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DIAGNOSIS AND ANALYSIS OF OLD CONCRETE STRUCTURES IN COASTAL ENVIRONMENT: FIELD INVESTIGATIONS, ANALYSIS & RECOMMENDATIONS

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ABSTRACT Deterioration of reinforced concrete structures results from external factors or internal causes within the concrete itself. Recently the aspects of concrete durability and performance have become a major subject of discussion especially when the concrete is subjected to severe environment. The findings of various studies earlier carried out on durability with respect to coastal structures are discussed in this paper. The NDT studies conducted on some old buildings at Sriharikota Island are analyzed and the major factor contributing to the deterioration of structures is presented. Chloride induced Corrosion is found to be main factor affecting both the concrete durability and strength. Recommendations for delaying the onset of corrosion in RCC structures in coastal structures are suggested. Corrosion inhibitors admixed in concrete are found to be possible solution for new structures.

KEYWORDS : Durability, Coastal Environment, Ndt Studies, Corrosion, Chloride Profiles, Chloride Induced Corrosion, Corrosion Inhibitors

1.0 INTRODUCTION

"Durability of hydraulic cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion or any other process of deterioration. Durable concrete will retain its original form, quality and serviceability when exposed to environment." **(ACI 201.2R-01[1]).** Deterioration of reinforced concrete structures results from external factors or internal causes within the concrete itself. The reduction in strength or damage to the surface of the concrete can result from physical and chemical aggression, or from mechanical damage caused by impact, abrasion, erosion or cavitation. Corrosion of steel bars is a main factor affecting both the concrete durability and strength.

The Research, Designs & Standards Organization (**RDSO**) - Indian Railway report **RDSO BS-14** has concluded that most of the structures built during the first half of the 20th century have performed well. However, quite a number of structures built during the last 30 years have suffered durability problems resulting in premature deterioration. The RDSO study concluded that structural damage due to reinforcement corrosion is the major factor, which adversely affected the strength, durability and stability of the structure (RDSO 1999) [2]. In the **United States**, according to the Federal Highway Association and based on 1995 prices, the infrastructure deficiencies due to corrosion has jumped from $300 billion in 1995 to $1.3 trillion in 2000 **[Roberge, P.R., (1999)][3].** In Canada, some studies found that rehabilitation cost for corrosion of reinforcing steel is estimated to be about $3.0 billion per year **[Elsener B., (2001)][4].** The experimental studies, especially on the structures those located at seafront in Egypt **(Hassan H. et al)**[5] revealed that the salt-laden weather has a severe negative effect on reinforced concrete buildings.

2.0 PRESENT STUDY:

Under this study some residential buildings which were built approximately 40 years back were selected to assess the structural condition of the buildings. The buildings are located at Sriharikota Island, India which is a land mass sandwiched between Bay of Bengal in the East and Pulicat lake in the West. Sriharikota Island is geographically located at 80.2^0 E and 13.7^0 N. The average elevation is about 4m and maximum elevation is about 10m above MSL. It is prone to severe weather phenomena like tropical cyclones, thunderstorms, and squally weather. SHAR being a coastal area, it experiences sea breeze and land breeze also. As per the report of Central Electrochemical Research Institute, Karaikudi **(Natesan et al. 2004)**[6] the places Sriharikota, Chennai Naval base, Mormugao Port, Port Blair, and Mettupalayam are extremely corrosive in India.

2.1 STRUCTURES DESCRIPTION:

The buildings are residential buildings which were built during the year approximately during 1975-76 were selected to assess the structural condition of the buildings. The building units are Ground + 2 units with Load bearing structure with RCC roof slab and other RCC elements like staircase, chajjas etc. The Grade of concrete adopted during construction is M15.

2.2 PRELIMINARY STUDIES CONDUCTED

To assess the condition of buildings using NDT methods, and evaluating electrochemical parameters of concrete the following procedure has been adopted.

This different studies conducted are as follows:

I. Visual observations / extent of distress.

II. Non-Destructive (ND) tests, such as,

- Profometer survey (to determine concrete cover thickness)
- Rebound Hammer test (to determine de-lamination zones)
- Ultrasonic pulse velocity test. (to assess integrity of concrete)
- III. Partially Destructive tests like
- Core sampling, extraction of cores and testing in the laboratory.
- Evaluation of Electrochemical parameters of concrete (pH, S, Cl-).
- Half-cell potential survey to determine extent of corrosion activity in the RC members, where corrosion symptoms are observed.
- Carbonation test at random locations on the R.C.C member, and in the extracted core samples.

2.3 IMPORTANT FINDINGS:

2.3.1 VISUAL INSPECTION:

The upkeep of the campus and buildings is observed to be good. However, due to marine environment the concrete and steel have undergone changes, and the reinforced concrete members in particular, have indicated changes in their properties, as a result of which distress is also exhibited in certain Blocks/quarters. The distress is observed in the form of cracking along the reinforcement, spalling of cover concrete, and exposure of reinforcement in many reinforced concrete members.

Figure 1 :: Spalled Beam element

Figure 2 :: Crack in the Tension zone of a beam

2.4 IMPORTANT FINDINGS FROM ND STUDIES

- Rebound hammer test values (RHV) on the surface at grid points and on the surface (at Random locations) in the slab portions, wherever taken are uniform. However higher compressive strength in some RCC members reflects carbonated cover concrete.
- Half – cell potential (HCP) survey using Copper-Copper sulphate half-cell was conducted on RCC members, where corrosion symptoms were observed. The HCP values observed showed more positive. Most results show Probability of 50% corrosion activity present in the reinforcement.
- It is observed from the Ultrasonic pulse velocity test results that the Slabs, columns & beams tested, have concrete integrity range from doubtful to good. Some of the UP values indicate that the concrete possess voids (honey combed in the interior portions).
- The mean compressive strength of cubes obtained is about 16 N/ Sqmm which is satisfactory with respect to the design strength of 15 N/ sqmm. The condition is to be assessed by considering all the parameters and not only the strengths.
- The in-situ carbonation tests on Slabs, Beam, column indicate that reinforcements are corroded due to carbonated layer reaching up to concrete cover thickness after the carbonation test. In the quarters, out of 14 tests, about 9 samples have shown signs of carbonation.
- As per IS : 456:2000, the maximum total acid soluble chloride content expressed as Kg/m^3 of concrete should be 0.6 for reinforced concrete. Therefore for reinforced concrete with 2400 kg / cum density, max chloride content works out to (0.6/2400)x 100= 0.025%. The Average chloride content of the test samples is 0.17% which is very high compared to the permissible value.

3.0 CONCLUSIONS & RECOMMENDATIONS:

The Chloride content in RCC structures is alarmingly high. Studies revealed that Chloride induced reinforcement corrosion is the predominant reason for the failure of RCC elements. The structures located here at study area were surrounded by chloride laden environment, which resulted in electrochemical corrosion of steel reinforcements. The ingress of chloride ions into the concrete affected the reinforcement steel and thereby corroding the reinforcement. The corroded reinforcement caused cracking and spalling of concrete. For localized repairs, Polymer modified cement mortar is suggested for the structures. High performance Repair mortars are available as protective coatings can be applied. Also, application of anti- carbonation coatings, Migratory corrosion inhibitors etc can be used as an effective measure for improving the durability of reinforced concrete structures.

For new structures, the addition of corrosion inhibitors in fresh concrete emerges to be a principal corrosion prevention method. Corrosion inhibitors, which come in powder, gel and liquid form can be introduced into the concrete mix at the time of construction for new structures to retard the rate of corrosion.

3.1 CORROSION INHIBITORS:

Corrosion Inhibitor is defined as "a chemical substance that decreases the corrosion rate when present in the corrosion system at suitable concentration, without significantly changing the concentration of any other corrosion agent." (ISO 8044- 1989).

Generally the mechanism of the inhibitor is one or more of three that are cited below:

- The inhibitor is chemically adsorbed (chemisorption) on the surface of the metal and forms a protective thin film with inhibitor effect or by combination between inhibitor ions and metallic surface;
- The inhibitor leads a formation of a film by oxide protection of the base metal;
- The inhibitor reacts with a potential corrosive component present in aqueous media and the product is a complex.

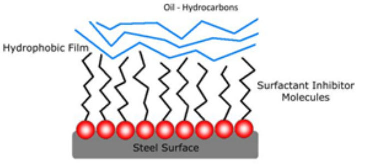

Fig 3: Mechanism of a conventional corrosion inhibitor

3.2 CLASSIFICATION:

The corrosion inhibitors can be classified in different ways.

3.2.1. BASED ON THE PHYSICAL MODE OF APPLICATION:

Those compounds which are added to the fresh concrete at the time of mixing for new structures are known as admixed inhibitors. Those compounds which are applied on the hardened concrete surface and are able to diffuse through concrete to the underlying rebar to form a monolayer film at the steel-concrete interface.

3.2.2 BASED ON THEIR MECHANISM OF PROTECTION.

- **Anodic Inhibitor :** Anodic inhibitors act on the dissolution of the steel and they reduce the corrosion rate by an increase in the corrosion potential of the steel. Passivating inhibitors like nitrites represent special types of anodic inhibitors and they are generally very effective inhibitors if present in sufficient concentrations. The most commonly used anodic inhibitor is calcium nitrite. Sodium nitrite, sodium benzoate and sodium chromate have also been used.
- **Cathodic Inhibitor :**Cathodic inhibitors act on the oxygen reaction on the steel surface and they reduce the corrosion rate by a decrease in corrosion potential. The most commonly used cathodic inhibitors are sodium hydroxide and sodium carbonate, which are supposed to increase the pH near the steel, and reduce the oxygen transport by covering the steel surface, Phosphates, silicate and polyphosphates are also used.
- **Mixed Inhibitor:** Mixed Inhibitor act on both anodic and cathodic sites and they reduce the corrosion rate without a significant change in the corrosion potential, generally by surface adsorption over the surface of the steel in contact with the inhibitor and consequently forming a thin protective layer. In mixed type inhibitors, material with the hydrophobic group that have polar groups such as N, S, OH is effective. Organic polymer compounds such as amines and amino alcohols are also used.

3.3 RESULTS OF STUDIES CONDUCTED ON CORROSION INHIBITORS:

Two commercially available corrosion inhibitors, Anodic inhibitor (Calcium Nitrite based) and Bipolar Inhibitor mixed in concrete made from Portland pozzolana cement (PPC) and Ordinary Portland cement (OPC) are studied in terms of modification of the workability and mechanical properties and durability parameters.

- There is no improvement in the workability of OPC concrete mixes or PPC concrete mixes by addition of both the Corrosion inhibitors compared to the control mix.
- The 3 days and 7 days compressive strength result yielded less values compared to the control mix for Calcium Nitrite inhibitor in OPC mixes. However the 28 days result is marginally more compared to the control Mix.
- Addition of Bipolar inhibitor at dosage of 5% resulted in the considerable reduction of compressive strength by about 33% to 36% in OPC mixes.
- The rapid chloride permeability tests revealed that the resistance of concrete for the ingress of chloride ions is improved by addition of corrosion inhibitors.

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