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# Prediction of Probability of Chloride Corrosion of Reinforcement in R.C.C. Structure- Critical Overview

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**ABSTRACT:** Corrosion in the reinforcement is detrimental to R.C.C. structure. Normally reinforcement embedded in the concrete does not corrode due to high alkaline environment after hydration of cement in the concrete. Corrosion in the reinforcement starts due to depassivation of reinforcement. Induction of chloride in the structure is the main reason for depassivation of reinforcement. If the reason and severity of corrosion of reinforcement can be assessed effectively, decision on rehabilitation of R.C.C. structure will be easier and foolproof. In most of the cases, reason for corrosion and their severity is not determined properly and hence rehabilitation of structure is not done efficiently. It is essentially required to devise a mechanism to detect the reason for corrosion and prediction of probability of corrosion in the reinforcement of structure to assess the severity of corrosion. In this review paper, focus is given in exploring the reason for corrosion in the reinforcement of R.C.C. structure, mechanism of chloride corrosion of reinforcement, factors affecting the chloride corrosion of reinforcement in the R.C.C. structure, measurement of corrosion of reinforcement in the R.C.C. structure, phases of corrosion in the reinforcement, determination of chloride content, and prediction of probability of corrosion. This review paper will definitely help the Structural Engineer to investigate the reason for corrosion and their impact in the structure effectively so that an efficient rehabilitation methodology can be suggested.

**KEYWORDS:** R.C.C., Corrosion, Structural rehabilitation, Chloride content, Probability, corrosion mechanism, depassivation, alkaline environment.

## I. INTRODUCTION

Concrete is a versatile material in construction of structure. Due to its versatility, it is utilized in construction of all type of Reinforced concrete structure. Concrete produces durable structure. It protects the embedded reinforcement from corrosion in R.C.C structure by providing alkaline environment. In alkaline environment of concrete, embedded steel reinforcement forms passive layer [1]. Passive layer of steel reinforcement in concrete is iron oxide layer comprising crystalline layer of  $Fe_3O_4$  with outer layer of  $\gamma Fe_2O_3$ . Passive layer of reinforcement is having self healing properties but gets destroyed due to attack of chloride ion. Due to depassivation or destroying of passive layer of reinforcement, corrosion in the reinforcement starts. Corrosion forms rust on the reinforcement during corrosion propagation. Due to formation of rust, cross section area of reinforcement gets reduced which cause the reduction in bond between reinforcement and concrete in R.C.C. structure [2]. Level of Chloride ion to initiate the corrosion in the embedded reinforcement is 0.1% soluble chloride ion by weight of cement of concrete. Threshold limit of chloride concentration in the R.C.C. structure is generally between 0.9 to 1.1 kg/m<sup>3</sup> of concrete to avoid the corrosion of reinforcement. Due to corrosion, internal stresses are produced in the structure which causes crack in the concrete surrounding reinforcement and eventually causes spalling off of the concrete [3]. Indian standard suggests acid soluble chloride in R.C.C. structure should not exceed 0.6 kg/m<sup>3</sup> of concrete to avoid the corrosion in the structure [4].

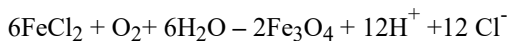
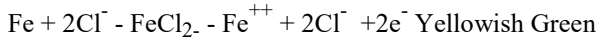
## II. MECHANISM OF CHLORIDE CORROSION OF REINFORCEMENT

pH value of pore solution in the matured concrete becomes more than 12.6 after hydration of cement in the concrete is completed. Due to high alkaline environment in the concrete, the reinforcement in R.C.C. structure is protected from corrosion. Corrosion in the structure starts due to induction of chloride ion in the concrete. Chloride ion is induced in

the concrete due to the reasons ( i ) water used in construction, (ii) cement, (iii) fine aggregate and coarse aggregate, ( iv) accelerator used in the concrete, (iv) presence of marine environment [5].

Chloride is present in the matured concrete in three states (i) chemically bound, (ii) free chloride and (iii) physically adsorbed. Main reason for corrosion in the reinforcement due to chloride is free chloride [5].

At high chloride concentration in concrete beyond threshold limit, corrosion in the reinforcement starts. Mechanism of corrosion in the reinforcement due to chloride in the concrete is as follows [5]



Reaction between reinforcement and free chloride is continuous. Free chloride acts as catalyst in the corrosion of reinforcement.

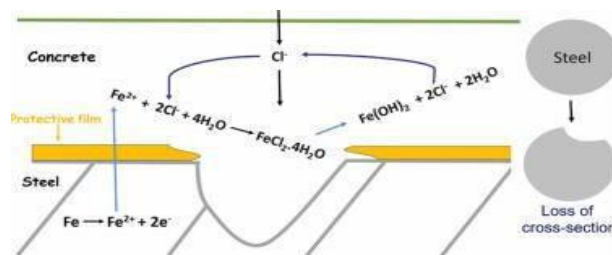


Fig.1 Role of Chloride ion as catalyst in corrosion of reinforcement [7].

During the chloride corrosion, there is breakdown of the passive surface and small pit is formed called anode. The passive surface is then act as cathode. This kind of corrosion when anode and cathode is intrinsic called microcell corrosion. In some cases of chloride corrosion cathode and anode is formed in separated areas and this type of corrosion is called macro cell corrosion [6].

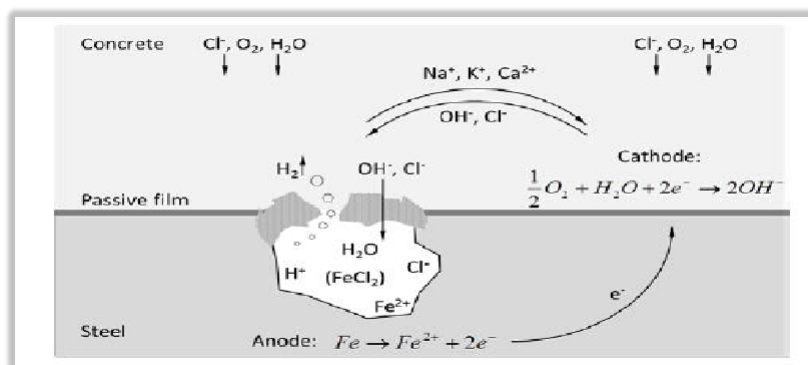
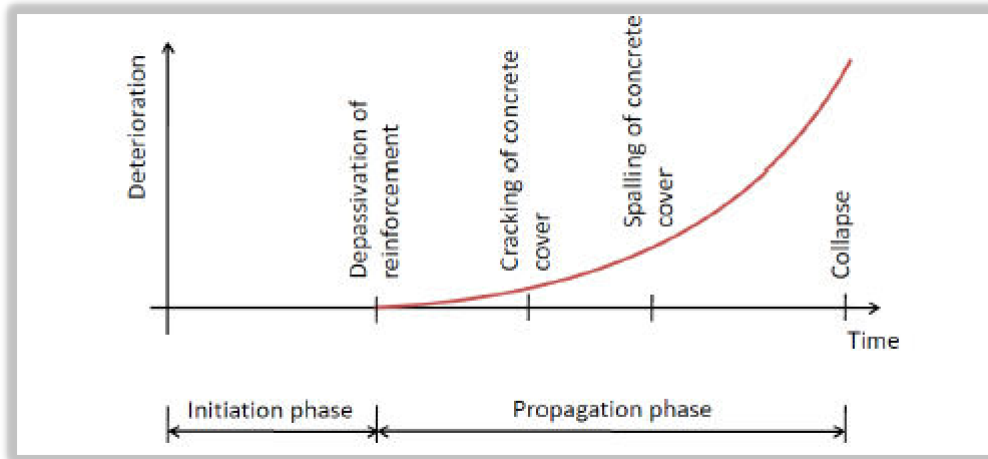


Fig.2 Schematic representation of chloride induced pitting corrosion in the reinforcement [11].

Corrosion in the reinforcement reduces the service life of R.C.C. structure. Service life of R.C.C. structure is divided in to two phases i.e. i) Initiation Period and ii) Propagation Period. During initiation period, reinforcement in the structure starts depassivation and in the propagation period, steel reinforcement start corrosion. After propagating period failure risk in the structure increases. [8]. Figure 3 explains the initiation period and propagation period.



**Fig.3 Initiation period and Propagation period of reinforcement in the R.C.C. structure [8].**

Corrosion in the reinforcement due to chloride is localized or pitting corrosion with less area of attack. Area of corrosion will be wide when concentration of chloride increases[9]. Corrosion potential of reinforcement in the structure decreases as the chloride content increases[10].

### III. FACTORS AFFECTING CHLORIDE CORROSION OF REINFORCEMENT

Corrosion of the reinforcement embedded in the concrete depends on the various factors such as (i) Concrete steel interface pH of pore solution, (ii) Steel Potential, (iii) cement type, (iv) surface condition of steel reinforcement, (v) moisture content, (vi) oxygen availability, (vii) water -cement ratio, (viii) resistivity of concrete, (ix) degree of hydration of cement, (x) type of steel reinforcement, (xi) Chloride ion source, (xii) Corrosion inhibitor, (xiii) age of concrete, (xiv) chemical admixture, (xv) concrete cover, (xvi) concrete quality and (xvii) mineral admixture[10,11].

### IV. MEASUREMENT OF CORROSION OF REINFORCEMENT IN R.C.C STRUCTURE

Half cell potential test is a very common method for detecting the corrosion of uncoated reinforcement in structure. In this method corrosion potential of reinforcement is measured to determine the probability of corrosion in reinforcement embedded in the structure. Half cell potential equipment consist of copper/ copper sulphate or Silver Silver Chloride reference electrode and clamp. During the corrosion two half cell is formed between anode and cathode of the reinforcement and hence this test measure the potential difference between half cell formed in the reinforcement and reference electrode in terms of corrosion potential. Corrosion potential is measured when the clamp is attached to the reinforcement embedded in the concrete and reference electrode is kept on the moist surface of concrete[12]. Fig. 4 explains the half cell potential measurement using Half cell potential equipment

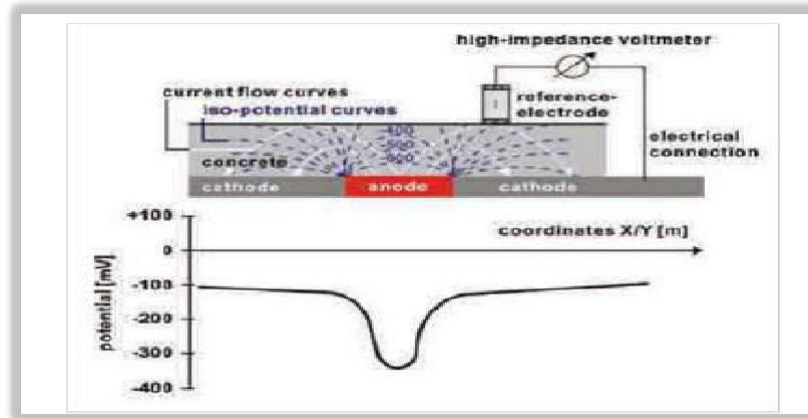


Fig. 4 Half Cell Potential Measurement method[12].

Half cell potential test data can be used for determination of corrosion potential for uncoated reinforcement embedded in concrete. Half cell potential test data can be represented by graphical representation call equipotential contour map. This map indicates the demarcation of corrosion affected area of structure[13]. Fig.5 represents the equipotential contour map of corrosion affected area of structure.

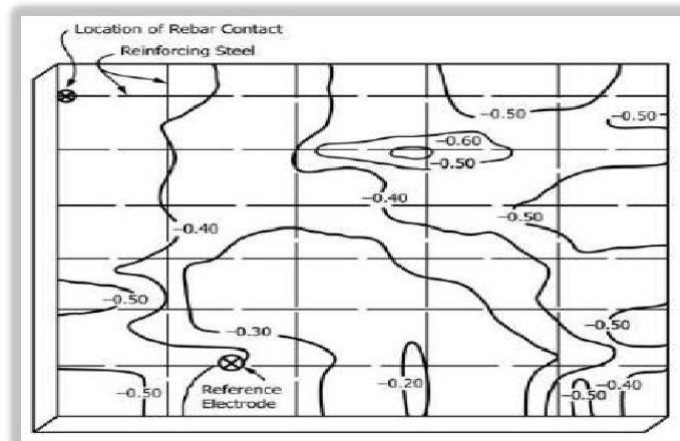


Fig.5 Equipotential contour of corrosion affected area [13].

Another method of representing the half cell potential test data is cumulative frequency diagram which shows the extent of corrosion affected area of structure. Fig. 6 explains the cumulative frequency distribution of half cell potential test data of corrosion affected area of structure[14].

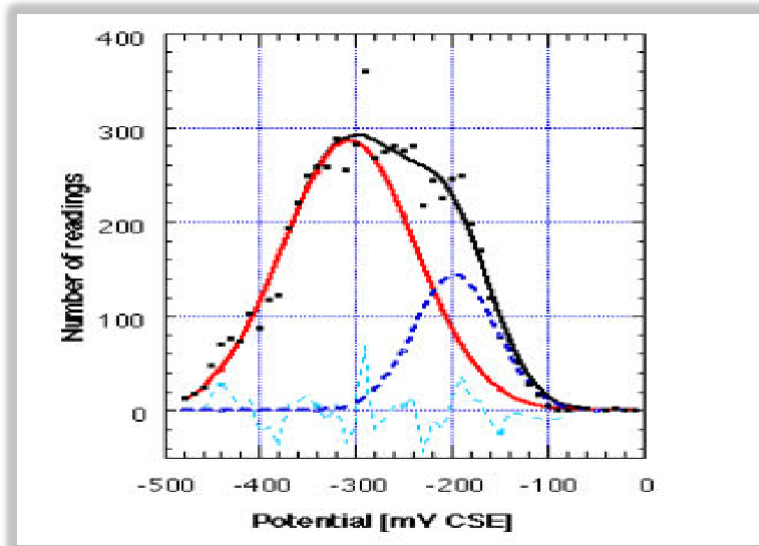


Fig.6 Frequency data of half cell potential data showing corrosion affected area of structure[14].

Half cell potential test is suitable not only for smaller depth detection of corrosion in the reinforcement but it detects larger depth corrosion in the structure. Half cell potential test can be used for design of anode layout in the reinforcement. Half cell potential test do not provide the details of corrosion rate quantity[14].

Another method of measuring corrosion in the reinforcement is resistivity method concrete. It is not providing the corrosion state of reinforcement directly but it can give the indication about the corrosion activity in the reinforcement if resistivity of concrete is decreased. Researcher has tried to establish relation between resistivity of concrete and corrosion rate in the fig.7 but due to scatter it cannot be properly analyzed [15].

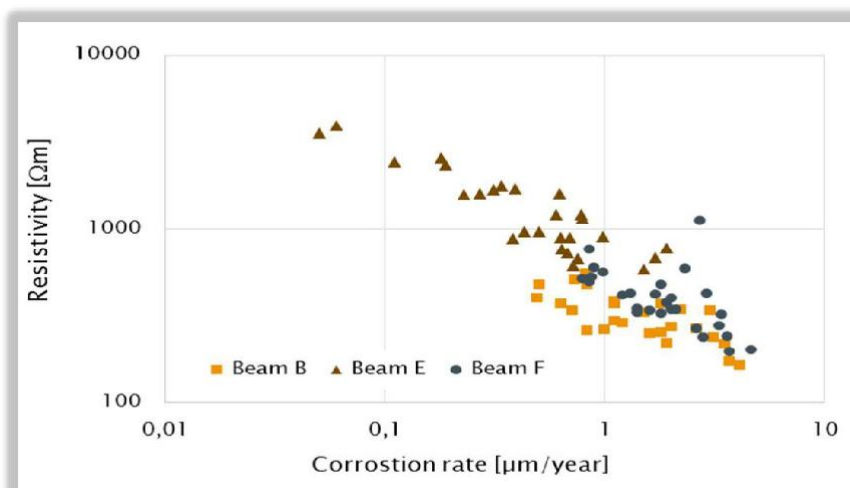


Fig.7 Comparison between resistivity of concrete and corrosion rate of reinforcement[15].

Apart from the above two methods there is one more method called Linear Polarisation Resistance(LPR) method to determine rate of corrosion in the reinforcement of structure in terms of corrosion current density. This test is based on the principle of measuring the change in potential of open circuit electrolytic cell when external current is applied to the electrolytic cell[9].

## V. DETERMINATION OF CHLORIDE CONTENT IN R.C.C STRUCTURE

All the chlorides in the concrete of structure are not mobile. Chloride associated with the cement matrix is also getting released once the pH of concrete matrix is reduced. Actual determination of chloride content in the concrete is essential for determination of exact damage in the structure due to corrosion and their repair[10]. Total chloride content in the concrete is evaluated by taking 1 gm of oven dried concrete powder( extracted from structure) passing through 160 micron sieve in a 250ml beaker and adding 50ml of 1:2 HNO<sub>3</sub>. Once the foam of mixture of concrete powder and HNO<sub>3</sub> is seized, it is boiled for 1 minute with agitation. Afterwards 5ml of 0.05 M AgNO<sub>3</sub> is added to the mixture and boil for one more minutes. After that it is filtered. Further filtrate is added with indicator solution and is titrated against 0.05M NH<sub>4</sub>SCN solution. Titration is done with 0.05M NH<sub>4</sub>SCN solution till colour of filtrate is changed to slight red brown color. Blank test is also done to determine the consumption of NH<sub>4</sub>SCN solution. Chloride content in % is determined by the following formula

$$\%Cl = \frac{3.5453 \times V_{Ag} \times M_{Ag} \times (V_2 - V_1)}{m \times V_2}$$

Where  $V_{Ag}$  is the volume of silver nitrate added,  $M_{Ag}$  is the real molarity of AgNO<sub>3</sub> solution,  $V_1$  and  $V_2$  are the volume of NH<sub>4</sub>SCN in the sample and blank test in ml,  $m$  is the mass of sample in gm[16]. Total chloride in the concrete is Acid Soluble chloride[17]. All the total chloride is not water soluble chloride. 50% to 85% total chloride content in the concrete is water soluble chloride[18]. Water Soluble chloride is responsible for corrosion in the reinforcement in the reinforced concrete structure. Some standard focuses on determination of Total chloride or acid soluble chloride in concrete to know the corrosion effect. If acid soluble chloride is more than the threshold level, then there is need to determine water soluble chloride to find the corrosion effect in reinforced concrete structure[17]. Water Soluble Chloride in the concrete is evaluated by taking 1000 gm concrete powder sample in 2000ml liter capacity beaker after crushing the concrete core extracted from structure to the level of 850 $\mu$  passed material. In the beaker containing concrete powder, 1000ml of distilled water is added and stirred further and warmed up to 15 minutes. This mixture is allowed to settle down for 24 hours and then 200ml of decanted sample is taken in 250ml beaker. After that solution is filtered through whatman filter paper no.1. 50 ml of filtrate is now taken in to 250 ml capacity conical flask. 5ml of 6N nitric acid is added to the filtrate. A known volume(X) of 25ml 0.02N Silver Nitrate solution is added to the filtrate. 1 ml. of ferric alum followed by 5ml of Nitrobenzene are added to it. All the mixture is shaken vigorously to coagulate the precipitate. Excess silver nitrate is titrated against Ammonium Thiocyanate solution till we get faint reddish brown color. Consumption of Thiocyanate solution is noted down as Y. Calculation of water soluble chloride content is calculated as per the following formula [19].

$$\text{Water soluble Chloride, percent} = 0.00142(X - Y)$$

where

$$x = \text{volume of silver nitrate added, in ml; and}$$

$$Y = \text{volume of 0.02 N ammonium thiocyanate}$$

consumed.

## VI. PREDICTION OF PROBABILITY OF CHLORIDE CORROSION IN R.C.C STRUCTURE

The corrosion initiation period in the structure depends upon penetration of chloride in to concrete, surface concentration of chloride, depth of concrete cover and value of threshold chloride level. Time to start corrosion is defined by the following formula[20].

$$dc^2 [\text{erf}^{-1}(1 - (C_{th}/C_s))]^2 / 4D$$

Where  $dc$  = depth of concrete cover,  $D$  is chloride diffusion coefficient,  $C_{th}$  = Threshold chloride concentration,  $C_s$  =

Surface chloride concentration. Probability of corrosion due to chloride in the structure is as follows

$$Pf(t) = P(T_i \leq t) = \int_0^t f_{T_i}(x) dx$$

Where  $f_{T_i}(x)$  is the probability density function of time to corrosion initiation. It is derived by Montecarlo simulation using the probability density function of  $D$  (chloride diffusion coefficient),  $dc$  (depth of concrete cover),  $C_s$  (Surface chloride concentration) obtained from field measurements and  $C_{th}$  (Threshold chloride concentration). This model is found accurate between 80% to 97% [20]. Researcher has tried to establish relation between Total chloride content and



Corrosion potential of reinforcement within a certain range of chloride content and the relation developed by the researcher is as follows[16].

$$E(\text{Corrosion potential.mv}) = -200.8 \times \text{Chloride}(\%) + 3.75$$

Accuracy of the above model is not ascertained by the researcher. Probability of the corrosion can be ascertained from corrosion potential from the following table 1[17].

Table 1 Probability of corrosion based on Half cell potential value

Half cell potential value measured as corrosion potential(mv)	Probability of corrosion in the reinforcement
More negative than -350mv	>95%
-200mv to -350mv	50%
More positive than -200mv	<5%

Many other researcher has also tried to predict the probability of corrosion in the reinforcement based on the corrosion potential or half cell potential value. Table 2 shows the relation of corrosion potential and probability of corrosion in the reinforcement[21].

Table 2 Probability of corrosion based on Half cell potential value

Corrosion potential(mv)	Probability of corrosion in the reinforcement
< -350mv	>90%
-200mv to -350mv	Uncertain
>-200mv	10%

From the above relationship, probability of corrosion of reinforcement can be predicted if the chloride content of concrete is known.

## VI. CONCLUSION

From the review of various literature findings as mentioned in this paper, the following conclusion can be drawn

- Reinforcement embedded in concrete forms passive layer due to alkaline environment (pH more than 12.6). Passive layer protects the embedded reinforcement from corrosion.
- Corrosion starts in reinforcement of structure when chloride ion inducts in the concrete. Free chloride in the concrete is responsible for corrosion. Free chloride is water soluble chloride in the concrete. For assessing the damage in the concrete due to corrosion, assessment of chloride in the concrete is essential. Corrosion in the reinforcement due to chloride corrosion cause local corrosion.
- Factors responsible for the corrosion in the reinforcement are pH of concrete chloride ion concentration in the concrete and free chloride concentration in the concrete.



- Corrosion phases in the reinforcement can be divided in to initial phase when depassivation starts in the reinforcement and propagation phase when corrosion in the reinforcement starts.
- Corrosion in the reinforcement can be measured by measuring Half cell potential test in terms of corrosion potential and it can also be measured by Linear Polarisation Resistance method in terms of Corrosion current density.
- Probability of corrosion in the reinforcement can be calculated by various model mentioned in this paper and its accuracy can be ascertained by actual field measurement.

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