NON-DESTRUCTIVE TECHNIQUES FOR CORROSION MONITORING IN RC STRUCTURAL MEMBERS

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Abstract: One of the major reasons behind the failure of Reinforced Concrete (RC) structures is the corrosion of structural rebars. As a result of the premature corrosion of reinforcement, the service life of the structures reduces and thus arise the need of indispensable repairs or replacement due to which huge governmental budget is spent annually. On the other hand, effective and early detection of the corrosion process helps to limit the extent of necessary repairs or replacement leading to a reduction in the cost associated with rehabilitation work. Thus, efficient monitoring techniques are required for assessment of the corrosion level in these structures so that the necessary maintenance and repair is carried out. It is therefore required to identify any possible durability problems within structures before they become serious. For the same, Non-destructive techniques (NDT) are found to be instrumental for in-situ evaluation of corrosion in structural rebars. This paper presents an overview of various non-destructive techniques for monitoring corrosion level in the reinforced concrete structures.

Keywords: reinforced concrete, non-destructive techniques, monitoring, corrosion.

1. INTRODUCTION
Corrosion of metallic reinforcing bars embedded in concrete has been identified as being one of the most predominant factors responsible for the strength degradation exhibited by the RC structures. The serviceability and the durability of the concrete structures is seriously impaired by the corrosion of reinforcing bars; damage to the concrete due to reinforcement corrosion manifests in the form of expansion, followed by cracking and eventually the spalling of the cover concrete. Therefore, control and monitoring of reinforcement corrosion assume a significant practical importance to prevent the premature failure of RC structural members. The present paper attempts to briefly present the pro and cons of different methods and techniques developed so far that helps engineers to assess the loss caused by the corrosion and consequential strength lose that a structural member would undergoes.

2. NON-DESTRUCTIVE TECHNIQUES (NDT) FOR CORROSION MONITORING
In recent years, various methods have been implemented for corrosion monitoring in the RC structures. For measurement of both qualitative and quantitative measurements of corrosion level, many electrochemical and non-destructive techniques are employed depending upon the requirement and the suitability. Monitoring of rebar corrosion in existing structures can be assessed by different methods like Open circuit potential (OPC), Surface potential (SP), concrete resistivity measurement, Linear polarization resistance (LPR) measurement, Tafel extrapolation, Galvanostatic pulse transient method, Electrochemical impedance spectroscopy (EIS), Harmonic analysis, Noise Analysis, Embeddable corrosion monitoring sensor, Cover thickness measurements, Ultrasonic pulse velocity technique, X-ray, Gamma radiography measurement, Infrared thermograph and by
visual inspection. The technique to be used may vary depending upon feasibility and requirement. From the recent practices in the past, a brief comparison between various techniques has been made.

2.1. Open circuit potential (OCP) measurements

The tendency of any metal to react with an environment is indicated by the potential it develops in contact with the environment. In reinforced concrete structures, concrete acts as an electrolyte and the reinforcement will develop a potential depending on the concrete environment, which may vary from place to place [1]. In this technique, electric potential value (in mV or V) is measured between steel reinforcement of RC and reference electrode by means of potential electrode, voltmeter, and connecting wire. It indicates the corrosion potential of steel inside RC. Thus, the result obtained is a single value that gives an indication of the steel condition rather than equipotential contours [4]. But, as compared to other NDT for assessment of corrosion in rebars, this technique is time consuming [2].

2.2. Surface potential (SP) measurements

During corrosion process, an electric current flow between the cathodic and anodic sites through the concrete and this flow can be detected by measurement of potential drop in the concrete [1]. Hence, surface potential measurement is used as a non-destructive testing for identifying anodic and cathodic regions in concrete structure and indirectly detecting the probability of corrosion of rebar in concrete. This is another useful non-destructive technique to know the condition of steel rebar embedded inside the concrete [12].

2.3. Concrete resistivity measurement

The resistivity method is another electrochemical method, which relies upon the principle that corrosion is an electrochemical process. An ionic current must pass between the anode and cathode areas for corrosion monitoring of RC structures [13]. The resistivity is an indirect indication of active corrosion of the steel reinforcement. The corrosion process will be slower if the resistivity of the concrete is high. The resistivity of concrete exposed to chloride indicates the risk of early corrosion damage, because low resistivity is always associated with rapid chloride penetration [14]. In this technique, the resistivity (ρ) of reinforced concrete, which the current can easily pass between anode and cathode areas of the concrete is measured (in ohm-metre) by an equipment consisting of current and potential electrodes, voltmeter or resistivity unit, and insulated wire. This technique for assessment of corrosion level is easy, fast, portable and inexpensive and thus, can be used for routine inspection [2]. But the reinforcement in the test region can provide a “short-circuit” path and cause erroneous reduction in the measurement [2].

2.4. Linear polarization resistance (LPR) measurement

The LPR technique has become a well-established method of determining the instantaneous corrosion rate measurement of reinforcing steel in concrete [15-18]. In this technique, the change in potential during reactions (polarization) is recorded using an electrode plate on the concrete surface. The equipment essentially consists of a reference electrode, counter electrode, voltmeter, ammeter, and connecting wires. The corrosion is evaluated in terms of corrosion current (A/cm²). In comparison to other techniques, this method requires short time for measurement and applies small perturbations that do not interfere with the existing electrochemical processes [2]. But in order to get full response, it takes time because of the electrical capacitance across the steel and concrete interface [5].

2.5. Tafel extrapolation

The Tafel extrapolation technique (TP) is another electrochemical method for calculating corrosion rate based on the intensity of the corrosion current (Icorr) and the Tafel slopes. Tafel slopes also could be used to calculate corrosion rate with LPR [19].

2.6. Galvanostatic pulse transient method

In this technique, the anodic current pulse is applied galvanostatically on the steel reinforcement from counter electrode paced on the concrete surface by a means of reference electrode, counter electrode, guard ring, and connecting wire [2]. Thus, corrosion is assessed in terms of potential resistance (kΩ.cm²). As compared to other techniques, it is a rapid device for
determining the corrosion rate of steel reinforcement in reinforced concrete. Moreover, it enables the display of corrosion rate, electrical resistance and potential value simultaneously. But, erroneous reading may be obtained due to cracks and delamination or due to unstable reading because of parallel or crossing of the rebars [2].

2.7. Electrochemical impedance spectroscopy (EIS).

In recent years, A.C. Impedance spectroscopy is being experimented as a useful non-destructive technique for quantifying corrosion of steel rebars embedded in concrete. Impedance Z is the ratio of A.C. voltage to A.C. current. An alternating voltage of about 10 to 20 mV is applied to the rebar and the resultant current and phase angle are measured for various frequencies [1].

2.8. Harmonic analysis

The harmonic analysis method is an extension of the impedance method. It is a relatively new technique, which is quicker to carry out and leads to results that are more straightforward than those of the electrochemical impedance method [1].

2.9. Electrochemical Noise Analysis

Electrochemical noise technique is an emerging technique for monitoring corrosion of reinforced concrete structures [20]. This technique enables information on the mechanism and rate of corrosion processes at areas identified in concrete structures. A low amplitude variation of the corrosion potential of steel in concrete is measured to obtain a noise data as a record of potential fluctuations in the form of power spectra [1].

2.10. Embeddable corrosion monitoring sensor

The Embedded Corrosion Instrument (ECI) is an electronic corrosion sensor that provides early warning of conditions that damage steel reinforcement, leading to cracking, spalling, and other deterioration of concrete structures [1]. By monitoring five key factors in corrosion, and by communicating these through a digital network, the ECI provides comprehensive, real-time information on structural conditions. This helps facilities managers to avert crises, save money on maintenance, and build a detailed record on each structure. The ECI is designed to monitor bridges, buildings, dams, erosion control structures, flood control channels, parking garages, piers, pylons, roadways, and spillways [1].

2.11. Cover thickness measurements

A covermeter or profometer is used for measuring concrete cover. By means of this it is able to detect rebar size, direction and position. Measurements are based on the damping of a parallel resonant circuit. An alternating current with a given frequency flows through the probe coil, thus creating an alternating magnetic field. Metal objects within the range of this field alter coil voltage as a function of cover and bar diameter. It comprises of a probe and an indicator unit. The electronic system, controls, indicator instruments are assembled on the indicator joint front panel. Eleven different bar diameter may be set in a rotary selector switch with a range from 8 to 34 mm. By means of this, the maximum cover thickness that can be measured is 120 mm. A loud audio signal and bright light on the detection head gives a clear warning of areas of low concrete cover (user programmable for depth of cover) [1].

2.12. Ultrasonic pulse velocity (UPV) technique

Elastic wave method is used to complete the assessment of the structural rebars. Since waves are reactive to damage such as cracks, voids, and also corrosion products, Wave- based damage detection excites transient waves to propagate into the concrete structure using sensors [6]. Ultrasonic Pulse Velocity (UPV) technique is one of the commonly used non-destructive elastic wave method. It involves measuring the speed of sound through concrete in order to detect the condition of the concrete and presence of steel corrosion [7, 8] in oxide and chloride environments [8-10].

In this technique, the equipment essentially consists of a transducer (transmitter and receiver), amplifier and oscillator. In this method, mechanical energy propagates through the concrete as stress waves. It is then converted into electrical energy by a second transducer [2]. It is advantageous over other methods as it has a large
penetration depth. Moreover, it is easy to use for estimating the size, shape and nature of the concrete damage.

2.13. X-ray, Gamma radiography measurement

Radiography technique is one of the non-destructive methods of testing concrete for obtaining information about concrete quality, defects within the reinforced concrete structures [2]. Use of radioactive isotopes for concrete testing has been employed in radiography studies. Radiography technique is reported to be a reliable method of locating internal cracks, voids and variation in density of concrete [1].

2.14. Infrared thermography (IRT)

In this technique, IR radiation emitted by a concrete material is converted into an electrical signal and is processed to create maps of the surface temperature by a means of multi spectrum camera [2]. Thus, the corrosion is evaluated in terms of radiation power (E). The results obtained from this technique are easy to interpret. Moreover, as compared to other techniques, its set-up is east and rapid, portable, and is a cost-effective technique [3]. But, in this method, there is no quantitative measurement (like size or depth) of corrosion damage [2].

2.15. Visual inspection

Visual inspection is a regular inspection method to assess corrosion damage on the surface of concrete structures. The appearance of the corroded area often provides valuable insight into the cause and the extent of corrosion. However, the method is very dependent on the inspector’s experience [2]. In addition, visual inspection is limited in its effectiveness to detect surface discontinuities due to steel corrosion and the unseen corrosion is difficult to spot [4, 11].

3. CONCLUSIONS

A number of non-destructive techniques for the corrosion monitoring of steel reinforcement have been reviewed in this paper. Each technique was reviewed in relation to principles, applications and limitations. The following conclusions have been made from the review of corrosion monitoring techniques:

1. Several electrochemical techniques (like OPC monitoring, resistivity method, polarization resistance, GPM, EN) for non-destructive rebar corrosion measurement are reviewed. It has been seen that each technique possess certain advantages and limitations. Thus, it has been recommended that a combination of measuring techniques should be suitably adopted to obtain maximum information for the effective assessment of corrosion of rebars. Though, precise quantitative measurements or the rate of corrosion cannot be assessed by these techniques, but significant benefits can be derived from even the qualitative data obtained from these electrochemical corrosion measurement techniques.

2. The development of corrosion monitoring systems for existing and new RC structures has been encouraged by the development of durable, embeddable sensors and inexpensive microprocessors. These integrated systems provide a more rational approach to the assessment of corrosion in RC structures by providing quantitative data and concrete condition and thus proves to be more efficient.

3. More information of the present and the future performance of the structure can be obtained by continuously monitoring the concrete cover and steel in real time.

4. For effective and planned maintenance, service life prediction and to prevent premature repair requirements, the quantitative data obtained from these non-destructive corrosion monitoring techniques play a vital role.

5. The effectiveness of repairs and the future repair cycle can be assessed by using the sensors on structures exhibiting corrosion.

REFERENCES


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