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Critical Appraisal of the Comparison of Mechanical and Non-destructive Testing of Concrete

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Abstract— This paper provides a critical review by studying the various research works conducted on concrete by performing Non-Destructive testing and Destructive Testing and thereby comparing the strength obtained from the both the types of tests which can determine the potential durability of the concrete. As a result the main conclusion of this study shall be firmly confined within the comparison of strengths only retrieved from testing methods, research papers, and topics centered on Non-destructive Testing/Destructive Testing methods. The present study helped us to arrive at a conclusion where we can further find the best testing method system that shall be applicable for various concrete structures and as well as in the concrete industry.

Keywords— Compressive Strength; Destructive testing(DT); Non –Destructive Testing(NDT); Ultra sonic pulse velocity (UPV); Rebound hammer.

I. Introduction

Concrete has become the oldest and most common construction materials in the world, due to its wide availability, durability, low cost and ability to sustain extreme weather environments. The most cost effective and efficient means of construction can be provided by concrete. It therefore becomes important to test concrete structures so as to determine whether the structure is suitable for its designed use or not.

The testing of concrete ranges from Non-Destructive tests where concrete specimen is not damaged to Destructive testing where the surface of the concrete specimen might be damaged. Destructive testing method is suitable and economically beneficial for the concrete specimens that are produced at a large scale. The main aim is to determine the service life and detect the weakness of design that might not show under normal working conditions.

Non-destructive testing determines flaws in materials which are in the form of cracks or variations in the structural properties that might lead to loss of strength in a concrete structure. Non-destructive tests are used worldwide to detect variation in structures, minute changes in surface finish and presence of cracks or other physical discontinuities.

Non –Destructive Testing plays an important role in everyday life and it has recently become a vital part of quality control process .It is adopted over the destructive testing because it gives all the information about the internal flaws, segregation and homogeneity of concrete without causing any damage to the concrete specimen while as the Destructive Testing gives information about the characteristics of concrete specimen but causes complete damage to the concrete specimen.

II. Literature Review

Ferhat Aydin and Mehmet Saribiyik [1] carried out experimental investigation to develop a relationship and correlate rebound hammer test (Non –Destructive Test) with compression test (Destructive Test). Cube specimens of and a no of core samples from different reinforced concrete structures were tested. Samples made from OPC(Ordinary Portland Cement) and various concrete mixes were prepared to cast (15*15*15 m3) cubes. Rebound hammer test and compressive test was performed on the specimens according to the codal provisions. Curves were drawn and the best fit correction factors for concrete compressive strength were obtained through processing the correlation among datasets. The results drawn from the investigation showed that use of rebound hammer test on existing buildings wasn't suitable to estimate strength of old concrete. The obtained curves from existing buildings needed correction factors of 0.50-0.80 to predict strength values of old concrete. Results also showed that rebound hammer tests could be used alone to estimate the strength of concrete specimens.

Mahdi Shariati *et al* [2] carried out an experimental study for assessing the strength of reinforced concrete structures through Ultra sonic pulse velocity and rebound hammer tests and a correlation between compressive strength of destructive tests and non-destructive test values was established. Main members of an existing building including column, beam and slab were tested by Non-destructive testing and Destructive testing. Calibration curves for each test method were drawn using regression analysis. Correlation between predicted and actual compressive strength of concrete was represented by plotting average rebound no/ultrasonic pulse velocity against compressive strength of each member. Rebound hammer test and Ultra sonic pulse velocity tests were performed on the members and regression model was achieved. The results obtained, showed that regression model achieved from the

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combination of two Non-destructive testing methods was more precise as compared to the individual methods. Results also showed that rebound number method was more competent in forecasting the compressive strength of concrete than Ultra sonic pulse velocity test method.

Rohit et al [3] carried out an experimental investigation on the flexural strength of plain and fiber reinforced High Volume Fly Ash Concrete by destructive and non-destructive techniques. Experiments were taken out on properties of fresh concrete by compaction factor tests and on hard concrete by flexural strength test. 53 grade OPC (Ordinary Portland Cement) and high range water reducing admixture based on naphthalene sulphonate was used. M25, M30 and M35 mixes were taken and poly carboxylate based super plasticizer was used. Compaction factor test and flexural strength tests were performed as destructive tests and UPV (Ultrasonic Pulse Velocity Test) was performed as nondestructive test. Charts and graphs were plotted between various percentages of fly ash and compaction factors and on comparison of compacting factors of various mixes. The results showed that pulse velocity decreases with increase in the fiber content up to 3.2%. There was a measurable gain by inclusion of polyester fiber over plain High Volume Fly Ash Concrete samples and significant gain beyond 28 days. The use of 12mm polyester showed a marginal effect on increase in the compressive strength at different ages. The increase in the percentage of fly ash showed a reduction in the percentage gain at different age of concrete. From the UPV results, regression yield analysis was carried out and showed the following equations for prediction of flexural strength at 28 days for different samples.

Table 1 Equations for prediction of flexural strength for Ultra sonic Pulse Velocity Test at 28 days.

Fiber/ Fly ash	50%	55%	60%
0%	fb= 0.0040-14.33	fb= 0.0040-13.34	fb=0.0020-6.183
0.15%	fb= 0.0080-14.80	fb= 0.0050-16.16	fb= 0.0010-2.130
0.25%	fb= 0.0030-9.162	fb= 0.0030-9.265	fb= 0.0020-5.425

Huai Shuai Shang *et al* [4] investigated about the compressive strength of concrete by using nondestructive methods. All the samples were made from locally available materials and were conformed to Chinese standard (GB 175-2007). Five sets of M20, M25. M30, M40 and M50 mixes were prepared and each set consisted of 21 concrete cube specimens of (150mm*150mm*150mm) size. Specimens were compacted through external vibration and demoulded 24 hours later. All the specimens were cured for a period of 27 days. Rebound hammer test was performed on the specimens and 16 readings were taken from each specimen. Once Non – Destructive Testing was completed, cubes were loaded to failure. Calibration curves for each rebound method were drawn using regression analysis. The results showed that use of rebound hammer was quite suitable to estimate and predict strength of concrete and it produced results which were reliable and close to true values. Therefore, the regression model for strength evaluation could be used safely for predicting concrete strength in all types of concrete engineering investigations.

Samia Hannachi and Mohamed Nacer [5] investigated about the application of the combined method for evaluating compressive strength on site. Ultra sonic pulse velocity and Rebound Hammer tests were combined and their measurements were calibrated with results of mechanical tests done on cylindrical specimens casted on site as well as on cores taken from existing structures. The tests were used to determine concrete quality by applying regression analysis modes on compressive strength of concrete in existing structures. Equations were derived using statistical analysis (simple and multiple regression) to estimate compressive strength of concrete on site. Correlation charts were plotted and regression equations were listed. The results showed that using more than one nondestructive technique provides a better correlation and would lead to more reliable strength evaluation of concrete. The results also showed that combined methods appeared more appropriate on conditions of on-site measurements as they were very fast, convenient and reasonable in cost.

Akash Jain *et al* [6] carried out an experimental investigation aiming at developing a method of combined use of both Nondestructive tests for assessing strength of concrete with greater accuracy. OPC (Ordinary Portland Cement) and PPC (Pozzolana Portland Cement) cements were used and preliminary testing was done on the materials. The concrete mix design for M20, M30, M40, and M50 was done using IS 456:2000 and IS 10262:1982. Total of 288 cubes were casted and samples were tested for ultra-pulse velocity and rebound number followed by Indian standards (IS 13311 part 2 1992). Relationship graphs were plotted between age of Ordinary Portland Cement/Portland Pozzolona Cement and rebound number and between age of Ordinary Portland Cement/Portland Pozzolona Cement and Ultra sonic pulse velocity. A relationship curve was also plotted between ultra-pulse velocity, rebound number and compressive strength. The results derived from the experiments showed that Ultra sonic pulse velocity test readings increased with age but the change was very small. It alone couldn't be used for finding out the compressive strength. The readings of rebound number also showed an increase with age and the approximate value could be directly determined by using rebound number only. Results also showed that if correlation was developed between rebound number and pulse velocity, more accurate results could be predicted and achieved.

K.V Ramana Reddy [7] investigated about the strength of concrete by various nondestructive testing methods and compressive testing. The main aim was to study about the quality of plain recycled aggregate and fly ash concrete of various mixes by Non –Destructive Testing. Non –Destructive Tests (combined rebound hammer and ultra-pulse velocity) technique and destructive testing techniques were taken out for assessment of compressive strength on concretes. Various

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concrete cubes with replacement of fly ash (10%, 20% and 30%) of M15, M20, M25, M30, and M40 mixes were designed and tested for compressive strength at 7, 24, 28, 56, and 90 days. A comparative study was made between the compressive strength, pulse velocity and rebound number for all mixes and curves were plotted. The results showed that pulse velocity and rebound number increased with the age of concrete and NDE (combined rebound hammer and ultra-pulse velocity) developed was more effective and could be incorporated in codal provisions for future references. Recycled aggregate concrete also showed 30% less strength than plain concrete and fly ash concrete showed 75% less strength than plain concrete as well.

Duna Samson *et al* [8] investigated about the correlation between nondestructive and destructive testing of compressive strength of concrete. Concrete cubes of size 100mm*100mm*100mm were casted using concrete grade of M20, M30, and M35 and were cured for 7, 14 and 28 days. Preliminary tests were performed on materials. Total of 90 cubes were produced and rebound hammer test was performed. 10 readings for rebound hammer compressive strength on each specimen were taken. Various tables for rebound number and compressive strength were drawn and correlations were listed out. Regression analysis was carried out using MINITAB 15 to establish a linear mathematical relation between compressive strength and rebound number. The results showed high rebound number in high compressive strength. Correlation coefficients of proposed models ranged between 92.1%- 97.9% which showed an excellent relation between compressive strength and rebound number. Average percentage of residual error for all proposed models was 1.78%, 1.29% and 1.32% for the concrete cubes which were cured for 14 and 28 days respectively. Results also showed that prediction of compressive strength of concrete to a high accuracy can be done if only the rebound number is known.

Jayant Damodar and M K Gupta [9] carried out an experimental investigation to develop ideal curve equation which could immediately predict the value of compressive strength of concrete. Comparison of compressive strength of cubes was made by normal as well as accelerated curing by which mathematical curve equations were developed later. OPC, PPC and PSC cements were used in the experimental work. First batch of 18 cubes for each of the mix grades of M20, M25, and M30 were casted and subjected to normal curing i.e. cubes were covered by gunny bags for a day and after that they were immersed in water tub before testing their compressive strength. Three cubes of each mix were tested for compressive strength after 1 and 3 days and an average result of three cubes was taken. Similar cubes were casted and tested for PPC and PSC. Second batch of 36 cubes for each of the mix grades of M20, M25 and M30 was casted. 18 cubes were subjected to accelerated curing and 18 cubes were cured in water tub at normal temperature. 3 cubes were taken out after 3 days and were placed in boiling water tub at 100 degrees for 3 hours before testing. Remaining cubes were immersed in water at room temperature and were tested after 7 and 28 days for complete strength. The results obtained from the experiment showed that OPC gained strength of 80% in the 1st day of accelerated curing while as PSC and PPC gained only 50% strength in the 1st day. These results could be used in future for predicting early strength of concrete. Accelerated curing techniques radically helped to increase the rate of strength gain. Results also showed that an ideal curve equation could be obtained and used in determining and computing compressive strength of concrete. The compressive gain was given by the following equation

$$Y = (ab)\ x$$

Where y represents compressive strength after particular no of days of curing, a represents factor comprising parameters different mix designs, b represents coefficient of no of days the system has been subjected to curing, type of curing and different water cement ratios used in the mix, and x represents no of days the cubes are subjected to curing.

Hitesh Patil *et al* [10] carried out an experimental investigation on comparative study of effect of curing on compressive strength of concrete by using nondestructive and destructive methods. Correlation between compressive strength of concrete and rebound number was developed. 27 cubes of M25 grade were casted and allowed to be kept for curing for 7, 14 and 28 days. Rebound hammer test and compressive strength test by Compressive Testing Machine of capacity 40 tones was done on 9 cubes of 7 days curing and repeated for 14 and 28 days respectively. The results obtained showed that rebound number increases as the compressive strength increases and vice-versa. As curing period increased, percentage strength decreased in compressive strength. For 28 days of curing decrease in percentage strength was less as compared to 7 days percentage decrease in strength. Average error in measuring compressive strength for 7, 14 and 28 days by rebound hammer and CTM was found out to be 20.01%, 1.37% and 0.99% respectively. Results also showed that compressive strength or rebound number could be produced if only one of the values was known.

Konapure and Jagale Richardrobin [11] carried out an experimental investigation for M20 and M25 grade of concrete and mix proportion of 1:2.9:3.02 and 1.98:3.88 and obtained a relationship between rebound hammer testing and destructive testing. 174 cubes were casted and 6 rebound no readings were obtained on each cube, at different locations of the specimen. The cubes were given a load of 7N/mm2 in CTM (Compressive Testing Machine). Concrete mix proportion was made for mix design of M20 and M25 grade of concrete upon which rebound hammer testing and compressive testing was done.

The results showed that the percentage difference of compressive strength for Non –Destructive test and Destructive test is low for laboratory specimens. The strength gaining of concrete as per age was not reflected by nondestructive testing. The results also showed that rebound hammer test gave more realistic results in early age of concrete. Three curves were plotted between rebound number and destructive strength testing and out of the three curves, the average curve gave the most reliable results to destructive values.

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Mulik Nikhil V *et al* [12] performed a series of nondestructive tests to investigate about the mechanical properties of concrete employed in laboratory specimens and buildings. SONReb (combined testing method) was adopted for the experimental study. 60 concrete specimens of size (150mm*150mm*150mm) were prepared to obtain a strength of 15 MPa, 20 MPa, 25 MPa, 30 MPa, 35 MPa, and 40 MPa. The specimens were cured for 28 days after which rebound hammer test, ultra-pulse velocity test, and compression test was performed on them. 20 random results were taken and linest function of excel was used to determine the coefficients. The results obtained showed that SONReb method of combined testing provided a reliable assessment for determining concrete compressive strength. A correlation coefficient of 0.789 and 0.672 was achieved for rebound number values and ultra-pulse velocity values respectively while as combining the two methods using SONReb, showed a higher correlation coefficient of 0.867. So the results clearly showed that higher value was seen for combined methods. So, combined methods were predicted to be more reliable in determining the compressive strength.

Pachghare and Shah [13] carried out a comparative experimental study of concrete by using compression and rebound hammer tests as Non-Destructive Testing and Destructive Testing respectively. Raw materials used by them were collected from nearby sources and preliminary tests were conducted on the materials used. Concrete of grades M20, M25, M30, M35, and M40 was used and the mix design was done in accordance with IS 10262 (2009). Concrete cubes of diameter 15cm*15cm*15cm were casted for freshly prepared concrete and 6 specimens for each grade were casted. Total of 30 cubes were casted for the whole experimental program. Rebound hammer and compressive test was performed on the cubes and a correlation was developed between compressive strengths by Compressive Testing Machine and corresponding rebound hammer carried out on the specimen. Results showed that rebound hammer provided a simple and quick method of obtaining concrete strength. An accuracy of 10.08% in 7 days and 10.50% in 20 days was achieved during the experimental work. The results also showed 100% strength of concrete as per design except of that of M35 grade.

Yuri Danilo Lopez *et al* [14] carried out a study on concrete compressive strength estimation by Non-Destructive testing . The main aim was to produce a correlation between results of surface hardness, Ultra Sonic Pulse Velocity test and compressive strength of structural concrete in bleachers of soccer stadium in Parana, Brazil. The concrete structure was 26 years old and had some severe defects such as corrosion, segregation, cracks and concrete spalling in one of the slabs. Mapping reinforcement was performed and Ultra Sonic Pulse Velocity test was done according to the IS standards. Total of 26 concrete specimens were obtained from all the structures of the bleachers. Rebar mapping was done for the defect of rebar corrosion at the base of the pillars. Concrete specimens were subjected to simple compression tests by CTM of load of 200 tones. Correlation curves between Non –Destructive Testing results were plotted. The results showed that stronger the concrete, higher shall be its surface index as well as its wave propagation velocity. Results also showed a good correlation between both surface hardness test and Ultra Sonic Pulse Velocity test. Curves obtained were established to be used for estimation of strength of concrete for other elements of the structure as well.

Hemraj R. Kumavat *et al* [15] carried out an experimental study on combined methods of Non –Destructive Testing in concrete and its evaluation of core specimen from existing buildings. Core tests, Ultra Sonic Pulse Velocity test and rebound hammer tests were performed on the specimens according to IS standards and by combining the two methods. Regression analysis was carried out and correlation coefficients were given. Charts were plotted between rebound numbers, Ultra Sonic Pulse Velocity test against compressive strength of the core specimen. The comparison showed that use of combined methods gives higher accuracy on estimation of concrete compressive strength. The results obtained gave correlation coefficient of 0.003 and 0.355 for rebound value and Ultra Sonic Pulse Velocity test value. A higher correlation coefficient of 0.441 was obtained when two methods were combined.

Sidhart Shankar and Hikmat Raj Joshi [16] carried out an experimental investigation on the comparison of concrete properties by performing Ultra Sonic Pulse Velocity test and rebound hammer as nondestructive tests and compressive testing as destructive test. 150mm , 100mm, and 200mm cylinders were taken from existing structures and nondestructive and destructive tests were performed on them as per IS standards. The aim of the testing was to derive a relation between Non-Destructive Testing and Destructive Testing. Regression analysis was carried out and graphs were plotted between rebound number and ultra-pulse velocity. The results showed that relation between compressive strength values from Non-Destructive Testing of target object must be incorporated with Destructive Testing so as to arrive at best analysis of the strength.

III. CONCLUSION

Various comparative investigations and studies done on destructive and nondestructive tests lists out some important results which are given as follows:

A) Adopting Non -Destructive Testing methods (combined UPV and RH) gives more accurate results for compressive strength of concrete.
B) Rebound number shows an increase with the increase in compressive strength and vice-versa.
C) Compressive strength or rebound number can be predicted if only one of the values is known.
D) Pulse velocity and rebound number readings increases with the age of concrete and rebound number could directly predict the approximate value of strength in concrete.
E) The use of more than one NDT method would provide a better correlation and would lead to more reliable strength evaluation of concrete.

F) The stronger the concrete, higher shall be its surface index and wave propagation velocity.

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