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Comparison of Destructive and Non-Destructive Testing of Concrete- A Review

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***Abstract*: Concrete has been the prime ingredient of any RC structure for ages. There have been many advancements in types of structures but concrete cannot be neglected. Simultaneously it is also necessary to check the quality of materials used. The quality of concrete can be checked by destructive as well as non-destructive methods. This paper discussed each of these methods in detail and compares them with each other giving out advantages of one over the other.**

Keywords: Compressive Strength, Concrete, DT, NDT, Rebound hammer, UPV.

1. INTRODUCTION

Concrete is the most used material in today's world, in the construction industry. It is a composite material produced by the combination of aggregates (fine/coarse), cement and admixtures if any (Samson *et al.*, 2014). By suitably adjusting the proportion of various ingredients, concrete with sufficient compressive strength can be developed. The oldest known concrete was found in Yugoslavia way back in 5600 BC while the concrete was used in abundance by Egyptians in around 2500 BC (Paul, 2013). The most important property of concrete is its strength which can be determined by destructive and non-destructive testing. DT is a method of testing to determine specimen's failure. The main objective of performing destructive testing is to determine the service life of the specimen and to detect the weakness of design that might not be shown under normal working conditions. NDT comprises of testing methods that are used to analyze the concrete specimen or structure without damaging or destroying it which is generally performed to investigate the material integrity of the specimen. NDT tests are used worldwide to detect variation in structures, infinitesimal changes in surface finish and location of cracks or other physical discontinuities (Carina, 1994). There are various destructive and non-destructive tests that can be employed for concrete. They are as follows:

- Rebound hammer test.
- Pulse- velocity test.
- Compression testing using CTM.

2. LITERATURE REVIEW

Kumavat *et al*., (2017) carried out an experimental study on combined methods of NDT in concrete and evaluation of core specimen from existing buildings. Ultra-pulse velocity, rebound hammer and core tests were performed on the specimens according to IS standards and combining the two methods. Regression analysis was carried out and correlation coefficients were given. Charts were plotted between rebound numbers, UPV 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 UPV value. A higher correlation coefficient of 0.441 was obtained when two methods were combined.

Lopez *et al.*, (2016) experimentally studied about the concrete compressive strength estimation by NDT. The main aim was to produce a correlation between results of surface hardness, UPV and compressive strength of structural concrete in bleachers of soccer stadium in Parana, Brazil. Concrete structure used in the study was 26 years old and had some severe deformities i.e. segregation, corrosion and cracks. Mapping reinforcement was performed and UPV test was done. 26 specimens of concrete were collected from the bleachers and rebar mapping was done for the defect of corrosion in the pillars. Correlation curves between NDT 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 UPV test.

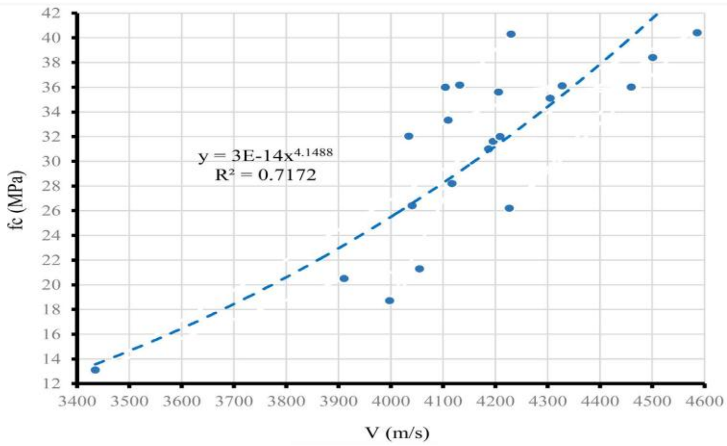

Fig 1: Compressive strength Vs velocity of concrete specimens (Lopez *et al.*, 2016)

Bhosale and Salunkhe (2016) experimentally found the relation between destructive and nondestructive tests on concrete. Different concrete mixes of M20, M25, and M30 were used and a slab of 2000*1000*200 mm was casted for each grade and cores were extracted from the slab. Cylinders of size 100*200 mm, Cubes of size 150*150*150mm and cubes of 150*150*150mm with inserted bar of size 16mm were casted .Casted cubes after 28 days were tested to obtain compressive strength using CTM. Rebound hammer test was performed and average of 12 readings were taken. Regression analysis was done and various correlations were achieved which are given as following:

- Relation between compressive strength of cylinders (f cyl) and cores (F cor)
  F cor = -0.034 f cyl2+ 2.586 f cyl -19.25
- Relation between rebound strength of cylinders(R cyl) and cores(R cor)
  R cor= -0.020 Rcyl2+2.15 R cyl -16.75
- Relation between rebound ultra-pulse velocity of cylinders (U cyl) and cores (U cor)
  U cor= 1.373 U cyl2+ 12.18 U cyl -22.95
- Relation between rebound strength(R cor) and UPV strength of cores (f cor)
  R cor= -0.050 f cor2 + 3.987 f cor – 31.16
- Relation between UPV (U cor) and compressive strength (f cor) of cores
  U cor= -0.003 f cor2+ 0.18 f cor +1.410
- Relation between rebound strength and UPV of cores
  U cor= -0.002 R cor2 +0.166 R cor + 1.671
- Relation between rebound strength and compressive strength of cylinders
  R cyl = -0.037 f cyl2 + 2.712 f cyl -19.85
- Relation between UPV and compressive strength of cylinders
  U cyl= 0.0222 f cyl + 3.64
- Relation between rebound strength and UPV
  U cyl= 0.001 R cyl2-0.052 R cyl + 4.355

Mulik *et al.*, (2015) performed a series of nondestructive tests to investigate 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 and the specimens were cured for 28 days after which rebound hammer test, ultra-pulse velocity test, and compression test was performed on them. The results showed that SONReb method of combined testing provided a reliable assessment for determining concrete compressive strength and a correlation coefficient of 0.789 and 0.672 was achieved for rebound number values and ultra-pulse velocity. A higher correlation coefficient of 0.867 was achieved using SONReb and combined methods were predicted to be more reliable in determining the compressive strength.

Konapure and Richardrobin (2015) experimentally studied 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. The results showed that the percentage difference of compressive strength for NDT and DT was low for laboratory specimens and 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.

Patil *et al.*, (2015) experimentally investigated on the comparative study of effect of curing on strength of concrete using DT and NDT methods. 27 cubes of M25 grade were casted and allowed to be cured for 7, 14 and 28 days and rebound hammer test and compressive strength test was performed on 9 cubes of 7, 14 and 28 days respectively. The results showed that rebound number increased as the compressive strength increased and vice-versa. For 28 days of curing decrease in percentage strength was less as compared to 7 days percentage decrease in strength and 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.

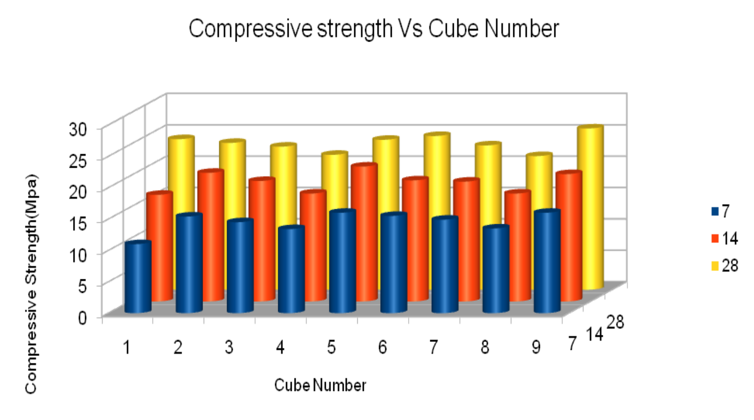

Fig 2: compressive strength vs. cube no at 7, 14 and 28 days (Patil *et al*., 2015)

Damodar and Gupta (2014) experimentally investigated to develop an ideal curve equation that could predict the value of concrete's compressive strength .OPC, PPC and PSC cements were used in the experimental work.18 cubes of 1st batch of M20, M25, and M30 grade were cast and subjected to normal curing. 3 cubes from every mix were tested for compressive strength at 1 and 3 days respectively and result of average of 3 cubes was taken. Similar cubes for PSC and PPC were cast and tested. 2nd batch of M20, M25 and M30 grade were cast. 18 cubes were subjected to normal curing while as 18 cubes were subjected to accelerated curing. Results obtained from the experiment showed that OPC gained strength of 80% in the 1st day of accelerated curing while as PSC and PPC only gained 50% strength in the 1st day and these results could be used in future for prediction of early strength of concrete. Results also showed that an ideal curve equation could be obtained and used in computing the compressive strength of concrete. The gain in compressive strength is given in the following equation

$$Y= (ab)\ x$$

Where y represents compressive strength, a represents factor comprising parameters of various design mixes, b represents coefficient of no of days the system has been subjected to curing and x represents no of days the cubes which are subjected to curing.

Table 1: Compressive strength comparison of Mix M20 (Damodar and Gupta, 2014)

Mix Grade	1 day	3 days	7 days	28 days
Mn20-OPC	4.00	9.39	19.55	23.48
Ma20-0PC	19.25	18.17	19.55	23.48
Ma20-PPC	12.74	10.22	16.74	22.88
Ma20-PSC	11.7	11.48	19.92	24.44
Where n-normal curing, a-accelerated curing				

Table 2: Compressive Strength Comparison of Mix M25 (Damodar and Gupta, 2014)

Mix Grade	1 day	3 days	7 days	28 days
Mn20-OPC	5.17	11.78	24.07	28.74
Mn20-OPC	22.96	22.37	24.07	28.74
Ma20-PPC	13.48	11.18	17.33	23.70
Ma20-PSC	12.66	12.10	19.25	25.33
Where n-normal curing, a-accelerated curing				

Table 3: Compressive Strength Comparison of Mix M30 (Damodar and Gupta, 2014)

Mix Grade	1 day	3 days	7 days	28 days
Mn20-OPC	5.53	12.93	24.74	30.74
Mn20-OPC	24.88	23.77	24.74	30.74
Ma20-PPC	17.18	14.44	22.96	31.70
Ma20-PSC	14.29	13.03	22.41	28.29
Where n-normal curing, a-accelerated curing				

Samson *et al.*, (2014) investigated about the correlation between nondestructive and destructive testing of compressive strength of concrete. Concrete cubes of size (100x100x100mm) were cast using M20, M30, and M35 grade concrete 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 and results showed high rebound number in high compressive strength. Correlation coefficients of regression models ranged between 92.1%- 97.9% which showed an excellent relation between rebound number and compressive strength. Results also showed that if only rebound number was known, the compressive strength of concrete could be easily predicted.

Table 4: Relationship between compressive strength and Rebound number after 7 days curing (Samson et al., 2014)

Grade	Slope(m)	Intercept(c)	Standard Deviation(s)	R^2 (%)	Significance
M20	1.19	-3.73	0.328	91.6	yes
M30	1.08	-2.85	0.354	92.1	yes
M35	0.778	2.83	0.384	92.6	yes

Table 5: Relationship between compressive strength and Rebound number after 14days curing (Samson *et al.*, 2014)

Grade	Slope(m)	Intercept(c)	Standard Deviation(s)	R^2 (%)	Significance
M20	0.834	1.55	0.268	94.5	yes
M30	0.644	5.49	0.251	97.9	yes
M35	0.503	8.73	0.433	97.1	yes

Table 6: Relationship between compressive strength and Rebound number after 28days curing (Samson *et al.*, 2014)

Grade	Slope(m)	Intercept(c)	Standard deviation	R^2 (%)	Significance
M20	0.649	4.91	0.456	97.1	yes
M30	0.728	-0.380	0.497	96.6	yes
M35	0.609	7.18	0.761	92.1	yes

Reddy (2014) carried out an experimental investigation to find out concrete's strength by various NDT methods and compressive testing. Various cubes of concrete 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 for all the mixes using (UPV, rebound number and compressive strength) and curves were plotted. Results showed that pulse velocity and rebound number increased with age of concrete. Recycled aggregate concrete also showed 30% less strength than plain concrete and fly ash concrete showed 75% less strength than plain concrete as well.

Akash Jain *et al.*, (2013) developed a method of combined use of both UPV and RH tests for assessing the strength of concrete with great accuracy. The concrete mix design for M20, M30, M40, and M50 was done using IS 456:2000 and IS 10262:1982 and a total of 288 cubes were casted. The 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 OPC/PPC and rebound number and between age of OPC/PPC and UPV. A relationship curve was also plotted between ultra-pulse velocity, rebound number and compressive strength. The results derived from the experiments showed that UPV readings increased with age but the change was very small and it alone could not 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.

Hannachi and Nacer (2012) investigated the application of the combined method of UPV and RH tests for evaluation of compressive strength. UPV and RH tests were calibrated with mechanical tests done on cylindrical specimens. The tests were used to determine quality of concrete using regression analysis modes. Equations were obtained by statistical analysis to analyze concrete's compressive strength on site. Correlation charts were plotted and regression equations were listed. The results showed that using more than one NDT provided a better correlation and lead to more reliable strength evaluation of concrete's strength. The results also showed that combined methods appeared more appropriate on conditions of on-site measurements as they were very fast, convenient and cost efficient.

Table 7: Regression equations for Cylindrical Specimens (Hannachi and Nacer, 2012)

Rebound hammer method	fc = -0.7708N+ 54.6389	R^2 = 0.3983
Ultra-pulse velocity method	fc = -0.0162V+97.54095	R^2= 0.5213
Combined method	fc=0.5752V-0.0261N+121.2976	R^2= 0.5452

Table 8: Regression equations for Cores (Hannachi and Nacer, 2012)

Rebound hammer method	fc = 0.3218N+5.3290	R^2= 0.0864
Ultra-pulse velocity method	fc =0.0088V-20.2771	R^2=0.0901
Combined method	fc = 0.0993V+14.5356N-0.0037V-371.4	R^2=0.1251

Shang *et al*., (2012) experimentally found the strength of concrete using NDT 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 containing 21 concrete cube specimens of the size (150x150x150mm). Rebound hammer test was performed on the specimens and 16 readings were taken for each specimen. Regression analysis was done and curves were drawn for rebound hammer method. Results showed that rebound hammer was found reliable in predicting early strength of concrete. Thus, it was concluded that, the regression model for strength evaluation could be safely used for the prediction of concrete strength in all types of concrete engineering investigations.

Table 9: Rebound Curve for Concrete measurement and error (Shang *et al*., 2012)

Regress Model	Function Expression	Correlative coefficient	Mean Relative Error (%)	Relative standard error
Exponential function 1	$f^c_{cu} = 6.004665xe^{(o.47xRm-0.017xdm)}$	0.824	12.43	15.33
Exponential function 2	$f^c_{cu} = 278.28xe^{(-77.23/Rm+0.009/dm)}$	0.850	11.88	14.7
Logarithm function	f^c_{cu} =-235.71+75.30xln(Rm) -0.53812x ln (dm)	0.868	11.21	16.88
Power function	$f^c_{cu} = 0.028x\ Rm^{1.9629}xdm^{-0.0155}$	0.850	11.17	14.05
Power exponential function	$f^c_{cu} = 6.00468x\ 1.0486^{Rm}\ X\ e^{-0.0177xdm}$	0.824	12.43	15.33
Complex exponential function	$f^c_{cu} = 0.032509x\ Rm^{1.941}\ x\ 10^{-0.00789xdm}$	0.852	11.04	13.75

Rohit *et al.*, (2012) experimentally investigated the flexural strength of plain and fiber reinforced high volume fly ash concrete (HVFAC) by destructive and non-destructive techniques. Experiments were conducted on M25, M30 and M35 mixes and poly carboxylate based super plasticizer was used. Compaction factor test and flexural strength tests were performed as destructive tests and UPV was performed as nondestructive test. Charts and graphs were plotted and the results showed that pulse velocity decreased with increase in the fiber content up to 3.2%. and polyester fiber showed significant gain beyond 28 days. The gain in the %age of fly ash exhibited a reduction in the percentage gain at different age of concrete. Regression yield analysis was carried out and following equations for prediction of flexural strength at 28 days for different samples were summed up as follows:

Table10: Equations for prediction of flexural strength for UPV at 28 days (Rohit *et al*., 2012)

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

Shariati *et al.*, (2010) assessed the strength of RC structures through UPV and rebound hammer tests and a correlation between DT and NDT tests was established. Main members of an existing building including a column, beam and slab were tested by NDT. Regression analysis was done and calibration curves were drawn. Correlation between predicted and actual compressive strength of concrete was interpreted by plotting average rebound no/ultrasonic pulse velocity against compressive strength of each member. Results obtained from the experimental study showed that regression model achieved from the combination of two NDT methods was more precise as compared to the individual methods. Results also showed that rebound number method was more effective in forecasting the compressive strength of concrete than the UPV test method.

Aydin and Saribiyik (2010) carried out experimental investigation to develop a relationship and correlation between rebound hammer test (NDT) and compression test (DT). Cube specimens of size 15*15*15 cm and a no of core samples from different RC structures were tested. Rebound hammer test and compressive test was performed on the specimens. The curves were drawn and the best fit correction factors for concrete compressive strength were obtained through processing the correlation among the datasets. The results drawn from the investigation showed that use of rebound hammer test on existing buildings was not found suitable for evaluation of strength in old concrete. Results also showed that rebound hammer tests could be used alone as a reliable means to estimate the strength of concrete specimens if the needed calibrations were done.

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Table 11: Regression outputs for 28 and 90 days' concrete specimens (Aydin and Saribiyik, 2010)

28 days concrete specimens	y = 11.61 A-52.033	R^2=0.856
90 days concrete specimens	y = 16.674 A- 238.31	R^2 = 0.9449

3. PRACTICAL APPLICATIONS

NDT can be used for in-service inspections to determine cracks due to fatigue, corrosion, damage and creep. Various discontinuities which can be determined by different NDT techniques include detection of surface and subsurface cracks, inclusions, pits and porosity. Homogeneity of concrete in foundations, walls and slabs can be determined using NDT. Quality of structural and surface protection measures of elements can be determined using NDT. The service life of both old and new structures can be predicted using NDT. NDT (combined method of UPV and RH) is being incorporated in codal provisions for future references for determining strength of in-situ concrete structures. Destructive testing can be used in determining material, mechanical and chemical properties of the materials.

From the overview of various experimental studies and investigations following conclusions were made:

- The comparative study showed that pulse velocity and rebound number increased with age of concrete and with increase of compressive strength.
- Compressive strength or rebound number could be produced if only one of the values was known to us.
- Results concluded that percentage difference between compressive strength by nondestructive and destructive testing was found out to be low for laboratory specimens.
- Rebound hammer was proved to be the most simple and quick method of obtaining the compressive strength of concrete specimens.
- The use of more than one non-destructive method would provide a better correlation, leading to predictable means of evaluation of strength in concrete.
- Combined methods (ultra-pulse velocity and rebound hammer) were predicted to be more reliable in determination of compressive strength of various concrete specimens.

4. CONCLUSIONS

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