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## Study on robustness of rebound hammer and ultrasonic pulse velocity measurement in several concrete damage levels

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# Study on robustness of rebound hammer and ultrasonic pulse velocity measurement in several concrete damage levels

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**Abstract.** The results of reading the rebound number in a hammer test and velocity in an ultrasonic pulse velocity (UPV) test are usually associated with concrete compressive strength. A correlation or regression is provided to convert those parameters. However, several factors can influence this correlation. One of them is the level of concrete damage. The purpose of this study is to look at the robustness of hammer and UPV reading data in various concrete damage conditions. Experiments were carried out by testing three groups of concrete strength: 25, 35, and 45 MPa. All the concrete was tested using the UPV and rebound hammer test. The damage was determined as concrete which has decreased compressive strength by 30% (low), 50% (medium), and 80% (high) of the initial strength. The initial strength was the maximum compressive strength on each concrete group which was determined by compression testing. The rebound hammer data shows the correlation results that are almost the same as the correlation provided by the manufactures for concrete without damage and slight damage. But this is not the case with medium and highly damaged concrete, showing the results of the highly distorted correlation. The greater the level of damage, the greater the deviation. For concrete which damage level up to 80%, there is a deviation ratio of up to 3.6 times compared to the correlation value provided by the tool. Furthermore, the reading of UPV has a constant correlation without being affected by damaged concrete conditions up to the velocity of 3500 m/s. Thus, in a rapid assessment of the strength and safety of existing concrete structures, the robustness of a hammer test implements in concrete with sound and slight damage, but for concrete with beyond of elastic damage conditions, it must be accompanied by other tools such as UPV or sampling core.

## 1. Introduction

The aging of reinforced concrete structures throughout the world has led to increasing demand for reliable tools of concrete damage assessment. Principally, to determine the strength of concrete in the existing structure, cylindrical specimens are usually taken from the structure and delivered to the laboratory to be tested for loading to obtain the actual compressive strength. This procedure is the most accurate method but it requires plenty of time and expensive. Therefore, to assess the strength of in-situ concrete more quickly, non-destructive testing (NDT) techniques have been developed. These techniques estimate the strength of existing structures by measuring some concrete properties and correlating these properties with the compressive strength or other mechanical properties of concrete [1]–[4].



In assessing the results of NDT readings to determine the strength of existing concrete is a challenge for NDT users [5], [6]. For more precise results, the NDT reading results are correlated to the results of the destructive test (core test) to obtain the conversion or regression of the compressive strength. However, in practice, because destructive testing is often not allowed in several structures and demands more time due to laboratory testing, thus the NDT reading is converted to compressive strength based on the correlation procedure provided by the manufacturer of the NDT apparatus [7].

Among the many NDT methods available, the most commonly used are rebound hammer and ultrasonic pulse velocity (UPV). This is due to the advantages possessed by these tools namely portable devices, lower costs, and easy to use. The principle of using a hammer rebound is to use a spring and measure the concrete surface hardness by evaluating the rebound number (RN). Furthermore, the value of the RN indicates the properties of surface hardness and is related to the compressive strength of concrete. Meanwhile, the principle of the UPV is to transmit ultrasonic waves through concrete and measure the propagation time of the waves inside the concrete to reach the receiving sensor. Good quality concrete will produce a higher ultrasonic wave velocity. Conversely, the condition of the damaged concrete is indicated by a lower velocity [8]–[10].

However, the results of NDT are influenced by various factors. Conducting a rebound hammer test shall consider the smoothness of the concrete surface, concrete geometric properties, concrete age, concrete internal humidity, type of coarse aggregate, type of cement, type of mold, and concrete damage due to carbonation on the concrete surface [1], [2], [4], [11], [12]. Furthermore, factors that contribute to UPV reading are the properties of concrete constituent materials such as aggregate and cement types, water-cement ratio, and age of concrete. In addition, the reinforcement that is embedded in concrete also produces different velocity readings [1], [2], [11], [12]. The influence of reinforcement in damaged concrete has been studied by [13]. Generally, reinforced concrete presents a greater velocity than concrete without reinforcement. However, in a damaged condition where the strength of the remaining concrete is only half or less than half, the concrete velocity readings with reinforcement are even smaller than those of damaged concrete without reinforcement. The delamination of the reinforcing steel to the concrete surface causing voids, which is inferred to be the cause of the decrease in the ultrasonic velocity. Thus, the condition of concrete damage is believed to have a major influence on the reading of NDT devices. In fact, the NDT method is obliged to evaluate the existing concrete which is supposed to experience damages. Therefore, the study on the robustness of NDT reading, especially in damaged concrete is on-demand and discussed in this paper.

## 2. Experiments

### 2.1. Materials

The specimen was concrete cubes with a size of 150 mm. Portland cement type 1 was used as a binder. Coarse aggregates were crushed stones with a maximum size of 20 mm. Fine aggregates were natural aggregates. The specific gravity of both coarse or fine aggregates were 2.6. Standard steel cube molds were used as formwork.

Three groups of concrete with different compressive strength were prepared, namely 25 MPa, 35 MPa, and 45 MPa. The water-cement ratio was kept the same on each concrete group which was 0.57, 0.48, and 0.43 for 25 MPa, 35 MPa, and 45 MPa respectively. The mixture proportions of the concrete can be seen in Table 1. Prior to being tested, concrete was cured for 28 days in the laboratory.

### 2.2. Method

The 28-day compressive strength testing using the compression testing machine provided the actual compressive strength on each concrete strength group. The damage was determined by applying a load of 30%, 50%, and 80% of the maximum compressive strength. Next, each concrete strength group with each level of damage was tested using a hammer and UPV. The crack-free surface was chosen when measuring the concrete using NDT followed by making the concrete surface smooth.

Furthermore, the hammer test was performed on nine measurement points of each side of the concrete cube. Whereas the UPV test was carried out using the direct method where the transmitter sensor was placed in the center of the cube side and the receiver sensor is placed at the center of the cube on the opposite side. Table 2 and Figure 1 present the concrete casting and testing method. The method of measurement is according to Indonesian Standard [14] and ASTM [15].

**Tabel 1.** Concrete mixture proportion

Water	Proportion (kg)		
	Cement	Coarse Aggregate	Fine Aggregate
205	360	1110	740
205	427	1070	713
205	477	1040	693

**Tabel 2.** Method of testing arrangement

Concrete Strength (MPa)	Concrete Condition				
	Intact : 0%	Damage: 30%	Damage : 50%	Damage : 80%	Maximum : 100%
25	RH, UPV	RH, UPV, CTM	RH, UPV, CTM	RH, UPV, CTM	CTM
35	RH, UPV	RH, UPV, CTM	RH, UPV, CTM	RH, UPV, CTM	CTM
45	RH, UPV	RH, UPV, CTM	RH, UPV, CTM	RH, UPV, CTM	CTM

RH : Rebound Hammer, UPV : Ultrasonic Pulse Velocity, CTM : Compression Testing Machine



**Figure 1.** Concrete casting and testing

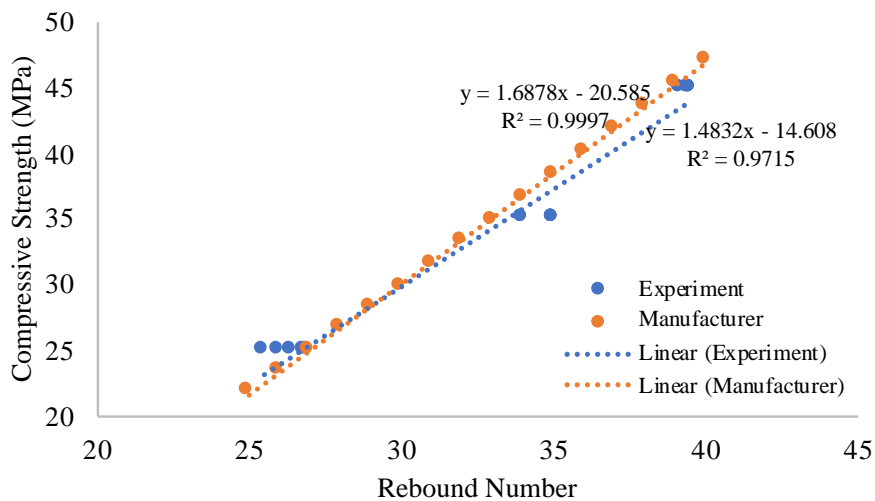
### 3. Results and discussion

#### 3.1. Robustness of RN and UPV on sound concrete

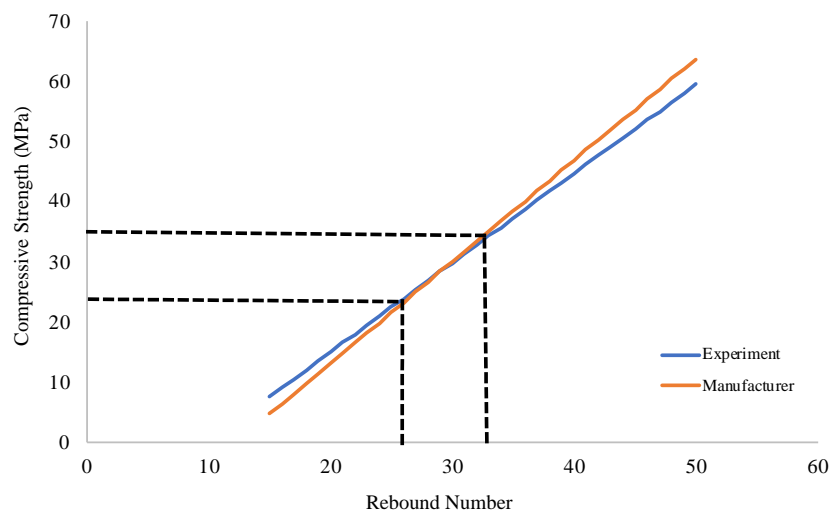
Reading of RN and UPV was conducted in advance prior to the concrete applied to a maximum compression load for determining the compressive strength. Thus, the relation between the reading of either RN or UPV and actual compressive strength can be shaping as illustrated in Figure 2. The values presented in Figure 2 are the average readings of RN and UPV on each concrete strength. In addition, the correlation between RN and predicted compressive strength from the manufacturer is also

provided as the comparison. Meanwhile, the correlation between UPV and compressive strength from other researcher is used as comparison since it is not provided by the manufacturer.

According to the experimental results, the relationship between the rebound number and compressive strength is linear as presented in Figure 2. This curve agrees with the calibration curve produced by many researchers [1], [2], [10], [16]. The larger value of RN gives a higher value of compressive strength. The consistent results show the robustness of hammer reading. The almost similar calibration curve is provided by Schmidt Hammer manufacturing company. The calibration curves of the manufacturing company are also presented in Figure 2 as a comparison. In the beginning when there is a relatively low rebound number the experimental curve hits the manufacturer curve. However, after passing the rebound number of 33 the experimental calibration curve provides a more conservative value. If a regression is developed as illustrated in Figure 3, three regions are clearly classified, namely, RN is smaller than 27, the calibration curve of the company curve is more conservative, between 27-33 both curves give the same calibration value and above 33 shows a conservative value for the experimental results.



**Figure 2.** Correlation between RN and compressive strength



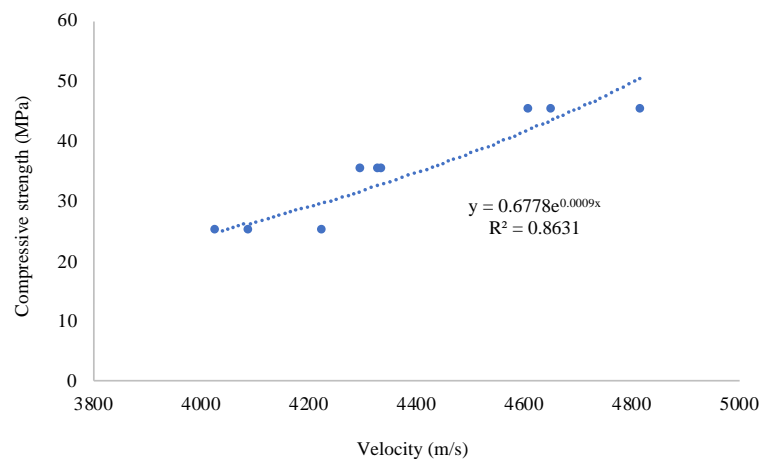
**Figure 3.** Calibration curve comparison

The correlation between ultrasonic velocity and compressive strength is given in Figure 4. The experimental data shows exponential relationships. This is in line with some studies [1], [2], [8], [9], [17] which is expressed as

$$f'_c = Ae^{Bv} \quad (1)$$

where  $e$  is a natural number and  $v$  is velocity and  $A$  and  $B$  are constants. The following regression is provided according to experimental data

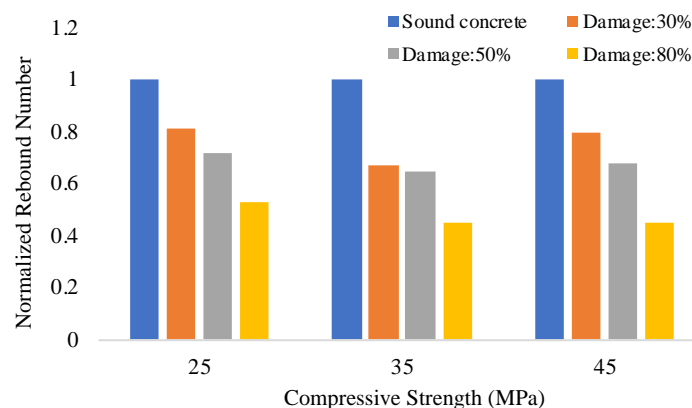
$$f'_c = 0.677e^{0.00009v} \quad (2)$$



**Figure 4.** Calibration curve of UPV

### 3.2. Robustness of RN and UPV on damaged concrete

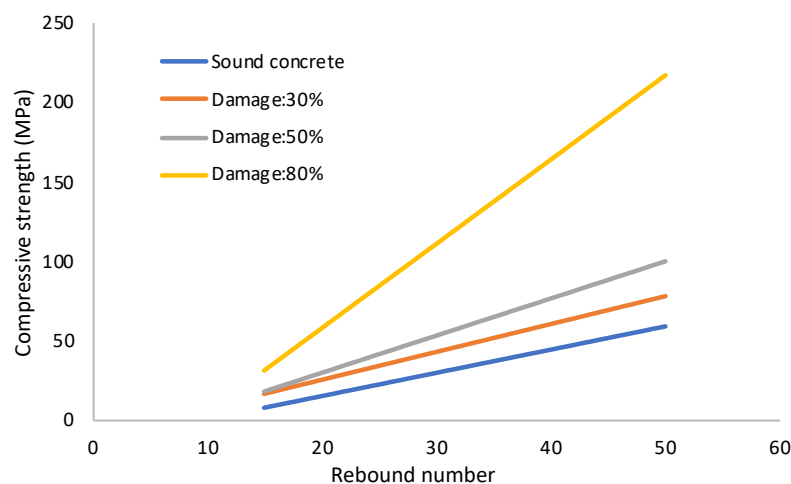
Damage has obviously influenced the reading of RN as presented in Figure 5. It shows the normalized RN in which RN in sound concrete having a value of 1. The RN has decreased in line with the increase in the level of concrete damage. The RN in concrete with a damage level of 30% drops slightly to around 20%. This value decreases repeatedly at the level of damage of 50% which is 30 to 40%. And at an 80% damage level, the RN is found only half of the sound concrete RN value.



**Figure 5.** Effect of damage to RN

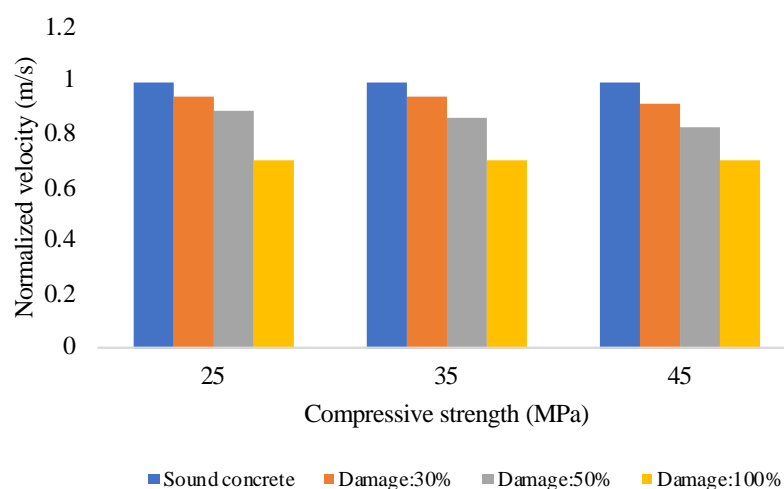
The calibration curve of the hammer test reading at each level of concrete damage is shown in Figure 6. A calibration curve for intact concrete is also provided as a comparison. The calibration curve is developed based on the regression of RN-compressive strength on each concrete damage condition. The higher level of concrete damage shows the greater gradient of the curve. Concrete that

has been damaged up to 80% produces a slope of 3.6 times the gradient of the calibration curve on sound concrete. The greater slope of the curve raises the compressive strength conversion value. For example, for the RN value of 25, for damaged concrete calibration curves gains a very large compressive strength value exceeds the actual compressive strength. In this case, it is supposed that the reading of a hammer test indicates less of robustness. This finding is similar to [11], [16] which concluded that the hammer test is not recommended for testing old concrete and even it is further suggested that it does not correlate the RN value with the existing concrete compressive strength because the results are not reliable.



**Figure 6.** Hammer test calibration curve for damaged concrete

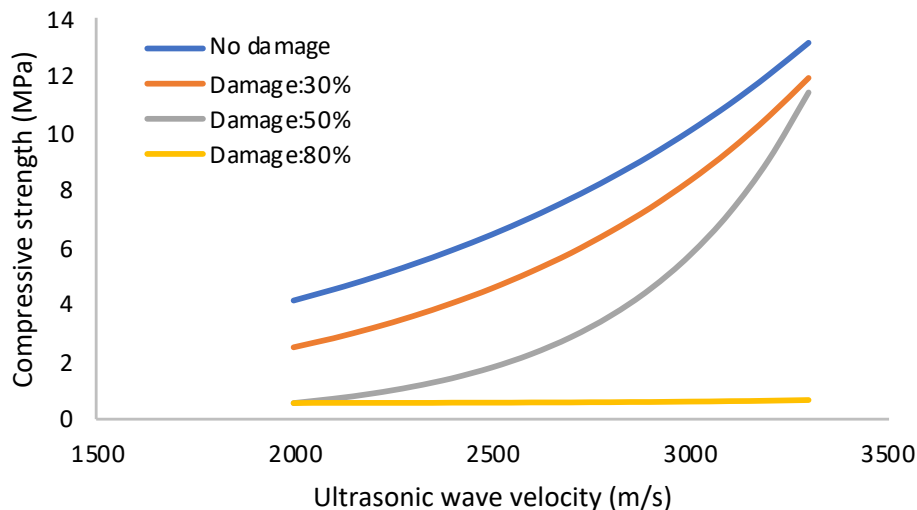
In case of UPV reading, similar to RN, concrete damage condition affects the velocity. More severe concrete damage produces smaller velocity. Other studies reveals the same finding as this research [1], [2], [5], [16]. More voids and cracks exist in damage concrete as the result the velocity decreases because the wave need more time to propagate inside the concrete. Figure 7 presents the normalized velocity of each compressive strength for several damage level. The unity belongs to sound concrete velocity. In average, the velocity loss is proportional to damage level which are 7%, 13% and 29% decrease of velocity for damage level of 30%, 50%, and 80% respectively.



**Figure 7.** Effect of damage to UPV



The calibration curve of UPV reading at each level of concrete damage is shown in Figure 8. A calibration curve for intact concrete is also provided as a comparison. The calibration curve is developed based on the regression of UPV-compressive strength on each concrete damage condition. UPV calibration curve show better robustness since the damage concrete produces a smaller velocity. However, the calibration curve is valid until velocity of 3500 m/s. The huge growth of compressive strength exceeds the compressive strength of sound concrete is found on 50% damage concrete since it has the greatest exponential constant of the curve.



**Figure 8.** UPV test calibration curve for damaged concrete

#### 4. Conclusion

- 1 Ultrasonic provides better robustness for measuring damage concrete.
- 2 Concrete that has been damaged up to 80% produces a slope of 3.6 times the gradient of the calibration curve on sound concrete during hammer measurement.
- 3 UPV calibration curve is valid until velocity of 3500 m/s for damaged concrete.
- 4 The huge growth of compressive strength exceeds the compressive strength of sound concrete is found on 50% damage concrete since it has the greatest exponential constant of the curve.

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