm what cavity. Cp is ich is almost exact to the actual thickness of 30cm.

Fig. 5.7 shows the measured result on the cavity 10x10x10cm included section of 30cm homogeneous concrete. According to the measurement, actual thickness of concrete surface to cavity top is 20cm, and measured thickness is 16.901cm which means measurement error of -3.099cm(15.493%). However, it seems that it's caused by short wavelength on shallow delamination and weathering of concrete surface.

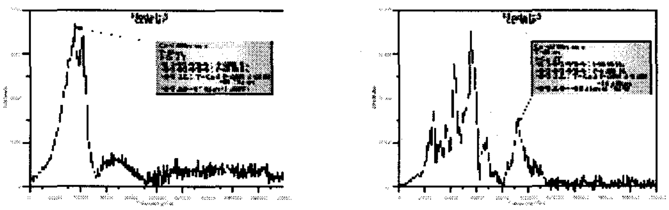


(a) 30cm thick (b) 20cm thick
Fig. 10. Spectrum from impact-echo test a solid plate of the Model 2.

As in model 1, the measurement result clearly displays the form of model 2, but the experiment was impossible due to several site conditions such as uneven concrete surface on some section and deterioration of the model. Also, in this section, not to mention the deterioration of the model, wavelength(10cm), thickness of the model, was too short because of shallow delamination to carry out successful experiment.

3.3 Thickness of tunnel lining Conditions and back cavity Detection(Model-3)

Model 3 was designed and produced like actual NATM tunnel lining structure, and cavity section was made in wood to create multiple using the big difference of concrete velocity(3600m/sec) and impedance. Fig.11(a) is the measured result on the concrete section without back cavity. The measured resonance frequency is 3550Hz, and the measured depth is 50.704cm, which was very accurate compared to the actual lining depth 50cm. Also, Fig. 11(b) is the measured result on the surface with back cavity. The measured resonance frequency is 9250Hz, and the measured depth was 19.459cm. In other words, like the cavity filled with air, cavity produced in wood with big impedance and concrete shows no difference in the measured results.



(a) 50cm thick (b) 20cm thick

Fig. 11. Spectrum from impact-echo test a solid plate of the Model 3.

4. Conclusion

Following results were given through above theoretical model calculation and model experiment.

1) In this study time domain and frequency domain interpretation by travel(arrival-time of wave)calculation were simultaneously tried. First of all, in the time domain interpretation, crack location as first arrival and amplitude change was found in case of having a crack in elastic wave experiment. In elastic wave experiment, big change of amplitude in relation with location of detector and detector without crack and big reduction of amplitude on detector located on the other side of crack, where wave source is located, with crack were shown. The further result interpretation on amplitude transformation aspect by vibration experiment is demanded.
2) The inverse calculation method of first arrival time calculated by ray method and finite element method was compared. In ray method, straight line tomography has the defect of having errors concerning velocity change and curved line geo-tomography has the defect of having enormous time spent for calculation. Supersonic exploration showed similar aspect of theoretical inverse calculation result and experiment measurement data inverse calculation result when cavity exists.
3) Model 1, 2 and 3, concrete slab form, used in tunnel safety diagnosis was measured its change of thickness to measure pore phenomenon of cavity inside and back tunnel lining. Almost accurate model thickness within 3cm error of frequency peak value depth, was found in the result of the experiment. Near 18% depth deviation as shown in expectation depth of 20cm. However, it's due to surface heterogeneity and shallow delamination phenomenon caused by weathering and deterioration of experiment model. In expectation depth 100cm shows approximately 18cm error of comparatively low frequency band on impact-echo method(impact-echo). Having bigger error as depth gets thicker is very usual, and considering measurement limit of impact-echo method, it's interpreted as accurate result value.
4) A pier was applied to the experiment pire in the laboratory model as the important civil structure besides the safety diagnosis of a tunnel. The measurement result on the point without cavity brought error within 1 cm of 40cm thick pire which is very accuprate.
5) the measured spectrum as a result of the detection for one-dimensional shape such as tunnel lining on the method of impact echo is much clear than three-dimensional shape such as pier structure and the error of measured value is a little.

The reason is that the vibration mode occurs largely in the FFT processing because the object such as bridge structure free surface has more than tunnel lining in the processing of multiple reflection of the impact-stress wave, and so the noise occurs.

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