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Effect of Cement-based Solid Product on the Impact-Echo Responses of Concrete Cask Storage for Low-Level Radioactive Wastes

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Abstract

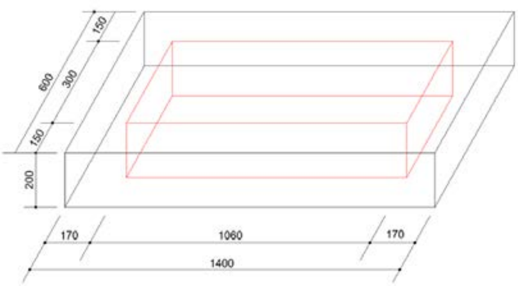
This study was performed to investigate the feasibility of estimating the compressive strength of cement-based solid product in the concrete cask storage for low-level radioactive waste disposal using impact-echo method. Rectangular concrete containers with specified compressive strength of 50 MPa were cast and after 28 days, cement-based composites for solidifying low-level radioactive waste were mixed for three levels of compressive strength: 7, 10 and 28 MPa. The variables of this study are the compressive strength of cement-based composite and the shape of concrete container (L and S type). To examine the compression wave properties of cement-based composites with different compressive strengths, compression waves before and after casting cement-based composites to the containers were measured and compared using impact-echo hammer. Test results indicate that impact-echo method is a promising nondestructive technique for evaluating the strength development of cement-based composites for solidifying low-level radioactive waste.

Keywords: Concrete, Compressive strength, Concrete cask storage, Compression wave, Impact-echo, Radioactive waste

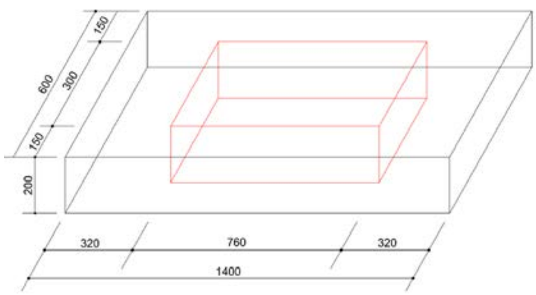
1 Introduction

After Fukushima nuclear accident in Japan, nuclear energy generation will reduce 27.7% of total energy production in Korea until 2025. However, Korea government can't give up the energy generation by nuclear power plant due to economic efficiency. Radioactive wastes are unavoidable by-product in nuclear energy production. The nuclear wastes must be managed and disposed of without pollution of people and the environment. Concrete cask storage is used for storing the spent fuel or low-level radioactive wastes. Solidification of radioactive waste is required to reduce their risks and facilitate their handling prior to disposal. Cement-based composites have been used for the immobilization of wastes. For disposal of nuclear wastes, it should be confirmed that the cement-based composites inside concrete cask storage have the required compressive strength.

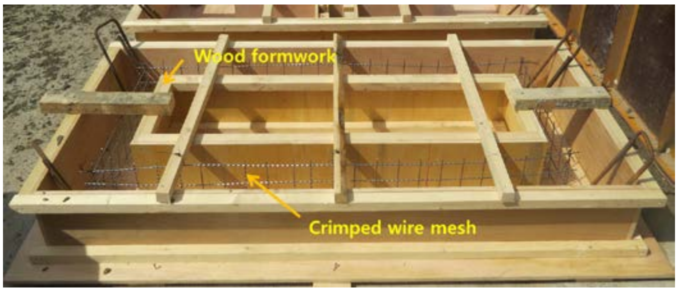
This paper provides the experimental results of impact-echo tests on the concrete cask storage to investigate the feasibility of impact-echo method to evaluate the compressive strength of cement-based composite to immobilize the radioactive waste in the concrete cask storage.



(a) L type



(b) S type



(c) Formwork and reinforcement

Fig. 1 Configuration and dimension of concrete cask storage (unit : mm)

2 Experimental Programs

To investigate the impact-echo response of concrete cask unit filled with cement-based composites with different compressive strengths, two types of concrete cask units such as L and S types were manufactured as shown in Fig. 1. The compressive strength of concrete cask units is 51.8 MPa at 28 days. The center of each concrete unit was reinforced with crimped wire mesh. To evaluate the effect of cement-based composites to solidify the radioactive waste on the impact-echo response of concrete unit, cement-based composite with compressive strength of 7, 10 and 28 MPa were poured into hardened concrete units at curing age of 28 days.

As shown in Fig. 2, impact-echo test systems consist of an impact source (hammer), accelerometers, and a portable computer with a high-speed data-acquisition system. An accelerometer was fixed at the upper surface that a transient stress pulse is introduced into a concrete cask unit by the mechanical impact hammer. The other accelerometer is positioned at the opposite surface of the impacting point.

Fig. 2 System for measuring impact-echo response of concrete cask storage

Eight concrete cask specimens included in the experimental program were summarized in Table 1. All specimens were external dimensions with 600 mm wide, 1,400 mm long and 200 mm thick. As shown in Figs. 1(a) and (b), L type specimens were a void with 300 mm wide, 1,060mm long and 200 mm thick at the center while S type specimens were a void with 300 mm wide, 760 mm long and 200 mm thick at the center. For L-0 specimen, the void was not filled with nothing while L-7, 10 and 28 specimens were filled with cement-based composites, i.e. solid products, with compressive strengths of 7, 10 and 28 MPa, respectively. The designation for S type specimens was the same as that for L type specimens.

At impacting on the surface of an elastic solid, three types of stress waves such as a Rayleigh (R) wave, a shear (S) wave and a compression (P) wave are generated. The impact-echo method is based upon monitoring and characterizing the propagation of the P-wave [1].

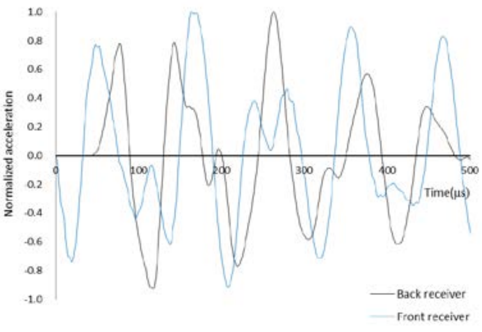
Table 1 Summary of test program

Specimen designation	Size wide x long x thick (mm x mm x mm)	Void size wide x long x thick (mm x mm x mm)	Solid product strength (MPa)
L-0	600 x 1,400 x 200	300 x 1,060 x 200	-
L-7	600 x 1,400 x 200	300 x 1,060 x 200	7
L-10	600 x 1,400 x 200	300 x 1,060 x 200	10
L-28	600 x 1,400 x 200	300 x 1,060 x 200	28
S-0	600 x 1,400 x 200	300 x 760 x 200	-
S-7	600 x 1,400 x 200	300 x 760 x 200	7
S-10	600 x 1,400 x 200	300 x 760 x 200	10
S-28	600 x 1,400 x 200	300 x 760 x 200	28

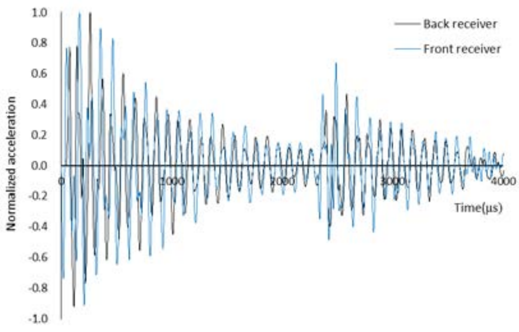
3 Test Results and Discussion

3.1 Acceleration waveforms

Fig. 3 shows the acceleration waveform obtained from L-0 specimen at an age of 28 days. The pulse generated by the impact undergoes multiple reflections between the front and back surface of concrete cask storage. As shown in Fig. 3, the recorded acceleration waveform has a periodic characteristic. Fig. 3(a) shows a typical initial set of waveforms obtained from front and back accelerometers. The arrival time of the direct P-wave between front and back waveforms was lapse. The lapse time of P-wave between front and back accelerometers was similar in the L and S type specimens without solid product while the lapse time of specimens with solid product reduced to the half of that of specimens without solid product. But the compressive strength of solid product in the concrete cask had little effect on the lapse time.



(a) Initial response



(b) Full response

Fig. 3 Typical acceleration waveforms of L type concrete cask storage

3.2 Amplitude spectrum

The fast Fourier transform (FFT) technique was used to gain the amplitude spectrum of the digital waveforms. Fig. 4 is typical spectrum obtained from the back acceleration waveforms of concrete cask storage specimens filled with solid products with different compressive strengths. As shown in Figs. 4(a) and (b), the largest amplitude peaks of L-0 and S-0 specimens occur at a frequency of 9.93 and 9.66 kHz, respectively. When the compressive strength of solid product in L type specimens ranged from 7 MPa to 28 MPa, the frequency at peak amplitude increased from 10.08 kHz to 10.98 kHz. In S type specimens, the frequency at peak amplitude also increased from 9.99 kHz to 10.53 kHz.

For both L and S type specimens, the frequency in the peak amplitude increase as the compressive strength of solid product increases. From existing research results on strength versus frequency relationship of concrete, these similar results were reported [1-5]. These results indicate that the compressive strength of cement-based composite as solid product for concrete cask storage is much related to the frequency at peak amplitude from acceleration waveform.

3.3 P-wave velocity

Each arrival of the P-wave at the back surface of the concrete cask storage specimen causes the pulse of the concrete surface. The time history of pulse, especially acceleration, can be obtained with accelerometers positioned at the front and back surface of concrete cask as shown in Fig. 2. The path length traveled by the P-wave between successive arrivals is the length (L) of the specimen. The time interval between successive arrivals of the P-wave at the back surface of the concrete cask specimen is Δt. Thus, the P-wave velocity (V_P) in the concrete cask can be drawn as

$$V_p = \frac{L}{\Delta t} \qquad (1)$$

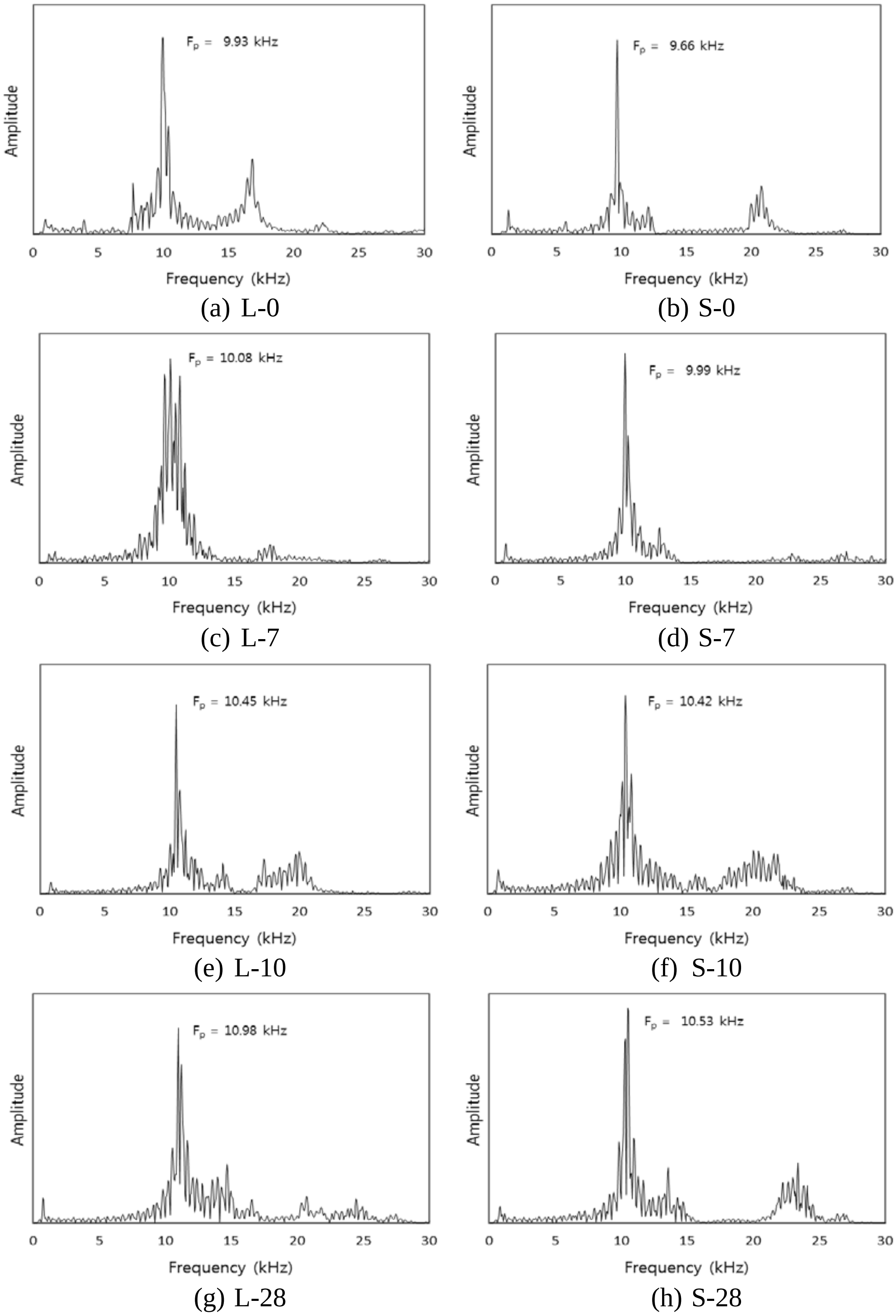
The frequency f_P of successive arrivals of the multiply reflected P-wave is equal to the inverse of Δt. The frequency can be obtained by using the principle of the Fourier transform.

$$f_p = \frac{1}{\Delta t} \qquad (2)$$

The P-wave velocity can be derived from above equation (1) and (2).

$$V_p = L\, f_p \qquad (3)$$

As shown in Fig. 4(a), the dominant peak in the spectrum of L-0 specimen at 9.93 kHz is the frequency f_P of the successive arrivals of the multiply reflected P-wave. Thus Δt, the inverse of f_P is 100.7 μs in this specimen.



(a) L-0 (b) S-0

(c) L-7 (d) S-7

(e) L-10 (f) S-10

(g) L-28 (h) S-28

Fig. 4 Typical amplitude spectrum of concrete casks from impact-echo tests

Table 2 Summaries of impact-echo test results

Specimen designation	Frequency, f_p (kHz)	Time interval, Δt (μs)	Velocity, V_p (km/s)
L-0	9.93	100.7	13.9
L-7	10.08	99.2	14.1
L-10	10.45	95.7	14.6
L-28	10.98	91.1	15.4
S-0	9.66	103.5	13.5
S-7	9.99	100.1	14.0
S-10	10.42	96.0	14.6
S-28	10.53	95.0	14.7

In this study, pulse responses from impact-echo tests for concrete cask storage with solid product with different levels of compressive strength are interpreted in the frequency domain. Eq. (3) is used to calculate the P-wave velocity of concrete cask specimen. Table 2 provides the P-wave velocity based on the experimental results from impact-echo tests for concrete cask specimens. As shown in Table 2, the P-wave velocity of concrete cask specimens increases as the compressive strength of cement-based composites used as solid product for concrete casks containing low-level radioactive waste increased. The P-wave velocity of concrete cask is much faster than those of cylindrical specimens reported in available literatures [1-5].

4 Conclusions

The following conclusions were drawn from the impact-echo tests of concrete cask filled with cement-based composites with different compressive strengths.

The P-wave velocity of concrete cask increased as the compressive strength of cement-based composite in the concrete cask increased. The impact-echo method shows a potential to be used to investigate the hardening of cement-based composites utilized as solid product to immobilize the radioactive waste in the concrete cask storage.

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