INVESTIGATION OF CORROSION AFFECTED CONCRETE STRUCTURES - A SYSTEMATIC APPROACH

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ABSTRACT

Damage to concrete structure due to corrosion of reinforcement is a matter of great importance for concrete technologist all over the world because it is directly related with serious risk to safety. The durability of concrete structure exposed to corrosive environment has not been to our expectation. Hence the need of hour is to investigate the corrosion affected concrete structures with great care and systematically. The results obtained from the various test methods should be interpreted with adequate caution so that the data can be made more meaningful. In this paper the author has made an attempt to present a systematic approach of investigation of corrosion afrected concrete structures highlighting guidelines for interpretation. Two case studies have also been presented.

INTRODUCTION

Corrosion of reinforcing steel represents the most wide spread form of deterioration of concrete structures. The statistics shows that more than 40% of the failure of structure is due to rusting of steel reinforcement. Corrosion prone as well as corrosion affected concrete structures require a systematic inspection and investigation in order to assess the condition of concrete, presence of corrosion activity and extent and severity of corrosion. Factors contributing to corrosion in concrete are:

1) Material (Constituents of Concrete)
2) Environmental Condition
3) Concrete cover thickness
4) Other factors such as design deficiencies, permeability, pH, cracks if any etc.

Investigation of corrosion affected concrete structure consists of several insitu testing system, which have their own merits and limitations. This paper presents a methodology for systematic insitu testing for condition assessment of corrosion affected concrete structure illustrated by two case studies involving a 20 years old residential building and a 25 years old RCC overhead water tank.

MECHANISM OF CORROSION

For corrosion to occur, it is necessary that both the passivating film on steel is destroyed and there exists a differential electrochemical potential within the steel concrete system. The pH value of concrete which is more than 11.5 is lowered by ingress of carbon dioxide, thus providing a corrosive environment while the passive layer can be broken when chloride ions migrate through concrete and reach a critical level at which the passivity is destroyed. Depending on oxidation state the iron increases 6 times in volume due to rusting, as a result of which expansive force acting on concrete surrounding the reinforcement causes cracking. After initiation of cracking, corrosion gets accelerateddue to further ingress of carbon dioxide and / or chloride. After the depassivation, galvanic cells get established with the formation of anodic and cathodic sites and there is a flow of current with moist concrete serving as electrolyte.

METHODS OF INVESTIGATION

Visual Observation

Visual observation is the starting point of inspection. Cracks, rust, staining and spalling are the most obvious defects which can be identified. But the defect observed visually must be investigated further to confirm the root cause. Cracking along the reinforcement can be an important indication that the reinforcement are subjected to corrosion. Fig-1 shows typical cracking, spalling and delamination of concrete cover.

INSITU TESTING OF CONCRETE

Rebound hammer test

It is a well recognised non destructive test method used for estimation of surface hardness, concrete compressive strength and comparative investigation. This measures the elastic rebound of concrete and also identify the presence of any delamination. The member to be tested is divided into well defined grid points having a spacing of approximately 300 x 300 mm. When the plunger is pressed against the concrete surface, the mass rebound from the plunger. The distance travelled by the mass is called rebound number. It is indicated by the rider moving along a graduated scale. This test can be conducted horizontally, vertically, upward, downward or at any intermediate angle. Location possessing very low rebound number will be identified as weak surface and such locations will be further identified as corrosion prone locations where the corrosion process may be active depending on other results. Table-1 gives guidelines for interpretation of rebound hammer test result with reference to corrosion.

Table-1 Quality of concrete based on Rebound Number

Average rebound number	Quality of Concrete
> 40	Very good
30 – 40	Good
20 – 30	Fair
< 20	Poor
0	Delaminated

Ultrasonic pulse velocity test

This is a quick, inexpensive means for checking uniformity and integrity of concrete. This method consists of measuring the time of travel of an ultrasonic pulse of 50-54 KHz frequency through the concrete medium to be tested. The time of travelbetween initial onset and the reception of pulse is measured electronically. The path length between transducers divided by time of travel gives pulse velocity. Higher the pulse velocity, lower the corrosion. Dynamic modulus of elasticity can be found by following equation.

$$E = \frac{\rho v^2 (1 = \mu)(1 - 2\mu)}{1 - \mu}$$

Where v = pulse velocity

ρ = density of concrete

μ = poission's ratio

Hence, strength of concrete can also be found out by following equation

Where $E_d = 22 + 2.8\sqrt{u}$

E_d = dynamic modulus of elasticity (GN/m^2) and

u = strength of concrete (MN/m^2)

The velocity value combined with rebound number can give more realistic assessment of concrete surface. Table - 2 gives guidelines for condition assessment of concrete surface based on UPV value.

Table-2

Concrete Quality based on UPV

Velocity	Concrete quality
> 4.0 Km / Sec	Very good to excellent
3.5 to 4.0 Km/Sec	Good to Very good
3.0 to 3.5 Km/Sec	Medium
< 3.0 Km/Sec	Poor

Covermeter Survey

This survey is conducted to assess the cover thickness in a specified location where damage has been identified and elsewhere for comparison on the same structure. The cover thickness is measured with the help of covermeter. This method also helps in assessing the diameter of reinforcement, spacing and distance of reinforcement from top surface. Table-3 gives guidelines for covermeter reading for corrosion assessment.

Table-3

Interpretation of cover thickness survey

Test results	Interpretation
1. Required cover thickness and good quality concrete	Relatively not corrosion prone
2. Required cover thickness and bad quality concrete	Corrosion prone
3. Very less cover thickness	Corrosion prone

Carbonation Test and pH Test

Carbon dioxide absorbed into the Concrete may convert the $Ca(oH)_2$ into $CaCo_3$ thereby reducing the pH value and consequently the protective value of Concrete. Hence Carbonation test is must. This test is conducted by drilling a hole on the concrete surface to different depth upto cover concrete, spraying with phenolphthalein and observing the colour change. Uncarbonated surface exhibits pink colour while carbonated concrete surface exhibits no change in colour. The pH value can be determined by analysing broken sample or core samples in the laboratory from water extracts and pH meter.

Chloride Test

Tins test is done by "Rapid Chloride Test Kit". The test consists of obtaining powdered sample by drilling, collecting the sample from different depth, mixing the sample with a special chloride extraction liquid by chloride ion sensitive electrode. With the help of calibration graph relating electrical potential and the chloride content, tlie chloride content of the sample can be directly determined.

Pullout test

This test is carried out to assess the strength of concrete. The ideal way to use pullout test in the field would be incorporate assemblies in the structure. These standard specimens cculd then be pulled out at any point of time. The force required denotes tlie strength of concrete. The stronger the concrete, the more is the force required to pullout.

INSITU TESING OF STEEL

Half Cell Potential Survey

In this test reinforcement is electrically connected and the voltage difference between the bar and the reference electrode in contact with concrete surface is observed. More negative potential shows more corrosion. Table - 4 gives guidelines for half cell potential value for interpreting corrosion.

Table - 4

Corrosion possibility by half cell potential

Corrosion	Potential
> 95 percent	More negative than – 350 mv
50 percent	– 200 to – 350 mv
< 5 percent	More positive than – 200 mv

Fig 2 shows set up for corrosion potential measurement.

Resistivity Mapping

The resistivity is usually defined as the resistance (ohm) between opposite face of a unit concrete cube. The test is conducted by driving four probs to serve as electrodes into concrete along a straight line at equal distance. A direct voltage is imposed between the two outer potentiometer electrode and the potential drop is measured between the inner electrodes. The resistivity is given by formula :

$$\rho = 2\,\pi D \frac{E}{1} = 27\pi DR$$

ρ = Mean resistivity (ohm cm)

D = Distance between electrodes

I = Current flowing between outer electrode (ampere)

R = Resistance (ohm)

Table 5 indicates the general guidelines of resistivity value based on which area having coiTOsion risk can be identified in concrete structures.

Table - 5

Resistivity Ohm-cm	Corrosion Probability
> 20,000	Negligible
10,000 – 20,000	Low
5000 - 10,000	High
< 5000	Very High

Case Studies

Two case studies involving a 20 year residential building and another 25 years old RCC overhead water tank, which were affected by corrosion are presented highlighting the test results and damage assessment.

Residential Building

The plan dimension of three storied building is 30 m x 6 m and height is 9m. The building consists of three block, each having staircase. Toilets are provided at eastern and western ends of building. The columns are connected with main and secondary beams. Cross section of columns are reduced at difference levels. The grade of concrete also varied from M25 to M20 for columns. For beams and slab, it is presumed that the grade of concrete used was Ml 5.

Reinforced Concrete Overhead Tank

The water tank is approximately 25 years old and essentially consists of a reinforced concrete cylindrical tank with circular dome shaped as base and top cover slab supported on reinforced concrete columns. The columns are said to be founded with independent footing connecting one inner and one outer column. Circumferential bracing are provided and outer and inner columns are connected with bracings in radial direction.

Investigation

The investigation generally follows the systematic approach presented in the paper.

Visual

Visual inspection consists of chipping of column in the entrance of building revealed that corrosion of reinforcement was the major cause of damage. Major damage was observed in toilet blocks. Concrete spalling was observed in beam, roof and sunshade of building. Cracks were also observed on the top of the roof. TSo damage was observed in the interior part of the building.

In water tank, the visible damage consisted of cracking and spalling of concrete mainly in circumferential bracings, junction of bracing and columns, and radial bracing connecting inner and outer columns. Corrosion of reinforcement was evident from the rods exposed at locations ofspallings. At severely corroded locations section loss as high as 50 percent was observed in the reinforcement. The tank portion did not show any visible damage except a certain amount of lime leakage in the bottom shell. Also there was no apparent water leakage in the tank portion and in supporting structure of the tank.

The test results generally indicated low UPV value, pH value of about 8.5 and less and carbonation depth greater than 19.

ASSESSMENT

A brief summary of findings is given below.

- The damage in the form of crack and spalling was occurred in those part of building, which were exposed to saline atmosphere and water.
- The cause of damage was corrosion of reinforcement.Corrosion was due to carbonation and ingress of chloride which had lowered tlie alkalinity of concrete.
- The damage was substantial in the bracings and in some locations of the column mainly due to inadequate cover thickness.
- Corrosion affected member were recognized as repairable considering the repair technology, and repair material available today.

CONCLUSION

i) This paper presents a systematic approach of investigation of corrosion affected concrete structure.

ii) No test results in isolation can help to arrive at meaningful findings.

iii) This investigation help to formulate repair measures more approximately and economically.

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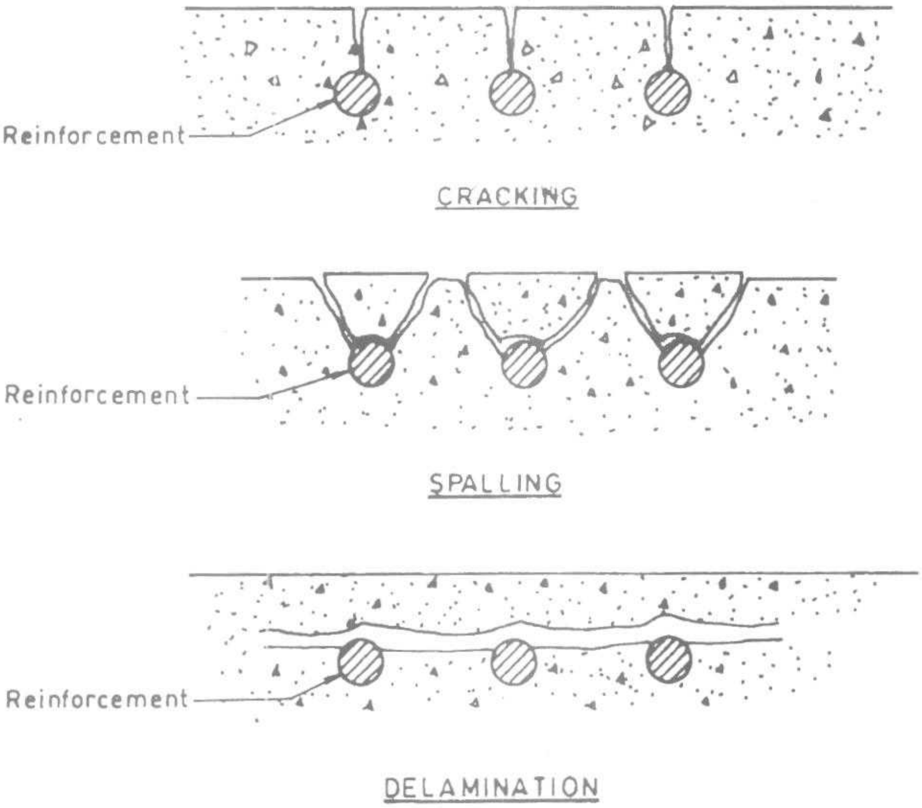

Fig.-1 DAMAGE INDUCED CORROSION, CRACKING, SPALLING AND DELAMINATION

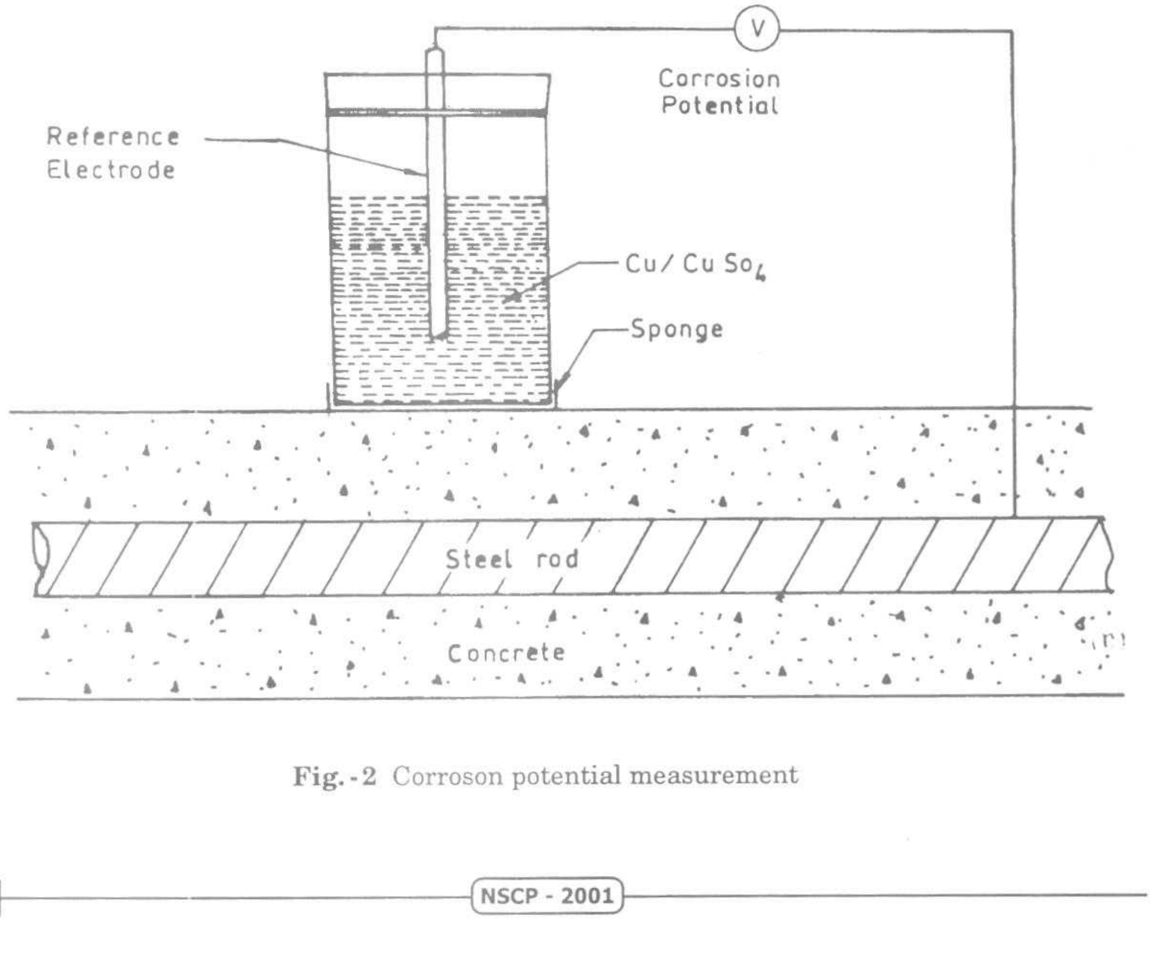

Fig.-2 Corroson potential measurement