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Structural Health Assessment of Dilapidated R.C.C. Framed Structure

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Abstract— *In India there are numerous old structures that are at the verge of damage. With due course of time the structure becomes weeks as the strength of concrete gets reduced. The reasons that can be considered for this reduced strength are poor quality of construction, improper maintenance, improper design mix, unskilled workmanship etc. Therefore the condition and performance of building must be checked from time to time. Structural health assessment is the appropriate solution to this issue. It enhances the performance of any existing structure. Non Destructive testing help to assess the health of structure & how much repairs, rehabilitation & retrofitting is required to bring back the structure in safe stable condition.In this case study non destructive testing is adopted to assess the condition and quality of concrete for 30 years old R.C.C. framed structure which is situated Nagpur. Various NDT methods such as Ultrasonic pulse velocity test, Rebound Hammer test, Depth of carbonation test, Half cell potentiometer test, pH test have been performed. Based on all test results & visual inspections it is found that the structure needs to be repaired & retrofitted.*
Keywords—*Non Destructive Testing, Repair, Rehabilitation, retrofitting*

I. Introduction

Non Destructive Testing (NDT) is a technique that inspects or test the materials or components by evaluating any discontinuities or differences in their characteristics without damaging any part of the structure. This test can be carried out on different components of the structure without actually destroying it.

In India there were so many old structures which have reduced strength in due course of time and deterioration start and use of such deteriorated structure is continued it may lead severe loss of life and property.

As we all knows that prevention is better than cure, the structural audit plays very important role in structural health assessment. Structural audit is an important technique to understand the condition of any existing structure and investigate all critical areas which demand immediate attention. It is mandatory as per Government Authorities.

Non destructive testing offers significant advantages of speed, cost and lack of damages in comparison with test methods which require the removal of sample for subsequent examination. These factors will permit more extensive testing and thus enable an investigation to be wider with respect to the concrete structure under examination than would otherwise be possible. Availability of results at the time of testing is also the important advantage of Non Destructive Testing.

Now, the term Structural Health Assessment is defined as to examine the overall health and performance of building. It is an important tool for knowing the real status of the building. During the assessment we observed and investigate all the critical areas etc.

Non Destructive Testing methods are techniques which plays a very important role to obtained internal defects, cracks in an object without damaging it. Non Destructive Test is quality assurance management tool which can give impressive results when handle correctly. It requires an understanding of various methods available, their capabilities and limitations, knowledge of the relevant standard and specification for performing the test. These techniques can be used to monitor the integrity of the item of structure throughout its design life.

The objective of present work is to adopting the Non Destructive Test for structural health assessment of 30 years old residential building which is situated in Mahal, Nagpur (Maharashtra) using Rebound Hammer Test, Ultrasonic Pulse Velocity, Depth of carbonation test, Half cell Potentiometer Test, pH test including Visual observations.

II. Methodology

A. Visual Observation

The detail visual observation were carried out on all structural members of building. the various observations were found like Corrosion, Major & Minor Cracks, Honeycombing, Reinforcement exposed at various location, seepage, water logging on slab etc. Visual observation and documentation of damaged concrete members of building has been made by photographic documentation.

Fig. 1. Reinforcement exposed, corrosion, cracks observed in Column

B. **Rebound Hammer Test**

The test involves the measuring of Rebound of a Schmidt Hammer by pressing against concrete surface to establish the :

a) Assessing the Compressive strength of concrete
b) Assessing the uniformity of concrete.
c) Assessing the Quality of Concrete in relation to standard requirements.
d) Assessing the quality of one element of concrete in relation to another.

In 1948 Ernst Schmidt a Swiss Engineer develop a device for testing concrete. When the plunger of rebound hammer is pressed against the surface of the concrete, the spring controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete. The surface hardness and therefore the rebound is taken to be related to the compressive strength of the concrete. The rebound is read off along a graduated scale and is designated as the rebound number or rebound index.

The rebound numbers are influenced by a number of factors like types of cement and aggregate, surface condition and moisture content, age of concrete and extent of carbonation of concrete. As per IS:13311 Part-2, the probable accuracy of prediction of concrete strength in a structure by rebound hammer test is +/-25%.

TABLE I. REBOUND CRITERIA FOR QUALITY OF CONCRETE GRADING

Average Rebound	**Quality of Concrete**
>40	Very Good hard layer
30-40	Good
20-30	Fair
<20	Poor concrete
0	Delaminated

Fig. 2. Rebound Hammer Test

C. **Ultrasonic Pulse Velocity Test**

Ultrasonic Pulse Velocity Test assess the homogeneity of concrete, presence of cracks, voids & other imperfections, changes in structure which may occur with time, quality of concrete in relation to standard requirement.

This is one of the most commonly used method in which the ultrasonic pulses generated by electro-acoustical transducer are transmitted through the concrete & measuring the time taken. Distance of path length divided by the time taken provides velocity of the waves through the concrete member being tested.

Though pulse velocity is related with crushing strength of concrete, yet no statistical correlation can be applied. The ultrasonic pulse velocity is influenced by path length, lateral dimension of specimen tested, presence of reinforcing steel, and moisture content of the concrete. The methods of measurements of ultrasonic pulse velocity through concrete are

a) Direct Transmission (Cross Probing).
b) Semi-Direct Transmission
c) Indirect Transmission (Surface Probing)

The instrument used for testing is Pundit Lab (30610001) UPV Instrument (Proceq) (Made in Switzerland).

The factors affecting the measurement of pulse velocity are:

a) Smoothness of concrete surface under test
b) Moisture condition of concrete.
c) Influence of path length
d) Temperature of concrete.
e) Effect of reinforcing bars.

TABLE II VELOCITY CRITERIA FOR QUALITY OF CONCRETE GRADING

Pulse Velocity	**Quality of Concrete**
Above 4.5 Km/Sec	Excellent
3.5 - 4.5 Km/Sec	Good
3.0 - 3.5 Km/Sec	Satisfactory
Below 3.0 Km/Sec	Doubtful

Fig. 3. Ultrasonic Pulse Velocity Test

D. **Depth of Carbonation Test.**

Carbonation of concrete occurs when the carbon dioxide in atmosphere in the presence of moisture reacts with hydrated cement to produce carbonate. carbonation process is also called as depassivation.

The method to establish the extent of carbonation in concrete by treating a freshly broken surface of concrete with a solution of 15mg Phenolphthalein & 10ml Ethanol diluted in 50ml of distilled water. The change of Pink color of concrete indicate carbonation free concrete while the uncolored indicated carbonation.

Fig. 4. Depth of Carbonation Test

E. **Half Cell Potentiometer Test.**

Half cell potentiometer test is used to indicate the corrosion activity associated with steel which is embedded in concrete. This is an apparatus given by ASTM C876 which include The Copper-Copper Sulphate Half Cell is used to indicated the probability of corrosion in reinforcing bar.

Very little current flows through the circuit Half cell makes electrical contact with concrete by means of porous plug and sponge. One end of wire is connected to steel reinforcement and other end is connected to standard electrode and readings are noted as seen on voltmeter. More negative value indicated the higher is the bar corrosion.

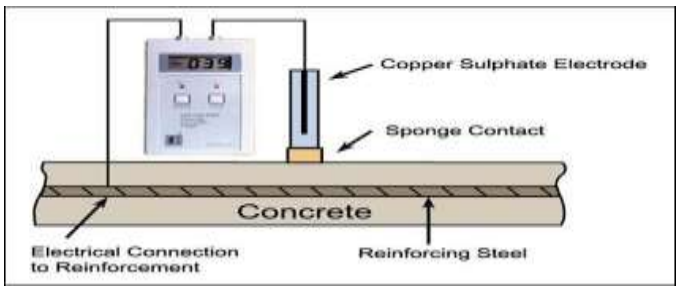

Fig. 5. Schematic View of Half Cell Potentiometer

http://civilonline2010.blogspot.com/2010/09/half-cell-electrical-potential-method.html

TABLE III CORROSION CONDITION OF REINFORCEING BAR

Copper / Copper Sulphate	Corrosion Condition
> -200 mV	Low (10% chances)
-200 to -350 mV	Intermediate
< -350 mV	High (<90 %)
< -500 mV	Severe Corrosion

F. **pH Test**

pH test is used to determine how well concrete can holds up over time. pH is the critical factor in the chemistry of concrete. The component of concrete are cement, sand, aggregate & water. cement is the binding material in concrete and has the pH approaching 11, which is very alkaline. if pH < 7 indicated acidic, pH > 7 indicated basic & pH = 7 is neutral. The pH of fresh concrete is 13, in order for the cement to hold together the other components of structure it is important for it remain at or near a pH of 11 .

The pH of concrete lowers when the carbon dioxide in the air comes in contact with concrete, the process is called carbonation. when the carbonation reaches the level of steel reinforcement, it attacks the thin protective layer of iron oxide surrounding the reinforcement and initiates corrosion. since steel can expand up to 6 times in size due to corrosion. The resulting pressure can cause the cracks in concrete. A standard pH meter is used to measure the pH of concrete [6].

Fig. 6. pH Test of concrete

III. Results Before Repair

G. Rebound Hammer Test

TABLE IV REBOUND HAMMER TEST RESULTS.

Sr. No.	Description	No. of Points	Rebound Hammer Test		
			Max.	Min.	Average
Ground Floor					
1.	Column	114	31.67	15	23.33
2.	Beam	18	30.33	27	28.66
3.	Slab	12	29.66	29.33	29.49
First Floor					
4.	Column	12	31	29	30
Second Floor					
5.	Column	14	32.57	31.71	32.14
Third Floor					
6.	Column	12	33.66	32	32.83
Fourth Floor					
7.	Column	12	36	32	34

H. Ultrasonic Pulse Velocity Test Results.

TABLE V ULTRASONIC PULSE VELOSITY TEST RESULTS.

Sr. No.	Description	No. of Points	Ultrasonic Pulse velocity Test (Km/SEC)		
			Max.	Min.	Average
Ground Floor					
1.	Column	98	3.53	1.4	2.46
2.	Beam	20	1.98	1.13	1.55
3.	Slab	17	2.3	1.4	1.85
First Floor					
4.	Column	7	2.3	1.87	2.08
Second Floor					
5.	Column	12	2.3	1.33	1.81
6.	Beam	4	1.94	1.87	1.90
Third Floor					
7.	Column	10	3.3	2.47	2.88

Sr. No.	Description	No. of	Ultrasonic Pulse velocity Test (Km/SEC)		
Fourth Floor					
8.	Column	14	3.3	2.83	3.06

I. Half Cell Potentiometer Test Results.

TABLE VI HALF CELL POTENTIOMETER TEST RESULTS.

Sr. No.	Description	Half Cell Potentiometer Test	
		Half Cell Readings (mV)	Average (mV)
1.	Column No..-C1	-355, -346, -321, -272, -241, -232, -223, -216, -168	-263
2.	Column No..-C2	-319, -317, -315, -250, -247, -240, -238, -224, -212	-262
3.	Column No..-C8	-341, -333,-321,-308, -302,-291,-279,-269, -263	-300
4.	Column No..-C9	-360, -359, -341, -332, -258, -245, -235, -218, -217	-285
5.	Column No..-C12	-501, -499, -418, -400, -397, -357, -348, -345, -343	-400
6.	Column No..-C16	-399, -320, -318, -305, -242, -237, -236,-211, -209	-275
7.	Column No..-C17	-339, -321, -315, -301, -297, -295, -287, -279, -277	-301
8.	Column No..-C21	-458, -441, -435, -408, -397, -391, -383, -380, -371	-407

J. pH Test Results.

TABLE VII PH TEST RESULTS.

Sr. No.	Description	Potential (mV)		
		40mm	80mm.	pH
1.	Column No..-C1	-171	-233	7.64 to 8.33
2.	Column No..-C3	-121	-074	7.12 to 6.23
3.	Column No..-C8	-123	-082	7.01 to 6.63
4.	Column No..-C13	-167	-140	8.23 to 7.23
5.	Column No..-C14	-173	-160	8.21 to 7.90
6.	Column No..-C19	-181	-172	7.01 to 6.89
7.	Column No..-C21	-173	-165	7.66 to 7.53
8.	Column No..-C23	-139	-081	7.23 to 6.51

Observations :

1) As per Rebound Hammer Test maximum readings are confirming to M10 to M15 grade of concrete that indicated the poor quality of concrete.

2) As per Ultrasonic Pulse Velocity test results it is observed that maximum readings are below 3.0 Km/sec that indicated the quality of concrete is doubtful.

3) As per Depth of Carbonation Test & pH test, the carbonation observed on various location of columns and beams.

4) As per Halfcell Potentiometer Test results maximum readings are in between -262 and -407 which indicate that there is severe corrosion found at most of the locations.

IV. Recommended Strengthening Scheme

A) REPAIR AND REHABILITATION

Based on all NDT test results & visual inspection it is recommended to provide grouting & Jacketing for columns with Epoxy Resin (Non Shrink free flow low viscocity solvent free epoxy grouting required) and polymer repair to damaged concrete for beams as per methodology and specification given below :

A. Epoxy Resin Grout to Column

Providing and injecting low viscosity solvent free epoxy in the ratio by grouting pump at a pressure @ 3-6 Kg/Cm^2 or as instructed by Engineer-in-charge etc.complete by considering 200mm x 200mm c/c gridalong honeycombing areas and 150mm x 150mm c/c grid along cracks.

B. Damaged Concrete Cracks

Open the cracks into "V" groove. Then providing and applying Epoxy + Silica Sand 1:2 mortar at the groove and finish at all heights, levels and surface etc. complete.

C. Micro Concrete

Providing and applying 50/100/150mm micro concrete as per specification or as instructed by Engineer-in-charge etc. complete.

D. Polymer Cement Based Grout.

Providing and injecting Polymer Cement Base Grout in the ratio by grouting pump at a pressure @ 3-7 Kg/cm2 or as instructed by Engineer-in-charge etc complete. After grouting is completed, after 24 hours, cut the nipples and seal it with polymer-modified mortar.

V. Recommended Strengthening Scheme

B) RETROFITTING

Reinforced concrete jacketing is most popularly used method for strengthening the columns. It improves the column flexural strength and shear strength by providing new longitudinal and transverse reinforcement around existing column. As per the Non Destructive test results it is recommended to provide jacketing due to low readings with respect to required readings to the columns. The design criteria is used as per IS 15988:2013 for strengthening of existing columns and IS:10262-2009 for concrete mix design proportion. As per the design calculations 150mm thick column jacketing is provided as per the methodology and specifications given below:

Column Jacketing:-

i] Remove loose cover from column surface by chipping hammer.
ii] Clean the surface with wire brush and force air.
iii] Drill the holes for fixing shear connectors. Clean the holes with force air and grout the shear connectors with HILTI Re500 V3 or HILTI Hy200 rebar chemical. After fixing the shear connectors clean the column surface.
iv] Place the new vertical and horizontal reinforcement as per design calculations.
v] Apply old and new epoxy bonding agent to existing column before doing new concrete.
vi] New jackted column must be cured for minimum 10 days.

Fig. 7. Column Jacketing

Fig. 8. Column Jackeing

VI. Results After Repair

TABLE VIII COMPARISION OF RESULTS AFTER JACKETING

Sr. No.	Description	Rebound Hammer Test (No.)		Ultrasonic Pulse Velocity Test (km/sec.)	
At Ground Floor		**Before Repair**	**After Repair**	**Before Repair**	**After Repair**
1.	Column-C1	26.67	32.66	2.72	4.8
2.	Column-C2	26.33	33.66	2.83	3.71
3.	Column-C3	28.66	33.00	2.60	3.66
4..	Column-C5	25.33	32.33	2.77	3.68
5.	Column-C8	25.00	30.33	3.11	3.69
6.	Column-C9	26.00	33.00	2.87	3.65
7.	Column-C16	28.33	32.33	2.63	4.89
8.	Column-C20	31.33	32.33	2.65	3.69
9.	Column-C21	31.67	33.66	2.88	3.71
10.	Column-C22	27.00	31.66	2.27	3.65
Average Readings		**27.63**	**32.49**	**2.73**	**3.91**

As per Rebound Hammer Test results it is observed that average readings are confirming to M25 to M30 Grade. [Ref. IS 13311 (PART II) 1992]

As per Ultrasonic Pulse Velocity Test results it is observed that average readings are in between 3.5 km/sec to 4.5 km/sec indicating good quality of concrete [Ref. IS 13311 (PART I) 1992]

VII. Conclusion

In this case study, various Non Destructive Tests have been performed on existing structure. Such as Rebound Hammer Test, Ultrasonic Pulse Velocity Test, Half cell Potentiometer Test, Depth of Carbonation Test & pH test. As per the test results the structure has been repaired and retrofitted to make it stable for static loading condition. After repair and retrofitting of the existing structure again Nondestructive Tests such as Rebound Hammer Test and Ultrasonic Pulse Velocity test have been performed to verify the current strength of concrete. As per Rebound Hammer Test it is found that maximum readings are confirming to M25 to M30 grade of concrete. As per Ultrasonic Pulse Velocity Test Results it found that maximum readings are coming in 3.69 to 4.89 Km/sec that indicated quality of concrete is good at maximum location. Hence test results conclude that this structure is now safe for all static loadings.

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