The effect of tranducer distance on the concrete crack depth measurement using PUNDIT

S Suhariyanto*, D P Arystianto and B A Raharjo
Civil Engineering Department, State Polytechnic of Malang, Indonesia

*suhariyanto.polinema@gmail.com

Abstract. The depth of crack in concrete structural elements can be measured using ultrasonic waves. One tool that can be used is PUNDIT. The research was conducted by measuring the depth of cracks on the concrete beam test object with a variation of the PUNDIT transducer distance. The purpose of this research is to determine the effect of the distance of the transducer (b) on the relative error (% error) measured in the cracked concrete depth. The results showed that the results of concrete crack depth measurements with the smallest relative error (% error) is obtained by adjusting the transducer distance to about 2/3 or 0.67 the thickness of the test object (h). At the distance of the transducer less than 0.67 or more than 0.67 the thickness of the test object, the relative error (% error) will be greater.

1. Introduction

The use of the PUNDIT (Portable Ultrasonic Non-destructive Digital Indicating Tester) as a concrete NDT (Non Destructive Test) tool in recent years has been growing. The results of testing using this tool are strongly influenced by many factors, so a lot of research is needed in order to get the best practice of using PUNDIT as an NDT tool on concrete structural elements in particular.

The depth of cracks in concrete structures can be measured using PUNDIT, whose working principle is based on measuring the travel time of ultrasonic waves that propagate in the concrete structure.

Accuracy, care and persistence are required in determining the depth of the crack, considering that the crack depth determines the handling that will be carried out on these structural elements.

The accuracy of measuring the crack depth using PUNDIT is influenced by the determination of the transducer distance.

Based on this, it is necessary to conduct research to determine the effect of transducer distance on the measurement of the depth of cracks using PUNDIT.

2. Literature review

2.1. Crack on concrete structures

Crack is a state of breaking or splitting of a structure without collapse. With cracks, it can cause the entry of hazardous chemicals, pollution, chloride, etc. into the structure.

Cracks in concrete can be divided into structural and nonstructural cracks. Structural cracks occur due to errors in design or loads that exceed the capacity, while non-structural cracks occur mostly due
to physical chemical processes in concrete in the early phase of concrete life. In general, non-structural cracks do not directly result in the weakening of the building structure.

In addition there are cracks called micro cracks, these cracks occur in the concrete hardening phase where these types of cracks will be difficult to detect because they are too small.

The width-narrow, length-shortness and depth of the cracks are influenced by many factors, including the cause of cracks, age of cracks and so on. Cracks that appear in structural elements such as beams, columns or slabs, must be detected immediately. Usually, handling that will be carried out is preceded by an investigation of the crack itself, namely the depth, width and length of the crack. Measuring the width and length of the crack is very easy to do because it is visually very clear, but the measurement of the depth of the crack is very difficult because it is not visible, plus if the cracks that occur are very small or termed micro cracks [1].

3. Non destructive test on concrete structures

Sulistyani R, Dyah et al. [2], stated that Non Destructive Test on concrete structures can be carried out using PUNDIT, which in principle works using the ultrasonic method. The ultrasonic method is a method that is widely used. The ultrasonic methods are used to detect/evaluate defects, measure dimensions, and characterize materials. The ultrasonic method system generally consists of a pulser/receiver, transducer and display equipment. Pulser / receiver is electronic equipment that can generate high voltage electrical pulses. Controlled by the pulser, the transducer generates high frequency ultrasonic energy. Sound energy is transferred and propagates through the material in the form of waves. When there is a discontinuity (such as a crack) along the wave path, some of the energy will be reflected back from the defect surface. A discontinuity will reflect the applied ultrasonic waves, so that the reflected wave recording device records the pulses from the reflected waves that are not from the surface of the test object. The reflected wave signal is then converted into an electrical signal by the transducer and displayed on the screen. The signal travel time can be converted directly to the distance the signal travels. From the signal, information about the location of discontinuities, size, orientation and other properties can be obtained. Ultrasonic waves are sound waves that have a frequency above the limit of human hearing. Based on the frequency, sounds can be distinguished:

- Infra sonic: \( f < 16 \text{ Hz} \)
- Audible sonic: \( 16 \text{ Hz} < f < 20 \text{ KHz} \)
- Ultrasonic: \( f > 20 \text{ KHz} \)
- Hypersonic: \( f > 1 \text{ GHz} \)

In the ultrasonic method, the frequency regions suitable for testing / examining a type of material are as follows:

- Aluminum, ceramics, steel: \( 2 - 10 \text{ MHz} \)
- Cast iron: \( 0.5 - 2 \text{ Hz} \)
- Concrete: \( f < 0.5 \text{ MHz} \)

Some of the advantages of ultrasonic methods are as follows:

- Sensitive to surface and subsurface discontinuities.
- The depth of penetration for defect detection or measurement is outperformed by other NDT methods.
- Only one-sided access is required when using pulse-echo technique.
- Highly accurate in determining reflector position and estimating the size and shape of defects.
- The preparation of objects is minimal.
- Electronic equipment produces instant results.
- Detailed drawings can be created by an automatic system.
- Can be used to measure thickness, apart from flaw detection.
Like all other NDT methods, the ultrasonic method also has limitations, namely:

- The surface of the test specimen must be able to transmit ultrasound.
- The skills and knowledge are more extensive than some of the other methods.
- Generally, a coupling medium is needed to help transfer sound energy into the object.
- Materials that are coarse, abnormally shaped, very small, very thin or inhomogeneous will be difficult to inspect.
- Pig iron and other coarse grained materials are difficult to inspect due to low sound transmission and lots of noise.
- Linear defects whose orientation is parallel to the direction of the sound may be difficult to detect.

3.1. Measurement of the depth of concrete cracks using pundit

PUNDIT (Portable Ultrasonic Non-destructive Digital Indicating Tester) as an NDT (Non Destructive Test) tool or many also call it the UPV Test, works based on measuring the travel time of ultrasonic waves that propagate in the concrete structure.

The ultrasonic waves are transmitted from the transducer transmitter which is placed on the concrete surface through the concrete material to the transducer receiver and the wave travel time is measured by the PUNDIT (Portable Unit Non Destructive Indicator Tester) Read-Out unit in m / second.

The equipment used for the concrete crack test with the Ultrasonic Pulse Velocity Test consists of:

- One Read-out Unit PUNDIT (Portable Unit Non Destructive Indicator Tester)
- Two 54 kHz Transducers (one each as a transmitter and receiver).
- One Calibration Bar and cables and connectors

One type of PUNDIT can be seen in the following figure:

![Figure 1. Proceq PUNDIT lab [3].](image)

The method used to measure the depth of cracks using PUNDIT is the Indirect Method. This method is used to measure the time the waves propagate from the transmitter to the receiver in one surface area, where when crossing the crack line there is a time jump.

To determine the depth of the cracks, 2 (two) measurements of wave propagation were carried out. The first is that the transmitter and receiver are placed opposite in one surface area with the same distance from the surface crack line, namely at a distance of X1, and then at a distance of X2. Measurement illustration as in the following figure 2:
Figure 2. Transducer distance (X1, X2), travel time (T1, T2) and crack depth (c) parameters [3].

Then the crack depth can be calculated by the following equation:

\[ c = \frac{1}{2} \sqrt{X_1^2 T_1^2 - X_2^2 T_2^2} \]

With:

- \( X_1 \) = distance between transducers (transmitter and receiver) on the first measurement
- \( X_2 \) = distance between transducers (transmitter and receiver) in the second measurement
- \( T_1 \) = time that the wave propagates from the transmitter to the receiver at the first observation
- \( T_2 \) = time that the wave propagates from transmitter to receiver in the second observation

If in the first measurement the distance between the cracked position and the transmitter is \( b \), and the distance between the receiver and the cracked position is also \( b \) in the opposite direction, then \( X_1 = 2b \). Furthermore, if in the second measurement the distance between the cracked position and the transmitter is \( 2b \), and the distance between the receiver and the cracked position is also \( 2b \) in the opposite direction, then \( X_2 = 4b \). Then the measurement illustration can be described as:

Figure 3. Parameters of Transducer Distance (b), Travel Time (T1, T2) and Crack Depth (c) [3].

Then the crack depth can also be calculated with the following formula:

\[ c = b \sqrt{\frac{4t_1^2 - t_2^2}{t_2^2 - t_1^2}} \]

The procedure for measuring the depth of concrete cracks using PUNDIT in outline show in figure 4.
Figure 4. Procedure of crack depth measurement using proceq PUNDIT lab [3].

4. Methodology
The research of the effect of the distance of the transducer on the measurement of the depth of concrete cracks using PUNDIT was carried out on 2 specimens as follows:

- The test object no 1 is a concrete beam (K350) with a length of 61cm, width 15cm and a depth of 13.5 cm and a crack depth of 3.25 cm and 7.5 cm in the mid span of beam. The crack depth measurements of the test object with 5 cm, 7.5 cm and 10 cm transducer distance variations.
- The test object no 2 is a concrete beam (K350) with a length of 75 cm, width 15 cm and height 15 cm and a crack depth of 8 cm in the mid span of beam. The crack depth measurement of the test object with 5 cm, 10cm and 15 cm transducer distance variations.
Figure 5. Sketch of test object no 1.

Figure 6. Sketch of test object no 2.

The picture of test object for this research are as follows figure 7:

Figure 7. Photo of object test.

The test is carried out by two people, one person tests the specimens using the PUNDIT tool while one person record the testing results. Photographs of test equipment and test implementation are as follows in figure 8 and 9:
5. Results and discussion
Measurement of crack depth with a variation of the transducer distance was carried out on concrete test object that were 28 days old with an estimated compressive strength of about 350 kg/cm$^2$ (direct speed measurement using PUNDIT around 3926 m/s).

The plotting graph of crack depth measurement results with variations in transducer distance is as follows figure 10, 11 and 12:

Figure 8. Photo of PUNDIT equipment.

Figure 9. Photo of crack depth measurement.
Figure 10. Plotting the measurement of crack depth with a variation of the transducer distance in Test Object No 1 $d_a = 3.25$ cm.

Figure 11. Plotting the measurement of crack depth with a variation of the transducer distance in Test Object No 1 $d_a = 7.5$ cm.

Figure 12. Plotting the measurement of crack depth with a variation of the transducer distance in Test Object No 2 $d_a = 8$ cm.
The relative measurement error (% error) of each test can be seen in the following table 1:

| Transducer Distance | Crack Depth | measured | actual | % Error |
|---------------------|-------------|----------|--------|---------|
|                     |              | b (cm)   | dt(cm) | da(cm)  |
| 5                   | 5,00        | 3,25     | 53,85  | min     | 41,54   |
|                     | 4,60        | 3,25     | 41,54  | max     | 53,85   |
|                     | 4,70        | 3,25     | 44,62  | average | 46,67   |
|                     | 3,00        | 3,25     | 7,69   | min     | 1,54    |
| 7,5                 | 3,20        | 3,25     | 1,54   | max     | 20,00   |
|                     | 3,90        | 3,25     | 20,00  | average | 9,74    |
|                     | 5,40        | 3,25     | 66,15  | min     | 66,15   |
| 10                  | NA          | 3,25     | NA     | max     | NA      |
|                     | NA          | 3,25     | NA     | average | NA      |

Based on the Table 1, it is known that in the testing of Test Object No 1 da = 3.25 cm:

- At 5 cm transducer distance, the relative error (% error) of concrete crack depth measurements is between 41.54% to 53.85% and the average% error of 46.67%
- At 7,5 cm transducer distance, the relative error (% error) of concrete crack depth measurements is between 1.54% to 20% and an average% error of 9.74%
- At the transducer distance of 10 cm, the relative error (% error) cannot be calculated, because the depth of the crack is unreadable.

Table 2. The Relative Measurement Error (% Error) in Test Object No 1 da = 7.5 cm.

| Transducer Distance | Crack Depth | measured | actual | % Error |
|---------------------|-------------|----------|--------|---------|
|                     |              | b (cm)   | dt(cm) | da(cm)  |
| 5                   | 3,90        | 7,50     | 48,00  | min     | 36,00   |
|                     | 4,80        | 7,50     | 36,00  | max     | 48,00   |
|                     | 4,30        | 7,50     | 42,67  | average | 42,22   |
|                     | 6,40        | 7,50     | 14,67  | min     | 14,67   |
| 7,5                 | 5,30        | 7,50     | 29,33  | max     | 40,00   |
|                     | 4,50        | 7,50     | 40,00  | average | 28,00   |
| 10                  | NA          | 7,50     | NA     | min     | NA      |
|                     | NA          | 7,50     | NA     | max     | NA      |
|                     | NA          | 7,50     | NA     | average | NA      |

Based on the Table 2 it is known that in the testing of Test Object No 1 da = 7.5 cm:

- At 5 cm transducer distance, the relative error (% error) of concrete crack depth measurements is between 36% to 48% and the average% error of 42.22%
- At 7,5 cm transducer distance, the relative error (% error) of concrete crack depth measurements is between 14,67% to 40% and an average% error of 28%
- At the transducer distance of 10 cm, the relative error (% error) cannot be calculated, because the depth of the crack is unreadable.
Table 3. The relative measurement error (% Error) in test object no 2 da = 8 cm.

| Transducer Distance b(cm) | Crack Depth | % Error |
|---------------------------|-------------|---------|
|                           | Measured dt(cm) | Actual da(cm) |       |
| 5                         |              |          |       |
| 2.80                      | 8.00         | 65.00    | min   |
| 5.80                      | 8.00         | 27.50    | max   |
| 2.80                      | 8.00         | 65.00    | average |
| 3.00                      | 8.00         | 62.50    |       |
| 8.40                      | 8.00         | 5.00     |       |
| 2.80                      | 8.00         | 65.00    |       |
| 2.80                      | 8.00         | 65.00    |       |
| 2.60                      | 8.00         | 67.50    |       |
| 2.40                      | 8.00         | 70.00    |       |
| 2.90                      | 8.00         | 63.75    |       |
| 5.30                      | 8.00         | 33.75    | min   |
| 8.90                      | 8.00         | 11.25    | max   |
| 6.50                      | 8.00         | 18.75    | average |
| 6.70                      | 8.00         | 16.25    |       |
| 10                        | 6.72         | 16.00    |       |
| 4.10                      | 8.00         | 48.75    |       |
| 7.60                      | 8.00         | 5.00     |       |
| 10                        | 4.90         | 38.75    |       |
| 7.60                      | 8.00         | 5.00     |       |
| 17.80                     | 8.00         | 122.50   | min   |
| 26.40                     | 8.00         | 230.00   | max   |
| 17.90                     | 8.00         | 123.75   | average |
| 15.40                     | 8.00         | 92.50    |       |
| 19.20                     | 8.00         | 140.00   |       |
| 15                        | 12.50        | 56.25    |       |
| 12.00                     | 8.00         | 50.00    |       |
| 6.10                      | 8.00         | 23.75    |       |
| 15                        | 11.80        | 47.50    |       |
| 11.70                     | 8.00         | 46.25    |       |

Based on the Table 2, it is known that in the testing of Test Object No 2 da = 8 cm:

- At 5 cm transducer distance, the relative error (% error) of concrete crack depth measurements is between 5% to 70% and the average% error of 55.63%
- At 10 cm transducer distance, the relative error (% error) of concrete crack depth measurements is between 5% to 48.75% and an average% error of 21.5%
- At 15 cm transducer distance, the relative error (% error) of concrete crack depth measurements is between 23.75% to 230% and an average% error of 93.25%

Based on measurements of the depth of concrete cracks in test object No 1 and 2 known:

- For specimen No. 1 with a thickness of 13.5 cm, the smallest relative error of measurement occurs at the transducer distance of 7.5 cm or at the distance of the transducer (b) ~ 0.56 thickness of the test object.
- For specimen No. 2 with a thickness of 15 cm, the smallest relative error of the test occurs at the transducer distance of 10 cm or at the distance of the transducer (b) ~ 0.67 thick of the test object.

The relationship between the transducer distance and the relative error (% error) of the concrete crack depth measurement can be seen in Figure 13.
Figure 13. Relationship between transducer distance and relative error (% error) concrete crack depth measurement.

Based on Figure 13 Relationship between Transduser Distance and Relative Error (% Error) Concrete Crack Depth Measurement known;

- The smallest relative error (% error) of measurement of concrete crack depth occurs at transducer distance \((b)\) around 0.67 the test object thickness.
- At the distance of the transducer \((b)\) less than 0.67 or more than 0.67 the thickness of the test object, the relative error (% error) will be greater.
- To get the results of the measurement of concrete crack depth with the smallest relative error (% error), it can be done by adjusting the distance of the transducer around \(2/3\) or 0.67 the height of the test object.

6. Conclusion

Based on research that has been done can be concluded:

- The smallest relative error (% error) of measurement of concrete crack depth occurs at transducer distance \((b)\) around 0.67 the test object thickness \((h)\).
- At the distance of the transducer \((b)\) less than 0.67 or more than 0.67 the thickness of the test object \((h)\), the relative error (% error) will be greater.
- To get the results of the measurement of concrete crack depth with the smallest relative error (% error), it can be done by adjusting the distance of the transducer \((b)\) around \(2/3\) or 0.67 the thickness of the test object \((h)\).
- To test the validation of the results of this research it is necessary to conduct a similar research by increasing the number of test object and repetition of testing. This research also needs to be developed for other concrete structural elements such as plates and columns.

Acknowledgments

The author would like to acknowledge the support provided by the DIPA P2M State Polytechnic of Malang.

References

[1] Linggasari D 2019 Estimating the Depth of Cracks in Concrete Using Ultrasonic Waves Journal of Muara Sains 3(1) 142-152
[2] Sulistyani R, Dyah and Sumaryanto 2010 Detection of the Depth of Concrete Cracks Using the Ultrasonic Method *Proceedings of PPI-PDIPTN* 51-55
[3] Operating Instructions Pundit Lab / Pundit Lab+ Ultrasonic Instrument 2017 Proceq