Comparison Between Predicted and Experimental Strength for Concrete via Compression and Non-destructive Method

Mustaqqim Abdul Rahim, Lee Choon Onn, Adib Fikri Abdul Manaf, Shahiron Shahidan, Sharifah Salwa Mohd Zuki, Mohamad Azim Mohammad Azmi, and Nor Hazurina Othman

Abstract Rebound hammer and ultrasonic pulse velocity are preferred as non-destructive testing methods whereas compression test is a type of destructive test. A general series of rebound hammer, ultrasonic pulse velocity and compression tests were carried out at a heavy concrete laboratory to obtain the necessary parameters and to develop correlation and calibration between the tests. A set of 36 concrete cubes measuring 100 × 100 × 100 mm were cast and subjected to water curing for periods lasting 7, 14, 21 and 28 days to obtain cube strength, rebound number, pulse velocity and pulse wave transmission period. Ultrasonic pulse velocity and rebound hammer tests were initially done before the compression test. The results showed that the differences between predicted strength and experimental strength (compression test) were 1.6 and 6.38% for the rebound hammer test and the ultrasonic pulse velocity test, respectively. This indicated that rebound hammer testing managed to predict strength more accurately compared to ultrasonic pulse velocity testing. Both non-destructive tests showed a margin of less than 10% error compared to destructive tests.

Keywords Rebound Hammer · Ultrasonic pulse velocity · Strength prediction · Experimental strength

M. A. Rahim (✉)
School of Environmental Engineering, University Malaysia Perlis, 02600 Arau, Perlis, Malaysia
e-mail: mustaqqim@unimap.edu.my

L. C. Onn
Poh Cheong (Malaysia) Sdn Bhd, Lot 1250/1251 Jalan Seelong, 81400 Mukim Senai, Johor, Malaysia

A. F. A. Manaf · S. Shahidan · S. S. M. Zuki · N. H. Othman
Faculty of Civil Engineering and Built Enviroment, Universiti Tun Hussein Onn, Batu Pahat, 86400 Parit Raja, Johor, Malaysia

M. A. M. Azmi
Departments of Civil Engineering, Center for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Education Hub Pagoh, 84600 Muar, Johor, Malaysia

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1 Introduction

It is important to test concrete structures after concrete has solidified to determine whether a particular structure is in the desired condition and suitable for its purpose without interrupting its properties. There are quite a number of parameters that can be determined by non-destructive tests such as density, modulus of elasticity, strength, surface hardness and surface absorption as well as reinforcement location, size and distance from the surface. At the same time, non-destructive tests are also used for maintenance work on existing building structures such as void detection, cracking and delamination [1].

Rebound hammer testing is an inexpensive method that can be used to determine the properties of concrete. It does not require any current but instead utilises springs to gain rebound energy. In addition, a rebound hammer can be reused, hence incurring low maintenance costs [2]. When the plunger of a rebound hammer is pressed to the top of a concrete surface, a spring-controlled mass with constant energy is made to hit the concrete surface and rebound. The distance of rebound for measuring the surface hardness is carried out using a graduated scale. The test surface can be horizontal or vertical but the instrument must be calibrated in a fixed position before the test begins. The value obtained from the graduated scale is known as a Rebound Number (rebound index). Several readings are required to ensure the accuracy of the rebound hammer and compressive strength values. Concrete with higher strength and stiffness will absorb less energy which results in a higher rebound value [2]. Meanwhile, the ultrasonic pulse velocity method involves longitudinal ultrasonic waves converted by mechanical energy passing through a concrete structure. The ultrasonic wave generated by a transducer penetrates through the concrete structure on one end of its surface. The wave then travels through the concrete structure and is converted to electrical signals received by another transducer on the opposite surface [3]. There are plenty of functions for ultrasonic wave velocity on concrete structures such as strength testing, homogeneity, trapped air, internal flaws, cracks, segregation, honeycombing, compaction, workmanship, durability and so on [4]. A compression test is categorised as a destructive test in accordance with BS EN 12390-3:200 [5]. A non-stop compressive load is usually applied to the specimen until the ultimate capacity is reached. The aim of this research is to develop the relationship between non-destructive and destructive tests on concrete.

2 Materials and Methods

2.1 Preparation of Materials

Concrete mixing is a process where Ordinary Portland cement (OPC), aggregate, sand (fine aggregate) and water are mixed uniformly and hardened to become concrete. Design grade concrete, namely M20, M25 and M30 were used in this research. According to JKR 20,800 Standard Specification for Building Works (JKR Standards [6]), grade M20, M25 and M30 concrete mixes require a cement, sand and aggregate ratio of 1:2:4, 1:1:5 and 1:1:2, respectively. Overall, 3 sets of 12 concrete test cubes were cast and used for the tests. Cube moulds measuring 100 × 100 × 100 mm were used to cast the specimens according to BS EN 12390-1:200 [7] (Fig. 1).

According to BS EN 1881: Part 203 [8], a flat ground location is recommended to ensure that the rebound hammer equipment is not positioned at an inclined angle. From Fig. 2, the plunger of the rebound hammer was pressed onto the surface center of the concrete cube specimens and held vertically downward at a right angle to the concrete specimens. Figure 5 shows the application of the rebound hammer at the centre of the concrete cube surface.

The ultrasonic pulse velocity method involves propagating ultrasonic waves generated through electric current in concrete and measuring the time taken for waves to propagate from one point to another. This method was conducted in accordance with BS EN 12504-4:2004 [9]. The equipment or generator of pulse waves called PUNDIT Lab consists of 2 transducers for wave transmission and reception purposes (Fig. 3).

(a) (b)

Fig. 1 Concrete specimen: **a** Cube specimen, **b** Curing process

Fig. 2 Rebound hammer on concrete surface

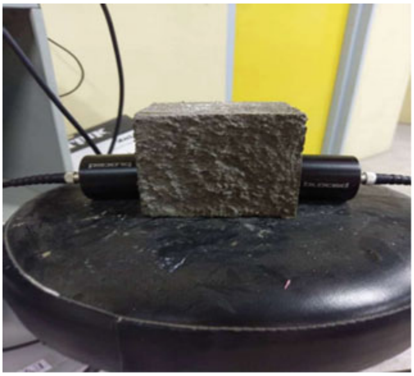

Fig. 3 Direct method of ultrasonic pulse velocity

3 Results and Discussions

From Fig. 4, higher initial experimental strength compared to the other two non-destructive tests can be observed. Afterwards, the lowest readings of experimental strength were recorded after a curing period of 14 and 21 days. The highest experimental strength was finally obtained after a curing period of 28 days.

From Fig. 5, only a small difference between the experimental strength and predicted strength was observed. The experimental strength and predicted strength were very close and concentrated. This indicates that the prediction of compressive strength from non-destructive testing is very accurate and close to the actual compressive strength prediction via destructive tests.

From Fig. 6, the results after a curing period of 7 and 14 days were unstable and not concentrated. The lowest experimental strength was recorded on the initial day of curing while the highest was recorded on day 14. After 14 days of curing, a stable and concentrated relationship between experimental strength and predicted strength was obtained.

From Table 1, the overall variation between experimental strength and predicted strength of the rebound hammer test lies in the range of −4.5 to 8.2%, with an average value of 1.6%. Meanwhile, the overall variation between experimental strength and predicted strength of the ultrasonic pulse velocity test lies in the range of 4.62 to 7.29%, with an average value of 6.38%. Finally, the overall difference between experimental strength and predicted strength through the ultrasonic pulse velocity test lies in the range of 4.2to 7.87%, with an average value of 6.62%. To sum up, the relationship between non-destructive and non-destructive tests of concrete can be developed through correlation between actual compressive strength of concrete test specimens with different concrete mix designs and curing periods. Actual compressive strength can be obtained from compression tests whereas the predicted strength can be obtained from rebound hammer and ultrasonic pulse velocity tests. From the results, both non-destructive tests show a margin of less than 10% error compared to the destructive test. Thus, non-destructive tests are

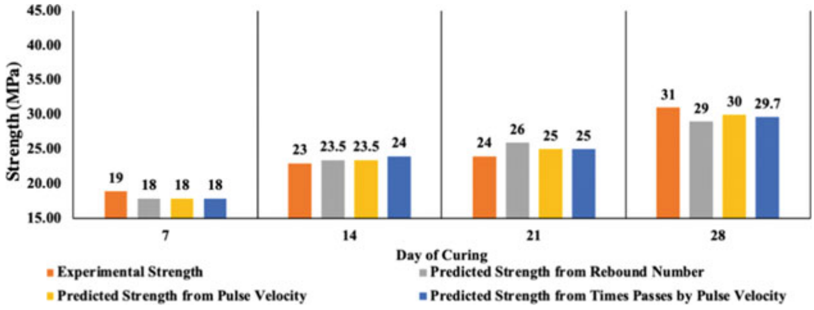

Fig. 4 The comparison between the predicted strength and experimental strength of grade M20 test specimens against day of curing

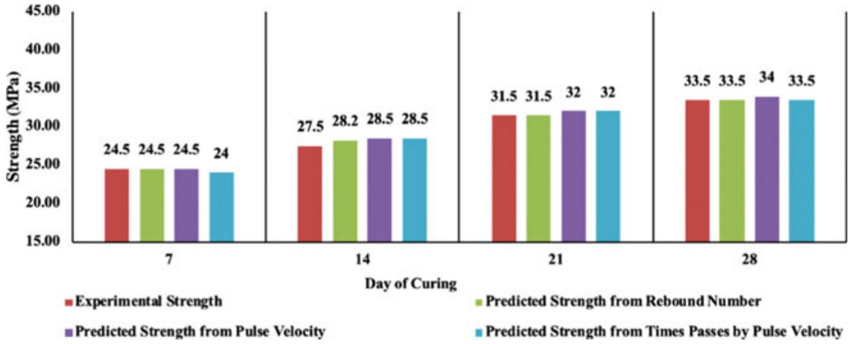

Fig. 5 The comparison between the predicted strength and experimental strength of grade M25 test specimens against day of curing

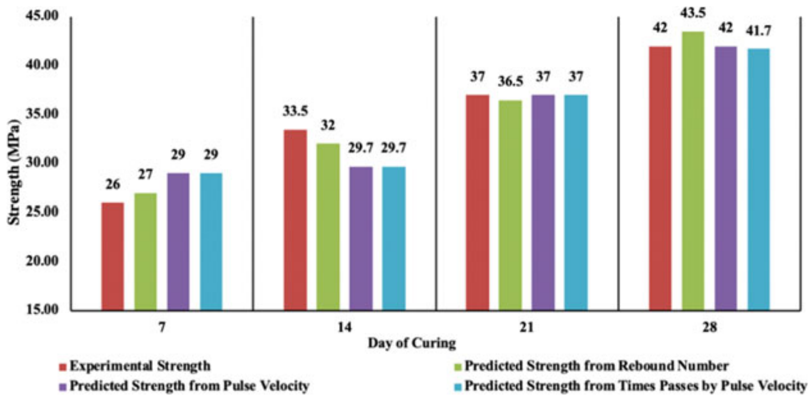

Fig. 6 The comparison between the predicted strength and experimental strength of grade M30 test specimens against day of curing

Table 1 The variation and average between experimental strength and predicted strength of concrete

Grade of test specimens	Overall variation between experimental strength and predicted strength by rebound hammer (%)	Overall variation between experimental strength and predicted strength by using pulse velocity (%)	Overall variation between experimental strength and predicted strength by using time passes through the specimens (%)
M20	8.20	7.22	7.8
M25	1.10	4.62	4.20
M30	-4.50	7.29	7.87
Average	1.6	6.38	6.62

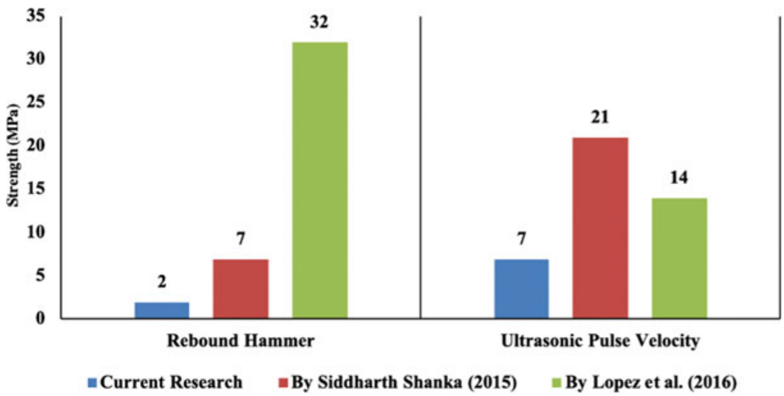

Fig. 7 The comparison between the predicted strength and experimental strength of grade M30 test specimens against day of curing

more suitable for predicting concrete strength as it does not affect the arrangement of inner particles and the life span of concrete.

In Fig. 7, it can be seen that this study obtained a lower average variation between experimental strength and predicted strength compared to two other studies. The regression equation developed by Siddharth and Joshi [10] was found to be acceptable and was integrated into this research for both non-destructive methods. The regression equation for the rebound hammer test developed by Lopez et al. [11] was less appropriate for this research. This may be due to several conditions, such as different practice codes, limited applications of the regression equation and strength or type of trendline during the development of the regression equation.

4 Conclusion

From the results, it is evident that the higher the rebound number, the higher the predicted strength. For the ultrasonic pulse velocity test, a direct method was applied to obtain 2 parameters namely, pulse velocity and pulse wave transmission period through the test specimens. Correlation graphs were plotted to obtain predicted concrete strength. Unlike the rebound hammer test, a positive linear correlation graph was obtained for the pulse velocity test whereas a negative linear was obtained for pulse wave transmission period. The exponential form for ultrasonic pulse velocity was found to be unsuitable since the coefficient of determination for both parameters was less than 50%. This indicates that the predicted strength was inaccurate. Meanwhile, the linear form for ultrasonic pulse velocity showed a relatively high coefficient of determination and was thus chosen to deduce the predicted strength of concrete.

From the ultrasonic pulse velocity test results, it can be concluded that the higher the pulse velocity, the higher the predicted strength. This is because the shorter the time needed for a pulse to be transmitted to a receiving transducer, the denser a material is, thus indicating that the material possesses high strength. The relationship of pulse velocity and time passes by pulse wave was inversely proportional. When the results of the rebound hammer test and the ultrasonic pulse velocity test were compared, it was found that the rebound hammer test has a higher coefficient of determination than the ultrasonic pulse velocity test. This suggests that the rebound hammer test shows greater accuracy for predicting concrete strength.

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