Indian Journal of Science and Technology, *Vol 9(30), DOI: 10.17485/ijst/2016/v9i30/99205, August 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Developments in Corrosion Detection Techniques for Reinforced Concrete Structures

Divyanshu Vikram Singh*, A. K. Sachan and Anupam Rawat

Department of Civil Engineering, Motilal Nehru National Institute of Technology, Allahabad - 211004, Uttar Pradesh,India;divyanshuvikram@gmail.com, anupam@mnnit.ac.in, sachan@mnnit.ac.in

Abstract

Objectives: In the era of the smart cities no infrastructure activity is possible without reinforced concrete structures and these structures face Corrosion of reinforcement. Every year there is a loss of billions required for repair and maintenance necessary for maintaining the performance of the infrastructure. Corrosion of the RCC rebar is responsible for the reduction of load carrying capacity of the structure. So detection of the corrosion is very important for further loss of any type. **Methods/Analysis:**For the corrosion detection in RCC structure it is very important to know about philosophy of the corrosion occurrence. In the current work various corrosion detection techniques were discussed including surface potential technique, radiography, vibrating wire and electrical strain gauges, Hough transform optical fiber sensors and embedded corrosion Instrument. All these methods are studied on the basis of the progressive detection criteria and the merits and the demerits of each method.**Findings:**On the basis of the review areas required improvement in environment corrosion interaction philosophy, simulation of acceleration rate of corrosion of steel,studies related to the transport of chlorides and carbonation process, corrosion cracking behaviour.**Novelty/Improvements:** This paper outlines the corrosion detection techniques on the progressive methods of the corrosion detection and points out the areas of improvement in detection philosophy.

Keywords: Corrosion, Detection Technique, RCC, Reinforced Concrete, Steel

1. Introduction

Modern construction has been inconceivable without the reinforced cement concrete. Reinforced concrete has been found as an economical and robust material in civil engineering structures. However, influence of the external condition of environment such as acid rain, chloride ingress[1], loading fatigue, and carbonization have coinciding damaging effects on concrete. As a result concrete get deteriorated and steel gets corroded. Corrosion is defined as the undesirable deterioration of a metal or an alloy caused by its interaction with the environment that adversely affects the properties of the metal/alloy, which should otherwise be preserved. Due to presence of alkaline environment which is provided by concrete and passivity of bars reinforcements were always believed to be "non-corrodible" but with the passage of time, chlorides ingress into concrete and reinforcement cover decreases and reinforcement steel becomes prone to corrosion damage. Corrosion is an unavoidable process it cannot be stopped; it can only be slowed down or prevented. Presently, corrosion of steel has become a serious problem worldwide, especially for structures exposed to weather[2]. To avoid the loss of serviceability life of structure and structural collapse repairing or replacement is required, which is leading to very high repair cost, sometime even above the initial construction cost[3]. Corrosion can be prevented by using inhibitors or removing oxygen from the surrounding of metal[4].

Reinforced concrete structures are very huge, so same steel bar can be subjected to different kind of corrosion at different ends. Corrosion of steel is closely related to concrete and environmental factors. Change in any one factor would affect each other and would certainly change

**Author for correspondence*

the whole equation, thus changing the corrosion behavior of steel. For example any change in temperature would increase concentration of chloride ions and moisture content inside concrete depends not only on moisture available in air but also depends on temperature cycle during day and night[5]. Thus we can see effect of environmental factors on corrosion of steel is very complicated. Thus it is needed to carefully study all the factors affecting corrosion and also the interaction among these factors needs to be investigated. Lack of appropriate techniques to study and monitor the corrosion process have made this research area more difficult.

2. Corrosion Phenomenon

Corrosion of steel bars starts after removal of passivity later which was formed over bars due to alkaline environment provided by concrete[6]. Depassivation occurs due to ingress of carbon dioxide into concrete which causes carbonation of concrete and also due to chloride penetration. Chlorides first attack passivating layer and remove it and then anode and cathode sites are formed, bars acts as anode from which steel gets corroded and concrete around bars acts as cathode at which corrosion products gets deposited. Chemical reactions occurring during corrosion of steel can be shown as in Figure 1.

$$\text{At anode:} Fe \rightarrow Fe^{2+} + 2e^-$$

$$\text{At cathode: } 2e^- + H_2O + ½O_2 \rightarrow 2OH^-$$

Equations leading to development of ferric oxide or rust are as:

$$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$$

$$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$$

$$2Fe(OH)_3 \rightarrow Fe_2O_3{\cdot}H_2O(rust) + 2H_2O$$

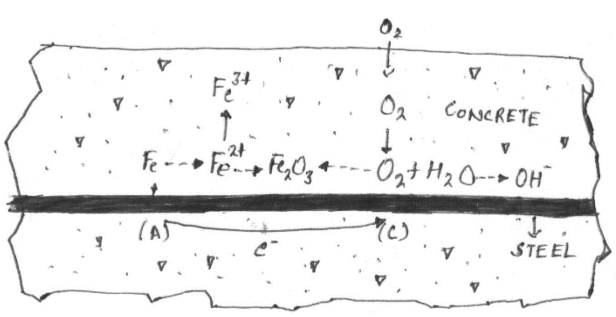

Figure1. Anode andcathode reaction duringcorrosion of steel[10].

Marines structures are exposed to sea water which have high amount of chlorides so adequate cover need to be given during reinforced cement concrete construction[7]. Cracking of concrete due to inadequate construction procedures should be avoided which if not prevented will allow oxygen[8] and water to ingress into concrete and reach steel bars and start corrosion during the early stage of a structure. Temperature[9] also plays an important role in corrosion, as the temperature increases reaction rate increases.

3. Damages caused in RCC due to Corrosion

Corrosion of steel is a worldwide problem. More than half of the structures are corroded and on other structures billions of dollars need to be spent for their repairs. Table 1 given lists estimates of loss due to corrosion prepared worldwide.

4. Corrosion Monitoring Techniques

4.1 Surface Potential Technique

During the process of corrosion of bars, anode and cathode sites are developed and between these sites transfer of electrons takes place. Thus current develops across these two points in concrete which can be measured by measuring the potential drop in concrete. This technique is a non-destructive method for testing the possibility of corrosion of reinforcements in concrete. In this technique surface potential of concrete helps us in identifying the possible cathode and anode regions and thus detecting the possibility of corrosion. Here two reference electrodes are taken and are placed symmetrical on the surface of concrete, one electrode is kept fixed and other electrode is moved across the structure as shown in Figure 2. The potential of moving electrode at different points is measured against fixed point by using a high impedance voltmeter. A positive reading will indicated a possible place of corrosion i.e. anode. More is the potential difference between fixed and movable electrode more severe is the corrosion[17].

One of the main advantages of this technique is that the reference electrodes need not to be directly attached to the reinforcements thus any structure can be checked for corrosion at any point of his life just by measuring potential[18].

Table1. Damage and economic loss due to corrosion of steel

Event	Damage	Economic Loss	Reference
Estimate in USA	Corrosion damage of Highway bridges	$ 90 -150billion	Federal highway Administration (2001)[11]
Estimate in USA	Cost of repairing bridge deck, substructures, car park	$200-450 billion	Transportation Research Board(2001)[12]
Estimate in UK	Corrosion damage of trunk and motorway bridges in England Wales	GBP 616.5 million	Wallband(2011)[13]
Estimate in UK	Annual cost of repairs to concrete structures	GBP 500 million	Rosenberg (1997)[14]
Berlin Congress hall collapse	Total Destruction due to collapse	-	Ise[illegible]002)
Post tensioned bridge collapse in Wales	Total destruction due to collapse	-	Woodward(1995)[15]
Multi-storey parking structure collapse inMinnesota	Total destruction due to collapse	-	Heidersbach(2001)[16]

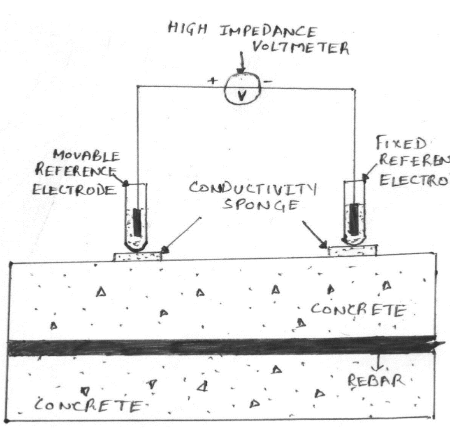

Figure 2. Schematic representation of SP measurement.

4.2 Radiography

Radiography technique is a very reliable method of non-destructive testing method for assessing the quality of reinforced cement concrete. It is based on the principle that with the help of a photon generator first photon are generated and later these photons are transformed into visible light with the help of fluorescent-metallic converter, so that a visible image can be obtained of damaged RCC from which defects such as corrosion of reinforcement, cracks can be located. Location of exact defect place and type of defect helps us in taking preventive measure more efficiently. Radiography methods are of two types, one is based on X-rays and other is based on Y-rays. These rays are electromagnetic rays which can penetrate the body of concrete and depending on the density, voids these rays attenuate from their fixed path which indicating a kind of damage within RCC which can't be found out using visual inspection. These radiations are highly dangerous so precautionary measures need to be taken while operating them[19].

4.3 Vibrating Wire and Electrical Strain Gauges

Conventional devices such as vibrating wire and electrical strain gauges have adequate strain measuring capability and have been successfully used in structural health monitoring because of their long term durability. These devices are embedded into concrete to measure stress variations within concrete. Due to corrosion of steel bars corrosion products gets deposited on bars because of which concrete begins to swell and cracks develop and as a result stresses are produced. Stresses can also be calculated when the modulus of elasticity, creep and thermal effects. Thus stresses identification will help in identifying the possible place of corrosion of steel and delamination in concrete.

4.4 Hough Transform

Hough proposed efficient method for detecting lines in an image based on this several algorithms have been developed to detect different shapes such as a line, circle etc.[20]. Hough transform is a circle detection technique which can automatically detect a corrosion pit in a microscopic image. In this technology all points in an input image is first converted into a parameter space which is represented by a 2D array having same size as of input image. Local extremes values in the array which represent corrosion pits are located using a maxima searching algorithm[21].

4.5 Optical Fiber Sensors

Nowadays, optical fiber sensors are very popular for assessing the health of the structure where strain measurement is not required. These sensors are based on intensity. These days these sensors have been used in structural health monitoring to detect corrosion, cracks, strain and displacement. In recent few years there has been numerous studies on application of optical fiber sensor in structure monitoring, these studies include many optical fibers such as fiber optic Bragg grating[22], fiber optic spectroscopy[23] and intensity based optical sensor. Recently plastic optical fiber is been used mostly for monitoring structures because of their low cost, easily usable and their high resistivity to fracture[24].

4.6 Embedded Corrosion Instrument

The Embedded Corrosion Instrument (ECI) is an electronic corrosion sensor which provides earlywarning of conditions that cause damage to steel reinforcement. ECI works by monitoring five key factors causing corrosion and transfer information over digital network about real time condition of the structure. By monitoring five key factors in corrosion, and bycommunicating these through a digital network, the ECI provides comprehensive, real-timeinformation on structural conditions. Five key factors of corrosion which are being monitored are –open circuit potential,linear polarization resistance, resistivity,chloride ion concentration and temperature. Thus it helps users to act before complete failure of the structure and save cost on huge repairs. ECI is a Non-Destructive Evaluation (NDE) device, it collects and delivers all datawithout requiring investigators to destroy samples, without visiting the site, and also without interrupting usage of structure. ECI transfers data over digital network so they are not interfered by radio waves, power lines and electromagnetic waves. Multiple ECI can be connected to a single data logger, thus saving huge amount of money in any structural monitoring project[25].The ECI are specially designed to monitor flood control channel, dams, erosion control structures, bridges etc.

5. Discussion and Future Recommendation

Development in the field of material science and engineering technology always impact the methods of reducing or preventing corrosion of reinforcement. In future there will be new corrosion resistant materials which will be developed and also efficient methods to control corrosion of reinforcement in structures might be developed and as long as metallic material is used in reinforced concrete structures corrosion can't be avoided only it can be reduced to negligible extent and thus increasing the durability of the structures. New materials developed in future will have new type of issues related to corrosion which need to be studied in detail and efficiency of new technology introduced for corrosion detection should also be compared with previous technology to find out the accuracy of corrosion detection.

First step towards finding a solution is to understand that why a problem is occurring and then next step is to solve the problem. Presently there are many issues related to corrosion of reinforcements in structures which still need to be solved by scientists. There is an urgent need to carry out the research in the following direction:

1) Basic mechanism of corrosion of steel need to be intensively studied. Basic process involved and reaction occurring during this process consequently leading to corrosion of steel should be understood and then only most effective methods could be developed to slow down the rate of reaction and thus preventing corrosion.
2) Environmental factors such as temperature[26], moisture[27] etc. affecting corrosion and their interaction with each other need to be intensively studied so that more accurately corrosion rate can be determined. Since these factors can't be completely avoided only they can be reduced to a certain extent such as by providing cover.
3) Simulation in laboratory and acceleration rate of corrosion of steel in reinforced concrete need to be researched. Improvements need to be made for acceleration tests and laboratory simulation.
4) Studies related to the transport of chlorides and carbonation process need to be intensively studied and even the relationship between developments of corrosion products which leads to cracking need to be deeply studied to know the progressive failure of concrete occurring due to corrosion of steel.
5) New methods for monitoring corrosion of steel based on computer simulation need to be developed which would consider effect of environmental factors into account besides basic factors such as temperature, moisture, chlorides and their interaction with one another.

6. Conclusion

Here few available corrosion detection techniques available have been reviewed to find out their advantages and disadvantages. With the developments of sensor and microprocessor controlling systems which can be integrated with the structure for monitoring of real time corrosion. Thus cost of monitoring has been considerably reduced. This real time monitoring of structures will help in condition monitoring of the structure and also help in predicting accurate life of the structure. Sensors located at interior and at surface of a structure are most effective in monitoring long term durability of concrete.

7. Acknowledgement

We are thankful to the Civil Engineering Department of Motilal Nehru National Institute of Technology, Allahabad for their constant support.

8. References

1. AndradeC, AlonsoC,SariaJ. Influence of relative humidity and temperature at on site corrosion rates. Proceedings of 4thcanmet/ACI International Conference on Durability of Concrete, Australia; 1984.
2. Pereira CJ, Hegedus LL. Diffusion and reaction of chloride ions in porus concrete. Proceedings of 8thInternational Symposium on Chemical Reaction Engineering, Great Britain; 1986.
3. BroomfieldJP.Uhlig'scorrosion handbook. Chapter 36. Second Edition. Revie RW,editor, Wiley;2000.
4. Norzila M, Ishak AS. Thermodynamic study of corrosion inhibition of mild steel in corrosive medium by piper nigrum extract. Indian Journal of Science and Technology. 2015 Aug; 8(17):1–7.DOI: 10.17485/ijst/2015/v8i17/63478.
5. BastidasE,Arteagaa,ChateauneufcA,Sanchez-SilvaaM, Bressolettec,SchoefsbF. Influence of weather and global warming in chloride ingress into concrete: a stochastic approach. Structural Safety. 2010 Jul; 32(4):238–49.
6. Hussain RR. Passive layer development and corrosion of steel in concrete at the nano-scale. Journal of Civil and Environmental Engineering. 2014 Apr; 4(3):116–20.
7. Venkatasubramaniana G,MideenaAS, Jha AK. Corrosion behavior of aluminium alloy Aa2219–T87 welded plates in sea water. Indian Journal of Science and Technology. 2012 Nov; 5(11):1–6.
8. IsmailA, AdanNH.Effect of oxygen concentration on corrosion rate of carbon steel in seawater. American Journal of Engineering Research. 2014; 3(1):64–7.
9. SeikhAH, Sherif E-SM. Effects of immersion time and temperature on the corrosion of API 5L grade X-65 steel in 1.0 M H_2SO_4pickling solution. International Journal of Electrochemical Science. 2014 Dec; 10(1):895–908.
10. Broomfield JP. Corrosion of steel in concrete: understanding, investigation and repair. E&FN SponPublication, London: Great Britain; 2011.
11. Federal Highway administration report to congress. FHWA publication company:Washington D. C.;2001.
12. Transportation research board. Highway de-icing comparing Salt and calcium magnesium. National Research Board Special Report 235: Washington D. C.; 1991.
13. Wallband EJ. The performance of concrete in bridges- A survey report of 200 highway bridges:HMSO London publication;2011.
14. Rosenberg A, Hausson CM,Andrade C. Materials science of concrete. Jpskanly(ed) Publication; 1997.p. 285–6.
15. Woodward R,Williams FW. Collapse of Yens-Y-Gwasbridge, West Glamorgan. Proceeding of the Institution of Civil Engineers; 1995. p.635–69.
16. Heidersbach R. Attorney's guide, to corrosion N salter (ed);2001.
17. YeihW,HuangR. Detection of the corrosion damage in reinforced concrete members by ultrasonic testing. Cement and Concrete Research Journal.1998Jul;28(7):1071–83.
18. Protection of reinforcement in concrete – An update, Galvanizing and other methods. Indian Lead Zinc Information Centre (ILZIC)Report, New Delhi; 1995.p. 36–7.
19. Boateng A, Danso KA, Dagadu CPK. Non-destructive evaluation of corrosion on insulated pipe using tangential radiographic technique. International Journal of Scientific andTechnology Research. 2013 Jun;2(6):7–13.
20. Song J,Lyu MR. A Houghtransform based line recognition method utilizing both parameter space and image space. The Journal of pattern Recognition Society. 2005 Apr; 38(4):539–52.
21. Wang Y, Cheng G. Application of gradient-based Hough transform to the detection of corrosion pits in optical images.Applied Surface Science. 2016 Mar; 366:9–18.
22. Smart Materials and Structures [Internet]. [Cited 2013 Dec]. Available from: http://ebooks.cambridge.org/chapter.jsf?bid=CBO9781139025164&cid=CBO9781139025164A007.
23. Cement and concrete Research [Internet]. [Cited 2008 Oct]. Available from: http://www.sciencedirect.com/science/journal/00088846/36/101985.
24. Measurement Science and Technology[Internet]. [Cited 2016May 10]. Available from:https://en.wikipedia.org/wiki/Measurement_Science_and_Technology.
25. Dunn RC, Ross RA, Davis GD. Corrosion monitoring of steel reinforced concrete structures using embedded instrumentation. Conference of NACE International; 2010Mar .

26. Al Zubaidy EAH, MohammadFS,Bassioni G. Effect of pH, salinity and temperature on aluminum cookware leaching during food preparation. International Journal of Electrochemical Science. 2011 Nov;6:6424–41.

27. Guma TN,AkuSY,Yawas DS,Dauda M. Effects of environmental and metallurgical factors on corrosion of steel- a review. International Journal of Innovative Research in Advanced Engineering. 2014 Nov; 1(11):94–105.