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To Establish Relation Between Destructive and Non-Destructive Tests on concrete

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Abstract— Non destructive test methods are used to examine the properties and compressive strength of hardened concrete. In existing concrete structures there was no direct relation between the results of non destructive tests. This paper describes the co-relation between Rebound hammer, Ultrasonic pulse velocity, core compressive strength and cylinder compressive strength of hardened concrete. It also describes the relation between bond strength and cube compressive strength and comparison of modulus of elasticity by different standards. An experimental program was carried out, involving both destructive and non destructive methods applied to different concrete mixtures, such as M20, M25 and M30.The slab of 2000 x 1000 x 200 mm were casted for each grade of concrete and cores were extracted from the slab. Also the Cylinders of size 100 x 200 mm were casted to compare the results. Cubes of size 150 x 150 x 150 mm and cubes of size 150 x 150 x 150 mm with inserted bar of size 16mm were casted and tested for compressive strength and pull out test respectively. Relationships were derived for rebound hammer, pulse velocity, compressive strength of cores and cylinders, compressive strength of cube and bond strength. The results show good behavior for these methods.

Keywords— Non destructive test (NDT), Rebound hammer, Ultrasonic pulse velocity, Compressive strength, Pullout test, core test, Cores, Cylinders.

INTRODUCTION

The Non Destructive Techniques have been grown during recent years. One of the prime objectives of Non- Destructive Testing (NDT) is to certify that the component being examined is fit for the intended service. These techniques are used for assessment of quality of construction.

Concrete has significantly influenced the nature of engineering projects. Concrete, as a composite material, is generally composed of cement, sand, aggregate, water, mineral admixtures and chemical admixtures. Considerable work has been conducted to develop rapid, non destructive tests (NDTs) that provide a reproducible measure of concrete quality in a structure. Unfortunately, as is usually the case in concrete testing, all these NDT generate results that are affected by various parameters such as aggregate type and size, age, moisture content, and mix proportion. Therefore, the correlation between measured properties and strength differs for various concretes and must be limited to the concrete in question. However, the NDTs are also convenient and have been used for many years in quality management of engineering materials. These tests are useful in determining the differences in concrete quality from one part of a structure to another. [1]

For fresh concrete it involves casting specimens of concrete and testing them for various properties. The concrete cube test and cylinder tests are the most popular tests and are used as the standard method of measuring compressive strength for quality control purpose.

Properties of hardened concrete have been examined by applying many non destructive techniques. Some of the non destructive evaluation techniques are Ultrasonic waves, Core testing, rebound hammer test, Pull out test. A known relationship between the result of in situ testing and the strength of concrete requires for the estimation of in place concrete strength. For existing construction the relationship has to be assessed on site correlation of non destructive test results to strength of core. [2]

The main objective of this paper is to develop a relationship between core compressive strength, casted cylinder compressive strength, Ultrasonic Pulse Velocity, Rebound strength. Also it develop relation between cube compressive strength & bond strength and found modulus of elasticity by different standard codes.

EXPERIMENTAL PROGRAM

A. Test specimen and testing programme

In this proposed work NDT methods are used to find compressive strength of concrete & to find relation between NDT methods and compressive strength. For that purpose slabs, cylinders, cubes, cubes with inserted bar were casted. For casting of a specimens 43 grade JK cement is used. Locally available river sand is used as fine aggregate. Locally available coarse aggregate of size 20 mm and 10 mm were used. The coarse aggregate were crushed ballast type aggregate which are found in Deccan trap region. The properties of material used are as follows:

MATERIAL USED:

1) Maximum size of aggregate = 20 mm.
2) Cement type = 43 grade JK cement.
3) Specific gravity of cement = 3.15
4) Specific gravity of fine aggregate = 2.77
5) Specific gravity of coarse aggregate = 2.8
6) Water absorption of coarse aggregate = 0.5%
7) Water absorption of fine aggregate = 1.1%
8) Free moisture content:
   i) Coarse aggregate = Nil.
   ii) Fine aggregate = 1%

Concrete mix design of grades M20, M25 and M30 were prepared using IS10262-1982. The mix proportions listed in table no. 1 were adopted for this experimental work:

TABLE I
MIX PROPORTION OF CONCRETE PER CUBIC METER

Concrete grade	**M20**	**M25**	**M30**
Cement (Kg/m3)	394.38	439.290	460
Water (Kg/m3)	199.16	193.68	194.12
20mm crushed aggregate (Kg/m3)	682.67	676.37	659.55
10mm crushed aggregate (Kg/m3)	557.28	553.39	562.58
Natural sand (Kg/m3)	593.14	573.35	461.21

Using above mix proportions cased test specimens are as follows:
1. For compressive strength of concrete, three Cube of size 150mm X 150mm X 150mmfor each grade of concrete were casted.
2.For Bond strength of concrete, three Cube of size 150mm X 150mm X 150mm with inserted bar of dia. 16mm for each grade of concrete were casted.
3. For extracting cores, slab of size 2000 mm X 1000 mm X 200mmfor each grade of concrete was casted.
4. For comparing results of cores, five moulds of cylinder
of size 100 X 200 mm for each grade of concrete were casted.

Casted cube after 28 days were tested to obtain compressive strength using standard compression testing machine. Pull out test were done on cube of inserted bar of dia. 16mm.

From pull out test bond strength is to be calculated. The bond strength between concrete and steel is calculated by formula, Load divided by surface area of inserted bar (i.e. Πdl).

After 28 days from casting date of slab 10 cores of 100mm diameter were extracted from each slab. The cores were drilled perpendicular to the direction of casting, so that drilled sample becomes undisturbed sample. The cores were extracted by using core cutter machine. Core test is direct method of assessing in-situ strength of concrete in a structural element. Drilled cylindrical core is removed from structure; tests may be performed on core to determine compressive strength and static modulus of elasticity of concrete is calculated from compressive strength.

In Rebound hammer test twelve hammer impacts were equally distributed on two opposite sides of each core and cylinder specimen that is sides which have been lying sideward during concreting. The rebound strength was calculated as the average of the twelve readings.

Ultrasonic Pulse Velocity Test operates on principle that stress wave propagation velocity is affected by quality of concrete. Pulse waves are induced in materials and the time of arrival measured at the receiving surface with a receiver. Electromagnetic 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 = Pulse velocity, L = Path length, T = time taken by the pulse to traverse that length.

Ultrasonic pulse velocity is influenced by elastic modulus, strength of concrete, density and moisture content.

After rebound hammer and ultrasonic pulse velocity test, the same cores and cylinders were destructively tested to obtain crushing strengths using standard compression machine.

TEST RESULTS

The following results were tabulated after testing specimen of cores and cylinders for rebound hammer, pulse velocity test and compressive strength. Also cubes and cubes with inserted bars were tested for compressive strength and bond strength respectively.

A. For M20 grade of concrete

TABLE II

CORE TEST RESULT

Sample No.	Rebound strength inclination angle = 0^0	UP V km/s	Comp. strength N/mm^2	Equivalent cube strength IS 516-1959	Density kN/m^3
1	20.6	3.88	21.7	25.75	23.82
2	21.39	3.94	22.4	26.74	24.97
3	20.34	3.88	21.5	25.43	23.87
4	21.2	3.9	21.8	26.50	22.74
5	20.9	3.9	21.7	26.13	23.65
6	19.77	3.84	21.1	24.71	23.74
7	21.98	3.95	22.8	27.48	24.65
8	23.02	4.02	23.7	28.78	24.89
9	21.49	3.92	21.9	26.86	23.87
10	21.18	3.92	22.1	26.48	23.96
Avg.	21.19	3.91	22.07	26.49	23.04

TABLE III

CYLINDER TEST RESULT

Sample No.	Rebound strength inclination angle = 0^0	UPV km/s	Comp. strength N/mm^2	Equivalent cube strength IS 516 -1959	Density kN/m^3
1	21.9	4.07	22.5	27.38	24.94
2	23.74	4.25	24.6	29.68	23.02
3	21.55	4.06	21.9	26.94	23.77
4	23.74	4.18	24.4	29.68	24.42
5	22.28	4.16	23.2	27.85	25.81
Avg.	22.64	4.14	23.32	28.30	23.39

TABLE IV

CUBE TEST RESULTS

Sample No.	Load (kN)	Compressive strength (N/mm2)	Average Compressive strength (N/mm2)
1	550.3	24.46	27.1
2	615.4	27.35	
3	663.6	29.49	

TABLE V

PULL OUT TEST RESULTS

Sample No.	Load (kN)	Bond strength (N/mm2)	Average Bond strength (N/mm2)	Average Bond strength (N/mm2) AS per IS 456-2000
1	43.69	6.45	7.45	1.92
2	59.88	8.84		
3	47.82	7.06		

B. For M25 grade of concrete

TABLE VI

CORE TEST RESULTS

Sample No.	Rebound strength inclination angle = 0^0	UPV km/s	Comp. strength N/mm^2	Equivalent cube strength IS 516-1959	Density kN/m^3
1	25.39	4.07	25.8	31.74	25.66
2	25.13	4.06	25.7	31.41	24.89
3	25.63	4.09	25.9	32.04	23.74
4	25.58	4.08	25.9	31.98	24.16
5	24.76	4.02	25.5	30.95	23.43
6	25.82	4.1	26	32.28	24.67
7	24.36	4.02	25.5	30.45	23.22
8	25.73	4.1	26	32.16	24.18
9	25.79	4.11	26.1	32.24	24.23
10	26.05	4.09	26.2	32.56	25.11
Avg.	25.42	4.07	25.86	31.78	24.33

TABLE VII

CYLINDER TEST RESULTS

Sample No.	Rebound strength inclination angle = 0^0	UPV km/s	Comp. strength N/mm^2	Equivalent cube strength IS 516-1959	Density kN/m^3
1	25.92	4.25	27	32.40	24.4
2	25.26	4.2	26.1	31.58	23.48
3	26.59	4.3	27.7	33.24	24.72
4	26.76	4.3	28.4	33.45	24.48
5	24.91	4.15	25.8	31.14	23.59
Avg.	25.88	4.24	27	32.36	24.13

TABLE VIII

CUBE TEST RESULTS

Sample No.	Load (kN)	Compressive strength (N/mm2)	Average Compressive strength (N/mm2)
1	803.5	35.71	32.36
2	762.3	33.88	
3	618.8	27.50	

TABLE IX

PULL OUT TEST RESULTS

Sample No.	Load (kN)	Bond strength (N/mm2)	Average Bond strength (N/mm2)	Average Bond strength (N/mm2) AS per IS 456-2000
1	65.23	9.63	8.55	2.24
2	56.15	8.29		
3	52.36	7.73		

C. For M30 grade of concrete

TABLE X

CORE TEST RESULTS

Sample No.	Rebound strength inclination angle = 0^0	UPV km/s	Comp. strength N/mm^2	Equivalent cube strength IS 516-1959	Densityk N/m^3
1	26.33	4.05	27.8	32.91	23.29
2	26.62	4	28.2	33.28	23.48
3	27.73	4.07	29.4	34.66	23.12
4	27.74	4.06	29.6	34.68	24.19
5	27.18	4.02	28.5	33.98	24.11
6	27.73	4.04	28.9	34.66	24.58
7	27.07	4.05	29.1	33.84	24.78
8	28.69	4.16	31.4	35.86	25.34
9	28.46	4.12	30.8	35.58	25.26
10	28.85	4.13	30.8	36.06	26.17
Avg.	27.64	4.07	29.45	34.55	24.4

TABLE XI

CYLINDER TEST RESULTS

Sample No.	Rebound strength inclination angle = 0^0	UPV km/s	Comp. strength N/mm^2	Equivalent cube strength IS 516-1959	Density kN/m^3
1	27.02	4.3	29.8	33.78	23.67
2	27.39	4.28	30.9	34.24	24.36
3	28.75	4.43	36.2	35.94	24.75
4	28.85	4.4	34.9	36.06	24.44
5	28.13	4.35	33.9	35.16	24.94
Avg	28.03	4.35	33.14	35.036	24.43

TABLE XII

CUBE TEST RESULTS

Sample No.	Load (kN)	Compressive strength (N/mm2)	Average Compressive strength (N/mm2)
1	806.4	35.84	35.09
2	784.6	33.27	
3	813.16	36.16	

TABLE XIII

PULL OUT TEST RESULTS

Sample No.	Load (kN)	Bond strength (N/mm2)	Average Bond strength (N/mm2)	Average Bond strength (N/mm2) AS per IS 456-2000
1	64.21	9.48	9.56	2.4
2	58.52	8.64		

3	71.53	10.56		

TABLE XIV

MODULUS OF ELASTICITY OF CONCRETE

	IS 456-2000	ACI 318-1995	BS 8110-1985 **(PART2)**	IS 13311-1992 **(PART1)**
FORMULA / **Grade of Concrete**	**Ec =** $5000\sqrt{fck}$ **(N/ mm²) X10^{-3} (kN/mm²)**	**Ec = 57000(fck)½ (Psi) X 145.0377 X10^{-3} (kN/mm²)**	**Ec,28 = Ko + 0.2 fcu,28 (kN/mm²)**	Dynamic modulus of elasticity $= E = \frac{\rho(1+\mu)(1-2\mu)V^2}{1-\mu}$ **(N/ mm²) X10^{-3} (kN/mm²)**
M20	26.69	24.36	25.70	29.99
M25	29.27	26.68	26.86	33.67
M30	30.64	27.82	27.51	33.81

Where,

Ec=Static modulus of elasticity

Ed= Dynamic modulus of elasticity

D. COMPARISON OF RESULTS

From observation table comparison of average rebound strength, average UPV and average compressive strength of cylinders and cores for M20, M25 and M30 grades of concrete is done. It observed that, 1. Average rebound strength of cylinders is greater than average rebound strength of cores. 2. Average UPV of cylinders is greater than average UPV of cores. 3. Average compressive strength of cylinders is greater than average compressive strength of cores.

The relation between average compressive strength of cubes (f_{cube}) and average compressive strength cylinders (f_{cyl}) are developed from above results is given below:

TABLE XV

RELATION BETWEEN CUBE AND CYLINDRICAL COMPRESSIVE STRENGTH.

Grade	**Relation between f_{cube} and f_{cyl}**	**Relation between f_{cube} and f_{cyl} as per IS 516-1959**
For M20	$f_{cube} = 1.16 f_{cyl}$	$f_{cube} = 1.25 f_{cyl}$
For M25	$f_{cube} = 1.20 f_{cyl}$	$f_{cube} = 1.25 f_{cyl}$
For M30	$f_{cube} = 1.06 f_{cyl}$	$f_{cube} = 1.25 f_{cyl}$

Calibration curves for rebound method and Ultrasonic pulse method are drawn using regression analysis. The relations were drawn by plotting the rebound number and Pulse velocity against the compressive strength.

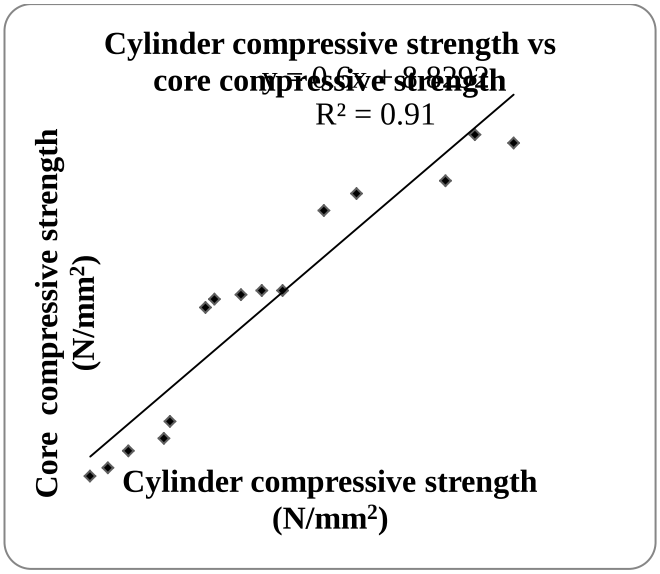

Fig.1: Cylinder compressive strength vs core compressive strength.

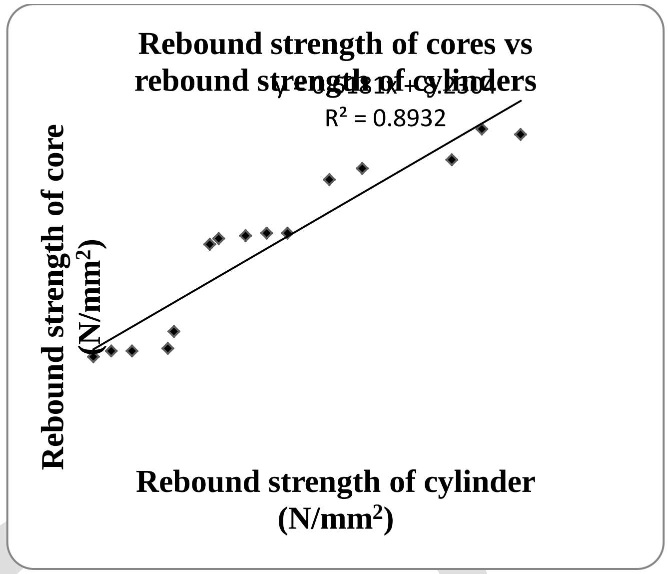

Fig.2: Rebound no. of cylinders vs rebound no. of cores.

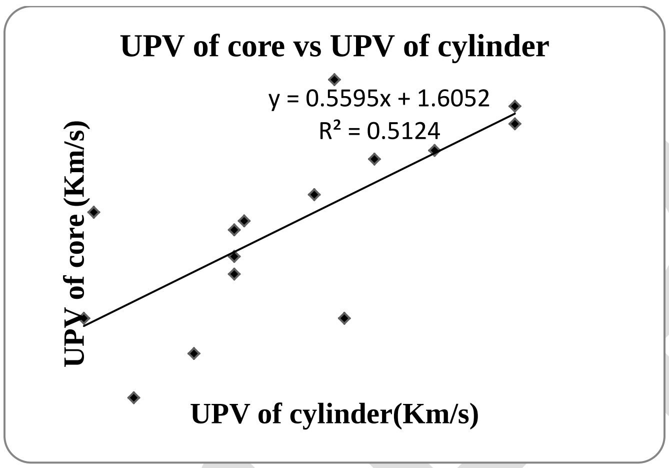

Fig.3: UPV of cylinders vs UPV of cores

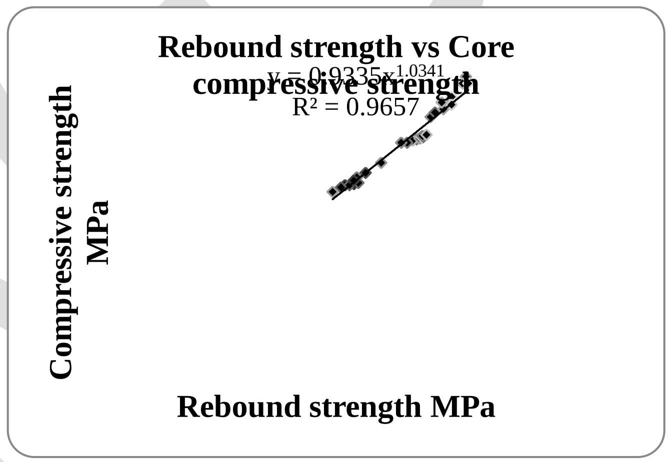

Fig.4: Core compressive strength vs rebound strength.

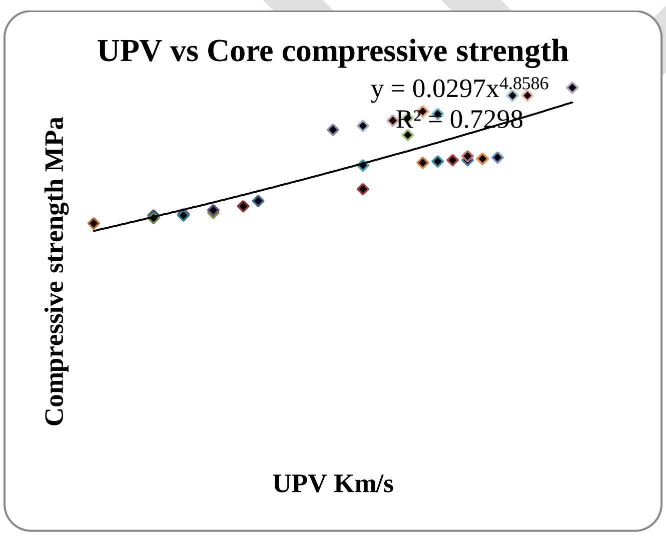

Fig.5: Core compressive strength vs UPV.

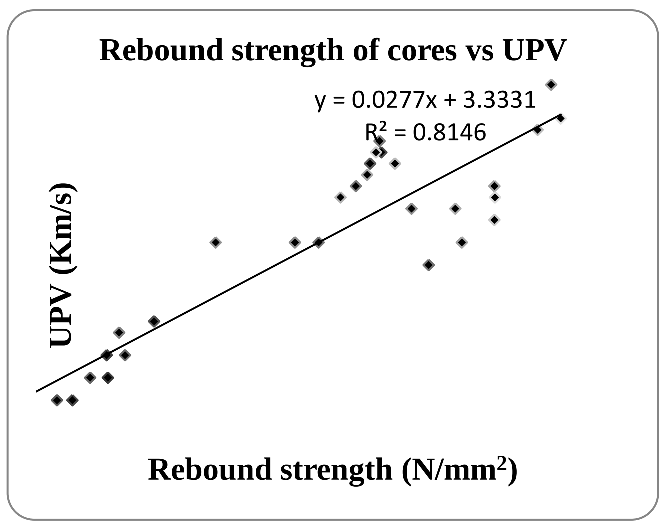

Fig 6: Rebound strength of cores vs UPV

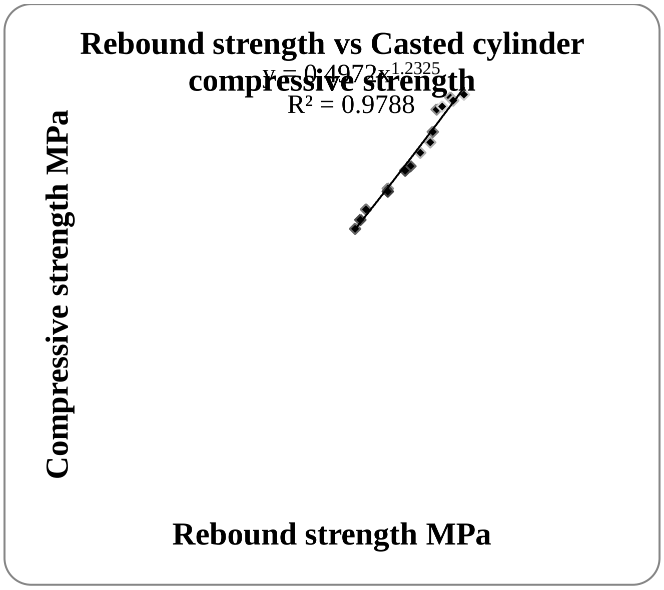

Fig.7: Cylinder compressive strength vs rebound strength

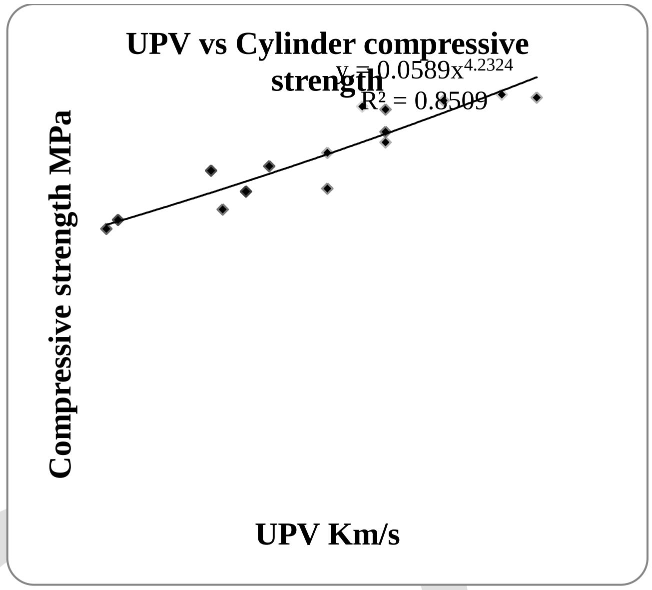

Fig.8: Cylinder compressive strength vs UPV.

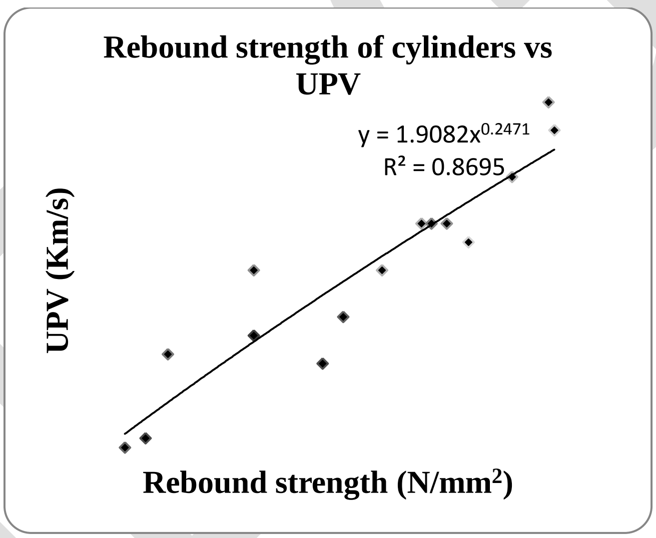

Fig 9: Rebound strength of cylinders vs UPV.

REGRESSION ANALYSIS

In the proposed work statistical methods are used for explanation of the tests results and the prediction of concrete strength. 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 of core even in a standard cylinder form.

This work included to predict the analytical relationships between

1. Crushing strength of core with casted cylinder
2. Crushing strength of core with rebound strength.
3. Crushing strength of core with UPV.
4. Crushing strength of casted cylinder with rebound strength.
5. Crushing strength of casted cylinder with UPV.
6. Crushing strength of cubes with bond strength.

For analysis process of the results regression analysis method was used. 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. In regression analysis we obtain a set of coefficients for an equation.

EQUATIONS OF RELATIONSHIP AFTER REGRESSION ANALYSIS

Different regress model of curve between rebound number, Pulse velocity and the compressive strength of concrete core according to the experimental data is given below:

TABLE XVI

REGRESS MODEL BETWEEN REBOUND STRENGTH, PULSE VELOCITY AND THE COMPRESSIVE STRENGTH OF CONCRETE CORE FOR COMBINATION OF M20, M25 AND M30 GRADE OF CONCRETE

Type of Equations	Core compressive strength vs Rebound strength Relations	Core compressive strength vs UPV relations	Rebound strength of core vs UPV relations
Linear	$f_{cor} = 1.099 R_{cor} - 1.428$ $R^2 = 0.962$	$f_{cor} = 30.53 U_{cor} - 96.93$ $R^2 = 0.700$	$U_{cor} = 0.027 R_{cor} + 3.333$ $R^2 = 0.814$
Exponential	$f_{cor} = 8.786e^{0.043} R_{cor}$ $R^2 = 0.976$	$f_{cor} = 0.193e^{1.214} U_{cor}$ $R^2 = 0.729$	$U_{cor} = 3.384e^{0.006} R_{cor}$ $R^2 = 0.815$
Logarithmic	$f_{cor} = 26.25\ln(R_{cor}) - 58.28$ $R^2 = 0.946$	$f_{cor} = 122.0\ln(U_{cor}) - 143.9$ $R^2 = 0.700$	$U_{cor} = 0.674\ln(R_{cor}) + 1.860$ $R^2 = 0.830$
Polynomial	$f_{cor} = 0.075 R_{cor}^{2} - 2.566 R_{cor} + 42.46$ $R^2 = 0.985$	$f_{cor} = -5.686 U_{cor}^{2} + 76.00 U_{cor} - 187.8$ $R^2 = 0.700$	$U_{cor} = -0.002 R_{cor}^{2} + 0.166 R_{cor} + 1.671$ $R^2 = 0.858$
Power	$f_{cor} = 0.933 R_{cor}^{1.034}$ $R^2 = 0.965$	$f_{cor} = 0.029 U_{cor}^{4.858}$ $R^2 = 0.729$	$U_{cor} = 2.340 R_{cor}^{0.168}$ $R^2 = 0.832$

TABLE XVII

REGRESS MODEL BETWEEN REBOUND STRENGTH, PULSE VELOCITY AND THE COMPRESSIVE STRENGTH OF CASTED CYLINDER FOR COMBINATION OF M20, M25 AND M30 GRADE OF CONCRETE.

Type of Equations	Cylinder compressive strength vs Rebound strength Relations	Cylinder compressive strength vs UPV relations	Rebound strength of Cylinder vs UPV relations
Linear	$f_{cyl} = 1.304 R_{cyl} - 6.314$ $R^2 = 0.975$	$f_{cyl} = 26.38 U_{cyl} - 85.10$ $R^2 = 0.848$	$U_{cyl} = 0.042 R_{cyl} + 3.174$ $R^2 = 0.875$
Exponential	$f_{cyl} = 7.583e^{0.049} R_{cyl}$ $R^2 = 0.981$	$f_{cyl} = 0.386e^{0.997} U_{cyl}$ $R^2 = 0.849$	$U_{cyl} = 3.296e^{0.009} R_{cyl}$ $R^2 = 0.876$
Logarithmic	$f_{cyl} = 32.44\ln(R_{cyl}) - 77.97$ $R^2 = 0.969$	$f_{cyl} = 111.8\ln(U_{cyl}) - 134.7$ $R^2 = 0.849$	$U_{cyl} = 1.046\ln(R_{cyl}) + 0.861$ $R^2 = 0.868$
Polynomial	$f_{cyl} = 0.035 R_{cyl}^{2} - 0.459 R_{cyl} + 15.61$ $R^2 = 0.977$	$f_{cyl} = -10.04 U_{cyl}^{2} + 111.5 U_{cyl} - 265.5$ $R^2 = 0.850$	$U_{cyl} = 0.001 R_{cyl}^{2} - 0.052 R_{cyl} + 4.355$ $R^2 = 0.882$
Power	$f_{cyl} = 0.497 R_{cyl}^{1.232}$ $R^2 = 0.978$	$f_{cyl} = 0.058 R_{cyl}^{14.232}$ $R^2 = 0.850$	$U_{cyl} = 1.908 R_{cyl}^{0.247}$ $R^2 = 0.869$

TABLE XVIII

RELATION BETWEEN CASTED CYLINDER AND CORE TEST RESULTS.

Types of equation	Cylindrical compressive strength vs core compressive strength	Rebound strength of casted cylinder vs Rebound strength of core.	UPV of casted cylinder vs UPV of core.
Linear	$f_{cor} = 0.6f_{cyl} + 8.829$ $R^2 = 0.91$	$R_{cor} = 1.098 R_{cyl} - 3.589$ $R^2 = 0.948$	$U_{cor} = 0.539U_{cyl} + 1.710$ $R^2 = 0.557$
Exponential	$f_{cor} = 13.17e^{0.023} f_{cyl}$ $R^2 = 0.890$	$R_{cor} = 7.484e^{0.046} R_{cyl}$ $R^2 = 0.941$	$U_{cor} = 2.248e^{0.135} U_{cyl}$ $R^2 = 0.559$
Logarithmic	$f_{cor} = 17.32\ln(f_{cyl}) - 31.87$ $R^2 = 0.935$	$R_{cor} = 27.51\ln(R_{cyl}) - 64.57$ $R^2 = 0.949$	$U_{cor} = 2.295\ln(U_{cyl}) + 0.683$ $R^2 = 0.562$
Polynomial	$f_{cor} = -0.034 f_{cyl}^{2} + 2.586 f_{cyl} - 19.25$ $R^2 = 0.958$	$R_{cor} = -0.020 R_{cyl}^{2} + 2.152 R_{cyl} - 16.75$ $R^2 = 0.949$	$U_{cor} = -1.373 U_{cyl}^{2} + 12.18 U_{cyl} - 22.95$ $R^2 = 0.607$
Power	$f_{cor} = 2.648 f_{cyl}^{0.681}$	$R_{cor} = 0.574 R_{cyl}^{1.157}$	$U_{cor} = 1.736 U_{cyl}^{0.577}$

	$R^2 = 0.921$	$R^2 = 0.945$	$R^2 = 0.563$

TABLE XIX

RELATION BETWEEN CUBE COMPRESSIVE STRENGTH AND BONDS STRENGTH.

Sr. No	Relations	Function	R^2
1	Linear	$f_{bd} = 0.256f_{ck} + 0.43$	0.975
2	Exponential	$f_{bd} = 3.237e^{0.030} f_{ck}$	0.985
3	Logarithmic	$f_{bd} = 7.845\ln(f_{ck}) - 18.50$	0.965
4	Polynomial	$f_{bd} = 0.020 f_{ck}{}^{2} - 0.987 f_{ck} + 19.43$	1
5	Power	$f_{bd} = 0.339 f_{ck} 0.934$	0.977

CONCLUSIONS

The following conclusions are drawn from the results obtained from the experimental work

1. The following relations are drawn by considering different parameters such as compressive strength, Rebound number and ultrasonic pulse velocity of casted cylinders & cores which are extracted from casted slab:

i) Relation between the compressive strength of cylinders and compressive strength of cores is $f_{cor}= -0.034f_{cyl}{}^{2}+ 2.586f_{cyl}-19.25$.

ii) The relation between rebound strength of cylinders and rebound strength of cores are $R_{cor}= -0.020R_{cyl}2+ 2.152R_{cyl}-16.75$and $R_{cor}= 27.51\ln(R_{cyl}) -64.57$.

iii) The relation between rebound ultrasonic pulse velocity of cylinders and ultrasonic pulse velocity of cores is $U_{cor}= 1.373U_{cyl}{}^{2}+12.18U_{cyl}-22.95$.

2. The following relations are drawn by considering different parameters such as compressive strength, Rebound strength and ultrasonic pulse velocity of cores which are extracted from casted slab:

i) The relation between rebound strength and compressive strength of cores is $R_{cor}= -0.050f_{cor}{}^{2}+ 3.487f_{cor}-31.16$.

ii) The relation between ultrasonic pulse velocity and compressive strength of cores is $U_{cor}= -0.003f_{cor}r^{2}+ 0.181f_{cor}+ 1.410$.

iii) The relation between rebound strength and ultrasonic pulse velocity of is $U_{cor}= -0.002 R_{cor}{}^{2}+ 0.166 R_{cor}+ 1.671$.

3. The following relations are drawn by considering different parameters such as compressive strength, Rebound number and ultrasonic pulse velocity of casted cylinders:

i) The relation between rebound strength and compressive strength of cylinders is $R_{cyl}= -0.037f_{cyl}{}^{2}+2.712f_{cyl}–19.85$.

ii) The relation between ultrasonic pulse velocity and compressive strength of cylinders is $U_{cyl} = 0.022f_{cyl}+ 3.64$.

iii) The relation between rebound strength and ultrasonic pulse velocity of cylinders $U_{cyl}= 0.001R_{cyl}{}^{2}–0.052R_{cyl}+ 4.355$.

4. There is well-built relationship between the cube compressive strength and bond strength. $f_{bd}= 0.020f_{ck}{}^{2}-0.987f_{ck}+ 19.43$,$R^2 = 1$. As R-square value is close to 1.0 it indicates that almost all of the variability with the variables specified in the model.

5. Modulus of elasticity is calculated by IS 456, BS 8110-1985 and ACI 318-1995code. After comparing the results it is found that modulus of elasticity calculated by IS 13311-1992 i.e. dynamic modulus of elasticity(Ed) is greater than the static modulus of elasticity (Ec) calculated by other methods.

The relation between static modulus of elasticity (Ec) and dynamic modulus of elasticity(Ed) is given below.

i.For M20 $E_d= 1.12 E_c$

ii.For M25 $E_d= 1.15 E_c$

iii.For M30 $E_d= 1.10 E_c$

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