Correlation of reinforcement concrete quality based on variations in UPV testing methods

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Abstract. Ultrasonic Pulse Velocity (UPV) test includes a simple Non Destruction Test (NDT) testing method, by utilizing ultrasonic waves. In the implementation of UPV testing with direct, semi-direct, and indirect methods give a quick result of different pulse velocity, with the same quality of concrete. Therefore, this study was conducted to get the correlation and correction value of all three testing methods with PUNDIT Lab+ tool on reinforced concrete. The study used a specimen of concrete beams 15x15x60 cm$^3$ with concrete quality K-275, K-250, K-225 each as much as 3 specimen. The average value of the measurement result with the direct UPV method is 12%, 7% and 5% less than the average value of the semi-direct method of UPV direction vertically, the semi-direct method of the UPV direction horizontally, and the indirect method UPV. Conversion of the measurement results for the direct UPV method of the semi-direct UPV vertical direction, semi-direct UPV direction horizontal and indirect UPV can use the regression equation $V_d = 0.2462 V_{sd-v} + 3192$, $V_d = 0.1073 V_{sd-h} + 3923.8$ and $V_d = 0.0195 V_{in} + 4341.8$.

1. Introduction
Nowadays, using of PUNDIT (Portable Unit Non-destructive Digital Indicated Tester) or UPV (Ultrasonic Pulse Velocity) is generally used for quality testing of concrete. UPV test includes simple NDT (Non Destruction Test) testing method, by utilizing ultrasonic waves. This test can determine the uniformity of concrete, knowing the quality of concrete, looking for depth of crack and know the density of the concrete. The PUNDIT tool works by knowing the travel time and the ultrasonic pulse velocity. The UPV test method is divided into three which are, Direct, Semi-Direct, and Indirect. These three methods make PUNDIT tools to be multifunctional and efficient in determining the quality of concrete.

In the implementation of UPV testing with direct, semi – direct, indirect results give a quick result of different pulse velocity, with the same quality of concrete mixture. Therefore, this research is done to get the correlation value of all three quality testing methods with PUNDIT Lab+ tool on reinforced concrete.

Many studies have been conducted to determine the factors affecting the results of the measurement, in addition there are some standard measuring guidelines with UPV [1, 2, 5], but information of UPV measurement with indirect and semi-direct methods still slightly. Generally,
previous research results state that the direct method is higher than the indirect and semi-direct methods on different concrete specimens made from the same batch [6, 8].

2. Literature Review

P. Turgut and O. F. Kucuk [7] observed ultrasonic pulse velocity on concrete. The main objective of this study was to identify the comparative relationships of direct, indirect, and semi-direct UPV measurements in concrete from different batches and with different compressive strengths. This method of research, using a concrete beam specimen of 30 specimens with a size 15x15x25 cm. Measurement of UPV direct, indirect and semi direct carried out at the age of 28 days with a distance of 250 mm, 150mm, and 195 mm on each side of the specimens. Compressive strength test is done from the coring result on the specimens with a size of 10x20 cm. The results of this study were obtained that the results of UPV indirect H greater 5% of indirect V, results UPV direct against indirect V, indirect H, semi-direct larger with a value of 9%, 4%, 4%, and direct regression results against indirect V, indirect H, semi direct generate a value of 0.97; 0.96; 0.93. Subsequently, R. Martin Simatupang et al. [3] observed the compressive strength concrete between Hammer Test, Ultrasonic Pulse Velocity (UPV) and Compression Test. This research purpose to provide the correlation value of Compressive strength concrete specimen result by using compression strength machine tool and non-destructive Testing (nondestructive test) using Hammer Test tool and UPV test. This research, using a cube specimen with a size 15x15x15 cm with each quality amounted to 15 specimens. For cylinder specimens size 15x30 cm with each quality amounted to 15 specimens. Quality variations used K-175, K-225, K-250. The study used experimental methods in the laboratory. At the age of concrete 28 days tested hammer test with angles 0° and 90° and direct transmission tested. Then, compressive strength tested and obtained the value of its correlate. The results of this study got equation for the quality of K-175, K-225, K-250 with cylinder specimens which are: C = -787.269 + 5.962H + 0.1191U, C = -710.025 + 1.0406H + 0.11508U, C = 471.838 - 0.6250H + 0.0922U whereas for cube specimens are: C = 259.677 - 0.6250H + 0.0213U, C = 501.952 - 0.2036H - 0.0403U, C = 832.988 - 0.5908H - 0.0971U. With the provisions C = Compressive strength (kg/cm²), H = Rebound Number (kg/cm²), U = Ultrasonic Pulse Velocity (m/s).

Nugroho and Budi [4] observed the correlation of ultrasonic pulse velocity and compressive strength on various quality variations of concrete. This research, purposed at knowing the relation between speed and compressive strength. This research was conducted with the use of various w/c 0.75, 0.62, 0.48, 0.38, 0.26 and 0.22 with a specimen of size 15 × 15 × 75 cm3 a total of 12 specimen. UPV tests were conducted at concrete age 7, 14, 21 and 28 days in Test direct, and age 28 days in indirect test. After tested UPV, the specimen was made of a cube block of 15 × 15 × 15 cm size in normal concrete and size 10 × 10 × 10 cm in high quality concrete. Then tested compressive strength and obtained the correlate. The results of this study got an exponential regression equation with y = 0.006e^{1.986x} on UPV with the direct method. While the indirect method for transducer distance of 10, 15, 20, 25 and 30 cm was obtained exponential regression equation is y = 0.010e^{1.948x} with the average correction factor of 1.045 on the direct method.

| Table 1. Concrete quality qualification |
|----------------------------------------|
| Longitudinal pulse velocity | ft/s | Quality of concrete |
| km/s.10^3 | >4.5 | >15 | Excellent |
| 3.5 - 4.5 | 12 - 15 | Good |
| 3.0 - 3.5 | 10 - 12 | Doubtful |
| 2.0 - 3.0 | 7 - 10 | Poor |
| <2 | <7 | Very poor |

PUNDIT (Portable Unit Non-destructive Digital Indicated Tester) or UPV (Ultrasonic Pulse Velocity) is a tool that uses ultrasonic waves to know the uniformity, quality of concrete, concrete
density and crack depth. Factors that affect rapid pulse velocity include the maximum diameter of the aggregate, compressive strength, age of the specimen, humidity of the specimen, temperature of the specimen, steel reinforcement, and uniformity. Some of the rules are reference: ASTM C597-02, EN 12504-04. In general, the UPV testing equation is based on ASTM C597 [1]:

\[ V = \frac{L}{T} \]  

Where:

\( V \) = Pulse velocity (m/s)

\( L \) = Distance between Transducer with receiver (m)

\( T \) = Travel time (s)

Figure 1. Graphic of Pulse Velocity against Concrete Compressive Strength

### 3. Eksperimental Programme

#### 3.1. Test specimens

The study used a specimen of concrete beams 15x15x60 cm³ with concrete quality K-275, K-250, K-225 each as much as 3 specimen. The beam is given the reinforcement of the longitudinal reinforcement using a diameter of 8 mm and a shear reinforcement in diameter 6 mm. More details can be seen in the table 2 and the figure 2 and 3.

Figure 2. Details of reinforcement position in specimen beam

Figure 3. Concrete beam specimen

| Specimen | Qty |
|----------|-----|
| B275     | 3   |
| B250     | 3   |
| B225     | 3   |

Table 2. Specimen
3.2. Test setup
3.2.1. Direct method. The Direct method is an UPV testing method where the transducer and receiver positions are faced separated by measuring lengths or specimen. The position of the transducer and receiver placement in the direct method is shown like figure 4. In this method, a test with a variation of measurement length is: 15 cm and 60 cm.

![Figure 4. Placement of the transducer and receiver in the direct method.](image)

3.2.2. Semi-direct method. The semi-direct method is an UPV testing method on the concrete surface side, where the transducer and receiver positions form an elbow like figure 5. In this method is divided of 2 measurement methods, which are: Semi-direct method of vertical direction and semi-direct method of horizontal direction. In the semi-direct method, testing with a variation of the transducer position and the receiver forms an angle of 45° vertically which is influenced by the shear reinforcement with different lengths of diagonal measurements. The diagonal transducer distance to the receiver used in this study has 3, which are: 106 mm and 175 mm.

![Figure 5. Placement of Transducer and receiver on semi-direct methods](image)

3.2.3. Indirect method. The indirect method is an UPV testing method on the concrete surface, as shown in figure 6. In this method is tested with a variation of measurement length with = 15 cm.

![Figure 6. Placement of Transducer and receiver in indirect method](image)

4. Result and Discussion
The results of this test are used to study the correlation of the three measuring methods generally used by UPV, which are direct, indirect and semi direct methods taken from some concrete quality. The data is analyzed by comparing the results of the pulse velocity resulting from the direct, indirect and
semi direct methods to determine the correlation of the three UPV testing methods. Therefore, an indirect or semi-direct method on UPV testing can be used in predicting concrete compressive strength. The test results are shown in figure 7-9.

Figure 7. The relation between direct UPV \( V_d \) and indirect UPV \( V_{in} \)

\[
V_d = 0.0195V_{in} + 4341.8 \\
R^2 = 0.7409
\]

Figure 8. The correlation between direct UPV \( V_d \) and semi direct UPV vertical direction \( V_{sd-v} \)

\[
V_d = 0.2462V_{sd-v} + 3192 \\
R^2 = 0.9994
\]

Figure 9. The correlation between direct UPV \( V_d \) and semi direct UPV horizontal direction \( V_{sd-h} \)

\[
V_d = 0.1073V_{sd-h} + 3923.8 \\
R^2 = 0.3451
\]

Figure 7-9 shows the correlation between direct UPV and indirect UPV methods; Direct UPV method and semi direct UPV vertical direction; Direct UPV method and semi direct UPV horizontal direction. The best-fit lines representing the relationships are given in table 3, where \( V_d, V_c, V_h, V_{in}, V_{sd-v}, \) dan \( V_{sd-h} \) indicate the direct UPV, indirect UPV in the concrete casting direction, indirect UPV in the horizontal direction, semi –direct UPV, Indirect UPV, semi-direct UPV in the vertical direction and semi-direct UPV in the horizontal direction, respectively.
Table 3. Several regression equation the correlations between the UPV measurements

| Regression equation, m/s | Regression equation, m/s | R²  |
|--------------------------|--------------------------|-----|
| Turgut & Kucuk (2006)    | \( V_d = 0.725 V_c + 1536.4 \) | 0.97 |
|                         | \( V_d = 0.686 V_h + 1561.3 \) | 0.96 |
|                         | \( V_d = 0.8274 V_s + 931.14 \) | 0.93 |
| In this study           | \( V_d = 0.0195 V_{in} + 4341.8 \) | 0.74 |
|                         | \( V_d = 0.2462 V_{sd} + 3192 \) | 0.99 |
|                         | \( V_d = 0.1073 V_{sd,h} + 3923.8 \) | 0.35 |

Table 4. The comparisons of UPV measurements

| Specimen number | \( V_d/V_{sd-v} \) | \( V_d/V_{sd-h} \) | \( V_d/V_{in} \) |
|-----------------|--------------------|--------------------|-----------------|
| B275            | 0.87               | 0.93               | 0.75            |
| B250            | 0.88               | 0.91               | 1.05            |
| B225            | 0.89               | 0.95               | 1.04            |
| Average         | 0.88               | 0.93               | 0.95            |
| Standard deviation | 0.01               | 0.02               | 0.17            |

Comparison of measurement results with direct, indirect, semi-direct vertical direction and semi-direct horizontal directions are shown on table 4. The average value of the measurement result with the direct UPV method is 12%, 7% and 5% less than the average value of the semi-direct method of UPV vertical direction, the semi-direct method of the UPV horizontal direction, and the indirect method UPV.

5. Conclusion

Based on the result and calculation of the research, the obtained conclusions are the average value of the measurement result with the direct UPV method is 12%, 7% and 5% less than the average value of the semi-direct method of UPV vertical direction, the semi-direct method of the UPV horizontal direction, and the indirect method UPV. Conversion of the results of measurements for the direct UPV method of semi-direct UPV vertical direction, semi-direct UPV direction horizontal and indirect UPV can use regression equations \( V_d = 0.2462 V_{sd,v} + 3192 \), \( V_d = 0.1073 V_{sd,h} + 3923.8 \) dan \( V_d = 0.0195 V_{in} + 4341.8 \).

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