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Evaluation of Strength of Concrete by Combine Use of NDT Techniques

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Abstract – *Due to limitation of traditional method to determine the different properties of concrete, new technological growth in the field of Non-Destructive Testing (NDT) are appear as a powerful quality control tool for resolving the properties of concrete quality. The exactness and reliability of Non-Destructive test are affected by the number of variable related with the harden concrete. Through most of the non-destructive method are based on statistics, it is noticed that in real practice many of this testing is done without use specific principles leading to incorrect results.*

The current work focus on the study of the accuracy in explaining the Non-Destructive Testing results of concrete structure and analysis of the NDT instrument such as Ultrasonic Pulse Velocity, Rebound Hammer and Impact Echo. An exploratory work is executed by involving both Non-Destructive and Destructive testing method applied to different concrete grade of M40. The specimens size of 150 mm consisting 50 cubes are casted for testing Purpose.

Relation between Destructive and Non-Destructive testing data is carried out by using statistical techniques such as Multiple regression analysis and Linear regression analysis, Microsoft Excel and Software MATLAB would be used for this purpose.

Keywords: *Compressive Load, Frequency Spectrum, Impact Echo Test, MATLAB, Non-Destructive test, Rebound Number, Ultrasonic Pulse Velocity(UPV).*

1. INTRODUCTION

The Non-destructive test of the concrete in present days has get a great importance in engineering value and practical value. The NDT has get growing awareness in recent years to check the quality characteristics of the structure. Experiment were made to compute some concrete properties apart from strength and then link them to stiffness, durability, strength or any other concrete properties. The Non-Destructive test are firstly gives quick response to physical properties of specimen and gives an indirect way of material performance. Depletion in the labour utilization of testing is the main advantages of Non-Destructive tests. Where the term “nondestructive” is given to any test that doesn’t affect or harm the the structural behavior of the elements and also leaves the structure in an allowable condition for the client.

In order to occur at an acceptable, reliable, suitable simple chart for strength development, used of the combination of the impact echo test, ultrasonic pulse velocity and rebound hammer in such countries; assuming that there is no available records about tested concrete. The three tests summary showing that their advantages and disadvantages is presented.

1.1 Rebound hammer

The Rebound Hammer is based on the principle that the rebound of an elastic mass depends on the hardness of the surface of concrete specimen against the mass strikes. It works on a principle that when the rebound hammer plunger pressed against the any surface of concrete specimen, the spring controlled mass rebounds and the amount of rebound mass depends upon the concrete surface hardness. It is use for the assessing the compressive strength of concrete surface with correlation between compressive strength and rebound index. The compressive strength of concrete is taken by the rebound number or Rebound index.

Factors influencing the test:

- Type of cement are to be use
- Type of coarse aggregate are to be use
- Rigidity, Shape and Size of the specimen
- Smoothness of the test surface of the concrete
- Age of the concrete specimen
- External and Internal moisture conditions of concrete surface
- Concrete surface carbonation.

1.2 Ultrasonic Pulse Velocity

It is an in-situ non-destructive test use to measure the quality and strength of concrete. By using this test the quality and strength of the concrete is measured by using the velocity of an ultrasonic pulse which passing through the surface of concrete. The Ultrasonic pulse is

generated by electro acoustical transducer. The pulse is passes through the concrete specimen from the transducer using a liquid coupling material such as cellulose paste or grease, it undergoes multiple reflections at the border of the different material phases in the concrete. A compound system of stress waves forms, which include both shear waves and longitudinal waves, and generate through the concrete. The waves arrives firstly at the receiving transducer are the longitudinal waves and these waves are change into an electrical signal by a second transducer.
Longitudinal pulse velocity is measured by using formula:

$$V = \frac{\text{width of the structure}}{\text{time taken by the pulse to go through the length}}$$

Where,

V is the pulse velocity.

Factors influencing on test:

- Moisture content of the concrete specimen
- Surface Conditions of concrete specimen
- Size and Shape of the Concrete specimen
- Temperature of Concrete
- Stress
- Effect of Reinforcing Bars

1.3 Impact echo method

Impact-echo is the non-destructive testing method of concrete structure is based on the impact generated sound waves that passes though the concrete specimen and reflected back by internal defect and external surface. In Impact-Echo testing, P-wave is important because the movement caused by S-waves is much smaller than those caused by P-waves at points located close to impact point. When the P-wave touches the back side of the member, it is reflected and move back to the surface where the impact generated. A transducer which is located next to the impact point picks up the waves disturbance due to the arrival of the P-wave. The P-wave is then move back into the specimen and the cycle start again. Thus between the two surfaces P-waves go through the multiple reflections. The waveform of surface displacement is measured related to the wave speed (v) of the member and the thickness (d) of the member. The frequency of P-wave reach at the transducer (f) is determined by the measured time-domain signal using the Fast Fourier Transform Technique (FFT). The frequencies can be used to measure the distance to the reflecting interface. The thickness of the member could be given by simple equation:

$$D = \frac{V}{2f}$$

Where, D - Distance ,
f - Dominant frequency of waves,
V - Velocity of compression waves in the test specimen.

Applications of Impact Echo Technique:

i. Achieve the Locating voids in concrete specimen, cracks, honeycombing structure in columns, beams, walls, slabs and structures like silos, tunnels.
ii. To find out the de-bonding of concrete overlays and asphalt.
iii. Achieve the damage due to thawing and freezing.

METHODOLOGY

Materials

The material used in this experiment and their characteristics are as follows:

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

Test Procedures

The compressive strength of concrete cube was found out by compressive testing machine (CTM). To obtain the compressive strength all samples was compress to failure using a digital compression machine. By using Ultrasonic Pulse Velocity the UPV was measured with the probe frequency of 50 kHz. To determine UPV in concrete the direct transmission technique was used. The procedure was based on IS 13311 (Part I): 1992. The NDE 360 Olson impact echo software is used to calculate frequency.

Mathematical Expression for Calculating Compressive Strength

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

RESULT AND DISCUSSION

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

SrNo.	Average Rebound Number	Avg. Velocity (Km/s)	Impact Echo (frequency) HZ	Compressive Strength (N/mm2)
1	38.66	4.026	13082.9	50.72
2	38.66	3.96	13070.9	54.10
3	39.34	3.957	12737.67	55.43
4	37.34	3.983	12737.7	52.1
5	39.01	4.22	12108	58.1
6	37.34	3.86	12868.9	50.90
7	37.01	3.94	13581	49.1
8	39.34	4.06	12170	51.34
9	42.34	4.21	12086.17	66.37
10	40.34	4.32	11529	67.8
11	40.34	4.28	12143	62.32
12	38.68	3.86	13058.3	53.92
13	40.68	4.14	12336.58	55.39
14	37.33	4.07	12251.84	52.45
15	39.33	4.13	12809	51.65
16	41.67	4.34	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 correlation between the crushing cube strength and rebound number of concrete. The best fit-line shows the correlation is obtained from MATLAB and follows as:

Y=f(x) = p1*x + p2

Where, Y is denoted as compressive strength and X is denoted as Rebound Number Coefficients (with 95% confidence bounds): p1 = 2.673, p2 = -47.59

Righteousness of fit:
SSE: 698.9
R-square: 0.7462
RMSE: 3.816
Adjusted R-square: 0.7411

Fig. 2 shows that the correlation between the crushing cube test and Ultrasonic Pulse Velocity of concrete. The best-fit line shows the correlation is obtained from MATLAB and follows as:

Y=f(x) = p1*x^2 + p2*x + p3

Where, Y is denoted as compressive strength and X is denoted as Ultrasonic Pulse Velocity, Coefficients (with 95% confidence bounds): p1 = 42.16, p2 =-311.5, p3 =624.9

Righteousness of fit:
SSE: 445.3
RMSE: 3.217
R-square:0.8035
Adjusted R-square:0.7944

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

Y=f(x) = p1*x^4 + p2*x^3 + p3*x^2 + p4*x + p5

Where, Y is denoted as Compressive Strength and x is denoted as Frequency Coefficients (with 95% confidence bounds): p1 = -3.703e-012, p2 = 1.852e-007, p3=-0.003467, p4 =28.76, p5 = -8.918e+004

Righteousness of fit:
SSE: 466.1
RMSE:3.415
R-Square:0.7718
Adjusted R-square:0.7490

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

X= 1.1927*(RN) + 2.7684* (UPV)
Y=f(x) = p1*x^3 + p2*x^2 + p3*x + p4

Where, Y is denoted as Compressive Strength and x is denoted as X Coefficients (with 95% confidence bounds):p1 = -0.05683, p2 =10.14, p3 = -599.3, p4 =1.181e+004

Righteousness of fit:
SSE: 339.5
RMSE: 3.115
R-square:0.8162
Adjusted R-square:0.8002

Fig.5 shows that the correlation between Ultrasonic Pulse Velocity, Crushing cube test and Frequency of concrete. The best-fit line shows the correlation is obtained from MATLAB and follows as:

X= 25.1734*(UPV) - 0.0037*(Frequency)
Y= f(x) = p1*x^2 + p2*x + p3

Where, Y is denoted as Compressive Strength and x is denoted as X, Coefficients (with 95% confidence bounds): p1 = 0.02016, p2 = -1.349, p3 = 67.58

Righteousness of fit:
SSE: 233.8
RMSE: 2.387
R-square:0.8857
Adjusted R-square:0.8801

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

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

Y=f(x) = p1*x^2 + p2*x + p3

Where, Y is denoted as Compressive Strength and x is denoted as X, Coefficients (with 95% confidence bounds): p1 = 0.0009999, p2 = 0.9846, p3 = -3.175

Righteousness of fit:
SSE: 250.1
RMSE: 2.672
R-square:0.8542
Adjusted R-square:0.8457

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

X=0.8644*(RN)+16.1514*(UPV) -0.0034*(Frequency)
Y=f(x) = p1*x + p2

Where, Y is denoted as Compressive Strength and x is denoted as X, Coefficients (with 95% confidence bounds):p1 = 1.013, p2 = -0.328

Righteousness of fit:
SSE: 164.2
RMSE: 1.672
R-square:0.9148
Adjussted R-square:0.9087

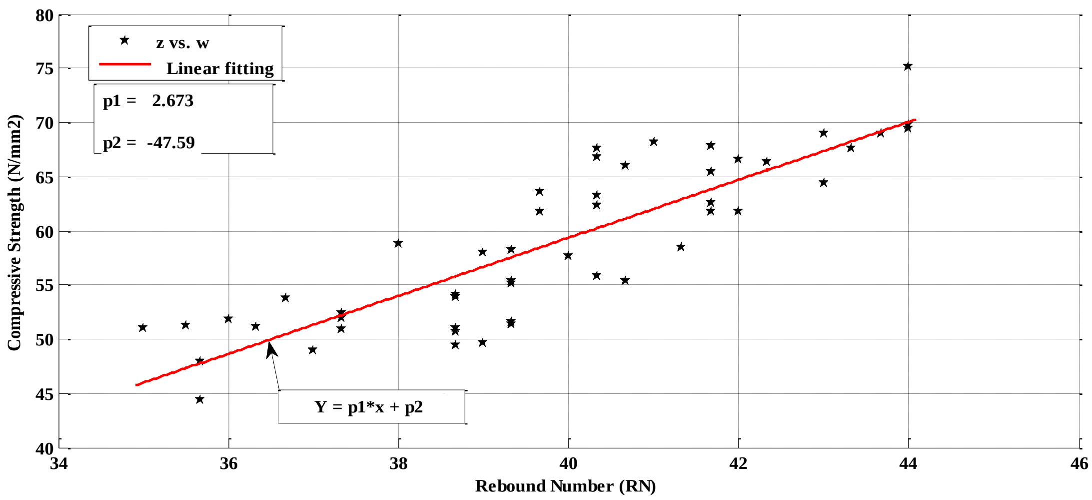

Fig. 1 Correlation between Rebound Number and Compressive Strength

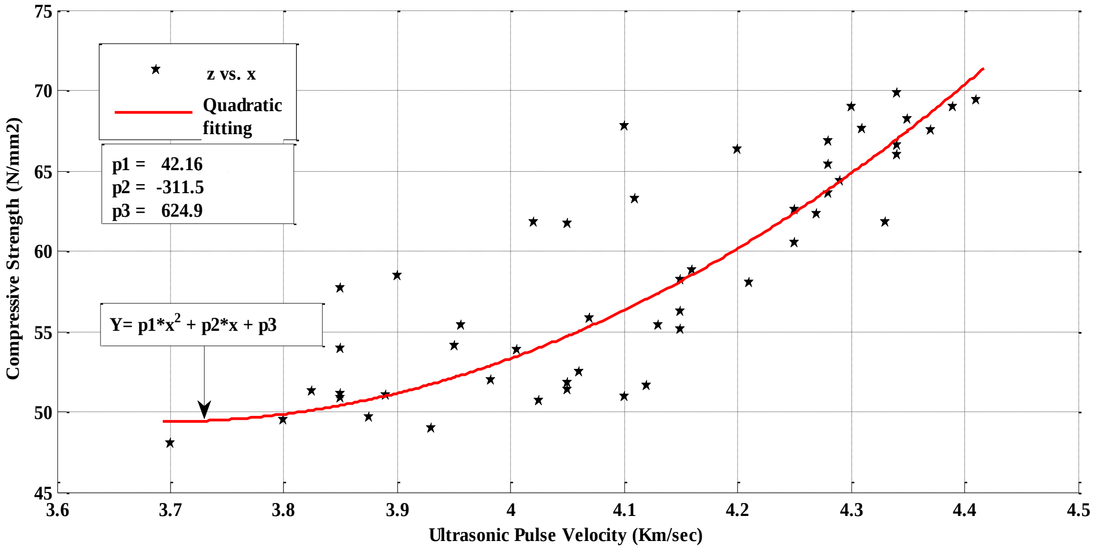

Fig. 2 Correlation between Ultrasonic Pulse Velocity and Compressive Strength

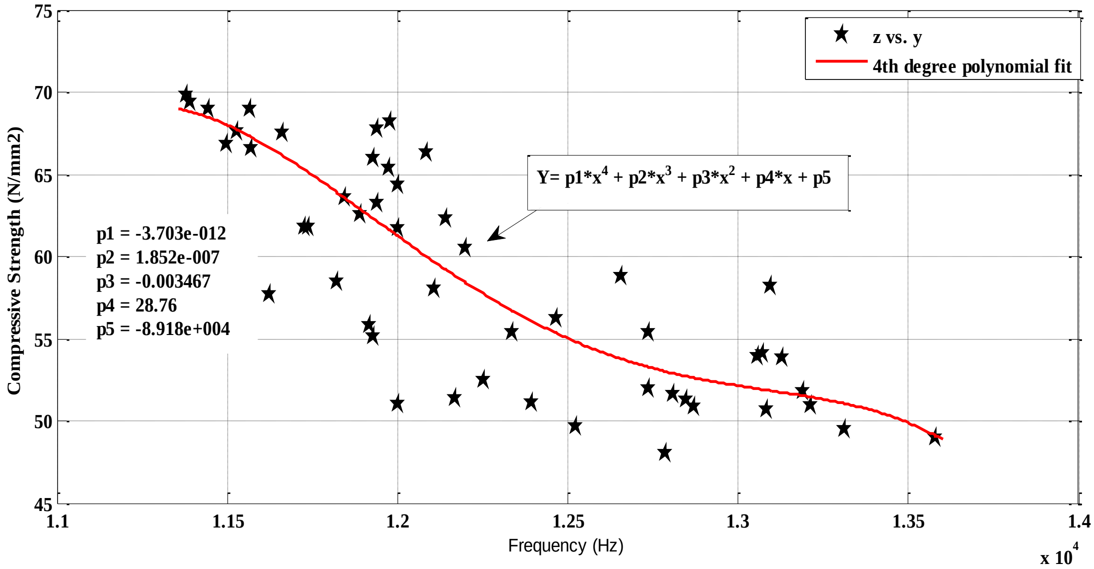

Fig. 3 Correlation between Frequency and Compressive Strength

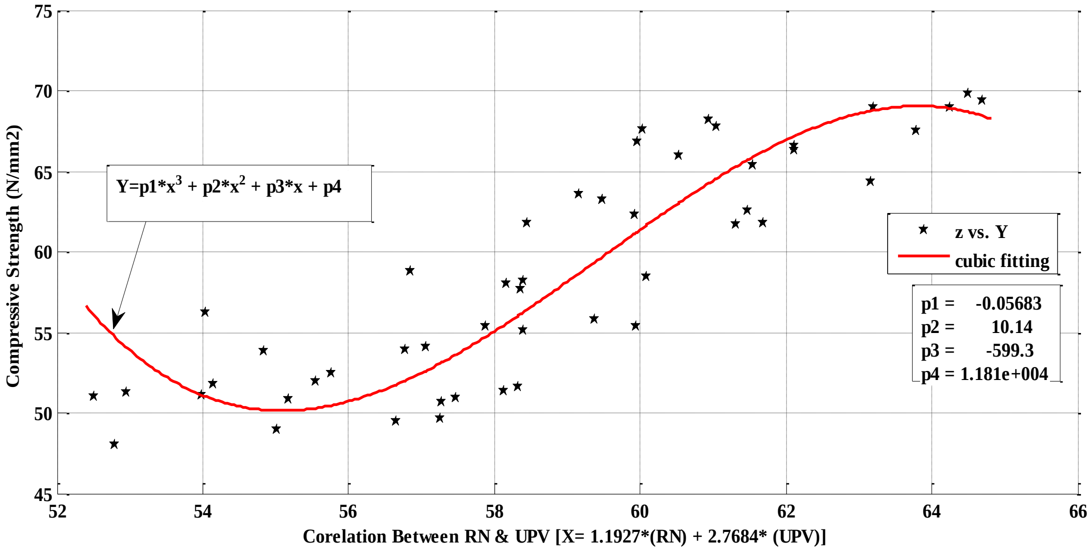

Fig.4 Correlation between Ultrasonic Pulse Velocity, Compressive Strength and Rebound Number

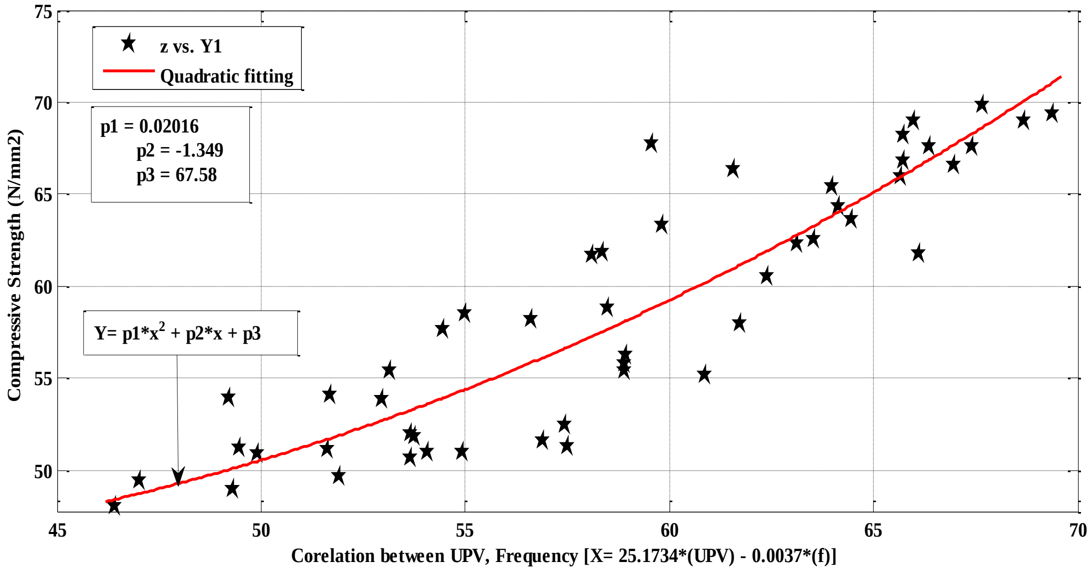

Fig.5 Correlation between Ultrasonic Pulse Velocity, Frequency and Compressive Strength

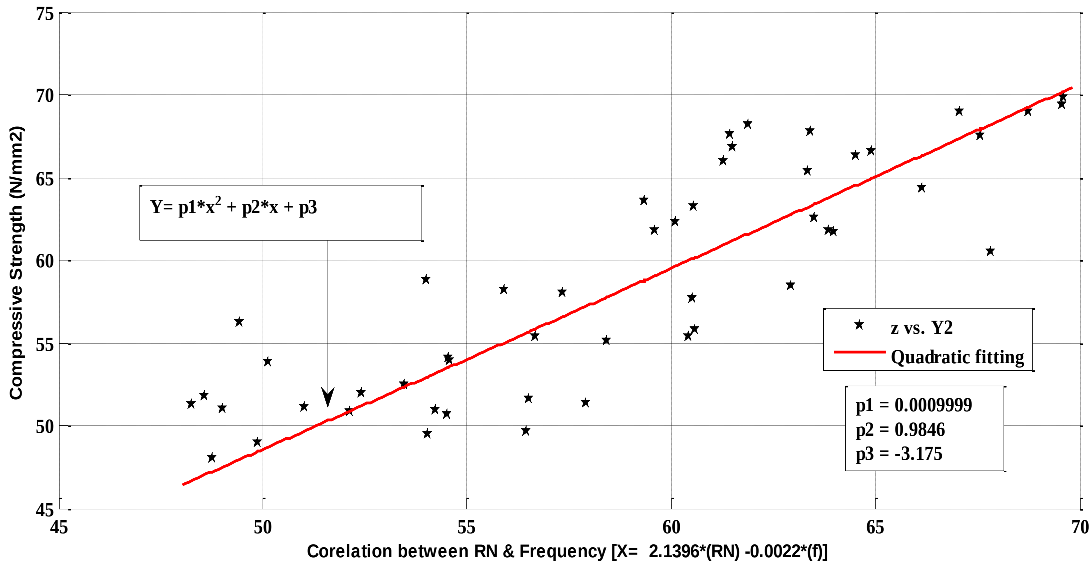

Fig.6 Correlation between Frequency, Rebound Number and Compressive Strength

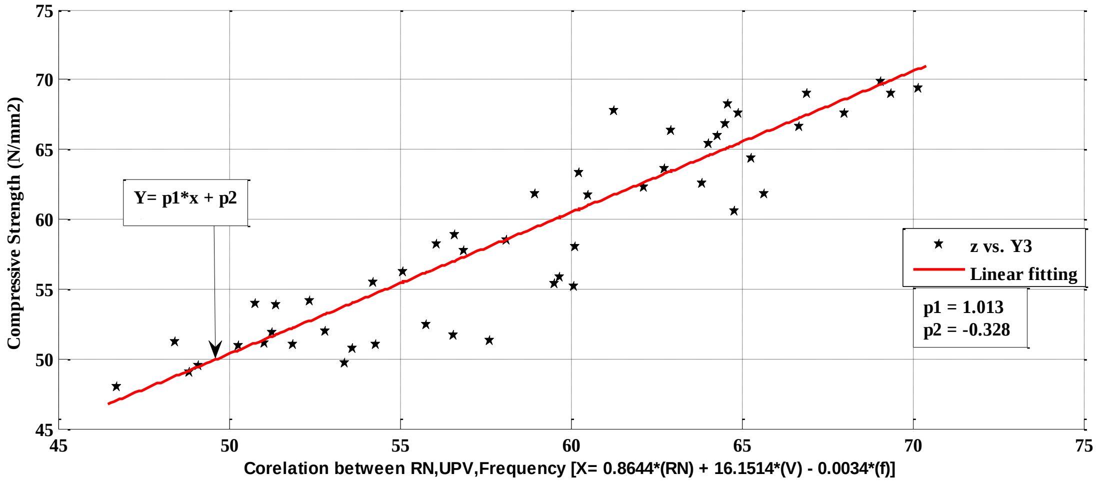

Fig.7 Correlation between Ultrasonic Pulse Velocity, Rebound Hammer, Frequency and Compressive Strength

Table.2:- RMSE value and R^2 value for relation between UPV, Rebound number, Compressive strength and Frequency

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
RMSE	3.816 0.7463	3.217	3.415	3.115	2.388	2.672	1.673
R 2 value	0.7462 3.816	0.8035	0.7718	0.8162	0.8857	0.8542	0.9148
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							

CONCLUSIONS

1. The use of Ultrasonic pulse velocity, Rebound hammer and Impact-Echo test alone is not suitable to predict the compressive strength of concrete because of variation of predict strength and actual Strength are 25.37% for Rebound hammer, 22.18% for impact-echo test and 19.64% for UPV.
2. But using combination of two method the variation are 18.39% for combination of UPV and Rebound hammer, 11.42% for combination of UPV and Impact-Echo,14.59 for combination of Impact-Echo and Rebound hammer.
3. But using combination of three method the variation is 8.51 % means approximately equal 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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