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An Experimental Study of Corrosion in RCC Structure: Prevention, Repair and Maintenance

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***Abstract*: Infrastructure development, that is going on today, all over the world, is like never before. Reinforced cement concrete is the most versatile and potentially one of the most durable materials that a designer can choose for almost any type of structure. It is because RCC can be mould into almost any desired shape; it is weather resistant, strong and durable under the normal exposure conditions. Today the major problem currently confronting the construction industry all over the globe is 'deterioration of RCC structures. The phenomenon is so pervasive that it has created almost a crisis-like situation and has put the engineering fraternity on red alert. A number of factors are responsible for early distress in RCC structure. However, all over the world. Rebar Corrosion in concrete' is seen as major cause of distress of structures and thus an issue of major concern in the sustainable infrastructure development. Worldwide, it is now confirmed that, even after specific national building code requirement of durability are followed, there is always a high risk of premature rebar corrosion in concrete. Even when, code specification for concrete cover and concrete quality are observed, rebar corrosion in concrete occurs, causing loss of serviceability and safety of RCC structures. The scale and extent of the problem is severe. In this research work one building from Mumbai is choose. Detailed structural audit conducted. Based upon those various reasons associated with rebar corrosion, corrosion mechanism and different methods to prevent rebar corrosion is proposed in this work.**

***Keywords*: Rebar corrosion, Distress, Deterioration, Weather resistant.**

1. Introduction

Concrete is a versatile, cost effective and easy to handle construction material, widely used next only to water. Its lack of adequate tensile strength is taken care by steel rebar's making the combination reinforced concrete (RC). In most cases, RC structures are durable and strong, performing well throughout its service life. However, in some cases, they do not perform adequately due to various reasons and one of the reasons being corrosion of steel rebar's. In fact, corrosion of the steel rebar's has become the major cause of deterioration of RC structures around the world. The corrosion of steel rebar's embedded in concrete is most frequently the result of the breakdown of the passive film formed due to highly alkaline environment around steel rebars. Two conditions can break down the passivating environment surrounding the rebar without attacking the concrete itself, one is the chloride attack and the other is carbonation. Rebar corrosion is generally accompanied by the loss of rebar cross section and accumulation of corrosion products, which occupy much larger volume than the original steel, thereby generating tensile stresses, which lead to cracking and spalling of concrete, commonly known as concrete cancer. Over the time, this problem reduces the strength capacity of the affected structure due to the loss of bonding action between steel and concrete, ultimately leading to loss of serviceability. It is reported that, the economic losses and damage caused by the corrosion of steel rebars in RC structures is the largest infrastructure problem faced by the industrialized countries. As a result, the repair costs constitute major part of the current spending on infrastructure. Corrosion consumes considerable portion of the budget of the country by way of either restoration measures or reconstruction. It is estimated that billions of dollars are spent annually on the maintenance and repairs of corroding RC structures in North America alone (Darek, 2012). India loses more than $40 billion a year, (about 4 per cent of the size of the total economy) due to corrosion in infrastructure and industry segments. Quality control, maintenance and planning for the restoration of these structures need non-destructive inspections and monitoring techniques that detect the corrosion at an early stage. For detection of corrosion and for determining rebar corrosion rate, several electro-chemical and non-destructive techniques are available. Conventional corrosion detection techniques based on electrochemical principles consists of potential measurements, alternating current impedance spectroscopy, gravimetric (mass loss) and linear polarization techniques. However, these techniques are affected by a number of factors. Hence, there is a need for development of a sensing technique to inspect the structure in real-time (to supplement routine inspections) so that corrosion could be detected and treated before significant cracking develops.

2. Scope

Interest of the research community in the corrosion problem has been increasing for several years because of the severe durability problems faced by RC structures due to rebar corrosion. This research aims at to study a corrosion detection and assessment and repair approach by assessing structure damaged due to corrosion by case study approach. For that a

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case study is conducted, and from the field tests on actual corrosion distressed structure.

3. Objectives

- To analyze the factors of corrosion propagation of concrete.
- To study the deterioration progress of reinforced concrete due to steel corrosion.
- To carry out a thorough review of state-of-the-art in corrosion detection and monitoring.
- To suggest various methods for repair of concrete damage due to corrosion.
- To review various corrosion detection and measurement methods and techniques.
- To review and study various corrosion mitigation/inhibition methods and materials.

4. Methodology

In this research work case study approach is adopted. In this test on field test required to obtained reliable data from structure is discussed. Mostly different NDT techniques adopted for asses strength and durability of structure is as. Non-destructive testing (NDT) methods are techniques used to obtain information about the properties or internal condition of an object without damaging the object. Non-destructive testing is a descriptive term used for the examination of materials and components in such way that allows materials to be examined without changing or destroying their usefulness. NDT is a quality assurance management tool which can give impressive results when used correctly. It requires an understanding of the various methods available, their capabilities and limitations, knowledge of the relevant standards and specifications for performing the tests. NDT techniques can be used to monitor the integrity of the item or structure throughout its design life.

1) *Schmidt's Rebound Hammer Test*

Objects:

The rebound hammer method could be used for:

- Assessing the compressive strength of concrete with the help of suitable co-relations between rebound index and compressive strength.
- Assessing the uniformity of the concrete.
- Assessing the quality of concrete in relation to the standard requirements.
- Assessing the quality of one element of concrete in relation to another.

Principle of test: The test is based on the principle that the rebound of an elastic mass depends on the hardness of the surface upon which it impinges. When the plunger of the rebound hammer pressed against the surface of the concrete, the spring-controlled mass rebounds and the extent of such rebound depend upon the surface hardness of concrete. The surface hardness and therefore the rebound is taken to be relation to the compressive strength of concrete. The rebound is read off along a graduated scale and is designated as the rebound number or rebound index.

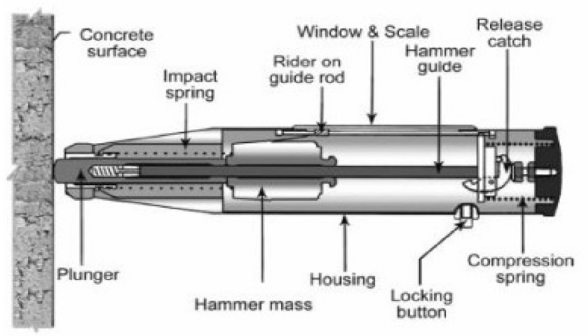

Fig. 1. Basic features of rebound hammer

Limitations: Although the rebound hammer provides a quick inexpensive means of checking the uniformity of concrete, it has serious limitations and these must be understood clearly for interpretation of test results.

2) *Ultrasonic Pulse Velocity Method*

The ultrasonic pulse velocity method is used for non-destructive testing of plain, reinforced and prestressed concrete whether it is precast or cast in-situ

Objects: The main objects of the ultrasonic pulse velocity method are to establish.

- The homogeneity of the concrete.
- The presence of cracks, voids and other imperfections.
- Changes in the structure of the concrete caused by the exposure condition, corrosion, wear etc. which may occur with time.
- The quality of the concrete in relation to the specified standard requirements.
- The quality of one element of concrete in relation to the another.
- The values of the dynamic elastic modulus of the concrete.

Principle: This is one of the most commonly used method in which the ultrasonic pulses generated by electro-acoustical transducer are transmitted through the concrete. In solids, the particles can oscillate along the direction of sound propagation as longitudinal waves or the oscillations can be perpendicular to the direction of sound waves as transverse waves. When the pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves is developed which includes longitudinal (Compressional), shear (Transverse) and surface (Rayleigh) waves. These transducers convert electrical signals into mechanical vibrations (transmit mode) and mechanical vibration into electrical signals (receive mode). The travel time is measured with an accuracy of +/- 0.1 microseconds. Transducers with natural frequencies between 20 kHz and 200 kHz are available, but 50 kHz to 100 kHz transducers are common.

The receiving transducer detects the onset of the longitudinal waves which is the fastest wave. Because the velocity of the pulses is almost independent of the geometry of the material through which they pass and depends only on its elastic property. Under certain specified conditions, the velocity and strength of concrete are directly related. The common factor is the density of concrete; a change in the density results in a change in a pulse velocity, likewise for a same mix with change in density, the strength of concrete changes. Thus, lowering of the density caused by increase in water-cement ratio decreases both the compressive strength of concrete as well as the velocity of a pulse transmitted through it.

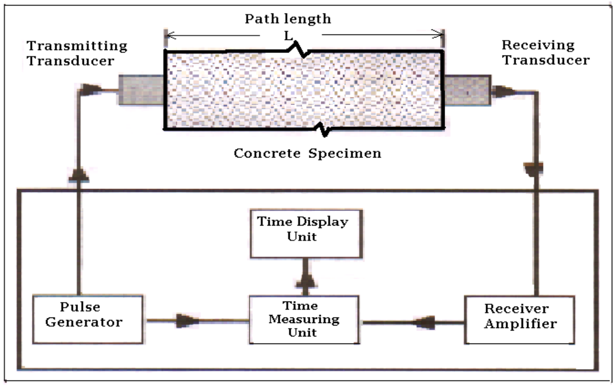

Fig. 2. Schematic diagram of ultrasonic pulse velocity method

Table 1
As per Table 2 of IS 13311 (Part 1): 1992

S. No.	Pulse Velocity by Cross Probing (km/sec)	Concrete Quality Grading
1	Above 4.5	Excellent
2	3.5 to 4.5	Good
3	3.0 to 3.5	Medium
4	Below 3.0	Doubtful

Note: In case of doubtful quality of concrete, it may be necessary to carry out further tests.

3) Half-Cell Potentiometer

Principle and Procedure: The instrument measures the potential and the electrical resistance between the reinforcement and the surface to evaluate the corrosion activity as well as the actual condition of the cover layer during testing. The electrical activity of the steel reinforcement and the concrete leads them to be considered as one half of weak battery cell with the steel acting as one electrode and the concrete as the electrolyte. The name half-cell surveying derives from the fact that the one half of the battery cell is considered to be the steel reinforcing bar and the surrounding concrete. The electrical potential of a point on the surface of steel reinforcing bar can be measured comparing its potential with that of copper – copper sulphate reference electrode on the surface. Practically this achieved by connecting a wire from one terminal of a voltmeter to the reinforcement and another wire to the copper sulphate reference electrode. Then readings taken are at grid of 1 x 1 m.

The risk of corrosion is evaluated by means of the potential gradient obtained, the higher the gradient, the higher risk of corrosion. The test results can be interpreted based on the following table.

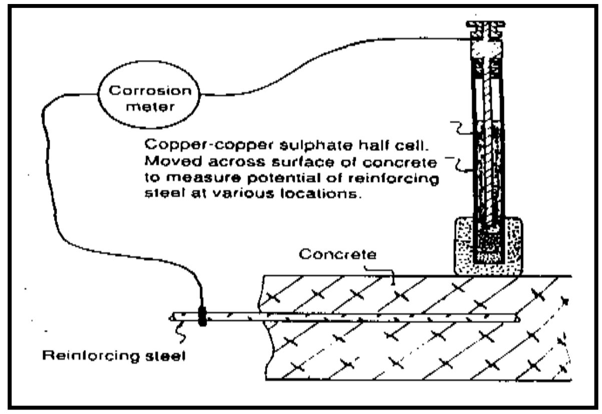

Fig. 3. Half-cell potential test

Table 2
Half-cell potential corresponding to percentage chance of corrosion activity

Half-cell potential (mv) relative to Cu-Cu sulphate Ref. Electrode	% Chance of corrosion activity
Less than -200	10%
Between -200 to -350	50% (uncertain)
Above -350	90%

Significance and Use: This method may be used to indicate the corrosion activity associated with steel embedded in concrete. This method can be applied to members regardless of their size or the depth of concrete cover. This method can be used at the any time during the life of concrete member.

Reliability and Limitation: The test does not corrosion rate or whether corrosion activity as already started, but it indicates the probability of the corrosion activity depending upon the actual surrounding conditions. If this method used in combination with resistivity measurement, the accuracy is higher. If the concrete surface has dried to the extent that it is dielectric, then pre wetting of concrete is essential.

5. Test Results & Analysis

In this project test results approach is adopted, so to fulfill that purpose one building from Mumbai was chosen, actual site visit was conducted to assess the structure. The structure was assessed based on the visual inspection and results of non-destructive tests. Structural audit is an important tool for assessing the structural health of the building. In this assessment the extent of distress occurred due to corrosion or any other reason, the residual strength of the structure and its fitness for rehabilitation.

Test results & analysis:

Uma Sadan, Bandra

General Information of Building:

Name of Building: Uma Sadan

Address: 1st Road, Near Kabutar Khana, off: S. V. Road, on Plot bearing CTS No. E/814, E/815, E/816, and Plot No. 43 and 44of Village Bandra – E, Khar (W)

Date of Inspection: 3rd Sept 2019

Year of Construction: 1971

Age: 49 years

Mode of Use: Residential

Type of Building: RCC framed

No. of Storey: G+4
No. of Wings: 1
Shape: Rectangular
Floor to Floor Height: 3.6m at ground floor and 2.7m at upper floor
Plinth level: 0.3m above ground level
Repair History: Not known
Visual Inspection and Critical Observations

Visual Examination of structure was the most effective and qualitative approach to evaluate the structural soundness and to identify the typical distress symptoms together with the associated problems. This provides following valuable information concerning its workmanship, structural serviceability and material deterioration mechanism. It gave a quick scan of the structure to assess its status of general health.

Building Common Area:

- Flooring is uneven and plinth is 0.3m above ground level.

External Faces:

- The building is a framed structure made of RCC columns, beams and slabs.
- The vertical wide crack has been observed in many of the corner columns. Columns are severally deteriorated at all positions up to upper floors showing cracks, delaminated cover concrete and corroded reinforcement.
- Similarly, the beams have been observed to be cracked with bulged cover concrete and corroded reinforcement.
- All chajjas have been severely deteriorated, portion of chajja has been observed to be broken/fallen at many locations.

Masonry and Plaster:

- Major plaster cracks have been observed at almost all locations on the exterior surface.
- Separation between RCC and masonry has been observed at a few locations.

Staircase and Passages:

- The staircase and passage have been observed to be in deteriorated conditions.
- The floor beams and columns have been observed with wide cracks and delaminated cover concrete at many locations.
- The RCC jali at the mid landing portion have been observed to be broken / fallen at many locations.
- The staircase flights have been observed to be deteriorated with cracks, delaminated cover concrete and corroded reinforcement at many locations.

Terrace:

- The terrace is partly covered with the tenement with RCC structures and also with Ladi-Coba-Ladi slab supported by steel sections.
- The slopes of the terrace and the cleanliness have not been observed to be maintained.
- The parapet walls have been observed to be cracked at many locations.

Table 3
Result of rebound hammer test

S. No.	Level	Location	Direction	Apparent Compressive Strength N/mm^2
1	Gr. Floor	C1	Horizontal	17.0
2	Gr. Floor	C2	Horizontal	15.0
3	Gr. Floor	C3	Horizontal	16.0
4	Gr. Floor	C4	Horizontal	17.0
5	Gr. Floor	C5	Horizontal	17.0
6	Gr. Floor	C7	Horizontal	Below 10
7	Gr. Floor	S1	Vertical	Below 10
8	Gr. Floor	B2	Horizontal	Below 10
9	Gr. Floor	C6	Horizontal	13.0
10	Gr. Floor	C8	Horizontal	16.0
11	Gr. Floor	C11	Horizontal	20.0
12	Gr. Floor	C10	Horizontal	16.0
13	Gr. Floor	C9	Horizontal	16.0
14	Gr. Floor	C12	Horizontal	13.0
15	Gr. Floor	B1	Horizontal	17.0
16	1st Floor	C13	Horizontal	20.0
17	1st Floor	B3	Horizontal	20.0
18	1st Floor	B4	Horizontal	20.0
19	2nd Floor	B5	Horizontal	17.0
20	2nd Floor	C14	Horizontal	16.0
21	3rd Floor	C15	Horizontal	13.0
22	3rd Floor	B6	Horizontal	16.0
23	3rd Floor	S2	Vertical	17.0
24	3rd Floor	B7	Horizontal	13.0
25	4th Floor	C16	Horizontal	19.0
26	4th Floor	C17	Horizontal	16.0
27	4th Floor	S3	Vertical	Below 10
28	4th Floor/ W.T	C18	Horizontal	16.0
29	4th Floor/ W.T	S4	Vertical	Below 10
30	4th Floor/ W.T	C19	Horizontal	17.0
Average apparent concrete strength based on Rebound Hammer Test is 15.95 N/mm^2				

Overhead Water Tank:

- RCC water tank (1no.) is provided on the terrace. Additional PVC water tank resting directly on the terrace slab of partly constructed terrace.
- Leakage of water has been observed from the base slab of over-head water tank.
- Supporting columns of the water tank have been observed to be cracked and also bulged cover concrete.

Internal Faces:

- Dampness to slabs and beams has been observed at many locations of the visited rooms.
- The slabs have been observed to be deteriorated showing severe seepage of water at many locations.
- Delamination/ Bulging of cover concrete and corroded reinforcement has been observed at many locations of the slab.
- Delamination/Bulging of cover concrete and corroded reinforcement has been observed at many locations of the beam.
- The lintel beams have been observed to be cracked at many locations and sagged at few of the locations.
- The columns have also been observed to be deteriorated showing cracks and delaminated cover concrete along with corroded reinforcement.

- Separation between RCC and masonry has been observed at many locations.

Non-Destructive Testing:

The test performed on existing structure to check the current structural condition and material uniformity is rebound hammer test, ultra-sonic pulse velocity test, half-cell potentiometer test, carbonation test and concrete core test.

Table 4
Result of ultra-sonic pulse velocity test

S. No.	Level	Location	Ultra-Sonic Pulse Velocity km/s	Apparent Quality of Concrete
1	Gr. Floor	C1	3.023	Medium
2	Gr. Floor	C2	1.631	Doubtful
3	Gr. Floor	C3	2.307	Doubtful
4	Gr. Floor	C4	2.342	Doubtful
5	Gr. Floor	C5	2.773	Doubtful
6	Gr. Floor	C7	2.836	Doubtful
7	Gr. Floor	S1	1.392	Doubtful
8	Gr. Floor	B2	1.291	Doubtful
9	Gr. Floor	C6	2.656	Doubtful
10	Gr. Floor	C8	4.006	Excellent
11	Gr. Floor	C11	2.948	Doubtful
12	Gr. Floor	C10	2.731	Doubtful
13	Gr. Floor	C9	3.015	Medium
14	Gr. Floor	C12	3.345	Medium
15	Gr. Floor	B1	2.927	Doubtful
16	1st Floor	C13	3.350	Medium
17	1st Floor	B3	3.131	Medium
18	1st Floor	B4	2.532	Doubtful
19	2nd Floor	B5	2.426	Doubtful
20	2nd Floor	C14	2.908	Doubtful
21	3rd Floor	C15	1.756	Doubtful
22	3rd Floor	B6	2.670	Doubtful
23	3rd Floor	S2	2.247	Doubtful
24	3rd Floor	B7	3.211	Medium
25	4th Floor	C16	3.525	Good
26	4th Floor	C17	2.478	Doubtful
27	4th Floor	S3	2.701	Doubtful
28	4th Floor/ W.T	C18	1.942	Doubtful
29	4th Floor/ W.T	S4	2.441	Doubtful
30	4th Floor/ W.T	C19	2.514	Doubtful
Average Ultra-Sonic Pulse Velocity is 2.635km/s, which indicates that apparent quality of concrete as poor or RCC members are cracked.				

Table 4
Ultra-sonic pulse velocity summary

Criteria	Concrete Quality	No. of readings
Above 4.5 km/s	Excellent	1
3.5 km/s to 4.5 km/s	Good	1
3.0 km/s to 3.5 km/s	Medium	6
Below 3.0km/s	Doubtful	22

Table 6
Result of half-cell potentiometer test

S.No.	Level	Location	Half Cell Potential (mv)
1	Gr. Floor	C1	-352
2	Gr. Floor	C2	-381
3	Gr. Floor	C3	-361
4	Gr. Floor	C4	-372
5	Gr. Floor	C5	-366
6	Gr. Floor	C7	-428
7	Gr. Floor	S1	-379
8	Gr. Floor	B2	-370
9	Gr. Floor	C6	-372
10	Gr. Floor	C8	-361
11	Gr. Floor	C11	-357
12	Gr. Floor	C10	-368
13	Gr. Floor	C9	-360
14	1st Floor	B3	-378
15	1st Floor	B4	-356
16	3rd Floor	C15	-367
17	3rd Floor	S2	-365
Average Half Cell Potential is -370.17 mv which indicates the probability of corrosion as 90%			

Table 7
Half-cell potential summary

Criteria	Probability of Corrosion	No. of readings
More than -200mv	10%	0
-200 mv to -350mv	50%	0
Less than -350mv	90%	17

Table 8
Result of carbonation test

S.No.	Level	Location	Depth of Carbonation in mm
1	Gr. Floor	C1	40
2	Gr. Floor	C2	35
3	Gr. Floor	C3	20
4	Gr. Floor	C4	30
5	Gr. Floor	C5	25
6	Gr. Floor	C7	40
7	Gr. Floor	S1	30
8	Gr. Floor	B2	25
9	Gr. Floor	C6	40
10	Gr. Floor	C8	30
11	Gr. Floor	C11	20
12	Gr. Floor	C10	40
13	Gr. Floor	C9	40
14	1st Floor	B3	20
15	1st Floor	B4	30
16	3rd Floor	C15	40
17	3rd Floor	S2	20
In RCC members, carbonation has reached to a depth of 30.88mm on an average. The carbonation has reached to the depth of cover concrete and will result in increased rebound number.			

Table 9
Result of core test

S. No.	Level and Location	Height (mm)	Diameter (mm)	Weight (gms)	Load (T)	Correction Factor for H/D Ratio	Equivalent Cube Strength (N/mm^2)
1	C1- Ground Floor	125	68	1035	3.2	0.99	12.657
2	C3- Ground Floor	130	68	1152	2.85	1.0	11.366
3	C6- Ground Floor	115	68	1009	2.4	0.96	7.938
4	C9- Ground Floor	115	68	998	2.6	0.98	9.335
Average compressive strength of concrete based on core test is 10.324 N/mm^2							

Chemical Analysis:

Table 10
Result of chloride content test

S.No.	Level	Location	Chloride Content in Kg/m^3
1	G-1	C1	0.240
2	G-1	C2	0.300
3	2nd Floor	C3	0.540
Average Chloride Content is 0.36 Kg/m^3			

Table 11
Result of sulphate content

S.No.	Level	Location	Sulphate expressed as SO_3 %
1	G-1	C1	<0.5%
2	G-1	C2	<0.5%
3	2nd Floor	C3	<0.5%
Average Sulphate Content expressed as SO_3 is less than 0.50 %			

Table 12
Result of pH

S.No.	Level	Location	pH
1	G-1	C1	9
2	G-1	C2	9
3	2nd Floor	C3	7
Average value of pH is 8			

6. Conclusion

- After combining the results of NDT tests and visual inspection, it can be concluded that the concrete of RCC structural elements is in severely deteriorated condition and the reinforcement have corroded to the extent of more than 50% reduction in diameter. Therefore, the building structure Uma Sadan is said to be in dilapidated and dangerous condition. Therefore, the structure shall be immediately pulled down to avoid the risk to the human lives.
- Average HCP is -370.17mv which indicates the probability of corrosion as 90%.
- Whenever there is chloride in concrete there is an increased risk of corrosion of embedded metal. The higher the chloride content, greater the risk of corrosion.
- The pH drops below 8 the steel is extremely susceptible to corrosion.
- Chemical test is performed to determine presence of agents which increase the risk of concrete deteriorations. Chloride increases the risk of corrosion and sulphates causes expansion and disruption of concrete. Low pH value indicates (<10) indicates de-passivation of reinforcement and can also be associated with carbonation. The reported maximum soluble chloride content in the test location is 0.05 kg/m^3 and is less than that permitted by BIS. It is concluded that active corrosion is present due to neutralization of the concrete pore solution due to carbonation.

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