NDT FOR STRUCTURAL HEALTH MONITORING

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Abstract: There is a phenomenal rise in construction activities in the field of civil engineering in the recent years. Major structures like buildings, bridges, dams are subjected to severe loading and their performance is likely to change with time. It is, therefore, necessary to check the performance of a structure through continuous monitoring. If performance deviates from the design parameters, appropriate maintenance is required. The life of a structure depends on initial strength and the post construction maintenance. It is for this reason that the necessity of structural health monitoring (SHM) is emphasized worldwide. There are several techniques to monitor the health of structures.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: Non-Destructive Testing, Rebound Hammer, Ultrasonic Pulse Velocity Test, Compressive Strength Test,

I. INTRODUCTION

Concrete is an excellent building material whose discovery has solved several construction problems. It is a very versatile material that can be formed into several shapes and sizes depending on the size and function of structural member required.

Concrete is a mixture of stone and sand held together by a hardened paste of cement and water. When the ingredients are thoroughly mixed, they make a plastic mass which can be cast or molded into a predetermined size and shape. When the cement paste hardens, the concrete becomes very hard like a rock. It has great durability and can carry high loads especially in compression. Since it is initially plastic it can be used in various types of construction; however, the forms used to produce the final shape cannot be removed until the concrete has developed enough strength by hardening. Where tensile stresses are imposed on the concrete, it must be reinforced with steel.

II. METHODS FOR NDT OF CONCRETE STRUCTURES

- Half-Cell Electrical Potential Method; used to detect the corrosion potential of reinforcing bars inconcrete.
- Schmidt/rebound hammer test; used to evaluate the surface hardness ofconcrete.
- Carbonation depth measurement test; used to determine whether moisture has reached the depth of the reinforcing bars and hence corrosion may beoccurring.
- Permeability test; used to measure the flow of water through theconcrete.
- Penetration resistance or Windsor probe test; used to measure the surface hardness and hence the strength of the surface and near surface layers of theconcrete.
- Cover meter testing; used to measure the distance of steel reinforcing bars beneath the surface of the concrete andpossibly to measure the diameter of the reinforcing bars.
- Radiographic testing; used to detect voids in the concrete and the position of stressingducts.
- Ultrasonic pulse velocity testing, mainly used to measure the sound velocity of the concrete and hence the compressive strength of theconcrete.
- Sonic methods using an instrumented hammer providing both sonic echo and transmissionmethods.
- 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 stressingducts.
- Infrared thermography, used to detect voids, delamination and other anomalies in concrete and also detect water entry points in buildings. (Jaggerwal&Bajpai,2014)

III. METHODOLOGY

The object of this research study is to formulate a correlation between rebound hammer method, ultrasonic pulse velocity and the compression method using different curing methods and assessing in-service structure as well as structures under construction for monitoring structural health.

To obtain these results, it is required to perform a series of tests on specimen in the laboratory. Notable amongst these were the determination of the physical properties of the aggregates and binders to be used, workability and setting time tests on the plastic mixes (varying percentage replacements values), compressive tests, nondestructive tests (rebound hammer and UPV) on the hardened mixes under different curing conditions. Other preliminary tests include specific gravity and density. On site procedures were also carried out on the Engineering auditorium for in-service and under-construction observations.

MATERIAL CONSTITUENTS, PROPERTIES AND MIX-PROPORTIONING

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

- Fine Aggregate (sand)
- Coarse aggregate (granite)
- Ordinary Portland cement
- Admixture (Master Rheobuild 850)
- Potable water.

IV. RESULTS AND DISCUSSION

This chapter discusses the results obtained from laboratory tests and field tests carried out on the strength indices of concrete using both destructive and non-destructive methods. This is essential to illustrate relationships between NDT and the standard compressive test of the same concrete specimens. Detailed description of the concrete mix has been provided in the previous chapter. The total volume of concrete used for laboratory experiments was to the tune of 0.135m3.

PRELIMINARYTEST

SIEVE ANALYSIS AND GRADATION OFAGGREGATES

Sieve analysis is used to find the amount of soil variation of the aggregates used in this project. It is carried out by allowing the aggregates pass through a series of sieves. The particle size distribution of the sand is shown below.
Initial dry weight of sample=1000g.

Table 1: Showing Sieve Analysis for Fine Aggregate

Test	Weight	Percentage	Cumulative Percentage	Percentage
Sieves	Retained (g)	Retained (%)	Retained (%)	Passing (%)
4.75mm	27.49	2.75	2.75	97.25
2.36mm	87.26	8.73	11.48	88.52
1.18mm	359.32	35.93	47.41	52.59
600µm	341.64	34.16	81.57	18.43
425µm	97.50	9.75	91.32	8.68
300µm	48.17	4.82	96.14	3.86
150µm	28.82	2.88	99.02	0.98
75µm	7.34	0.73	99.75	0.25
Pan	2.46	0.24	99.99	0.01

The particle size distribution of the granite is shown below.
Initial dry weight of sample = 3000g.

Table 2: Showing Sieve Analysis for Coarse Aggregate

Test	Weight	Percentage	Cumulative Passing	Percentage
Sieves	Retained (g)	Retained (%)	Retained (%)	Passing (%)
37.5mm	0	0	0	100
25mm	0	0	0	100
19mm	1039.87	34.66	34.66	65.34
12.7mm	1778.79	59.29	93.95	6.05
9.53mm	127.92	4.26	98.21	1.79
5mm	20.99	0.70	98.91	1.09
2.36mm	0.89	0.03	98.94	1.06
1.18mm	0.51	0.02	98.96	1.04
<75µm	22.69	0.76	99.72	0.28
Pan	8.34	0.27	99.99	0.01

The particle size distribution of the Coarse is shown below.
Initial dry weight of sample= 2025g.

V. CONCLUSION

Amongst other applications, NDT methods can be used for concrete strength determination and concrete damage detection. With a focus on concrete strength alone, we employed Rebound Hammer Test (RHT) and Ultrasonic Pulse Velocity (UPV) test results as the NDT comparatives to the conventional laboratory crushing values and then observed how it varied over time. The research is constitutive of both laboratory and computational components. It tested for the extent to which these two NDTs can either be applied independently or collectively to assess the compressive strength of concrete using existing structures and concrete specimens in the laboratory.
Laboratory studies involved the use of concrete samples with the same grade as the live structural members whose crushing values was compared with corresponding Rebound Numbers-RN and Ultrasonic Pulse velocities. Multiple regression studies on "today's" RN and UPV of Grade M30 concrete structure was also conducted to establish the validity of existing mathematical models on the variation of concrete compressive strength with time. This instituted the extent of acceptability of RN and UPV results in terms of the age of concrete. Upon correlation with laboratory results, we could inaugurate the conditions for the best use of RN and UPV either independently or in combined usage especially as a function of time. 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 Office building located at the 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 the computational capabilities of 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 existingstructures.

From the analysis and validation of existing model, R2 values which range between 0.275 and 0.742 for rebound hammer shows an inconsistent correlation when compared to ultrasonic pulse velocity root mean squared values of 0.649 and 0.952 for air curing and water curing respectively. Although, water curing gave a better correlation than air curing, the air curing system most accurately represent site condition where concrete is usually not cured beyond a week of casting. Also, predicted values of today's early age strength development skewed better in favor of Ultrasonic Pulse velocity than Rebound hammer. However, observation shows that rebound hammer is well suited for early age assessment than ultrasonic pulse velocity. This is also evident in the projection of strength development from 56days to today's strength in both in-service and under-construction sites used in this investigation.

One may therefore conclude that a combined use of pundit and rebound hammer as Non- destructive test methods for assessment of both early age and aging concrete will give more desirable results than each used in isolation. However, the Ultrasonic Pulse velocity equipment stands a better chance as a tool for structural health monitoring; though relatively more expensive.

Lastly, while past research work shows sufficient correlation between rebound number and compressive strength, the concrete assessed were of low grade. However, low correlations have been observed in this investigation for high strength concrete.

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:

- Rebound Hammer should be used for early age concrete development tests where non-destructive methods are required. For instance, concrete structure under construction.
- Ultrasonic Pulse Velocity should be used for aged concrete of about 10-15years and above to obtain more accurate results.

FUTURE RESEARCH

More investigative efforts be exerted into establishing genuine relationship between high performance concrete and rebound hammer as this work will go a long way to establish the suitability of rebound hammer as a tool for aging concrete. Other curing methods may also be employed alongside. There is a general assumption that the relationship between Crushing value, Rebound Hammer and Ultrasonic Pulse velocity is linear. This assumption has been heavily relied upon by most research works in this area. Therefore, an invaluable frontier to be established in this field will be to prove this assumption otherwise with compelling Figurative evidence, using non-linear theory. Lastly, this growing field requires vastness in programming and computational mechanics. A researcher in this field will be highly sought after if those requisites are there. Hence, investigative novel methods should be developed to bridge this loop.

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