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NUMERICAL SIMULATION STUDY ON EXPOSED REINFORCED ANTI-CORROSION LAYER DAMAGE OF THE CROSS-SEA BRIDGE UNDER THE MARINE ENVIRONMENT

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ABSTRACT

To solve the problem of low precision of numerical simulation of the exposed reinforced anti-corrosion layer damage of the cross-sea bridge, we use the stress ratio between the double slash and the reinforced anti-corrosion layer to analyze the parameters and the damage rate in different qualities of reinforced anti-corrosion layers, use Ansys software to build reinforced finite element model, and analyze the damage degree when the inclination angle was 15 °, 45 ° and 60 °, respectively. The experimental results showed that the proposed method can improve the numerical simulation efficiency, the numerical simulation results, the experimental results, and the theoretical analysis results have good consistency and stability.

Keywords: Cross-sea bridge, Reinforced, Anti-corrosion damage, Numerical simulation

INTRODUCTION

The cross-sea bridge is currently a very important offshore project in China, and has an extraordinary influence on our national economy and transportation environment. But the exposed steel bars of the cross-sea bridge in the marine environment is susceptible to salt corrosion, steel corrosion [1], as well as erosion caused by wave erosion and so on. In the northern waters, it also caused by freezing and thawing cycle damage phenomenon. In order to have a better analysis, numerical simulation is needed [2]. In traditional methods, the stochastic aggregate model is used to analyze the constitutive relation of the damage interface and the mechanical properties of the concrete. Sometimes when the numerical simulation is carried out, the results are inconsistent with the actual results, and the efficiency is low [3]. It will increase the post-repair reinforcement work [4], cost a lot of manpower and material resources [5], and with the emergence of structural failure [6]. In this paper, a numerical simulation method of the exposed reinforced anti-corrosion layer damage in the marine environment based on the double slash is proposed.

DAMAGE ANALYSIS OF EXPOSED REINFORCED ANTI-CORROSION LAYER OF SEA-CROSSING BRIDGE

In the process of building a sea-crossing bridge, it is very important to select the reinforcement constitutive relationship for the exposed steel bars, here we use the double slash model which can reflect the reinforcement of the steel bars, to make the constitutive relation simple and conform to the actual [7]. The formula is shown as follows:

$$\begin{cases} \sigma_s = E_s\varepsilon_s, E_s = f_y / \varepsilon_s \le \varepsilon_y \\ \sigma_s = f_y + \left(\varepsilon_s - \varepsilon_y\right)\tan\theta', \tan\theta' = E_s' = \dfrac{f_u - f_y}{\varepsilon_u - \varepsilon_y}, \varepsilon_y \le \varepsilon_s \le \varepsilon_u \end{cases} \tag{1}$$

Where σ_s represents the steel bar stress, ε_s represents the steel strain, f_y represents the yield strength of the bar, E_s represents the modulus of the initial elasticity of the reinforcement, ε_y represents the yield strain of the reinforcement, θ' represents the strengthening section stress in double slash model, E_s' represents reinforced section elastic modulus of the reinforcement in double slash model, f_u represents the behalf of the ultimate strength of steel, ε_u represents the behalf of the ultimate strain of steel.

Under the influence of the double damage factors of the reinforcement layer and the reciprocating load, the cross-section area, ultimate strength, yield strength and elastic modulus of the steel will change. To avoid the analysis is too complex, assuming that the elastic modulus is not affected by the steel damage and the impact of reciprocating loads. The cross-section area, the yield strength and the ultimate strength of the steel affected by the reciprocating load double damage factor is shown as:

$$f_y(n) = \sigma_{\max}\left(N_f\right)\left\{1 - \frac{\lg n}{\lg N_f}\left[1 - \frac{\sigma_{\max}\left(N_f\right)(1-\eta_m)}{(1-1.049\eta_m)\, f_y}\right]\right\} \tag{2}$$

When the damage rate of reinforced anti-corrosion layer is $0 \le \eta_m \le 2\%$:

$$A_s(n) = \left\{1 - \frac{n}{N_f}\left[1 - \frac{\sigma_{\max}\left(N_f\right)(1-\eta_m)}{(1-1.049\eta_m)\, f_y}\right]\right\}(1-\eta_m)A_s \tag{3}$$

When the damage rate of reinforced anti-corrosion layer is $2\% \le \eta_m \le 10\%$:

$$A_s(n) = \left\{1 - \frac{n}{N_f}\left[1 - \frac{\sigma_{\max}\left(N_f\right)(1-\eta_m)}{(1-1.049\eta_m)\, f_y}\right]\right\}(0.985 - 0.97\eta_m)A_s \tag{4}$$

When the damage rate of reinforced anti-corrosion layer is $10\% < \eta_m \le 20\%$:

$$A_s(n) = \left\{1 - \frac{n}{N_f}\left[1 - \frac{\sigma_{\max}\left(N_f\right)(1-\eta_m)}{(1-1.049\eta_m)\, f_y}\right]\right\}(0.938 - 0.95\eta_m)A_s \tag{5}$$

$$\frac{f_u(n)}{f_y(n)} = 1.5 \tag{6}$$

Where $f_y(n)$ represents the remaining yield strength of the steel bar, $f_u(n)$ represents the ultimate strength of the steel bar, $\sigma_{\max}\left(N_f\right)$ represents the maximum stress at the time of fatigue damage of the steel bar, n represents the number of cycles, η_m represents the mass breakage rate of the reinforced anti-corrosion layer, $A_s(n)$ represents the remaining cross-sectional area of the steel bar, and A_s represents the area of the initial section of the steel bar.

The stress ratio [8] refers to the ratio of the minimum stress to the maximum stress under the reciprocating load. The magnitude of the stress refers to the difference between the maximum stress and the minimum stress. In this paper, formula (7) is introduced tocontact the stress ratio, the damage rate and the fatigue life under the premise of guaranteeing the same maximum stress, and then combined the formulas (2) to (6) to process the numerical simulation. The advantage of the formula (7) is: surface equation [9] is fitted according to the natural damage of reinforced components, so that the structure or components are as close as possible when meet the premise of safe operation. The fatigue life of the damaged steel structure or component is:

$$\log N_f = \left(15.138 + 0.086\eta_s\right) - \left(3.687 + 0.051\eta_s\right)\log S_{rc} - k\sigma_A \tag{7}$$

Where N_f represents the fatigue life or the number of cycles, η_s represents the average cross-sectional breakage of the steel, S_{rc} represents the nominal stress amplitude, k represents the influence factor of the guarantee rate, and σ_A represents the standard deviation of the naturally damaged steel bars obtained by statistical analysis of the test results.

Analysis of equations (2) to (7) can be found that when the maximum stress of the fatigue failure of the steel is kept constant, increased the stress ratio at the same damage rate, the stress amplitude of the steel is gradually reduced, resulting in the fatigue life of the steel increased which caused the strength and cross-sectional area of the steel bar decreased and gradually weakened. Finally, the bearing capacity of the damaged steel bar is affected by the reciprocating load, as shown in the following Figure 1.

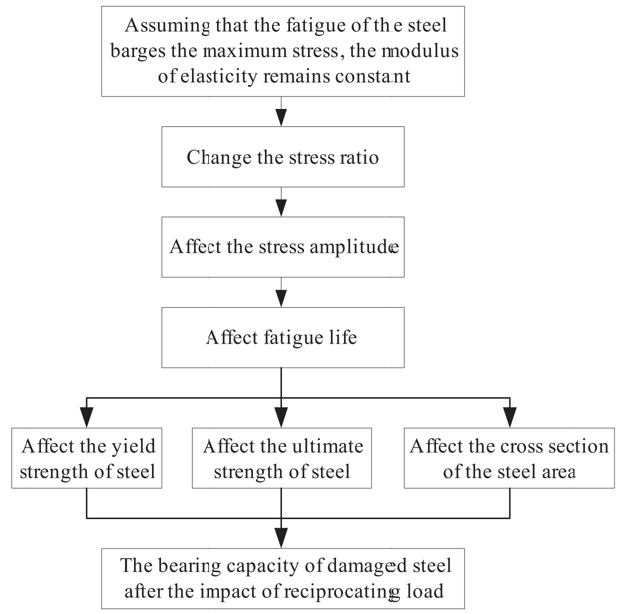


Fig. 1. Effect of Stress Ratio on the Bearing Capacity of Damaged Steel after the Reciprocating Load Is Applied

Using the above diagram, it is possible to better analyze the numerical simulation of the reinforced anti-corrosion layer damage.

NUMERICAL ANALYSIS OF THE REINFORCED ANTI-CORROSION LAYER DAMAGE

The finite element model was established by using Ansys software [10-12]. The finite element parameters were set up: the thickness of the interface between reinforced concrete and concrete was 0.1mm, the elastic modulus was 15GPa, the Poisson's ratio was 0.25, the reinforced model was HRB335, and the density was 7800kg /m^3. The finite element model established under the above parameters is shown in Figure 2 and Figure 3.

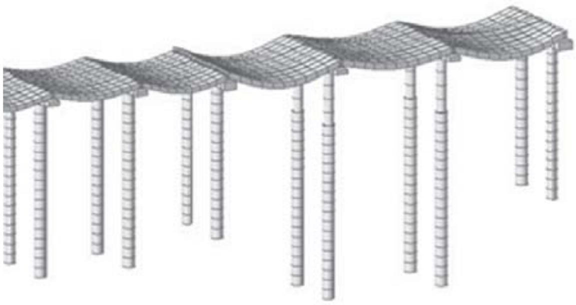
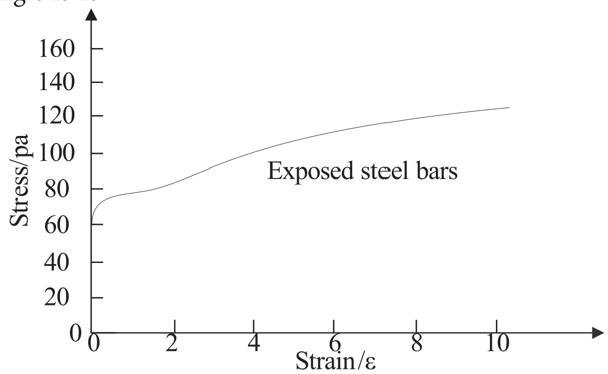
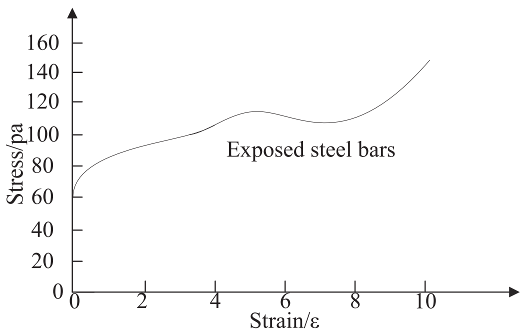


Fig. 2. Finite Element Model of the Steel Bars

(A) Damage Degree of the Steel Bar When the Inclination Angle Is 15 °



(B) Damage Degree of the Steel Bar When the Inclination Angle Is 45 °



(C) Damage degree of the Steel Bar When the Inclination Angle Is 60 °

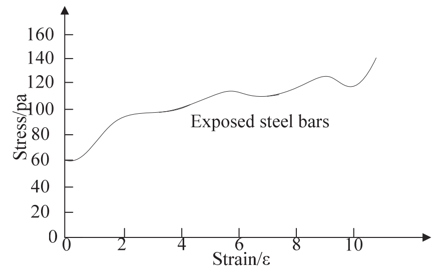


Fig. 3. The Damage Degree of the Steel Bars at Different Inclination Angles

When the inclination angle is 15 °, the stress distribution is uneven, and the crack is bent at the bottom of the steel specimen [13,14].

When the inclination angle is 45 °, the middle part of the stress is obviously uneven, the test process, when the bottom corner of the sample has not yet begun to break, the layers have been clearly dislocation.

When the inclination angle is 60 °, the numerical simulation is similar to the 45 ° model, but the 60 ° sample is damaged at the bottom corner and then damaged the layer.

EXPERIMENTAL RESULTS AND ANALYSIS

To prove the reliability of the proposed method, an experiment is required. Experimental platform was established under SPSS20.0 environment, the experimental data were taken from a cross-sea bridge, the reinforced anti-corrosion layer was observed for 1 month, record the damage process.

A. SIMULATION RESULTS OF STRESS CHANGES IN DIFFERENT METHODS

The Figure4 showed the numerical simulation results of the relationship between the stress and strain of the reinforced anti-corrosive layer damage caused by seawater. Figure 5 showed the numerical simulation results caused by other factors.

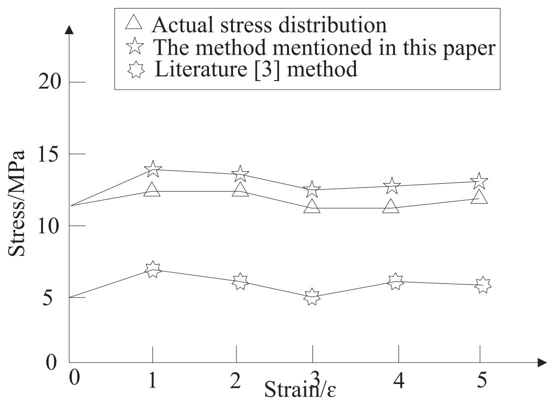


Fig. 4. Relationship between Stress and Strain in Different Methods under Seawater

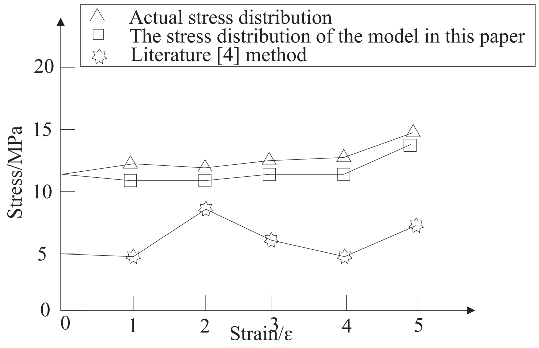
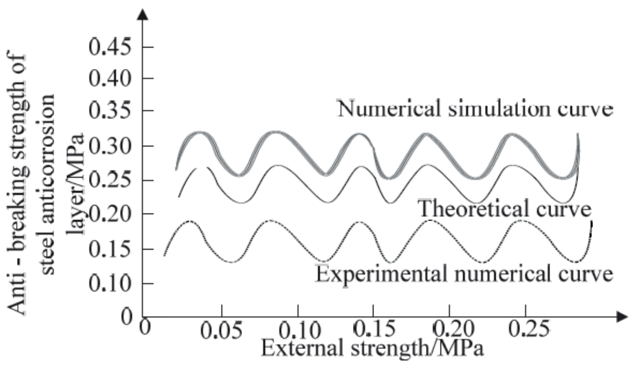


Fig. 5. Relationship between Stress and Strain in Different Methods under Other Factors

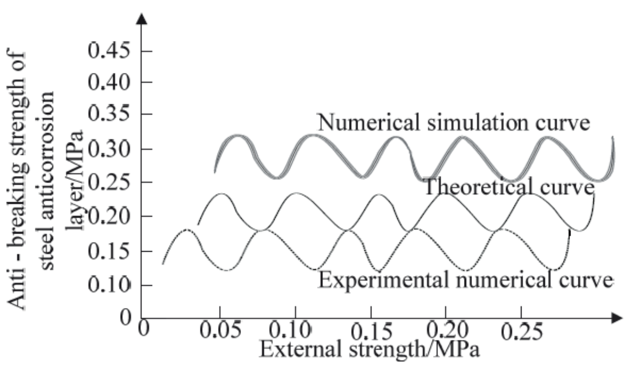
B. COMPARISON OF NUMERICAL SIMULATIONS IN DIFFERENT METHODS

The Figure 6 showed the experimental results, theoretical analysis and numerical analysis of different methods. Figure 7 showed the comparison of the experimental and simulated load versus deflection curves for different methods.

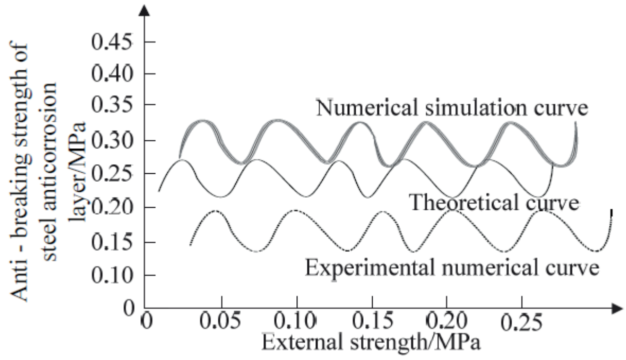
(A) Experimental Results of the Proposed Method and the Relationship between the Theoretical Analysis and Numerical Analysis



(B) Experimental Results of the Method Proposed in Literature [5] and the Relationship between the Theoretical Analysis and Numerical Analysis



(C) Experimental Results of the Method Proposed in Literature [4] and the Relationship between the Theoretical Analysis and Numerical Analysis



(D) Experimental Results of the Method Proposed in Literature [3] and the Relationship between the Theoretical Analysis and Numerical Analysis

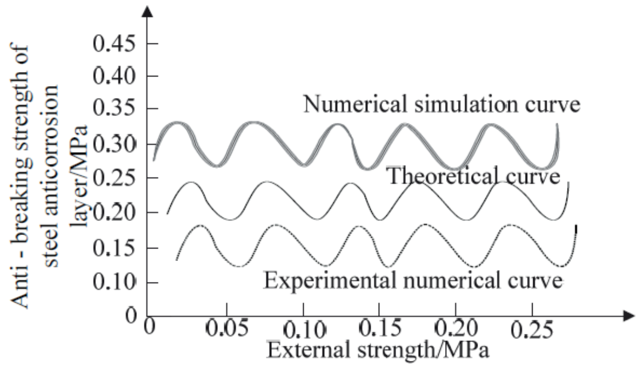
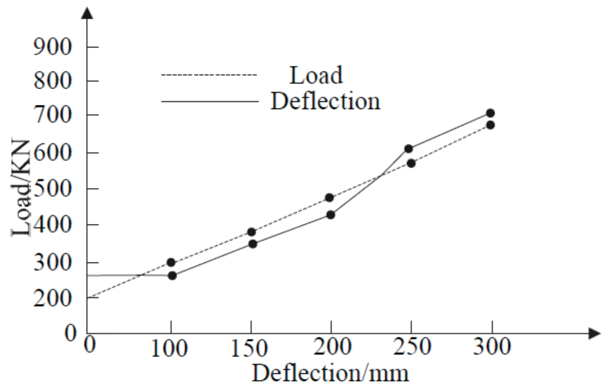
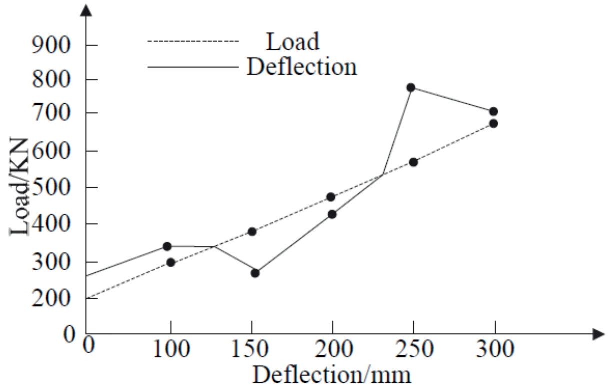


Fig. 6. Experimental Results Different of Methods and the Relationship between the Theoretical Analysis and Numerical Analysis

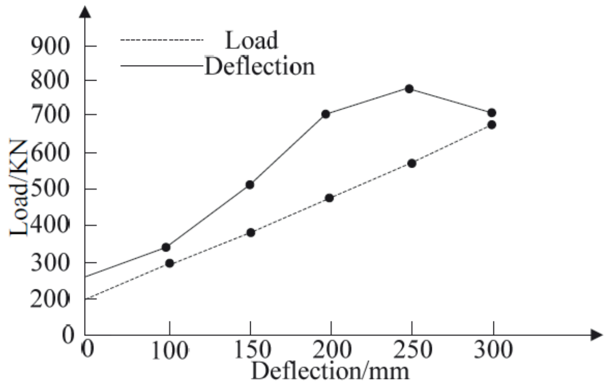
(A) Experimental and Simulated Load and Deflection Curves in the Proposed Method



(B) Experimental and Simulated Load and Deflection Curves in the Method Proposed in Literature [6]



(C) Experimental and Simulated Load and Deflection Curves in the Method Proposed in Literature [4]



(D) Experimental and Simulated Load and Deflection Curves in the Method Proposed in Literature [5]

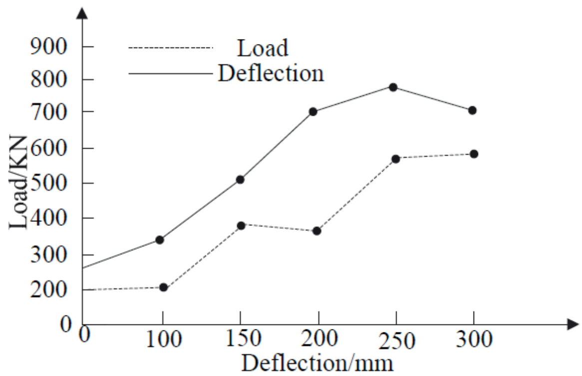


Fig. 7. Comparison of Experimental and Simulated Load and Deflection Curves in Different Methods

DISCUSSION

Figure.4 and Figure.5 showed that the stress simulation results of the exposed reinforced anti-corrosive layer damage of the cross-sea bridge are consistent with the actual stress changes by using the proposed method [14]. The proposed method utilizes the double slash model which can reflect the reinforcement of the steel after the yield section and make the constitutive relation simple and consistent with the actual, improve the distribution consistent of the simulation stress and the actual stress [15]. Compared with the experimental results, theoretical analysis and numerical analysis in other methods showed in Figure 6 and Figure 7, the results of the proposed method are in good agreement with the experimental and theoretical analysis. In the proposed method, the experimental data and the load values in the simulation results are almost linear, which further proved the proposed method has stability [16-18].

CONCLUSION

The numerical simulation of the exposed reinforced anti-corrosion layer damage under the marine environment in the current method cannot achieve high-precision modeling and analysis. The proposed method analyzed the reinforced anti-corrosion layer damage with the stress ratio of the double slash model, established the finite element model by using Ansys software, and analyzed the damage degree of steel bar at 15, 45 and 60°, respectively, complete the numerical simulation and analysis of steel bar damage. The experimental results showed that the proposed method can provide a reference for the study of the exposed reinforced anti-corrosion layer damage for the cross-sea bridge.

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