

Assessment of Concrete Strength by Combination of Non-Destructive Techniques

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Abstract – Due to limitation of conventional method to determine the different characteristics properties of concrete, new technological breakthrough in the field of non-destructive testing (NDT) are emerging as a powerful quality control tool for determination of various characteristic properties of concrete qualitatively. The accuracy and reliability of non-destructive test are influence by the number of variable associated with the harden concrete. Through most of the non-destructive method are based on statistics, it is observed that in actual practice much of this testing is done without use statistical principles leading to erroneous results.

The present work focus on the study of the reliability in interpreting non-destructive testing results of concrete structure and calibration of the NDT instrument such as Rebound Hammer, Ultrasonic Pulse Velocity, and Impact Echo. An experimental work is carried out involving both destructive and Non-destructive testing method applied to different nominal concrete grade of M40. The specimens consisting 50 cubes of size 150mm are casted for the correlation purpose.

Correlation between destructive and Non-destructive testing data is established using statistical techniques such as linear regression analysis, and

Multiple regression analysis. Software MATLAB and Microsoft Excel would be used for this purpose.

Keywords: Compressive Load, Rebound Hammer, Ultrasonic Pulse Velocity, Frequency Spectrum, Impact Echo Test, Non-Destructive Testing, MATLAB.

INTRODUCTION

For direct determination of the strength of concrete, concrete specimens must be loaded to failure. Because of that, special techniques have been developed. Attempts were made to measure some concrete properties other

than strength, and then relate them to strength, durability, or any other property.

Reduction in the labour consumption of testing is the main advantages of Non Destructive tests. A decrease in labour consumption of preparatory work, a smaller amount of structural damage, a possibility of testing concrete strength in structures where cores cannot be drilled and application of less expensive testing equipment, as compared to core testing.

However, the term "nondestructive" is given to any test that does not damage or affect the structural behavior of the elements and also leaves the structure in an acceptable condition for the client.

In order to arrive at a suitable, reliable simple chart for strength evaluation, the author used the combination of the rebound hammer ,ultrasonic pulse velocity and impact echo testers in such countries; assuming that no records about tested concrete are available. A summary about the three tests, showing their advantages and disadvantages, is presented.

1.1 Rebound hammer

Principal

The Schmidt rebound hammer is a surface hardness tester. It works on the principle that when the plunger of rebound hammer pressed against the surface of the concrete, the spring-controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete. The rebound Number/Rebound index is taken to be related to the compressive strength of concrete. The rebound is read off along a graduated scale given on the Rebound hammer and is designated as the rebound number or rebound index.

Factors affecting on test

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

1.2 Ultrasonic Pulse Velocity

Principle

A Electro-acoustical transducer is produced pulse of longitudinal vibrations, which is held in contact with one surface of the concrete under test. When the pulse generated is transmitted into the concrete from the transducer using a liquid coupling material such as grease or cellulose paste, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves develops, which include both longitudinal and shear waves, and propagates through the concrete. The first waves to reach the receiving transducer are the longitudinal waves, which are converted into an electrical signal by a second transducer. Electronic timing circuits enable the transit time T of the pulse to be measured.

Longitudinal pulse velocity (in km/s or m/s) is given by:

$$V = \frac{L}{T}, \text{ where}$$

V- is the longitudinal pulse velocity,

L-is the path length,

T- is the time taken by the pulse to traverse that length.

Factors affecting on test

- Surface Conditions and Moisture Content of Concrete
- Path Length, Shape and Size of the Concrete Member
- Temperature of Concrete
- Stress
- Effect of Reinforcing Bars

1.3 Impact echo method

In Impact-Echo testing, P-wave is of primary importance because the displacement caused by P-waves is much larger than those caused by S-waves at points located close to impact point. When the P-wave reaches

the back side of the member, it is reflected and travels back to the surface where the impact was generated. A sensitive displacement transducer next to the impact point picks up the disturbance due to the arrival of the P-wave. The P-wave is then reflected back into the member and the cycle begins again. Thus the P-wave undergoes multiple reflections between the two surfaces. The recorded waveform of surface displacement has a periodicity related to the thickness (d) of the member and the wave speed (v). The frequency of P- wave arrivals at the transducer (f) is determined by transforming the recorded time- domain signal into the frequency domain using the fast Fourier transform technique (FFT). The frequencies associated with the peaks in the resulting amplitude spectrum represent the dominant frequencies in the waveform. These frequencies can be used to determine the distance to the reflecting interface. As a result the thickness of the member could be defined by simple equation:

$$d = \frac{v}{2f}$$

Where, d-is distance,

f -is dominant frequency,

V -is velocity of compression waves in the test material.

Applications of Impact Echo Technique

- i. Locating voids, de-laminations, cracks, honeycombing in beams, columns, slabs, walls and structures like tunnels, silos and chimney stacks.
- ii. Detecting de-bonding of asphalt and concrete overlays and repair patches from concrete substrates
- iii. Detecting the presence of damage due to freezing and thawing.

METHODOLOGY

Materials

The material used in this investigation and their characteristics are here summarized.

Cement	locally available Ordinary Portland Cement (53 grades).
Fine Aggregate	locally available sand has been used.
Coarse Aggregate	Locally available crushed coarse aggregate with a nominal maximum aggregate size of 20mm has been used.

Test Procedures

The actual compressive strength of concrete cube was found out using compressive testing machine, all samples was finally compress to failure using a digital compression machine to obtain concrete compressive strength, UPV was measured using Ultrasonic Pulse Velocity meter with the probe frequency of 50 kHz. The direct transmission technique was used to determine UPV in concrete. The procedure was based on IS 13311 (Part I): 1992. Rebound hammer test were conducted as described in IS 13311 (Part II): 1992. Frequency can measured using NDE360 Olson impact echo software.

Mathematical Expression for Calculating Compressive Strength

A mathematical relation between compressive strength, rebound number, frequency and ultrasonic pulse velocity can be developing using regression analysis. The regression analysis will be done from the values of rebound number, frequency and ultrasonic pulse velocity at no loading condition. Regression analysis done by using MATLAB software.

RESULT AND DISCUSSION

The Rebound Number, Ultrasonic Pulse velocity, Frequency obtained by various cubes was given in following table.

Sr No	Avg. Rebound Number	Avg. Velocity (Km/s)	Impact Echo (frequency) HZ	Compressive Strength (N/mm2)
1	38.67	4.025	13082.8	50.71
2	38.67	3.95	13070.8	54.09
3	39.33	3.956	12737.66	55.42
4	37.33	3.982	12737.6	52
5	39.00	4.21	12107	58
6	37.33	3.85	12868.8	50.89
7	37.00	3.93	13580	49
8	39.33	4.05	12169	51.33
9	42.33	4.2	12086.16	66.36
10	40.33	4.31	11528	67.6
11	40.33	4.27	12142	62.31
12	38.67	3.85	13058.2	53.91

13	40.67	4.13	12336.57	55.38
14	37.33	4.06	12251.83	52.44
15	39.33	4.12	12809	51.64
16	41.67	4.33	11737	61.78
17	40.33	4.28	11499	66.84
18	43.33	4.37	11660.25	67.56
19	43.00	4.29	12000	64.36
20	38.67	3.8	13312	49.47
21	44.00	4.41	11392	69.38
22	41.67	4.25	11890	62.58
23	39.33	4.15	11928.33	55.16
24	39.67	4.28	11844	63.6
25	44.00	4.34	11380	69.82
26	42.00	4.34	11571	66.58
27	40.67	4.34	11928	65.96
28	35.50	3.825	12847.6	51.24
29	41.67	4.28	11975	65.42
30	40.33	4.07	11916.66	55.82
31	40.00	3.85	11621.66	57.69
32	43.67	4.39	11444.56	69
33	39.67	4.02	11726.16	61.82
34	41.33	3.9	11821.3	58.49
35	38.00	4.16	12656.16	58.84
36	39.33	4.15	13095.8	58.22
37	35.00	3.89	11999.66	51
38	44.00	4.25	12200	60.53
39	42.00	4.05	11999.6	61.73
40	40.33	4.11	11940.33	63.29
41	43.00	4.3	11564.5	68.98
42	36.33	3.85	12392	51.11
43	35.67	3.7	12785.33	48
44	39.00	3.875	12523.33	49.69
45	38.67	4.1	13213.83	50.98
46	36.00	4.05	13190	51.82
47	35.67	4.15	12464	56.25
48	36.67	4.005	13130.5	53.82
49	41.00	4.35	11976.16	68.22
50	41.67	4.1	11940	67.78

Fig. 1 shows the relationship between rebound number and the crushing cube strength of concrete. The best-fit line representing the relationship is obtained from MATLAB and given as follows:
Y=f(x) = p1*x + p2

Where, Y as Compressive Strength and x as Rebound Number, Coefficients (with 95% confidence bounds): $p_1 = 2.673$, $p_2 = -47.59$

Goodness of fit:
 SSE: 698.9
 R-square: 0.7463
 Adjusted R-square: 0.7411
 RMSE: 3.816

Fig. 2 shows the relationship between Ultrasonic Pulse Velocity and the crushing cube strength of concrete. The best-fit line representing the relationship is obtained from MATLAB and given as follows:

$$Y=f(x) = p_1*x^2 + p_2*x + p_3$$

Where, Y as Compressive Strength and x as Ultrasonic Pulse Velocity, Coefficients (with 95% confidence bounds): $p_1 = 42.16$, $p_2 = -311.5$, $p_3 = 624.9$

Goodness of fit:
 SSE: 445.3
 R-square: 0.8036
 Adjusted R-square: 0.7945
 RMSE: 3.218

Fig. 3 shows the relationship between Frequency and crushing cube strength of concrete. The best-fit line representing the relationship is obtained from MATLAB and given as follows:

$$Y=f(x) = p_1*x^4 + p_2*x^3 + p_3*x^2 + p_4*x + p_5$$

Where, Y as Compressive Strength and x as Frequency, Coefficients (with 95% confidence bounds): $p_1 = -3.703e-012$, $p_2 = 1.852e-007$, $p_3 = -0.003467$, $p_4 = 28.76$, $p_5 = -8.918e+004$

Goodness of fit:
 SSE: 466.1
 R-square: 0.7719
 Adjusted R-square: 0.7491
 RMSE: 3.414

Fig.4 shows the relationship between Rebound Number, Ultrasonic Pulse Velocity and crushing cube strength of concrete. The best-fit line representing the relationship is obtained from MATLAB and given as follows:

$$X = 1.1927*(RN) + 2.7684*(UPV)$$

$$Y=f(x) = p_1*x^3 + p_2*x^2 + p_3*x + p_4$$

Where, Y as Compressive Strength and x as X, Coefficients (with 95% confidence bounds): $p_1 = -0.05683$, $p_2 = 10.14$, $p_3 = -599.3$, $p_4 = 1.181e+004$

Goodness of fit:
 SSE: 339.5
 R-square: 0.8161
 Adjusted R-square: 0.8003
 RMSE: 3.114

Fig.5 shows the relationship between Ultrasonic Pulse Velocity, Frequency and crushing cube strength of concrete. The best-fit line representing the relationship is obtained from MATLAB and given as follows:

$$X = 25.1734*(UPV) - 0.0037*(Frequency)$$

$$Y = f(x) = p_1*x^2 + p_2*x + p_3$$

Where, Y as Compressive Strength and x as X, Coefficients (with 95% confidence bounds): $p_1 = 0.02016$, $p_2 = -1.349$, $p_3 = 67.58$

Goodness of fit:
 SSE: 233.8
 R-square: 0.8858
 Adjusted R-square: 0.8802
 RMSE: 2.388

Fig.6 shows the relationship between Rebound Number, Frequency and crushing cube strength of concrete. The best-fit line representing the relationship is obtained from MATLAB and given as follows:

$$X = 2.1396*(RN) - 0.0022*(Frequency)$$

$$Y=f(x) = p_1*x^2 + p_2*x + p_3$$

Where, Y as Compressive Strength and x as X, Coefficients (with 95% confidence bounds): $p_1 = 0.0009999$, $p_2 = 0.9846$, $p_3 = -3.175$

Goodness of fit:
 SSE: 250.1
 R-square: 0.8541
 Adjusted R-square: 0.8458
 RMSE: 2.673

Fig.7 shows the relationship between Rebound Number, Ultrasonic Pulse Velocity, Frequency and crushing cube strength of concrete. The best-fit line representing the relationship is obtained from MATLAB and given as follows:

$$X = 0.8644*(RN) + 16.1514*(UPV) - 0.0034*(Frequency)$$

$$Y=f(x) = p_1*x + p_2$$

Where, Y as Compressive Strength and x as X,
 Coefficients (with 95% confidence bounds): $p_1 = 1.013$,
 $p_2 = -0.328$
 Goodness of fit: SSE: 164.2
 R-square: 0.9149
 Adjusted R-square: 0.9088
 RMSE: 1.673

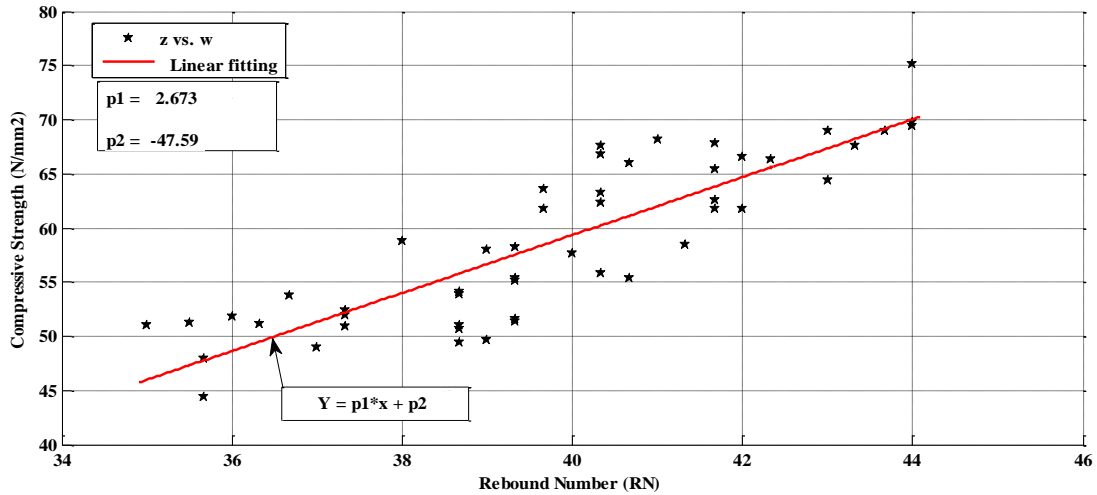


Fig. 1 Relationship between Rebound Number and Compressive Strength

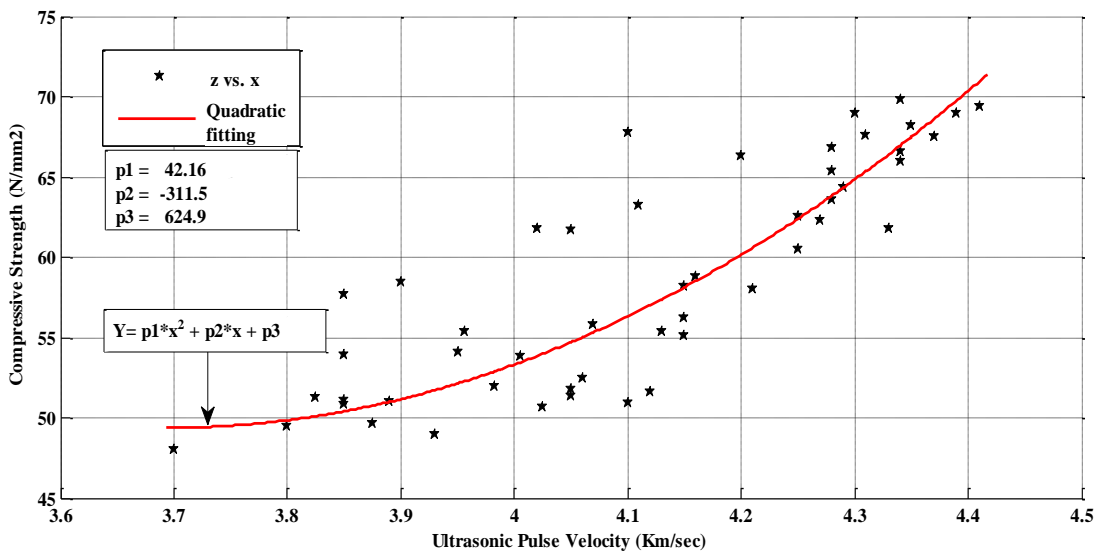


Fig. 2 Relationship between Ultrasonic Pulse Velocity and Compressive Strength

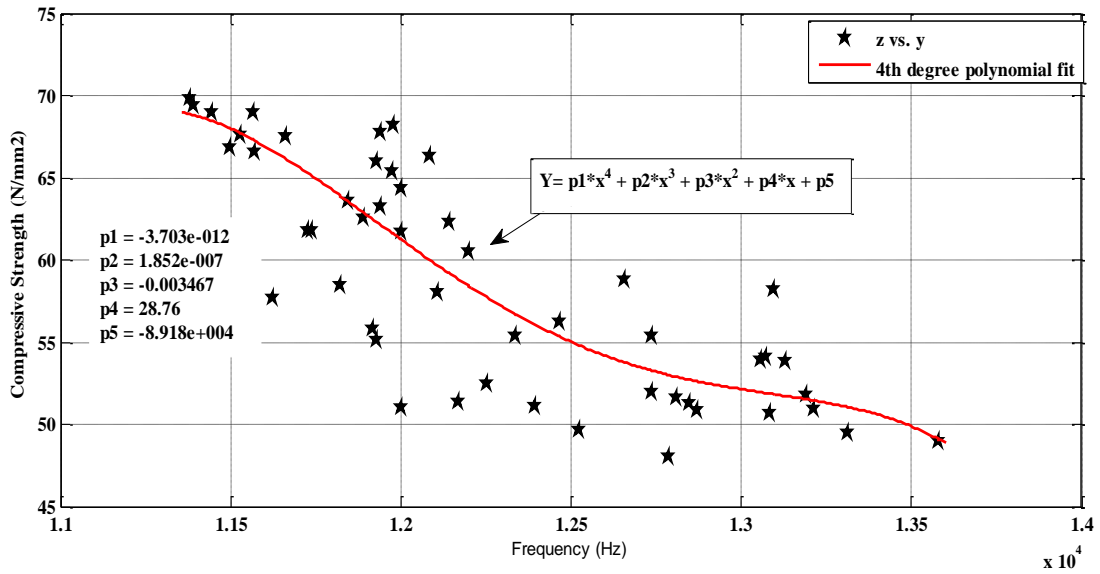


Fig. 3 Relationship between Frequency and Compressive Strength

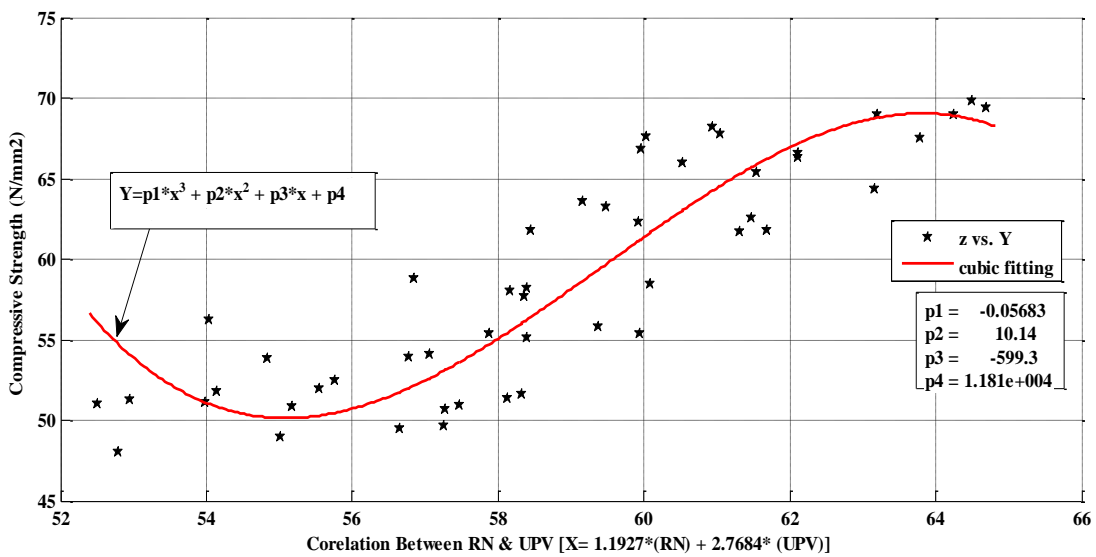


Fig.4 Relationship between Rebound Number, Ultrasonic Pulse Velocity and Compressive Strength

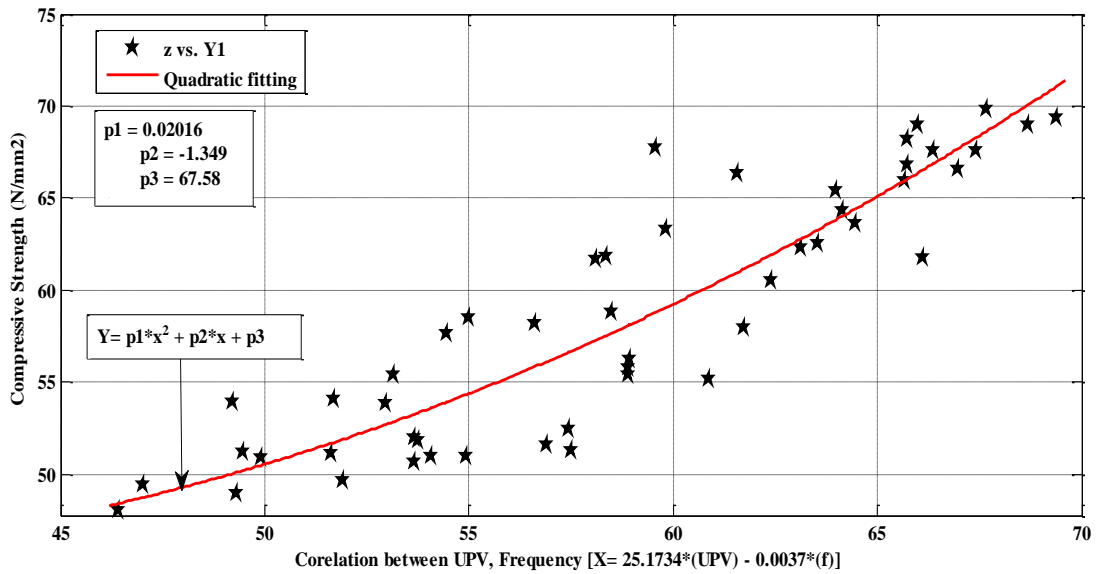


Fig.5 Relationship between Ultrasonic Pulse Velocity, Frequency and Compressive Strength

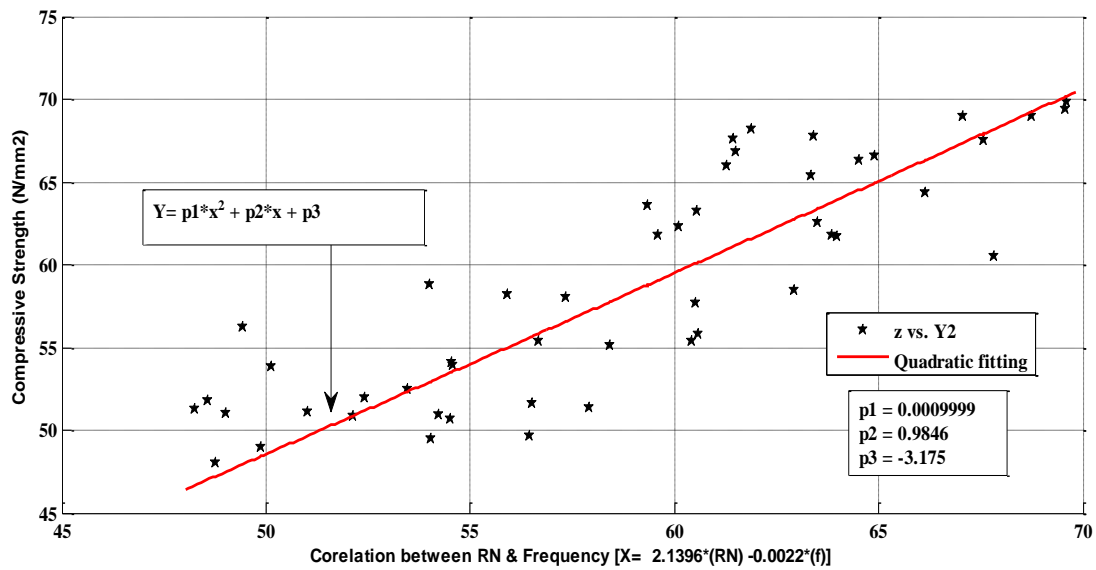


Fig.6 Relationship between Rebound Number, Frequency and Compressive Strength

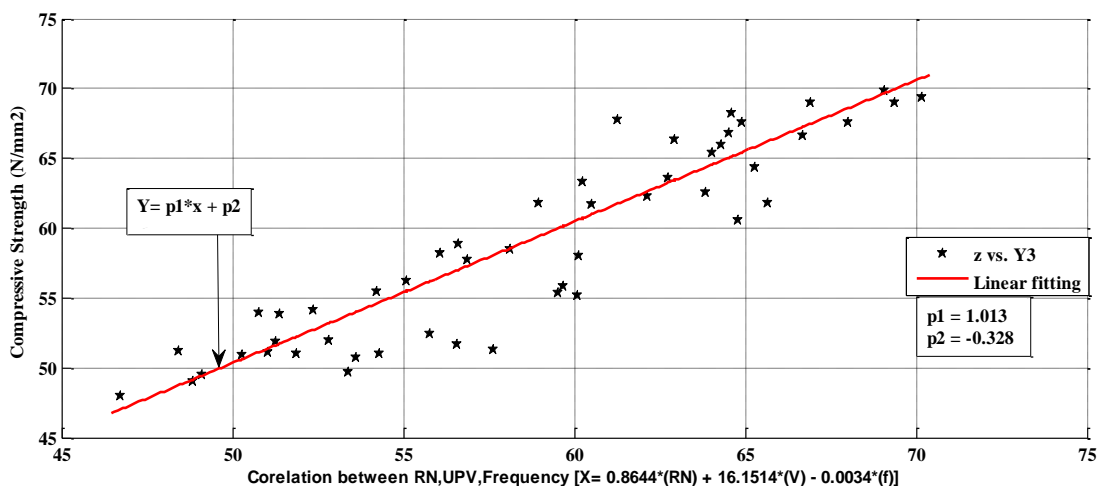


Fig.7 Relationship between Rebound Number, Ultrasonic Pulse Velocity, Frequency and Compressive Strength

Table.2:- R² value and RMSE value for correlation between Rebound number, Upv, Frequency and Compressive Strength

DATA	Rebound Number Vs CS	UPV (Km/s) Vs CS	Frequency Vs CS HZ	RN & UPV Vs CS	UPV & Frequency Vs CS	RN & Frequency Vs CS	RN, UPV & Frequency Vs CS
R ² value	0.7463	0.8036	0.7719	0.8161	0.8858	0.8541	0.9149
RMSE	3.816	3.218	3.414	3.114	2.388	2.673	1.673
Data around regression line (%)	74.63	80.36	77.19	81.61	88.58	85.41	91.49
Residual Data (%)	25.37	19.64	22.81	18.39	11.42	14.59	8.51

CS:-Compressive Strength (N/mm²),RMSE:- Residual Mean Square Error, RN:- Rebound Number, UPV:-Ultrasonic Pulse Velocity

CONCLUSION

1. The use of Rebound hammer, Ultrasonic pulse velocity and Impact-Echo test alone is not suitable to predict the compressive strength of concrete because of variation of actual Strength and Predicted Strength are 25.37% for Rebound hammer, 19.64% for UPV, 22.18% for impact-Echo test.
2. But using combination of two method the variation are 18.39% for combination of Rebound hammer and UPV, 11.42% for combination of UPV and Impact-Echo,14.59

for combination of Rebound hammer and Impact-Echo.

3. But using combination of three method the variation is 8.51 % means nearer to actual value of compressive strength.
4. The use of the combined three methods produces results that lie close to the true values when compared with other methods.
5. The correlation can be extended to test existing structures by taking direct measurements on concrete elements and with help of that NDT

data we easily take the decisions about the maintenance of the structure.

6. Use of multiple regressions is recommended over a simple regression to increase the accuracy of data.

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