Study on the Corrosion Determination Method of Steel Bar Embedded in Concrete Structure Exposed to Total Corrosion Zones in Marine Environments

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Abstract. Chloride ions in marine environment can significantly accelerate the corrosion of steel bars in concrete structures, which threaten the safety and durability of engineering structures. This paper presents a method for the corrosion determination of steel bar in concrete structures in marine corrosion zones. Based on the simulation chamber which can reproduce the actual corrosion environment in atmosphere, wave, tide, immersion and buried zones, the volume loss rate of the corroded steel bar in the total corrosion area is quantitatively analyzed with the three-dimensional scanning technology, and the rule of the vertical corrosion rate of the concrete structure in the total corrosion zones is obtained. The test results show that the method can accurately simulate the corrosion characteristics of steel bars in the complex environment of the total corrosion zone. The test method also provides a scientific basis for the life evaluation and durability design of reinforced concrete structures.

Keywords: Concrete; Steel Bar; Determination Method; Corrosion Zone; Marine Environments

1 Introduction

Concrete structures in marine environment are exposed to high chlorine salt, alternating dry and wet and multi-factor coupled corrosion environment for a long time, resulting in accelerated corrosion of steel bars, structural cracking and performance degradation [1,2]. There are significant differences in vertical corrosion in marine corrosion zones (including atmospheric, wave, tidal, immersion and buried zones). Existing steel corrosion determination methods are mainly carried out for a specific corrosion zone [3,4], and traditional single environmental simulation methods are difficult to accurately evaluate the corrosion rule under actual service conditions. There are few researches on the chamber and rules for simulating the total corrosion zone of the ocean.

In addition, in order to obtain the rule of steel bar corrosion under the influence of the ocean corrosion zones, it is not possible to cut and weigh the steel bar vertically before concrete pouring, then connect the steel bar, and then cut and weigh the steel bar respectively after it is buried in the concrete pouring corrosion. The corrosion change

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of the steel bar in this section can be obtained by the weight difference of the steel bar before and after the concrete pouring corrosion. Although some scholars have tried to adopt this method, it has changed the basic corrosion principle of steel bar after all, and there is a big difference with the actual environment [5-7].

In this paper, a high-precision quantifiable determination method of corrosion rate using 3D laser scanning is proposed to solve the shortcomings of single chlorine salt simulation and determination methods in existing standards. The method can also provide technical support for durability optimization of marine engineering structures [8,9].

2 Review of Corrosion Determination Methods of Steel Bar

The corrosion determination methods of steel bar are usually divided into non-destructive testing methods and damage detection methods [10,11].

Non-destructive determination technology includes physical detection and electrochemical detection, such as half cell potential method, natural potential method, resistance rod method, ray method and acoustic emission detection method and so on. These methods can only be qualitative determination of corrosion rate for steel bar at home and abroad.

The damage determination of reinforced concrete is carried out by physical method. In the laboratory, this method is generally used for determination. The determination of dimensions is consistent with the determination of weight, and 3 points were taken to take the average value. The corrosion performance of steel bar was evaluated by determining the weight loss rate of each rebar and the ratio of weight loss rate of test rebar to that of comparison rebar. The advantage of the damage detection method is that it can directly observe, measure and calculate the corrosion of steel bar, so the result of damage determination is very accurate. At the same time, there are also many problems in damage detection. For example, the area of exposed steel bars will affect the results of corrosion determination, and certain damage may be caused to the structure during determination. Moreover, the applicable engineering scope of this method is small, and it cannot be adopted in many cases. The damage determination technology has great limitations and limited application scope in some cases where the structure should not be broken, so this method is rarely used in practical engineering.

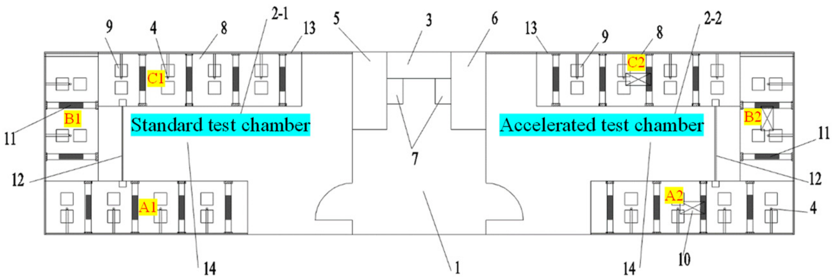
However, no matter the non-destructive determination or damage determination method is used, it is aimed at the influence of a single corrosion environment in the ocean, and it is difficult to reflect the corrosion characteristics under the multi-dimensional transmission of the corrosion zones. It is urgent to develop an efficient and accurate determination method to describe the corrosion of steel bars under the corrosion zones in the marine environment.

3 Determination Method for Corrosion of Steel Bar in Total Corrosion Zones

3.1 Simulation Marine Environment Chamber Design

A simulated marine environment chamber (Figure 1) is made, which can simulate the total corrosion zones in marine environment. In this chamber, different concentrations of salt can be sprayed by ultrasonic nebulizer to simulate the atmospheric environment. PVC pipe and pump are used to realize wave impact to simulate the environment of wave zone. The water pump is used to realize the periodic rise and fall of the liquid level to simulate the tidal environment. The specimen is completely immersed in the solution to simulate the immersion zone. The plane layout of the environment chamber is shown in Figure 2.

Fig. 1. Simulated marine environment chamber.



1 -- Environmental parameter control room; 2-1 -- Standard test chamber; 2-2 -- Accelerated test chamber; 3 -- Electric control box; 4 -- Ultrasonic atomizer; 5 -- Temperature and humidity control box; 6 -- Ambient temperature regulator; 7 -- Blower; 8 -- Test tank; 9 -- Specimen; 10 -- Hernia lamp; 11 -- Wave maker; 12 -- Tidal simulator; 13 -- PVC pipe; 14 -- Channel.

Fig. 2. Plane layout of the environment chamber.

Using this simulated marine environment chamber, we can perform the following multi-scenario and multi-parameter analysis:

1) By comparing the samples in area B1 with those in area B2, we can study the influence of immersion with high chloride ion concentration and salt spray on chloride ion transport efficiency in an environment without tidal action;

2) Area A1 and area C1 are connected, forming a tidal circulation system, with a dry and wet cycle of 12h, 6h wet and 6h dry. The chloride ion concentration was at the normal level of 3%;

3) Area A2 and area C2 are connected to form an accelerated tidal circulation system, with a dry and wet cycle of 8h, wet 4h and dry 4h. The chloride ion concentration is high concentration level of 10%;

4) The area A1C1 is compared with area A2C2, and the influence of standard environment and accelerated environment on the transport efficiency of chloride ions in concrete is studied.

3.2 Specimen Preparation

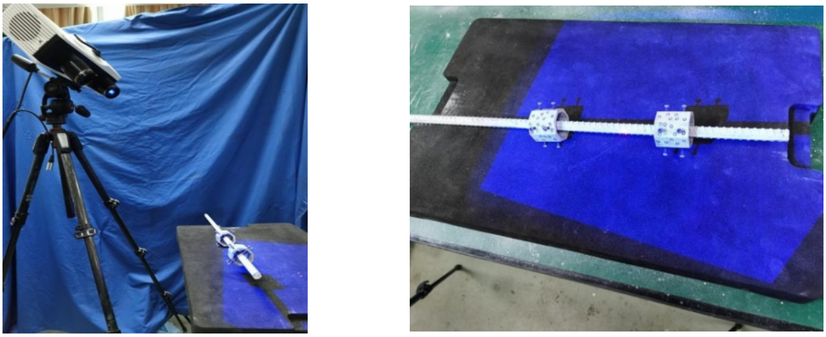
The concrete specimens were made. The strength grade was C30 and the size was 150 mm×150 mm×1000 mm. Six steel bars with a diameter of 16 mm were built in, and the thickness of the protective layer was 15 mm (Figure 3a). After the concrete specimens are poured and cured, the prepared specimens are placed in the determination chamber (Figure 3b).

(a) (b)

Fig. 3. Concrete specimens.

3.3 Test and Result

Before concrete pouring, 3D scanning equipment is used to scan the whole area of the steel bar to preserve the original 3D condition. After corrosion of steel bar, the specimens are taken out from the environment chamber according to a certain period. The concrete is destroyed, the corroded steel bars are taken out from the concrete specimen. Then a three-dimensional scan is carried out to obtain the section area of each section (0.001m interval) of the corroded steel bar. At last, the distribution law of the corroded steel bar along the vertical section is obtained by using the two volume differences before and after. The three-dimensional scanning diagram of the corroded steel bar is shown in Figure 4.



(a) (b)

Fig. 4. Three-dimensional scanning diagram of the corroded steel bar.

As can be seen in Figure 4, a steel bar is being measured using a 3D laser scan. Steel bar is placed on a table, and a scanning device is set up next to it. The measuring equipment is composed of CCD camera lens and raster projection lens. The projection device projects the grating onto the rebar, and the grating image projected onto the surface of the steel bar is captured by a CCD camera. LED blue light source with a narrow blue spectrum have the characteristics of low light diffraction effects and image noise. Professional software algorithms, combined with anchor labels, can automatically integrate multiple single scan data to ensure accurate and complete scanning of corroded steel bars. The measuring resolution of the device is greater than 5 million pixels CCD, the accuracy of a single amplitude is 6μm, and the comprehensive accuracy is <0.05mm/m. This method has high precision and accuracy.

The measurement principle of the method is as follows: The steel bar is divided into *i* sections along the longitudinal line, and the steel bar is scanned by the 3D laser scanner to obtain high-precision point cloud data. The 3D model of each section before corrosion is constructed and its initial volume V_{i0} is calculated. After rust occurs, the scanning process is repeated to obtain the 3D model of each section after corrosion, and the volume V_i is calculated. The volume loss rate of each segment can be described by Equation 1.

$$\xi_i = \frac{V_{io} - V_i}{V_{io}} \times 100\% \quad (1)$$

Where

ξ_i is the volume loss rate, in %;

V_{i0} is the initial volume, in m^3;

V_i is the volume after being taken out of concrete, in m^3;

V_{i0}- V_i is the volume loss of each segment, in m^3;

I is the serial number of each segment of the bar.

By using the above method, the curve of corroded area of each section of the corroded steel bar is shown in the Figure 5 below.

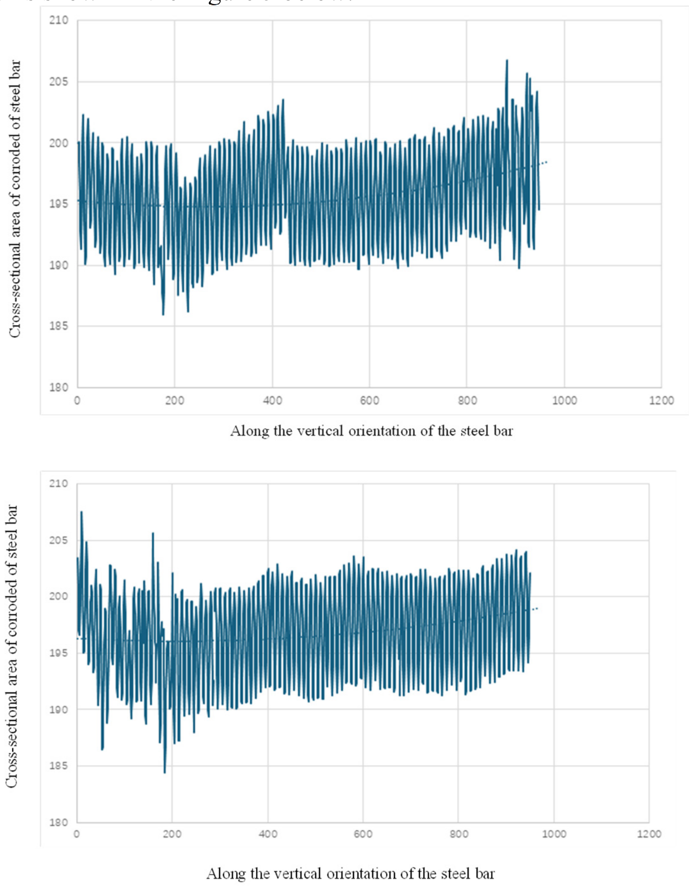


Fig. 5. Corrosion curve of steel bar along vertical orientation.

4 Conclusion

Based on the results presented above, the conclusions are obtained as below:

(1) Relying on the development of the steel corrosion chamber, the marine environment in the total corrosion zones can be reproduced.

(2) Through multi-dimensional environmental simulation and three-dimensional scanning technology, the efficient and accurate quantitative determination method of steel corrosion rate in different corrosion zones of the ocean was realized.

(3) The method accurately reflects the vertical corrosion distribution characteristics and provides a reliable basis for the durability design of concrete structures.

In future, the method can be combined with artificial intelligence to optimize data to improve analysis efficiency. The method can also be extended to other marine engineering applications.

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