SAM QUEST- Journal of Emerging Innovations
Vol.1, Issue 1, pp. 37-41, June 2024
Available online at: www.samglobaluniversity.ac.in

Research

Monitoring the Performance of Reinforced Concrete Structures

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Received: 12/Jun/ 2024; **Accepted**: 17/Jun/2024; **Published**: 25/Jun/2024.

Abstract: Demolition of steel in concrete structures with reinforcement reduces the life and sturdiness of structures. Resulting in enormous costs for inspection and maintenance, corrosion of reinforcing steel causes most of the damage to the reinforced concrete structures. Consequently, standards in inspections of structures are required to assess their condition. However, interpreting test data is not easy, because outcomes are considerably influenced by the surrounding environment to which the structure is exposed. This paper describes the in-situ monitoring of various concrete structures in Bhopal city using different Non-destructive testing equipment for determining the performance and condition of concrete structures.

Keywords: Concrete, Condition, Corrosion, NDT, Performance

Introduction

Non-destructive testing methods (NDT) can be applied to old and new structures. 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. In either case, if destructive testing alone is used, for instance, by removing cores for compression testing, the cost of coring and testing may only allow a relatively small number of tests to be carried out on a large structure which may be misleading. The process of SHM involves monitoring a structure over some time using appropriate sensors, extracting damage-sensitive features from the measurements given by the sensors, and analyzing these features to determine the current state of the structure. In the traditional methods, the material is broken down to determine mechanical properties, such as strength, toughness, and hardness. However, NDTs are performed in a manner that does not affect the future usefulness of the reinforced concrete (RC) structures. According to Somerville (1994), present performance and rate of deterioration are the significant parameters influencing and controlling the residual life of concrete structures. The rate of degradation and corrosion of steel in RC structures depends on the exposure conditions of the structure and the extent of maintenance. However, these severe environments can cause corrosion of reinforcement as long as the required amount of oxygen and moisture is available at the rebar level in concrete structures (Hussain and Ishida 2012). For monitoring and evaluating the condition of deteriorating structures better in-situ NDT inspection techniques are needed (Rens et al. 1997), these methods relate some physical and chemical properties of concrete structure to its strength, performance, and service life.

Failure of concrete structures due to carbonation or chloride ingress-induced corrosion of reinforcement may be a major problem causing significant loss of cash and time. Hence, there it's required to completely understand the basic causes of failure and monitor the condition of structures. Effective methods for in-situ monitoring are fundamental requirements for planning maintenance, repair, and removal of RC structures. Information regarding conditions required the determination of parameters like the concrete cover, carbonation depth, chloride content, half-cell potential, and age of the structure. In the present research parameters such as concrete cover, carbonation depth, chloride content, and half-cell potential were determined by conducting in-situ testing over several structures for monitoring the condition and performance of concrete.

A brief review of similar work

In-situ performance degradation of concrete structures increases with age, and after a certain period repair and maintenance of structures is required. So, it is required to evaluate the present condition of structures through in-situ and laboratory experiments. In the last few decades, several similar attempts have been made to evaluate the condition of existing structures by performing in-situ and lab tests.

Several mechanical and physical properties of concrete structures are often referred to assess the condition and capacity of the structures. Pascale et al. (2003) carried out an experimental program involving both destructive and non-destructive techniques applied to various substantial blends, with 3D shape strength shifting from 30 to 150MPa, to characterize a connection among strength and boundaries. Tests performed are beat speed, bounce back hammer, pull-out, test entrance, miniature coring, and joined techniques. Almir and Protasio (2000) utilized NDT techniques to decide the compressive strength of cement and the connection between the deliberate mechanical or actual properties and the strength.

A few specialists performed various sorts of NDT tests, for example, mechanical, substance, electrochemical, and attractive techniques to assess the condition by joining the outcomes. Rens and Kim (2007) assessed a steel span utilizing a few NDT techniques, for example, visual investigation, hammer sounding, Schmidt hammer, UPV testing including tomographic imaging. Bhadauria and Gupta (2007) introduced contextual analysis of weakened water tanks arranged in the semitropical area of India. Boundaries estimated are substantial cover, carbonation profundity, chloride fixation, compressive strength, and so forth. NDT strategies utilized are, Cover-meter, Phenolphthalein marker test, Quantab test, Potentiometric Titration, Schist's sledge test, and UPV test. Amleh and Mirza (2004) performed the substantial cover test, half-cell Potential, consumption rate, electrical resistivity, chloride content at steel level (%), steel bar mass misfortune (%), retention, beat speed, compressive strength, carbonation profundity, Petro-realistic assessment, and penetrability test. Dias and Jayanandana (2003) performed nondestructive methods of visual examination, scrutiny of drawings, ultrasonic heartbeat speed estimations, Cover-meter overviews, and center testing for the condition evaluation of RC structures.

The proliferation of waves or impressions of various beams like X-beam, through substantial designs can be utilized to distinguish the decay level of substantial designs. Shiotani et al. (2009) utilized the Acoustic Discharge (AE) method to assess the primary state of a substantial scaffold. Cascante et al. (2008) introduced a philosophy for the ND assessment utilizing the multichannel investigation of surface waves (MASW). Nachiapan and Cho (2005) dissected erosion items utilizing X-beam diffraction and nuclear retention spectroscopy to track down minerals present in them. Akuthota et al. (2004) introduced the exploratory aftereffects of involving close-to-handle microwave NDT procedures for distinguishing disbond in an exceptionally pre-arranged carbon fiber built-up polymer (CFRP) supported mortar test. Gassman and Tawhed (2004) introduced the aftereffects of an NDE testing program performed to survey the harm in substantial extension by utilizing the Effect reverberation technique. Popovics et al. (1998) evaluated the uneven pressure wave estimation technique in concrete. This strategy gives important data on the condition of material, when admittance to only one side surface is conceivable, for example, for the instance of substantial asphalts.

Ultrasonic heartbeat speed is involved by numerous specialists for the appraisal of substantial properties by utilizing travel season of longitudinal waves over a known distance. Sharma and Mukherjee (2011) involved ultrasonic-directed waves for observing the movement of rebar erosion in chloride and oxide climates. Shah and Hirose (2010) introduced a trial examination of the substantial application of nonlinear ultrasonic testing methods. Ervin et al. (2009) made an

Ultrasonic Detecting Organization to survey support disintegration. Stergiopoulou et al. (2008) introduced a technique for NDT of metropolitan substantial foundations utilizing UPV estimations and applied it to substantial carports. UPV has been utilized as a sign of substantial quality.

Electrochemical techniques are utilized by numerous specialists to distinguish the disintegration level of designs. Sangoju et al. (2011) studied the consumption conduct of steel in broken Conventional Portland Concrete (OPC) and Portland Pozzolana Concrete (PPC) cement by estimating chloride particle vulnerability, absorptivity, half-cell potential, resistivity, all-out charge passed, and gravimetric weight reduction. Bola and Newtson (2005) chose five locales for field assessment of support erosion, porousness, chloride particle focus, half-cell potential, polarization obstruction, and pH esteem. Buddy et al. (2002) explored the rate and measure of consumption of steel in concrete. Tests performed for dissecting consumption are half-cell potential, potentiodynamic, sped-up electrolytic erosion tests, and sped-up carbonation tests. Costa and Appleton (2002) depicted a progression of contextual investigations of various sorts of substantial designs, exposed to a cruel marine climate that crumbled because of chloride-instigated erosion.

From the above conversation, it has been seen that a large percentage of the scientists and researchers perceived substantial concrete cover, carbonation depth, chloride content, half-cell potential, and period of designs as significant boundaries impacting the condition, solidness, and life of designed structures.

Experimental Study

In the current investigation several non-destructive field tests, shown in Table 1, were performed on different concrete structures to evaluate the performance and condition of structures.

Table 1. NDT Methods used in the present research.

S. No.	Parameter	NDT method	Principle
1.	Concrete cover	Cover meter	Electromagnetic induction
2.	Carbonation depth	Rainbow indicator	Carbonation reduces the pH of the concrete
3.	Chloride concentration	Rapid Chloride Test	The potential difference of unknown solution is compared with the potential difference of solutions with known chloride concentration
4.	Corrosion	Half-cell potential.	The electric potential of rebar's is measured relative to half-cell and indicates the probability of corrosion

(i) Concrete cover: Concrete cover to reinforcement acts as the first line of defense against physical and chemical attacks from the environment, and is measured and recorded with the help of a cover meter. The concrete cover of all the structures is plotted in Fig. 1

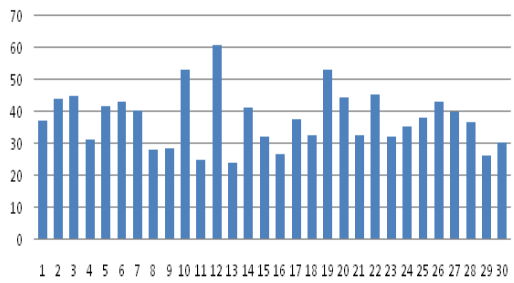

Fig. 1. Concrete cover.

(ii) Carbonation depth: Carbonation depth for concrete structures is determined by using rainbow indicator spray, a freshly broken piece of concrete or a newly cut core is sprayed and allowed to dry and the approximate pH of the paste is indicated by colors indicated on the spray. Carbonation depth and concrete cover are important parameters if Carbonation depth is close to or more than the concrete cover then corrosion starts and accelerates. Results are plotted in Fig. 2 and 3.

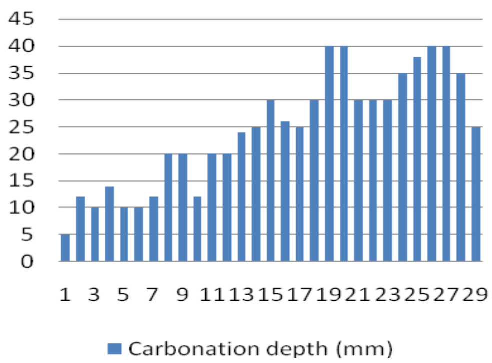

Fig. 2. Carbonation depth.

(iii) Chloride content: Rapid Chloride Test (RCT) can be used to determine chloride content from dust samples taken from a depth varying between 25-30 mm. The generally accepted threshold value is 0.2% of chloride ions by the weight of the concrete.

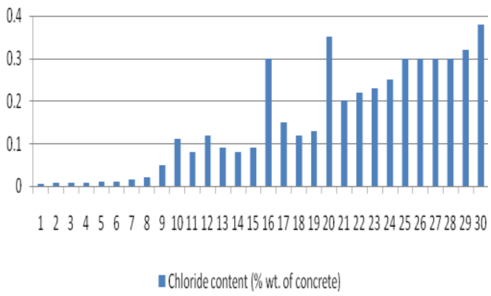

Fig. 4. Chloride content.

(iv) Half-Cell Potential: It is a widely used method for evaluating the corrosion state, it involves the measurement of the potential of embedded steel relative to a reference half-cell placed on a concrete cover. The half-cell consists of a metal rod immersed in a solution of its own ($Cu/CuSO_4$ or Ag/AgCl). The metal rod is connected with reinforcement steel by a voltmeter. The value of potential difference measured by half-cell indicates the percentage of Corrosion. In the present study, an Ag/AgCl half-cell is used to evaluate the percentage of corrosion according to Table 2.

Table 2. Presents criteria according to ASTM C876 for $Cu/CuSo_4$.

S. No.	Half Cell Potential (mV)	% chance of corrosion
1.	>-119	10
2.	-119 to -269	50
3.	<-269	90

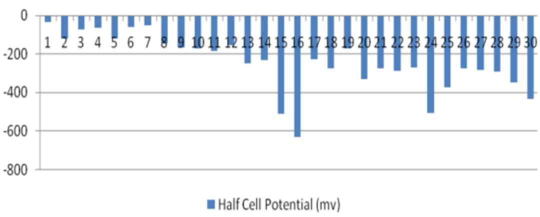

Fig. 5. Half Cell Potential Values.

(i) Age of structure: From the results it has been observed that an increase in the age of structure increases the probability of corrosion as it increases the carbonation depth and chloride content with age, as shown in Fig 6, 7and 8.

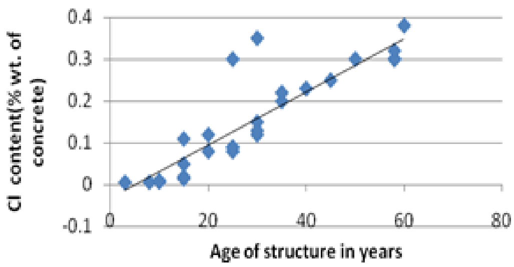

Fig. 6. Variation of Chloride content with age.

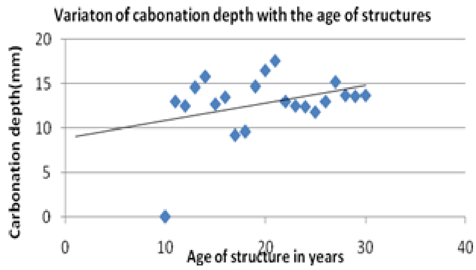

Fig. 7. Variation of Carbonation depth with age.

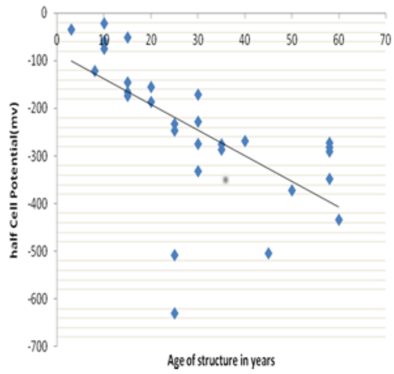

Fig. 8. Variation of Half Cell Potential with age.

Conclusion

This paper discussed the results of an in-situ survey conducted on a few structures of Bhopal city; it has been observed that with the increase in age of the structures the deterioration of concrete increases (Fig. 1-6). The age of the structure influences the condition and corrosion state of the structure.

Parameters such as carbonation depth, concrete cover, chloride content, and half-cell potential are investigated *in situ* and field investigations indicate that carbonation depth, chloride content, and concrete cover have significant effects on rebar corrosion.

Acknowledgments

The authors acknowledge the support of SAM Global University, Raisen during the study.

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