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Evaluation of the longitudinal reduction in reinforcing steel diameter due to corrosion in experimental reinforced concrete beams using a statistical model

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KEYWORDS

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Degradation
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ABSTRACT

Corrosion of steel reinforcement is one of the main issue of reduced load-bearing capacity and durability of reinforced concrete structures. In this study, the degree of reduction in steel reinforcement diameter due to corrosion was evaluated by accelerated corrosion testing on reinforced concrete beams labeled D21, D22, D23, and D24. After the corrosion process was complete, the steel bars were removed, the corrosion products were cleaned, and the remaining diameter was measured at various locations along the length of the steel bars. The data were processed using statistical methods, frequency plots were constructed, and normal distribution analysis was performed to evaluate the characteristics of the reduction in diameter of Φ12 and Φ16 steel bars in the beams. The results showed that the reduction in steel reinforcement diameter was uneven along the longitudinal direction of the beams, with Φ16 steel bars exhibiting a higher average reduction value and greater dispersion compared to Φ12 steel bars. The research results provide important experimental data for evaluating the degree of corrosion and remaining load-bearing capacity of corroded reinforced concrete beams.

1. Introduction

Currently, reinforced concrete structures are an significant role in the development of each country, especially under the increasing population in urban areas, so the demand for housing is a difficult problem. Therefore, the development of high-rise buildings is inevitable to ensure the needs of society, and reinforced concrete structures are one of the main types of structures used due to their many advantages. However, despite its outstanding advantages, reinforced concrete structures are still not immune to environmental impacts that reduce the durability of the structure, with corrosion being one of the main causes affecting the durability of the material, leading to a decrease in the load-bearing capacity of the structure, especially in coastal areas. There have been studies on corrosion caused by chloride ions, which reduces the bond between steel and concrete, leading to concrete cracking, peeling of the protective concrete layer and destruction of reinforced concrete structures [1], [2].

There are studies on the corrosion mechanism and the effect of corrosion on the load-bearing capacity of reinforced concrete structures. Currently, researchers worldwide often apply the method of accelerated corrosion in laboratory conditions. With forced current techniques used to shorten the corrosion time, it is possible to observe long-term effects in a shorter period of time [3], [4].

Many recent studies have shown that corrosion in reinforced concrete structures is often non-uniform. Due to many reasons such as the inhomogeneity of concrete, the appearance of cracks and the degree of contact with the environment, localized corrosion can occur in the structure, leading to non-uniform degradation along the length of the reinforcement [4], [5], [6]. This non-uniformity will have significant effects on the load-bearing capacity of reinforced concrete structures, as local area degradation is one of the causes of failure patterns without clear rules [7], [8].

Currently, there are many simulation methods, among which the finite element method has been used and developed by many researchers to further clarify and predict corrosion behavior in reinforced concrete structures. Modeling has been applied to simulate cracking due to corrosion caused by the influence of uneven chlorine distribution, showing the failure process of the structure [9], [10]. In addition, new models have been proposed to simulate the spatial and temporal variation of corrosion to further clarify the degradation process of the structure [11], [12].

On the other hand, there are experimental studies aimed at evaluating the influence of uneven corrosion on the load-bearing capacity of reinforced concrete structures under long-term loading in a chlorine environment, showing that corrosion occurs more dangerously in purely bending zones, leading to a significant reduction in the bending capacity of reinforced concrete structures [3], [13]. These studies highlight the importance of evaluating corrosion models when analyzing the remaining load-bearing capacity of reinforced concrete structures.

Based on the above analyses, this study investigates the longitudinal reduction of reinforcing steel diameter in corroded

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reinforced concrete beams experimentally. After corrosion, the remaining diameter of the reinforcing steel is measured at different locations along the reinforcing bar to determine the degree of corrosion. This result contributes to building a dataset on the reduction of reinforcing steel diameter due to corrosion in beams, which serves as a basis for analyzing and evaluating the performance of corroded reinforced concrete structures and simulating structural behavior using the finite element method.

2. Experiment programe

This experiment aimed to evaluate the degree of corrosion and diameter reduction of reinforcing steel in D21, D22, D23, and D24 beams after accelerated corrosion testing under laboratory conditions. The beams were fabricated with different proportions of recycled concrete (RAC), measuring 200 x 300 x 1800 mm, and were reinforced with two Φ16 bars in the tension zone, two Φ12 bars in the compression zone, and Φ6 stirrups. The corrosion process was carried out using accelerated corrosion testing for 3 months. After the corrosion process was complete, the steel bars in the beams were removed, cleaned of corrosion products, and their remaining diameters measured at various points along the bars using calipers.

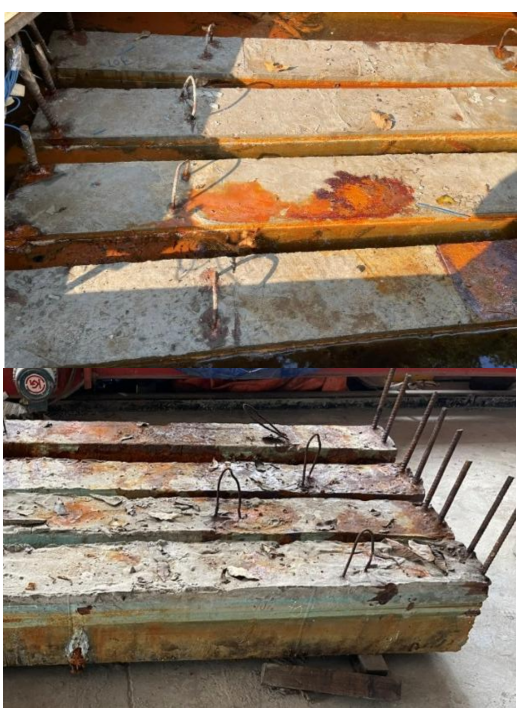

Figure 1. Beam sample during and after corrosion.

3. Survey of Reinforcement Steel Diameter in Beams

After completing the accelerated corrosion treatment process using forced current in a 3 % NaCl solution, beams D21, D22, D23, and D24 underwent detailed surveys to assess the degree of reduction in reinforcing steel diameter due to corrosion. The survey was conducted as follows (Figure 2):

- Demolishing the concrete and cleaning the reinforcement: The reinforcing bars are carefully removed from the beam. All steel bars are thoroughly cleaned with wire brushes and a solution to remove rust and corrosion products from the surface.

- Determining measurement positions: For each reinforcing bar, measurement positions are pre-determined at intervals of 20 cm along the length of the bar (positions: 0, 20, 40, ..., 180 mm) for all reinforcing bars of beams D21, D22, D23, and D24.

- Measuring the remaining diameter: At each determined position, the remaining diameter of the reinforcing bar is measured using an electronic caliper with an accuracy of 0.01 mm. Diameter measurements are taken for four reinforcing bars of each beam.

Figure 2. Survey of steel reinforcement diameters.

4. Assessment of Reduction in Reinforcement Diameter

To assess the degree of reduction in reinforcing steel diameter due to corrosion, data from beams D21 to D24 were statistically analyzed. When constructing the model, anomalous data were removed to avoid bias in the analysis process.

Figure 3 shows that the reduction in reinforcing steel diameter Φ12 in the beams is relatively concentrated around the mean value $\mu = 10.521$, with a standard deviation $\sigma = 1.584$ ($N = 144$). The majority of reduction values fall within the range of approximately 9 to 12, indicating widespread and relatively uniform corrosion among the surveyed beams. The normal distribution curve shows that the data tends to approach a normal distribution, indicating that the corrosion process is quite stable with few anomalous values. However, some significantly larger reduction values are present, reflecting locations where the reinforcing steel is subjected to localized corrosion.

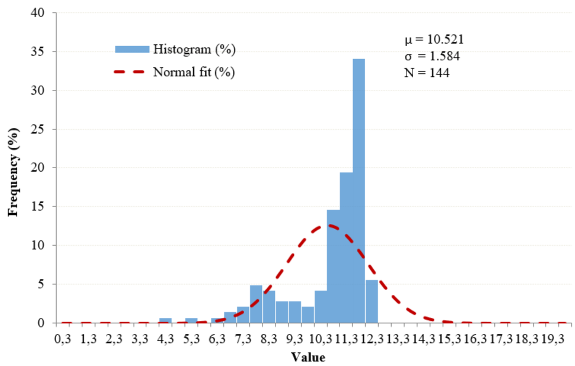

Figure 3. Frequency chart of reduction in the diameter of reinforcing steel Φ12 of beams D21, D22, D23 and D24.

Figure 4 shows that the average diameter reduction of the Φ16 reinforcement has a higher value, $\mu = 13.813$, and a larger dispersion with $\sigma = 2.323$ ($N = 106$). The frequency distribution is more widespread than that of Φ12, indicating non-uniform corrosion and significant variation between beams. The normal distribution curve shows a tendency towards larger reduction values, reflecting the possibility that the Φ16 reinforcement is more susceptible to severe corrosion. This suggests that the lower reinforcement of the beams is exposed to a more corrosive environment than the Φ12 reinforcement of the beams.

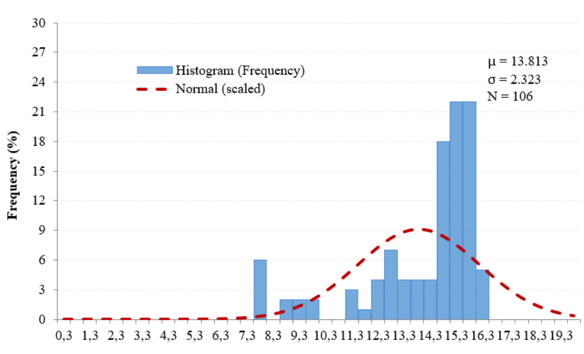

Figure 4. Frequency chart of diameter reduction of Φ16 reinforcing steel in beams D21, D22, D23, and D24.

From the two charts, it can be seen that Φ16 reinforcing steel has a higher average diameter reduction and greater dispersion compared to Φ12, indicating that the degree and unevenness of corrosion in Φ16 is more serious. This is of significant importance in evaluating the remaining load-bearing capacity of corroded reinforced concrete beams and also serves as a basis for selecting appropriate reinforcement, repair, or replacement solutions in construction projects.

5. Conclusion

- From the results of accelerated corrosion testing and statistical analysis of the reduction in diameter of reinforcing steel in D21-D24 beams, the following conclusions can be drawn:

- The reduction in diameter of reinforcing steel due to corrosion is uneven along the beam's longitudinal direction, clearly shown by the frequency distribution of the reduction values obtained at the measurement locations. This indicates the localized nature of the corrosion process of reinforcing steel in reinforced concrete structures.

- For Φ12 reinforcing steel, the diameter reduction values are mainly concentrated around the average value with a relatively narrow distribution, indicating a relatively uniform level of corrosion. Conversely, Φ16 reinforcing steel has a larger average diameter reduction and higher dispersion, demonstrating a more severe level of corrosion compared to Φ12 reinforcing steel in the beams.

- The frequency histogram combined with the normal distribution curve shows that the experimental data tend to approach a normal distribution, allowing the use of statistical models to simulate and predict the degree of reduction in reinforcing steel diameter due to corrosion.

- The research results confirm that assessing reinforcing steel corrosion should not only be based on average values but also on the frequency of occurrence and the degree of dispersion of the reduction values, accurately reflecting the random and localized nature of corrosion.

- This is an important basis for evaluating the remaining load-bearing capacity of corroded reinforced concrete beams, and also serves to simulate corroded reinforced concrete structures and propose repair and strengthening solutions in actual construction projects.

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