Corrosion Monitoring Of RCC Structure By Using Corrosion Expansion Sensor

Ms. Aparna Jagtap
Assistant Professor, Department of Civil Engineering, DGOIFOE,swamichincholi,Daund,Pune

Abstract—**Corrosion of embedded reinforcing steel and the complication of concrete structures is a worldwide problem. Damages due to corrosion reduces the service life of structures and can create serious problem. Visual inspections are not effective for knowing the initiation of corrosion because most of the damage remains observed until cracking and spalling of the concrete occur. Traditional techniques for determining the presence and rate of corrosion are expensive and difficult to find out. The sensors would be installed in new construction or in new portions of rehabilitated structures. The positioned of reinforcing steel adjacent before concrete placement. If corrosion is detected, an owner can take action against corrosion and pretend the service life of the structure. In this project, corrosion expansion sensors were used to monitoring the rate of corrosion in reinforced concrete beam with the help of strain calibration experiment, sensitivity measurement, corrosion mass loss rate and material composition with the help of Minitab software. It is not possible to take the long life result from traditional methods of monitoring the corrosion in structure but corrosion monitoring by using embedded sensors is improved the response latency. Experimental and analytical work used in this project gave the good comparative results for corrosion monitoring.**

Index Terms—**Reinforced concrete structure, reinforcement corrosion, corrosion sensor, sensitivity.**

I. Introduction

Corrosion is basically process in which metal like a steel when expose to water get oxidized and formation of rust is take place. due to corrosion there are important risks of failure and even of collapse that could have an impact on different aspects, such as humans, social, economic and environmental. The main structural damages are reduction of the reinforcement bar diameter, loss of bond between the steel bars and the concrete, steel breaking and concrete cracking. Corrosion monitoring in concrete is difficult because it contains many variables. The temperature and the concentration of dissolved species, such as chlorides, dramatically affect the type of corrosion and its rate. The controlling parameters generally fluctuate with time, requiring frequent, real-time measurements . A complete corrosion measurement system must be capable of making accurate measurements not only of electrochemical parameters related to the corrosion rate , but also of other important environmental parameters such as temperature, chloride ion concentration, concrete electrical resistivity and oxygen availability [1].

Reinforced concrete structures have the potential to be very durable and capable of withstanding a variety of adverse environmental conditions. However, failures in the structures do still occur as a result of premature reinforcement corrosion. The maintenance and repair of bridges and buildings for their safety requires effective inspection and monitoring techniques for assessing the reinforcement corrosion . Engineers need better techniques for assessing the condition of the structure when the maintenance or repair is required. These methods need to be able to identify any possible durability problems within structures before they become serious [2].

1.1 Mechanism of Corrosion-

Corrosion of reinforcement has been considered as serious problem in concrete construction worldwide. The most important causes of corrosion initiation of reinforcing steel are the effect of chloride ions and carbon dioxide to the steel surface. After initial stage of the corrosion process, the corrosion products are covered in the restricted space in the concrete around the steel. Their formation within this area sets up stresses, which crack and spall the concrete cover .

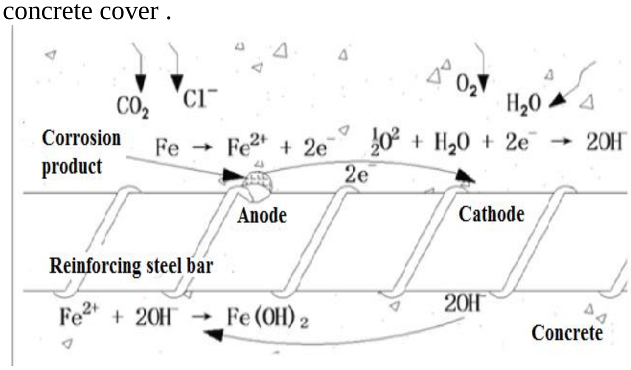

Figure 1.1 Schematic diagram of reinforcing steel corrosion in concrete as an electrochemical process [2].

The corrosion of ordinary steel is unavoidable. This is because, under atmospheric conditions, the iron in the steel is unstable . it is necessary to know the condition of steel and the effect of iron oxide . For iron at ordinary atmospheric conditions, the lowest energy state is an oxide, that is, a type of rust. The presence of atmospheric oxygen provides the important part to form the iron oxide. At ordinary temperatures, the transformation is very slow; but if water is present, the transformation proceeds repetitively, and the iron goes in the form of rust. Due to this transformation of iron to rust corrosion occurs at steel. There are two major factors that cause the passive oxide coating to break down: 1) The presence of chloride ions, 2) Carbonation.

1.2 Causes of corrosion in RCC structure-

There are some circumstances, in which the concrete cannot be expected to give the desired, almost indefinite, protection to steel reinforcement. These circumstances are,

(i) Due to the full thickness of concrete cover is not given to the reinforcement due to error in construction.

(ii)Due to the concrete contain chloride, present in high concentration in the materials from which concrete is made.

(iii) Due to the concrete exposed to sea water to deicing salt or to acid.

In these circumstances it is very desirable to know whether or not the steel may be corroding.

1.3 Effect of corrosion of reinforced concrete elements-

The loss of structural ability of reinforced concrete elements affected by steel corrosion is mainly due to following three main terms which are related to corrosion:

i) Loss of steel section because of corrosion.
ii) Loss of bond strength.
iii) Loss of concreting because of cover cracking and spalling.

1.4 Sensors-

Sensor is a device used to detect changes in environment and send the info to other electronics in terms of computer processing. Due to long term result, most of the structures using sensors for monitoring purpose and long term result. Sensors are divided on the basis of their functions in the field of temperature, humidity, sensitivity and their long term performance. Following are the different type of sensors widely used in structures as:

i) Temperature sensor
ii) Ultrasonic sensors
iii) Pressure sensor
iv) Piezoelectric sensor
v) Magnetostractive sensor
vi) Fiber optical sensor

a) Embeddable corrosion monitoring sensor-

A corrosion sensor is a device that shows a response which can be recorded upon corrosion of an object. Corrosion sensors are embedded in the object to be monitored or placed in the environment to be monitored . corrosion monitoring and handling of invisible objects provided by the sensors is an important advantage of a corrosion sensor. Low cost, sensitivity, and reproducibility are some important disadvantages of corrosion sensors. Considering these, researcher moved towards the production of corrosion sensors, which can be used as corrosion monitoring tools.

Corrosion sensors are used for many purpose , where corrosion is a serious issue for the strength or quality of objects, such as aircrafts, bridges and buildings made up of concrete. In the valuation of corrosion activities, visual inspection is a common step . Appearance of corrosion cracks parallel to the reinforcement are good signs of corroded rebar. Many nondestructive evaluation techniques have been developed to detect corrosion of reinforcement at an early stage. Polarization resistance measurements, half-cell potential and resistivity are practically found out even for on-site evaluations .

Other measurement techniques for corrosion monitoring are harmonic analysis, electrochemical frequency modulation and electrochemical noise measurement method. However, every methods have their limitations and sometimes suitable for laboratory usage. The use of fiber optic sensor for instance, yielded a good result for corrosion measurements, but the material itself is too brittle and difficult to work with silver chloride (AgCl) sensor and saturated calomel electrode sensor are considered unsuitable for site purposes.

1.4.1 Basic Principle of the Fiber Optical Brillouin Sensing Technique –

Fiber optics are utilized both as sensing elements and signal transmission media. The fiber optical Brillouin sensing technique is based on the Brillouin scattering phenomena. When a short light pulse is started into and transmitted along the fiber, the frequency of the Brillouin backscattering light can be measured at the same end. The time interval between sending the pulse and receiving of the backscattered light provides the information of the temperature or strain distributed along the fiber optic. The backscattered Brillouin frequency is shifted from the incident light frequency because of the temperature variation and strain variation along the optic fiber .The packaging structure of Brillouin corrosion expansion sensor is shown in below figure.

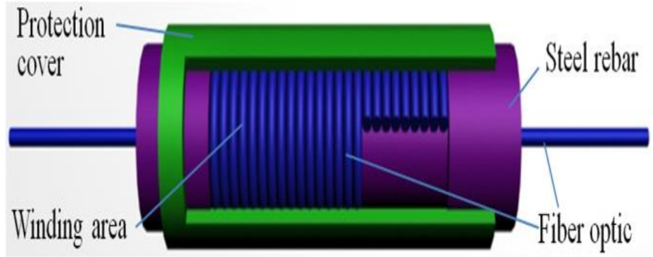

Figure 1.2 Basic packaging structure of the Brillouin corrosion expansion sensor [4].

The successful applications in different areas show that fiber optical Brillouin sensing technique offers a bright prospect owing to its distinct capability to monitor temperature and strain distribution along the sensing fiber optic.

A. Objectives-

In present project work, study is carried out to monitor corrosion of RCC structure by using corrosion expansion sensor. On the basis of work required in this project objectives are divided as following,

1) Using embedded corrosion sensors, fiber optic coil winding method is adopted for monitoring corrosion expansion in steel rebar.
2) To conduct strain calibration experiment to obtain strain coefficient for monitoring corrosion expansion strain.
3) To derive mass loss rate evaluation formula to evaluate the assessment result in sensors.
4) To establish corrosion sensing network.
5) By using experimental data, temperature compensation technique will be developed.

II. LITERATURE REVIEW

A. General

The literature review gives the idea about the previous research had been done related to corrosion monitoring for different types of material and non-destructive methods for the building with the help of non destructive method like embedded sensors method, corrosion sensors method, temperature sensors method. Review of those presented as given below.

Mohammad Ismail, et al**.** 1studied detection of corrosion in concrete by using embedded sensor. In this paper, to monitor corrosion potential and corrosion rate parameters of reinforcement capacitance based embedded sensor was developed . To evaluate corrosion activity in concrete samples for that capacitance-based sensor was developed.

Ha-Won Song, et al.2 presented all the electrochemical and nondestructive techniques from the point of view of corrosion assessment and their applications to bridges, buildings and other civil engineering structures. Causes occurs due the effect of corrosion on reinforced concrete structure.

Xuefeng Zhao, et al.3 this paper describes a method to monitor corrosion expansion of steel rebars in steel reinforced concrete structures as fiber optic coil winding method was proposed, discussed and tested. This technique was based on the fiber optical Brillouin sensing technique. Due to this for obtaining strain coefficient of single mode optical fiber,a strain calibration experiment was designed and conducted.

Xiaoyi Bao, et al.4 this paper presented the distributed fiber optical sensor system based on Brillouin scattering the structural strain measurement of the steel beam with. The experiments were conducted both in the lab and in outdoor conditions. When it was in outdoor environment, the temperature compensation must be taken into account for the sunlight radiation effects.

Tsuneo Horiguchi, et al.5this paper reviewed the developments of a temperature sensing technique and distributed strain that uses brillouinscattering in single mode optical fibers. This technique was based on strain temperature induced changes in the frequency changes in the sensors.

Nihal Abdelhamid Taha, et al. 6 studied an experimental investigation into the residual strength and mechanical properties of corroded reinforcing bare bars. this paper explained the impressed current technique which is commonly used for accelerating reinforcement corrosion. The corrosion rate calculated by using mass loss rate and by using penetration rate method.

ASTM G102. 7 this standard provided the calculation of corrosion rates and related information from electrochemical measurements.it gave the information about the calculation method for converting the corrosion current density values into mass loss rate or penetration rate.

Alireza Joshaghani, et al. 8 studied the optimizing pervious concrete pavement mixture designby using the Taguchi method. In this paper researcher studied the evaluation of mechanical properties of concrete. Taguchi design of experiments was used to optimize the performance of these characteristics.

Concluding Remark

This literature survey says that the corrosion monitoring of concrete structures by using embedded sensors system gives the long term and effective results compare to other methods. Other non destructive methods are not more effective as compared to embedded sensor system. Optimization of material properties of beam specimen gives the more effective results for knowing the which material combination give the good results compare to other combinations. To account for the variation of corrosiondue to the environment, it is important to develop a methodology for determining the representative value of the corrosion rate in one structure. Measurement of sensitivity of embedded sensor provides the effective result related to the service life of the beam specimen.

III. METHODOLOGY

Casting of beam specimen

↓

To embed corrosion sensor into beam specimen

↓

Accelerated corrosion experiment

↓

Measurement of sensitivity

↓

Strain calibration experiment

↓

Optimization of material properties by using Taguchi method

↓

To develop the temperature compensation technique

Figure 3.1 Flow chart

IV. EXPERIMENTAL WORK

Beam specimen were selected for study with the dimension 500 × 150 × 150 mm and concrete mix design was made with water cement ratio as per the norms of IS 10262:2009. Reinforcement is used of 8mm, 10 mm and 12 mm diameter embedded in concrete. While doing casting of beam it is necessary to place the sensors inside the specimen carefully. Three different kinds of sensor with different material configurations were inserted into the beam specimen. Total eighteen number of beam specimens were casted. After this beam placed into water tank for 28 days curing. After completing curing process accelerated corrosion experiment were performed for corrosion occurrence. For this experiment NaCl solution used for doing the effect of corrosion effectively on rebar. 12V voltage was passed continuously into that setup due to which the steel bar were corroded. Following figure shows the experimental setup of corrosion accelerated experiment.

Figure no.4.1- Experimental setup of accelerated corrosion Experiment.

After doing the accelerated corrosion experiment, it was necessary to find out the sensitivity status of beam specimens for that sensitivity measurement were performed with the help of digital oscilloscope. Following figure shows the experimental setup of sensitivity measurement.

Figure no.4.2- Sensitivity measurement

It was necessary to find out the strain of beam specimen, by using strain gauge instrument strain was measured and also the flexural strength of beam specimens were measured with the help of UTM machine. Following figure shows the setup of these experimental work.

Figure no. 4.3- Experimental setup for calculation of strain and flexural strength.

Diameter loss after corrosion was measured by breaking the beam specimen. With the help of that readings mass loss rate was calculated. With the help of all experimental data optimization of properties of all eighteen beam specimens were found out with the help of Minitab software.

V. RESULT AND DISCUSSION

Below table no.1 shows the mass loss rate of beam specimen. Following formula used for calculation of mass loss rate.

Mass loss rate-

1] $MR = k_2 i_{cor} EW$ (1)

Table no. 1- Calculation of mass loss rate

Table No. 2- Measurement of sensitivity

.

Strain calibration experiment and calculation of flexural strength-

Table No. 3- Measurement of strain and flexural strength.

Specimen	Strain	Deflection	Flexural strength
A_8	-0.0341	-1.3	3.2
A_{10}	-0.032	-0.98	2.26
A_{12}	- 0.03	-0.92	2.21
B_8	-0.0276	-1.05	3.08
B_{10}	-0.035	-1.1	2.23
B_{12}	-0.0249	-1.23	2.02
C_8	-0.035	-2.36	2.24
C_{10}	-0.035	-1.05	1.18
C_{12}	-0.06	-1.02	1.21
D_8	-0.03	-1.31	3.18
D_{10}	-0.039	-1.05	2.21
D_{12}	-0.034	-1.54	1.33
E_8	-0.032	-2.32	3.2
E_{10}	-0.034	-1.26	1.18
E_{12}	-0.034	-2.34	2.23
F_8	-0.042	-1.24	1.81
F_{10}	-0.045	-2.32	2.04
F_{12}	-0.032	-2.05	2.32

VI. CONCLUSION

It was observed that in most of cases of structure, principle of planning and designing was adopted. By using sensors into the structures it can be good for long term monitoring. Due sensors system lots of difficult work can be done effectively and easily. Sensors system gives more effective result than other non destructive tests. For proper corrosion monitoring of structure it is difficult to monitor embedded corrosion of steel rebar accurately, but due to sensor system this work automatically converted into efficient and effective monitoring system. Optimization of material by using Minitab software gave the best result for knowing the which sample will give long term corrosion effect. This project gave the good and efficient method to determining the corrosion into structure.

ACKNOWLEDGMENT

This paper would not have been written without the valuable advices and encouragement of Mr. C. B. Nayak, guide of ME dissertation work. Authors special thanks go to all the professors of civil engineering department of VPKBIET, Baramati, for their support and for giving an opportunity to work on corrosion monitoring of RCC structure by using corrosion expansion sensor

Specimen	Voltage applied [V]	Diameter of Before corrosion [mm]	Diameter of bar after corrosion [mm]	Mass loss rate [MR] [g/m^2d]
A_8	12	8	7.45	68.76
A_{10}	12	10	9.52	42.155
A_{12}	12	12	11.38	29.50
B_8	12	8	7.52	67.56
B_{10}	12	10	9.48	42.512
B_{12}	12	12	11.54	28.689
C_8	12	8	7.62	67.42
C_{10}	12	10	9.58	41.892
C_{12}	12	12	11.48	28.83
D_8	12	8	7.48	68.62
D_{10}	12	10	9.42	42.155
D_{12}	12	12	11.48	28.832
E_8	12	8	7.48	67.324
E_{10}	12	10	9.54	42.162
E_{12}	12	12	11.64	28.198
F_8	12	8	7.42	69.394
F_{10}	12	10	9.62	41.283
F_{12}	12	12	11.52	28.788

References

1) Mohammad Ismail, Siti Fatimah A. R and Bala Mohammad, "*Embedded sensor for detecting corrosion of reinforcement in concrete",* Advanced materials and research, Vols. 250-253, (2011), p 1118-1123.

2) H. W. Song and V. Saraswathy, "*Corrosion Monitoring of Reinforced Concrete Structures – A Review",* International Journal of Electrochemical Science, (2007), Vol. 2, p 1- 28.

3) X. Zhao, P. Gong, and J. Lu, "*Brillouin Corrosion Expansion Sensors for Steel Reinforced Concrete Structures Using a Fiber Optic Coil Winding Method*, Journal of Sensors", (2011), Vol. 11, p 10798-10819.

4) Xiaoyi Bao, A. Brown and T. Bremner, " *Strain measurement of the steel beam with the distributed Brillouin scattering sensor*", (2012)

5) Tsuneo Horuguchi and Toshio Kurashima, " *Development of a distributed sensing technique using Brillouin scattering",*(2010) Vol. 13, p 7

6) Nihal Abdelhamid Taha and Mohammad Morsy, " *Study of the behavior of corroded steel bar and convenient method of repairing"* (2015) , *HBRC* Journal.

7) ASTM G102, "*Standard practice for calculation of corrosion rates and related information from electrochemical measurements."*

8) Alireza Joshaghani, Ali Akbar and Omid Ataei, " *Optimizing previous concrete pavement mixture design by using Taguchi method",* Construction and building material, (2015), p 317-325.

9) C. A. Galindez-Jamioy and J. M. L´opez-Higuera, "*Brillouin Distributed Fiber Sensors: An Overview and Applications"*, Journal of Sensors, (2012), p 1-17.

10) H. A. Razak and F. C. Choi, "*The effect of corrosion on the natural frequency and modal damping of reinforced concrete beams",* Engineering Structures,(2001), Vol. 23, p 1126–1133.

11) H. N. Li, D. S. Li and G. B. Song, "*Recent applications of fiber optic sensors to health monitoring in civil engineering", E*ngineering Structures, (2004), Vol. 26, p 1647–1657.

12) I. Martínez and C. Andrade, "*Examples of reinforcement corrosion monitoring by embedded sensors in concrete structures"*, Cement & Concrete Composites, (2009), Vol. 31, p 545–554.

13) J. Rodri'guez, L. M. Ortega and J. Casal, "*Load carrying capacity of concrete structures with corroded reinforcement"*, Construction building Material, (1997) , Vol. 2(4), p 239-248.

Specimen	Voltage [V]	Frequency [Hz]	Sensitivity status
A_8	12	49.853	low
A_{10}	12	51.783	Medium
A_{12}	12	53.653	High
B_8	12	49.789	Low
B_{10}	12	51.580	Medium
B_{12}	12	52.789	Medium
C_8	12	48.823	Low
C_{10}	12	50.845	Medium
C_{12}	12	51.758	Medium
D_8	12	48.753	Low
D_{10}	12	51.782	Medium
D_{12}	12	52.871	High
E_8	12	48.823	Low
E_{10}	12	51.824	Medium
E_{12}	12	52.751	High
F_8	12	49.728	Low
F_{10}	12	51.782	Medium
F_{12}	12	52.821	High