Finding an Unified Relationship between Crushing Strength of Concrete and Non-destructive Tests

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1- ABSTRACT

There are many test methods to assess concrete in situ, such us Non-destructive Tests methods (Schmidt Hammer and Ultrasonic Pulse Velocity), and these methods consider indirect and predicted tests to determine concrete strength in situ, whereas these tests affected by many parameters depend on the nature of materials used in production concrete. So, there is a difficulty in determine strength of hardened concrete in situ precisely by this methods. This research aim to find unified relationship connect the results of these tests and correlate them with the results of crushing strength of cubes by using statistical methods in the analyzing process depending on laboratory tests carried on concrete cubes with different mixing ratios and different curing conditions, and finding correlation curves to predict the strength of concrete much better.

2- INTRODUCTION

Instead of the good care in the design and production of concrete mixture, many variations are happened in the conditions of mixing, degree of compaction or curing conditions which make many variations in the final production. Usually, this variation in the produced concrete have been assessed by standard tests to find the strength of the hardened concrete, and inspite of the type of these tests, considered a good one to determine the quality during the process of producing concrete but they have some considerable disadvantages, such as the test sample may be not present the concrete in the structure actually.
So, as a result, many trials were carried out in the world to develop fast and cheap non-destructive methods to test concrete in the labs and structures and to observ the behavior of the concrete structure during along period, such these tests are Hammer test such as Schmidt Hammer and Ultrasonic Pulse Velocity test.

3- NON-DESTRUCTIVE TESTS NDT

3-1 Ultrasonic Pulse Velocity test UPV

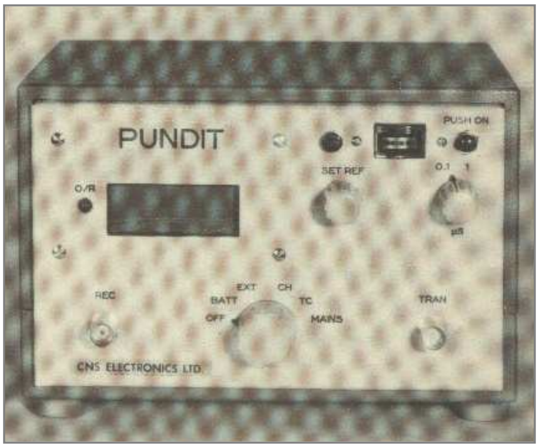
The principle of this test is to produce a pulse of longitudinal vibrations by an electro-acoustical transducer (Transmitter) which is held in contact with one surface of the concrete under test. After traversing a known path length in the concrete, the pulse of vibrations is converted into an electrical signal by a second transducer (Receiver). Electronic timing circuits enable the transit time of the pulse to be measured. Pic 1 illustrate the UPV equipment which known commercially as PUNDIT.

Using the UPV technique considers a means of studying the homogeneity of concrete, whereas the variations in the concrete properties cause variations in the pulse velocity resulting from the variation in the concrete quality.

In homogeneous concrete (uniform density and free from any defects), the pulse travel between the transducers in a short straight path. Whereas when the pulse traveling through concrete having air-voids or flaws or any other defects, there is a negligible transmission of energy through concrete so the first pulse to arrive at the receiving transducer will have been diffracted around the periphery of the defect and the transit time will be longer than in similar concrete with no defect.

In this case, statistical values such as standard deviation or coefficient of variation could use in determine the concrete homogeneity.

In addition, pulse velocity in concrete may be influenced by path length, lateral dimensions of the specimen tests, presence of reinforcing steel and moisture content of the concrete.

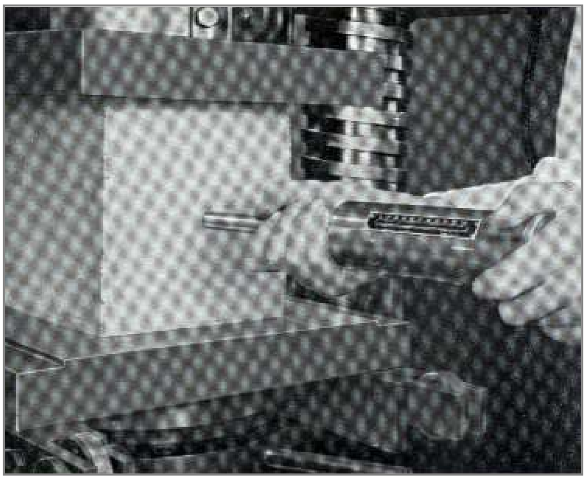


PIC. 1: Ultrasonic Pulse Velocity test equipment

3-2 Schmidt Hammer Test

This NDT method had been developed in 1948 and became widely used because provides a quick, inexpensive means of testing concrete in lab and in the precast industry.

This method depend on the Rebound principle, and to carry out the test, the plunger of the equipment is pressed strongly against the concrete surface under test, an impact will cause, and while the hammer is still in its testing position, he equipment index is read to the nearest whole number. This reading is designated as the Hammer Rebound No. Pic 2 shows the equipment of Schmidt Hammer.



Pic 2: Schmidt Hammer test equipment

Although the many advantages of this method, it has serious limitations and these must be recognized. The results of this method are affected by:

- Smoothness of surface
- Size, shape and rigidity of the specimen
- Age of test specimen
- Surface and internal moisture condition of the concrete
- Type of coarse aggregate

- Type of cement
- Type of mold
- Carbonation of concrete surface

Schmidt Hammer test can used to determine the concrete uniformity and for comparative investigations by draw contour lines for Rebound No. cover all the concrete surface under test.

4- PREVIOUS RESEARCHES

Many previous trials carried out to determine concrete strength by using a combined method in testing concrete, which depend on two non-destructive tests and finding a correlation between these two methods and the compressive strength of the concrete. The experiments which used this method are still too few.

Facaoaru [6], the pioneer researchers in this field, apply this method in a wide range in Romania. His method summarized by taking average of three readings for the UPV and average of six readings for Rebound No. and determines the compressive strength by using three dimensional curves.

Also, Reo'f [6] made wide experiments covered standard concrete cubes, there compressive strength ranged between (10-15) kN/mm2, and made the three tests on them in many ages. Then, for each cube, took an average of rebound no. of Schmidt hammer and UPV, and from these three test results determined a combined relationship between the non-destructive tests and the crushing strength.

Also, Kheder [7] made a research using results of tow non-destructive tests (UPV & Hammer tests), the research was in two stage, the first one was to determine the compressive strength by using different mixing ratios and densities for dry and wet conditions, and develop mathematical relationships by using multiple linear regressions. Whereas in the second stage determined linear correlation between the predicted compressive strength made in the first stage and the actual strength taking from limited number of cores cutting from the same structure.

5- RESEARCH STEPS

The concrete strength taking from cubes made from the same concrete in the structure differ from the strength determined in situ because the methods of measuring the strength influenced by many parameters as mentioned previously, so the cube strength taking from the samples produced and tests in the traditional method will never be similar to in situ cube strength.

Also, the results taking from the non-destructive tests, rebound no. and UPV, are predicted results and do not present the actual results of the concrete strength in the structure.

So, this research aim to find a correlation between crushing strength of the cube and results of the non-destructive test (UPV & Hammer) for the same cube by using statistical methods in the explanation of tests results.

The research covers 161 test results taking from 161 concrete cubes with 150x150 mm. Some of these cubes took from mixtures designed for the purpose of this research by using ordinary Portland cement compatible with the Iraqi standard (No. 5), with 15 and 25 N/mm^2 designed strength and for different curing conditions. The others took from M. Sc. Thesis used in it Ordinary Portland cement except 6 cubes used sulphate resisting Portland cement, these cubes cured by soaking them in water for 30 days before the test.

The age of the cubes in the two groups ranged between 7 to 138 days. All the cubes produced by using fine aggregate within the Zone 1 and the maximum size of the coarse aggregate ranged between (5-19) mm. Table 1 shows the details of these cubes.

Table 1: details of cubes used in the research

<table>
<tr><td>Size of Cubes</td><td>No. of Cubes</td><td>W/C</td><td>Cement Type</td><td>Mixing Ratio</td><td>curing</td></tr>
<tr><td rowspan="4">150 mm</td><td rowspan="3">155</td><td rowspan="3">0.45</td><td rowspan="3">Ordinary Portland cement</td><td>1 : 2 : 4</td><td rowspan="3">Dry & Wet</td></tr>
<tr><td>1 : 3 : 6</td></tr>
<tr><td>1 : 1 : 2</td></tr>
<tr><td>6</td><td>0.45</td><td>Sulphate Resisting Portland cement</td><td>1 : 2 : 4</td><td>Wet</td></tr>
</table>

UPV test carried out for each cube, taking the average of two reading (one reading for each opposite faces) by using the equipment known commercially as PUNDIT [4] and pulses with 54 kHz frequency, then Schmidt Hammer test was carried out for the same cube by fixed it in the crushing strength machine and amounted to 2.5 N/mm2 force approximately and took the average of 10 readings of rebound no. by Schmidt Hammer device Then the cube was crushed and the reading of the crushing force was recorded. Table 2 shows the tests results.

Table 2: results of the three tests

Item	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Crushing Strength (N/mm^2)	161	42.22	11.11	53.33	31.164	7.523	56.578
R (Rebound No.)	161	33	15	48	35.47	6.5	42.25
UPV (μ/sec)	161	0.97	3.89	4.86	4.554	0.207	4.291

6- DISCUSSION AND CONCLUSION

We can turn to the statistical methods in the process of explanation the tests results and the prediction of concrete strength, in the case of the test was carried out in satisfactory way and standard tools. Whereas the statistical methods proved that have a good value. In fact, turning to the statistical concepts indispensable in the analysis of any test result related to the mechanical strength of the concrete which obtained in lab from the compressive strength test carried out to a sample even in a standard cube form [8].

The first steps in this research included predict the analytical relationships between crushing strength of cube and rebound no. and UPV. The regression analysis method was used in the analysis process of the results by using STATISTICA ver. 5.5 PC software, whereas this program depends on Least Square Theory in the analysis process. The goal of regression method is to fit a line through points (results) so that the squared deviations of the observed points from that line are minimized. Regression allows the researcher to obtain a set of coefficients for an equation. The principle of the analysis concept depend on that the similar the variability of the residual values around the regression line relative to the overall variability, the better is our prediction. For example, if there is no relationship between the X and Y variables, then the ratio of the residual variability of the Y variable to the original variance is equal to 1.0. if X and Y are perfectly related then there is no residual variance and the ratio of variance would be 0. in most cases, the ratio would fall somewhere between these extremes, that is, between 0 and 1.0 1.0 minus this ratio is referred to as *R-square* or the coefficient of determination. This value is interpretable in the following manner:

If we have an *R-square* of 0.4 then we know that the variability of the Y values around the regression line is 1-0.4 times the original variance, in other words we have explained 40% of the original variability, and are left with 60% residual variability. Ideally, we would like to explain most if not all of the original variability. The *R-square* value is an indicator of how well the model fit the data, e.g., an *R-square* close to 1.0 indicates that we have accounted for almost all of the variability with the variables specified in the model.

Many trials were carried to predict the correlation between rebound no. and crushing strength for the samples, and we obtained better correlation represented by the following power equation:

$$\mathbf{S_c = 0.788\ R^{1.03}} \qquad \textbf{(1)}$$

Where:
S_c= Crushing Strength N/mm^2
R= Rebound No.

R-square obtained for this equation was 0.77, in other words, we could explain 77% of the variability for the data around the regression line and 23% of the residual data could not explained by this equation. Fig 1 shows this equation.

The same trials carried to predict the correlation between UPV and crushing strength and we obtained the following exponential equation:

$$\mathbf{S_c = 1.19\ EXP\ 0.715U} \qquad \textbf{(2)}$$

Where:
S_c= Crushing Strength N/mm^2
U= UPV (μ/sec)

And *R-square* for this equation was 0.59 which means that we could explain 59% of the variability for the data around the regression line and 41% remained without explanation. Fig 2 shows the equation 2.

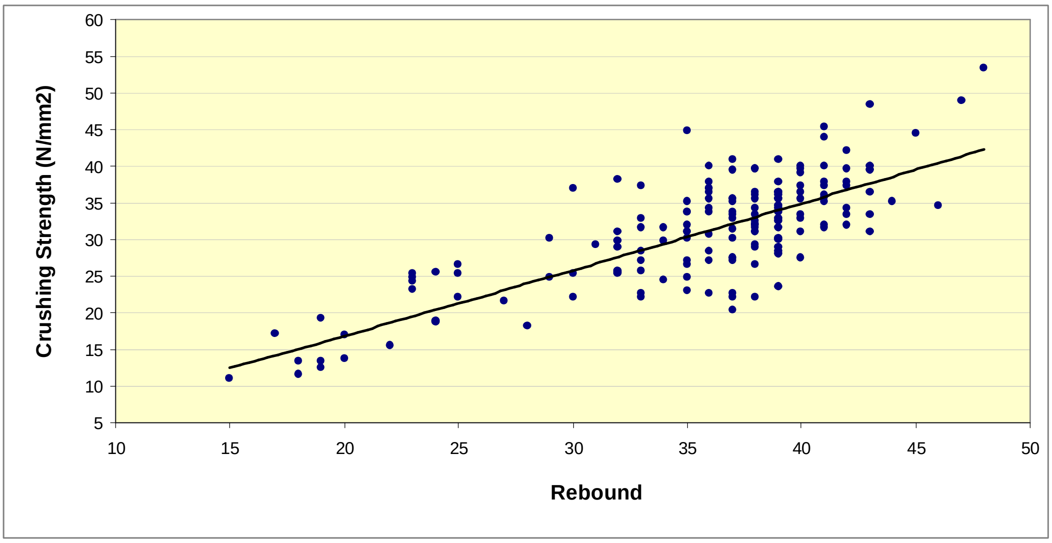


Fig 1: correlation equation between crushing strength and rebound no.

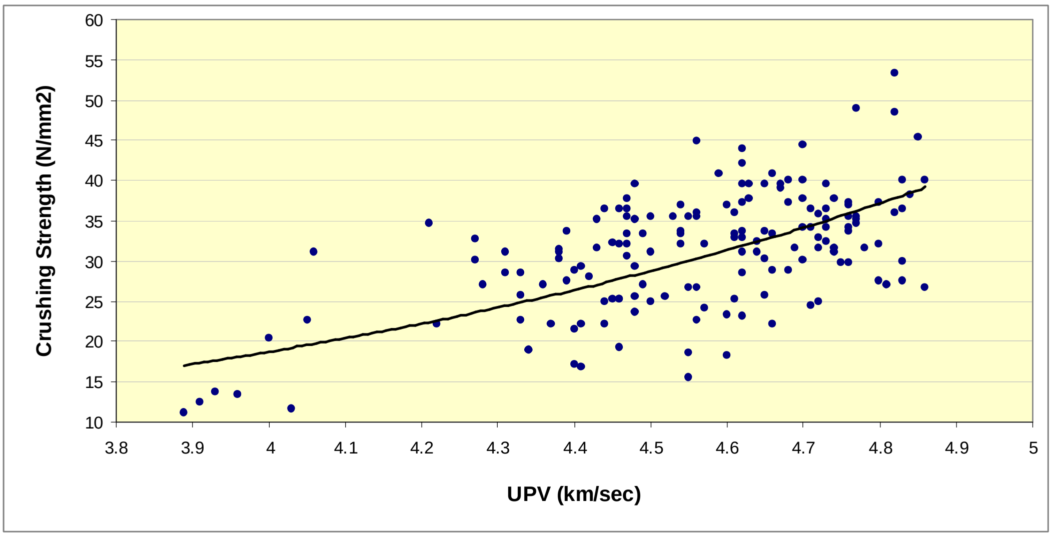


Fig 2: correlation equation between crushing strength and UPV

From equation 1 and 2 we can conclude that the dependency on one test method (Hammer or UPV) will not give good results to predict the concrete strength in situ, whereas the maximum percent for results explanation obtained was 77% from equation 1.

And as mentioned previously, these two methods have many and different limitations prevent from relying completely on one test results.

So, equations 1 and 2 were related to each other to find different regressions and obtained better correlation between R and U presented by the following equation:

$$\mathbf{S_c = 0.356\ R^{0.866}\ EXP\ 0.302U} \qquad \mathbf{(3)}$$

And from this correlation, we rise the percent of explanation results to 80%, whereas the *R-square* for this equation is 0.80. And this the maximum value was obtained for these form of equations, where many theories were carried on the type and form of correlation combined these three tests and *R-square* never exceed this limit. Fig 3 shows the correlation between the three tests.

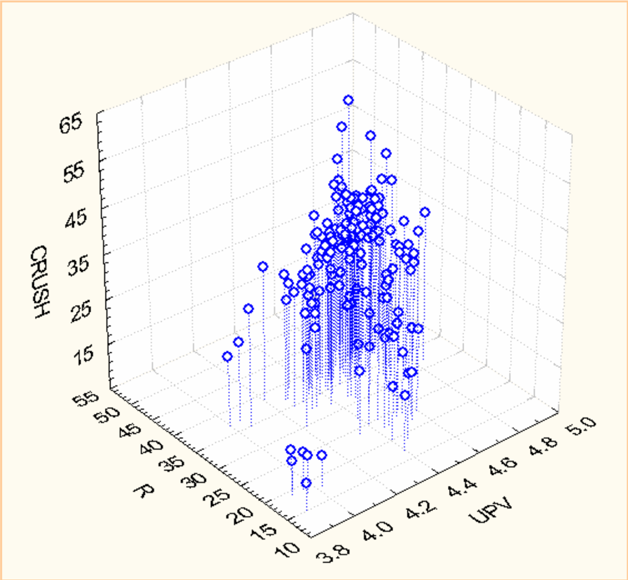


Fig 3: correlation between R, UPV and crushing strength

From 161 results test carried out to 161 cubes, 150x150 mm in dimension, all produced from different concrete mixtures and wide range of strength, we could conclude:

- There is a strong correlation between crushing strength, rebound no. and UPV obtained from concrete cubes, which presented by the good coefficient of determination R-square.
- From equation 3, we can determine the concrete strength in situ for any structure member by just determine rebound no. and UPV for that member.

7- REFERENCES

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