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Destructive and Non-Destructive Testing Methods for Condition Monitoring of Concrete Elements

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***Abstract*—The deterioration of concrete structures in the last few decade's calls for effective methods for condition evaluation and maintenance. This resulted in development of several non-destructive testing (NDT) and destructive testing (DT) techniques for monitoring civil infrastructures. NDT and DT play an important role in the condition monitoring of existing RC structures. NDT methods are known to be better to assess and evaluate the condition of RC structures practically and in some special cases adopt DT techniques to get the exact results. The estimation of mechanical properties of concrete were carried out by destructive and non-destructive methods. In this context, the crushing of the samples is the destructive test to determine the concrete strength. The rebound hammer test is normally used in the field of non-destructive tests to determine the compression strength of concrete. This work was divided in to two phases. In the first phase design C30 concrete mix with varying water / cement ratio of 0.35, 0.40, 0.45 and 0.50. Twelve concrete cube specimens were cast of size 150 x 150 x 150mm. An experimental study was conducted to determine the compressive strength of concrete by Universal Testing Machine (UTM) and non-destructive test (Rebound Hammer) after 28th days of curing. In this study, age of concrete, with different water / cement ratio for NDT and actual compressive strength concrete using DT were determined. In the second phase, design of under reinforced beam over a span of 750mm (length) x 100mm (width) x 150mm (depth) was cast with water cement ratio 0.45 and tested in the laboratory after 28 days of curing. NDT (Rebound Hammer) and DT (UTM) techniques was used to determine the compressive strength of concrete. The result shows that better correlation between destructive and non-destructive methods for cubes and beam.**

Keywords—Non-destructive test, Rebound hammer, Reinforced concrete beam, Compressive strength.

I. INTRODUCTION

Non- destructive testing is one of the most powerful and reliable tools. The importance of conducting nondestructive test for condition assessment of the RCC structures has grown considerably in recent times, due to increase in number of structures, showing signs of distress. The standard life of RCC frame structure is considered to be 60 - 80 years. But it has been reported that, many of the buildings completing just 20 - 25 years of their life. The crushing of the specimens is the usual destructive test to assess the strength of concrete, Non-destructive methods like rebound hammer test and ultrasonic test do not damage buildings. Have an inventory of structures and conditions. This investigation focuses on the extent of carbonation of the structure and the extent of corrosion of the reinforcement and theoretical remaining concrete life.

Destructive testing is carried out to the elements failure, in order to understand a structure performance or material behavior under different loads. Destructive testing explores failure mechanisms to determine the mechanical properties of material such as yield strength, compressive strength, tensile strength, ductility and fracture toughness. NDT methods explore indications of properties without reaching component or assembly failures. These tests are generally much easier to carry out and most suitable and economical and considered to be the most reliable type of testing, while non-destructive testing is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. Non-destructive testing can be applied to both old and new structures (Jedidi Malek, 2014).

For new structures, the principal applications are likely to be for quality control or the resolution of doubts about the quality of materials or construction. The testing of existing structures is usually related to an assessment of structural integrity or adequacy. There are various types of testing used in destructive testing such as hardness testing, impact testing, tensile testing and bend testing and basically all considered to be damaging the concrete somehow

.Non-Destructive testing also have many devices and ways that have been developed such as; rebound hammer which is used to find the compressive strength of the concrete, the rebound of an elastic mass depends on the hardness of the surface against which its mass strikes. When the plunger of the rebound hammer is pressed against the surface of the concrete, the spring-controlled mass rebounds and the extent of such a rebound depends upon the surface hardness of the concrete (Darshakkumar.V.Mehta, 2015).

II. LITERATURE REVIEW

This chapter presents a background of the information needed on the development of destructive and non-destructive testing of concrete element, the reviews are published about the Destructive and Non-destructive testing methods for condition monitoring of concrete elements

2.1 Kumavat H R (2015). The main objective of this paper is to case study the uses of the non-destructive testing to evaluate and measure the building age and strength throughout the years also the paper focuses on standard testing processes of NDT and the operation for obtaining accuracy and the problems created during testing and the limitations of the tests. On-destructive testing is a large group of techniques analyzing and testing used in the industry to evaluate the mechanism and properties of the materials specifically concrete without destroying or causing any damage, while conducting this case study various types of testing were used such as core test, ultrasonic pulse velocity, compressive strength, rebound hammer etc. As a result in the building structure it was observed that the half-cell potential reading of concrete beam is 15% more than the concrete column, the reading has shift in between 200mv to 500mv. There was 50 to 75% of expectation of corrosion in beam member, due to shifting towards more negative values getting chances of corrosion of reinforcement, considering all factors including the possibility of the cover concrete therefore it was estimated that the concrete had a compressive strength range from 20-26 MPa averagely this strength were found to be up to 5 % lower than the minimum required as per Indian codes of practice. The present methods for ultrasonic testing of concrete require direct contact between the concrete surface and the transducers.

2.2 Helal J. (2015). The main objective of this paper is to evaluate and clear concerns of concrete by analysing, identifying and describing the most successful methods of NDT that is applied to concrete elements. The NDT of cement was observed to be increasing expanding acknowledgment as a method for assessing the quality, consistency, solidness and different properties of existing solid structures therefore the authors think that the extensive use of NDT is driven by economic matters and safety.

In a pre-emptive endeavour to destroy the issues connected with auxiliary disintegration, novel in-site testing procedures have been designed to take into account the evaluation of concrete development, charging and adjusting lifecycle phases of a structure. For this study it was found that the biggest part of NDT strategies depend on comparing tried parameters and built up correlations. Observational analysis that is given by makers was found unacceptable due to the results. Where material, it is prescribed to conduct test correlation process for the NDT of concrete. As a result the authors predicted the future of NDT of concrete that it's gaining acceptance as means of evaluating material integrity and strength.

2.3 Saleem M. (2012). The intent of this paper is to case study and apply nondestructive evaluation to a five storied concrete frame Structure that was constructed 12 years ago. The research work which is conducted is focused on developing the adequacy of an existed RC building structure. The author is using a combination of testing methods that each test has its own limitations and its results where it may be affected due to several factors including: environmental exposure; age of structure; process of measurement; type of constituent materials and curing conditions, That's why the researchers used combination of tests, to attain more accurate results to either accept or reject the structure due to testing results to assure the safety of future use. Two types of testing that the authors conducted which are core test and load test where in the load test proved that the first floor slab was inadequate, in the other hand the core test showed acceptable concrete strength in all the floors As presented in the results cores from all levels exhibited compressive strength higher than 3000 psi except core of the lower ground floor. The author concluded that even after twelve years of exposure to all types of environmental conditions the structure tests reconfirms that if construction quality is good concrete has the ability to withstand the environmental pressure and preserve its strength and integrity for a long time.

2.4 Jedidi Malek & Machta Kaouther (2014). The main objective of this technical paper is to present the measurements of compressive strength and modulus of elasticity determined from destructive and non-destructive tests, the study encourages the use of NDT because non-destructive testing is simple to use and also has economic advantages also they are suitable for taking measurements on site and taking continuous measurements. The different results of the testing's conducted such as compression strength and rebound hammer appeared that the compressive strength is determined by destructive test (compression test) and Non-destructive test (rebound hammer test) at different ages of the concrete, the results also showed that at the ages of 7 and 14 days, the resistances obtained by the compression test were higher than those obtained by the rebound hammer test. The percentage of the respective average differences between the compression test and rebound hammer at the ages of 7 days and 14 days were 14% and 17%. The percentage of the respective average differences between the

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compression test and rebound hammer at the ages of 7 days and 14 days were 14% and 17%. The C30 concrete cubes and the reinforcement beam were cast in the college laboratory for the availability of all machinery.

III. EXPERIMENTAL PROGRAMME

In this study mix design for C30 concrete grade for the cubes with different water cement ratio of 0.35, 0.40, 0.45.0.50 and 0.45 W/C ratio used for the under reinforcement beam. The tests were done for both specimens after 28 days of curing.

3.1 Preparation of C30 concrete cubes

C30 grade concrete cubes were cast with different water cement ratio the mix design adopted are presented in the Table 1.

Table 1 Concrete Ingredients and mix proportions

Sl. No	Mix Ratio	Cement kg/m^3	Fine Agg. kg/m^3	Coarse Agg. kg/m^3	W/C	Nos.
1.	C30	394	799.7	982	0.35	3
2.	C30	394	799.7	982	0.40	3
3.	C30	394	799.7	982	0.45	3
4.	C30	394	799.7	982	0.50	3

3.2 Casting

After the concrete mix is prepared the workability and consistency of concrete was tested by slump test Total number of cubes was 12 Nos were casted and tested in the college laboratory after 28 days of curing. The casting process are shown in Fig.1. After demoulding the concrete cubes it was cleaned to make sure that there is no oil or dirt attached, the 12 cubes were cured in the water tank for 28 days.

Fig.1 Cast cubes with different w/c ratio

4.4 Preparation of under reinforcement beam

Under reinforced beam was cast in the college laboratory with water cement ratio of 0.45, bottom tension reinforcement 2H8 and top 2H6 with stirrups of 6mm diameter 150 mm C/C (Fig.2 and 3). After cleaning the beam grid marking is done both side and top. The grid distance not more than 15cm. Each side 4 tests were conducted and average rebound No calculated. This rebound number converted into compressive strength in concrete as per ASTM C805-79 standard. The testing procedures are shown in Figs.5 and 6

Fig.2 RC beam casting Fig.3 Finished beam

3.3 NDT for cubes and RC beam

After 28 days of curing NDT test was conducted for cubes -12Nos and one RC beam. Each cube 3 tests were conducted one at top and other two at sides. For each and every cube rebound number were calculated from the average of 3 rebound numbers. The test procedure for cubes are shown in Fig.4.

Fig.4 NDT for cubes

Fig.5 Grid marking on beam

Fig.6 NDT for beam

3.4 DT for cubes

The concrete specimen's compressive strength were identified by applying the cube compressive strength test. The concrete cubes at the size 150 x 150 x 150mm were tested by the Universal Testing Machine (UTM) 28 days of curing. The details are show in Fig.7.

Fig.7 Destructive testing for cubes

Totally 12 Nos of C30 grade concrete cubes specimens of size 150 x 150 x 150mm were tested on two opposite sides and top, the results were obtained, it varies from 32 N/mm^2 to 25 N/mm^2 with water cement ratio 0.35 to 0.50. The NDT Rebound hammer test were conducted based on ASTM C805-79.
The compressive strength test results based on NDT and DT for cubes are shown in Figs. 8 and 9 and presented in the Table 2.
Totally 8 tests were conducted for both sides at a grid interval of 15cm. The average values of rebound number are presented in Table 3. Then the NDT value of the beam converted into compressive strength (N/mm^2). Then this values were compared with cube of same water cement ratio (0.45) are shown in Fig.10.

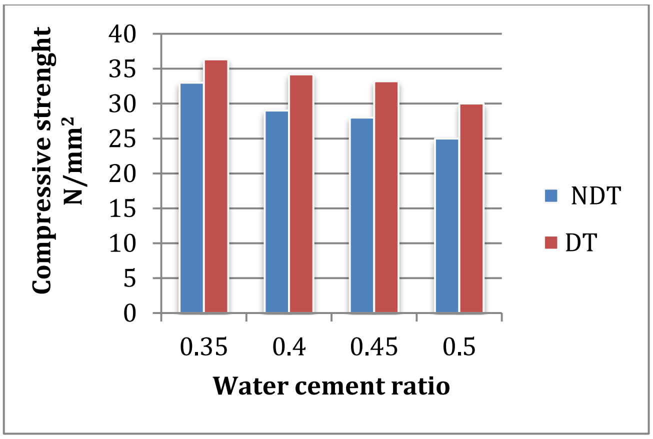

Fig.8 NDT and DT compressive strength for cubes (bar chart)

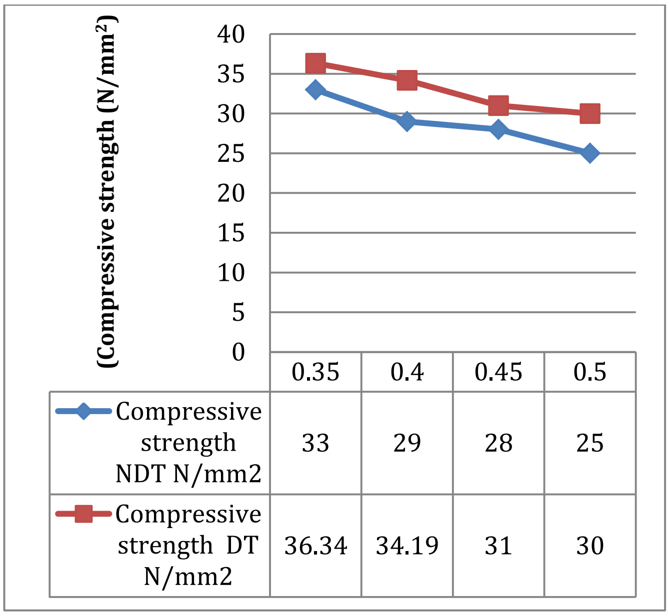

Fig.9 NDT and DT compressive strength for cubes (graphical representation)

Table 2 Compressive Strength (N/mm^2) for C30 grade concrete cubes both NDT and DT

Sl. No	W/C ratio	Nos	Curing period	Average Rebound No	Compres-sive strength NDT N/mm^2	Compres sive strength DT N/mm^2	Variation with respect to DT (%)
1	0.35	3	28 Days	33	32	36.34	11.50%
2	0.40	3		30	29	34.19	15.00%
3	0.45	3		29	28	33.2	15.70%
4	0.50	3		27	25	30	16.7%

IV ANALYSIS AND DISCUSSION OF RESULTS

4.1 Concrete cubes and beam

The average compressive strength from NDT 32 to 25 N/mm^2 with w/c ratio range from 0.35 to 0.50 and destructive testing 36.24 to 30 N/mm^2 of same water cement ratio.
The percentage variation for compressive strength of rebound hammer and destructive test varies from 11.50% to 16.70% with respect to destructive testing. The values from NDT and DT gives closer result, the variations not more than 16.5% it is evident that NDT by rebound hammer proves good performance for health monitoring of structural elements in general the rebound number increases as the strength increases but it is also affected by a number of parameters such as the characteristics of the mixture, surface carbonation, moisture condition, rate of hardening and curing type.

Table 3 RC Beam and cube compressive strength using NDT

Sl. No	Mix	W/C ratio	Speci -men	Curing period	Average Rebound No	Compr-essive strength of NDT N/mm^2	Variation (%)
1	C30	0.45	RC beam	28 days	29.5	29	3.4%
2		0.45	CC		29	28	

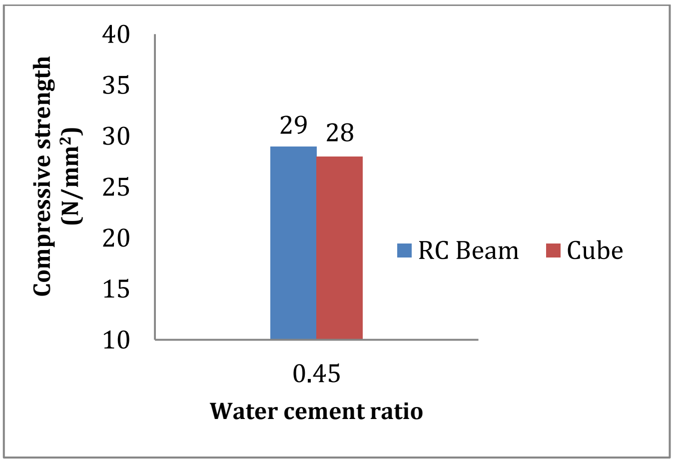

Fig.10 RC Beam and cube compressive strength

The RC beam with the size of 750mm x 100mm x 150mm was tested with NDT by rebound hammer. The average compressive strength is 29 N/mm^2. The concrete cube specimen of same 0.45 W/C ratios, the compressive strength of 28 N/mm^2. For NDT concern cube and RC beam shows almost the same result.

V CONCLUSION

Based on the experimental results the following conclusions all drawn:

- C30 grade concrete cubes were cast with different W/C ratio of 0.35, 0.40, 0.45, and 0.50. The cubes are tested after 28 days curing for both NDT and DT.
- From NDT the characteristics compressive strength of concrete after 28 days curing were tested, it shows 32, 29, 28 and 25 N/mm^2 for W/C ratio o.35, 0.40, 0.45 and 0.50 respectively.
- The DT for the same cubes by UTM the compressive strength are 36.34,34.9,33.2 and 30 N/mm^2 for W/C ratio – 0.35,0.40,0.45 and 0.50.
- The percentage variation for NDT and DT is 11.50%, 15%, 15.70% and 16.70%. For W/C ratio 0.35, 0.40, 0.45 and 0.50. These values are very closer to each other.
- For RC beam with water cement ratio of 0.45 was cast and tested after 28 days curing.
- The NDT for beam average compressive strength is 29N/mm^2 and cube with same W/C ratio (0.45) reflects the compressive strength of 28 N/mm^2, for NDT concern both PCC and RCC almost similar.
- The increasing rebound number is representing the higher compressive strength.
- The Rebound hammer provides an cheap, simple and quick method of determining the concrete strength
- The results are affected by factors such as smoothness of surface, size of the CC specimen, moisture condition of the concrete and the type of cement used.
- Schmidt Hammer rebound tests can be used to estimate the strength of concrete to reduce the number of cores taken from the structures.

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