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Full Length Research Paper

Assessing the strength of reinforced concrete structures through Ultrasonic Pulse Velocity and Schmidt Rebound Hammer tests

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The experimental studies using Ultrasonic Pulse Velocity and Schmidt Rebound Hammer as Non-Destructive Tests (NDT) were presented in this paper to establish a correlation between the compressive strengths of compression tests and NDT values. These two tests have been used to determine the concrete quality by applying regression analysis models between compressive strength of in-situ concrete on existing building and tests values. The main members of an existing structure including column, beam and slab were included in the study. The relationship between compression strength of concrete collected from crashing test records and estimated results from NDT's records using regression analysis was compared together to evaluate their prediction for concrete strength. The test results show that the rebound number method was more efficient in predicting the strength of concrete under certain conditions. A combined method for the above two tests, reveals an improvement in the concrete strength estimation and the latter shows better improvement. Applying combined methods produces more reliable results that are closer to the true values. The resulting strength calibration curves estimation was compared with other results from previous published literatures.

Key words: Non Destructive Testing (NDT), Schmidt Rebound Hammer (SRH), Ultrasonic Pulse Velocity (UPV), NDT combined method, compressive strength, regression analysis.

INTRODUCTION

The Non Destructive Testing (NDT) of concrete has a great technical and useful importance. These techniques have been grown during recent years especially in the case of construction quality assessment. The main advantage of non-destructive testing method is to avoid the concrete damage or the performance of building structural components. Additionally, their usage is simple and quick. Test results are available on the site and the possibility of concrete testing in structures is demanding in which the cores cannot be drilled and the use of less expensive equipments (Hobbs and Tchoketch, 2007). The Schmidt rebound hammer (SRH) and the ultrasonic pulse velocity (UPV) tests, are useful non-destructive tests, which are so familiar recently and they are useful when a correlation can be developed between hammer/ultrasonic pulse velocity readings and the strength of the same concrete. This non-destructive measurement method has proved to be of real importance in all constructions serving the purpose of testing and as an effective tool for inspection of concrete quality in concrete structures (Solís-Carcaño and Moreno, 2008). Moreover, the calibration curve supplied by the equipment do not needs much confidence because of using many cubic samples and standard mixture for producing this curve.

Many Non-destructive methods have been applied to examine the empirical research of non-destructive testing methods. A literature survey (Leshchinsky, 1991) in using non destructive methods used for concrete testing summarized the benefits of non destructive tests. The

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Figure 1. Pulse velocity testing equipment (PUNDIT).

use of Ultrasonic Pulse Velocity (UPV) to the non-destructive assessment of concrete quality has been extensively investigated for decades. It is more likely to assess the quality and characteristics of at site concrete and composed of measuring the transit time of an ultrasonic pulse velocity through the concrete (Solís-Carcaño and Moreno, 2008). The velocity of the signals pass through in a concrete depends on the density and elasticity. According to the theory of the sound propagation in solids, the sound transmission velocity is depends on the density and the elastic modulus of the concrete and it is independent of the excitation frequency that causes the agitation. The excitation may cause longitudinal (compression) waves and transverse (shear) waves in the concrete (Hobbs and Tchoketch, 2007). Numerous data and the correlation relationships between the strength and pulse velocity of concrete have been arranged. Galan (1967) reported a regression analysis to predict compressive strength of concrete based on sound characteristics like UPV and estimated concrete strength and damping constant.

A particular transducer must be used in the purpose of determining dynamic elastic modulus and Poisson's ratio of concrete and based on the wave type (longitudinal or transverse). There is not any standard correlation between concrete compressive strength and the ultrasonic pulse velocity and this matter was controlled by many aspects (Turgut, 2004). However, the value of this method to estimate the quality of concrete is based on the fact that the curve slope between the two variables is comparatively coherent. Consequently, a calibration curve between compressive strength and ultrasonic pulse velocity obtained for each concrete is needed otherwise not enough dependability would be attained (Popovics and Popovics, 1997). The nature of the aggregates which is one of the major aspects that is generally more plentiful, rigid, and resistant part in concrete influences this correlation and changes the elastic properties of the concrete (Sturrup et al., 1984).

TEST EQUIPMENTS

The UPV equipment (e.g. PUNDIT) includes a transducer, a receiver and an indicator for showing the time of travel from the transducer to the receiver (Figure 1) (Pundit manual 1998). Ultrasonic pulse uses fast potential changes to create vibration that leads to its basic frequency. The transducer is firmly attached to concrete surface to vibrate the concrete. The pulses go through the concrete and reach the receiver (ASTM, 2002).

The pulse velocity can be determined from the following equation:

$$V=L/T \quad (1)$$

where V = pulse velocity (km/s), L = path length (cm), T = transit time (μs).

Based on this technique, the velocity of sound in a concrete is related to the concrete modulus of elasticity:

$$V = \sqrt{\frac{E}{\rho}} \quad (2)$$

where, E = modulus of elasticity, ρ=density of the concrete.

The transducer detects the pulses which reach first and it is usually the leading edge of the longitudinal vibration. The positions of pulse velocity measurements are categorized in, a: Opposite faces (direct transmission), b: Adjacent faces (semi-direct transmission) or c: Same face (indirect or surface transmission) which are shown in Figure 2.

In this study, the direct method is used for column, semi-direct method for beam and in-direct method for slab. The latter method is suitable for quality assessment in concrete while the pulse velocity depends only on modulus of elasticity not shape of concrete.

The Schmidt Rebound Hammer (SRH), known as the Rebound or Impact Hammer test is considered as a non-destructive method, widely used for assessing rock quality materials considering surface rebound hardness that is related to the compressive strength. This test is fast, cheap and an important guide test for rock material description. The methodology of the SRH test is expected to ensure the trustworthy data achievement and on site or the laboratory analysis (Amasaki, 1991). SRH includes a spring loaded piston with steel mass (Figure 3) as explained In British Code (BS1881 part 202, 1986). The SRH as a hardness test works in a way that the

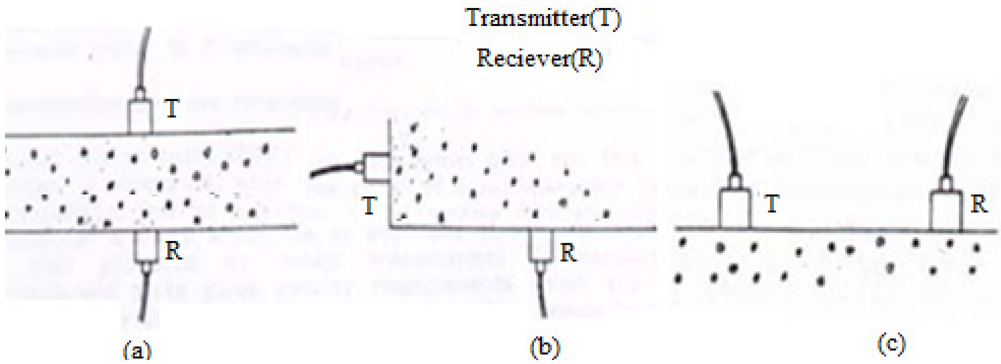

Figure 2. Direct (a), Semi-direct (b) Indirect (surface) transmission (c).

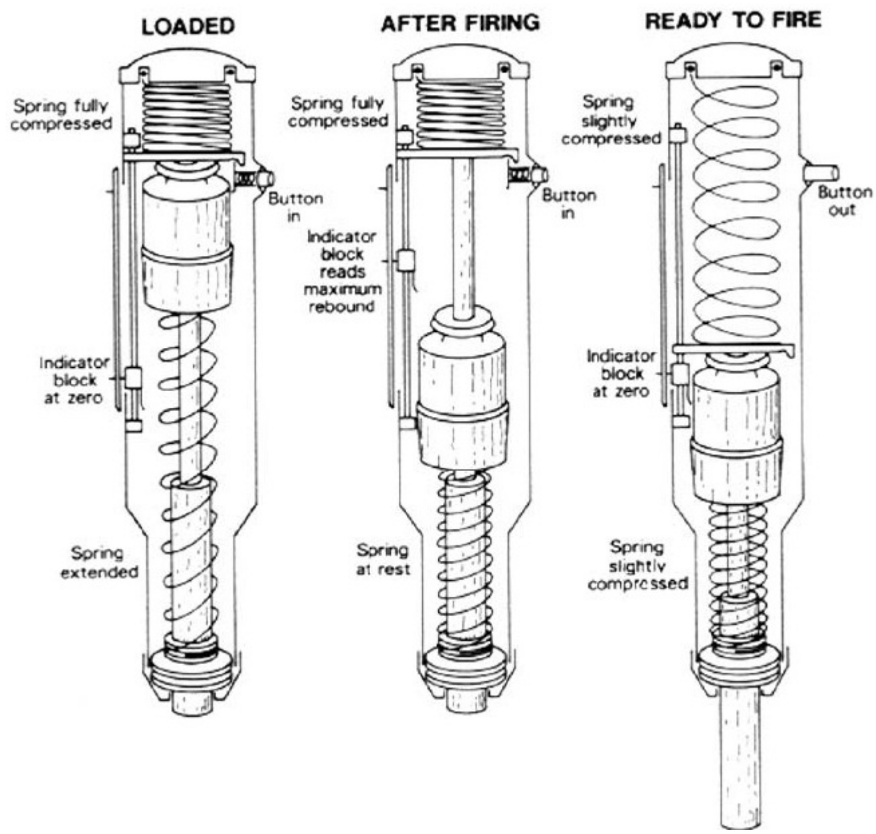

Figure 3. Operational system of a Schmidt Rebound Hammer (SRH).

rebound of an elastic material is related to its surface hardness against the hitting material. Based on the standard, the energy attracted by the concrete is according to its strength rebound of an elastic material (ACI Committee, 1988). The kinetic energy equals to the energy released by the key spring of the piston in the straight impact direction which it is released onto the hammer (Basu and Aydin, 2004) even if this test involves impact problems and the related stress-wave propagation (Qasrawi, 2000). Concrete surface should be carefully selected and prepared to be used by polishing so that the test surface is then ground smooth. A fixed power then applies by pushing the hammer against the surface. The slope angle of the hammer affects the result. After the impaction, the rebound readings should be recorded. There is not any distinctive relationship between hardness and strength of concrete but experimental data relationships can be obtained from a given concrete (Basu and Aydin, 2004). A common normalization procedure which could be used for any type of Schmidt hammer with the same nominal design fired in any direction (Galan, 1967). However, the relationship between hardness and concrete strength depends on issues affecting the concrete surface such as saturation degree, temperature, carbonation surface preparation and location (Willetts, 1958; Amasaki, 1991) also the type of

Figure 4. UPV and SRH tests in site.

Table 1. Concrete mix proportion.

Ingredient	Cement (Kg/m^3)	Coarse aggregate (Kg/m^3)	Fine aggregate (Kg/m^3)	Water (kg/m^3)	Retarder (ml/m^3)	SP (ml/m^3)
Amount	390	1020	805	195	1150	2305

aggregate, mix proportions, hammer type, and hammer inclination affect the results (Grieb, 1958). Surfaces with scaling, honeycombing, high porosity, or rough texture must be avoided. All samples must be at the same age, moisture conditions and the same carbonation degree (Qasrawi, 2000). It is essential to take 10 to 12 readings for each surface and by the existence of aggregate and voids instantly under the plunger the test is sensitive (Neville and Brooks, 1987).

Obviously by just using the SRH, the concrete surfaces reflect. Based on British Code (BS1881 part 202, 1986), the measured number by rebound hammer is an indication of the first 30-mm depth of concrete. Another research (Aydin, 2009) recommended a method for determining the Schmidt hammer rebound hardness. According to a research by Teodoru (1989), the SRH obtained results are only delegate of the outer concrete layer with a thickness of 30 to 50 mm. The simplicity of obtaining the suitable correlation data in a given instant causes the rebound hammer to be most useful for quick surveying in large areas of similar concrete types in the considered construction (Qasrawi, 2000). Also the advantages of using rebound hammer in concrete presented (Neville, 1973) and stated that the rebound hammer test should not be accepted as a replacement for compression test but another researcher (Bilgin et al., 2002) strongly showed the importance of SRH used for mechanical excavators with gathering arms, such as tunnel heading machines, may extensively improve daily advance rates. This is a very easy test to conduct and the rebound value is a good symptom of rock characteristics and gives significant correlation with net breaking rates of rebound hammers.

The non-destructive methods for evaluation of the actual compressive strength of concrete in existing structures are based on experimental relations between strength and non-destructive parameters. Manufacturers typically give experimental relationships for their own testing system of devices.

Regression analysis approach is used as destructive testing in this research to obtain a mathematical relationship using SRH and UPV for investigation the reinforced concrete buildings.

TEST PROGRAMME

Main members of an existing structure including column, beam and slab were tested by NDT methods (Figure 4).

Material properties and test procedure

Concrete mix proportion (Table1) used by the construction company in Malaysia respect to (M523 part 2 1993) which is the Standard for specifying, production and compliance criteria for the ready-mixed concrete supply in Malaysia that was adopted from British codes (BS5328, 1976).

The design slump would be limited from 25 to 75 mm and the coarse aggregate used has a nominal maximum size of 19 mm while the fine aggregate has a fineness modulus of 2.70.

The relationship between compression strength of concrete collected from crashing test records and estimated results from NDT's records was established and compared. Both, the Schmidt Rebound Hammer (SRH) and the Ultrasonic Pulse Velocity (UPV) tests, are only useful provided that a correlation can be developed between the rebound number/ultrasonic pulse velocity readings and the strength of the same concrete. This study planned to adapt the Schmidt Rebound Hammer (SRH) equipment and the Ultrasonic Pulse Velocity (UPV) tester to investigate the concrete structures in site. A combined method for the above two tests is established in order to improve the strength estimation of concrete.

TEST SPECIMENS

All specimens for compression test were cubes of 150 mm side

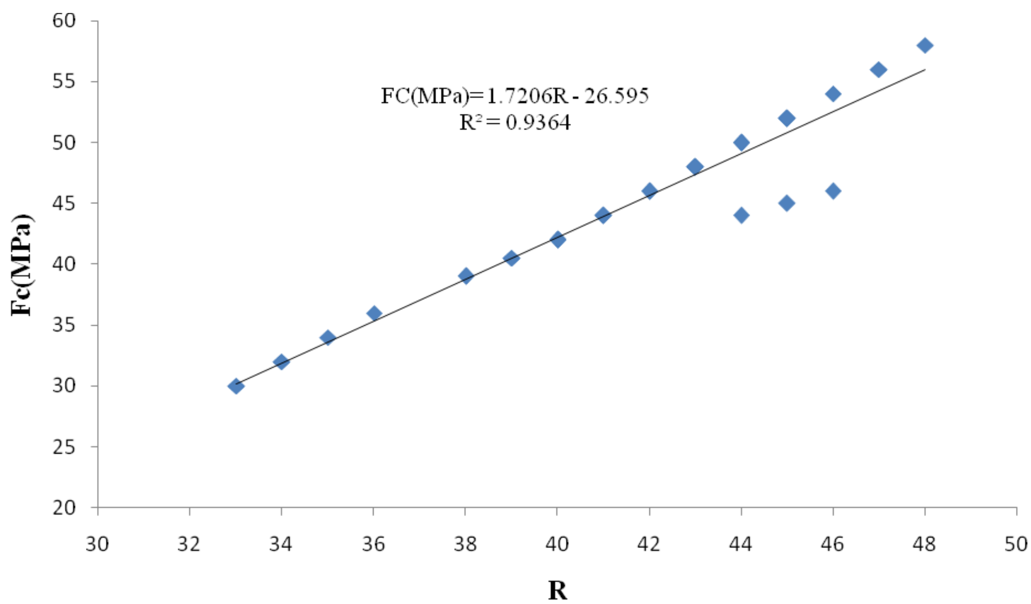

Figure 5. Rebound number/compressive strength calibration curve.

length for concrete strength recording. The loading speed for 150 mm side length cube was used is 13.5kN/s. The compressive strength of hardened concrete was determined by using specimens tested at 1, 3, 7, and 14 days intervals. Two specimens were tested and the averaged results for each strength test at each age were used.

SCHMIDT REBOUND HAMMER (SRH) TEST

The rebound number was obtained by taking 36 readings for column, 18 readings for beam and 24 readings for slab. Readings were done in a horizontal position for beam/column and vertical position for slab as described in British codes (BS1881 part 202 1986). The mean rebound number and mean strength obtained from compression strength test of specimens provided the data to construct a correlation curve.

ULTRASONIC PULSE VELOCITY (UPV) TEST

Each concrete member for UPV test was tested as described in British codes (EN 12504-4, 2004). The pulse velocities are measured in direct and semi direct method between opposite faces for column, adjacent faces for beam and indirect method for slab. The UPV readings, there are 36 readings for beam, 12 readings for column and 20 readings for slab. For this test also, the mean strength obtained from UPV and mean strength obtained from each member provided the data to achieve a correlation curve.

ANALYSIS AND RESULTS

Calibration curves for each test method are drawn using regression analysis. The correlation relation between predicted and compression strength of concrete are represented by plotting the averages of rebound number/ultrasonic pulse velocity against the compressive strength of each member.

Schmidt Rebound Hammer (SRH) results

The best fit line, which represents the relationship between the rebound number and the compressive strength of concrete, is a straight line which has the following equation:

$$f_c(R)=1.7206R - 26.595 \quad (3)$$

where, R is the rebound number.

The number of used data in the correlation is n = 18. The R^2 value is found to be 93.6%, which indicates a significant correlation. The 95% prediction interval is quite narrow (f_c ±4.42 MPa) where most of the data values are within this interval (Figure 5). The standard error are found to be S.E. = 2.1024.

Ultrasonic Pulse Velocity (UPV) results

The best-fit curve that represents the relationship has the following equation:

$$f_c(V)=15.533V - 34.358 \quad (4)$$

where, V is the ultrasonic pulse velocity.

The number of data used in the correlation n = 18. The R^2 value is found to be 91.9%, which indicates a significant correlation. The 95% prediction interval is quite wider than the previous one (f_c ±11.39 MPa) where the most data values are within this interval. (Figure 6) and the standard error are found to be S.E. = 3.3746.

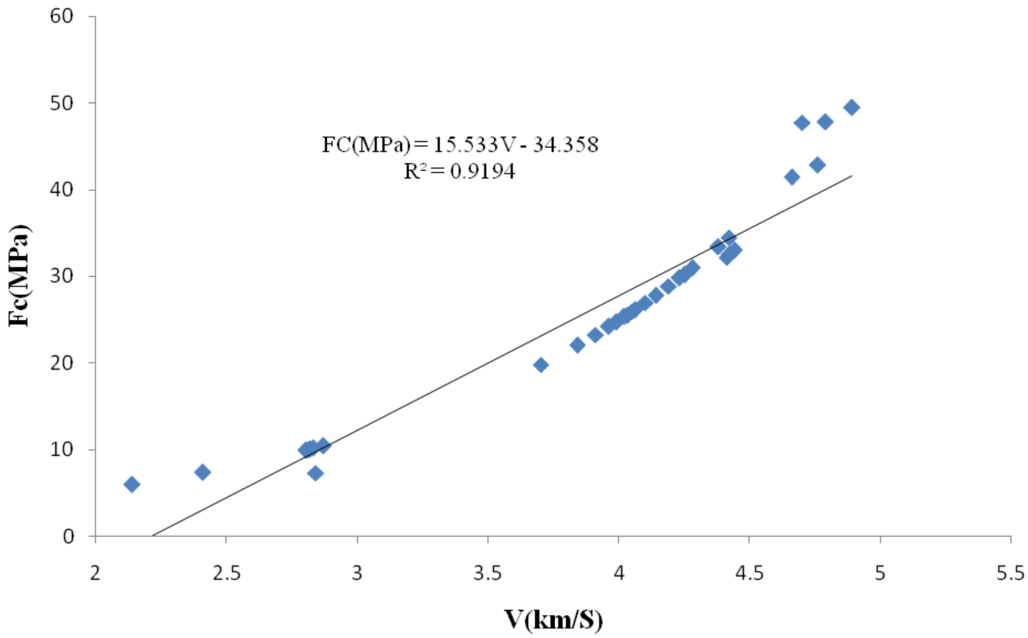

Figure 6. Ultrasonic Pulse Velocity (UPV)/compressive strength calibration curve.

Combined analysis

Dependability of results was enhanced while the combination of two NDT methods was used together. To analyze the combined method, a multiple regression was used to predict the concrete compressive strength. Consequently, the results showed a significant correlation between compression strength, UPV and rebound numbers together (Mahdi Shariati, University Putra Malaysia, M.S thesis 2008). The compressive strength can be predicted from the combined ultrasonic pulse velocity and rebound number using equation 5 with R^2 = 0.95 where the n=18 and S.E. =1.8491 and the 95% prediction interval is quite narrow (f_c ±3.7 MPa):

$$f_c(V)=-173.04+4.07V^2+57.96V+1.31R \quad (5)$$

where, V is the ultrasonic pulse velocity and R is the rebound number.

DISCUSSION

Obviously, the Schmidt Hammer Rebound (SRH) with best fit line has a better correlation than UPV. The regression model achieved from combination of two NDT methods are more precise and closer to the experimental results to those results that were achieved from individual methods.

COMPARISON WITH OTHER PUBLISHED WORKS

The compressive strength of concrete predicted by the author's calibration curve is higher than the other ones, achieved by other researchers (Figures 7 and 8) and SRH calibration curve is almost close to the manufacturer's calibration curve but for UPV calibration curve is the furthest one from the manufacturer's calibration curve. The effect of different features such as the proportions of aggregate, water/cement ratio, curing could be the cause of this difference and it does not mean less confident of this method.

CONCLUSION

The rebound number method appears to be more competent in forecasting the compression strength of concrete compare than the ultrasonic pulse velocity method. However, the development of calibration curves to conform both the Schmidt Rebound Hammer (SRH) and the UPV testing techniques for usual concrete mixes showed that the use of these two methods individually is not appropriate to predict an accurate estimation for concrete strength. The use of the Schmidt Rebound Hammer (SRH) test for strength estimation of in situ concrete alone is not recommended unless using an available specific calibration chart.

The use of combined methods produces more trustworthy results that are closer to the true values when compared to the use of the above methods individually. An acceptable level of precision was additionally appreciated for concrete strength estimation. Therefore, for engineering investigation, the resulting regression model for strength evaluation could be used securely for

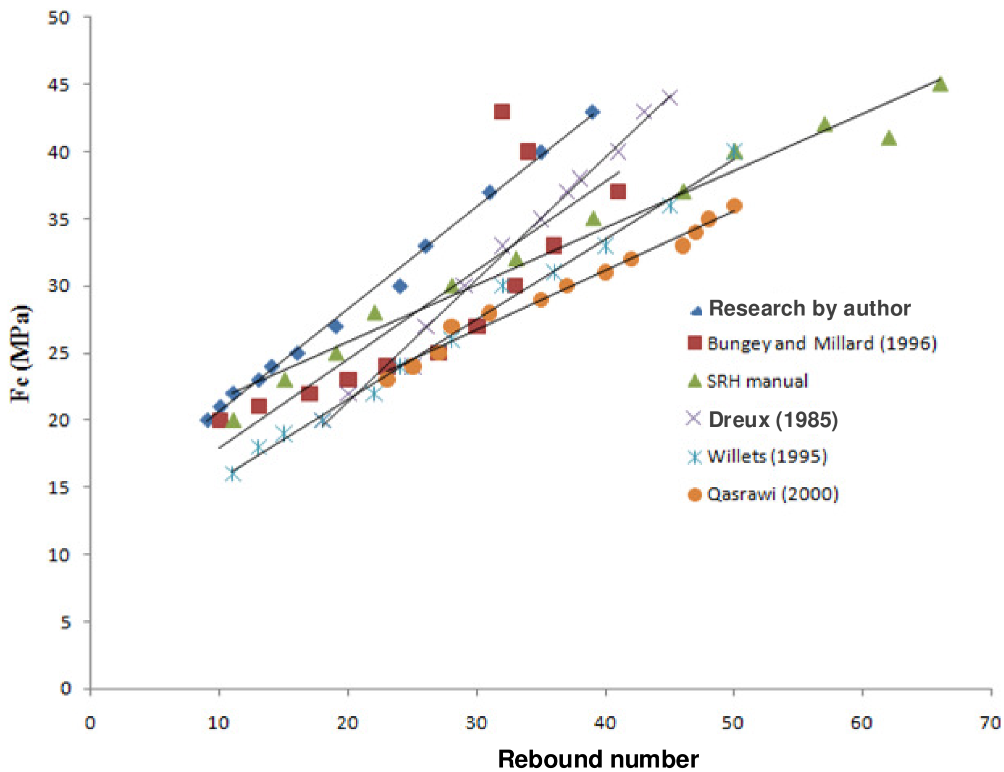

Figure 7. Comparison of Schmidt Rebound Hammer (SRH) test with others.

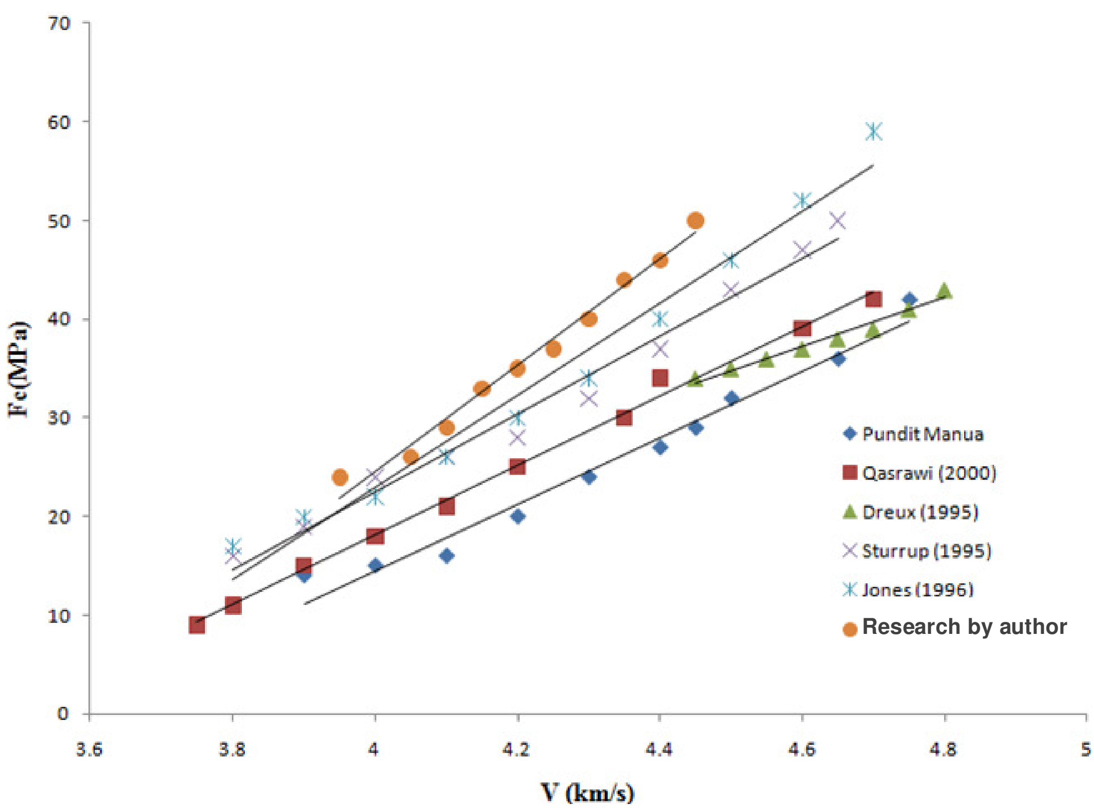

Figure 8. Comparison of Ultrasonic Pulse Velocity (UPV) test with others.

concrete strength estimation.

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