CRACK DEPTH MEASUREMENT OF REINFORCED CONCRETE BEAMS USING UPV

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ABSTRACT

Cracks in the concrete should not be ignored because it can cause serious problems. Cracks in concrete usually terms only in wide of rift, so a review of crack depth is needed. Crack depth can be measured by Ultrasonic Pulse Velocity (UPV). UPV test is one of the Non Destructive Tests on the building. UPV testing is influenced by several factors such as reinforced steel. The aim of this study is to determine the accuracy of crack depth in reinforced concrete beams with a thickness of concrete cover measured by UPV. Four variations of 15 concrete beams and one variation of unreinforced beam with thick concrete cover are used in this study. Three test specimens are used for each variation. The thickness of concrete cover is measured at point of 2 cm, 3 cm, 4 cm, and 5 cm. The concrete beams of 15 x 20 x 50 cm in size were designed with 8 cm crack depth. Artificial crack in the concrete beam is generated in a way to give the sealing of cracks in the aluminum zinc plate formwork before casting occur. Crack protection removed from the formwork with duration of 3-4 hours after casting. Crack depth measured by UPV test is done after 28 days concrete age. The results showed that there is a relative error of crack depth measured with UPV test. The average relative error of concrete with a thickness cover of 2 cm, 3 cm, 4 cm, and 5 cm was respectively 6.80 %, 6.63 %, 5.48 % and 4.91 %. The average relative error of unreinforced concrete was 4.59 %. Statistical analysis with one way F test shows that there is no significant difference between the relative error of crack depth measured with UPV test at each cover depth variation and unreinforced concrete with $\alpha = 0.05$.

Keyword : UPV, Crack width, Crack depth, Reinforced concrete.

INTRODUCTION

Crack on concrete should not be ignored because it is one of the main causes of collapse. Therefore, preliminary investigation of concrete structure is needed. Crack examination in term of the crack width is not enough to evaluate the damage of concrete building. It is also necessary to measure the crack depth of concrete.

Ultrasonic waves are classified as sound waves which can propagate in a medium. Sound waves can propagate in a solid medium, liquid and gas but cannot propagate in empty space. Sound waves require a medium to propagate. The difference of medium passed by ultrasonic waves caused the waves' speed at each medium is different from one another. So the depth of cracks in concrete can be measured by using ultrasonic pulse velocity test (UPV). UPV utilizes ultrasonic wave propagation to measure the depth of cracks in concrete. UPV measures the transit time of the ultrasonic waves distance on concrete and be analyze as the speed of the wave. UPV test is one of Non Destructive Test (NDT), which has been widely used for building examination.

The works of UPV are basically by transmitting waves of vibration on concrete and receiving vibrations then calculating the transmit time of the propagation of the wave vibrations (VM Maholtra & NJ Carino, 2004).

The velocity of wave vibration is shown by the UPV test instrument as shown in **Figure 1** based on transmitting time which has been calculated.
In general, the relationship of speed, time, and distance can be obtain from the following equation:

$$V = \frac{L}{T}$$

Where : V = Speed (m/s)
L = Distance (m)
T = Time/travel time (s)

Figure 1. UPV Test Tool: Pundit Lab (+)
(Source : www.proceq.com)

UPV test accuracy is affected by the ultrasonic wave velocity in the test specimen. There are various factors that affect the speed of the wave at the UPV test as follows:

1. The distance between transmitter and receiver
2. The condition of concrete surface
3. Concrete temperature
4. The influence of steel reinforcement.

UPV has many advantages to test the quality of concrete without causing damage. In general, the utilities of UPV are (VM Maholtra & NJ Carino, 2004):

1. Estimating concrete compressive strength
2. Analyzing concrete homogeneity
3. Measuring crack depth
4. Analyzing concrete's durability
5. Finding elastic modulus of concrete.

Furthermore, UPV test can indicate concrete quality based on the speed of the wave through. Concrete quality assessment based on the speed of the waves that pass through can be seen in **Table 1**.

One of UPV tests on concrete is measuring the crack depth. This measuring can be carried out by using indirect method, which is a measuring method where transmitter and receiver are put on a surface, as shown in **Figure 2**. The transit time of the ultrasonic waves crack depth can be found with transit time.

Table 1. Wave Speed and Concrete Quality

Wave Speed (m/s)	Concrete Quality
Above 4500	Very Good
3500 – 4500	Good
3000 – 3500	Fair
Under 3000	Bad

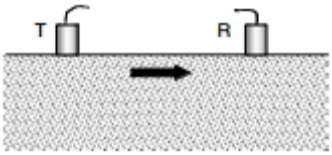


Figure 2. Indirect Transmission Method

The aim of this study is to determine the crack depth measurement accuracy with UPV tests in reinforced concrete, and the effect of concrete cover thickness on crack depth measurement results using UPV test.

METHOD

Reinforced concrete beams which were tested have variation of concrete cover with a thickness of 2 cm, 3 cm, 4 cm, 5 cm and one unreinforced sample variation.

Artificial crack was made by giving zinc plate bulkhead before casting. The aluminum zinc plate used size of 8 x 25 cm. The artificial crack depth is planned 8 cm. The longitudinal reinforcement

used ∅8 and transversal reinforcement ∅6. The concrete will be tested at the age of 28 days. Amount of specimens are 15 samples, in which details of variation of the test object can be seen in **Table 2**.

UPV test is done in indirect way. Transmitter and receiver are put in X distance, along 5 cm from the artificial crack line. The frequency of transmitter and receiver used is 54 KHz. The artificial crack depth can be calculated if the transmit time has been read.

The result is compared to conventional measurement.

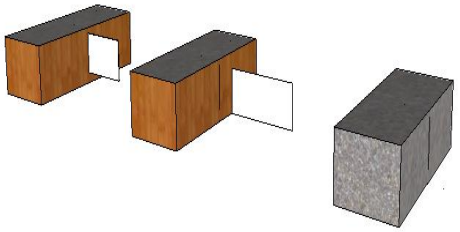
Table 2. Research Design

Sample	Concrete Cover Variations				
	Un-reinforced	2 cm	3 cm	4 cm	5 cm
Specimen of each variation	3	3	3	3	3
Total	15				

The artificial crack is constituted by given baffle made of zinc plate in specified position. Casting is achieved in the side of the beams so the surface where the artificial crack appeared is flat. The creating of artificial crack is shown in **Figure 3.**

Crack measurement can be obtained by the time and distance of wave. Transmitter and receiver are put opposite order in the concrete surface at a certain distance. The measurement is done in the cracked side of the concrete. The distance between transmitter and receiver is arranged in concrete surface. In this research, the effective distance of UPV's transducer which is used is 5 cm. The data is collected in area location that has been determined as shown in **Figure 4.**

In **Figure 5**, a thin iron bar is used and put into the artificial crack to measure the actual crack depth, so the depth can be measured.



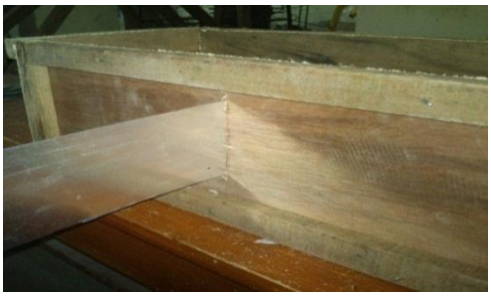


Figure 3. The forming of artificial crack

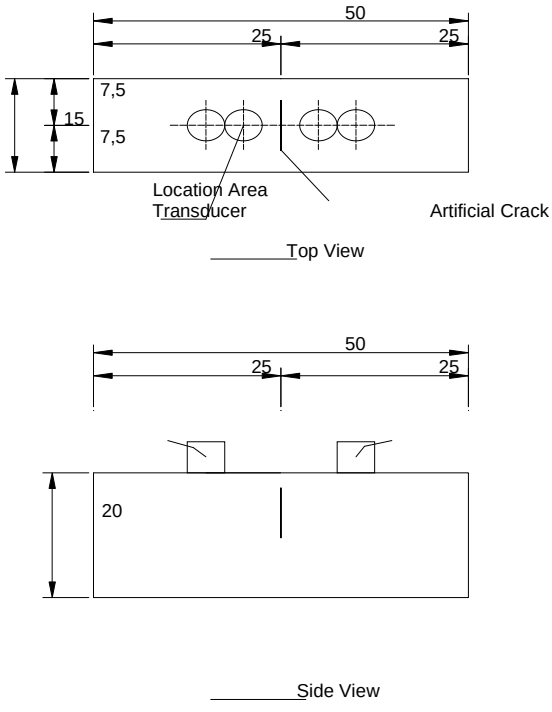


Figure 4. Location of crack depth data collection

Figure 5. Measuring the actual crack depth

RESULT

In this research, there are 5 times of casting. The average cylinder compressive strength result of each casting can be seen in **Figure 6.**

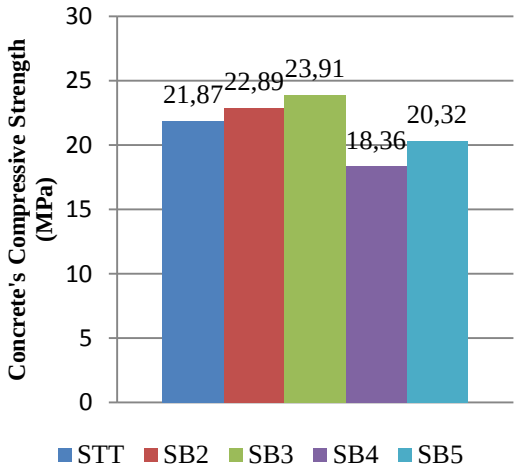


Figure 6. Averaged compressive strength test result

The concrete quality can be seen based on the ultrasonic waves. In this research, each cylinder sample quality is tested by using UPV. For the ultrasonic waves speed trial, direct method transmission is used here. The result can be seen in **Table 3.**

Temperature is one of impact factors in UPV test. Extreme weather and concrete temperature could affect the wave speed which passed the concrete. Based on **Table 4** the lowest average temperature of each specimen is 25,4^{o}C and the highest is 26,5^{o}C

The average crack depth in UPV measurement of each specimen can be seen in **Table 5.**

The comparison of the average UPV test measurement and actual crack depth of each variation can be seen in **Figure 7** to **Figure 11**. In each variation there are 3 specimens.

Table 3. Concrete Quality

Num.	Code	Wave's speed (m.s)	Quality
1	STT $_1$	4014	Good
2	STT $_2$	4046	Good
3	SB2 $_1$	3942	Good
4	SB2 $_2$	3903	Good
5	SB3 $_1$	3880	Good
6	SB3 $_2$	3242	Fair
7	SB4 $_1$	3356	Fair
8	SB4 $_2$	3916	Good
9	SB5 $_1$	3906	Good
10	SB5 $_2$	3360	Fair

Table 4. Average Temperature of Specimen

Code	Temperature (^{0}C)		
	I	II	III
TT	25,4	25,8	26,0
S2	25,7	26,2	26,3
S3	26,0	26,2	26,5
S4	26,5	26,5	26,5
S5	26,5	26,5	26,3

Table 5. Average Crack Depth by UPV Test

Code	Method	Crack Depth(cm)		
		I	II	III
TT	Actual	8,4	8,7	8,4
	UPV Test Average	8,1	8,2	8,0
S2	Actual	6,8	6,8	8,8
	UPV Test Average	7,5	7,3	8,4
S3	Actual	8,8	9,5	8,2
	UPV Test Average	8,3	9,1	7,4
S4	Actual	8	8,3	7,8
	UPV Test Average	7,6	7,9	8,2
S5	Actual	7,6	7,9	9
	UPV Test Average	8,0	8,1	8,6

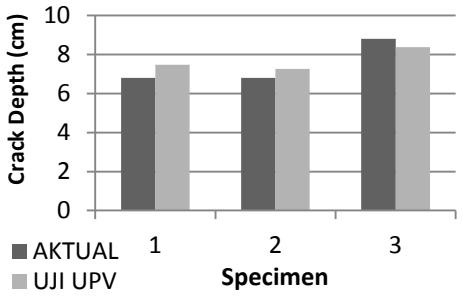


Figure 8. The Comparison Result of Average UPV Test Measurement and the Actual Crack Depth in Beam with Concrete Cover of 2 cm

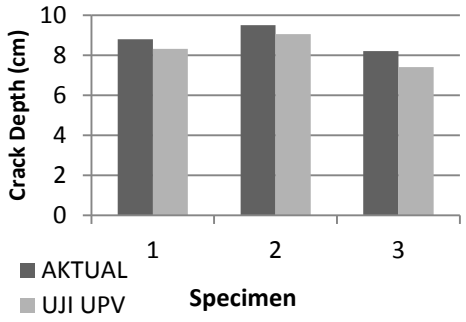


Figure 9. The Comparison Result of Average UPV Test Measurement and the Actual Crack Depth Beam with Concrete Cover of 3 cm

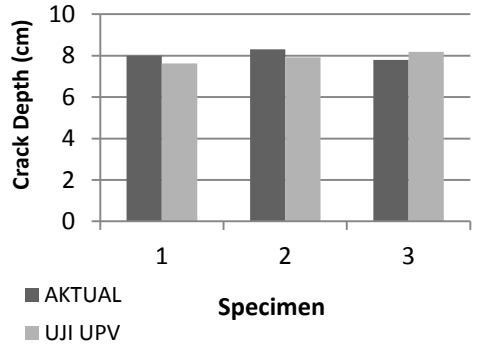


Figure 10. The Comparison Result of UPV Test Measurement and the Actual Crack Depth in Beam with Concrete Cover of 4 cm

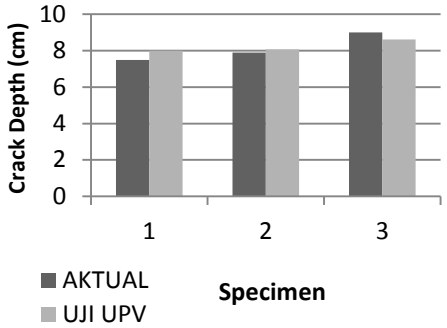


Figure 11. The Comparison Result of Average UPV Test Measurement and the Actual Crack Depth in Beam with Concrete Cover of 5 cm

Figure 7 to **Figure 11** shows that most of the average UPV test result are lower than the actual crack. 5 of 15 specimens of the average result of UPV test are higher than the actual crack depth. It is difficult to be predicted because the condition of each specimen is not always similar.

DISCUSSION

The difference of crack depth measurement by UPV test is showed by the relative error in each concrete cover thickness. The relative error is obtained from the comparison between actual crack depth and absolute error of measurement result. The absolute error is absolute value of the difference between the actual value and the approximate value.

Table 6. Average Relative Error

Code	Relative Mistake			Average RM
	I	II	III	
TT	3,27	6,03	4,46	4,59
S2	7,35	6,62	6,44	6,80
S3	5,40	4,74	9,76	6,63
S4	5,86	5,12	5,45	5,48
S5	5,26	4,75	4,72	4,91

Based on **Table 6,** the average relative error in concrete's crack depth measurement in 2 cm, 3cm, 4 cm, and 5 cm cover thickness serially are 6,80%; 6,63%; 5,48%; and 4,91%. In unreinforced concrete relative mistake by the UPV test is 4,59%.

The relative error tends to decrease from small-covered concrete to bog-covered concrete. But, it is difficult to determine the limit of reinforcement's effect because the data is not similar in every variation of specimen. Un-reinforced concrete is used as benchmark because it is not affected by the reinforcement. Thus, it is proved that the bigger cover thickness, the lover certain reinforcement effect. So, the relative mistake of concrete with big cover will not be so different to unreinforced concrete.

CONCLUSION AND DISCUSSION

Based on the data, the higher cover thickness of the concrete, the smaller relative error of UPV crack depth analysis will be. Better measurement accuracy obtained if the UPV crack depth measurement is achieved to unreinforced concrete. The hypothesis of one-way ANOVA analysis is concluded that the difference of relative error of each variation has not shown a significant value.

It can be recommended by the authors as follows:

(1) The generating of crack should be more precise in the same depth as the crack that have been designed to improve the data collection;
(2) The surface of the specimen should be flat. If it is not, the small hole in concrete surface could affect the UPV test;
(3) Data collection should be taken more around cracked area. So the measurement data could be obtained better;
(4) Further UPV test is needed for diagonal shape crack, number of cracks which more than one, variations of crack width and transducer distance.

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