A Review of Research on Nondestructive Testing Methods for Steel Corrosion

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Abstract: In the construction of water conservancy, hydropower, water transportation and other projects, reinforced concrete is the main building material. At the same time, steel corrosion is also a very common phenomenon. The volume expansion of steel corrosion products will cause volume stress inside the concrete, which will cause cracks to peel off, which will reduce structural stress and durability, and seriously affect the safety performance of the structure. Therefore, the problem of rusting of reinforced concrete is an urgent problem to be solved. By analyze the causes of corrosion of steel bars, introduce the physical methods and chemical methods of steel corrosion detection, and provide basic detection principles and detection methods for non-destructive testing of steel corrosion.

Keywords: steel bar; corrosion; concrete; non-destructive testing

1. Introduction

Reinforced concrete is the most widely used civil material at present. In recent years, the durability of reinforced concrete has attracted the world's attention. Among them, the corrosion of reinforcement has the greatest impact on the durability of concrete, and it is also the most important and direct factor that causes the decline of the durability of concrete. In general, steel bars are very corrosion resistant. As in the high alkaline concrete, a passivation film will be formed on the surface of the reinforcement, which can effectively prevent the corrosion of the steel bar [1]. However, the corrosion of reinforced concrete is still common, and the corrosion of reinforced concrete is a complex process, and scholars' research on the corrosion detection and monitoring methods of reinforced concrete has never stopped. Nondestructive testing is the main research direction of reinforced concrete structure testing. In the construction of water conservancy, hydropower, water transportation and other projects, reinforced concrete is the main building material. Corrosion of steel bars is a very common phenomenon. The volume expansion of corrosion products of steel bars will lead to volume stress in the concrete, resulting in cracks, peeling off, reducing the mechanical performance and durability of the structure, and seriously affecting the safety performance of the structure. Therefore, the corrosion of reinforced concrete is an urgent problem to be solved [2].

At present, the phenomenon of steel bar corrosion is very common in the construction of high-speed railway, large-scale bridge across the river and sea and seaport wharf. Experts in the field of concrete science and engineering and government departments have carried out in-depth research on it.

In 1990s, SHRP project was launched in the United States, in which the effect of steel bar corrosion on the durability and service life of concrete structure was studied. From the end of last century to the beginning of this century, duracrete project and cost project in Europe systematically studied the influence of steel bar corrosion on concrete structures. At present, DFG project in Germany and RILEM project in France have carried out comprehensive experimental research and theoretical analysis on the problem of steel corrosion. Many other research institutions have set up independent topics to study the corrosion of steel bars in concrete. The detection of corrosion of steel bars has become an important topic of non-destructive testing and durability research in structural engineering. It has important practical significance and rich academic value to carry out this research [3].

2. The Reason of Steel Bar Corrosion

The phenomenon of steel bar corrosion is a common engineering phenomenon. Why does it happen? First of all, due to the poor quality of concrete or the insufficient thickness of the concrete cover, the concrete cover is carbonized to the surface of the steel bar by carbon dioxide, which reduces the alkalinity around the steel bar, resulting in the corrosion of the steel bar. Or due to the chloride intervention, the chloride ion around the steel bar is high, which can cause the destruction of oxide film around the steel bar.

The corrosion of steel bars caused by chloride ions is generally uneven, that is large cathode and small anode, resulting in common pitting and pit corrosion [4]. At present, there are some differences in the expression of the critical chloride ion concentration used to judge the depassivation of steel bars caused by chloride ions, mainly including the free chloride ion content as an important percentage of water cementitious materials or concrete, the critical chloride ion concentration and the ratio of the free chloride ion concentration to the concentration of hydrogen peroxide.

According to the reason of steel bar corrosion, the detection methods of steel bar corrosion in concrete structure are mainly divided into two categories, one is physical method, the other is electrochemical method. They have their own advantages and disadvantages, which will be discussed later.

3. Physical Detection Method of Steel Corrosion

The physical method reflects the corrosion of steel bars by measuring the changes of physical properties such as resistance, electromagnetic, thermal conductivity and acoustic wave caused by steel bars. At present, the main measurement methods include resistance probe method, eddy current detection method, ray method, infrared thermal image method, magnetic field measurement method, etc. The advantages of physical methods are simple operation and little environmental impact. But its disadvantage is that it can only be used for qualitative analysis, and it is difficult to carry out quantitative analysis. At present, the physical method is basically in the experimental stage.

3.1. Resistance Probe Method

In this method, the resistance probe made of the same material of steel bar is used to complete the corrosion detection. Firstly, the probe is embedded in the concrete, and the resistance measurement is completed by using the principle of electric bridge, as shown in Figure 1, so as to detect the corrosion of steel bars in reinforced concrete. To some extent, resistance probe method will be interfered by steel bars and other uncertain factors, its accuracy cannot be guaranteed, but its advantages are low detection cost, so it can be applied to detect different types of steel corrosion [5].

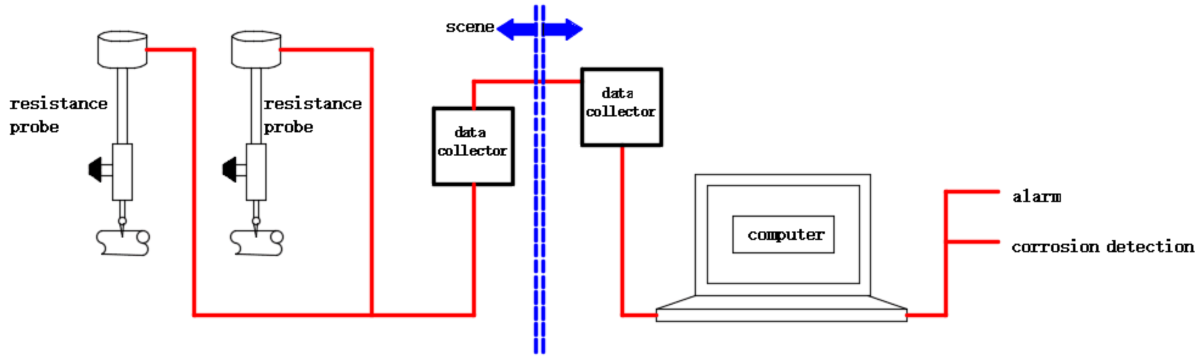

Figure 1. Resistance probe corrosion monitoring system diagram.

The calculation formula of corrosion rate is shown in Equation [6],

$$V = \frac{8760 \times (H_2 - H_1)}{T_2 - T_1}. \quad (1)$$

Where: T_1 and T_2 are the time between two measurements. H_1 and H_2 are distance between two measurements.

3.2. Eddy Current Testing Method

Eddy current detection method is based on the principle of electromagnetic induction. When the detection coil with alternating current is close to the conductive steel bar, eddy current occurs in the steel bar due to the coil magnetic field. The size and phase of the eddy current are affected by the conductivity of the steel bars material, and the reaction magnetic field produced by the eddy current makes the impedance of the detection coil change, so it can judge whether the reinforcement is corroded.

Eddy current testing does not need close contact between the testing coil and the tested material, does not need coupling agent, does not need to fill between the testing coil and the workpiece, the workflow is more simple and easy to realize automation. However, this method is only suitable for conducting materials which can produce eddy current, and has certain limitations.

4. The Reason of Steel Bar Corrosion

Electrochemical method is the main method to reflect the corrosion degree of steel bar, and it is also a non-destructive testing method. It has the advantages of fast detection speed, high sensitivity, continuous tracking and field measurement. By measuring the corrosion state and instantaneous corrosion rate of steel bars, the service life of steel bars can be predicted [7]. At present, electrochemical methods mainly include half-cell potential method, AC impedance method, linear polarization method, concrete resistance method, electrochemical noise method, constant electricity method, etc. Electrochemical method has been paid more and more attention because of its simple equipment and high measurement accuracy, which is suitable for on-site detection. Electrochemical method has become the main development direction of nondestructive testing of steel bar corrosion.

4.1. Figures and Tables

Electrochemical Impedance Spectoscopy (EIS) is a common measurement method in the laboratory. It is a method to study the electrochemical characteristics of the object by measuring the impedance flood in the frequency domain. If a proper model is established, this method can be used to study the micro electrochemical characteristics of materials and processes, as shown in Figure 2, so it has been widely used in the research of steel corrosion measurement [8].

During the corrosion of steel bars, anodes and cathodes are formed at different potential sections on the surface of steel bars, and the surface of steel bars at the anode part is in an activated state, releasing electrons. There is enough water and oxygen on the surface of steel bars at the cathode, and the following reactions are carried out.

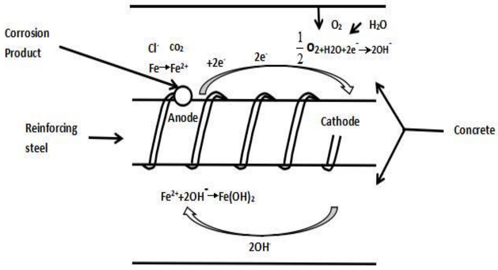

Figure 2. Corrosion process diagram.

Reaction at anode:

$$\mathrm{Fe} \rightarrow Fe^{2+} + 2e$$

Reaction at cathode:

$$H_2O + \frac{1}{2}O_2 + 2e \rightarrow 2\ (\mathrm{OH})^{-}$$

The iron ion formed by the reaction of cathode and anode combines with the hydrogen ion to form ferrous hydroxide:

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

Iron hydroxide can be produced by the interaction of ferrous hydroxide and oxygen in water.

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

In short, impedance spectroscopy is to measure the response voltage. On the contrary, applying voltage and measuring reaction current can get material impedance spectrum, and then calculate corrosion parameters by impedance spectrum. For this system, the functional relationship between voltage V, current I and resistance Z is shown in formula (2).

$$V(t) = z(t) \times I(t) \quad (1)$$

Where, t represents time, $V(t)$ and $I(t)$ are time-varying voltage and current respectively, and $Z(T)$ is reaction impedance.

Two methods to represent the impedance spectrum are derived, they are Nyquist graph method (Figure 3) and Bode method (Figure 4).

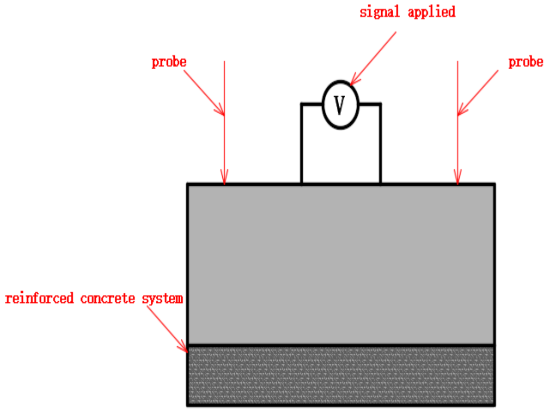

Figure 3. Simple structure diagram for measuring corrosion of steel bars by AC impedance method.

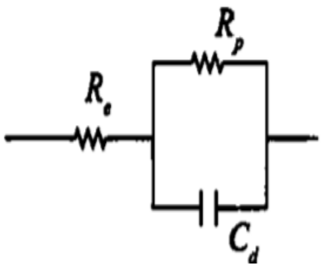

Figure 4. Simple structure diagram for measuring corrosion of steel bars by AC impedance method [9].

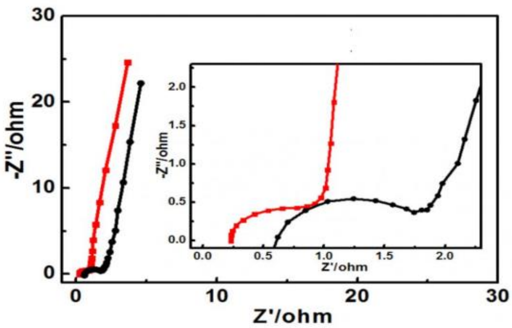

Figure 5. AC impedance measurement results view.

The above view can be obtained according to the AC impedance method experiment as shown in Figure 5, and then the final conclusion can be obtained through the analysis view to judge the corrosion of steel bars.

4.2. Half-Cell Potential Method

Half-cell potential method is the simplest and most commonly used method to detect the corrosion state of steel bars. It has been widely used in experiments and practical projects. Its practical measurement method is to connect a wire with a voltmeter, and then connect the other end of the voltmeter with the saturated calomel electrode to form a circuit as shown in Figure 6. The indication of the voltmeter is the potential of the measured steel bar. The surveyors can find out the positive and negative areas of the steel bars and determine the corrosion parts of the steel bars in the structure by collecting a large number of data. Its greatest advantage is that it can measure the potential value of different points, draw the equipotential map, so as to judge the cathode and anode areas of the structure, the corrosion and non-corrosion areas of the structure, and the approximate corrosion degree. More importantly, the type of corrosion can also be determined. The disadvantage of this method is that it cannot quantitatively reflect the corrosion rate of steel bars, but the test process of this method is relatively simple, the development is relatively mature, and it has broad application prospects [10].

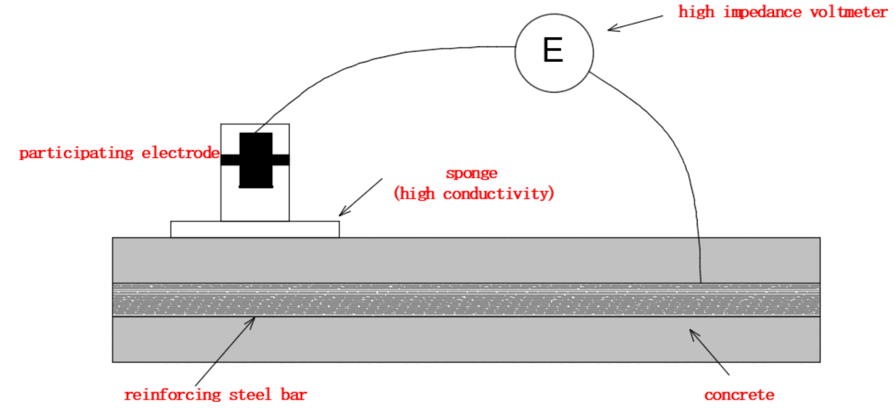

Figure 6. Schematic diagram of half-cell potential detection [11].

4.3. Electrochemical Noise Method

Electrochemical noise (EN) mainly refers to the fluctuation of electrode potential and current in electrode / electrolyte system. For corrosion system, it refers to the spontaneous fluctuation of electrode potential and current flowing through the electrode of corrosion metal electrode in electrolyte solution [12], as shown in Figure 7. Electrochemical noise method is an electrochemical method based on stochastic process theory and statistical method. It is used to study the spontaneous change of corrosion current. The main advantage of this method is that the measurement is not affected by the size of the element, and it can also be monitored remotely. But its disadvantages are slow measurement speed, complex data analysis and no potential drift caused by corrosive noise in the external environment. At present, it is rarely used in the laboratory and engineering field, so it is difficult to accurately measure the corrosion rate of steel bars at the current technical level [13].

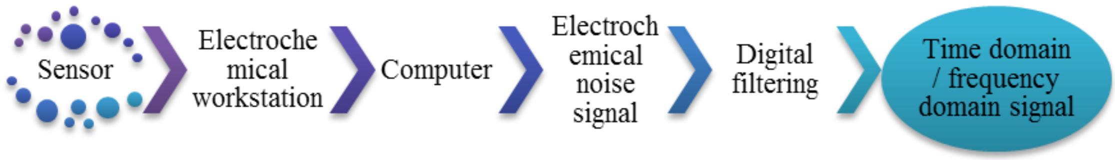

Figure 7. Electrochemical noise method system design.

5. Conclusions

This paper describes the great harm brought by steel corrosion, and also introduces a series of nondestructive testing methods for steel corrosion. The existing schemes are indeed various, with rich theoretical foundation, but there are still some problems in actual operation. Many methods stay in the theoretical or laboratory testing stage, which is difficult to realize in the actual large-scale engineering application. Half-cell potential method is still a common method in teaching experiment and practical engineering, but it has some shortcomings, including the results obtained in the experiment are not very satisfactory, it is difficult to successfully measure the accurate experimental data of steel bar corrosion. In my opinion, on the basis of complete theoretical support for various test methods, what is lacking now is better experimental equipment and more standardized experimental operation. Under the condition of funds and other conditions, it is necessary to increase the investment in experimental equipment for scientific research in this area, hoping to produce more excellent nondestructive testing methods in physics and electrochemistry in the near future.

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