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# STUDY ON NON- DESTRUCTIVE TESTING FOR STRUCTURAL ANALYSIS

[1]Akshay Ashok Sathawane, [2]Prof. Dharmendra Singh
[1]Scholar M.Tech (Structure), [2]Guide
, Department of Civil Engineering, RNTU, Bhopal (M.P).

***Abstract: - Indian construction industries structural health monitoring system to keep a high level of structural safety, durability and performance of the infrastructure in each country, an efficient system for early and regular structural assessment is urgently required. The quality assurance during and after the construction of new structures and after reconstruction processes and the characterization of material properties and damage as a function of time and environmental influences is more and more becoming a serious concern. Non-destructive testing (NDT) methods have a large potential to be part of structural health monitoring. Various NDT methods can be used for the assessment of existing structures, have become available for concrete structures, but are still not established for regular inspections. Therefore, the objective of this project is to study the structural health of material applicability, performance, availability, complexity and restrictions of NDT.***

***This investigation included four phases; the first of which involved the use of destructive and non-destructive mechanisms to assess concrete strength on cube specimens. The second phase of the research focused on site assessment for the two building located at Ujjain (one under construction and the other in-service) using rebound hammer and ultrasonic pulse velocity tester. The third phase was the use of linear regression analysis model using software to establish a relationship between rebound number and calibrated strength values as well as ultrasonic pulse velocities with their corresponding calibrated values all in relation to standard compressive strength on cubes and values obtained from existing structures.***

***Keywords: NDT, Rebound Hammer, Ultrasonic Pulse Velocity Test, Compressive Strength Test,***

## 1. INTRODUCTION

Typical situations where non-destructive testing may be useful are, as follows: Quality control of pre-cast units or construction in situ.

- Removing uncertainties about the acceptability of the material supplied owing to apparent non-compliance with specification.
- Confirming or negating doubt concerning the workmanship involved in batching, mixing, placing, compacting or curing of concrete.
- Monitoring of strength development in relation to formwork removal, cessation of curing, pre-stressing, load application or similar purpose.
- Location and determination of the extent of cracks, voids, honeycombing and similar defects within a concrete structure.
- Determining the concrete uniformity, possibly preliminary to core cutting, load testing or other more expensive or disruptive tests.
- Determining the position, quantity or condition of reinforcement.
- Increasing the confidence level of a smaller number of destructive tests.
- Determining the extent of concrete variability to help in the selection of sample locations representative of the quality to be assessed.
- Confirming or locating suspected deterioration of concrete resulting from such factors as overloading, fatigue, external or internal chemical attack or change, fire, explosion, environmental effects.
- Assessing the potential durability of the concrete.
- Monitoring long term changes in concrete properties.
- Providing information for any proposed change of use of a structure for insurance or for change of ownership.

## 2. METHODS FOR NDT OF CONCRETE STRUCTURES

- Half-Cell Electrical Potential Method; used to detect the corrosion potential of reinforcing bars in concrete.
- Schmidt/rebound hammer test; used to evaluate the surface hardness of concrete.
- Carbonation depth measurement test; used to determine whether moisture has reached the depth of the reinforcing bars and hence corrosion may be occurring.
- Permeability test; used to measure the flow of water through the concrete.
- Penetration resistance or Windsor probe test; used to measure the surface hardness and hence the strength of the surface and near surface layers of the concrete.
- Cover meter testing; used to measure the distance of steel reinforcing bars beneath the surface of the concrete and possibly to measure the diameter of the reinforcing bars.
- Radiographic testing; used to detect voids in the concrete and the position of stressing ducts.

- Ultrasonic pulse velocity testing, mainly used to measure the sound velocity of the concrete and hence the compressive strength of the concrete.
- Sonic methods using an instrumented hammer providing both sonic echo and transmission methods.
- Tomographic modelling, which uses the data from ultrasonic transmission tests in two or more directions to detect voids in concrete.
- Impact echo testing, used to detect voids, delamination and other anomalies in concrete.
- Ground penetrating radar or impulse radar testing, used to detect the position of reinforcing bars or stressing ducts.
- Infrared thermography, used to detect voids, delamination and other anomalies in concrete and also detect water entry points in buildings. (Jaggerwal & Bajpai, 2014)

This research work therefore aims to achieve the following:

1. To establish an unequivocal relationship between non-destructive and destructive test methods for higher grade concrete and compare with results with similar works.

2. To structurally appraise the compressive strength of structure under construction as well as in-service structure using non-destructive test methods.

## 3. METHODOLOGY

MATERIAL CONSTITUENTS, PROPERTIES AND MIX-PROPORTIONING

The various materials used in this project obtained from different sources include:

a) Fine Aggregate (sand)

b) Coarse aggregate (granite)

c) Ordinary Portland cement

d) Admixture (Master Rheobuild 850)

e) Potable water.

## 4. EXPERIMENTAL TEST PROCEDURES

The experimental procedure began with the preliminary investigation on the appropriate concrete mix design to arrive at the exact weights of concrete constituent-granite, sand, cement, water and admixture that will enable us to achieve the intended M48/50 concrete grade with which the Office Building was built. The design mix was done figuratively in tandem with a test casting of cubes using ultra tech cement before Lafarge cement was later adopted with the use of admixture. It ended with the compressive strength determination of 50 cubes as well as rebound hammer test with ultrasonic pulse velocity tests that were carried out on both the cubes and structures.

## 5. PRELIMINARY INVESTIGATION

The preliminary investigation carried out is to determine the properties of each material. The tests include:

- Sieve analysis
- Specific gravity
- Bulk density
- Dry density
- Moisture content
- Aggregate crushing value and impact value.

Apparatus:

1. Mechanical Sieve Shaker

2. Sieve brush

3. Weighing Balance

4. Various Sizes of Sieve Ranging from 2.36mm - 65µm

5. Drying oven

## 6. RESULTS AND DISCUSSION

CORRELATION/REGRESSION ANALYSIS ON REBOUND HAMMER RESULTS VERSUS COMPRESSIVE STRENGTH FOR AIR CURING SPECIMENS

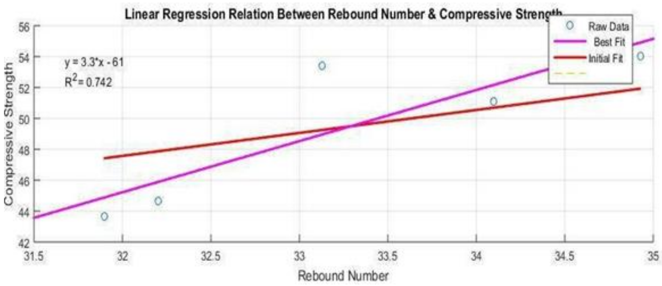



Figure G4.1: Correlation/Regression Analysis On Rebound Hammer Results Versus Compressive Strength For Air Curing Specimens

Observation: The above shows an R2 = 0.742 which is an indication of a fairly strong correlation between rebound number and compressive strength for air-cured specimens.

RELATIONSHIP BETWEEN REBOUND AND STANDARD CRUSHING VALUES FOR WATER CURING SPECIMENS

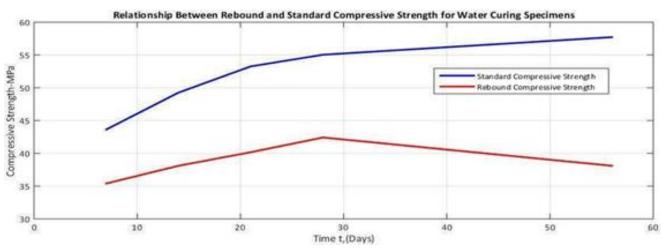



Figure G4.2: Relationship Between Rebound And Standard Crushing Values For Water Curing Specimens

Observation: It is obvious from the above that the rebound converted values (based on the charts provided in 2.2 above) gives a better early age correlation compared to the latter days which is like the observation for air curing.

CORRELATION/REGRESSION ANALYSIS ON REBOUND HAMMER RESULTS VERSUS COMPRESSIVE STRENGTH FOR WATER CURING SPECIMENS

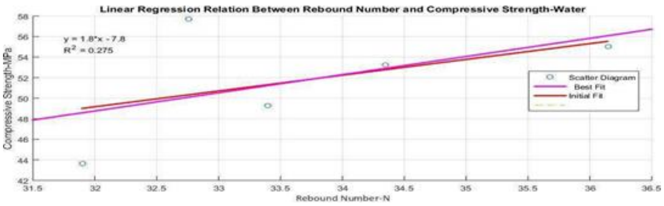



Figure G4.3: Linear Regression Between Rebound Number and Compressive Strength-Water Curing

Observation: The above shows an R2 = 0.275 which is an indication of a weak correlation between rebound number and compressive strength for water-cured specimens. However, this seeming lack of correlation stemmed from the relatively low rebound number at 56 days compared to the compressive strength. It is a further indication that the reliability of rebound hammer reduces as the age of concrete increases. Below is the regression analysis excluding the 56 days' result. It is quite clear that this gives a better

correlation; R2 = 0.916.

RELATIONSHIP BETWEEN ULTRASONIC PULSE VELOCITY AND STANDARD CRUSHING VALUES FOR AIR CURING SPECIMENS

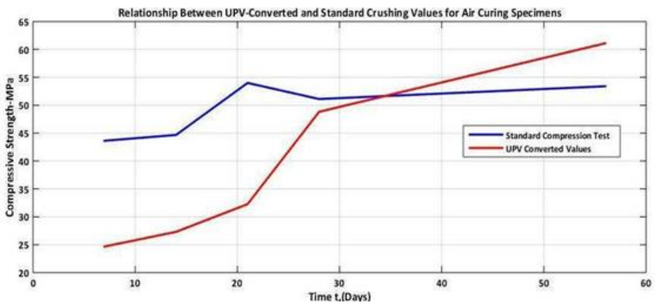



Figure G4.4: Relationship Between Upv And Standard Crushing Values For Air Curing Specimens

Observation: It is obvious from the above that the ultrasonic pulse velocity converted values (based on the charts provided in 2.3 above) gives a lower early age correlation compared to the latter days. One may therefore hypothesize that UPV may be more suitable for aged concrete testing. We can test this hypothesis as we shall soon see.

CORRELATION/REGRESSION ANALYSIS OF ULTRASONIC PULSE VELOCITY RESULTS VERSUS COMPRESSIVE STRENGTH-AIR CURING SPECIMENS

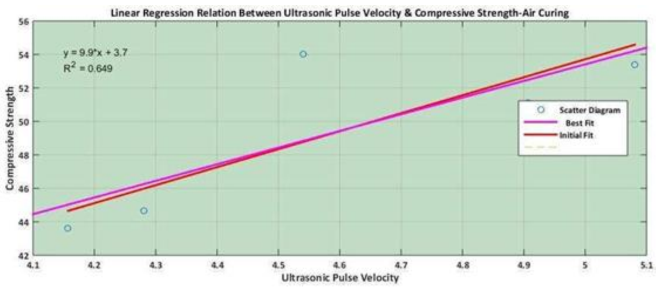



Figure G4.5: Linear Regression Relations Between Ultrasonic Pulse Velocity(Km/s) & Compressive Strength (MPa)-Air Curing

Observation: The above shows an R2 = 0.649 which is an indication of a fairly strong correlation between ultrasonic pulse velocity and compressive strength for air-cured specimens.

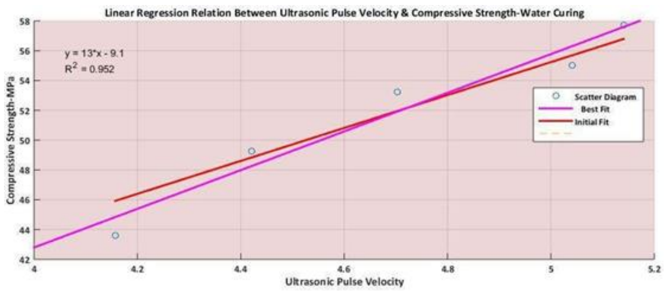
RELATIONSHIP BETWEEN ULTRASONIC PULSE VELOCITY AND STANDARD CRUSHING VALUES FOR WATER CURING SPECIMENS

Observation: It is obvious from below that the ultrasonic pulse velocity converted values (based on the charts provided in 2.3 above) gives a lower early age correlation compared to the latter days. Same observation was noted for air curing but the degree of variation will be assessed for the regression graph as we shall soon see.

Figure G4.6: Relationship between UPV-Converted and Standard Crushing Values for Water Curing Specimens.

CORRELATION/REGRESSION ANALYSIS ON ULTRASONIC PULSE VELOCITY RESULTS VERSUS COMPRESSIVE STRENGTH FOR WATER CURING

Figure G4.7: Linear Regression Relation Between Ultrasonic Pulse Velocity (Km/s) &




Compressive Strength for Water Curing System.

Observation: The above shows an R2 = 0.952 which is an indication of an extremely strong correlation between ultrasonic pulse velocity and compressive strength for water-cured specimens. This is the most positive correlation observed so far. It therefore hints that water cured specimen may probably be best observed using the Pundit Equipment rather than Rebound Hammer.

GENERAL RELATIONSHIP BETWEEN UPV AND STRENGTH VALUES FOR AIR AND WATER CURING METHODS

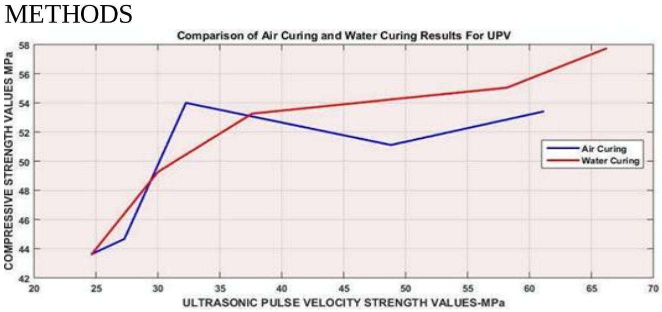



Figure G4.8: Comparison of Air Curing and Water Curing Results for UPV

Observation: The above shows a fairly similar trend in strength gain. However, it can be noticed that the air-cured samples experienced early strength gain than the water counterparts. On the long run, the water-cured samples developed higher strength as the air samples was tending towards a strength decline.

GENERAL RELATIONSHIP BETWEEN REBOUND NUMBER AND STRENGTH VALUES FOR AIR AND WATER CURING SYSTEMS

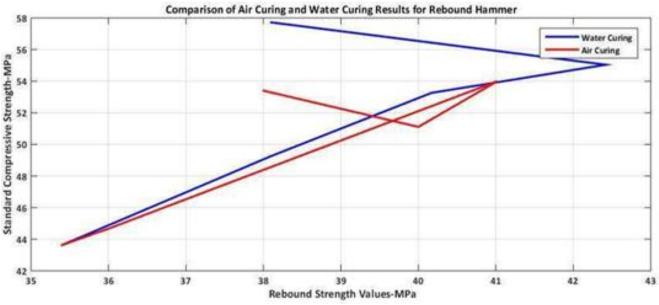



Figure G4.9: Comparison of Air Curing and Water Curing Results for Rebound Hammer

Observation: While Rebound strength values improved in both systems up to about 42Mpa, a sharp decline was observed afterwards. This in either an indication that rebound hammer is not suitable for high strength concrete or ageing concrete or both.

GENERAL RELATIONSHIP FOR STANDARD STRENGTH GAIN FOR AIR AND WATER CURING SYSTEMS

Observation: The 28-day strength for the water curing system is 89% of the 28th day strength which is just 1% less than the standard. However, this is not the same for the air curing system which is 105.6%. This abnormal. In short, the water curing system gives a better strength development pattern closer to conventional concrete strength pattern that the air curing system

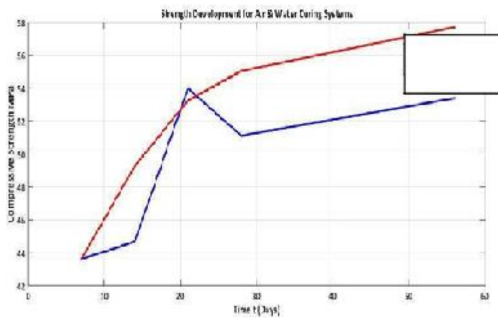


Figure G4.10: Comparison of Air Curing and Water Curing Results for Standard Strength Gain

PROJECTION OF CURRENT STRENGTH (UPV, RN AND ACV) VALUES TO FUTURE TERMS (0-15 YEARS) FOR AIR CURING SYSTEM BASED ON TEST RESULTS-COLUMN

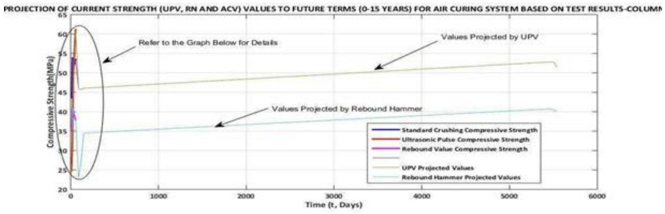



Figure G4.11: Projection of Current Strength (UPV, RN AND ACV) Values to Future Terms (0-15 Years) For Air Curing System Based On Test Results-Column

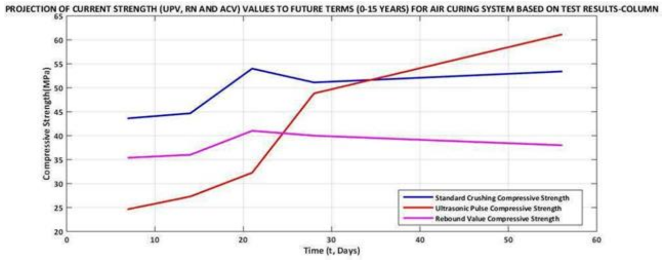
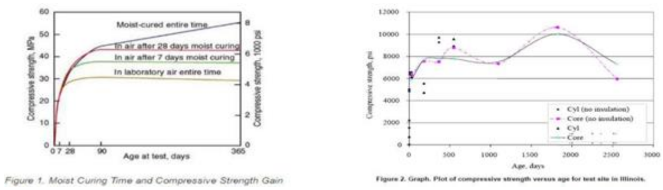



Figure G4.11b: Early Age Strength (UPV, RN AND ACV) Properties for Air Curing System Based On Test Results-Column

Observation: 4.11 above shows a haphazard strength development during the early age of concrete after which a sharp drop was noticed. This drop here when compared to past work in Figure 1 shows that air cured concrete loses strength over time while a more comprehensive study carried out shows that this drop was later succeed by an increase in strength as shown in Figure 2. Hence, our results for UPV above show a similar agreement to the two observations when combined while Rebound Hammer show a lower estimate but similar pattern




PROJECTION OF CURRENT STRENGTH (UPV, RN AND ACV) VALUES TO FUTURE TERMS (0-15 YEARS) FOR AIR CURING SYSTEM BASED ON TEST RESULTS-BEAM

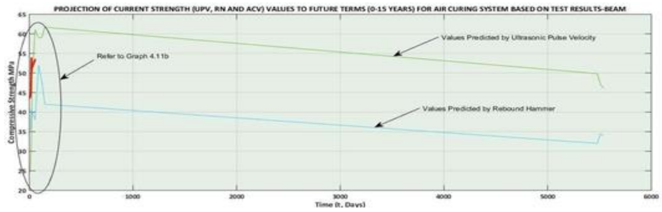


Figure G4.12: Projection of Current Strength (UPV, RN AND ACV) Values to Future Terms (0-15 Years) For Air Curing System Based on Test Results-Slab

PROJECTION OF CURRENT STRENGTH (UPV, RN AND ACV) VALUES TO FUTURE TERMS (0-15 YEARS) FOR AIR CURING SYSTEM BASED ON TEST RESULTS-SLAB

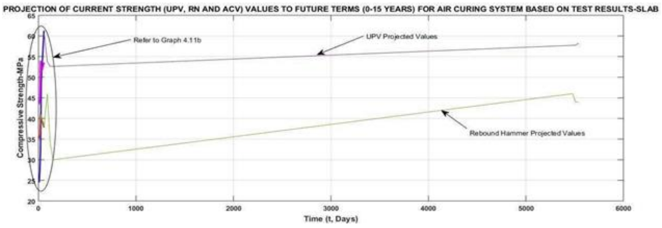



Figure G4.13: Projection of Current Strength (UPV, RN AND ACV) Values to Future Terms (0-15 Years) For Air Curing System Based on Test Results-Slab

Observation: 4.12 and 4.13 above show a haphazard strength development during the early age of concrete after which a sharp drop was noticed just like 4.11. However, the predicted values for beam experienced a continuous but slow decline over time, corroborating the result for 4.11. 4.13 however shows an increase in slab strength followed by a sharp decline. It suggests the beam results for the Office building are probably incongruent with the M30Grade Specification as predicted by the rebound hammer. This anomaly is also observed for beam results in old building. Refer to Appendix I for more details.

TABULAR COMPARISON BETWEEN EXPERIMENTAL AND PREDICTED VALUES OF COMPRESSIVE STRENGTH USING REBOUND HAMMER

Table 4.7: Tabular Comparison between Experimental and Predicted Values of Compressive Strength Using Rebound Hammer

| | 28th Day $F_{cu}$ (N/mm²) | | | 56th Day $F_{cu}$ (N/mm²) | | |
|---|---|---|---|---|---|---|
| Curing System | Experimental | Predicted | Variation (%) | Experimental | Predicted | Variation (%) |
| Air Curing | 51.11 | 40.00 | -21.7 | 53.40 | 38.00 | -28.8 |
| Water | 55.04 | 42.42 | -22.9 | 57.72 | 38.10 | -33.99 |

Observation: The above shows unacceptability and grave underestimation of concrete strength. This variation however is more pronounced with increasing concrete age which further buttresses the initial hypothesis that rebound hammer might be better suited for early age concrete rather than aging concrete.

TABULAR COMPARISON BETWEEN EXPERIMENTAL AND PREDICTED VALUES OF COMPRESSIVE STRENGTH USING ULTRASONIC PULSE VELOCITY

Table 4.8: Tabular Comparison Between Experimental and Predicted Values of Compressive Strength Using Ultrasonic Pulse Velocity

| | 28th Day $F_{cu}$ (N/mm²) | | | 56th Day $F_{cu}$ (N/mm²) | | |
|---|---|---|---|---|---|---|
| Curing System | Experimental | Predicted | Variation (%) | Experimental | Predicted | Variation |
| Air Curing | 51.11 | 48.82 | -4.48 | 53.40 | 61.10 | 14.41 |
| Water | 55.04 | 58.19 | +5.72 | 57.72 | 66.18 | 14.65 |

Observation: The above shows congruence though with a general mild positive exaggeration of concrete strength by the values predicted by Ultrasonic Pulse velocity.

This variation however is negative for the air curing specimen of 28th day. Generally, one may be inclined to assert that UPV readings give better accuracy than rebound hammer and is more suited for ageing concrete which is the emphasis of Structural Health Monitoring.

## 7. CONCLUSION

1. In summary, ultrasonic pulse velocity tests have a great potential for concrete control, particularly for establishing uniformity and detecting cracks or defects.

2. At the junction of beams and columns the results seems more accurate and proper, this is because of proper compaction and attention given during casting as it is junction of beam and column joint compared to other area.

3. Also, when compare all NDT results taken over slab then strength of concrete at edges is 8% -10% higher than the center of slab. In case of column there is variation of 35% -40% in strength; at the base of the column it is higher as compaction occurred due to weight of the column.

4. Measurements were not accurate and representative when compared to the cubes used to constructtheplots.The use of the combined methods produces results that lie close to the true values when compared with other methods.

5. The final results were compared with Rebound Test and Ultrasonic pulse velocity test which actual results obtained from samples extracted from existing structures and find out best methods for NDT.

### RECOMMENDATIONS

The research findings in this work demonstrate that ultrasonic pulse velocity appears more reliable in predicting possible compressive strength of concrete especially for aging concrete which is the major focus of structural health monitoring in concrete structures. However, it should be used with caution and with proven reliable calibration(s). Results show that pundit values give a higher statistical confidence than rebound number. One may therefore recommend:

1. Rebound Hammer should be used for early age concrete development tests where non-destructive methods are required. For instance, concrete structure under construction.

2. Ultrasonic Pulse Velocity should be used for aged concrete of about 10-15years and above to obtain more accurate results.

3. Combined use of both methods may be applied to middle-aged concrete of about 3-6 years.

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