A Study to Establish Correlation Between Rebound Value and Compressive Strength of Concrete Using Materials Available Locally in Nagpur

Aman Raj, Pramod Deshmukh, and Pradeepa.S

Abstract—This study has been taken to investigate the exact rebound-strength relationship of different grades of concrete, as the curves generated for traditional hammers are outdated. Using the material available in the Nagpur region, cube specimens were cast and tested as per IS:516-1959 [1]. Several sets were cast with varying cement contents, decided by mix design, to give a strength range of 10 to 50 Mpa. However, for this study, the Target Mean Strength Standard Deviation factor is not considered. We tested these sets for compressive strengths; each specimen was checked for rebound value for compressive Strength, each specimen was checked for rebound value on four faces. Thus, for each specimen, data for rebound value and Compressive Strength is available. Using this data, a curve for Compressive Strength and rebound value was plotted. The curve generated indicated that the strengths obtained for the same rebound value are higher than that using the traditional curve. There is an increase of about 47% up to a strength of 21 Mpa. From 21 to 38 Mpa, this increase is almost constant to about 30%. From this point forward, the rate of increased Strength reduces by 25% and 14% at 40 Mpa and 45 Mpa, respectively.

Index Terms— Compressive Strength, Rebound Value Ernst Schmidt, Rebound Hammer Test

I. INTRODUCTION

During construction, to ensure the Strength of concrete that is being used, it is a routine practice to cast concrete cubes and test for compressive Strength. However, it is found that despite adequate quality assurance; variance in concrete Strength from batch to batch is inevitable. In addition, the number of test specimens is usually so small that they can be considered as random tests. Thus, there can be uncertainty about the exact Strength of concrete in the structure.

Sometimes, as particularly in case of failures, rebound hammer tests are employed. However, the depth of influence of hammer impact is so small that actually, it represents properties of concrete for outer 30-50 mm. Hence, at times it is difficult to relate rebound value and the Strength of concrete as a whole. Also, the strength curves generated for rebound hammers are some fifty years ago- and are being applied universally. It is possible, that there can be different curves for different ingredients used in concrete – as the overall property of concrete is the combined representation of all the materials.

The present study is intended to establish a relation between Schmidt Rebound Hammer Number and the compressive Strength for concrete produced using the material utilized around Nagpur.

In the Nagpur region, Basalt rock is available – and coarse aggregates are manufactured by crushing this parent rock. Fine aggregates come from two major sources: River Wainganga and River Kanhan. These two rivers contain Quartz sand-which is a weathered product of Feldspar due to their origin from Quartz and Feldspar-rich Madhya Pradesh. These two materials share 70-80% of the volume of concrete. Hence, the properties of these two materials have a substantial effect on concrete parameters. For the same mix proportion, aggregates from a weaker parent rock, porous sandstone for example, when used, concrete exhibits lower strengths as compared to that when a relatively stronger aggregate, say Limestone, is used.

So, the basic properties of aggregates always affect the properties of concrete. The modulus of elasticity (of concrete) is primarily influenced by the elastic properties of the aggregate and to a lesser by the conditions of curing and age of concrete, the mix proportions, and the type of cement [2]. The same code relates to elasticity and compressive Strength as

$$E = 5000\sqrt{F_{ck}}$$

Similarly, flexural and tensile strengths are also related to compressive strengths, Thus, different properties of concrete are related to uniform parameter compressive Strength and hence, determination of true compressive Strength in-situ becomes essential.

In situ Strength can be assessed using the Schmidt rebound hammer. Different types of hammers are available and for each hammer, a correlation curve between rebound value R and the compressive Strength is provided. The curves, however, were developed when the use of Ordinary Portland Cements (OPC) was predominated. These may not be apt under material qualities.

The materials chosen for the study are –

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Aman Raj, *Under Graduate Student, Civil Engineering, Visvesvaraya Institute of Technology, Bengaluru, India.*

Pramod Deshmukh, *Director Technical Highway Division, Geotech Services Pvt. Ltd., Nagpur, India.*

Pradeepa.S, *Assistant Professor, Civil Engineering, Sir M Visvesvaraya Institute of Technology, Bengaluru, India*

A. Portland Pozzolana Cement

This cement is being used in most of the projects except for a few government-funded projects. M15, M20, M25, M30, M35, and M40 grade of cement was procured.

B. Coarse Aggregate

In Nagpur, coarse aggregates are crushed stone. After testing, 20 mm aggregates were found to be oversized while 10 mm aggregates were flakey.

C. Natural Sand

The sand conformed to grading zone 2 of IS:383-1963 [3].

D. Admixture

Conplast SP 430 G8 of Fosroc Chemicals was used.

II. PLAN

A. Ensuring Uniformity of Material

In this phase, initial testing on the material is carried out. Repeat tests are made to ensure that the material is homogenous. If required, the material is remixed or blended with other additional materials to maintain uniformity.

B. Finalizing Concrete Mix Design

Once, the quality and uniformity of ingredients were ensured, mix design was taken up. The initial theoretical design was worked out as per IS:10262-2009[4]. Mixes were prepared using the finalized material and were checked if any correction was necessary. Once necessary corrections were made, trials were taken by varying cement contents. Strengths were checked at 28 days to freeze the cement content for required Strength.

C. Specimen Casting and Testing

After the finalization of concrete mix designs, a set of 12 cubes were cast per grade for each curing period of 7 days and 28 days. Density as determined during mix design was maintained as standard density.

D. Data Analysis

Once the results are available, trend analysis was conducted using software such as Microsoft Excel regression or CurveExpert curve fit. During curve fitting, parameters such as residuals, standard error, correlation coefficient, etc. are also determined. Attempts were made to get simple fits such as quadratic for easy interpretation of strengths. Also, when the correlation coefficient is less than 0.98 (which approaches 1.0 for the perfect fit), range i.e., upper and lower bound limits for application of curve are defined.

III. CONCRETE MIX DESIGN

For the study, the concrete mixes to be used for different strengths were designed. Standard Deviation is a parameter that is used when mixes are to be designed in the laboratory and is to be used at the site. In such cases, a margin for Strength is necessary for laboratory to site conditions.

In this case, since the specimens were cast under laboratory conditions, this factor of standard deviation has been neglected.

Here, the design of the highest grade M45 concrete has been shown.

A. Finalized Mix for Grade M45 Concrete

The process of finalization of mix design of M45 concrete has been shown below-

1) Design Stipulation

The following design stipulations are considered based on the casting conditions and requirements of IS: 456-2000 [2].

TABLE I: DESIGN STIPULATION FOR M45 CONCRETE

Properties	Stipulations
Type of Concrete	Reinforced Concrete
Degree of Exposure	Moderate
Degree of Quality Control	Good
Degree of Workability	50-75 mm Slump
Maximum Size of Aggregate	20 mm (Oversized)
Maximum Water Cement ratio	0.50
Minimum Cement Content	300 kg/m^3

2) Target Mean Strength (ft)

The target mean strength is given as:

$$f_t = f_{ck} + K.S$$

Here,

f_{ck} = Characteristic Strength Required

K = A statistical value based on the accepted proportion of lower test results and number of tests: 1.65 for 5% test results below f_{ck}.

S = Standard Deviation taken as 5.0 Mpa

In this case, the standard deviation is neglected because specimens are processed and tested under laboratory conditions, and the margin for site use is not applicable. Hence, target means Strength is considered as grade designation i.e., 45 Mpa.

3) Trial 1

The initial mix worked out as per IS:10262-2009 [4] is given under –

TABLE II: TRIAL 1 RESULT

Properties	Trial 1
Mix Proportion	1: 1.38: 2.70
Water Cement Ratio	0.38
Cement Content	452 kg/m^3
Admixture	1.0%
Initial Slump Observed	125 mm
Actual Density	2472 kg/m^3

The following observations were made –

a) The workability achieved is much higher, as, against a requirement of 50-75 mm, the actual slump achieved was 125 mm. As this much workability was not required, the water-cement ratio was reduced to 0.35. Hence, a correction of -0.03 is necessary for the water-cement ratio.

b) Sand content in mix calculated as per [4] was 33.7%. At this sand content, the mix indicated slight segregation. Hence, to produce a cohesive mix, sand content was increased to 35%.

c) Since 20mm aggregates are oversized, instead of grading the aggregates to meet IS:383-1970 [3] all-in-grading requirements, aggregates were proportioned by emphasizing more on cohesiveness and workability of the mix rather than grading. This is because the practice of maintaining the cohesiveness of concrete mix is being followed on-site, and the basic object of the proposed study is to establish a correlation between the Strength of as-used-on-site concrete and not a standard one.

Different proportions of ingredients were tried by varying the proportions –to get a cohesive and workable mix. The aggregates proportion was finalized as 60: 40 (20: 10) with 35% sand content.

4) Trial 2

The trial was conducted with necessary corrections in the mix, but with a cement rounded to 450 kg/m^3. The details of the mix are given below –

TABLE III: TRIAL 2 RESULT

Properties	Trial 2
Mix Proportion	1 : 1.44 : 2.68
Water Cement Ratio	0.35
Cement Content	450 kg/m^3
Admixture	1.0%
Initial Slump Observed	75 mm
7 Days Strength	32.6 Mpa
28 Days Strength (Accelerated)	46.9 Mpa

After trial 2, the following observations were made –

a) The mix prepared with 35% sand content showed good workability.

b) Strength achieved is satisfactory for M45

5) Trial 3 & 4

Two additional trials with 435 kg/m^3 and 465 kg/m^3 were also tried. This is because, if the previous mix indicated higher Strength, then by reducing the cement content, the mix can be optimized. On the other hand, if trial 2 showed lower Strength, then cement content was to be increased, so, these two trials were done simultaneously to avoid the delay in design, had the previous mix indicated inapt Strength.

TABLE IV : TRIAL 3 AND 4 RESULTS

Properties	Trial 3	Trial 4
Mix Proportion	1 : 1.51 : 2.80	1 : 1.38 : 2.58
Water Cement Ratio	0.38	0.32
Cement Content	435 kg/m^3	465 kg/m^3
Admixture	1.0%	1.0%
Slump Observed	60 mm	70
7 Days Strength	30.2 Mpa	43.2 Mpa
28 Days Strength	41.4 Mpa	61.3 Mpa
Remarks	Strength does not comply with target Strength	Strength is much Higher than required

6) Finalized Mix for M45

Based on the above test results, the mix used for trial 2 was finalized.

B. Finalized Mix for Different Grades of Concrete

The finalization of mix design for M15, M20, M25, M30, M30, M35, and M40 was done similarly as shown above for M45. Multiple Trials were done for each grade of concrete before deciding the Mix design closest to Target Mean Strength. The finalized mix designs are presented below-

TABLE V: FINALIZED MIX FOR M15, M20, AND M25 CONCRETE

Properties	M15	M20	M25
Mix Proportion	1:2.59:4.81	1:2.35:4.36	1:2.34:3.97
Water Cement Ratio	0.50	0.50	0.48
Cement Content (kg/m^3)	275	300	325
Sand Content (kg/m^3)	712	705	696
Coarse Aggregates 20mm@60% (kg/m^3)	794	785	774
Coarse Aggregates 10mm@40% (kg/m^3)	529	523	516
Admixture Dosage (%)	1.4	1.2	1.0
Admixture (kg/m^3)	3.85	3.6	3.25
Water Content (w.r.t WC ratio) (l/m^3)	137.5	150.0	156.0
Water Absorption of CA @1.1% (l/m^3)	14.6	14.4	14.2
Water Absorption of CA @1.3% (l/m^3)	9.3	9.2	9
Total Water Content (l/m^3)	161.4	173.6	179.2

TABLE VI: FINALIZED MIX FOR M30, M35, M40, AND M45 CONCRETE

Properties	M30	M35	M40	M45
Mix Proportion	1:1.9:3.52	1:1.72:3.2	1:1.58:2.93	1:1.44:2.68
Water Cement Ratio	0.45	0.41	0.38	0.35
Cement Content (kg/m^3)	360	390	420	450
Sand Content (kg/m^3)	684	671	664	648
Coarse Aggregates 20mm@60% (kg/m^3)	760	749	738	724
Coarse Aggregates 10mm@40% (kg/m^3)	507	499	492	482
Admixture (%)	1.0	1.0	1.0	1.0
Admixture (kg/m^3)	3.6	3.9	4.2	4.5
Water Content (w.r.t WC ratio) (l/m^3)	162.0	159.9	159.6	157.5
Water Absorption of CA @1.1% (l/m^3)	13.9	13.7	13.5	13.3
Water Absorption of CA @1.3% (l/m^3)	8.9	8.7	8.6	8.4
Total Water Content (l/m3)	184.8	182.3	181.7	179.2

IV. PREPARATION OF SAMPLES FROM MIX

With the finalized design mixes, specimens were cast. For each mix, a set of six cubes were cast. Cement content for each mix was maintained as designed. During casting, tests were conducted on fresh concrete. Test for the slump of concrete was conducted immediately after mixing and discharging concrete from the mixer. Compaction factor was also conducted after the Slump test on the same mix.

Specimens were cast as specified by the standards. Each mold was filled with concrete in three layers. After pouring the first layer 5 cm thick, the mold was vibrated by placing it in the table vibrator. Vibrations were imparted for a short duration – just enough to make the placed concrete even and leveled. After this, the layer was scrapped using a trowel so that it can form a strong bond with the next layer. After this, the next layer was placed and the same procedure was repeated.

When the mold was filled (three layers), surplus concrete was scrapped using a trowel. The surface was then finished by rolling a tamping bar. Immediately after casting, appropriate unique identification was engraved on each specimen. The identification scheme was so selected as not to confuse the identical specimens physically as well as in records. The specimens thus cast were stored separately under the temperature of 27±2 °C and relative humidity of +90%. Under this condition, the specimen molds were maintained for 24 hours. After this, the specimens were demolded carefully and immediately placed in the curing tank for the required curing period.

The temperature of the curing tank was maintained at 27±2 °C. After seven days, the specimens were removed temporarily and the water was replaced with fresh water. The water used for curing was the same as that used for mixing. Immediately after the curing period is over, the specimens were taken out from the tank, wiped dry, and taken for testing.

V. Results of Rebound Hammer Test

Immediately after taking out specimens from the curing tank, they were tested for Rebound Value using Schmidt Hammer. Following operations were performed while testing for rebound value –

a) Immediately after wiping the sample dry, it was placed on the Compression Testing Machine. It was ensured that the specimen is exactly in center with the line of action of the force of the CTM.

b) Sand After placing the specimen, it was loaded to the stress intensity of 7 N/sq.mm. It was ensured that the load was applied gradually without any shock. For this, the stress-controlled servo CTM was used, with a pacing rate of 5.2 KN/sec. Once, the desired stress intensity is reached, the load was made stable (157.5 KN, i.e., 7 N/sq.mm on 150 × 150 mm specimen.)

c) Using the rebound hammer, the impacts were imparted to the specimen – while it was still loaded. Ten sets of impacts were imparted on each face for averaging. In the first cycle, R values were observed on the front and back face i.e., Face 1 and Face 3. After this the load was released, the specimen was rotated by 90 Degree along the vertical axis, thus, making Face 2 and Face 4 the front and back face. The specimen was loaded again and the R values were observed for both of the faces.

d) Rebound value for the set, i.e., absolute R value is considered as the average of all the readings for each set.

VI. Summary of Results

The average of Compressive Strengths of 6 samples and Rebound Value for 4 faces of 6 samples were calculated for result calculation. Based on the aforementioned tests, the following results were yielded -

TABLE VII: Mean Compressive Strength and R value

Concrete Grade	Compressive Strength Mpa	Absolute Average R value
M15	17.8	18.7
M20	21.5	24.5
M25	27.8	28.0
M30	31.6	29.5
M35	37.9	32.5
M40	42.6	36.0
M45	46.9	39.5

VII. Data Analysis

The strength and Rebound value data summarized from the detailed testing is analyzed. As a practice, rebound value as X data and strengths in Mpa as Y data were fed to CurveExpert – a curve-fitting software**.**

The software used regression analysis based on the data supplied and came up with the based fitted curves. It also gives a correlation coefficient – which for the best-fit curve shall approach 1.0. Best on the output, the best three fitted curves are selected for further analysis.

The three models which indicate the best fit is graphically shown below. The fitting was done using Here S is the Strength to be estimated in Mpa and R is the rebound value a dimensionless quantity.

A. The Sinusoidal Fit

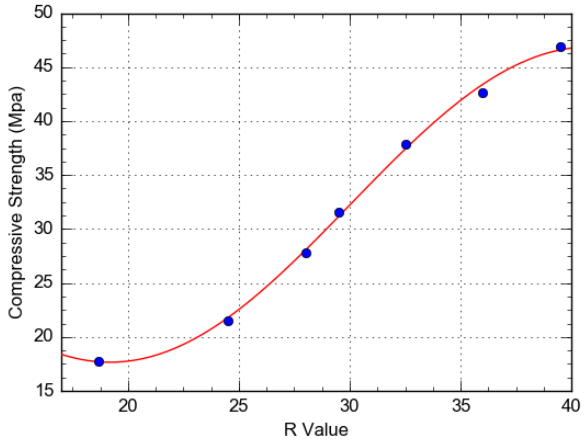

Fig. 1. Sinusoidal Fit

$$S = 32.27 + 14.6\cos(0.145R + 0.358)$$

In this case, the correlation coefficient is 0.99905077. This is almost equal to 1.0 and well above the targeted value of 0.98. Hence, upper and lower limits for this equation are not required.

B. The Polynomial Fit

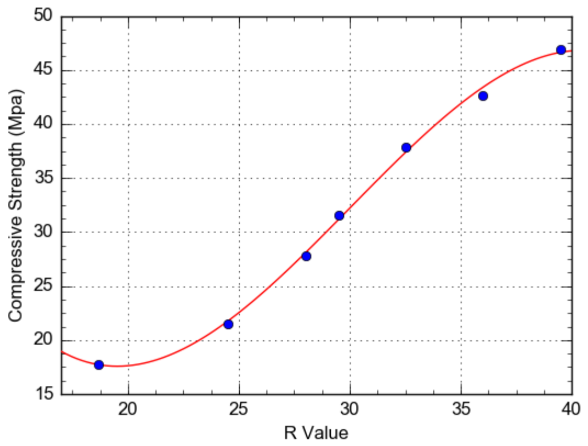

Fig. 2. Third Degree Polynomial Fit

$$S = -0.0064R^3 + 0.57R^2 - 15.1R + 141.3$$

The correlation coefficient is 0.99903763, which is marginally lower than Sinusoidal fit. Hence, this is ranked second.

C. The Richard's Model

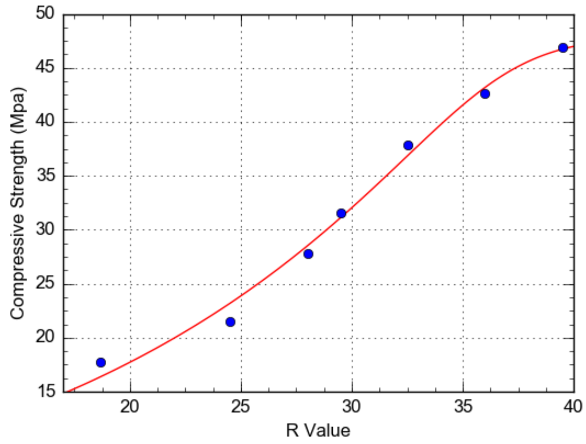

Fig. 3. Richard's Model Fit

$$S = \frac{48}{(1+e^{18.4-0.5R})^{\frac{1}{8.4}}}$$

This equation is ranked third based on the correlation coefficient. However, the correlation coefficient is much lower when compared with the Sinusoidal and Polynomial fit. Hence, this equation is discarded.

D. Error when using Polynomial and Sinusoidal Fit

When the finalized two equations are used while estimating strengths, there is a small error. This is tabulated in the following table –

TABLE VIII: SINUSOIDAL FIT ERROR

R Value	Actual Strength (Mpa)	Estimated Strength using Sinusoidal Fit (Mpa)	Error (Mpa)	% Error
18.7	17.8	17.7	0.1	0.6
24.5	21.5	21.8	-0.3	-1.4
28.0	27.8	28.0	-0.2	-0.7
29.5	31.6	31.1	0.5	1.6
32.5	37.9	37.4	0.5	1.3
36.0	42.6	43.4	-0.8	-1.9
39.5	46.9	46.6	0.3	0.6

TABLE IX: THIRD-DEGREE POLYNOMIAL FIT ERROR

R Value	Actual Strength (Mpa)	Estimated Strength using Sinusoidal Fit (Mpa)	Error (Mpa)	% Error
18.7	17.8	17.6	0.2	1.1
24.5	21.5	21.6	-0.1	-0.5
28.0	27.8	27.9	-0.1	-0.4
29.5	31.6	31.0	0.6	1.9
32.5	37.9	37.2	0.7	1.8
36.0	42.6	43.2	-0.6	-1.4
39.5	46.9	46.4	0.5	1.1

With the two equations finalized, the error in estimating Strength is shown in the above tables. It can be seen that while using both the curves, the maximum error in determining the Strength is 1.9%. The correlation coefficients of both equations are in close agreement. Although the Sinusoidal equation has a higher ranking, the use of third-degree polynomial fit is easier and more practicable.

Due to its simpler nature, the polynomial equation is finalized as a correlation curve.

VIII. COMPARISON WITH ORIGINAL SCHMIDT CURVE

The third-degree polynomial curve is compared with the original Schmidt rebound hammer curve. This is shown in the following graph –

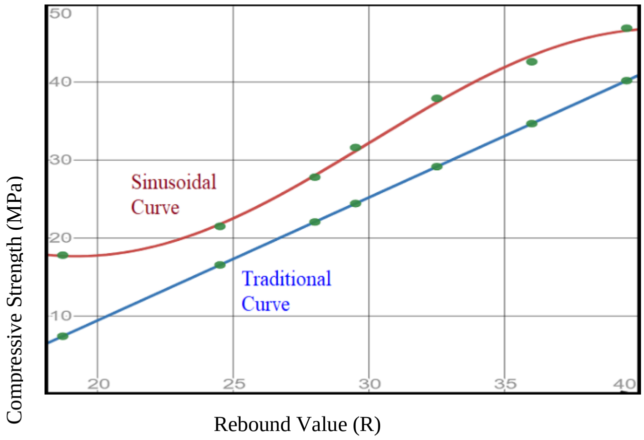

Fig. 4. Sinusoidal and Traditional Curve

From above, it can be seen that while using the traditional curve as provided with the hammer, conservative results are obtained. The new curve generated through this study gives a relatively higher value of compressive Strength for the same rebound number.

As the new curve has been generated using the local material, this can be used for the sites around Nagpur using the concrete in gradients available around Nagpur.

IX. CONCLUSION

From the test results and data analysis, it can be concluded that, when the material used in concrete is Portland Pozzolana Cement (PPC) and locally available materials around Nagpur, the established curve gives conservative values. For local materials, a new curve as given below can be used.

$$S = -0.0064R^3 + 0.57R^2 - 15.1R + 141.3$$

This equation is valid for a strength range of 15 to 45 Mpa.

The main advantage of this curve is to have continuous quality assurance on ongoing concreting activities. Curves can be developed for early age strengths at the site itself. Once the surveys are established, there is no need to wait for compressive strength results for a period of 7 or 28 days as often done. After 3 days of casting concrete, its Strength can be estimated using the on-site established curves. As such if there is any deviation in the correlation, appropriate corrective action can be taken on time.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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