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EVALUATION OF IMPACT TESTING METHOD AND ULTRASONIC PULSE VELOCITY METHOD FOR ESTIMATING THE COMPRESSIVE STRENGTH OF REINFORCED CONCRETE STRUCTURES

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ABSTRACT

The purpose of this study is to compare and analyze estimated error of compressive strength in single-story structures using the impact testing method and ultrasonic pulse velocity method, and to review on-site applicability of these methods. The necessity of the diagnosis method using the composite nondestructive test method to confirm the reliability of the estimation is confirmed.

Keywords: impact testing method, ultrasonic pulse velocity method, compressive strength, reinforced concrete structures

NOMENCLATURE

M	ideal elastic body, mass
V	initial velocity
K	spring constant
x	displacement on the concrete surface
$\sqrt{MK}$	mechanical impedance
a	constant
Z	impedance value
N	reduction rate of elastic modulus
V_p	velocity (m/s)
M	Constrained modulus (MPa)
E	Young's modulus (MPa)
ρ	Density
v	Poisson's ratio

1. INTRODUCTION

The nondestructive test is widely used in the field of diagnosis and maintenance to evaluate the degree of damaging of structures caused by aging, and the demand for this test method is expected to continue increasing.

The purpose of this study is to compare and analyze estimated error of compressive strength in single-story structures using the impact testing method and ultrasonic pulse velocity method, which are non-destructive test methods, and to review on-site applicability of these methods.

2. IMPACT TESTING METHOD

The theory applied to the impact testing method is as described by T. Sakai et al. (2010). Displacement on the concrete surface caused by collision of the hammer is defined as x, and Eq. (1) can be expressed as below according to the law of energy balance. According to Hooke's law, force F can be expressed as Eq. (2). x_{max} is determined by Eq. (2) and can be substituted into Eq. (1) to derive Eq. (3).

$$1/2MV_0^2 = 1/2Kx_{max}^2 \tag{1}$$

$$F_{max} = Kx_{max} \tag{2}$$

$$\sqrt{MK} = F_{max}/V_0 \tag{3}$$

Which is calculated by dividing maximum force into initial velocity that occurs upon hammer impact. Spring constant corresponds to elastic modulus of the concrete surface. The correlation between elastic modulus and compressive strength is known. In fact, since maximum impact force of hammering is proportional to 1.2th power of impact velocity, impact velocity can be compensated as shown in Eq. (4) when calculating mechanical impedance.

$$\sqrt{MK} = F_{max}/V_0^{1.2} \tag{4}$$

In relation to estimation of compressive strength of concrete, the relationship between mechanical impedance index of concrete and elastic modulus is as expressed by Eq. (5).

$$E = aZ^N \tag{5}$$

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N is 4 if strain does not change and 3 in the case of ordinary concrete. The constant changes according to maximum strain of concrete.

3. ULTRASONIC PULSE VELOCITH METHOD

The ultrasonic pulse velocity method estimates the compressive strength of concrete by measuring the ultrasonic pulse velocity from the pulse passing time between the transmitter and receiver at certain distances in a concrete structure, as described in ASTM C597-09 and KS F 2731. As the time between the generation and arrival of the wave is recorded by the electrical equipment, the wave velocity can be obtained if the distance traveled by the wave is known. Assuming the behavior of concrete to be elastic, the propagation velocity of the wave can be expressed as equation (6).

$$V_p = \sqrt{\frac{M}{\rho}} = \sqrt{\frac{E(1-v)}{\rho(1+v)(1-2v)}} \tag{6}$$

4. EXPERIMENTS AND RESULTS

In this study, reliability of estimated compressive strength of reinforced concrete structures was evaluated by manufacturing single-story reinforced concrete structures comprised of vertical members and horizontal members as shown in Fig. 1, with height of 2,400mm, width of 2,400mm and height of 1,600mm. Two structures were made according to size of members, divided into 24MPa and 30MPa according to design compressive strength. Two structures were made for each strength as shown in Table 1 and Fig. 1. One of the structures had column thickness of 250x250mm and 400x400mm, girder thickness of 250mm and 350mm, wall thickness of 100mm, 200mm and 300mm, and slab thickness of 150mm and 180mm. The other structure had column thickness of 300x300mm and 500x500mm, girder thickness of 450mm and 550mm, wall thickness of 150mm, 250mm and 350mm, and slab thickness of 210mm and 240mm.

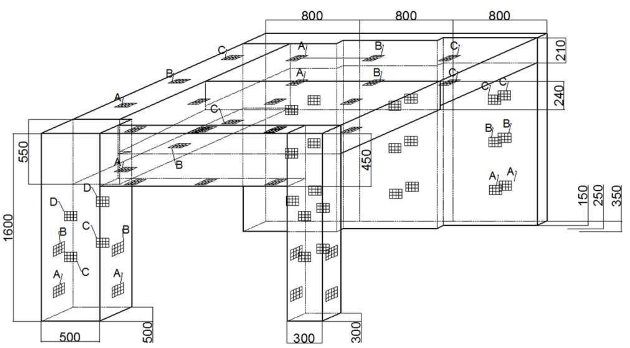

FIGURE 1: SHAPE OF SPECIMEN

Estimation of compressive strength using the impact testing method was performed in accordance with NDIS 3434, and estimation of compressive strength using the ultrasonic pulse velocity method was performed in accordance with ASTM C 597 and KS F 2731. Measuring devices used were CTS-02V4 of Nitto and Freedom data pc platform of Olson.

TABLE 1: LIST OF SPECIMENS

Specimen	Designed size (mm)	Specimen	Designed size (mm)
1 RC24C250	250x250	11 RC30C250	250x250
2 RC24C300	300x300	12 RC30C300	300x300
3 RC24C400	400x400	13 RC30C400	400x400
4 RC24C500	500x500	14 RC30C500	500x500
5 RC24W100	100	15 RC30W100	100
6 RC24W150	150	16 RC30W150	150
7 RC24W200	200	17 RC30W200	200
8 RC24W250	250	18 RC30W250	250
9 RC24W300	300	19 RC30W300	300
10 RC24W350	350	20 RC30W350	350
21 RC24G250	250	25 RC30G250	250
22 RC24G350	350	26 RC30G350	350
23 RC24G450	450	27 RC30G450	450
24 RC24G550	550	28 RC30G550	550
29 RC24S150	150	33 RC30S150	150
30 RC24S180	180	34 RC30S180	180
31 RC24S210	210	35 RC30S210	210
32 RC24S240	240	36 RC30S240	240

Estimation of compressive strength using the impact testing method was performed in accordance with NDIS 3434, and estimation of compressive strength using the ultrasonic pulse velocity method was performed in accordance with ASTM C 597 and KS F 2731. Measuring devices used were CTS-02V4 of Nitto and Freedom data pc platform of Olson.

The results of estimating compressive strength of the single-story reinforced concrete structures using the impact testing method were summarized in the order of the vertical members and the horizontal members. Among the vertical members, estimated compressive strength of the column member for design strength of 24MPa is 25.0MPa for thickness of 250mm as shown in Table 2, showing mean error of 17.9% compared to the compressive strength test results for the core specimen. Mean estimated compressive strength for thickness of 300mm is 27.7MPa, showing mean error of 9.1% compared to the compressive strength test results for the core specimen. Mean estimated compressive strength for thickness of 400mm is 25.1MPa, showing mean error of 17.6% compared to the compressive strength test results for the core specimen. Mean estimated compressive strength for thickness of 500mm is 27.9MPa, showing mean error of 8.4% compared to the compressive strength test results for the core specimen.

Among the horizontal members, estimated compressive strength of the girder member for design strength of 24MPa is 27.6MPa for thickness of 250mm as shown in Table 3, showing mean error of 9.5% compared to the compressive strength test results for the core specimen. Mean estimated compressive strength for thickness of 350mm is 28.6MPa, showing mean error of 6.2% compared to the compressive strength test results

TABLE 2: RESULTS OF EXPERIMENTS(VERTICAL)

No.	Impact testing			Ultrasonic pulse velocity		
	Estimation (MPa)	Error ratio (%)		Estimation (MPa)	Error ratio (%)	
1	25.0	17.9	13.3	27.1	11.1	26.4
2	27.7	9.1		23.1	24.3	
3	25.1	17.6		21.2	30.7	
4	27.9	8.4		18.5	39.4	
5	26.1	14.4	12.4	23.9	21.7	46.9
6	27.2	10.7		19.5	36.2	
7	27.2	10.7		20.6	32.3	
8	28.2	7.7		13.9	54.4	
9	25.7	15.9		12.6	58.6	
10	25.9	15.2		6.7	77.9	
11	24.2	33.2	32.1	29.7	11.1	30.6
12	24.3	32.7		26.4	27.1	
13	23.1	36.1		23.7	34.6	
14	26.7	26.3		18.2	49.7	
15	22.2	38.5	31.4	19.6	45.9	59.8
16	24.6	31.9		15.0	58.7	
17	27.1	25.0		12.4	65.7	
18	25.5	29.4		19.6	45.9	
19	25.3	30.1		12.8	64.5	
20	24.0	33.6		7.8	78.3	

TABLE 3: RESULTS OF EXPERIMENTS(HORIZONTAL)

No.	Impact testing			Ultrasonic pulse velocity		
	Estimation (MPa)	Error ratio (%)		Estimation (MPa)	Error ratio (%)	
21	27.6	9.5	8.1	22.3	26.9	36.9
22	28.6	6.2		21.0	31.1	
23	25.8	15.4		17.1	43.9	
24	30.1	1.3		16.6	45.6	
25	25.1	30.7	25.1	22.7	37.3	49.1
26	25.8	28.7		18.3	49.4	
27	26.2	27.6		18.4	49.2	
28	21.3	41.2		14.3	60.5	
29	28.2	7.5	10.3	18.8	38.4	47.2
30	25.2	17.4		16.0	47.5	
31	27.9	8.5		16.8	44.9	
32	28.1	7.9		12.8	58.0	
33	27.7	23.5	25.5	19.9	45.0	54.7
34	25.9	28.5		15.2	58.0	
35	25.4	29.8		16.1	55.5	
36	28.9	20.2		14.4	60.2	

for the core specimen. Mean estimated compressive strength for thickness of 450mm is 25.8MPa, showing mean error of 15.4% compared to the compressive strength test results for the core specimen. Mean estimated compressive strength for thickness of 550mm is 30.1MPa, showing mean error of 1.3% compared to the compressive strength test results for the core specimen.

Based on compressive strength estimated using the impact testing method, overall mean error of estimated compressive strength is 22.7% for the column member and 21.9% for the wall member. Overall mean error for the vertical members is 22.3%. Overall mean error of estimated compressive strength is 16.6% for the girder member, 17.9% for the slab member, and 17.3% for the horizontal members. Overall mean error of estimated compressive strength for all structures is 19.8%. Based on compressive strength estimated using the ultrasonic pulse velocity method, overall mean error of estimated compressive strength is 28.5% for the column member and 53.4% for the wall member. Overall mean error for the vertical members is 40.9%. Overall mean error of estimated compressive strength is 43.0% for the girder member, 51.0% for the slab member, and 47.0% for the horizontal members. Overall mean error of estimated compressive strength for all structures is 44.0%.

4. CONCLUSION

Based on compressive strength of the structures estimated, overall mean error was 19.8% for the impact testing method and 44.0% for the rebound hardness method. It is necessary to investigate the variation of the error ratio of the estimated compressive strength according to the member size and reinforcement. And the necessity of the diagnosis method using the composite nondestructive test method to confirm the reliability of the estimation is confirmed.

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