Condition Evaluation of Concrete Through Ultrasonic Pulse Velocity

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Abstract Testing of ultrasonic pulse velocity (UPV) is one of the most famous and actual non-destructive techniques used in the evaluation of concrete properties in structures. In this paper, an approach has been proposed for evaluating the actual condition of concrete structures, by relating to UPV which is significantly influenced by concrete compressive strength, concrete cover, surface hardness and frequency of concrete mix prepared. The present study is done by means of the experimental data obtained from testing numerous casted concrete cubes and existing structures. Cubes have been casted using plain cement based on concrete mix design taking reference from IS code.

Keywords Ultrasonic pulse velocity · Compressive strength · Concrete cover · Surface hardness and frequency of concrete

1 Introduction

Concrete has been used as a construction material for several years. Structural design methods of concrete structures traditionally focus on the compressive strength and construction. However, the field experience in the previous years has established that concrete structures degrade with age. Henceforth, a steady weakening in material properties is observed, and this explains degradation in the presentation and life of a structure. Repair and rehabilitation of degrading concrete structures is needed at regular interval to preserve the performance. Due to being deficient in the performance of building structures in past decades, there is an increasing curiosity in the range of harm assessment and preservation of concrete structures.

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Deprivation and weakening of structures initiated by substantial and chemical damage results in the reduction in conduct with age, physical injury exists due to fire, recession and increased stresses, whereas chemical damage occurs due to bitter environment. Lack of robustness of concrete structures or the beginning of cracking has been caused mainly due to harsh environment.

Failure of "concrete structures earlier than serving of its proposed life is a universal problem and the circumstances are predominant in harsh regions of the world where lofty temperature, humidity and salinity subsist".

The valuable "life of a structure without significant maintenance and replacement depends on the degradation rate of the embedded reinforcement and surrounding cover". Previous to this deprivation starts, violent elements such as chlorides or carbon dioxide must go into the concrete in adequately high concentrations, to the depth of the rooted reinforcing steel. Weakening of reinforced concrete (RC) structures caused by corrosion of steel is an expansive process. This method damages the adjacent concrete and declines the steel as it rusts. Concrete also degrades and worsens as of chemical reactions among and under the cement template, aggregate and in moisture. However, the first line of defense against these deterioration mechanisms is cover to reinforcements in RC structures. An optimum concrete cover delays the ingress of harmful agents in concrete structures.

For concrete structures, surface hardness and concrete cover of the concrete has been mostly considered responsible for durable life of concrete structures. Therefore, designers emphasize on these properties.

"NDT methods have been used since the last three decades for observing RC structures; now it has been known that NDT plays a vital role in observing the existing form of RC structures. NDT methods are acknowledged to be superior to evaluate the condition of RC structures practically". NDT is the usually used weapon in civil engineering, mechanical engineering, electrical engineering, automobile engineering etc. NDT plays a critical role in cost-effective operation, safety and reliability of structure, with resultant benefit to the community.

In comparison to destructive testing, the non-destructive testing is an evaluation of the present existing condition without making damage, stress or demolishing the test object. The destruction test of the object usually makes destructive testing more expensive and it is also unsuitable in many situations. The quality of novel concrete structures is reliant on several parameters such as type of cement, type of aggregates, water-cement ratio, curing and environmental conditions. In addition to this, the controlled execution during construction also contributes a lot to attain the desired quality (Fig. 1).

Fig. 1 NDT methods

2 Following the Objectives of the Present Research

I. To study about several parameters influencing the durability and condition of concrete.
II. To summarize the advantages and limitations of UPV method, cover meter and rebound hammer.
III. To propose a method for determining the condition of concrete by measuring UPV.
IV. To propose a correlation between UPV and different properties of concrete cubes and existing concrete structures.

3 Literature Review

Monitoring and estimation of concrete situation are very much significant in the field of structural concrete study. In-situ systems can be used for structural monitoring projects to obtain these data, which would be significantly precious since the field data could be used to assess the material properties.

Paktiawal and Alam [1]. As per order to observe the variation in setting of concrete with age by means of destructive and Non-destructive testing, Grade M60 concrete cubes were prepared with different content of different types of industrial wastes under loaded and unloaded conditions. In the first set of mix, the fine aggregate was replaced by the waste glass powder with diverse amount of 0, 10, 20, 30, and 40% by weight. “Secondly, the cement was replaced by waste of aluminum with dissimilar percentages of 0, 2, 4, 7, and 12, along with the addition of LDPE with 3.5, 7, 12.5, and 21%. In the third mix LDPE was added with different amounts of 0, 3.5, 7, 12.5, and 21 % by cement weight. It has been observed that the commercial wastes utilized in this research with different replacement levels decrease the ultrasonic pulse velocity count under unloading states at the age of 28, 210 and 270 days". The outcomes related to UPV and hardness of surface for all categories of wastes in loaded conditions are observed lower than that of unloading conditions.

Yin et al. [2] recommended a damage revealing technique to recognize damages made by "Flexural loading in ultra-high-performance fiber-reinforced concrete (UHPFRC) material" and named as cross-modulated vibro-acoustic technique. In this investigation, cross-modulated vibro-acoustic technique is suggested in which at dissimilar flexural harm levels, a model of contact nonlinearity at interfaces is made to set up the nonlinear parameter Dα. On the basis of ASTM C215 (02), the usual RF test is carried out to match up with the outcomes of the suggested cross-modulated vibro-acoustic technique. This study also shows the functionality of the cross-modulated vibro-acoustic technique to observe the damage growth in ultra-high-performance fiber-reinforced concrete (UHPFRC) structure. Finally, it has been concluded that the suggested cross-modulated vibro-acoustic method is a precise and reliable approach to check progressive harm in concrete structures.

El Mir and Nehme [3], the Schmidt hammer is classified as a cost-effective non-destructive testing tool. In this research, an extensive investigation is done on hundred of concrete varieties produced from a number of types, to determine the compressive strength and recognize the restraints and precincts of rebound hardness. water-binder ratio, water-powder ratio, compaction, supplementary cementitious materials and admixtures are comparatively affecting the reaction of rebound index of the Schmidt hammer by means of repeatability for prophecy of compressive strength. In order to enhance this statement, the additional porosity measurements were also done.

Tsioulou et al. [4] examined "Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) with dissimilar quantities of steel fibers. Appropriate empirical non-destructive models have been developed with the help of compressive and tensile test results alongside with Ultrasonic Pulse Velocity and Rebound Hammer measurements. It has been concluded that The mechanical properties of this material are of great importance and the growth of non-destructive techniques is essential for the assessment of the mechanical features of existing structures".

Ur Rehman et al. [5] reviewed NDT methods relevant to concrete bridges. A detailed note has been made on the methodology, advantages and disadvantages along with recent researches related to NDT. Different damage stages, having less reliance on inspector finding, are proposed. Also, a flow chart based on damage stages besides the NDT methods and potential corrective measures is suggested for cyclic health monitoring of structures. A correlation between the most common troubles encountered by the field engineers and NDT methods is determined and advised. Finally, the significance of structural health monitoring (SHM) is emphasized.

Amini et al. [6] developed models for predicting the compressive strength of concrete, without considering the past maintenance record of the building. Performed ultrasonic pulse velocity (UPV) and rebound hammer (RH) tests over several cylindrical samples of concrete.

Pucinotti [7]. Several destructive and non-destructive tests had been conducted on a significant historic building in Reggio Calabria. It has been observed from the results that due to changes in the in-situ mechanical properties of the concrete; it is needed to calibrate the strength determined by non-destructive testing of concrete.

Malek and Kaouther [8]). An investigational study has been carried out to determine the crushing strength of concrete through destructive and non-destructive testing at the age of 7, 14 and 28 days. For destructive testing compression tests and for non-destructive testing rebound hammer tests have been conducted. The effect of several parameters on the modulus of elasticity has been investigated through a pulse velocity test. These parameters are the age of concrete and the water/ cement ratio.

Bogas et al. [9]. "The crushing strength of several concrete mixes produced using lightweight aggregate has been assessed using the non-destructive UPV method". "In this study, almost 84 separate compositions have been prepared and tested after 3 and 180 days of curing, compressive strengths of these samples is ranging about 30–80 N/mm^2".

Jain et al. [10] conduct a preliminary study in which the reaction of concrete ingredients, proportion of concrete mix, and "variables related to workmanship on the Rebound Number and "Ultrasonic Pulse Velocity of concrete were evaluated". In this study combined use of both the NDT techniques had been done and found more effective".

Hajjeh [11] performed several destructive and non-destructive tests on several laboratory casted concrete cubes. Regression investigation is carried out and several relationships were determined and correlated between non-destructive testing method which is Schmidt rebound hammer test and concrete destructive compression test. Schmidt hammer has been applied in both vertical and horizontal positions. The standard concrete cubes had been made with a range of mix proportions that yielded standard cube crushing strengths.

Hannachi and Guetteche [12] applied rebound hammer and ultrasonic pulse velocity methods to establish the concrete quality through regression analysis models between compressive strength of in-situ concrete on existing structure and the non-destructive test values. The combined method has been used and equations are derived using statistical analysis to estimate compressive strength of concrete on site. The reliability of the technique for the prediction of the strength has been discussed for a case study.

Wang et al. [13]. Degradation of concrete structures means steady and slow declination in performance of concrete. It significantly takes place due to corrosion caused by carbonation and chloride ingress. Several researchers worked on this topic, they estimated the useful life of concrete Structures in several steps, namely ingress of harmful chemicals, corrosion of embedded steel and cracking of cover.

4 Experiment of Programs and Results

a. Preparation of several concrete mixes using plain and blended cement by varying the proportions of ingredients.
b. Determining the density of prepared concrete mixes of both pain and blended concrete
c. Preparation of number of 150 mm cube specimens and their curing under standard conditions.
d. Place the cubes in a compression testing machine under an initial load of approximately 15% of the ultimate load to restrain the specimen. Ensure that cubes are in saturated surface dry conditions. Then UPV tests have to be performed as per Indian codes.
e. Test the cubes to failure in compression and obtain its compressive strength.
f. Selection of different concrete structures suitable for testing surface hardness, concrete cover and UPV.

Results of calibration test are shown in Table 1, it has been observed that actual compressive strength obtained from crushing strength test are higher than the values obtained from rebound hammer test, so the average calibration factor is +1.92. Hence, a correction factor of +1.92 is required to be added to the values of compressive strength (Fig. 2).

Table 1 Results of calibration test

Cube no.	Concrete grade	Crushing strength (7 days)	Strength obtained through curve on hammer
1	M-15	9.6	7.96
2	M-15	10.1	8.02
3	M-20	13.1	11.03
4	M-20	12.8	11.06
5	M-25	17.9	15.79
6	M-25	17.4	15.51

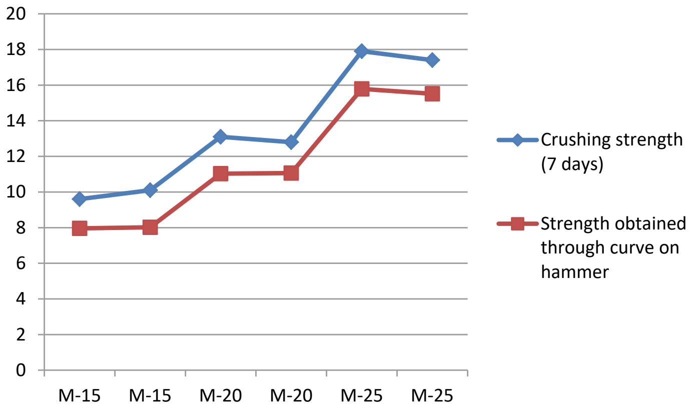

Fig. 2 Results of calibration test

During the in-situ testing, twenty-five concrete structures were tested and parameters such as age, compressive strength and ultrasonic pulse velocity were determined. The values obtained for the above parameters are summarized in Table 2. Here the values of UPV and compressive strength are the average of the respective values obtained for various elements of that structure.

Table 2 Results of In-situ data

S. no.	Structure	Strength (MPa)	Corrected strength (Mpa)	Concrete cover (mm)	UPV (m/s)
1	Structure 1	20	21.92	30	4200
2	Structure 2	20	21.92	30	4025
3	Structure 3	19	20.92	40	3904
4	Structure 4	17	18.92	30	3986
5	Structure 5	16	17.92	35	3800
6	Structure 6	16	17.92	35	3740
7	Structure 7	16	17.92	33	3624
8	Structure 8	14	15.92	40	3560
9	Structure 9	14	15.92	32	3508
10	Structure 10	23	24.92	35	3400
11	Structure 11	13	14.92	40	3310
12	Structure 12	22	23.92	40	3260
13	Structure 13	12	13.92	50	3200
14	Structure 14	12	13.92	35	3255
15	Structure 15	12	13.92	30	3145
16	Structure 16	21	22.92	32	3180

(continued)

Table 2 (continued)

S. no.	Structure	Strength (MPa)	Corrected strength (Mpa)	Concrete cover (mm)	UPV (m/s)
17	Structure 17	13	14.92	45	3020
18	Structure 18	14	15.92	32	3120
19	Structure 19	22	23.92	42	3000
20	Structure 20	23	24.92	40	2980
21	Structure 21	16	17.92	36	3085
22	Structure 22	17	18.92	40	2940
23	Structure 23	13	14.92	42	2860
24	Structure 24	18	19.92	42	2820
25	Structure 25	19	20.92	42	2746

Table 3 Data obtained by testing of cubes

Cube no.	UPV (m/s)	Density of concrete (Kg/m^3)	Crushing strength (f) of Cubes (MPa)
1	3720	2300	13.2
2	3830	2200	12.6
3	3750	2400	14.5
4	3620	2400	15.9
5	3740	2100	13.3
6	3760	2200	13.9
7	4090	2500	9.1
8	3980	2400	9.5
9	3820	2600	14.4
10	3710	2100	16.3
11	3610	2200	17.9
12	3780	2400	12.4
13	3790	2300	12.6

(continued)

Data obtained from crushing strength and UPV tests over prepared concrete cubes were presented here. Data obtained from testing of cubes has been presented in Table 3 and Fig. 3.

5 Conclusions and Discussion

1. The model performs sufficiently in the estimation of UPV or condition of concrete.

Table 3 (continued)

Cube no.	UPV (m/s)	Density of concrete (Kg/m^3)	Crushing strength (f) of Cubes (MPa)
14	3810	2100	12.5
15	3880	2200	11.8
16	3790	2300	12.6
17	3740	2400	15.2
18	3690	2500	13.7
19	3710	2100	13.6
20	3700	2300	13.7
21	3650	2500	14.5
22	3840	2400	12.7
23	3790	2200	13.7
24	3800	2400	11.4
25	3700	2600	13.8
26	3850	2100	10.3
27	3790	2200	11.5
28	3710	2200	13.3
29	3690	2300	18.5
30	3650	2300	19.2
31	3620	2500	17.6
32	3820	2600	12.4
33	3700	2300	15.5
34	3650	2200	14.7
35	3760	2400	12.2
36	3780	2400	11.8
37	3770	2300	12
38	3800	2200	11.5
39	3880	2400	12.1
40	3660	2400	14.1
41	3720	2100	16.7
42	3670	2300	14.2
43	3680	2300	18.7
44	3720	2400	13.3
45	3980	2500	9.5
46	3670	2100	14.3
47	3730	2300	12.8
48	3690	2200	15.6
49	3710	2400	15.9
50	3820	2400	14.4

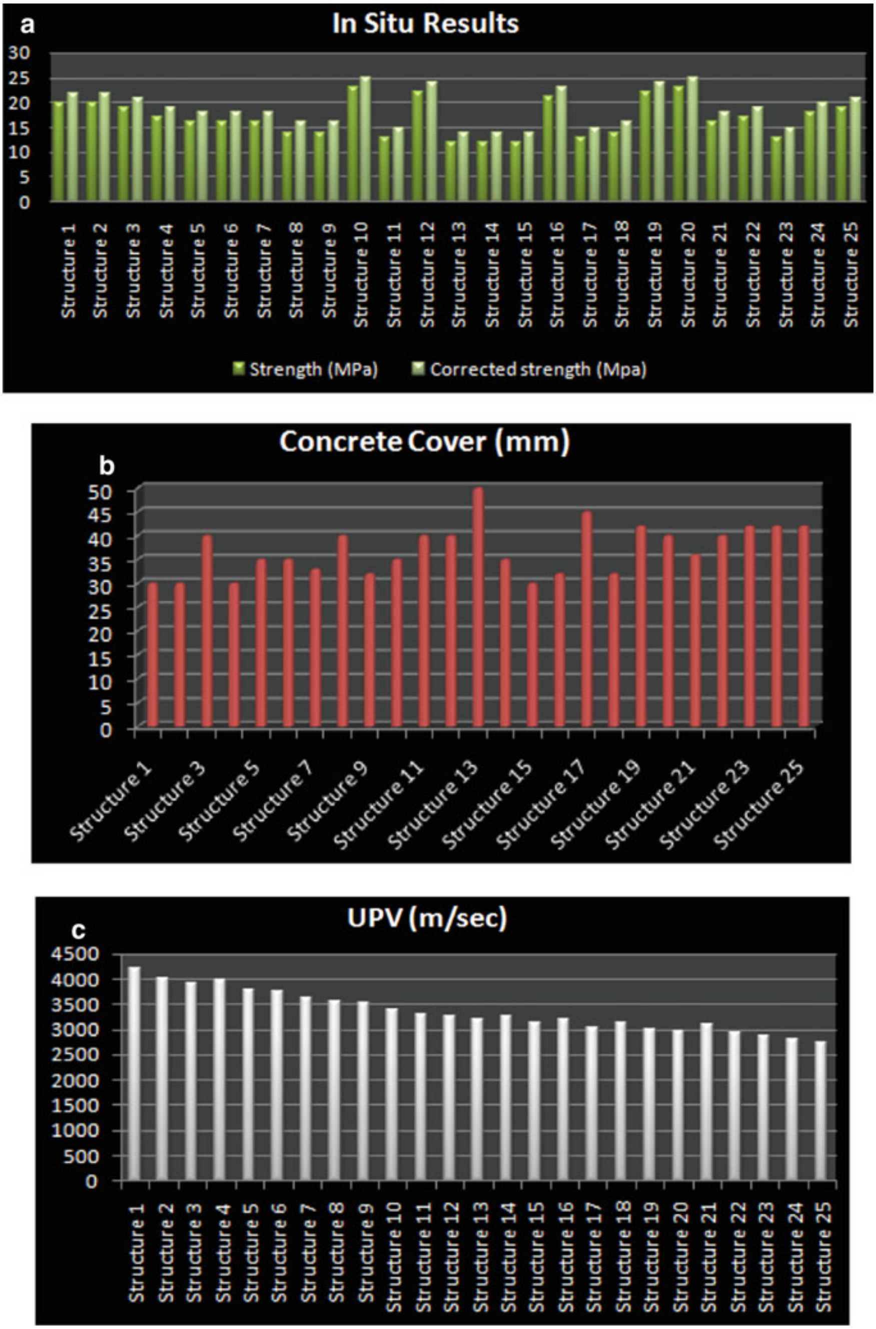

Fig. 3 In-situ data (**a–c**)

2. The prediction made using the proposed model shows a high degree of consistency with experimentally evaluated condition of concrete specimens by UPV. Thus, the present study suggests an alternative approach of predicting the condition of concrete structures against other in-situ methods.
3. In this research, next to the crushing strength to estimate the condition, density parameter has also been taken into consideration. When the density, which can be easily determined, has been taken into account, it has been useful for more accurate prediction of concrete condition.
4. This current study employed data set which is composed of limited pairs of input and output vectors. Therefore, it would be reasonable to propose further works using more data sets from various areas that could be needed to generalize the conclusions in this study.

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