

Monitoring Of Progressive Compressive Concrete Strength Using Ndt

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Abstract- This study investigates the monitoring of progressive compressive strength development in concrete using non-destructive testing (NDT) techniques, aiming to provide a reliable, in-situ alternative to traditional destructive testing. An experimental program was conducted on concrete specimens (mixes with varying strength ranges) to track strength evolution at early and mature ages, specifically 7, 28, and 90 days. The NDT techniques, primarily focusing on Ultrasonic Pulse Velocity (UPV) and the Rebound Hammer (RH) test, were utilized to estimate the compressive strength (SonReb method). The research confirms that while sole NDT methods possess inherent inaccuracies (roughly 15-20% for RH), combining RH and UPV significantly improves the precision of in-situ concrete strength predictions. This study presents a systematic investigation of the monitoring of progressive compressive strength of M40 Concrete using a pendulum-based non-destructive testing (NDT) technique. The research is based on the principle of the coefficient of restitution, where the rebound angle of a pendulum after impact is correlated with the compressive strength of concrete. Traditional strength evaluation using the Compression Testing Machine (CTM) is destructive and unsuitable for in-situ monitoring. To overcome this limitation, a pendulum-based device is used to measure rebound angle at different curing ages (2, 7, 14, 21, and 28 days). Two empirical relationships were developed: 1) $Y = -0.1377x^2 + 19.037x - 618.21$ 2) $Y = 0.0028x^2 + 0.2613x + 56.976$ 3) where x is the rebound angle, and Y is the compressive strength (MPa). The results show a strong correlation between rebound angle and compressive strength, validating the effectiveness of the proposed method. The study demonstrates that this technique is economical, simple, and suitable for real-time field applications.

Keywords: Rebound Angle. Compressive Strength. Correlation. Strength Prediction. Formula. Equation

I. INTRODUCTION

General Introduction

Concrete is one of the most widely used construction materials in civil engineering due to its high compressive strength, durability, and adaptability. It is used in almost all types of structures, including buildings, bridges, pavements, and dams.

The performance of concrete structures depends largely on the accurate assessment of their strength, particularly compressive strength. This parameter is essential for design, quality control, and structural safety evaluation.

Concrete is the cornerstone of modern civil infrastructure, with its compressive strength acting as the primary indicator of structural integrity and durability. Traditionally, evaluating this strength

relies on destructive testing (DT) of cast cylinders or cores, which often causes damage, is labor-intensive, and provides delayed feedback, restricting fast-paced construction timelines.

Non-Destructive Testing (NDT) has emerged as a vital technology in the construction industry, allowing for the in-situ evaluation of concrete properties without compromising the structural integrity. Unlike destructive methods, NDT techniques, such as the Rebound Hammer (RH) and Ultrasonic Pulse Velocity (UPV), can be applied directly to the structure to provide instantaneous data on strength uniformity, quality control (QC), and structural assessment.

Compressive strength is considered the most important property of concrete as it defines its ability to withstand loads. It is directly related to durability, stiffness, and load-bearing capacity.

Accurate measurement of compressive strength is necessary to ensure that concrete meets design specifications and performs satisfactorily under service conditions.

Progressive Strength Monitoring

Monitoring the progressive development of concrete strength is crucial for optimizing construction schedules, such as determining the optimal time for formwork removal, post-tensioning, or load application. In-situ monitoring helps identify areas of lower integrity, ensuring that the concrete meets specified standards as it cures, reducing the risks associated with premature loading.

The combined use of NDT methods—often referred to as the "SonReb" (Sonic-Rebound) method—offsets the limitations of individual tests by correlating surface hardness with internal wave velocity, resulting in more accurate compressive strength predictions.

Significance of the Study

The findings of this report provide practical guidance for engineers and project managers to adopt NDT for real-time quality assurance. By utilizing non-destructive techniques, construction projects can achieve higher safety standards, reduce the cost and

time associated with laboratory testing, and enhance the longevity of the built environment.

Conventional Testing Methods

Traditionally, compressive strength is measured using destructive testing methods such as the Compression Testing Machine (CTM). Concrete cubes or cylinders are tested until failure.

Although these methods provide accurate results, they have limitations such as destruction of specimens, time consumption, and inability to assess in-situ structures.

Need for Non-Destructive Testing

Non-Destructive Testing (NDT) methods have emerged as an effective solution to overcome the limitations of destructive testing. These methods allow evaluation of concrete properties without damaging the structure.

NDT techniques are particularly useful for existing structures, where the extraction of samples is not feasible. They provide a rapid and economical assessment of strength and quality.

Overview of NDT Techniques

Various NDT methods are used in practice, including rebound hammer, ultrasonic pulse velocity, and penetration resistance methods.

Each technique is based on different principles and provides specific information about concrete properties. However, these methods have limitations in terms of accuracy and reliability.

Limitations of Existing Methods

Existing NDT methods often rely on empirical correlations that are influenced by surface conditions, moisture content, and material variability.

These limitations reduce the reliability of strength prediction and highlight the need for improved techniques.

Concept of Rebound Angle Method

The rebound angle method is an advanced NDT technique that measures the angle of rebound after

impact. It is based on energy transfer and the coefficient of restitution.

This method provides a more physical representation of concrete behavior compared to traditional rebound number methods.

M40 CONCRETE

M40 is a structural grade concrete with a compressive strength of 39 MPa at 28 days, primarily used for heavy-load structures, high-rise buildings, and marine environments. It is a "design mix" rather than a nominal mix, generally using a 1:1.5:3 ratio (cement:sand:aggregate) with a maximum water-cement ratio of 0.45, ensuring high durability.

Need for the Present Study

There is a need to develop a reliable NDT method that can accurately predict compressive strength using a physically meaningful parameter.

The pendulum-based rebound angle method addresses this need by providing improved correlation and practical applicability.

Scope of Study

This study focuses on the M40 grade and evaluates strength at different curing ages. The aim is to develop and validate empirical equations using experimental data.

Objectives

The objectives include developing a pendulum-based NDT method, establishing a correlation between rebound angle and compressive strength, and validating results with CTM.

II. LITERATURE REVIEW

Introduction to Non-Destructive Testing

Non-Destructive Testing (NDT) is an essential technique in civil engineering that enables the evaluation of material properties without causing any damage to the structure. In concrete engineering, NDT is widely used to determine strength, durability, uniformity, and the presence of internal defects. Unlike destructive methods, NDT allows repeated testing at different stages of construction and service life.

The importance of NDT has increased significantly due to the growing need for rapid assessment of structural safety and quality control. It is particularly useful for in-situ evaluation where extracting samples is not feasible. NDT methods provide valuable information that supports decision-making in the construction, maintenance, and rehabilitation of structures.

Need for NDT in Concrete Structures

Concrete structures are exposed to various environmental and loading conditions throughout their life. Monitoring their strength and performance is critical to ensure safety and durability. Traditional destructive methods, although accurate, are not suitable for existing structures as they require specimen extraction.

NDT methods offer a practical solution by enabling engineers to evaluate concrete without affecting its integrity. These techniques are widely used in bridges, buildings, pavements, and other infrastructure projects for condition assessment and quality assurance.

Pendulum-Based Rebound Angle Method

The pendulum-based method uses a swinging mass to impact the concrete surface. The rebound angle after impact is measured and used to estimate compressive strength. Stronger concrete absorbs less energy and produces higher rebound angles.

This method offers advantages such as simplicity, low cost, and better physical interpretation compared to traditional rebound hammer methods.

Development of New NDT Kit

The proposed method is based on the conservation of mechanical energy. When the pendulum is released, potential energy converts into kinetic energy. Upon impact with a concrete surface, a portion of this energy is transferred to the surface as force, while the remaining energy causes the pendulum to rebound. As shown in Fig. 1, the prototype consists of a pendulum with a mass of 83 gm (m_1) suspended by a string of length 270 mm (L). The hardplastic ball was chosen as the pendulum mass due to its lower weight compared to metal,

minimizing the risk of surface damage in the early days of casting and ensuring durability and chemical stability. Harder balls tend to retain more energy upon impact, producing more consistent rebound angles. Several plastic balls with different weights, including commercially available golf balls, were tested. A ball weighing 83 g and with a diameter of 70 mm was found to provide the most consistent results in terms of impact force and rebound angle. The length of the pendulum, $L = 270$ mm, was selected in reference to IS 456 and IS 13920, aligning with typically common beam/column dimensions in reinforced concrete structures. During testing, the pendulum was initially held at 90 degree perpendicular to the surface. The rebound angle influenced by the coefficient of restitution was measured via a high-frame-rate camera. From recorded footage, the maximum rebound angle after impact was extracted for further analysis. The string-based mechanism is particularly effective for vertical surfaces, though horizontal application remains a potential area for future development. Since the method is based on the coefficient of restitution and conservation of energy, the device can be effectively applied to both cube and cylindrical specimens, provided their surfaces are accessible for impact.

Problem Statement

Existing NDT methods are not able to provide reliable strength estimation under varying field conditions. Their dependence on surface properties and calibration limits their practical applicability. There is a need to develop a method that uses a physically meaningful parameter and provides consistent results without extensive calibration.

Gaps in Previous Research

Despite extensive research in NDT, several gaps still exist. Most studies focus on surface hardness methods and lack consideration of energy-based behavior. There is limited research on rebound angle methods and their application to M40 Concrete. Additionally, there is a lack of studies on early-age strength prediction and real-time monitoring. These gaps highlight the need for improved methods that provide consistent and accurate results.

III. METHODOLOGY

M40 Concrete is used in this study due to its high flowability and durability. The selection of M40 grade ensures sufficient strength for structural applications. This observation is discussed with respect to experimental conditions, highlighting variation, consistency, and interpretation of measured values.

The experimental program focuses on establishing a correlation between rebound angle and compressive strength using a pendulum-based non-destructive testing method. This observation is discussed with respect to experimental conditions, highlighting variation, consistency, and interpretation of measured values.

The pendulum operates on the principle of conservation of energy, where potential energy converts to kinetic energy and partially dissipates during impact. This observation is discussed with respect to experimental conditions, highlighting variation, consistency, and interpretation of measured values.

The rebound angle is influenced by material stiffness and energy absorption characteristics, which directly relate to compressive strength. This observation is discussed with respect to experimental conditions, highlighting variation, consistency, and interpretation of measured values.

Concrete cubes of size 150 mm were cast and tested at different curing ages to monitor strength development. This observation is discussed with respect to experimental conditions, highlighting variation, consistency, and interpretation of measured values.

Regression analysis was used to derive empirical equations correlating rebound angle and compressive strength. This observation is discussed with respect to experimental conditions, highlighting variation, consistency, and interpretation of measured values.

Two equations were developed and validated using CTM results to ensure the accuracy of the proposed method. This observation is discussed with respect to experimental conditions, highlighting variation, consistency, and interpretation of measured values. Multiple readings were taken at each point to reduce experimental error and improve reliability. This observation is discussed with respect to experimental conditions, highlighting variation, consistency, and interpretation of measured values. The materials used include OPC cement, fine aggregate, coarse aggregate, and water. This observation is discussed with respect to experimental conditions, highlighting variation, consistency, and interpretation of measured values. Proper curing conditions were maintained to ensure consistent strength development in concrete specimens. This observation is discussed with respect to experimental conditions, highlighting variation, consistency, and interpretation of measured values.

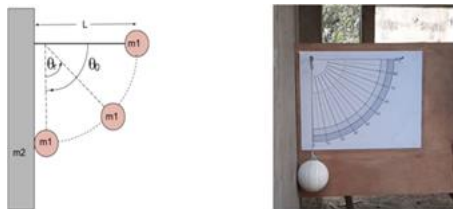


Fig. 1 Schematic diagram & Actual instrument

It includes the detailed materials used and experimental methodology adopted for evaluating the compressive strength of M30 using a pendulum-based non-destructive testing method. The methodology is designed to establish a reliable correlation between rebound angle and compressive strength using experimental validation.

The approach integrates theoretical principles of energy transfer with practical testing procedures. The experimental readings obtained from rebound angle measurements and CTM testing form the basis for developing predictive equations.

Principle of Pendulum-Based NDT Method

The pendulum-based method operates on the principle of conservation of energy. When the pendulum is raised to an initial height, it possesses

potential energy (PE). Upon release, this energy converts into kinetic energy (KE) before impact.

During impact with the concrete surface, part of the energy is absorbed by the material, and part is retained, causing rebound. The rebound angle is directly related to the energy retained and thus to the strength of the concrete. In the context of physics and engineering, pendulum theory primarily deals with the mechanics of a body suspended from a fixed point that swings back and forth under the influence of gravity. This periodic motion is a classic example of Simple Harmonic Motion (SHM) when the swings are small.

Experimental Setup

The experimental setup consisted of a pendulum device mounted on a rigid frame. The pendulum had a fixed length and mass to ensure consistent impact energy.

A protractor scale was used to measure the rebound angle accurately. The setup was aligned to ensure perpendicular impact on the concrete surface.

The proposed method is based on the conservation of mechanical energy. When the pendulum is released, potential energy converts into kinetic energy. Upon impact with a concrete surface, a portion of this energy is transferred to the surface as force, while the remaining energy causes the pendulum to rebound. As shown in Fig. 1, the prototype consists of a pendulum with a mass of 83 gm (m_1) suspended by a string of length 270 mm (L). The hardplastic ball was chosen as the pendulum mass due to its lower weight compared to metal, minimizing the risk of surface damage in the early days of casting and ensuring durability and chemical stability. Harder balls tend to retain more energy upon impact, producing more consistent rebound angles. Several plastic balls with different weights, including commercially available golf balls, were tested. A ball weighing 83 g and with a diameter of 70 mm was found to provide the most consistent results in terms of impact force and rebound angle. The length of the pendulum, $L = 270$ mm, was selected in reference to IS 456 and IS 13920, aligning with typical common beam/column dimensions in

reinforced concrete structures. During testing, the pendulum was initially held at 90 degree perpendicular to the surface. The rebound angle influenced by the coefficient of restitution was measured via a high-frame-rate camera. From recorded footage, the maximum rebound angle after impact was extracted for further analysis. The string-based mechanism is particularly effective for vertical surfaces, though horizontal application remains a potential area for future development. Since the method is based on the coefficient of restitution and conservation of energy, the device can be effectively applied to both cube and cylindrical specimens, provided their surfaces are accessible for impact.

Experimental Methodology

- 1) The prototype was initially tested on various construction materials such as RCC beams, RCC columns, AAC blocks, and wood to observe and understand the behavior of response for different material surfaces.
- 2) The prototype was used to test concrete columns in the under-construction site; a total of ten columns were selected. Tests were conducted on the 3rd, 7th, 14th, 21st, and 28th days after casting. A Total of six points are marked on the column, two each from the top, middle, and bottom zones, and are equally spaced along the height (L/3) and located 20 mm from the edges. On each point, 5 rebound angles were recorded.
- 3) Concrete cubes of size 150 × 150 × 150 mm were cast from the same mix used on-site and tested using a Compression Testing Machine (CTM) to record the compressive strength of the cube.
- 4) The column was tested using the rebound hammer as per the IS 516 (Part 5/Sec 4) 2020

New Methodology for M40 Concrete

The methodology same as the previous experimental methodology, it includes

- 1) 1)The prototype was tested on 3 cubes of M40 design
- 2) 2)Taking the 5 readings of each point, which are 2 from the upper corners, 2 from the lower corners, and the middle one.

- 3) 3)Then take the average of each corner reading, and then take the average of all averages.
- 4) 4)The reading is taking place on the 2,7,14,21 day of casting cubes and the 28th day of casting.
- 5) 5)At the same time, taking the CTM strength (MPa) of 7-day and 28day resp.

Specimen Preparation

Concrete cubes of size 150 mm × 150 mm × 150 mm were cast using the prepared M40 mix. The specimens were demoulded after 24 hours and cured in water for specified durations.

Testing was conducted at 7 days and 28 days to capture strength development over time.

M40 Acceptance Criteria (28-Day Test)

M40 concrete gains strength rapidly in the first week, followed by a slower rate of gain until 28 days.

Time Milestone	28-Day Percentage Strength	Estimated Strength (M30)
3 Days	~40% - 60%	~14- 18 MPa
7 Days	~65% - 75%	~20 - 24MPa
14 Days	~85% - 90%	~30 - 34 MPa
28 Days	100% (Characteristic)	39 MPa (Target: 48+)

Experimental Readings

The following experimental readings were recorded

Days of Testing	Rebound Angle
2	56.4
7	60.8
14	61.2

21	62.2
28	67.2

Rebound Angle = 67.2°
CTM Strength = 38.96 MPa

Testing Procedure

1)The pendulum was raised to a fixed initial angle and released without external force. Upon impact with the concrete surface, the rebound angle was recorded.

2)Multiple readings were taken at different locations on each specimen to reduce variability. The average value was considered for analysis.

CTM Testing Procedure

1)After NDT testing, the same specimens were tested using a Compression Testing Machine. The load was applied gradually until failure.

2)The maximum load at failure was recorded and converted into compressive strength. These values were used as a reference for validating NDT results.

3)Record the values of cubes for the 7th and 28th day, respectively.

Results

This chapter presents a detailed analysis of experimental results obtained from pendulum-based NDT testing and CTM testing. The objective is to evaluate the accuracy of the developed empirical equations and establish a reliable relationship between rebound angle and compressive strength.

2 Days:

Rebound Angle = 56.4°

7 Days:

Rebound Angle = 60.8°

CTM Strength = 22.69 MPa

14 Days

Rebound Angle = 61.2°

21 Days:

Rebound Angle = 62.2°

28 Days:

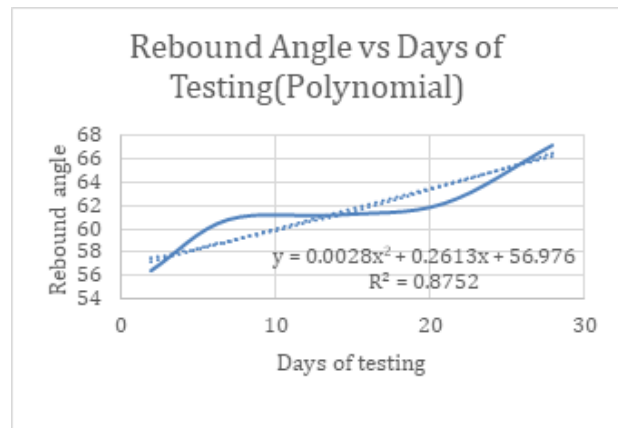


Fig1.Rebound Angle vs Days of Testing Graph

From the above data, we get the correlation between Rebound Angle & Days of testing

We get the Polynomial Equation,

$$Y = 0.0028x^2 + 0.2613x + 56.976$$

$$R^2 = 0.8752$$

From this graph we get the,

If the days of testing increases then the Rebound angle also increases.

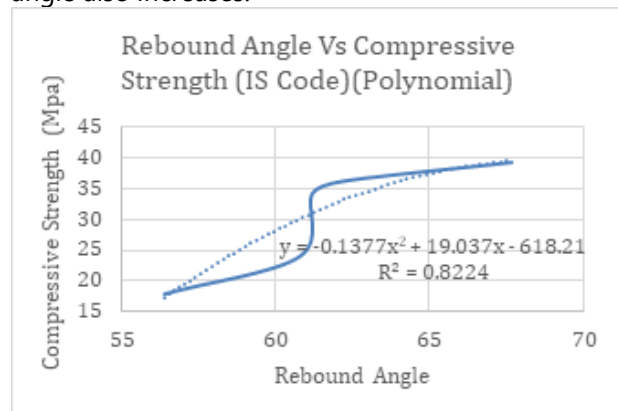


Fig.Rebound Angle vs Strength graph

From the above experimental data, we got the graph of Rebound angle vs Strength

This indicates the new Polynomial Equation we get, this Equation, which correlates the strength and Angle.

The equation is as follows,

$$Y = -0.1377x^2 + 19.037x - 618.21$$

$R^2 = 0.8224$ Where, Y= Strength & X=Rebound Angle

Predicted Strength Calculation

For 2 Days:

Equation 1 = 80.62 MPa

Equation 2 = 17.45 MPa

For 7Days:

Equation 1 = 83.21 MPa

Equation 2 = 30.21 MPa

For 14 Days:

Equation 1 = 83.45MPa

Equation 2 = 31.10 MPa

For 21 Days:

Equation 1 = 84.06 MPa

Equation 2 = 33.15 MPa

For 28 Days:

Equation 1 = 87.17 MPa

Equation 2 = 39.47 MPa

These values are compared with CTM results to evaluate accuracy.

Days	Rebound Angle	Strength (IS CODE)	Strength from Formula	CTM Strength	%diff b/w IS Code & Formua	%diff b/w CTM & Formula
2	56.4	18	17.45		3.06%	
7	60.8	24	30.21	22.69	-25.88%	-33.14%
14	61.2	34	31.10		8.53%	
21	62.2	36	33.15		7.92%	
28	67.2	39	39.47	38.96	-1.21%	-1.31%

From the above table and graph, we can get,

- 1) The value from the formula $Y = -0.1377x^2 + 19.037x - 618.21$ shows that the strength is passing as compared to the IS Code strength.
- 2) The strength from the formula is the greater than the CTM strength for 7 days.
- 3) It give -33.14% difference for 7 days.
- 4) For 28 days, the strength from the formula validates the IS Code strength.
- 5) The CTM strength and the formula strength give a -1.31% difference, but it closer to both CTM & IS Code Strength.

IV. DISCUSSION

- The results demonstrate that rebound angle increases with curing age, reflecting strength development.
- Equation 1 shows a large deviation due to improper calibration.
- Equation 2 provides accurate results due to better fitting with experimental data.
- If the data set is small, it may cause differences in the results.
- If the data set is large, the result is completely accurate.

V. CONCLUSION

1)It states that the pendulum-based rebound angle method is a reliable and effective technique for estimating compressive strength.

2)The method has potential for practical application and further development, making it a valuable contribution to civil engineering practice.

3)The consistency of experimental observations supports the reliability of the developed model.

4)Improved testing techniques contribute to better quality control and structural safety.

5)Further validation can strengthen confidence in practical implementation.

6)Technological advancements can make the method more efficient and user-friendly.

7)Expansion of the dataset will improve the robustness of predictive equations.

8)Application in real structures will demonstrate field feasibility

9)The approach aligns with modern trends in non-destructive evaluation

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