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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 M20, M30, and M40. The specimens consisting 20 each 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*— Rebound Hammer, Ultrasonic Pulse Velocity, Frequency Spectrum, Impact Echo Test, Non-Destructive Testing, Compressive Load, Goodness of fit, R-square, RMSE, MATLAB.

I. 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 ``non-destructive" is given to any test that does not damage or affect the structural behaviour 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

An 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:
$V = L/T$, 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:
$d = V/2f$
Where, d-is distance,
f -is dominant frequency,
V -is velocity of compression waves in the test material.

Applications of Impact Echo Technique

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

II. 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 AggregateLocally 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. Frequency can measured using NDE360 Olson impact echo software.

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 will be done from the values of frequency and ultrasonic pulse velocity at no loading condition. Regression analysis done by using MATLAB software.

III. RESULT AND DISCUSSION

All The Ultrasonic Pulse velocity and Frequency obtained by various cubes was given in following table.
Table No. I: Experimental Data of M20 Grade And M30 Grade Cube Obtained Using Non-Destructive and Destructive.

Sr. No.	For M20 Grade Concrete Cube				For M30 Grade Concrete Cube			
	Average Rebound Number (RN)	Average Velocity (Km/s)	Frequency using Impact Echo (Hz)	Compressive Strength (N/mm2)	Average Rebound Number (RN)	Average Velocity (Km/s)	Frequency using Impact Echo (Hz)	Compressive Strength (N/mm2)
1	27.5	4.227	12758	30.84	36.3	4.262	12270	43.96
2	29.2	4.271	12177	33.33	35.2	4.155	12309	40.62
3	28.5	4.270	12535	32.00	38.0	4.341	12131	45.82
4	30.2	4.311	11998	35.11	36.0	4.234	12333	42.08
5	29.8	4.310	11812	35.07	35.5	4.219	12452	41.02
6	27.0	4.226	12588	30.80	35.8	4.238	12262	42.29
7	28.0	4.225	12370	31.33	34.0	4.127	12476	39.99
8	26.0	4.182	12690	29.56	34.5	4.156	12430	40.09
9	25.5	4.163	12670	28.44	38.0	4.282	12286	44.38
10	29.2	4.241	12370	32.22	37.5	4.290	12175	45.02
11	28.0	4.355	11860	36.71	38.0	4.310	12160	45.73
12	27.3	4.324	12599	30.22	36.8	4.266	12119	43.07
13	28.3	4.250	11998	33.29	34.7	4.155	12405	38.82
14	24.8	4.110	12742	27.56	37.5	4.315	12220	44.76
15	27.7	4.234	12422	32.22	36.3	4.278	12330	43.29
16	31.3	4.329	12277	35.07	37.0	4.349	12140	45.87
17	30.5	4.395	11849	36.71	36.3	4.156	12375	41.33
18	31.0	4.416	11876	37.11	35.2	4.123	12460	39.69
19	29.5	4.310	12184	34.76	35.8	4.230	12350	41.56
20	28.7	4.245	12705	31.24	36.8	4.270	12260	44.13

Table No. II: Experimental Data of M40 Grade Cube Obtained Using Non-Destructive and Destructive Testing

Sr. No.	Average Rebound Number (RN)	Average Velocity (Km/s)	Frequency using Impact Echo (Hz)	Compressive Strength (N/mm2)
1	39.5	4.218	12512	49.11
2	40.3	4.271	12452	52.98
3	42.0	4.408	12220	57.42
4	38.5	4.177	12552	49.11
5	38.0	4.191	12463	48.36
6	37.7	4.152	12700	44.02
7	39.0	4.185	12560	49.96
8	37.5	4.152	12556	46.67
9	40.2	4.264	12460	50.22
10	40.0	4.290	12477	52.80
11	39.0	4.323	12450	51.82
12	40.5	4.340	12276	54.84
13	42.0	4.383	12231	56.13
14	42.0	4.385	12250	55.60
15	41.0	4.385	12241	55.42
16	40.2	4.348	12261	55.20
17	40.0	4.283	12440	52.67
18	41.8	4.438	12210	58.36
19	39.0	4.302	12556	50.67
20	38.2	4.160	12649	48.00

The following results have been obtained by interpretation of the NDT and Destructive testing data. Table I to Table II provides detailed experimental data of Rebound Number, Ultrasonic Pulse Velocity, Frequency Using Impact Echo testing and Crushing Compressive Strength for a cube specimen of grade M20, M30 and M40. Results are consisting of seven equation from each grade of M20, M30, M40 obtained using simple regression and multiple regression analysis of experimental data of grade M20, M30, M40 cube specimen. Determination of strength of concrete in-situ has been main purpose of this work so that only seven correlations have been described.

1. *Correlation between Rebound Number and Compressive Strength*

$$Y= P1 \times (RN) + P2 \quad \text{……………. (1)}$$

Where: RN = Rebound Number
Y = Compressive Strength (N/mm2)
Table No. III: Coefficients and Goodness of Fit for Correlation between Y and RN.

Variable		Grade of Concrete		
		M20	M30	M40
Coefficients	P1	1.369	1.709	2.439
	P2	-6.194	-19.32	-45.13
Goodness of fit	SSE	35.5	14.25	37.32
	R^2	0.7572	0.8494	0.8663
	RMSE	1.404	0.8899	1.44

R^2 value obtained for correlation between Rebound Number and compressive strength for a concrete cube grade M20, M30, and M40 have been 0.7572, 0.8494, 0.8663 that means equation (1) could Explain 75.72%, 84.94% and 86.63% of the variability for the data around the regression line and 24.852%, 15.06% and 13.37% of the residual data could not explain bye this equation It has been observed that coefficient of determination R^2 value increased as grade of concrete increased. Graphical presentation of correlations are shown in following fig. 1

2. *Correlation between Ultrasonic Pulse Velocity and Compressive Strength*

$$Y= P1 \times (Upv) + P2 \quad \text{……………..… (2)}$$

Where: Upv = Ultrasonic Pulse Velocity (Km/sec.)
Y = Compressive Strength (N/mm2)
Table No. IV: Coefficients and Goodness of Fit for Correlation between Y and Upv

Variable		Grade of Concrete		
		M20	M30	M40
Coefficients	P1	33.04	29.82	39.75
	P2	-108.4	-83.69	-118.3
Goodness of fit	SSE	26	8.419	25.92
	R^2	0.8222	0.8611	0.8771
	RMSE	1.202	0.6839	1.2

R^2 value obtained for correlation between compressive strength and Upv for a concrete cube grade M20, M30, and M40 have been 0.8222, 0.8611, 0.8771 that means equation (2) could Explain 82.22%, 86.11% and 87.71% of the variability for the data around the regression line and 17.78%, 13.89% and 12.29% of the residual data could not explain bye this equation It has been observed that coefficient of determination R^2 value increased as grade of concrete increased. Graphical presentation of correlations are shown in following fig. 2

3. *Correlation between Frequency using impact Echo and Compressive Strength*

$$Y= P_1 \times (Frequency) + P_2 \quad \text{….………..(3)}$$

Where: Y = Compressive Strength (N/mm^2)
Frequency = Frequency using Impact Echo (Hz)
Table No. V: Coefficients and Goodness of Fit for Correlation between Y and Frequency

Variable		Grade of Concrete		
		M20	M30	M40
Coefficients	P1	-0.007	-0.016	-0.024
	P2	122.7	236.3	342.1
Goodness of fit	SSE	28.28	12.77	34.57
	R^2	0.8066	0.8218	0.8762
	RMSE	1.254	0.9226	1.386

R^2 value obtained for correlation between compressive strength and impact echo testing for a concrete cube grade M20, M30, and M40 have been 0.8066, 0.8218, 0.8762 that means equation (3) could Explain 80.66%, 82.18% and 87.62% of the variability for the data around the regression line and 19.34%, 17.82% and 12.38% of the residual data could not explain bye this equation It has been observed that coefficient of determination R2 value increased as grade of concrete increased. Graphical presentation of correlations are shown in following fig. 3.

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

$$Y= P1 \times (X) + P2 \quad \text{…………….. (4)}$$

Where: Y = Compressive Strength (N/mm^2)
X = Correlation between Rebound Number and Upv
[X= A x (RN) – B x (Upv)]

Table No. VI: Coefficients and Goodness of Fit for Correlation between RN, Upv and Y

Variable		Grade of Concrete		
		M20	M30	M40
Coefficients	P1	1.111	1.229	1.149
	P2	-3.894	-9.736	-7.585
	A	1.4567	1.6122	2.6386
	B	-2.095	-3.7242	-12.39
Goodness of fit	SSE	13.89	7.85	17.72
	R^2	0.8924	0.9	0.9059
	RMSE	0.9033	0.7234	1.168

R^2 value obtained for correlation between Rebound Number, Ultrasonic Pulse Velocity and compressive strength for a concrete cube grade M20, M30, and M40 have been 0.8924, 0.9, 0.9059 that means equation (4) could Explain 89.24%, 90% and 90.59% of the variability for the data around the regression line and 10.76%, 10% and 9.41% of the residual data could not explain bye this equation It has been observed that coefficient of determination R^2 value increased as grade of concrete increased. Graphical presentation of correlations are shown in following fig. 4.

5. Correlation between Ultrasonic Pulse Velocity, Frequency using impact Echo and Compressive Strength

$$Y= P1 \times (X) + P2 \quad \text{……………..} (5)$$

Where: Y = Compressive Strength (N/mm^2)
X = Correlation between Upv and Frequency
[X= A x (Upv) – B x (Frequency)]

Table No. VII: Coefficients and Goodness of Fit for Correlation between Upv, Frequency and Y.

Variable		Grade of Concrete		
		M20	M30	M40
Coefficients	P1	0.9984	0.9571	0.9684
	P2	0.0511	1.91	1.68
	A	19.41	23.4	30.42
	B	0.0041	0.0046	0.0063
Goodness of fit	SSE	10.52	5.448	11.78
	R^2	0.9281	0.9311	0.9429
	RMSE	0.7644	0.5661	0.8581

R^2 value obtained for correlation between Ultrasonic Pulse Velocity, impact echo testing and compressive strength for a concrete cube grade M20, M30, and M40 have been 0.9281, 0.9311, 0.9429 that means equation (5) could Explain 92.81%, 93.11% and 94.29% of the variability for the data around the regression line and 7.19%, 6.89% and 5.71% of the residual data could not explain bye this equation It has been observed that coefficient of determination R^2 value increased as grade of concrete increased. Graphical presentation of correlations are shown in following fig.5.

6. Correlation between Rebound Number, Frequency using impact Echo and Compressive Strength

$$Y= P1 \times (X) + P2 \quad \text{……………..} (6)$$

Where: Y = Compressive Strength (N/mm^2)
X = Correlation between RN and Frequency
[X= A x (RN) – B x (Frequency)]

Table No. VIII: Coefficients and Goodness of Fit for Correlation between Upv, Frequency and Y.

Variable		Grade of Concrete		
		M20	M30	M40
Coefficients	P1	0.943	1.024	0.9147
	P2	1.651	-1.138	4.857
	A	1.4163	1.6387	2.2221
	B	-0.0006	-0.0014	-0.0029
Goodness of fit	SSE	10.71	6.206	11.77
	R^2	0.917	0.9177	0.9398
	RMSE	0.7939	0.6432	0.8858

R^2 value obtained for correlation between Ultrasonic Pulse Velocity, impact echo testing and compressive strength for a concrete cube grade M20, M30, and M40 have been 0.917, 0.9177, 0.9398 that means equation (6) could Explain 91.7%, 91.77% and 93.98% of the variability for the data around the regression line and 8.3%, 8.23% and 6.02% of the residual data could not explain bye this equation It has been observed that coefficient of determination R^2 value increased as grade of concrete increased. Graphical presentation of correlations are shown in following fig.6.

7. Correlation between Rebound Number, Ultrasonic Pulse Velocity, Frequency using impact Echo and Compressive Strength

$$Y = P1 \times (X) + P2 \quad \text{....................... (7)}$$

Where: Y = Compressive Strength (N/mm^2)
X = Correlation between RN, Upv and Frequency
[X= A x (RN) + B x (Upv) + C x (Frequency)]
Table No. IX: Coefficients and Goodness of Fit for Correlation between RN, Upv, Frequency and Y

Variable		Grade of Concrete		
		M20	M30	M40
Coefficients	P1	0.9957	0.9623	0.9601
	P2	0.14	1.676	2.138
	A	0.3827	0.5901	0.7785
	B	14.8308	15.7284	20.4343
	C	-0.0034	-0.0037	-0.0054
Goodness of fit	SSE	7.906	3.98	9.521
	R^2	0.9459	0.9496	0.9539
	RMSE	0.6627	0.4839	0.7214

R^2 value obtained for correlation between Ultrasonic Pulse Velocity, impact echo testing and compressive strength for a concrete cube grade M20, M30, and M40 have been 0.9459, 0.9496, 0.9539 that means equation (7) could Explain 94.59%, 94.96% and 95.39% of the variability for the data around the regression line and 5.41%, 5.04% and 4.61% of the residual data could not explain bye this equation It has been observed that coefficient of determination R^2 value increased as grade of concrete increased. Graphical presentation of correlations are shown in following fig. 7.

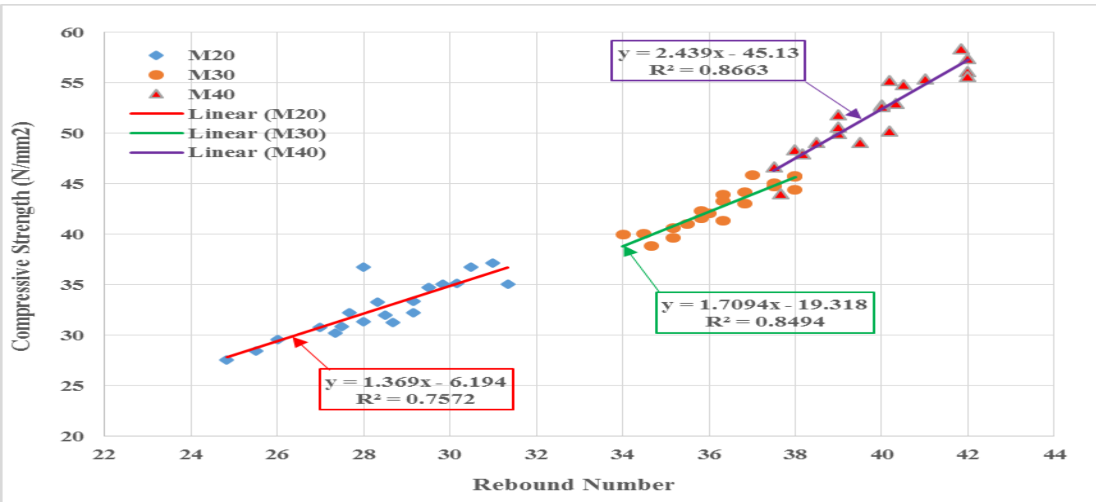

Fig. 1 Relationship between Rebound Number and Compressive Strength

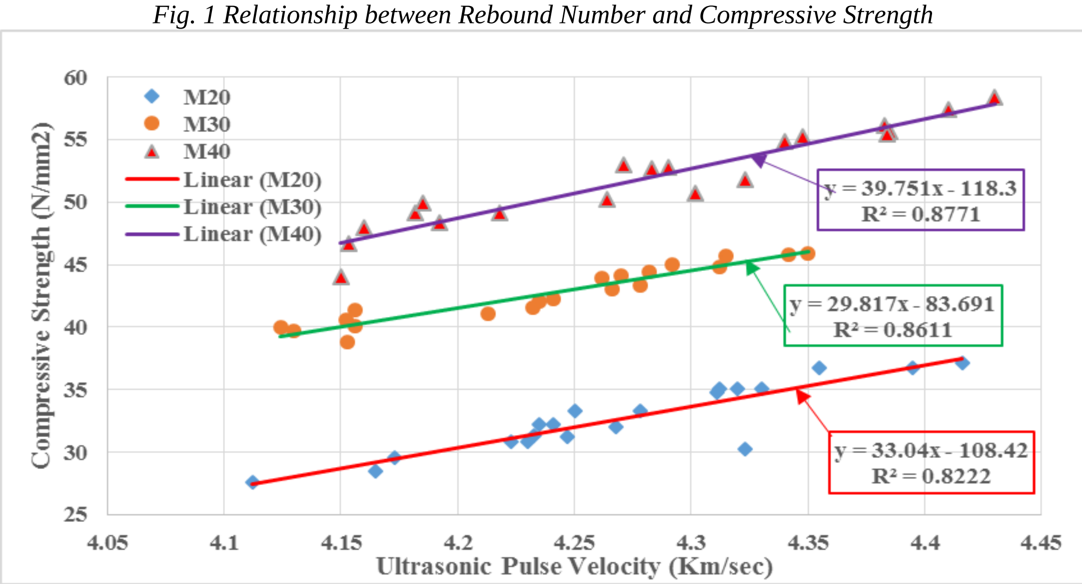

Fig. 2 Relationship between Ultrasonic Pulse Velocity and Compressive Strength

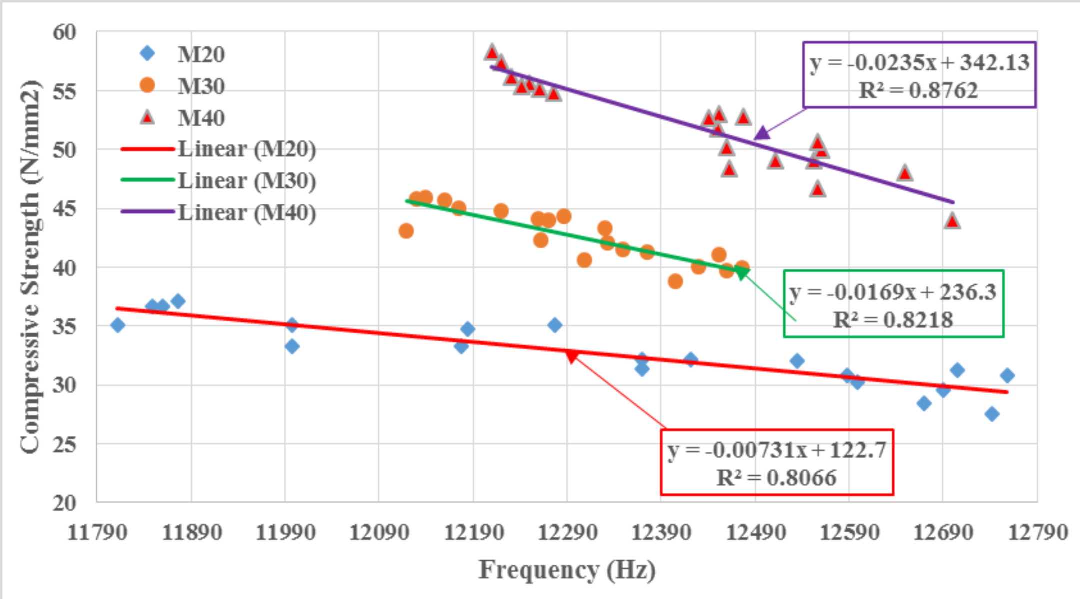

Fig. 3 Relationship between Frequency using Impact Echo and Compressive Strength

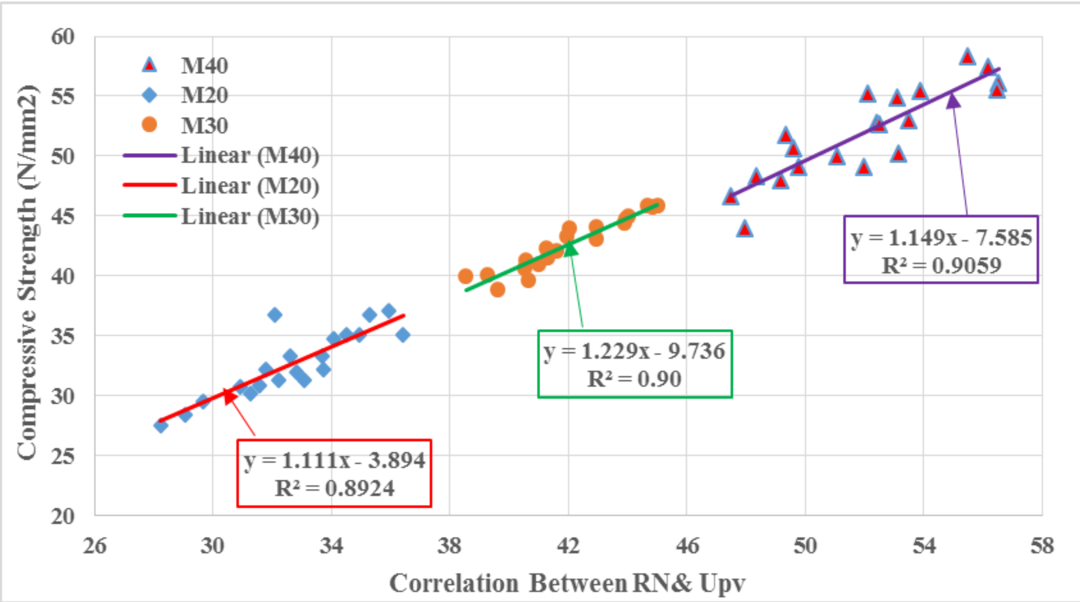

Fig. 4 Relationship between Rebound Number, Ultrasonic Pulse Velocity and Compressive Strength

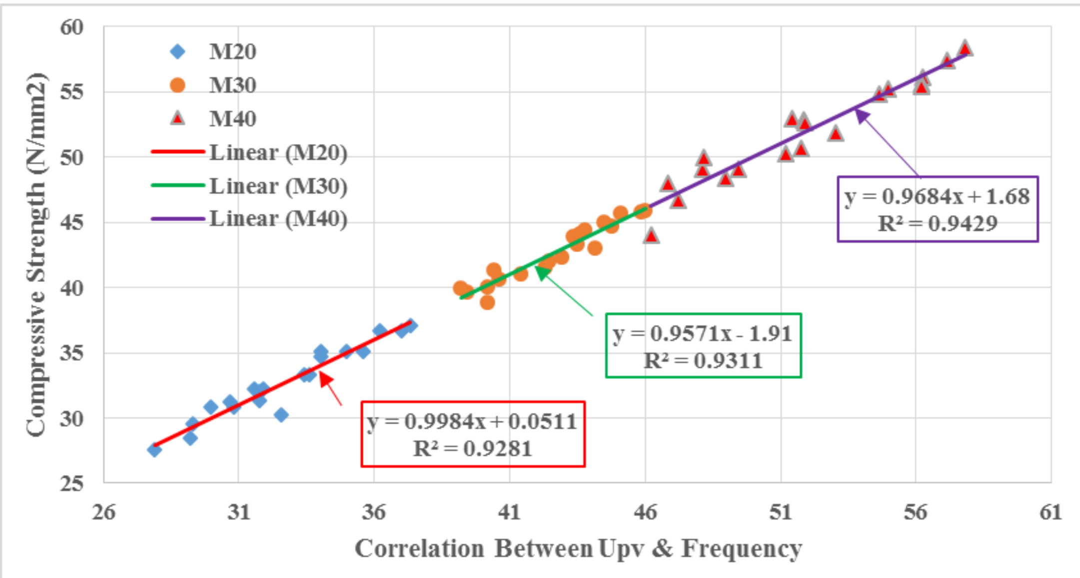

Fig. 5 Relationship between Ultrasonic Pulse Velocity, Frequency and Compressive Strength

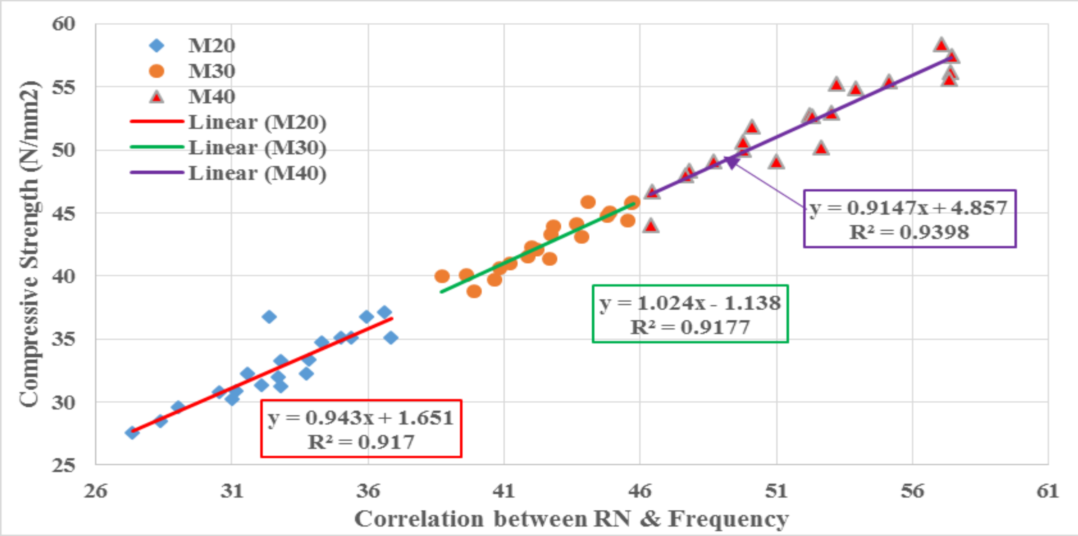

Fig. 6 Relationship between Rebound Number, Frequency and Compressive Strength

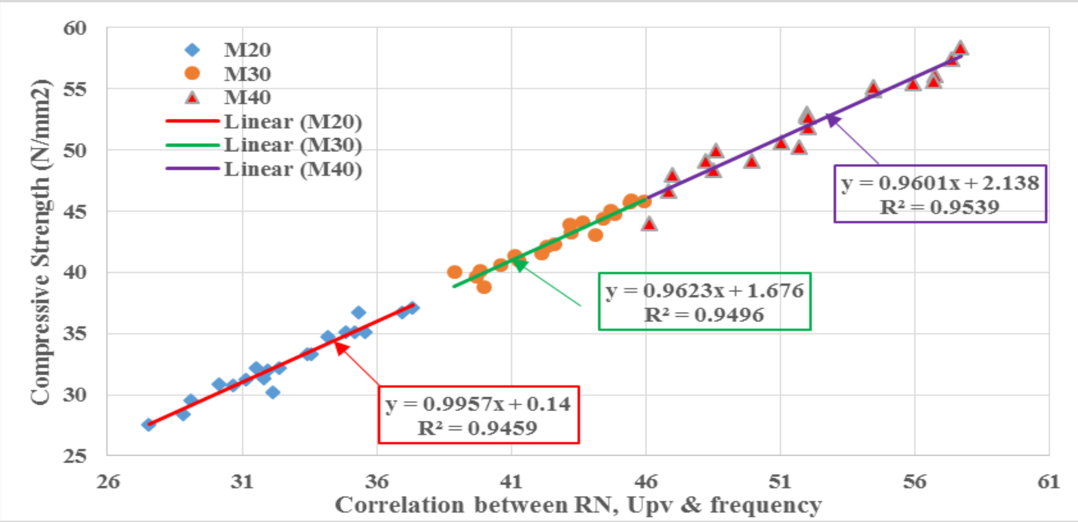

Fig. 7 Relationship between Ultrasonic Pulse Velocity, Frequency and Compressive Strength

IV. 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 greater variation of actual Strength and Predicted Strength.
2. But using combination of two method such as Rebound Hammer and Ultrasonic pulse velocity the variation in between 9.41% to 10.76%, Ultrasonic pulse velocity and Impact-Echo test the variation in between 5.71% to 7.19%, and Rebound Hammer and Impact-Echo test the variation in between 6.02% to 8.3%. Depending upon grade of concrete.
3. But using combination of three method such as Rebound Hammer, Ultrasonic pulse velocity and Impact-Echo test the variation in between 4.61% to 5.41%. Depending upon grade of concrete.
4. For the above results it can be observed that the R^2 value increases with the grade of concrete increases it means that variation between actual Strength and Predicted Strength are reduces.
5. The use of the combined three methods produces results that lie close to the true values when compared with other methods.
6. 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.
7. Use of multiple regressions is recommended over a simple regression to increase the accuracy of data.

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