Reinforcement Corrosion Assessment Through Half – Cell in Concrete Structure Exposed in Marine Environment

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ABSTRACT
Reinforced Concrete structures deteriorate under water in the Marine environment. It is not the disintegration of concrete itself, but the electrochemical corrosion of the reinforcing steel. Corrosion of steel reinforcement is one of the main causes of damage in concrete structures. The most critical and serious problems to the durability and safety of concrete structures. The corrosion of reinforcement in under water of R.C.C. structures depends on the factors of steel, water cement ratio, concrete cover, salinity of water, here an attempt is made to know the corrosion of reinforcement in under water of concrete structures in conjunction with factors grade of concrete, construction material, design type, quality control measures used. The present study is an attempted to assess the corrosion in under water of R.C.C. structures through Non-Destructive test studies by use of Ultra Sonic Pulse Technique & half-cell potentiometer. The tests reveals that detrimental amount of chloride ions are capable of penetrating in a good quality concrete beyond that it is a practical limit for concrete cover thickness.

It is anticipated that the application of findings of this research will result in fewer structures of reinforcement corrosion in concrete structures and improved methods of repairing corrosion induced in existing structure and preventive method for the new concrete structures.

KEYWORDS:
Bridge, corrosion, reinforcement concrete, steel, Non Destructive Tests, marine environment, carbonation, chloride, sulphate, sea water, corrosion mechanism field testing, anode, cathode, passively, alkalinity coatings half cell potential, inhibitors, durability, serviceability, electrochemical reactions.

INTRODUCTION:
The concrete provides reinforcing steel with an excellent corrosion protection under normal conditions. The high alkaline environment in concrete results in the formation of tightly adhering films which protects the steel from corrosion. Corrosion of reinforced steel occur in concrete due to poor quality, inadequate consideration of service environment or change in environment the service life of the concrete structures.
The corrosion of metals, especially steel in concrete has received increasing attention in recent years because of its wide spread occurrence and high cost of repairs associated with the same. The corrosion of steel reinforcement was first observed in marine structures and manufacturing plants [1]. The consequent extensive research on factors contributing to steel corrosion has increased in understanding the mechanism of corrosion, especially concerning the role of chloride ions. It is anticipated that the application of findings of this research will result in better understanding the dynamics of corrosion of under water concrete structures exposed to adverse environment.
Chloride ions are considered to be the major cause of premature corrosion of steel
reinforcement. Carbonation of concrete results in reduction of its alkalinity, thereby permitting corrosion of embedded steel. The rate of corrosion of steel reinforcement embedded in concrete is also influenced by environmental factors. Other factors which affect the rate and level of corrosion are heterogeneities in the concrete and steel, PH of the concrete pore water, cracks in concrete, stray currents etc. Design features also play an important role in the corrosion of embedded steel.[11]

The research on corrosion has not till date identified a class of reinforcement which will not corrode under Marine / under water environment. However, research has pointed to the need for quality concrete, careful design, good construction practices and reasonable limits on the amount of chloride in the concrete mix ingredients. Other measures which are being investigated include the use of corrosion resistance steel, corrosion inhibitors, protective coating on steel and concrete surface.

CORROSION
The interaction of materials with their environment which results drastically deterioration of their properties that vital to performance in service is corrosion. [1] Corrosion is defined as the destruction / deterioration of a material because of reactions with its environment. [2]

MECHANISM OF CORROSION [3]
The Electrochemical reactions are indicates below as, at Anode, Ferrous ion pass into at the anode, ferrous ion goes into solution i.e.,

\[ \text{Fe} = \text{Fe}^{++} + 2\overline{e} \]  

(1)

A cathode, the reaction will occurs to accept electrons. In aerated sea water oxygen will serve as electron acceptor.

\[ \text{O}_2 + 2\text{H}_2\text{O} + 4\overline{e} = 4\text{OH} \]  

(2)

In case of neutral, Alkaline and anaerobic condition water can serve as an electron acceptor with evolution of hydrogen

\[ 2\text{H}_2\text{O} + 2\overline{e} = \text{H}_2 + 2\text{OH} \]  

(3)

\[ (1) \& (2) = 2\text{Fe} + 2\text{H}_2\text{O} + \text{O}_2 = 2\text{Fe}^{++} + 4\text{OH} = 2\text{Fe(OH)}_2 \]  

(4)

Resulting compound is Ferrous hydroxide further oxidized to Ferric Salt known as red rust. [5]

Types of Inspection and Field Tests: [12]
The type of inspection methods shall be specified. The frequency of the inspection shall be evaluated. The most important inspection method and their relative ability to detect corrosion of steel in concrete. The general inspection methods for concrete deterioration are : 1. Visual Inspection 2. Photographical Inspection 3. Ultra sonic, manual & automatic, 4. Radiography. The corrosion of steel detection are carried out by the methods of electrical resistance, linear polarization, electrochemical impedance, Galvano pulse technique and half-cell potentiometer. Most widely used method for corrosion detection of steel reinforcement in under water of concrete structure is “Half - Cell Potential.”

BRIDGE CASE STUDY:
The Present case Study of Bridge is known as Panvel Creek Bridge which is main access from Belapur, Navi Mumbai to Urban (JNPT) Medium and Heavy Traffic with container load Vehicles are plying. The Bridge is 38 years old, having total length of 397.00 meters and 13.10 meters width, 9.50 meters carriageways 1.8 meter footpath on either side. Bridge is rested on support of circular pier with pile foundation. There is a 3.5 – 4.0 Mtrs. difference between high tide level and low tide levels due to which piers have been affected to a large extent. This is what we call the ‘Splashing zone’. Where the RCC is exposed constant to sea water on its surface Figure-1 and 2. The half-cell potential is an indication
of relative probability of corrosion activity, and the guideline described in ASTM C 876 provides general principles for evaluation of the reinforcing steel corrosion in concrete using the potential measurement of pier concrete in splash zone. [10]

The Bridge: Structure is in Contact with saline water under marine environment. To know ingress of carbonation, chloride and sulphate chemical tests are carried on concrete and assessed quality through Ultra Sonic pulse velocity test Fig.-3. The Test report on ultra sonic pulses velocity, Chloride & sulphate and carbonation are tabulated in table-1 and table-2.

**Fig. – 1: During Low Tide Level**

<table>
<thead>
<tr>
<th>Concrete Sample pH Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sr. No.</strong></td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

**Concrete sample sulphate ingestion**

<table>
<thead>
<tr>
<th><strong>Sr. No.</strong></th>
<th><strong>Pier No.</strong></th>
<th><strong>APRIL-MAY 2011</strong></th>
<th><strong>MAY-JUNE 2012</strong></th>
<th><strong>APRIL-MAY 2013</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>0.07</td>
<td>0.07</td>
<td>0.075</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>0.06</td>
<td>0.075</td>
<td>0.085</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>0.052</td>
<td>0.065</td>
<td>0.08</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>0.042</td>
<td>0.05</td>
<td>0.055</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>0.034</td>
<td>0.04</td>
<td>0.05</td>
</tr>
</tbody>
</table>

**Concrete Sample Chloride ingress**

<table>
<thead>
<tr>
<th><strong>Sr. No.</strong></th>
<th><strong>Pier No.</strong></th>
<th><strong>APRIL-MAY 2011</strong></th>
<th><strong>MAY-JUNE 2012</strong></th>
<th><strong>APRIL-MAY 2013</strong></th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>0.33</td>
<td>0.345</td>
<td>0.35</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>0.28</td>
<td>0.285</td>
<td>0.29</td>
</tr>
</tbody>
</table>

**Fig. – 1: During Low Tide Level** (Case Study Bridge)
Fig. – 2: During High Tide Level (Case Study Bridge)

Fig. – 3: Concrete Sample Extracting

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Pier No.</th>
<th>APRIL-MAY 2011</th>
<th>MAY-JUNE 2012</th>
<th>APRIL-MAY 2013</th>
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<tbody>
<tr>
<td>1</td>
<td>3</td>
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<td>5</td>
<td>7</td>
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<td>2</td>
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<td>10</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

The following guidelines are applicable for ‘Direct method’ only. Indicating concrete condition qualitatively. [As per IS 13311 Part-I (1992)]

1. Velocity below 3.00 Km/sec indicates ‘DOUBTFUL’ quality concrete.
2. Velocity between 3.00 to 3.50 Km/sec indicated ‘MEDIUM’ quality concrete.
3. Velocity between 3.50 to 4.50 Km/sec indicates ‘GOOD’ quality concrete.
4. Velocity above 4.50 Km/sec indicates ‘EXCELLENT’ quality concrete.

The ultrasonic test data report confirms that the concrete quality which fall in ‘good’ quality concrete further need monitoring. To evaluate the corrosion of steel reinforcement in the concrete structures the Half-cell potential test is carried where the most deterioration of the concrete condition is seen through the concrete test report as carried out. The most severe part of concrete surface seen in the ‘Splash Zone’ on pier. The test data of half cell potential carried report is in the table-4.
TABLE 4: GUIDELINE FOR HALF CELL POTENTIAL DATA INTERPRETATION [9]
(As per ASTM C876)

<table>
<thead>
<tr>
<th>Calomel (SCE)</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>More positive than – 200 mV</td>
<td>More than 90% probability that corrosion is not accruing.</td>
</tr>
<tr>
<td>- 200 mV to – 350 mV</td>
<td>Corrosion activity is uncertain</td>
</tr>
<tr>
<td>More negative than – 350 mV</td>
<td>More than 90% probability that corrosion is occurring.</td>
</tr>
</tbody>
</table>

The observation regarding which are falling in the range of -345mv to -440mv indicates the high probability of corrosion activity occurrence.
DISCUSSION:
The structure under investigation is M30 grade concrete. The test of ultrasonic pulse velocity on RCC pier concrete quality observed as per the data report is medium to good. The quality decline from ‘Good’ to Medium conditions need further test such as chloride, sulphate and carbonation test etc. It is observed that the chloride & sulphate content in concrete is above acceptable limit. Average carbonation depth is seen 5mm & pH value in the concrete sample has dropped to considerably low levels. The average reading is around 10.6 as against the normally required 12.5 - 13.0. The half cell potential test data depicts the probability corrosion response in concrete of reinforcement steel is falling in the range of -345mv to -440 mv which shows the high probability of corrosion activity process occurrence. The concrete quality declining to medium indicates the surrounding saline environment is in continuous process to deteriorate concrete in strength and durability. The chloride & sulphate content is found above the acceptable limit indicating the high salinity of surrounding environment (Creek Water) influencing the concrete through electrochemical action. The pH value in concrete dropped below normal range and is 10.6. Chloride, sulphate attack & reduced pH value results in decline of concrete strength. The piers have been affected due to difference between high tide levels and low tide levels to large extent which is generally referred as ‘Splashing zone’. The effect of high salinity in creek water has propagated to depassivate the protective layer on reinforcement steel presence of carbon and oxygen to electrochemical reaction and reduction in pH concentration give rise to corrosion of steel.

CONCLUSION:
- Chloride ion and carbonation testing help to establish whether passive film has been destroyed.
- The Concrete samples test results are increased with interval of time Sulphate, Chloride, carbonation depth and PH Value decreased.
- Chloride, Sulphate attack & reduced PH Value given in decline of concrete strength.
- The surrounding saline environment is in continuous process to deteriorate concrete in strength & durability.
- Quality of Concrete detected through USPV shows concrete strength in decreasing with time interval.
- Chlorination and Carbonation is major effect on concrete surface under Marine Environment. For disintegration of concrete surface.
- The large difference between high & low tide levels the piers affected large extent in splashing zone.
- The Half – Cell potential test shows probability of corrosion response in concrete high salinity in creek water propagated to depassivate the protective layer of reinforcement steel.
Poor quality of concrete, improper structural design, bad workmanship, corrosion of steel by chloride ions, dimensional expansion and contraction caused by cyclic wetting and drying, chemical attack on concrete both internal (Alkali aggregate) and external (Chloride & Sulphate attack) are found to influence the strength reduction of concrete structure.

Corrosion risk assessment allows identification of the more critical parameters where close attention is needed for monitoring the safety and durability of structures.

Study results show that the saline environment in underwater concrete piers especially those which are exposed to splashing zone accelerate corrosion more than the normal levels expected. Hence the normal cover thickness of concrete becomes inadequate and fails to prevent corrosion effectively.

Concrete quality and concrete cover are known to vary spatially over the concrete surface, normally caused by different concrete batches and the variability of workmanship. The chloride concentration is also spatially variable for corrosion initiation and propagation.

The normal cover depth to concrete elements as per IS 456:200:2642 should not be less as specified in severe & very severe exposure condition and extreme condition.

The concrete cover depth shall be increased by +5 to 10mm in addition to the nominal depth as specified in the codes for the reinforcement above 12mm diameter bars. The increased cover depth delays carbonation and chloride corrosion for resisting to delay the electro-chemical process & reduction in carbonation depth.

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REFERENCES