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Estimation of Surface Open Crack Depth in Concrete Structure using Ultrasonic Pulse Velocity (UPV) Technique

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ABSTRACT

This paper reviews how to evaluate the depth of surface-opening cracks using ultrasound with the time-of-flight diffraction (TOFD) approach. This method is a good tool for practical use. It is cheap, straightforward, and simple and gives a quick estimate of crack depth. Some mathematical equations are given to determine the depth of surface opening cracks in IS 516 (Part 5/Sec 1) and other standards. These expressions are derived from two time-of-flight measurements conducted with the indirect transmission mode. In this investigation methodology, five measurements were made (UPV) for calculating each median or mean crack depth. Described three methods, such IS 516 method, BS 1881 Method, and Proceq (In-Built) method, were used to calculate the depth of surface opening cracks observed in the reinforced foundation. Based on the findings, relatively compared all these three methods of crack depth measurement

1. INTRODUCTION

Cracks in concrete provide essential information about the strength and durability of concrete structures. The cracks may appear due to several degradation mechanisms, such as repeated loading, differential settlement, chemical attacks, drying shrinkage, and freeze-thaw cycles. While in some cases, surface opening cracks may only affect the aesthetics of the concrete surface. In most cases, they indicate structural distress and decreased durability. Cracks are a warning sign for the structure, so its strength may be quickly assessed to see whether it needs to be repaired or strengthened.

The crack depth estimation can be performed by Ultrasonic Pulse Velocity Test (UPVT) with a time-of-flight approach (TOFD). The principle of this UPV testing work is to transmit the ultrasonic waves from the transmitter on one side of the crack to the receiver on another side of the crack on a concrete surface so that the wave is measured by the Read-Out PUNDIT unit (Portable Unit Non Destructive Indicator Tester). Before measurement, the distance between the transmitter and receiver is determined, and the ultrasonic wave velocity in concrete material can be calculated and used to estimate the crack depth.

The estimated crack depth measurements with UPVT by different methods give differences in the same reinforced concrete structure of the same quality. Therefore, this paper presents to determine the influence of steel reinforcement in concrete and the effective distance of the transducer in measuring the concrete crack depth by different methods.

2. LITERATURE REVIEW

The PUNDIT Ultrasonic Pulse Velocity (UPV) instrument is used to assess the quality of concrete. It comprises two transducers (i.e., Transmission and Receiving transducers). The transmission transducer sends pulses and receiving transmitter detects those pulses. An in-built electronic time device measures the time taken to move these pulses from known path length (i.e., distance between two transducers). The pulse velocity (V) is calculated by using the following:

$$\text{Pulse velocity } [V] = \frac{L}{T}$$

Where L = Distance between transmitter and receiver

T = Time of flight

The time the pulse taken to travel through the concrete is independent of the geometry of the material through which it passes and depends only on its material properties. The Schematic diagram of the pulse velocity test circuit is presented in Figure 1.

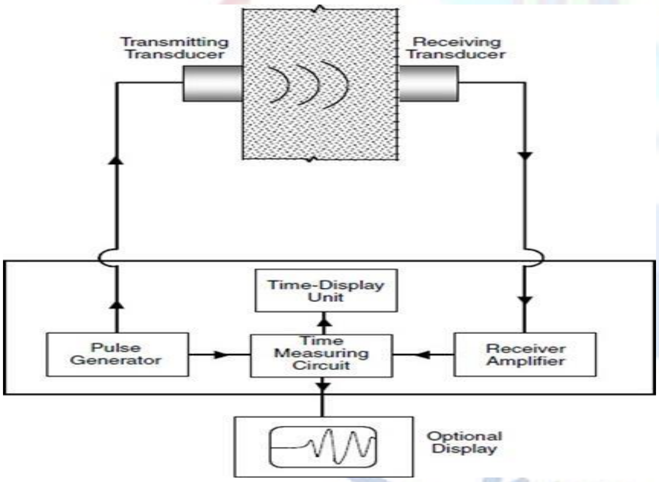


Figure 1: Schematic diagram of the pulse velocity test circuit

2.1 Influence of UPV test conditions:

2.1.1 Surface conditions and moisture content of concrete: A sufficiently smooth test surface is usually necessary for achieving a good connection between concrete surfaces and the transducer during the pulse velocity measurements. Therefore, the concrete surface must be smoothed before taking UPV measurements if the surface is found to be rough and uneven. In general, ultrasonic pulse velocity through the concrete increases with the moisture content of the concrete. This influence is more for low-strength concrete than high-strength concrete. The pulse velocity of saturated concrete may be up to 5 percent higher than that of similar dry concrete.

2.1.2 Path length, shape, and size of the concrete member: Due to the intrinsic heterogeneity of concrete, shorter path lengths generally result in more variable and slightly higher pulse velocities. Therefore, it is necessary to propose a sufficient path length to avoid errors caused by heterogeneity. RILEM has advised the following minimum path lengths:

a. 100 mm for concrete having a maximum aggregate size of 30 mm

b. 150 mm for concrete having a maximum aggregate size of 45 mm Usually, the pulse velocity is not dependent on a specimen's size and shape.

2.1.3 Temperature of concrete: The pulse velocity measurements in concrete are not considerably affected by variations in concrete temperature between 5°C and 30°C. But, there can be a 5% reduction in pulse velocity when the temperature is between 30°C and 60°C. Below freezing temperature, the free water available in the pores freezes within concrete, resulting in an increase in pulse velocity up to 7.5%.

2.1.4 Stress to which the structure is subjected: The normal level of stress in the element under test has no effect on pulse velocity. When the concrete is subjected to high levels of static or repeated stress, say 60 percent of the ultimate strength or greater, micro- cracks develop within the concrete, which will reduce the pulse velocity significantly.

2.1.5 Reinforcement bars: The presence of steel reinforcement is one of the most critical factor that affects the pulse velocity of concrete. Steel has a pulse velocity between 1.2 and 1.9 times that of plain concrete. As a result, pulse velocity values in reinforcing concrete are usually higher than those in plain concrete. In order to avoid the uncertainties caused by the higher pulse velocities in steel, reinforcement in the path length should usually be avoided while taking readings.

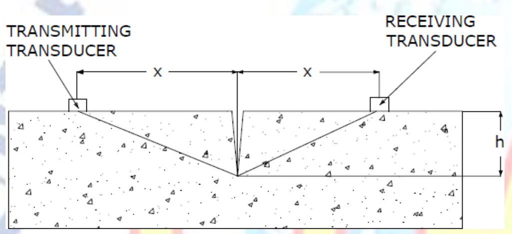
2.1.6 Contact between the transducer and concrete: The reading will be affected by poor contact. To improve contact between the test surface and transducer, grease or other couplants are applied on both the test surface and transducer surface.

2.1.7 Cracks and voids: When an ultrasonic pulse traveling through concrete encounters a concrete–air interface, there is negligible energy transmission across this interface. Thus any air-filled cracks and voids lying immediately between two transducers will obstruct the direct ultrasonic beam when the projected void length is greater than the width of the transducers and wavelength of sound used. When this happens, the first pulse to arrive at the receiving transducer will have been diffracted around the periphery of the defect, and transit time will be longer than in similar concrete with no defect. This effect can be used to locate flaws, voids, or other defects up to 100 mm in diameter or depth. Minor defects have little or no impact.

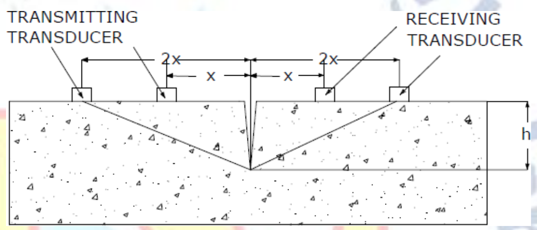
3. EXPERIMENTAL METHODOLOGY

Based on a review of the literature, it is considered that the most accurate approach for determining crack depth in concrete is the UPV method. This method uses ultrasound to measure the depth of surface opening cracks in concrete structures. Three indirect measuring techniques are used in this study:

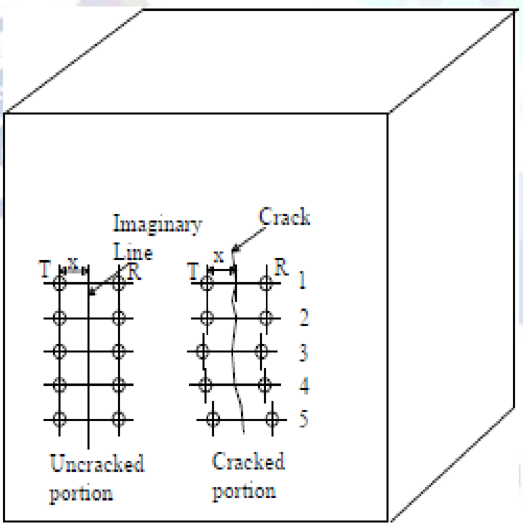
1. IS 516 Method,
2. BS 1881 Method, and
3. Proceq PUNDIT equipment procedure (in-built option in apparatus)



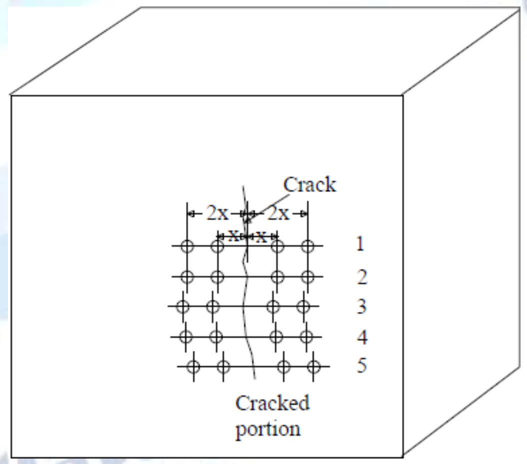
2A: Schematic diagram showing the position of tranducers in IS 516 Method



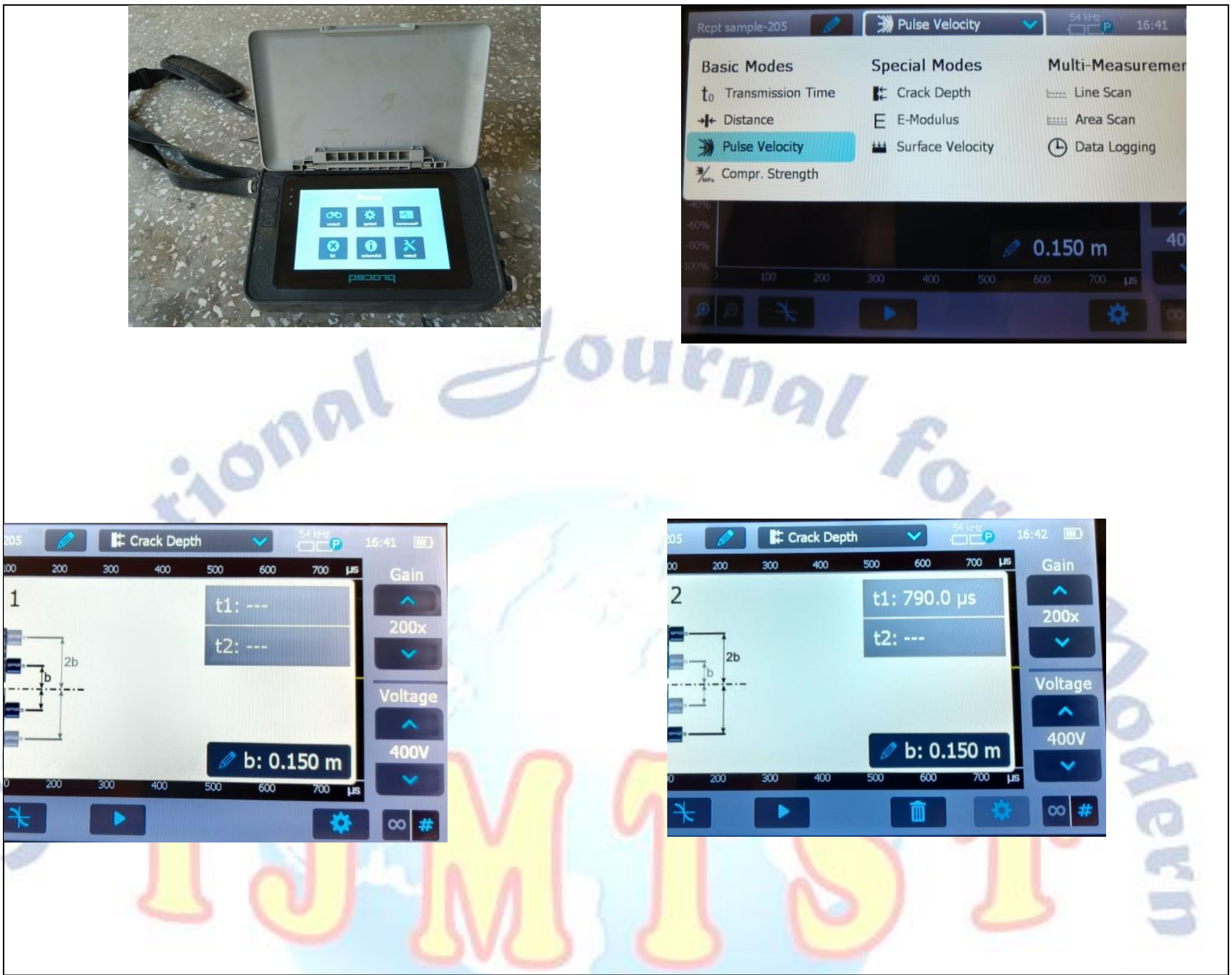
2C: Schematic diagram showing the position of tranducers in BS 1881 Method



2B.Arrangement of tranmitter (T) and receiver (R) for estimation of crack depth by using IS 516 method



2D.Arrangement of tranmitter (T) and receiver (R) for estimation of crack depth by using BS 1881 method



2E: Arrangement of tranmitter (T) and receiver (R) for estimation of crack depth by using Proceq PUNDIT equipment procedure (in-built option in apparatus)

Figure 2: Measurement methods used

3.1 IS 516 Method

This method estimates the crack depth (h) by placing a transmission transducer at a distance x to one side of the crack and the receiving transducer at a distance x to the other side of the crack. The time-of-flight for a total distance of 2x is then measured on the cracked surface (T_c). Similar to the above procedure for the same distance, i.e., 2x, the time-of-flight is measured on the same type of concrete surface with no cracks (T_s). The T_c and T_s were measured for different values of x, such as x = 10 cm and 15 cm. The position of transducers is shown in 2A of Figure 2. Five rows with a vertical spacing of 10 cm were considered, and the arrangement of transducers is shown in 2B of Figure 2 for estimating the average crack depth for each x distance. The following equation can calculate the depth of crack (h):

$$h = x\sqrt{\frac{T_c^2 - T_s^2}{T_s^2}}$$

Where:

2x = Distance travelled in the un-cracked /cracked surface

T_c = Time-of-flight around crack

T_s = Time-of-flight along the surface of the same type of concrete without any crack

3.2 BS 1881 Method:

In this method, the crack depth (h) is estimated by placing a transmission transducer at a distance of x and 2x to the one side of the crack and placing the receiving transducer at a distance of x and 2x to the other side of the crack. The time-of-flight for a total distance of 2x and 4x are then measured on the cracked surface are T_1 and T_2, respectively. The position of transducers is shown in 2C of Figure 2. Similar to the above procedure, the time-of-flight of the total distance is measured for different values of x (i.e., 10cm, 15cm, and 20cm). Five rows with a vertical spacing of 10cm were also considered, and the arrangement of transducers is shown in 2D of Figure 2 to estimate an average crack depth for each value of x. The depth of the crack (h) is expressed as:

$$h = x\sqrt{\frac{4T_1^2 - T_2^2}{T_1^2 - T_2^2}}$$

Where:

x = Distance from transducer to the crack

T_1 = Time-of-flight when transducer and receiver are placed at x distance from crack

T_2 = Time-of-flight when transducer and receiver are placed at 2 x distance from crack

3.3 Proceq PUNDIT equipment procedure (in-built option in apparatus)

This method is the same as the BS 1881 Method. The Proceq PUNDIT (PL200) equipment has an in-built function that directly estimates the depth of the crack. The arrangement of the transducers is the same as the method described in section 4.2. To calculate the average crack depth for each x distance, five rows with a vertical spacing of 10cm were also considered. The transducers are arranged as shown in 2E of Figure 2 for measurement.

4. TEST RESULTS:

In order to compare all the methods mentioned above to estimate the crack depth observed in the reinforced concrete foundation, all methods were employed to measure crack depth. The time-of-flight measurements are taken according to each of the three methods. The results are these three methods are presented in Table 1-3.

Table 1: Estimation of crack depth – by using IS 516 Method

Row No	X (cm)	T_{uc} (µs)	T_c (µs)	Depth of crack h (cm)	Median (cm)	SD (cm)	Mean (cm)
R- 1	10	49.0	57.0	5.97	5.72	1.46	4.87
R- 2	10	46.5	54.5	6.11			
R- 3	10	48.4	55.7	5.72			
R- 4	10	46.9	49.6	3.48			
R- 5	10	42.8	44.8	3.09			
R- 1	15	70.3	77.3	6.89	4.75	1.79	5.06
R- 2	15	77.0	79.4	3.77			
R- 3	15	73.4	80.8	6.90			
R- 4	15	72.2	73.6	2.97			
R- 5	15	70.5	73.9	4.75			

Note: X =Distance between crack/ imaginary line (as in case of uncrack area), h = Depth of crack, T_{uc} = Time-of-flight *in un-cracked surface in µs, T_c =* Time-of-flight *around crack in µs*

Table 2: Estimation of crack depth – by using BS 1881 Method

Row No	x (cm)	T_1 (µs)	T_2 (µs)	Depth of crack h (cm)	Median (cm)	SD (cm)	Mean (cm)
R- 1	10	57.0	111.1	2.68	3.48	1.03	3.79
R- 2	10	54.5	101.2	4.75			
R- 3	10	55.7	107.8	3.04			

R- 4	10	54.6	100.7	4.99			
R- 5	10	50.8	97.4	3.48			
R- 1	15	83.4	157.2	6.28			
R- 2	15	79.4	156.4	3.06			
R- 3	15	78.6	151.3	4.95	4.22	1.28	4.39
R- 4	15	73.6	143.1	4.22			
R- 5	15	78.9	154.8	3.45			
R- 1	20	108.7	213.5	4.46			
R- 2	20	107.9	212.0	4.42			
R- 3	20	111.7	220.1	4.03	4.46	0.62	4.74
R- 4	20	108.4	211.2	5.40			
R- 5	20	111.3	216.9	5.38			

Note: X = Distance from transducer to the crack in cm, T_1 = Time-of-flight *when transducer and receiver are placed at x distance from crack in μs, T_2 =* Time-of-flight *when transducer and receiver are placed at 2x distance from crack in μs,h = Depth of crack in cm*

Table 3: Estimation of crack depth - by using Proceq PUNDIT equipment procedure (in built option in apparatus)

Row No	x (cm)	T_1 (μs)	T_2 (μs)	Depth of crack, h (cm)	Median (cm)	SD (cm)	Mean (cm)
R- 1	10	57.1	108.3	3.9			
R- 2	10	59.0	103.4	6.1			
R- 3	10	56.3	105.2	4.5	4.50	1.42	4.80
R- 4	10	59.0	104.3	6.4			
R- 5	10	51.7	99.9	3.1			
R-1	15	84.0	163.0	4.4			
R- 2	15	81.2	154.7	5.6			
R- 3	15	81.9	154.2	6.3	5.60	0.91	5.40
R- 4	15	95.8	185.6	4.5			
R- 5	15	86.9	163.9	6.2			
R- 1	20	116.5	227.2	5.3			
R- 2	20	110.9	215.5	5.7			
R- 3	20	111.7	220.0	4.1	5.30	0.90	5.12
R- 4	20	101.5	199.6	4.3			
R- 5	20	107.5	207.9	6.2			

Note: x = Distance from transducer to the crack in cm, T_1 = Time-of-flight *when transducer and receiver are placed at x distance from crack in μs, T_2 =* Time-of-flight *when transducer and receiver are placed at 2x distance from crack in μs*

5. CONCLUSION

i. The investigation concluded that the distance of transducers and reinforcement affects the accuracy of UPV testing results. The IS 516 method estimated the minimum and maximum median crack depth around 4.75 and 5.72 cm, which is higher than the minimum and maximum estimated median crack depth of 36.49% and 28.25% by the BS 1881 method and 5.56% and 2.14% made by Proceq Method. The comparison of maximum and minimum median crack depths estimated by different methods is presented in Figure 3.

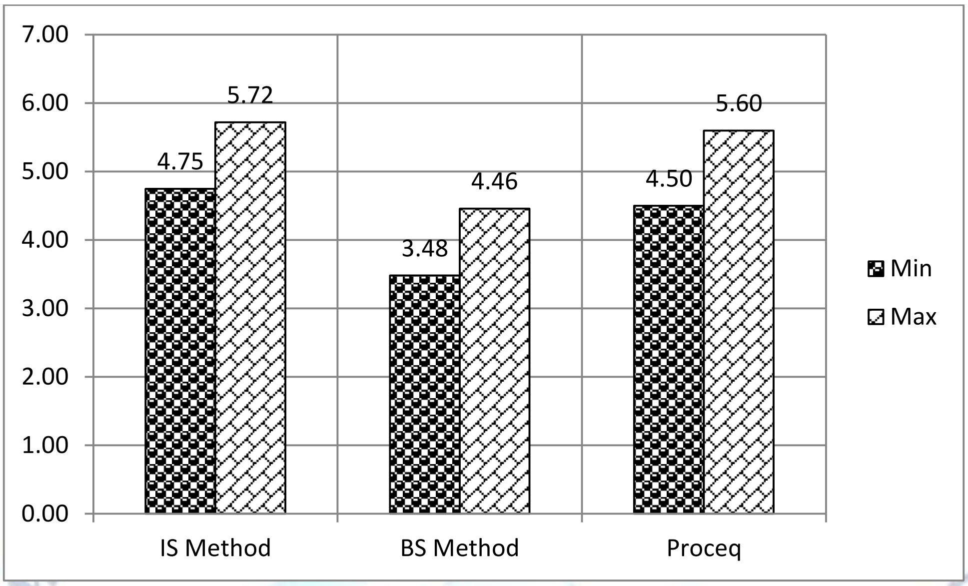


Figure 3: Comparison of estimated minimum and maximum median crack depth of 3 methods

ii. The investigation concluded that the distance of transducers and reinforcement affects the accuracy of UPV testing results. The IS 516 method estimated the minimum and maximum mean crack depth around 4.87 and 5.06 cm, which is higher than the minimum and maximum estimated mean crack depth of 28.50% and 6.75% by the BS 1881 method and 1.46% and -6.30% made by Proceq Method. The comparison of maximum and minimum mean crack depths estimated by different methods is presented in Figure 4.

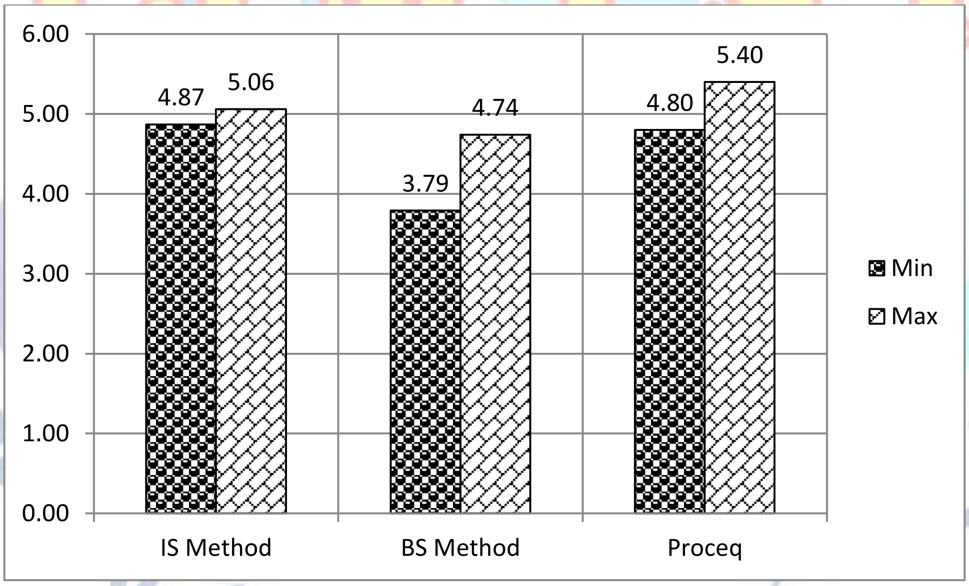


Figure 4: Comparison of estimated minimum and maximum mean crack depth of 3 methods

6. ACKNOWLEDGMENTS

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Conflict of interest statement

Authors declare that they do not have any conflict of interest.

REFERENCES

[1] ASTM C 597 1999 Standard Test Method for Pulse Velocity through Concrete. Annual Book of ASTM Standards

[2] BS 1881 Part 203 1986 Recommendations for Measurement of Ultrasonic Pulse Velocity Through Concrete
[3] Proceq 2017 Pundit Lab Operating Instruction (Switzerland: Proceq)
[4] J H Bungey, S G Millard, M G Grantham, Testing of concrete in structures, 4 ed. Taylor & Francis, 2006
[5] ACI Committee 224. Causes, evaluation, and repair of cracks in concrete structures, ACI 224.1R-07. American Concrete Institute, 2007
[6] BS EN 12504-4:2004 Testing concrete - Part 4: Determination of ultrasonic pulse velocity
[7] Baehaki , Andi M and Yohanes G R, Experimental study of crack depth measurement of concrete with ultrasonic pulse velocity (UPV), IOP Conf. Series: Materials Science and Engineering 673 (2019) 012047,IOP Publishing,doi:10.1088/1757-899X/673/1/012047
[8] Roberto C. A. PINTO , Arthur MEDEIROS , Ivo J. PADARATZ ,, Patrícia B. ANDRADE, Use of Ultrasound to Estimate Depth of Surface Opening Cracks in Concrete Structures, The Open Access NDT Database
[9] MOHD. AMRAN HASBULLAH*, ROHANA YUSOF,MOHD. NAZARUDDIN YUSOFF, Assessing the performance of concrete structure based on the width of the crack using UPV, Journal of Engineering Science and Technology,Special Issue on ISSC'2016, April (2017) 17 – 25
[10] Eunjong Ahn , Hyunjun Kim , Sung-Han Sim , Sung Woo Shin , and Myoungsu Shin, Principles and Applications of Ultrasonic-Based Nondestructive Methods for Self-Healing in Cementitious Materials, Materials 2017, 10, 278; doi:10.3390/ma10030278 www.mdpi.com/journal/materials