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RESEARCH ARTICLE

Robust Analysis of Various Measurement Uncertainty Parameters in Rebound Hammer Test

Prashant Awachat[1]*, **Vinayak Dakre**[1], **Pranav Charkha**[2], **Siva Reddy Vundela**[3]

1 Assistant Professor, Department of Mechanical Engineering, G H Raisoni University, Amravati, India
2 Professor and Dean, School of Engineering and Technology, D Y Patil University, Talegaon, Pune
3 Director (Technical), National Institute of Solar Energy (NISE)

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* **Corresponding author**.

pnawachat@gmail.com

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Abstract

Objective: The major objective of the proposed work is to determine the concrete's expected compressive strength by evaluating the consistency of concrete using Rebound Hammer Test. Further, the determination of the quality of one component of the concrete relates to the quality of another component based on the concrete meeting criteria established by the several standards in the literature. **Methods:** Laboratory professional's needs to properly correlate the compressive strength with the observations of rebound hammer normally called as rebound index. Since test readings are affected by number of parameters, measurement uncertainty plays vital role in deciding the output of test. Analytical method as per the guidelines of GUM (Guide to the Expression of Uncertainty in Measurement) and Monte Carlo simulation is used for obtaining uncertainty value in measurement of compressive strength. As per the proposed test procedure total 10 test blocks made up of concrete are selected for testing. For each block 6 readings are taken using rebound hammer. The rebound index (RI) obtained in reading is then converted to compressive strength (CS) value. **Findings:** The obtained test results are compared with the simulation values obtained from Monte Carlo simulation. The results shows that the magnitude of evaluated uncertainty values are on higher side as compare to simulated uncertainty values. **Novelty and applications:** In this paper uncertainty related to compressive strength measurement using rebound hammer test is evaluated by considering the effects of various parameters related to instrument, test procedure and test environment. This obtained uncertainty values provides reliable information about compressive strength of concrete structures.

Keywords: Measurement; Measurement Uncertainty; Rebound Hammer Test; Compressive Strength; Monte Carlo Simulation

1 Introduction

Measurement of compressive strength of concrete using non-destructive tests such rebound hammer test, faces many challenges due to large variations in test readings. Laboratory professional's needs to properly correlate the compressive strength with the observations of rebound hammer normally called as rebound index. Since test readings are affected by number of parameters, measurement uncertainty plays vital role in deciding the output of test. The concrete's compressive strength can be quickly and easily determined using the rebound hammer test. This non-destructive test was developed by Swiss engineer Ernst Schmidt in 1948. Rebound hammers, feature a mass controlled by a spring that moves along a plunger which is situated inside the cylindrical container [1,2] . Overall, the measurement result is merely known as an approximation of the measurand's value, and it is only completed after combining the uncertainty with final obtained result. This is because all measurements are subject to the errors, it is adequately and frequently claimed that a measurement result outcome is only complete if it is accompanied by a quantitative description of its uncertainty [3,4]. Measurement uncertainty also describes how genuinely the true value of the measur and is known, assuming that no undiscovered systematic errors are impacted by the measurement. In measurement science obtaining the test results is very straightforward process. Laboratory professionals just need to follow the measurement manual steps to get the result, while calculating the uncertainty related to these results needs more consideration. Test results accompanied with uncertainty value provides the reliable value of measurand. The uncertainty evaluation procedure will also need to take into consideration of a number of variables that have an impact on the measurement result. To measure the uncertainty, all factors are potentially influenced by the outcome which is considered, such as (repeatability, testing speed, temperature, etc.) [3,5,6].

In general, commonly a measurement result is influenced by a large number of influence quantities and parameters. While it is very hard to identify all of them, the most important one can be identified and the size of their impacts are on the measurement result approximated. Furthermore, it may be mathematically represented in terms of their affect and the measurement outcomes. In this paper, a technique for determining measurement results in the field of non-destructive testing methods using Rebound Hammer Test and their related uncertainties are established. This process for determining measurement test uncertainty could be used in a variety of fields, including metrological measurement. To reduce measurement uncertainty and also to increase the accuracy of data, the methodology can be implemented for various testing instruments in laboratories [7–9]. In most of the studies on non-destructive methods propagation of uncertainty is mainly dependent on repeatability of measurement results but it is needed to focus on all parameters associated with particular measurement process which may contribute in final uncertainty value. The effects of qualitative factors which contributes in uncertainty are considered largely in case of measuring instrument but very fewer attention is given on impact of these parameters on test specimen. It is necessary to integrate both the instrument and test specimen related parameters to get suitable results. Overall, the uncertainty in a rebound hardness test is caused by both systematic and random influences; although, these can be been evaluated. In specifically, the approach of measurement uncertainty analysis can be used to determine the size of systematic errors. It is observed that the systematic errors had the significant impact on the overall measurement value. From a statistical control point of view, the proportion of the inherent error sources can de been analyzed.

2 Methodology

The methodology upon which the rebound hammer test is based is that the degree to which an elastic mass bounces back after striking a concrete surface is directly proportional to the surface's degree of hardness. Compressive strength of test specimen is connected with the reading of a rebound hammer. On a standard scale, the rebound value is expressed as a rebound index. The hammer's body features a graph from which the compressive strength can be easily determined [3,10–12]. In case of rebound hammer test researchers can only apply regression equations that they have obtained from the results of laboratory tests within the parameters that have been set for that particular implementation. As a result, the accuracy of measuring strength using the rebound hammer may be lower than anticipated. The coefficient of variation shows a diminishing trend with increasing mean compressive strength, however there is no such trend detected with increasing mean rebound index. This shows that the influencing parameters have impact on the coefficient of variation. These influencing parameters are moisture content, carbonation, surface condition of test specimen, size of test specimen, temperature, etc. Figure 1 shows the primary parts of rebound hammer are, body (housing), plunger, hammer mass, impact spring and compression spring. The hammer mass is secured to the plunger rod, and the amount of rebound is determined by use of a rider on guide rod. The rider is connected to window scale available on the body from which rebound number (index) can be directly read [13,14].

For the evaluation of measurement uncertainty during estimation of compressive strength using rebound hammer both type A and type B components of uncertainty are considered as per the GUM approach. These uncertainty components consist of parameters like repeatability, calibration, moisture content and bias [15,16].

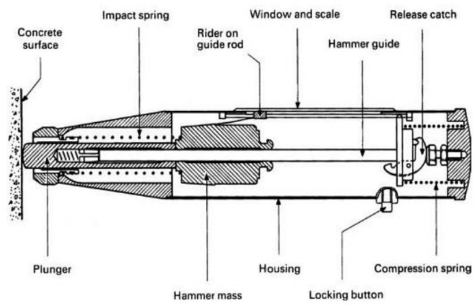

Fig 1. Rebound hammer parts

2.1 Uncertainty in instrument readings due to repeatability

The type A standard uncertainty (U_r), arising from repeated measurements on the concrete block is determined by equation (1)[3],[9,10].

$$U_r = \frac{\sigma}{\sqrt{n}} \tag{1}$$

Where, σ is the standard deviation of compressive strength measurements obtained from rebound index value on concrete cube n is the number of rebound index measurements made on concrete cube

Therefore with $\sigma = 4.39$ and $n = 10$

$$U_r = \frac{4.39}{\sqrt{10}} = 1.388\, N/mm^2 \tag{2}$$

Degree of freedom, $V_r = 10 - 1 = 9$

2.2 Standard uncertainty due standard test anvil used for calibration of instrument

Type B Uncertainty U_{cal} occurred due to calibration process is calculated by using equation (3)[11]

$$U_{cal} = \frac{Deviation\ in\ compressive\ strength}{\sqrt{3}} \tag{3}$$

From the calibration report, standard test anvil (GZ11) is used with calibration accuracy of $\pm$ 2 (2.5%).

Since the average rebound index is 27.65, corresponding variation in reading is 0.69

Therefore $\quad Maximum\ rebound\ index = 27.65 + 0.69 = 28.34$

$$Minimum\ rebound\ index = 27.65 - 0.69 = 26.96$$

The corresponding compressive strength values for maximum rebound index and minimum rebound index is 25.5 and 24 respectively

$$Deviation\ in\ compressive\ strength = 25.5 - 24 = 1.5 N/mm^2$$

Hence, assuming rectangular distribution, the standard uncertainty due to calibration U_{cal} is,

$$U_{cal} = \frac{1.5}{\sqrt{3}} = 0.866\ N/mm^2$$

Degree of freedom, $V_{cal} = \infty$

2.3 Uncertainty due to moisture content of concrete

A wet surface will give rise to underestimation of the strength of concrete calibrated under dry conditions concrete, this can be about 20% lower than in an equivalent dry concrete. Since average compressive strength is 24.81 N/mm^2 20% lower value, deviation in compressive strength is 4.96 N/mm^2

Hence, assuming rectangular distribution, the standard uncertainty due to moisture content of concrete is,

$$U_m = \frac{4.96}{\sqrt{3}} = 2.86\, N/mm^2 \tag{4}$$

For type A evaluation considering rectangular distribution, degree of freedom, $V_m = \infty$

2.4 Uncertainty due to operator bias

The operator bias obtained from the operator could be taken into consideration. For this systematic uncertainty, bias for operator can be stated using $\pm$ 0.5 limits at 95% confidence level. By using the inverse normal distribution function , φ^{-1} the standard uncertainty (U_b) due to bias can be calculated by using equation (5) [12].

$$U_b = \frac{k}{\varphi^{-1}\left(\frac{1+p}{2}\right)} = 0.263\, N/mm^2 \tag{5}$$

Where k denotes the value of limits and p is the confidence level, therefore

For type A evaluation considering rectangular distribution, degree of freedom, $V_b = \infty$

2.5 Combined standard uncertainty

Individual standard uncertainties of repeatability, calibration, moisture content and bias determined by Type A and Type B assessments needs to be combined together to obtain the final combined standard uncertainty (UC) as per the equation (6) [9,13–16].

$$UC = \sqrt{U_r^2 + U_{cal}^2 + U_m^2 + U_b^2} = 3.309\ \ N/mm^2 \tag{6}$$

2.6 Expanded uncertainty

The value of the compressive strength is generally thought to lie somewhere in a range surrounding the test result. Expanded uncertainty in rebound hammer test is the form of uncertainty developed to fulfil this criterion. The process of estimation of expanded uncertainty (U) starts with utilizing the separate uncertainty and degrees of freedom values of repeatability, calibration, moisture content and bias for the calculation of effective degrees of freedom (V_{eff}) using equation (7) [[16].

$$V_{eff} = \frac{UC^4}{\frac{U_r^4}{V_r} + \frac{U_{cal}^4}{V_{cal}} + \frac{U_m^4}{V_m} + \frac{U_b^4}{V_b}} = 78.33 \approx 80 \tag{7}$$

From Student-t distribution table at 95% level of confidence for effective degree of freedom$V_{eff} = 80$, coverage factor $K =$ 1.99

The expanded uncertainty (U) is obtained with the help of combined uncertainty (UC) and coverage factor (K) as per the equation (8)

$$U = K \times UC = 6.586\, N/mm^2 \tag{8}$$

3 Result and Discussion

Before starting the testing rebound hammer is calibrated with the help of test anvil which is made up of high BHN hard steel and test specimen surface is properly polished with grinding stone. As shown in Figure 2 hammer is vertically pressed against the test surface and plunger is released. Instrument remains in locking position at this stage.

After locking rebound hammer is separated from the surface of test specimen and rebound index reading is noted from the scale available on the body of hammer as shown in Figure 3. The obtained rebound index value is converted into compressive

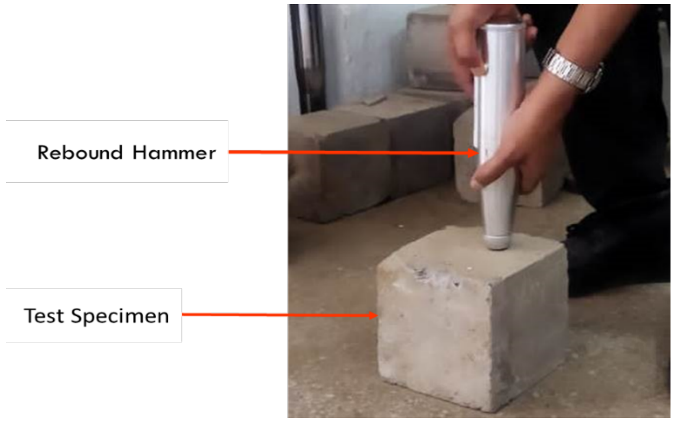

Fig 2. Rebound hammer testing on concrete specimen

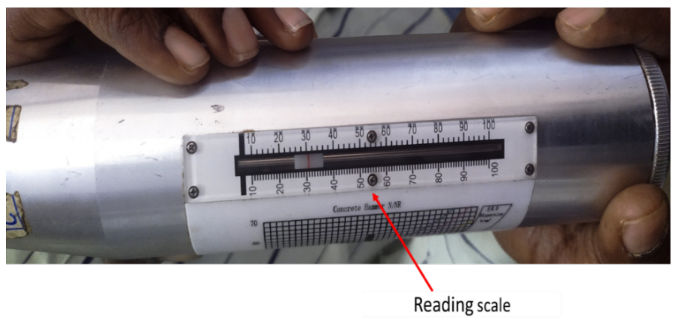

Fig 3. Reading of rebound index

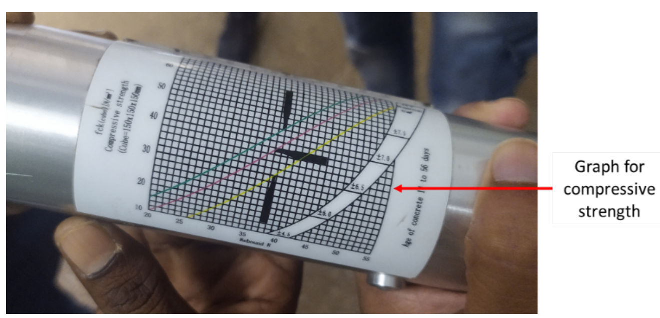

Fig 4. Rebound index Vs Compressive strength graph

strength value by using the standard graph provided on the body of hammer [14–16]. This process is repeated for number of locations on the test surface.

As per the above mentioned test procedure total 10 test blocks made up of concrete are selected for testing. For each block 6 readings are taken using rebound hammer. The rebound index (RI) obtained in reading is then converted to compressive strength (CS) value. Table 1 shows the observations of rebound hammer test on all 10 test specimens.

In Monte Carlo Simulation, the final combined uncertainty and expanded uncertainty in rebound hammer test was obtained from repeatability, calibration, moisture content of concrete and bias. In this simulation process a set of total 10000 random numbers is generated for these parameters and finally standard deviation of all 10000 values obtained by using equation (9)

$$\sigma(u) = \sqrt{\frac{\sum (Xi - X_{avg})^2}{N}} = 1.052 \ N/mm^2 \tag{9}$$

Table 1. Observations of rebound hammer test

Test Block No	Observation No	1	2	3	4	5	6
1	RI	21	26	23	22	25	24
	CS (N/mm^2)	15.5	22	18	17	21	19.5
2	RI	30	29	38	35	28	29
	CS (N/mm^2)	28	27	41.5	36	25.5	27
3	RI	30	26	28	31	30	27
	CS (N/mm^2)	28	22	25.5	30	28	24
4	RI	28	28	27	28	31	27
	CS (N/mm^2)	25.5	25.5	24	25.5	30	24
5	RI	24	26	30	26	28	32
	CS (N/mm^2)	19.5	22	28	22	25.5	32
6	RI	24	23	26	21	24	23
	CS (N/mm^2)	19.5	18	22	15.5	19.5	15.5
7	RI	29	36	24	30	32	27
	CS (N/mm^2)	27	38	19.5	28	32	24
8	RI	32	27	28	31	26	31
	CS (N/mm^2)	32	24	25.5	30	22	30
9	RI	22	26	24	23	23	27
	CS (N/mm^2)	17	22	19.5	18	18	24
10	RI	28	32	34	26	28	35
	CS (N/mm^2)	25.5	32	35	22	25.5	36

Where,Xi, are the absolute values obtained in simulation

$Xavg$ is the average of absolute values which is 1.591

N is the Total number of absolute values i.e.10000

Considering 95% confidence level the final expanded uncertainty is appears to be 3.483 N/mm^2 (14.04%) by neglecting the 5% values from the set of 10000 values as shown in Figure 5.

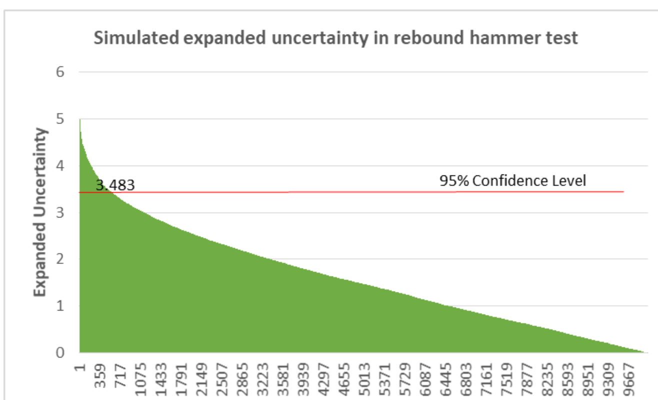

Fig 5. Expanded uncertainty in rebound hammer test using MCM

Figure 6 shows the four major components (Repeatability, Calibration, Moisture and Bias) comparison and oobservations of rebound hammer test for both simulated and evaluated uncertainties. It is observed that moisture content have highest impact in overall uncertainty with the uncertainty value of 1.422 and 2.86 for simulation and evaluation process respectively. In evaluation process after moisture content repeatability of readings, calibration of instrument and operator bias contributes with the uncertainty value of 1.388, 0.866 and 0.263 respectively. Whereas in simulation process repeatability of readings, calibration of instrument and operator bias contributes with the uncertainty value of 0.896, 0.432 and 0.131 respectively. As per the above results the percentage wise contribution of moisture, repeatability, calibration and bias for both situations simulated and evaluated, it is observed that each parameter contributes in same manner for both the situations. Figure 7 shows that moisture content of test specimen contributes around 53.19 % followed by repeatability, calibration and bias with 25.81%, 16.11% and 4.89% respectively in overall uncertainty value of compressive strength.

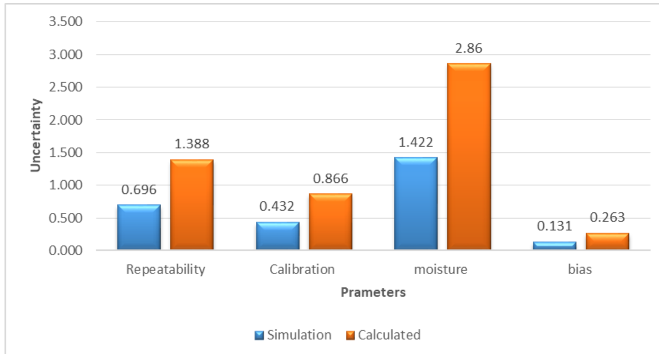

Fig 6. Comparison of Simulated and evaluated parameters inrebound hammer test

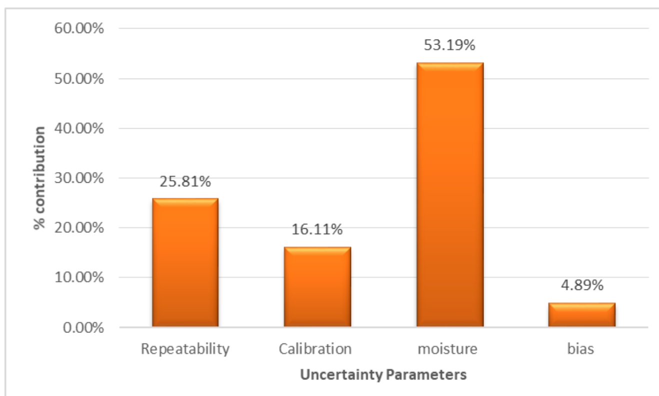

Fig 7. Parameter wise impact in overall uncertainty in rebound hammer test

4 Conclusion

For the evaluation of compressive strength of concrete using rebound hammer test, the expanded uncertainty associated with the test result is 26.55 % at 95% level of confidence with coverage factor $K = 1.99$ hence, compressive strength of concrete cube$CS = 24.81 \pm 6.586\ N/mm^2$. Test results of rebound hammer test which is normally used for onsite inspections are mostly affected by environmental conditions such as moisture content of test site. Hence based on the above results laboratory professional can concentrate on the parameters which mostly affect the result and produces the large variations. The properly calculated uncertainty values provides controlled test results which helps to provide reliable information for predicting life of concrete structures.

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