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EFFECTIVENESS OF ULTRASONIC METHOD IN DETECTION OF CONCRETE DETERIORATION

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ABSTRACT

Tests were performed to evaluate the feasibility of using Ultrasonic Pulse Velocity Method (UPVM) in detecting defect and determining its depth during the early age concrete. Five reinforced concrete (RC) slabs grade 30 and 40 specimens at day 3, 7, 14 and 28 with a fabricated void at a known location were used. The results obtained were compared to determine the accuracy of the method hence the effectiveness of the method with different strength and as the concrete matures. This method detects defects in specimens during the early age. The accuracy varies with concrete strength and as the concrete mature. The test results indicate the method can be used to assess the in-situ properties of concrete or for quality control on site. The method showed better accuracy with stronger concrete detects defects with the accuracy ranging from 55.75-99.05% from day 3-28 (full strength) respectively.

Keywords: non-destructive testing, concrete, Ultrasonic Pulse Velocity Method, defects detection and accuracy

INTRODUCTION

The deterioration of concrete in a structure is a result of several degradation mechanisms that caused a decreased in the integrity of the structure. The state of deterioration is often invisible and is only evident when there is a significant reduction in the load carrying capacity. Ensuring better performance of concrete structures requires early defects detection. Defects are often introduced during casting and detection during in-service life is often too late to remedy the situation. In the past years great improvement has been made in the field of non-destructive testing in civil engineering (NDT-CE) and this trend will certainly continue and even accelerate. Keywords like quality control, monitoring, maintenance or replacement, building inspection and the like highlight this development.

NDT-CE will doubtlessly helps outline future tasks and identify objects to be tested. Available solutions must be optimized. Testing strategies will have to be developed for special applications, for e.g. how to use the different techniques, to combine them with numerical calculations, to check the accuracy of test results and to interpret them. Potential users of NDT-CE should be able to judge the benefits of the different techniques and test instruments. NDT-CE can be applied to each stage of an item's construction. The materials and welds can be examined using NDT-CE and either accepted, rejected or repaired. NDT-CE techniques can then be used to monitor the integrity of the item or structure throughout its design life.

Base on the information obtained for Ultrasonic Pulse Velocity Method (UPVM), all the work that have been done in relation to defect detection and depth of defect determination are limited to in-service structures for case-study and on laboratory research specimens that are more than 28 days of age. None of them are done on early age structures or specimens except for the monitoring of strength development in concrete [1][2][5][6].

The scope of this study is to test and compare the accuracy between different concrete strength and different concrete age by using the ELE PUNDIT 6, **P**ortable **U**ltrasonic **N**on-Destructive **D**igital **I**ndicating **T**ester (UPVM) [4] for detecting the location and depth of defects. The main interest is to correlate concrete age and how it affects the accuracy of defect detection.

MATERIALS AND METHODS

Ten reinforced concrete (RC) slabs with prerecorded location and depth of fabricated void namely the actual void depth (i.e. 37.5mm) of grade 30 and 40 respectively were prepared. The proportions of the concrete mix are summarized in Table 1 and 2.

Table 1: Grade 30 RC Slab (500 x 300 x 75)

Cement	Fine Aggregate Sand	Coarse Aggregate 20mm	Water
4.706 kg	13.858 kg	17.680kg	2.340 kg
1	2.94	3.76	0.5

Slump = 10-30 mm cured at room temperature

Table 2:Grade 40 RC Slab (500 x 300 x 75)

Cement	Fine Aggregate Sand	Coarse Aggregate 20mm	Water
4.500 kg	8.07 kg	12.105kg	2.25 kg
1	1.79	2.69	0.5

Slump = 10-30 mm cured at room temperature

All the specimens were tested from day 3, 7, 14 and 28 with UPVM. The accuracy of the testing methods was determined by comparing the prerecorded location and depth voids. The method of testing and determining the void location and void depth at different age are as follows.

Ultrasonic Pulse Velocity Method (UPVM)

The indirect method of testing is used since it is the best method to determine the effective path length [3,4]. Figure 1 shows the indirect method for detecting void. The void depth can be estimated using the following equation:

$$t = \frac{x_0}{2}\sqrt{\frac{V_s - V_d}{V_s + V_d}} \qquad \text{Equation 1}$$

Where V_d is the pulse velocity in the defect concrete (km/s), V_s is the pulse velocity in the sound concrete (km/s) and t is the depth of the defect (mm), x_0 is the distance at which the change of slope occurs (mm). Table 3 showed the data obtained from the test. Figure 2 showed the transit time (μs) versus distance (mm) for the determination of void depth. A change of slope in the plot indicates the presence of void i.e. 200mm as shown in Figure 2.

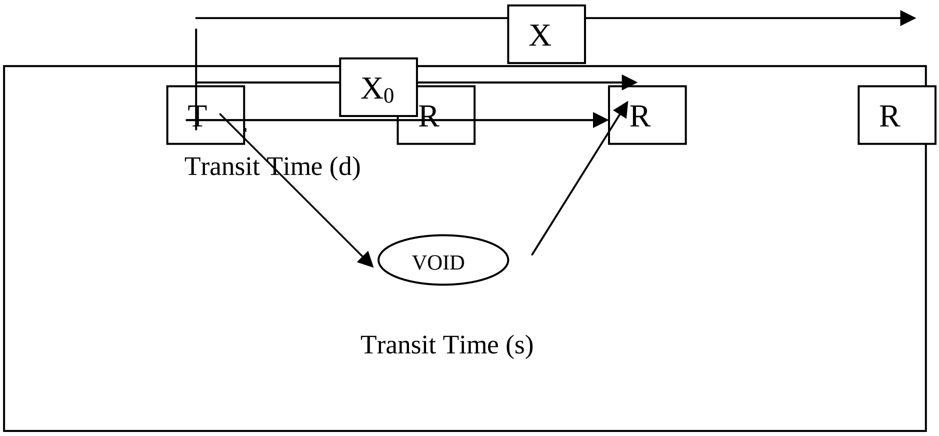

Table 3 UPVM Test Data: Slab 1 (Grade 30) and Slab 6 (Grade 40)

DISTANCE (mm)	Transit Time (μs)							
	Day 3		Day 7		Day 14		Day 28	
	Grade 30	Grade 40	Grade 30	Grade 40	Grade 30	Grade 40	Grade 30	Grade 40
100	13.0	14.5	14.6	12.5	12.9	11.7	16.1	11.4
200	41.4	44.0	41.5	36.9	42.6	36.1	46.0	38.7
300	67.8	71.0	66.1	77.6	70.4	75.3	68.8	74.3
400	89.5	99.7	86.2	98.0	92.4	96.4	91.4	95.3

All the depth detected was calculated using Equation 1 and the results were tabulated in Table 4. The detected depth was than compared with the actual void depth. From Table 4 a typical calculation for RC Slab 1 Grade 30 at day 28 using Equation 1 is presented below.

$$t = \frac{200}{2}\sqrt{\frac{5.873 - 4.499}{5.873 + 4.499}} = 36.39\text{mm}$$

Accuracy = (Detected void depth/Actual void depth) x100
= (36.39/37.5) x100 = 97.05%

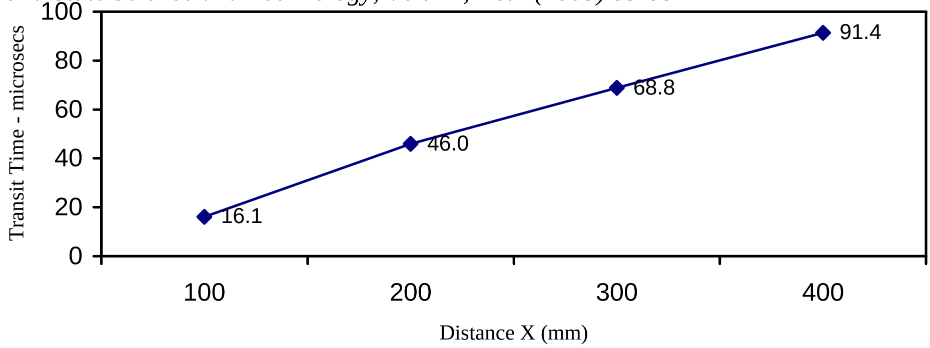

Figure 2. Void Depth Determination by the Indirect Method for RC Slab 1 (Grade 30) at day 28

Table 4. Ultrasonic Pulse Velocity Test Results: Slab 1 (Grade 30) and Slab 6 (Grade 40)

CONCRETE AGE DAYS	X_o (mm)		V_s (Km/s)		V_d (Km/s)		t Void Depth (mm)		Accuracy %	
	30	40	30	40	30	40	30	40	30	40
3	200	200	5.271	5.172	4.829	4.545	20.91	25.40	55.75	67.73
7	200	200	5.375	6.522	4.813	5.540	23.46	28.53	62.56	76.08
14	200	200	5.584	6.732	4.695	5.547	29.41	31.07	78.69	82.84
28	200	200	5.873	6.810	4.499	5.159	36.39	37.01	97.05	98.70

RESULTS AND DISCUSSIONS

The use of stress wave propagation to monitor the development of early-age mechanical properties is not a new idea. In this study, two parameters namely void location and void depth are used to determine the accuracy of the method. Changes in strength of concrete with age that are influenced by porosity are the significant factor affecting the accuracy of readings since all other properties are similar for both specimens.

Figure 3 showed the accuracy versus age for RC Grade 30 and 40 using UPVM. From the figure, the accuracy of this method increased as the specimens matures. The results indicate that changes in aggregate, moisture and air void affects the readings of the method as shown by the 2 different grade specimens. Grade 30 specimens yield less accuracy than grade 40 specimens. Ultrasonic pulse velocity of reinforced concrete is affected by changes in the hardened cement paste. The changes in the water/cement ratio affect the modulus of elasticity of the hardened cement paste. Pulse travels faster through a water-filled void compared with an air-filled one. Therefore the moisture condition of concrete affects the pulse reading.

As the concrete age, the moisture content decreases and it can be observed from Figure 3 that as the concrete mature the detection of void is more accurate. The results also showed that UPVM is not accurate enough in detecting the exact void depth. This is due to the sensitivity of UPVM to air humidity. Another reason is due to the mix design of the concrete specimens. Referring to Table 1 and 2 for the two mixes, Grade 30 has more coarse aggregate than Grade 40 and this explained why Grade 40 specimen is more accurate in determining the depth of the void for both methods. Less homogeneous specimen yield less accurate reading since coarse aggregate can diffract the pulse or ultra

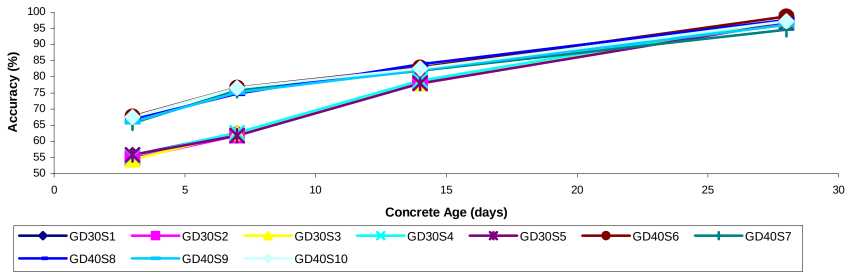

Figure 3: Accuracy versus RC Grade 30 and 40 using UPVM

CONCLUSIONS

For the purpose of quality control on site, the use of UPVM enable detecting defect in concrete structure as early as day 3. Based on the present study it is concluded that detection of defect location is possible as early as day 3 after the removal of formwork. The defect depth determination is possible with accuracy ranging from 55.75-98.70% for UPVM. Stronger concrete gives better accuracy in determining the depth of defect. The actual performance of in-situ concrete during early age is yet to be fully understood. Therefore, more studies and further research on actual bridge structure should be conducted. Porosity and other effects that changes concrete properties during early age should also be taken into consideration for further research.

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