Case study of strength evaluation of structural concrete using rebound hammer test

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One of the most widely spread techniques to estimate the compressive strength of concrete is the rebound hammer test, also known as Schmidt Hammer test. It is one of the most useful Non Destructive techniques in evaluation of concrete structures. In spite of a large number of scientific works trying to calibrate the test, to identify the parameters affecting its results and to estimate its reliability, the original Schmidt curve is still provided by the producers along with the hammer and is used in Structural Engineering Applications. This paper discussed an extensive research, and application, of this technique to assess the compressive strength of a raft foundation of a government building, showing that several phenomena strongly affect the test: moisture content, maturity, stress state among the others. The present paper gives a combined test method for compressive strength assessment by a suitable correlation between the two tests- Rebound Hammer Test and the test by compressive testing machine. The Rebound Hammer Test was performed on a raft foundation. According to the rebound number obtained, corresponding compressive strength value was determined from the calibration graph provided along with the instrument. Initially the instrument was calibrated using 150x150x150 mm concrete cubes. The results were verified using compression testing machine and these were reliable. It is found that the use of NDT techniques like Rebound Hammer Test is much reliable and can well be fit to assess the quality of concrete structures.

REBOUND HAMMER TEST

The rebound hammer is one of the most popular nondestructive testing methods used to investigate concrete. Its popularity is due to its relatively low cost and simple operating procedures. The rebound hammer is also one of the easiest pieces of equipment to misuse; thus, many people do not trust the rebound test results.

Nondestructive testing or Non-destructive testing (NDT) is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. NDT stands for non-destructive testing. In other words it is a way of testing without destroying. This means that the component- the casting, weld or forging, can continue to be used and that the non destructive testing method has done no harm. In today's world where new materials are being developed, older materials and bonding methods are being subjected to higher pressures and loads, NDT ensures that materials can continue to operate to their highest capacity with the assurance that they will not fail within predetermined time limits.

NDT can be used to ensure the quality right from raw material stage through fabrication and processing to pre-service and in-service inspection. Apart from ensuring the structural integrity, quality and reliability of components and plants, today NDT finds extensive applications for condition monitoring, residual life assessment, and energy audit.

Common NDT methods include ultrasonic, magnetic-particle, liquid penetrant, radiographic, remote visual inspection (RVI), eddy-current testing, and low coherence interferometry. NDT is commonly used in forensic engineering, mechanical engineering, electrical engineering, civil engineering, systems engineering, aeronautical engineering, medicine, and art. NDT methods may rely upon use of electromagnetic radiation, sound, and inherent properties of materials to examine samples.

Developed in Germany in 1930, the rebound hammer test (RHT), based on ASTM C805 and BS 4408 Part 4, can be utilized for testing concrete surface hardness. In 1948, Schmidt developed the Schmidt rebound hammer test. This device is universally used because of a hardened steel hammer impacted on the concrete by a spring. The RHT is a convenient NDT. The surface of hardened concrete is struck with the hammer, and concrete compressive strength is estimated via the surface hardness rebound value. This rebound number is shown on a scale and will be between 10 and 100. The Impact Hammer is another name for Schmidt Hammer.

In 1979, the ASTM listed the rebound hammer testing method (ASTM C 805-79) as a standard testing method, explaining that this method can be used to estimate the uniformity of concrete and detect areas of inferior quality within a concrete structure; however, it is not a substitute for concrete strength testing methods. The general view held by many users of the Schmidt rebound hammer is that it is useful in assessing concrete uniformity and in comparing one concrete against another, but can only be used as a rough indication of concrete strength in absolute terms.

Table 1. Impact energy required for rebound hammers

Sr. no.	Application	Approximate impact energy required for the rebound hammers (Nm)
i	For testing normal weight concrete	2.25
ii	For light weight concrete or small and impact sensitive parts of concrete	0.75
iii	For testing mass concrete ,example in roads, hydraulic structures and air field pavements	30.00

When the RHT is performed, kinetic energy from the impact and amount of lost kinetic energy affect the rebound value. Typically, the amount of energy lost during contact between the pole and concrete must be determined via the stress-strain relationship of the concrete; therefore, rebound energy is correlated with the concrete strength and rigidity. However, the accuracy of RT needs to be improved in real applications when estimating concrete strength using the surface rebound value. Low strength concrete will have a low rebound value. However, when two concrete specimens have the same strength and different rigidities, the resulting rebound values may not equal each other. The amount of energy lost with low-rigidity concrete is greater than that lost with high-rigidity concrete. The reason for this difference may be associated with material parameters. For instance, the amount of coarse aggregate and how aggregate is mixed in a concrete mixture affect the concrete rigidity, thus affecting the rebound value.

According to IS 13311 (Part 2), the approximate energy required in rebound hammer is shown in Table 1.

METHODOLOGY

"Standard Test Method for Rebound Number of Hardened Concrete", summarizes the procedure as "A steel hammer impacts, with a predetermined amount of energy, a steel plunger in contact with a surface of concrete, and the distance that the hammer rebounds is measured." The device (Figure 1) consists of a plunger rod and an internal spring loaded steel hammer and a latching mechanism. When the extended plunger rod is pushed against a hard surface, the spring connecting the hammer is stretched and when pushed to an internal limit, the latch is released causing the energy stored in the stretched spring to propel the hammer against the plunger tip.

The hammer strikes the shoulder of the plunger rod and rebounds a certain distance. There is a slide indicator on

Figure 1. Rebound hammer
Source: www.aliexpress.com

the outside of the unit that records the distance traveled during the rebound. This indication is known as the rebound number. By pressing the button on the side of the unit, the plunger is then locked in the retracted position and the rebound number (R-number) can be read from the graduated scale. A higher R-number indicates a greater hardness of the concrete surface. The tests can be performed in horizontal, vertically upward, vertically downward or any intermediate angled positions in relation to the surface. The devices are furnished with correlation curves by the manufacturer.

SIGNIFICANCE AND OBJECTIVE

This method is applicable for the following uses:

- To assess the in-place uniformity of concrete.
- To delineate regions in a structure of poor quality or deteriorated concrete.
- To estimate in-place strength if a correlation is developed.

This standard also states that to use the device to estimate in-place strength, a relationship between strength and rebound number needs to be established for the specific concrete mixture design of interest.

TESTING PROCEDURE

- One of the ways to use the rebound hammer is to locate those areas that may need additional investigation. In this procedure the round hammer is used at several locations to identify those areas that have a lower rebound number. Since the structure would have the same mixture, curing history, moisture content, etc., the rebound hammer can identify those areas that appear to have the weakest concrete.
- Another procedure used is to compare rebound numbers of the concrete that you know is acceptable from a recent placement. This part of the structure has the concrete already evaluated by cores, cylinders or cubes and the concrete strength met the project requirements.
- In this procedure you would determine the rebound numbers of the concrete known to be acceptable. The investigator would then test the concrete with the rebound hammer that needed to be investigated. If the rebound numbers for concrete being investigated are approximately the same or higher than the concrete that had met the project specifications, the tested concrete can be determined to be acceptable. If the rebound numbers in the area being tested are lower, then additional investigations would need to be done by the engineer.
- Some of the guidelines has to be taken which are summarized below:

  1. **Concrete age** : Concrete should be 14 to 56 days old. Accurate readings may be possible sooner for higher strength concrete mix, but 3,500 PSI concrete should not be tested until at least two weeks after pouring old concrete (two months or greater) should be tested only after the outer surface has been ground down 1/4 to 1/2 inch.

  2. **Surface condition** : The surface of the concrete at the point tested must be smooth, dry, and free of honeycombing. Otherwise, rebound readings will be low Indicating a weaker concrete than is actually the case.

  3. **Location of test points** : The concrete to be tested must be at least four inches thick. It is alsorecommendedthatreadingsbetakenonly where the concrete has been in contact with the form. These conditions are most easily satisfied if the readings are taken along the edge of the tank on the sides and ends where the adjoining concrete face (i.e., wall, top, or bottom) can support the point of contact.

     Care must be taken that the actual test point are no closer than one inch from the edge of the tank or from another test point. Readings should never be taken on the tank top or bottom (Figure 2).

  4. **Steps** : The concrete cube specimens are held in a compression testing machine under a fixed load, measurements of rebound number taken and the n the compressive

strength determined according to IS 516: 1959 fixed load required is of order of 7 N/mm^2 when the impact energy of the hammer is about 2.2 Nm. The load should be increased for calibrating rebound hammers of greater impact energy and decreased for calibrating rebound hammers of lesser impact energy. 150 mm cube specimens are preferred for calibrating rebound hammers of lower impact energy (2.2 Nm) whereas for rebound hammers of higher impact energy test cubes should not be smaller than 300 mm.

- Remove hammer from case and press the plunger end against a hard surface to release the plunger from the locked position (Figure 2). (Do not press lock button while doing this.)
- Position hammer horizontally with plunger end against tank at a point which satisfies the criteria of paragraph 3 above.
- Slowly apply pressure until hammer fires. This will occur when only approximately 1/2 inch of the plunger is still visible. Do not press the lock button during this step.
- With the hammer still pressed against the tank, read the rebound number off the scale provided on the hammer. If it is necessary to move the hammer before reading, press the lock button. The rebound number should be read to two significant figures. (e.g., 26, 31, 35).
- Repeat the above procedure at different points around the tank until a total of ten readings has been taken (Figure 3).

Figure 2. Rebound hammer in use
Source: www.wikipedia.org

5. **Interpretation of results** : Calculate the average of the ten readings. If any single reading differs from the average by more than seven units, discard it and recalculate average using the remaining readings. If more than two readings differ from the average by more than seven units, discard all readings and test the tank again. Compare the average reading with the IS values provided in Table 2 and round off to the nearest increment of 50 to obtain the concrete quality.

As per IS 13311 (Part 2), the quality of concrete according to rebound number is shown in Table 2.

Factors affecting rebound number

- **Surface smoothness** – The surface texture significantly affects the R-number obtained. Tests performed on a rough-textured finish will typically result in crushing of the surface paste, resulting in a lower number. Alternately, tests performed on the

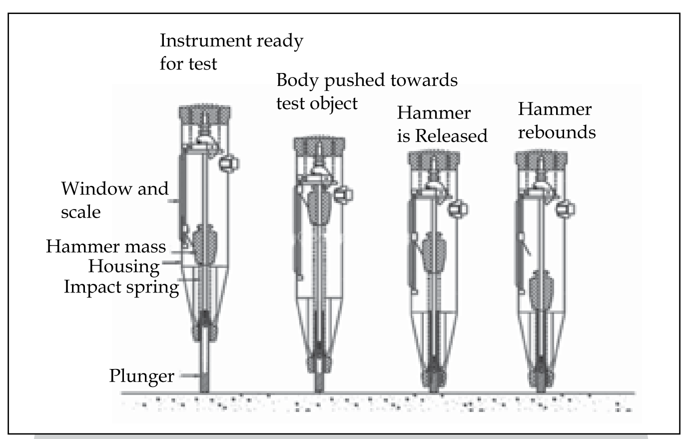

Figure 3. Working of rebound hammer
Source: theconstructor.org

same concrete that has a hard, smooth texture will typically result in a higher R-number. Therefore, it is recommended that test areas with a rough surface be ground to a uniform smoothness. This can be achieved easily with a Carborundum stone or similar abrasive stone.

- **Age of concrete** – Concrete continues to develop strength with age due to cement hydration. This is the reason behind the development of data relating rebound numbers to the compressive strength of the concrete mixture or cores from the structure. Testing of concrete less than 3 days old or concrete with expected strengths less than 1000 psi is not recommended. This is because the R-numbers will be too low for an accurate reading, and the testing will be more destructive to the concrete surface.

- **Moisture content** – This has a profound effect on the test results. Dry concrete surfaces result in higher rebound numbers than wet surfaces.

- **Surface carbonation** – With greater amounts of surface carbonation, higher rebound numbers will be obtained. Rebound numbers of a carbonated surface can be as much as 50 percent higher than non-carbonated surfaces. Older concrete surfaces may have much deeper amounts of surface carbonation than younger concrete.

- **Aggregate, air voids, and steel reinforcement** – The presence of materials in the immediate area where the plunger comes into contact with the concrete will have an obviously profound effect as well. If the test is performed over a hard aggregate particle or a section of steel reinforcement, the result may be an unusually high rebound number. ASTM C805 states that tests directly over reinforcing bars with cover less than 0.75 inches should not be conducted.

Table 2. Quality of concrete according to rebound number

Average rebound number	Quality of concrete
>40	Very good hard layer
30 – 40	Good layer
20 – 30	Fair
< 20	Poor
0	Delaminated

- **Temperature** – Tests should not be performed on frozen concrete surfaces. Wet concrete at temperatures of 32ºF or less may result in higher rebound numbers. Low concrete temperature has a major effect on the rate of cement hydration, which results in slower setting and rate of strength gain (Figure 4). A good rule of thumb is that drop in concrete temperature by 20°F [10°C] will approximately double the setting time.

- **Calibration of the rebound hammer** - Carrying out periodic calibration of rebound hammer using standard anvil is desirable. However for new and retrofit concrete construction, rebound hammer is calibrated on concrete test cubes for a given source of constituent materials (viz. cement, sand and stone aggregate), this calibration data can be used with reasonable accuracy in arriving at equivalent in-situ cube strength of relatively new concrete (i.e. not more than three months old concrete). This calibration exercise may be carried out in a concrete lab by casting cubes of designed mix

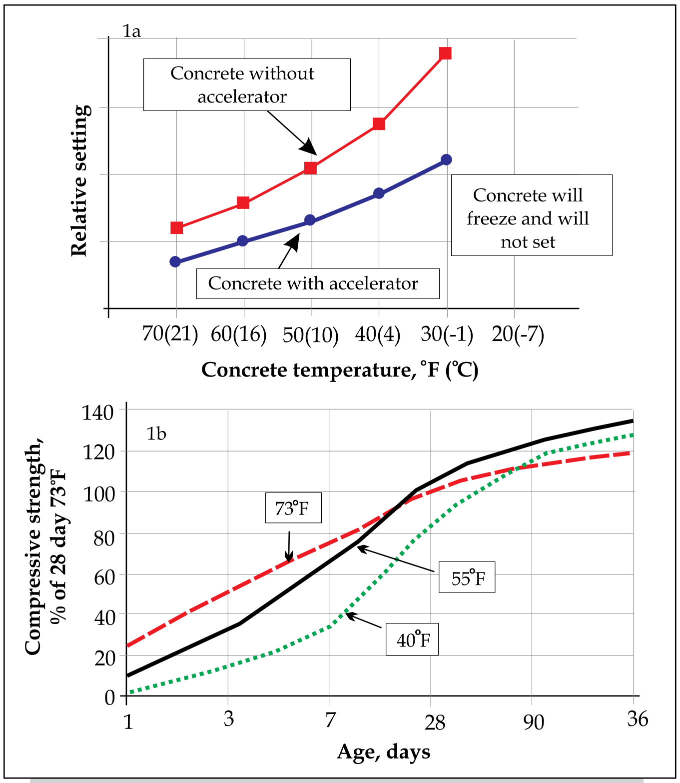

Figure 4. Effect of temperature on setting time and compressive strength

and testing these under controlled condition with rebound hammer as well as test to destruction in compression. Calibration graphs then can be drawn (Figure 5). Large number of readings is desirable to reduce the effects of variability in readings due to various localized as well as instrument factors.

The value of R (rebound number) can be used to estimate the compressive strength (CS) of cube sample using the following equation (Franklin, 1989):

$$\text{Log10 CS} = 0.00088(\gamma)(R) + 1.01$$

where γ = unit weight of sample.

Advantages of using Schmidt rebound hammers

1. A small amount of structure damage occurs in testing, usually negligible.
2. It makes possibility of testing concrete strength in structures where cores cannot be drilled.
3. It has an application of less expensive testing equipment, Low power consumption.
4. Simple operation doesn't need high consumption of labor, or intensive training.
5. Ideally suited for on-site testing, Handy for difficult to access or confined test areas (i.e. working overhead).

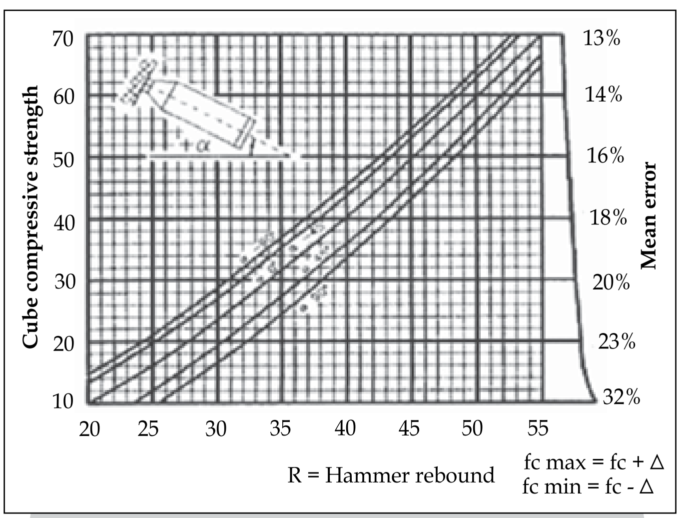

Figure 5. Calibration chart of rebound hammer

EXPERIMENTAL ANALYSIS

It is well known that the rebound hammer test consists of the calibrated impact of a mass against the surface of concrete mass through a φ=20mm plunger. Due to the reduced dimension of the impact area, smaller than the maximum size of the aggregates, the test strongly depends on local heterogeneity of the material: hidden aggregates at short distance from the impact area, voids due to improper mix, water content and finishing of the surface, concrete maturity, etc.

In this paper, an experimental campaign was carried out at the construction site of a Punjab Government Building.

In order to determine the compressive strength of the raft foundation laid at the site, rebound hammer test was performed in the first week of February 2014 for the purpose. The test points included certain points on the beam and the raft (mat). Since the weather was rainy during this testing period, dry and wet factors were taken into account.

The initial experimental analysis was as follows (February 2014):

The compressive strength obtained from the above test was not satisfactory as the site conditions were wet. The compressive strength obtained was too low as it was raining during the testing period and the low temperatures affected the gain in strength of the foundation (Table 3).

Therefore, the test was performed again after 28 days when the concrete had gained sufficient strength in the month of March 2014. The site was dry and the weather conditions were quite favorable. The new test readings were as follows:

In order to evaluate the calibration factor of rebound hammer 3 cube specimens provided were analyzed on the compression testing machine in the laboratory. The calibration of rebound hammers for beam and rafts is shown in Tables 4 and 5.

Table 3. Beam-wise and raft-wise cube strength in N/mm^2

Beam name	Point reading			Average	Position	Graph cube strength (N/mm^2)	Surface dry/wet	Multiplying calibration factor	Corrected cube strength (N/mm^2)
B-12	32	36	37	35	H	32	Dry	1.00	32
B-9	30	38	38	35	H	32	Dry	1.00	32
B-1	34	34	30	33	H	28	Dry	1.00	28
B-7-1	27	35	32	31	H	25	Dry	1.00	25
B-14	32	31	28	30	H	24	Dry	1.00	24
B-2	30	30	26	29	H	22	Dry	1.00	22
B-12-2	26	22	30	26	H	18	Dry	1.00	18
B-13	27	28	24	26	H	18	Dry	1.00	18
B-4	24	28	30	27	H	18	Dry	1.00	18
B-7-2	22	26	30	26	H	18	Dry	1.00	18
B-8	22	25	33	27	H	18	Dry	1.00	18
B-10	25	26	23	25	H	17	Dry	1.00	17
B-3	18	30	28	25	H	17	Dry	1.00	17
B-11	19	28	26	24	H	15	Dry	1.00	15
B-5	22	24	25	24	H	15	Dry	1.00	15
B-6	24	19	22	22	H	12	Dry	1.00	12
								Average	21
Raft name									
F-B15	24	22	20	22	V	16	Wet	1.20	19
F-B18	20	18	22	20	V	14	Wet	1.20	17
F-2B	18	20	12	17	V	12	Wet	1.20	14
F-B14	20	18	17	18	V	12	Wet	1.20	14
F-B16	14	20	16	17	V	12	Wet	1.20	14
F-B17	16	14	18	16	V	12	Wet	1.20	14
F-B4	19	10	15	15	V	12	Wet	1.20	14
F-B5	20	18	14	17	V	12	Wet	1.20	14
F-B6	16	15	14	15	V	12	Wet	1.20	14
								Average	15
Cube tested at site	20	23	22	22	H	12	Dry	Strength as per Compressive Strength test (N/mm^2)	14
Cube tested at lab	48	48	48	48	H	54	Dry	Strength as per Compressive Strength test (N/mm^2)	46
Average calibration ratio=0.5*(46/54+14/12)=1									

Remarks : The above individual values may have an error of +-25% from the actual strength. However on average basis the value may be seen as representative. Thus it may be inferred that the strength of concrete near surface in beams is close to M20 and that in raft near surface is close to M15.

Dimensions of the cube were - 150x150x150 mm.

Hence calibration factor for horizontal position = (0.864+0.798+1.10)/3 = 0.92

Hence calibration factor for vertical position = (0.920+0.890+0.860)/3 = 0.89

The compressive strength corresponding to rebound hammer values for the beams are charted as follows (March 2014):

The compressive strength corresponding to rebound hammer values for the raft are charted as follows:

The result obtained after 28 days of initial testing was found to be satisfactory as the compressive strength value obtained was 30 N/mm^2. The previous results ranged between 15-20 N/mm^2 which were too low.

INTERPRETATION OF RESULTS

The initial testing had certain unfavorable factors affecting it which hindered the final results. So the test conducted after 28 days provided satisfactory results as weather and site conditions had improved. The final result can be interpreted as follows:

- The random test point results for the project site showed lower strength in February 2014 after the initial experimental analysis. Lower winter temperature might have influenced the test results.
- The rain around the testing day might have influenced the test results.
- Low concrete temperature has a major effect on the rate of cement hydration, which results in slower setting and rate of strength gain.
- A drop in concrete temperature by 20°F [10°C] approximately doubles the setting

Table 4. Calibration of rebound hammer (for beams)

Specimen cube no.	S. no.	Rebound hammer value			Average	Position	Load at failure (kN)	Experimental compressive cube strength (N/mm^2)	Graph cube strength (N/mm^2)	Calibration factor
		(i)	(ii)	(iii)						
1	1	46	48	45	47.83	H	1050	46.66	54	0.864
	2	46	54	48		H				
2	1	42	33	36	37.66	H	647.2	28.76	36	0.798
	2	36	38	41		H				
3	1	38	30	30	33.5	H	718	31.91	29	1.10
	2	34	36	33		H				

Table 5. Calibration of rebound hammer (for raft)

Specimen cube no.	S. no.	Rebound hammer value			Average	Position	Load at failure (kN)	Experimental compressive cube strength (N/mm^2)	Graph cube strength (N/mm^2)	Calibration factor
		(i)	(ii)	(iii)						
1	1	46	46	45	46.80	V	1200.60	53.36	58	0.920
	2	46	52	46		V				
2	1	42	36	36	38.50	V	861.07	38.27	43	0.890
	2	38	38	41		V				
3	1	40	32	32	36.00	V	735.30	32.68	38	0.860
	2	38	36	38		V				

Table 6. Compressive strength corresponding to rebound hammer values for the beams

S. no.	Beam name	Rebound hammer value			Average	Position	Graph cube strength	Estimated calibration factor	Equivalent estimated cube strength (N/mm^2)
		(i)	(ii)	(iii)					
1	B-12 b	53	39	43	45	H	44	0.92	40.48
2	B-7	39	46	37	41	H	41	0.92	37.72
3	B-9	41	42	40	41	H	41	0.92	37.72
4	B-91	37	34	38	36	H	32	0.92	29.44
5	B-12 a	30	39	40	36	H	32	0.92	29.44
6	B-13	39	32	37	36	H	32	0.92	29.44
7	B-4	30	34	30	31	H	26	0.92	23.92
								Average	32.59

time. The slower rate of setting and strength gain can be accounted for the delay in gaining compressive strength.

- The exposed concrete gained strength in 28 days due to continuous curing and increase in atmospheric temperature.
- In the month of March 2014, the rebound hammer test results indicated that the concrete used in beams and rafts had sufficiently gained strength to satisfy the requirement of M25 grade concrete on average basis.
- The individual estimated sample strength of the concrete varied from 26N/mm^2 to 40N/mm^2 indicating that the homogeneity of the concrete might have been affected (Tables 6 and 7).
- The individual test results as per the manufacturer specifications may have an error of up to +-25%.

The average compressive strength of the beams after the application of calibration factor was determined to be approx. 30 N/mm^2 and for the raft was 30 N/mm^2 (Tables 6 and 7).

Table 7. Compressive strength corresponding to rebound hammer values for the rafts

S. no.	Raft name	Rebound hammer value			Average	Position	Graph cube strength	Estimated calibration factor	Equivalent estimated cube strength (N/mm^2)
		(i)	(ii)	(iii)					
1	RB-5 b	37	38	37	37	V	40	0.89	35.60
2	RL2	38	29	32	33	V	36	0.89	32.04
3	RB-7	32	31	33	32	V	34	0.89	30.26
4	RB-5 a	28	32	32	31	V	32	0.89	28.48
5	RL1	32	29	29	30	V	31	0.89	27.59
6	RL3	28	26	25	26	V	25	0.89	22.25
								Average	29.37

Remarks : The above individual values may have an error of +/-25% from the actual strength. However on average basis the value may be seen as representative. Thus it may be inferred that the strength of concrete near surface in beams is close to M32.59 and that in raft near surface is close to M29.37.

CONCLUSION

The rebound hammer provides an inexpensive and quick method for non-destructive testing of concrete in the laboratory and in the field. This test is conducted to assess the relative strength of concrete based on the hardness at or near its exposed surface. The limitations of the hammer should be recognized and taken into account when using it. It cannot be overstressed that the hammer must not be regarded as a substitute for standard compression tests but rather as a method useful in checking uniformity of concrete and comparing one concrete against another but it can only be used as rough indication of concrete strength in absolute terms. Estimation of surface strength of concrete by the rebound hammer within an accuracy of ±20 to ±25% may be possible only for specimens cast, cured, and tested under conditions similar to those from which the correlation curves are established. Rebound hammers test the surface hardness of concrete, which cannot be converted directly to compressive strength, flexural strength, elastic modulus, etc and also because of the inherent uncertainty of estimating strength with a rebound number, the test is not intended as the basis for acceptance or rejection of concrete.

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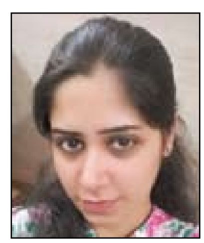

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