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To Establish Correlation Between Destructive and Non-Destructive Compressive Strength Test of Concrete Cube by Regression Model

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Abstract: ***Although as we know that the performance given by non destructive test is easy and among several destructive and non destructive methods for finding the compressive strength of concrete structures. Rebound hammer is very well known instrument used in non destructive testing through which the compressive strength could be easily judged. But during the analysis and interpretation of the test data's it was found that the job was tough and the tests conducted by it were highly affected by the nearby surrounding conditions as well as results were influenced by the characteristics of concrete. This problem can be solved by developing relation between actual compressive strength of concrete and NDT results. In this work correlation is developed between destructive and non destructive testing considering local conditions.***

Keywords: Destructive test, Non Destructive test, Rebound Hammer, Compressive Strength

1. Introduction

Concrete is certainly maximum used material in universe, in the construction works. Concrete is a compound material which created by the mixture of aggregates (fine, coarse), cement water and admixtures. It is suitably adjusting the proportion of various elements; concrete with plenty of compressive strength can be developed. The initial known concrete was found in Yugoslavia way back in 5600 BC spell the concrete was used in prosperity by Egyptians in 2500 BC (Paul, 2013). This method of testing to determine the concrete cube failure. The main purpose of fulfilling a function destructive testing is to know the service life of the Concrete cube and to notice the frailty of design that effectiveness not be shown under normal working conditions. NDT construct of testing methods is to use analysis the compressive strength of concrete cube or structure lacking damage it which is usually performed to examine the material advantage of the Concrete specimen. To determine variation in the structure NDT tests are used in worldwide, minor changes in surface finish of concrete and at the crack or other physical changes on the surface of concrete (Carina, 1994). Unluckily, in the case of concrete testing, all these NDT test give results which is touched by the various parameters like as type of aggregate, size of aggregate, age, moisture content in concrete, and mixed proportion of materials. Consequently, the established relationship between consistent properties and strength differs for different concretes an question.

However, the NDTs are also comfortable and have been used for long times in quality management of engineering construction materials. These tests are suitable to determining the differences in concrete quality from one part of a structure to another part of structure. The rebound hammer test (RHT), developed in Germany in 1930, it can be used for testing of concrete surface hardness. This template, modified in MS Word 2007 and saved as a "Word 97-2003 Document" for the PC, provides authors with most of the formatting specifications needed for preparing electronic versions of their papers. All standard paper components have been specified for three reasons: (1) ease of use when formatting individual papers, (2) automatic compliance to electronic requirements that facilitate the concurrent or later production of electronic products, and (3) conformity of style throughout a conference proceedings. Margins, column widths, line spacing, and type styles are built-in; examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

1) For strength evaluation of concrete structures -

- Rebound hammer test
- CAPO test
- Penetration test
- Ultrasonic Pulse Velocity method
- Pull out test
- Pull off test
- Break off test

2) For determination of corrosion condition of reinforcement, .reinforcement diameter and cover -

- Half cell potentiometer
- Resistivity meter test
- Test for carbonation of concrete
- Prfometer
- Micro Cover meter.

2. Literature Review

Mr. Ayaz mahmood [1] For determination of concrete and detection of concrete damage, NDE methods are applied. Rebound hammer test and Ultra-sonic pulse velocity test will be conducted on specimens and the column, beams, slabs of two double storied buildings in NIT Rourkela. 6 Cubes were casted, pointing at different mean strengths, and then tested and observed by rebound hammer and Ultrasonic pulse velocity method and observed compressive strength with the help of Rebound numbers and Velocity. Also the graphs are plotted between rebound number vs. compressive strength and velocity vs compressive strength.

Mhammadreza Hamidian [7] in this paper authors basically used Rebound hammer test and UPV test on specimen and established structure and found compressive strength of concrete and make the comparison with actual compressive strength found from compressive testing machine. Monitoring of structural health by NDT methods make the comparison of UPV and RSH (Schmidt Rebound Hammer) were taken out in lab and site. The experimental observations by using NDT methods cleared that a good relation exists between compressive strength, SRH and UPV. The SRH creates method of deriving concrete strength with the rate of accuracy of ±15 to ±20 percent and the UPV method is a good instrument for both established structures under construction structures with the accuracy of within ±20%.

Kumara et al., (2017) has done experiment in which studies were made on joint methods is to determine compressive strength of cube by NDT and examination of core specimens from laid buildings. On the samples, ultra pulse velocity, core test and rebound hammer were conducted. Coefficients relations and regression analysis were taken out. Graphs were also generated. All this comparison gives high degree of accuracy on calculation of compressive strength of concrete. By the results it was found that rebound hammer have 0.003 and UPV value have0.355 correlation coefficient.

Lopez et al., (2016) studied lots on NDT. For research work, he selected a concrete structure which was 26yrs old and that structure has many problems regarding cracks, corrosion and segregation.UPV test was conducted.26 samples of structural concrete were collected and rebar mapping was done. With the different NDT results correlation curves were plotted. Finally it showed that as much as concrete is strong, its surface index and wave propagation high.

Bhosale and Salunkhe (2016) have done wok on NDT and found the relation between destructive and non destructive tests on concrete cubes. Concrete mix of M20, M25, M35 were taken. For each grade, cubes of size150*150*150mm and cubes of 150*150*150mm and 16mm steel bar were casted and CTM machine were used after 28 days. Rebound hammer test also conducted and average 12 readings were taken and by this different correlation were raised.

Konapure and Richard robin (2015) also gave relation between destructive and non destructive test on concrete. For this purpose, he usedM20 andM25grade of concrete with proportion of 1:2.9:3.02 and1.98:3.88.Number of cubes casted were 174and 6 no. of rebound readings were taken on each cube with a load of 7N/mm. in CTM .He found that the rebound hammer test results were so under the acceptance and real in compare to the NDT tests for lab samples. The averages of three curves plotted between destructive and non destructive testing were taken.

3. Rebound Hammer Test

3.1 Non destructive methods for determining strength

To find the strength of concrete different Non Destructive Methods are present which depends on the fact that certain physical properties of concrete could be compared to strength. Such properties include hardness, resistance to penetration, rebound capacity and ability to transmit ultrasonic pulses in concrete structure. The non destructive methods are rebound hammer test (Schmidt hammer test), pull out tests, Cut and pull out tests (CAPO test), ultrasonic pulse velocity (UPV) concrete tester and penetration test (Windsor probe).

1) CAPO Test

Accuracy of compressive strength on site can be estimated by CAPO-TEST. Steps for post-installed pullout tests, such as CAPO-TEST, are included in C900. When location is selected for a CAPO-TEST, it must be cleared that reinforcing bars are not within the failure region.

2) Penetration test

The Windsor probe as shown is the good way of testing penetration. For measuring the penetration of probes, the Windsor probes contained of a powder activated gum or driver, alloy steel probes, cartridge, and other related equipments. Penetration depth indicates the compressive strength of the concrete. Calibration charts are also provided by the manufacturer.

3) Ultrasonic pulse velocity method

For NDT testing of concrete ultrasonic pulse velocity method is used. The aim of the ultrasonic pulse velocity method are to establish

- The uniformity of the Concrete
- Cracks, Voids and other defect
- Structure Variations of the Concrete Caused by the surrounding conditions, Corrosion, Wear etc. which may present with time,
- The Quality of the Concrete.

4) Pull out and pull off tests

The force required to extract insert from a concrete mass, the pull out test is adopted. The equipments needed for this test are:

a) For applying pull out force, a ram on a bearing ring is required.
b) To apply force, dynometer is required.
c) Steel rod or discs.

5) Pull off test

Pull off test is based on microprocessor, portable hand operated and mechanical unit for measuring the tensile strength of concrete in situ. The tensile strength be correlated with the compressive strength using early established empirical correlation charts. The equipments for pull off test shall are:

(a) 50mm dia steel disc with threaded rod screw
(b) Pull off tester

The pull of test could be used to find

a) The compressive strength of concrete
b) Tensile strength of in situ concrete
c) The adhesive strength of all kinds of applied coatings
d) The bond strength of concrete surface.

4. Regression Analysis

This chapter presents the development of correlation curve between the values of Rebound number and crushing strength of concrete obtained through compression testing machine.

4.1 Regression performed by other researchers

Samarin (1967) showed that for concrete structures presented in Australia and similar conditions, the relationship between rebound hammer number (*R*) and the compressive strength (*S*) is nearly linear and is given by eqn. (4.1)

$$S = a0 + a1\ R \qquad (4.1)$$

Where a0 and a1 are constants

Liu et al. (2009) performed nondestructive tests such as rebound hammer to obtain relationships between strength and various parameters. The resulting correlation between compressive strength 'Y' (Kgf/cm^2) and rebound number 'X' in downward position obtained is shown in eqn. (4.2) –

$$Y=23.085X- 145.02 \qquad (4.2)$$

Bzeni and Ihsan (2004) related the values obtained from non destructive test methods such as rebound hammer, ultrasonic pulse velocity and combined method with data obtained from destructive test method crushing strength of casted cubes. The rebound number has been measured over the casted cube specimens through digital Schmidt hammer as per ASTM C 805-02. Each cube has been fixed in the compression testing machine by imposing a pressure of approximately 5 MPa. Five readings have been taken on each side of two opposite smooth surfaces of the cube, thus a total of 10 readings were taken on each cube. Then average reading has been used for each cube. The following relation-ship has been obtained –

$$S = 0.045 * R^{1.82} \qquad (4.3)$$

Where S is compressive strength (MPa) and R is Rebound Number in horizontal position. Hence, by substituting rebound numbers of present research in above equation, values of compressive strength obtained are presented in table 4.3. Hajjeh (2012) performed destructive and non-destructive tests over laboratory casted concrete cubes. Regression analysis has been carried out to determine relations between non-destructive testing named as Schmidt rebound hammer test and concrete destructive compression test. Schmidt hammer had been applied in both vertical and horizontal positions. Linear relationships between compressive strength (f) in MPa and rebound number (R) for both horizontal and vertical positions are –

<u>Horizontal Position</u>-

$$f = 1.0501*R – 11.8402 \qquad (4.4)$$

<u>Vertical Position</u>-

$$f = 0.98888*R – 14.2361 \qquad (4.5)$$

Thereafter, by substituting rebound numbers of present research in above equation, values of compressive strength obtained are presented in table 4.4.

4.2 Regression analysis of experimental data

Relationships between Rebound number, in horizontal and vertically downward conditions (Nh, Nd), and compressive strength (S) have been obtained by applying regression analysis tool.

(a) *Rebound hammer in horizontal position*

A graph has been plotted with rebound number (Nh) and compressive strength (S) in MPa of respective concrete cubes, as shown in fig., for performing regression analysis. By curve fitting tool, best fitted relationship with highest regression coefficient is shown in eqn. 4.6.

$$S = 1.21* Nh – 14.12 \qquad (4.6)$$

(b) *Rebound hammers in vertical position*

Thereafter, a graph has been plotted between values rebound number (Nd) and compressive strength (S) in MPa, for rebound hammer applied in vertical direction. Best fitted relationship with highest regression coefficient is shown in eqn. 4.7.

$$S = 1.33*(Nd) – 14.34 \qquad (4.7)$$

Now, values of compressive strength of respective cubes, though above eqns. (4.6) and (4.7) have been presented in Table 4.5.

5. Figures and Tables

a) Figures

Figure 5.1: Testing of cubes

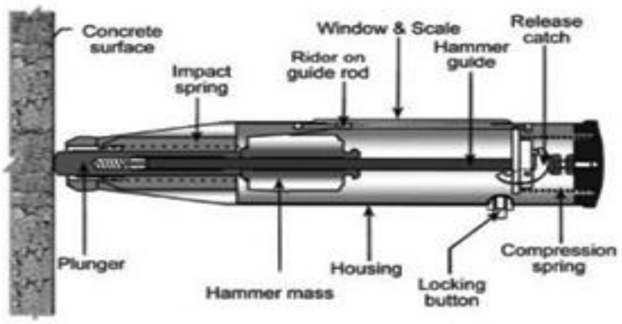

Figure 5.2: Rebound hammer

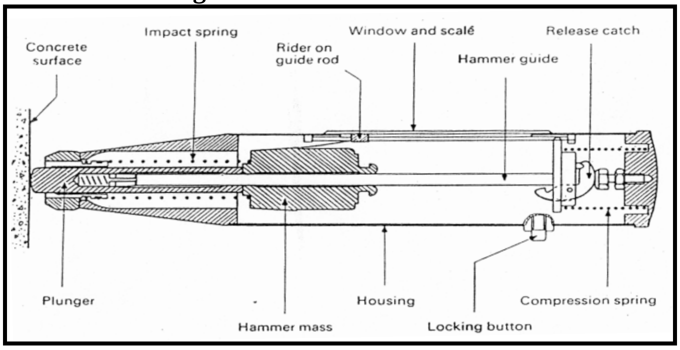

Figure 5.3: Basic Features of Rebound Hammer

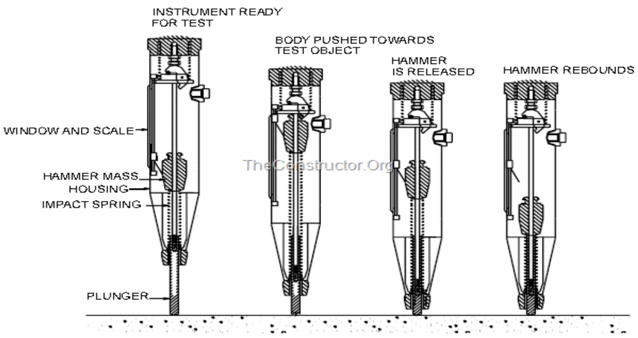

Figure 5.4: Schematic Cross Section of Rebound Hammer & Principle of Operation

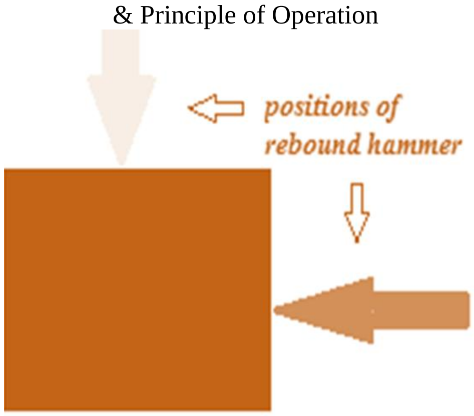

Figure 5.5: Positions of rebound hammer

b. Tables -

Table 5.1: Data obtained by testing of cube

Sr. no.	Rebound Number (Nh)	Compressive strength in MPa	Rebound Number (Nd)	Compressive strength in Mpa	Crushing strength (f) of Cube (Mpa)
1	32	22.68	27	20.74	21.75
2	29	18.91	25	17.44	17.25
3	33	24.23	31	25.83	26.14
4	36	28.14	32	27.60	26.63
5	26	15.40	22	13.80	13.57
6	24	13.15	21	10.95	12.50
7	33	24.23	31	25.83	26.10
8	23	12.39	21	10.95	13.50
9	25	13.80	24	16.52	14.70
10	20	10.28	20	12.26	11.60
11	21	10.98	20	12.26	12.60
12	21	10.98	20	12.26	11.80
13	28	17.44	25	17.44	16.50
14	30	20.74	28	21.35	19.40
15	27	16.50	25	17.44	15.86
16	28	17.44	25	17.44	17.60
17	24	13.15	22	13.80	14.41
18	25	13.80	23	15.40	13.15
19	22	12.14	20	12.26	13.20
20	28	17.44	27	20.74	15.75
21	27	16.50	24	16.52	25.35
22	29	18.91	25	17.44	26.50
23	24	13.15	21	10.95	27.25
24	24	13.15	22	13.80	18.64
25	27	16.50	23	15.40	23.65
26	33	24.23	30	24.23	25.35
27	35	27.60	31	25.83	26.50
28	36	28.14	33	28.14	27.25
29	30	20.74	29	22.685	18.64
30	32	22.68.	31	25.83	23.65

Table 5.2: Compressive strength obtained using eqn. (4.2)

Cube No.	Rebound No. (Downward position)	Compressive Strength in MPa from eqn. (4.2)
1	27	47.82
2	25	43.21
3	31	57.06
4	32	59.37
5	22	36.85
6	21	33.97
7	31	57.06
8	21	33.97
9	24	40.9
10	20	31.69
11	20	31.69
12	20	31.69
13	25	43.21
14	28	50.14
15	25	43.21
16	25	43.21
17	22	36.85
18	23	38.6
19	20	31.69
20	27	47.82
21	24	40.9
22	25	43.21
23	21	33.97
24	22	36.58
25	23	38.6
26	30	54.75
27	31	57.06
28	33	61.68
29	29	52.44
30	31	57.06

Table 5.4: Compressive strength of cubes obtained through both the eqns.

Cube No.	Compressive strength obtained through eqn. (4.6)	Compressive strength obtained through eqn. (4.7)
1	24.6	21.57
2	20.97	18.91
3	25.81	26.89
4	29.44	28.22
5	17.34	14.92
6	14.92	13.59
7	25.81	26.89
8	13.71	13.59
9	16.13	17.58
10	10.08	12.26
11	11.29	12.26
12	11.29	12.26
13	19.76	18.91
14	22.18	22.9
15	18.55	18.91
16	19.76	18.91
17	14.92	14.92
18	16.13	16.25
19	12.5	12.26
20	19.76	21.57
21	18.55	17.58
22	20.97	18.91
23	14.92	13.59
24	14.92	14.92
25	18.55	16.25
26	25.81	25.56
27	28.23	26.89
28	29.44	29.55
29	22.18	24.23
30	24.6	26.89

Table 5.5: 7 days strength of cube with rebound hammer in horizontal position

Cube no.	Concrete Grade	Crushing strength (7 days)	Rebound number in horizontal position	Strength obtained through curve on hammer	Values from eqn. 4.6
1	M-20	12.8	22	12.14	12.5
2	M-20	12.6	21	10.98	11.29
3	M-20	12.7	22	12.14	12.5
4	M-25	15.9	23	12.39	13.71
5	M-25	16.2	24	13.15	14.92
6	M-25	15.9	23	12.39	13.71

Table 5.6: 7 days strength of cube with hammer in vertical position

Cube no.	Concrete Grade	Crushing strength (7 days)	Rebound number in Vertical position	Strength obtained through curve on hammer	Values from eqn. 4.7
1	M-20	12.9	20	12.39	12.26
2	M-20	13.2	21	13.03	13.59
3	M-20	13.2	22	13.78	14.92
4	M-25	16.9	23	15.40	16.25
5	M-25	17.4	24	16.50	17.58
6	M-25	17.5	25	17.44	18.91

Table 5.7: Calibration of curve provided on hammer in Horizontal position

Cube no.	Grade of concrete	Values from eqn. 4.6 (1)	Strength obtained through curve on hammer (2)	Difference (1) - (2)
1	M-20	12.50	12.14	0.36
2	M-20	11.29	10.98	0.31
3	M-20	12.50	12.14	0.36
4	M-25	13.71	12.39	1.32
5	M-25	14.92	13.15	1.77
6	M-25	13.71	12.39	1.32

Average difference = 0.906

Table 5.8: Calibration of curve provided on hammer in Vertical position

Concrete cubes		Values from eqn. 4.7 (1)	Strength obtained through curve on hammer (2)	Difference (1) - (2)
Cube no.	Grade of concrete			
1	M-20	12.26	12.39	-0.13
2	M-20	13.59	13.03	0.56
3	M-20	14.92	13.78	1.14
4	M-25	16.25	15.4	0.85
5	M-25	17.58	16.5	1.08
6	M-25	18.91	17.44	1.47
		Average value = 0.828		

Values of compressive strength calculated from eqn. (4.6) and (4.7) were compared with values obtained through curve provided with hammer to investigate the errors.

c) Graphs

5.1 (a) Rebound hammer in horizontal position

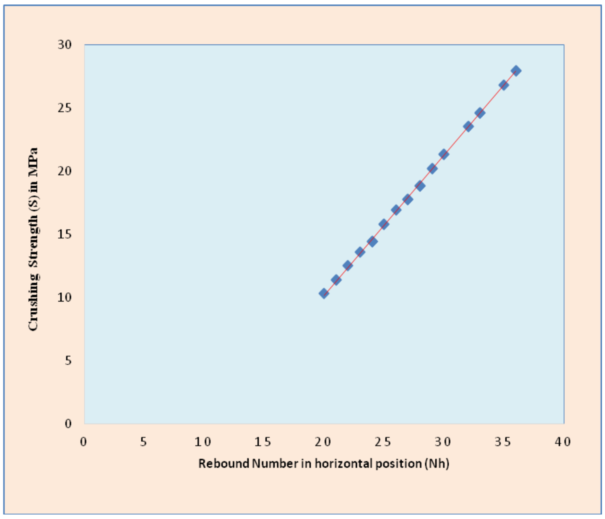

Figure 5.1: Relationship between RM and CS for horizontal position

5.2 (b) Rebound hammer in vertical position

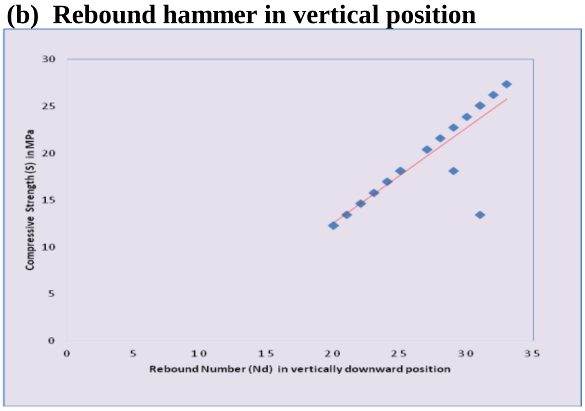

Figure 5.2: Relationship between RM and CS for vertical position

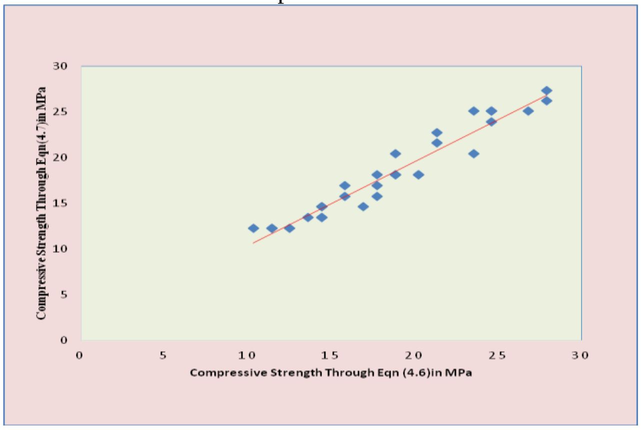

Figure 5.3: Relation between compressive strength obtained by both the eqns

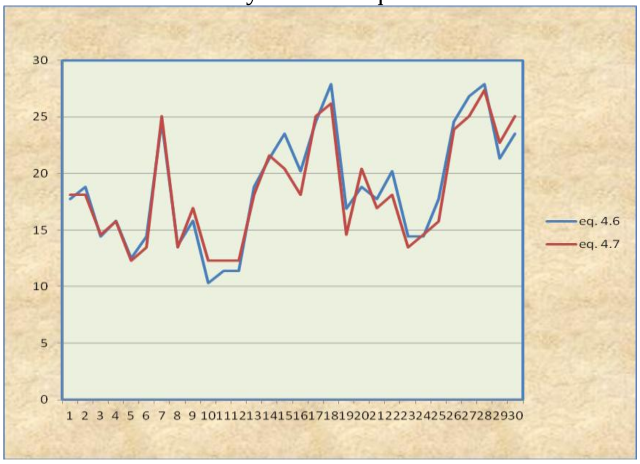

Figure 5.4: Comparative study between above eqns.4.6 and 4.7

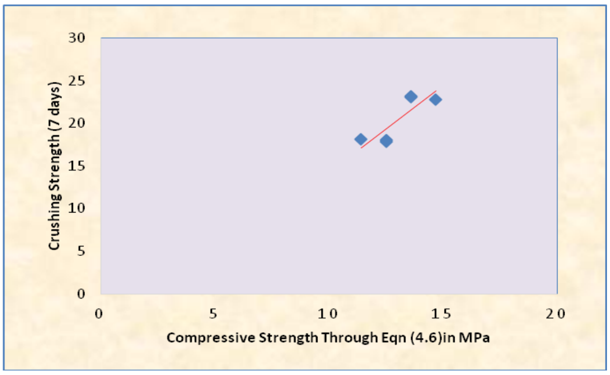

Figure 5.5: Comparison between values of compressive strength through eqn. 4.6 and 7 days strength

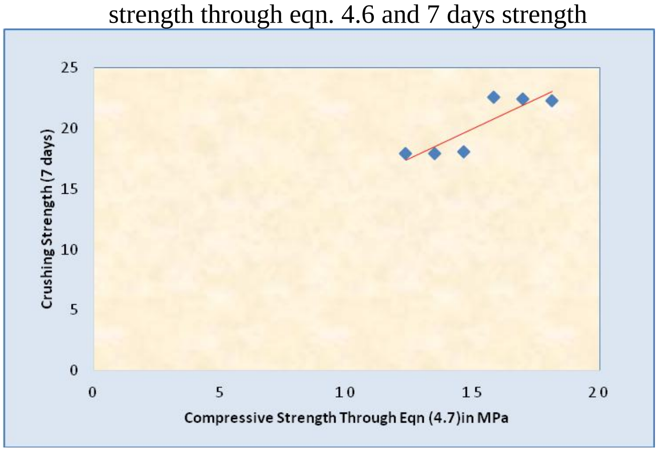

Figure 5.6: Comparison between values of compressive strength through eqn. 4.7 and 7 days strength

6. Conclusions and Future Scope

1) Rebound hammer is provided with a correlation curve for determining the compressive strength by measuring rebound number. However, values obtained may get affected by material properties and testing conditions. Hence, local correlation curves have been developed and equations are generated for evaluating more reliable values of compressive strength through rebound hammers.
2) Following equations have been developed for horizontal and vertical positions of rebound hammer.

   S=1.21*(Nh)–14.12 (Horizontal)

   S=1.33*(Nd)–14.34 (Vertical)
3) To validate both the proposed equations experimentally, new cubes with concrete grades M-20 and M-25 and (3 cubes of each grade) were cast and tested. Henceforth, results of crushing test are found to be comparable with values obtained using rebound hammer and proposed equations.
4) For validating the above equations, results obtained from above two equations have been compared in above figures a good correlation has been obtained.

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