

# Estimation of Thickness of Concrete Structures using the Impact Echo Method and Ultrasonic Pulse Velocity Method

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<http://dx.doi.org/10.5659/AIKAR.2016.18.4.179>

**Abstract** The structure must be periodically checked and measures must be taken to prevent deterioration in building construction. From this point of view, a nondestructive test is essential to estimate whether the construction of buildings is proper, and whether the dimension of depositing concrete is consistent and without damage. This study estimated the thickness of the concrete component of construction framework using the ultrasonic velocity method and the impact echo method, in order to investigate reliability of the estimation of the thickness of normal strength concrete and high strength concrete, leading to the following conclusions. In the estimation of the thickness of the concrete structures, specimens of normal strength of 24MPa and specimens of high strength of 40MPa demonstrated an average error rate of 5.1% and 2.2%, respectively. The impact-echo method, one of the non-destructive tests, is verified as an efficient diagnostic technique. With this information, we will determine specific standards for the maintenance of structures, and the re-creation of lost building blueprints.

*Keywords: Estimation, Thickness, Concrete Structures, Impact -Echo Method, Ultrasonic Pulse Velocity Method, Nondestructive Tests*

## 1. INTRODUCTION

### 1.1 Objectives of the Study

It has been reported that concrete as a construction material is excellent in durability, semi-permanent, and has a life of approximately 70-100 years under normal circumstances. It has been used widely in construction and civil engineering structures. In recent years, however, degradation caused by salt damage, carbonation, freeze-thaw, and alkali aggregate reactions in addition to structural factors have frequently caused concrete structures to fail in terms of durability.

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This paper was presented at the 2016 ISAIA(International Symposium on Architectural Interchanges in Asia) in Japan and is republished as a special paper after the review of this journal.

This paper was made with the support of capstone design program for 2014 Hanbat National University and National Research Foundation of Korea(NRF, No. 2012R1A2A2A01012013).

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A nondestructive test is applied to measure the durability of these existing structures without destroying them. Also, the nondestructive test is applied to check the structural safety of new buildings, as well as that of existing buildings, and applied to measure the durability in remodeling situations. A nondestructive test is a fault detection technique to investigate the wholesomeness, function, and reproduction state of faults. It is also possible to check the wholesomeness and improve reliability by applying appropriate non-destructive tests for each purpose. To assess the construction management and durability of an existing structure, the structural strength and the status inside the structure should be determined. Usually, the compressive strength of the concrete test piece specimen prepared onsite is checked for structures under construction.

However, the accurate estimation of strength cannot be made because of the difference in conditions onsite and in an experiment room, which includes the concrete tarsal, consolidation, and curing conditions for the concrete structure and test piece specimen. A core can be collected to test quality parameters such as the strength, strain, size, cavities, and defects. However, this method causes damage to the building and is of limited value because a certain part cannot represent the total quality of the structure. So, to secure accurate data, non-destructive measurement of the strength of a concrete structure is required. J.Alexandre Bogas and al.(2013), D. Breyse(2012), W. L. Lai and al.(2013).

The Korean government has recognized the importance of nondestructive testing; they confirmed an implementation plan for non-destructive test technology in April 2008 and announced an investment plan worth a total of 6357 billion KRW. The Ministry

of Science and Technology; Ministry of Commerce, Industry and Energy; and Ministry of Construction and Transportation invested 52%, 43%, and 5%, respectively, of the total amount in this plan. About the investment, 6171 million KRW and 120 million KRW were invested in R&D and infrastructure reinforcement, respectively.

The structure must be periodically checked and measures taken to prevent deterioration in construction of buildings. We have determined that a comprehensive quality control is required to maintain quality in terms of safety and durability. From this point of view, a nondestructive test is essential to estimate whether the construction of buildings is proper, and whether the dimension of depositing concrete is consistent and without damage. Design drawings can be created based on the estimation of the thickness of the framework component by a nondestructive test. In this study, we performed reliability evaluations via nondestructive testing on concrete structures. The test methods used were the ultrasonic pulse velocity method and the impact-echo method.

## 1.2 Literature Review

Research to apply non-destructive test methods to concrete structures began as early as 1934, and research of non-destructive test methods to investigate concrete structure entered a new phase in the wake of the case in which fresh concrete was defective in 1973. The impact echo method, one of the aforementioned nondestructive tests, is a method by which to check the bulk wave which is reflected from the surface of a discontinuity or the interfaces between heterogeneous media, and returned to the surface as a waveform by impacting the surface of a specimen. Sansalone and Carino, (1998) and Y. Lin and al. (1992) from the National Bureau of Standards studied the relationship between the velocity of the compressional wave and the thickness and faults of the framework component, as well as that of heterogeneous material, by applying the impact-echo technique to general structures. They converted the velocity of reflected wave into the frequency domain, determined the frequency which caused the peak amplitude, and noted the arrival time of reflected waves. Research on the ultrasonic velocity method and the impact-echo method has been conducted by Han (2012), who estimated the strength of cyclic aggregate concrete via the ultrasonic pulse velocity method and the impact-echo method. Kang and al. (2013) have suggested the relationship between the thickness of the framework component and crack depth, and measured the related crack depths. However, most studies concentrate on strength estimation and fault location estimation. For the estimation of the thickness of concrete, Hong and al. (2013) have conducted research to estimate the thickness of slabs and the size of pillars, which is limited to a simulated specimen. The review of reliability in accordance strength of data on the slope and each framework component of the concrete structure is unresolved.

## 2. ESTIMATION METHOD OF CONCRETE THICKNESS

### 2.1 Elastic Property of Stress Wave

Among types of stress waves propagated according to the medium by an impact on the elastic body (Figure 1), a body wave is propagated through the interior of a medium by compression and tension of the medium particle (P-wave) or shear movement

moving left and right or up and down (S-wave). A surface wave (R-wave) is generated when the medium has a free surface such as the ground surface. A pressure wave (a 'Primary' or 'P' wave) is the first to return after transmission.

This wave makes a parallel sequence move in the wave progression direction of particle motion, and evokes volumetric strain without shearing strain. A shear wave progresses its particle motion vertically against the direction of wave progression; this is called 'Secondary' or 'S' wave as it arrives next after the pressure wave. The shear wave evokes shearing strain without volumetric strain. If lateral displacement is strained, the velocity of the pressure wave ( $V_p$ ) is determined as in Equation (1) by the elastic modulus of medium and density (Davis and al., 1998).

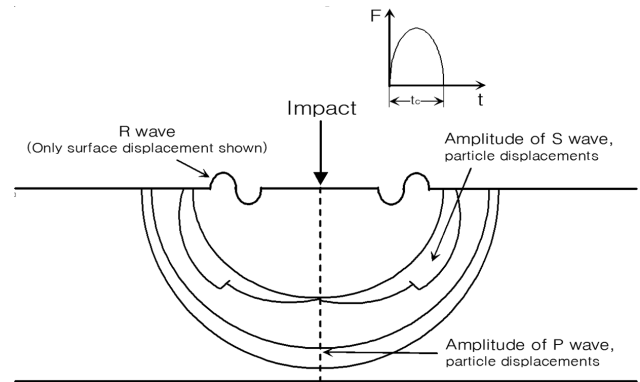


Figure 1. Elastic Wave Occurred by Impacts

$$V_p = \sqrt{\frac{M}{\rho}} = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}} \quad (1)$$

where  $M$  is the constrained modulus;  $E$  is Young's modulus;  $\rho$  represents density; and  $\nu$  is Poisson's ratio.

In a bar type medium that permits lateral displacement, the pressure wave ( $V_p$ ) is determined by Equation (2) (Davis and al., 1998).

$$V_p = \sqrt{\frac{E}{\rho}} \quad (2)$$

The shear wave velocity is determined as in Equation (3) by the shear elastic modulus and density (Lin and al., 1992).

$$V_s = \sqrt{\frac{G}{\rho}} \quad (3)$$

Where shear modulus

$$G = \frac{E}{2(1+\nu)} \quad (4)$$

The velocity of a Rayleigh wave is a function of shear velocity ( $V_s$ ) and Poisson's ratio as in Equation (5) (Davis and al., 1998).

$$V_R = \frac{0.87+1.12\nu}{1+\nu} V_s \quad (5)$$

**2.2. Impact Echo Method**

The impact-echo method is based on the use of temporal stress waves created by elastic impact. If any mechanical impact is added on the surface, the volumetric wave (P, S wave) that is transmitted to the test sample with a round wave surface, and a surface wave (R wave) is transmitted to the sample surface with cylinder type wave surface. When a volumetric wave encounters discontinuum such as a crack, hole or border between different media layers, it is returned to the surface where a stress wave occurs. As surface displacement by the P wave is echoed from discontinuum in media such as cracks, holes or borders between different media layers is far larger than the surface displacement created by the S wave, the wave form detected from the surface can be regarded as a waveform created by a P wave. If the impact-echo method can determine defects in the medium and dimensions of the test sample, it is possible to estimate concrete defects. If the ray velocity of the P wave is known, it can measure the arrival time of the echo wave to determine the continuum location inside the test sample (Lin and Sansalone, 1992), (Sansalone and Streett, 1997). Fig. 3(d) shows a diagram of the impact-echo method. If a stress wave from the hypocenter is recorded by an accelerometer and its record is transformed to the frequency domain through Fast Fourier Transformation (FFT) from the time domain, the first mode frequency becomes the maximum amplitude frequency; resonant frequency by multiple-echo and pressure wave velocity can be determined. The equation is shown in Equation (5) with the distance to the echo border surface on the plate structure (Sanalone and Carino, 1998), (Lin and al. 1992).

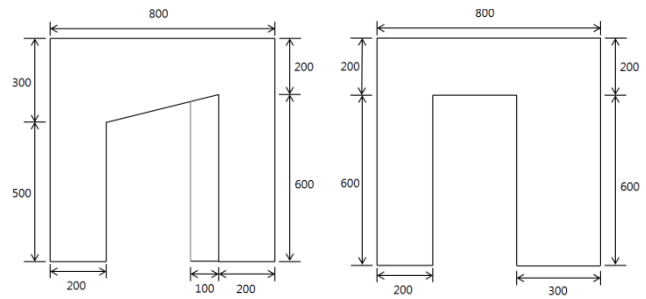
$$D = \frac{V_p}{2f} \tag{5}$$

Where D is the depth of structures;  $V_p$  is the compressive wave velocity; and f is the resonant frequency.

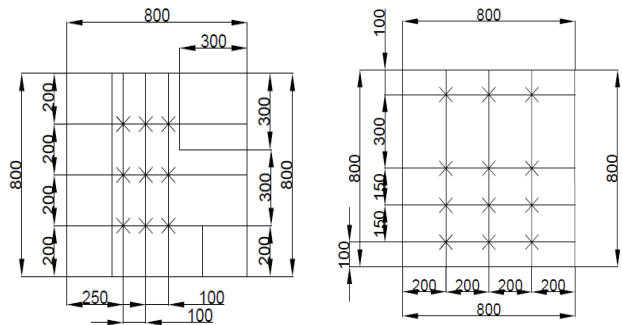
**2.3. Ultrasonic Pulse Velocity Method**

In this method, an ultrasonic wave is transmitted by a piezoelectric material into an experimental body such as a concrete structure or metallic material, and the ultrasonic wave returning from the boundary surface of the two different materials is received to evaluate the existence, position, size, and features of the discontinuity. This method is superior to other test methods in terms of penetration. The ultrasonic wave comprises a piezoelectric material, audible sound wave, and ultrasonic wave; types of waves include the longitudinal, transversal, surface, and plate waves. The ultrasonic pulse velocity differs depending on the density and elasticity of the material, and the features and elasticity of the material can be determined from the velocity. The positions of defects can be determined by measuring the time spent by the wave to reach and return from the defect positions.

The relationship between the material characteristics and ultrasonic pulse velocity is given by (1). In 1945, Lesile and Cheesman of Canada were the first to develop the ultrasonic pulse velocity method, which estimates the compressive strength of concrete by determining the velocity of an ultrasonic wave passing through, and Jones et al. developed equipment using vacuum tubes in 1948. In Great Britain and in Netherlands, the portable ultrasonic non-destructive digital indicating tester (PUNDIT) was developed. This made it possible to digitally to measure the propagation time of an ultrasonic wave without using vacuum tubes; research has continued since then, and the work by Whitehourst was adopted as the ASTM standard in 1951(Hong and Cho, 2006).



(a) Plan of Specimens (1/2)



(b) Plan of Specimens (2/2)



(c) Shape of Specimens

Figure 2. Experiment Plan

Table 1. Concrete mixed table

Design Strength (MPa)	Unit weight (kg/m <sup>3</sup> )					
	W	C	FA	S	G	AE
24	175	286	51	845	904	0.80
40	167	328	141	850	870	5.16

W: water, C: cement, FA: Fly ash, S: sand, G: gravel RG: recycled aggregate, AE: AE water reducing

Ultrasonic wave testing is based on the fact that the probe scans the energy of a sound wave on a test piece, and the test piece reacts to reflect the sound wave. In other words, instant energy is given to a probe by an electrical source; the probe briefly vibrates to send a pulse of sound to the test piece and then stops vibrating. When the sound wave reflected inside the test piece returns to the probe, the probe regains the sound wave and starts the vibration again. The ultrasonic pulse velocity method is as follows. When a short and strong electrical signal is sent to a transformer, which makes it

vibrate according to the resonance frequency, the vibration of the transformer is propagated to the concrete through contact media such as grease and a rubber couplant, and this is sensed by the receiving transformer on the opposite side. Because the time spent by the wave from start to arrival is recorded by an electrical device, the wave velocity can be calculated when the distance the wave travels is known. Besides the concrete strength, the wave velocity is influenced by the water content and reinforcement. When the status of concrete changes from dry to saturated, the wave velocity increases by about 5%.

The transducers are coupled to the test surfaces using a viscous material, such as grease, or a non-staining ultrasonic gel couplant if staining of the concrete is a problem. Transducers of various resonant frequencies have been used, with 50-kHz transducers being the most common. Generally, lower-frequency transducers are used for mass concrete (20kHz) and higher-frequency transducers (>100kHz) are used for thinner members where accurate travel times have to be measured. In most applications, 50-kHz transducers are suitable. A correction factor that considers the influence of reinforcement has been proposed. Figure 3(c) is a conceptual diagram of the Ultrasonic Pulse Velocity method.

### 3. EXPERIMENTS

#### 3.1. Plan of Experiments

Table 2. Ultrasonic Pulse Velocity

No.	Ultrasonic Pulse Velocity									
	24MPa (m/sec)					40MPa (m/sec)				
	1	2	3	4	5	1	2	3	4	5
1	3571	3030	3703	3703	3448	3846	2941	4166	4166	4000
2	3703	3030	3571	3846	3571	3846	2941	4166	4166	4000
3	3571	2941	3571	3846	3571	4000	2941	4166	4166	4000
4	3571	3030	3571	3703	3571	4000	3030	4166	4166	4000
5	3571	2941	3571	3846	3571	4000	2941	4347	4166	4000
6	3571	2857	3571	3703	3571	3846	2941	4347	4000	3846
7	3571	3030	3571	3846	3571	4000	2941	4166	4166	3846
8	3571	3030	3703	3846	3571	4000	2857	4166	4166	3846
9	3571	2941	3571	3846	3571	4000	2941	4166	4347	4000
10	3703	3030	3703	3846	3571	3846	3030	4166	4166	4000
11	3703	2941	3448	3703	3571	3846	2857	4347	4166	4000
12	3703	2941	3703	3846	3571	3846	2941	4347	4166	4000
13	3703	2941	3703	3846	3571	3846	2941	4166	4166	4000
14	3571	2941	3571	3846	3571	4000	2941	4166	4347	4000
15	3703	3030	3703	3846	3571	4000	2857	4166	4347	4000
16	3571	3030	3703	3703	3571	3846	2941	4347	4166	4000
17	3703	3030	3703	3846	3571	4000	2941	4347	4347	4000
18	3571	3030	3571	3846	3571	4000	2941	4347	4347	3846
19	3571	2941	3571	3703	3703	3846	2941	4347	4166	4000
20	3571	3030	3703	3846	3703	4000	2857	4166	4347	3846
Average	3617	2986	3624	3803	3578	3931	2933	4238	4212	3962

Specimens are slabs that are 800 mm long, 800 mm wide, and 300 mm or 200 mm thick, as shown in Figure 2. Walls are 800 mm long, 800 mm wide, 300 mm thick, 200 mm wide, and are made at the design strengths of 24MPa and 40MPa, as shown in Table 1. Five test pieces for measurement of average ultrasonic velocity are made of 100 mm × 200 mm according to their strengths. Estimated

positions of thickness are determined at the respective positions in the framework component, as shown in Figure 2.

The ultrasonic velocity was measured a total of 20 times in accordance with KS F 27319 at the center position of the test piece to calculate the ultrasonic velocity after 28 days, as shown in Figure 3. The experiment was performed in accordance with ASTM C 1384-0410 to estimate the thickness of the concrete structure using the impact-echo method.

#### 3.2. Results of Experiments

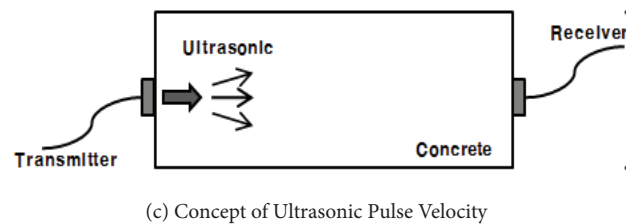
The average ultrasonic velocity of the 24MPa test pieces was 3522m/sec, and the average ultrasonic velocity of the 40MPa test pieces was 4085.75m/sec, as shown in Table 2.



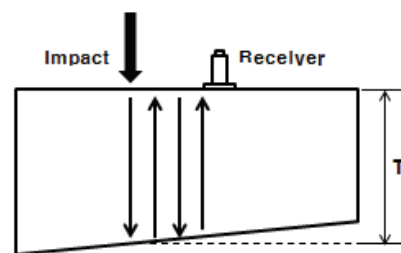
Ultrasonic Pulse Velocity



Impact-Echo method



(c) Concept of Ultrasonic Pulse Velocity



(d) Concept of Impact Echo Method

Figure 3. Nondestructive Test

According to the results of experiments on the estimation of the thickness using the impact-echo method,



Table 3. Results of Specimen 1(24MPa)

24MPa				
Part	Peak frequency (Hz)	Estimation Thickness (mm)	Real Thickness (mm)	Error rate (%)
S1(a)	8919.2	199.7	203	1.6
S1(b)	8333.3	212	203	4.4
S1(c)	8691.5	205	203	0.1
S2(a)	6895.1	255	244	4.5
S2(b)	6998.7	251.3	244	3.0
S2(c)	7031.3	250	244	2.5
S3(a)	5891.9	299.3	286	4.7
S3(b)	5859.4	301	286	5.2
S3(c)	6250	282	286	1.4
800W(a)	2311.2	762	797	4.4
800W(b)	2311.2	762	797	4.4
800W(c)	2246.1	784	797	1.6
W1(a)	9049.4	195.7	196	0.2
W1(b)	8821.6	201.3	196	2.7
W1(c)	8984.4	196.9	196	0.5
W2(a)	8951.8	197.7	198	0.2
W2(b)	8170.6	215.3	198	8.7
W2(c)	8528.7	206.3	198	4.2
W3(a)	8463.5	208.3	200	4.2
W3(b)	8789.1	201	200	0.5
W3(c)	8398.4	209.7	200	4.9
300 C(a)	7226.5	244.3	301	19
300 C(b)	6477.8	277.7	300	7.4
300 C(c)	7421.9	237	300	21
200 C(a)	8854.3	203.7	198	2.9
200 C(b)	7812.5	225	199	13
200 C(c)	9993.6	181.3	201	9.8

Table 4. Results of Specimen 2(40MPa)

40MPa				
Part	Peak frequency (Hz)	Estimation Thickness (mm)	Real Thickness (mm)	Error rate (%)
S1(a)	10124	201.7	201	0.35
S1(b)	10059	203	201	0.1
S1(c)	10254	199	201	0.1
S2(a)	8496.1	240	245	2.0
S2(b)	8496.1	240	245	2.0
S2(c)	8496.1	240	245	2.0
S3(a)	7031.3	291	288	1.0
S3(b)	7454.5	276	288	4.2
S3(c)	7031.3	291	286	1.0
800W(a)	2604.2	785	798	1.6
800W(b)	2604.2	785	798	1.6
800W(c)	2539.1	805	798	0.9
W1(a)	9765.3	209	198	5.6
W1(b)	10026.3	203.7	198	2.9
W1(c)	10026.3	203.7	198	2.9
W2(a)	10058.6	203	198	2.5
W2(b)	10156.3	201	198	1.5
W2(c)	10124	201.7	198	1.9
W3(a)	10123.7	201.7	199	1.4
W3(b)	10091.3	202.3	199	1.7
W3(c)	10156.3	201	199	1.0
300 C(a)	7356.8	279.7	296	8.3
300 C(b)	7324.2	279.7	296	8.3
300 C(c)	6902.6	299	296	1.0
200 C(a)	10156.3	201	200	0.5
200 C(b)	10286.7	198.7	202	1.6
200 C(c)	10026.3	203.7	202	0.8

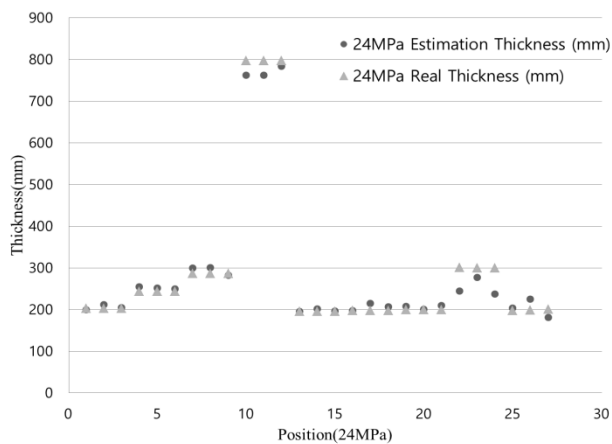


Figure 4. Estimated results of 24MPa Specimen

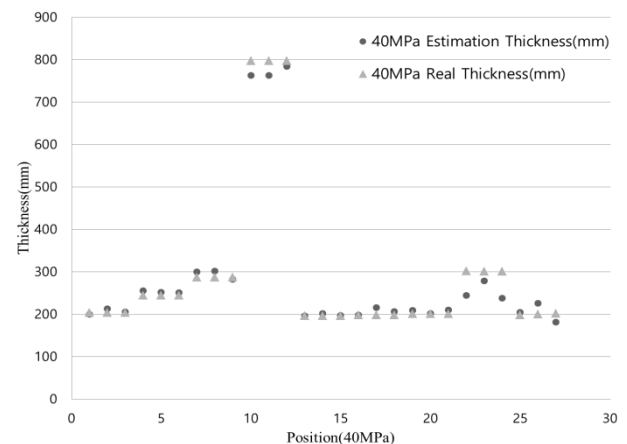


Figure 5. Estimated results of 40MPa Specimen

specimen slabs showed an average error rate of 3.0, wall 3.0%, pillar 12.2% and an overall average error rate of 6.1%, which provides a relatively accurate estimation of thickness.

Slabs showed an average error rate of 1.4%, wall 1.9%, column 3.4% and an overall average error rate of 2.3%, as shown in Table 3, Table 4, Figure 4 and Figure 5, for the specimens of 40MPa design strength. This provides an accurate estimation of thickness, as in the case of the specimens of 24MPa design strength. In addition, the average error rate was as low as 2.0%, 3.3%, and 3.8% in the

slope-structural slab of the 24MPa specimens, and the average error rate in the slope-structural slab of the 40MPa specimens was 0.2%, 2.0%, 2.1%. this is as low as those of the slope-structural slabs of the 24MPa specimens, which provides accurate estimation of the thickness of concrete slope structures and their reliability.

#### 4. CONCLUSIONS

This study estimated the thickness of the concrete component of

construction framework using the ultrasonic velocity method and the impact-echo method, in order to investigate reliability of the estimation of the thickness of normal strength concrete and high-strength concrete, leading to the following conclusions.

In the estimation of the thickness of the concrete structures, specimens of normal strength of 24MPa and specimens of high-strength (40MPa) demonstrated an average error rate of 5.1% and 2.2%, respectively. The impact-echo method, one of the non-destructive tests, is verified as an efficient diagnostic technique. With this information, we will determine specific standards for the maintenance of structures, and the re-creation of lost building blueprints.

of Concrete Structures using Impact Echo Method based on Stress Waves. *Journal of the architectural institute of Korea*, 22, (11), pp11-18

(Received Oct. 28, 2016/Revised Dec. 9, 2016/Accepted Dec. 14, 2016)

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