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The Accuracy of Ultrasonic Pulse Velocity Method in the Detection of Distress for Reinforced Concrete Structure

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Abstract: An experimental study been made in evaluating the accuracy of Ultrasonic Pulse Velocity Method in detecting distress in reinforced concrete has been made. Tests were undertaken to evaluate the viability of using Ultrasonic Pulse Velocity Method (UPVM) in detecting distress and determining its depth during the early age concrete. Five Reinforced Concrete (RC) slabs of grade 25, 30, 40 and 50 specimens at day 3, 7, 14 and 28 with a fabricated distress namely void at a known location were used. The results obtained were then compared with the known location and between concrete ages to determine the accuracy of the method hence the effectiveness of this method. UPVM detects distress in specimens during the early age. The test results indicate that the method can be used to assess the in-situ properties of concrete or for quality control on site as for the detection of the presence of distress but not for accurate of depth of distress particularly right after the removal of formwork. The result showed better accuracy with stronger concrete in the detection of depth of distress with the accuracy ranging from 51.81-99.62% from day 3-28 (full strength) respectively.

Key Words: Non-destructive Testing, Ultrasonic Pulse Velocity Method, Distress Detection Porosity, Accuracy

Introduction

Material distress is defined as the physical deterioration or breaking down of the concrete into small fragments or construction defect. The distress in concrete structure is a result of several degradation mechanisms that caused a decreased in the integrity of the structure such as acid attack, chemicals, chlorides or sulphates attack. Meanwhile honeycombing occurs as a result of construction defects due to improper construction technique or poor workmanship. The level of distress 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 distress detection. Distress or defects are often introduced during casting and detection during in-service life is often too late to remedy the situation.

Previous work that have been done with Ultrasonic Pulse Velocity Method (UPVM) in relation to distress detection and depth of distress determination were 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 (Bungey,1980 and 1982; Neville, 1987).

The purpose of this study is to evaluate the accuracy of ELE PUNDIT 6, Portable Ultrasonic Non-Destructive Digital Indicating Tester (UPVM) (PUNDIT, 1992) for detecting the location and depth of distress at early age concrete. The main attention is to correlate concrete properties with age and how it affects the accuracy of defect detection.

Materials and Methods

Five Reinforced Concrete (RC) slabs of grade 25, 30, 40 and 50 respectively with prerecorded location and depth of fabricated void namely the actual void depth (i.e. 37.5mm) were prepared. The proportions of the concrete mix are summarized in Table 1, 2, 3 and 4.

Table 1:Grade 25 RC Slab (500 x 300 x 75)

Cement	Fine Aggregate Sand	Coarse Aggregate 20mm	Water
4.805 kg	14.35 kg	18.157kg	2.403 kg
1.000	2.99	3.78	0.5

Slump = 10-30 mm cured at room temperature

Table 2: 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
1.000	2.94	3.76	0.5

Slump = 10-30 mm cured at room temperature

Table 3: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
1.000	1.79	2.69	0.5

Slump = 10-30 mm cured at room temperature

Table 4:Grade 50 RC Slab (500 x 300 x 75)

Cement	Fine Aggregate Sand	Coarse Aggregate 20mm	Water
4.305 kg	7.07 kg	10.165kg	2.17 kg
1.000	1.64	2.36	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 method was determined by comparing the prerecorded location and depth of void with the results obtained. The methods of testing such as determining the void location, void depth in concrete at different age is as follows.

Table 5: UPVM Test Data: Slab 1 (Grade 25), Slab 6 (Grade 30), Slab 11 (Grade 40) and Slab16 (Grade50)

DISTANCE (mm)	Transit Time (μs) Day 3		Day 7		Day 14		Day 28	
	Grade 25	Grade 30	Grade 25	Grade 30	Grade 25	Grade 30	Grade 25	Grade 30
100	12.7	13.0	12.8	14.6	13.7	12.9	17.5	16.1
200	40.6	41.4	39.6	41.5	44.7	42.6	48.4	46.0
300	65.8	67.8	59.7	66.1	68.9	70.4	64.8	68.8
400	87.6	89.5	79.5	86.2	90.5	92.4	89.3	91.4

DISTANCE (mm)	Transit Time (μs) Day 3		Day 7		Day 14		Day 28	
	Grade 40	Grade 50	Grade 40	Grade 50	Grade 40	Grade 50	Grade 40	Grade 50
100	14.5	15.7	12.5	11.7	11.7	10.8	11.4	10.8
200	44.0	47.6	36.9	32.8	36.1	34.6	38.7	35.9
300	71.0	73.1	77.6	80.8	75.3	76.8	74.3	78.0
400	99.7	99.7	98.0	99.1	96.4	98.9	95.3	97.5

Table 6: Ultrasonic Pulse Velocity Test Results: Slab 1 (Grade 25), Slab 6 (Grade 30), Slab 11 (Grade 40) and Slab 16 (Grade 50)

DAYS	X_o (mm)		V_s (Km/s)		V_d (Km/s)		t Void Depth (mm)		Accuracy %	
	25	30	25	30	25	30	25	30	25	30
3	200	200	5.345	5.271	4.956	4.829	19.43	20.91	51.81	55.75
7	200	200	5.278	5.375	4.849	4.813	20.56	23.46	54.83	62.56
14	200	200	5.456	5.584	4.872	4.695	23.78	29.41	63.41	78.69
28	200	200	5.765	5.873	4.591	4.499	33.67	36.39	89.79	97.05

DAYS	X_o (mm)		V_s (Km/s)		V_d (Km/s)		t Void Depth (mm)		Accuracy %	
	40	50	40	50	40	50	40	50	40	50
3	200	200	5.172	5.073	4.545	4.456	25.40	25.45	67.73	67.86
7	200	200	6.522	6.723	5.540	5.625	28.53	29.81	76.08	79.52
14	200	200	6.732	6.845	5.547	5.698	31.07	30.23	82.84	80.63
28	200	200	6.810	6.978	5.159	5.269	37.01	37.36	98.70	99.62

UPVM: The indirect method of testing is used since it is the best method to determine the effective path length (BSI,1970). Fig: 1 shows the indirect method for detecting void. The void depth can be estimated using the following equation:

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

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 5 showed the data obtained from the test. Fig. 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 Fig. 2.

All the depth detected was calculated using Equation 1 and the results were tabulated in Table 6. The detected depth was than compared with the actual void depth. From Table 6 a typical calculation for RC Slab 6 (Grade 30) at day 28 using Equation 1 is presented below.

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

= 36.39mm

Accuracy = (Detected void depth/Actual void depth) x10
= (36.39/37.5) x100
= 97.05%

Results and Discussion

In this study, two parameters namely void location and void depth are used to determine the accuracy of UPVM. Changes in the 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 all specimens.

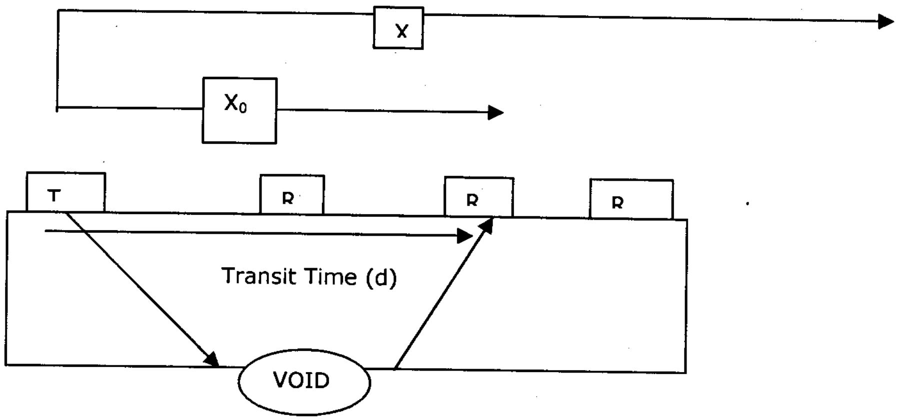

Fig.1: Void Detections Using the Indirect Method [4]

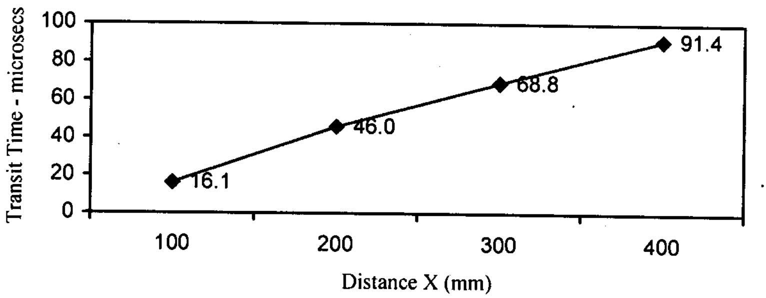

Fig.2: Void Depth Determination by the Indirect Method for RC Slab 6 (Grade 30) at Day 28

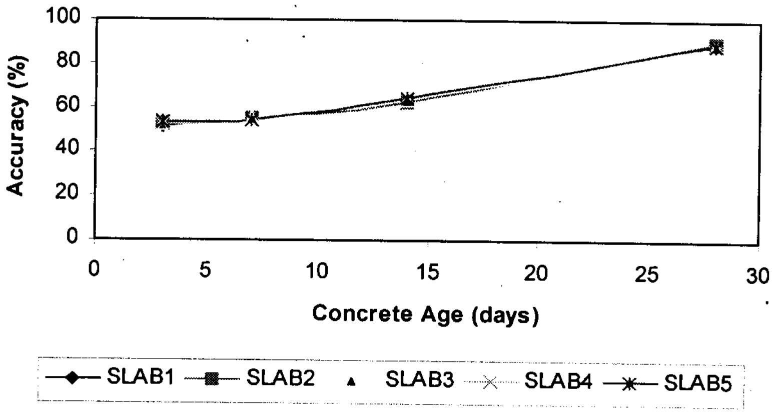

Fig.3: Accuracy Versus Age for UPVM for RC GD 25

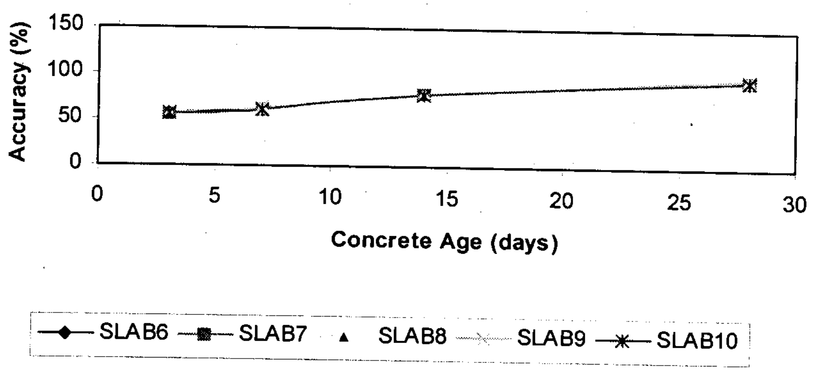

Fig. 4: Accuracy Versus Age for UPVM for RC GD 30

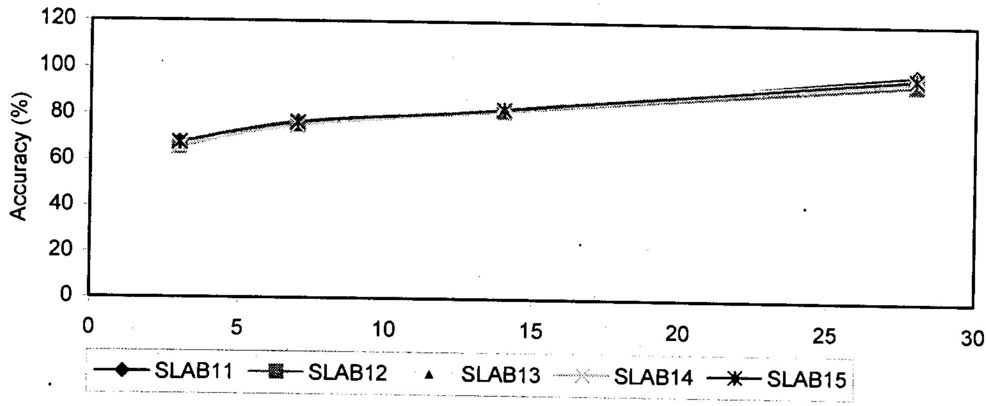

Fig. 5: Accuracy Versus Age for UPVM for RC GD 40

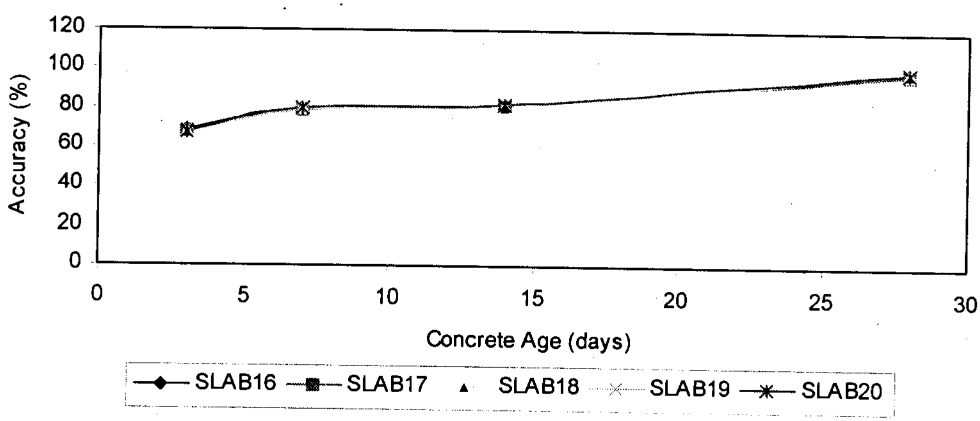

Fig. 6: Accuracy Versus Age for UPVM for RC GD 50

Figure 7: Accuracy of UPVM versus Concrete Age and Correlation with Porosity for RC GD 25(Slab 1-5) GD30(Slab6-10)GD40(Slab11-15) and GD40(Slab16-20)

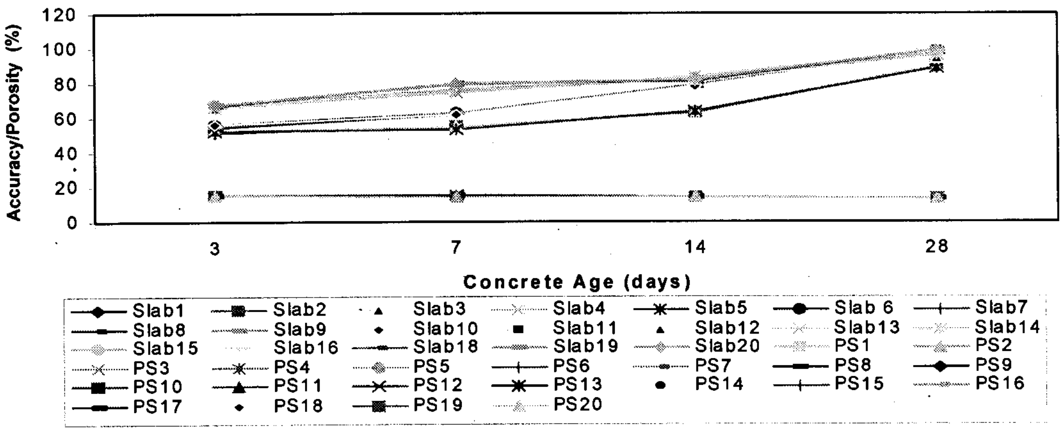

Figure 3-6 showed the accuracy versus age for RC Grade 25, 30, 40 and 50 using UPVM. It can be seen from these Figures, the accuracy of this method increased as the specimens matures. The results indicate that changes in aggregate, moisture and air void affects the readings of this method as shown by the 4 different grade specimens. Grade 25 specimens yield less accuracy than higher grade 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 and wave reading. As the concrete age, the moisture content decreases and it can be observed from these Figures that as the concrete mature the detection of void is more accurate. This is due to the sensitivity of UPVM to air humidity.

Another reason is due to the mix design of concrete specimens. Referring to Table 1,2,3 and 4 for the four mixes, Grade 25 has the highest amount of coarse aggregate content than higher-grade specimens and this explained why Grade 50 specimens obtained the highest accuracy in determining the depth of the void at all ages. Less homogeneous specimen yields least accuracy since coarse aggregate can diffract the pulse or ultrasonic wave.

Fig. 7 showed the correlation between percentage of accuracy and porosity of UPVM for RC Grade 25, 30, 40 and 50 with concrete age respectively. As the concrete strengthened, the percentage of porosity decreased. Porosity is expressed as a fraction of volume of voids to the total volume of concrete. The porosity was determined from the relationship between compressive strength and porosity graph. (Neville, 1987) It was observed that the decreased of porosity as the concrete matures increases the accuracy of UPVM. The reason for this is based on the testing principle for UPVM (PUNDIT, 1992) i.e. where the presence of void on the path will increase the path length as it goes around the void. Concrete with higher porosity acts like bigger voids and this will affect the readings.

Conclusion

The use of UPVM enables detecting the presence of distress in concrete structure as early as day 3 but not the exact depth of distress. This is good for the purpose of quality control on site. Based on the present study it is concluded that detection of the presence of distress is possible as early as day 3 after the removal of formwork. The distress depth determination is possible with accuracy ranging from 51.81-99.62%. Stronger concrete gives better accuracy in determining the depth of distress at all ages. Theoretically, porosity of concrete has significant effect on the accuracy of the defect depth. It was observed that decrease of porosity with age increase the accuracy. The actual performance of in-situ concrete during early age is yet to be fully understood. Besides porosity, other effects that changes concrete properties during early age should also be taken into consideration for further research.

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