Study on the Influence of Non-Uniform Corrosion on the Reliability of New Steel-Mixture Composite Bridge

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Abstract. The ABAQUS software was used to study the effect of non-uniform corrosion on the reliability of the new steel-concrete composite girder bridge. The non-uniform corrosion mechanism was analyzed, and the formation process of the pitting corrosion pit was known. Combined with Python programming, the random etching pit of the structural floor was established, and the stress of the steel bottom plate of the new steel-concrete composite beam bridge before and after corrosion was explored, and it was found that the stress of the steel bottom plate in the middle span under non-uniform corrosion increased by 18.2% compared with the non-corrosion. Further calculating the reliability index of the bridge before and after corrosion, all met the requirements of the specification, and it was found that the reliability index of the new steel-concrete composite girder bridge under non-uniform corrosion was reduced by 15.5% compared with the non-corrosion.

Keywords: non-uniform corrosion; New-type steel-concrete composite beam bridge; ABAQUS; Reliability index

1 INTRODUCTION

The traditional corrugated steel web composite box girder is easy to crack the concrete bottom plate under the action of positive bending moment [9]. In recent years, domestic scholars have improved it, and put forward a new type of steel-concrete composite structure -- corrugated concrete composite structure bridge with steel bottom plate. After the concrete bottom plate is replaced by the flat steel bottom plate, the structure's self-weight is further reduced, the use of concrete is reduced to a certain extent, the problem of domestic steel overcapacity is solved to a certain extent, the construction process is reduced, the construction cost is saved, and the structure has good economic benefits [4] [6] [16]. Gansu has a vast area, diverse geology and climatic types. In general, the climate is dry, and the temperature difference between day and night is large. The corrosion problem of various types of salts, especially in the environment of de-icing salt, is more serious (Figure 1). Due to the initial defects of bridge manufacturing process, non-uniform corrosion often occurs.

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Fig. 1. Corrosion diagram of steel structure

Research on the reliability of traditional corrugated steel web composite beam Bridges has achieved certain results. Xu Ruijing [13] adjusted the sub-coefficient of bending and shear bearing capacity of corrugated steel web composite girder bridge by comparing the specifications, and the sensitivity analysis found the main factors affecting the reliable index of the bearing capacity of the composite beam. Ma Wei, Liu Yang et al.[5][7] used ABAQUS to establish the welding model of corrugated steel web and flange plate with different twists and angles, calculate the residual stress field distribution near the weld, and establish the fatigue limit state equation of welding details based on the theory of linear elastic fracture mechanics, and calculate its fatigue reliability index. Since the structure of steel floor wave web concrete composite box girder was proposed in recent years, it has been put into use at Lanzhou Zhongchuan Airport (Figure 2), there is currently no research on this new structural reliability problem.

Fig. 2. Lanzhou Zhongchuan Airport Terminal 2

The uniform corrosion of structure can be simulated by the finite element method of uniform cross-section reduction, but the non-uniform corrosion is difficult to simulate. According to the existing research content, the shell element is simulated for the steel bottom plate, and the random corrosion pit is established for the bottom plate of the structure combined with python programming. For the calculation of reliability, the traditional Monte Carlo method, response surface method and first order second moment method are generally used [1] [14] [15]. In this paper, considering the high efficiency and accuracy of reliability calculation, the hybrid analysis method will be used to analyze the reliability of new steel-concrete composite beam bridge. Combined with ABAQUS finite element simulation, the reliability analysis of steel plate corrugated web concrete composite beam bridge under non-uniform corrosion is made by using the existing content.

2 ANALYSIS OF NON-UNIFORM CORROSION MECHANISM

The non-uniform corrosion of steel is mainly point corrosion. The existing research shows that the pitting pits are mainly conical and spherical, and when the corrosion volume is the same, the influence of the pitting pits on the ultimate strength of the material can be ignored [11] [12]. In Cl- containing medium, the surface of steel will appear pitting corrosion, which is called point corrosion [10]. The breakdown potential on the anode passivation curve is ε_B and when it is higher than ε_B, the steel will have point corrosion. Therefore, the more positive the ε_B of the steel, the more resistant to point corrosion. The medium contains depolarizing cations Fe+, Cu+, etc., which accelerates point corrosion.

This research group takes T3 terminal of Lanzhou Zhongchuan Airport as an example, the prototype is 30m double-box single-room corrugated steel web combination simple supported beam, according to the similarity theory to do 1:9 scale model.

The span of the box beam is L=3.4m, the beam is 0.4m high, the roof is 1m wide, the thickness is 0.05m, the bottom plate is 0.58m wide, and there is a transverse partition at the fulcrum, L/4 and the middle of the span, the material is C50 concrete; The web adopts corrugated steel plate, the thickness is 3mm, the bottom plate adopts flat steel plate, the thickness is 5mm, the material is Q345 steel plate; The web and the top plate are embedded shear connectors. The test beam is shown in Figure 3

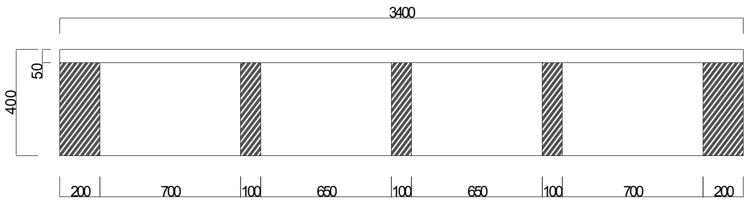

Fig. 3. Elevation of the test beam (mm)

Due to the inevitable inclusion in the production process of the test beam, of course, such problems are very common in the construction of actual Bridges [2] [8]. Point corrosion originates from inclusions. Galvanic corrosion is first produced at the junction of inclusions and the body, and then the corrosion products overflow. The bottom corrosion products arch out the inclusions due to volume expansion, thus forming a point corrosion pit, as shown in Figure 4.

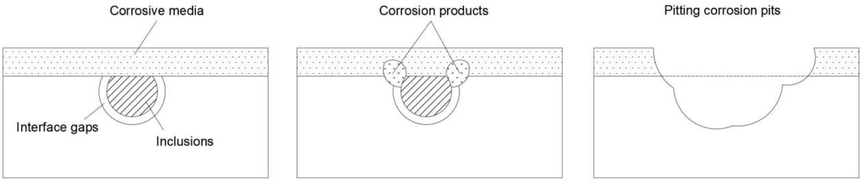

Fig. 4. Schematic diagram of formation of point corrosion pits

Finally, through the expansion of the point corrosion pit, the bridge structure is damaged.

3 THE INFLUENCE OF NON-UNIFORM CORROSION ON THE NEW TYPE COMPOSITE BEAM BRIDGE WITH CORRUGATED STEEL WEBS

Considering only the reduction, the thickness of the concrete roof and steel bottom plate after corrosion of the test beam is 43mm and 4.1mm, and the finite element model considering corrosion is established according to this method. In this paper, shell element is used to simulate the structural steel bottom plate, and circular pit and conical pit are used to simulate the corrosion, the radius is 1~5mm, and the depth is 0.1~0.5mm. Combined with python programming, the random pitting was established on the bottom plate of the structure, and the erosion ratio was determined according to the ratio of pitting area to the bottom plate area (10% in this paper). The Abaqus model is shown in Figure 5.

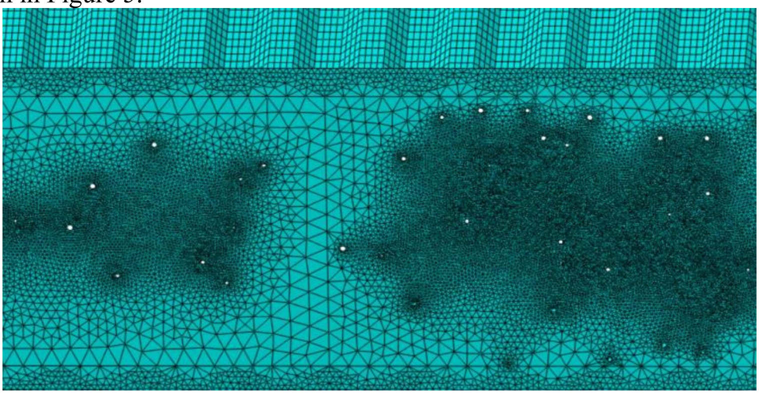

Fig. 5. Point corrosion model of steel bottom plate

In order to analyze the stress change of the structure after random corrosion of the bottom plate, the mises stress cloud graph of the random corrosion bottom plate model under 15mm displacement loading was taken, as shown in Figure 6. The normal stress cloud map of the bottom plate under the action of 80kN concentrated force before and after corrosion was obtained, as shown in Figure 7 and Figure 8.

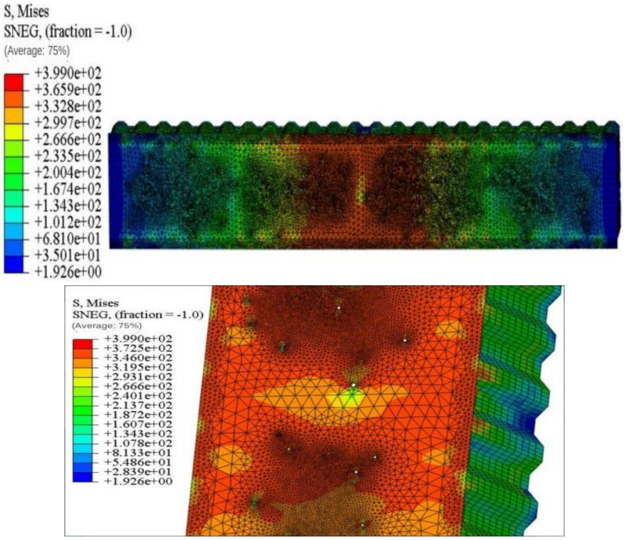

Fig. 6. mises stress cloud map of bottom plate corrosion pit model

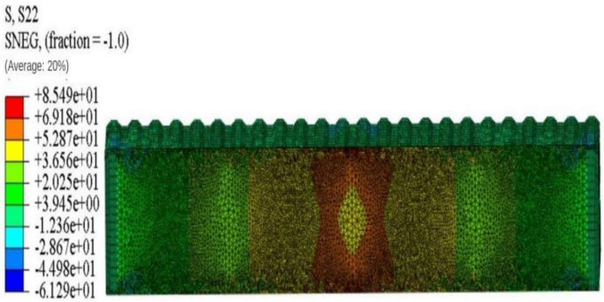

Fig. 7. Normal stress cloud map of uncorroded steel bottom plate

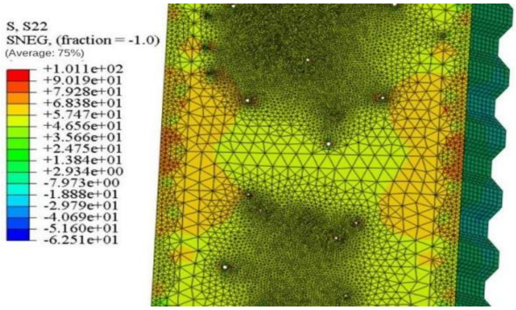

Fig. 8. Normal stress cloud diagram of the bottom plate of corroded pit model

As can be seen from Figure 6, local random erosion had a certain impact on the stress distribution of the structure, and the distribution was no longer symmetrical, but the mises stress maximum value was still near the intersection of the mid-span bottom plate and the web plates on both sides. Mises yield stress and distribution of the structure were greatly affected by erosion pits, and the stress concentration points increased.

It can be seen from Figure 7 and Figure 8 that the maximum tensile stress of uncorroded steel bottom plate under 80kN load is 85.4MPa, and the maximum tensile stress of corroded pit model bottom plate is 101.1MPa, which is 18.2% higher than that of uncorroded structure. It can be seen that the non-uniform corrosion has a great impact on the stress of the structure, and the corrosion pit will cause a new stress concentration point.

4 RELIABILITY ANALYSIS

Taking T3 terminal of Lanzhou Zhongchuan Airport as an example, the 30m double-box single-room corrugated steel web composite simple supported beam was simulated by Abaqus software. The finite element model before and after corrosion is established, and the mid-span deflection under different concentrated loads is calculated. The results are shown in Table 1.

Table 1. Values of mid-span vertical displacement before and after corrosion

Values of vertical displacement in mid-span before and after corrosion								
Load(kN)	10	20	30	40	50	60	70	80
Deflection(mm)	0.36	0.72	1.08	1.44	1.80	2.16	2.52	2.88
Value of mid-span vertical displacement after corrosion								
Load(kN)	10	20	30	40	50	60	70	80
Deflection(mm)	0.39	0.78	1.17	1.56	1.95	2.34	2.73	3.12

The limit equation of state is:

$$Z = R - S = \frac{FL^3}{48EI} - w = \frac{F30^3}{48 \times 3.45 * 10^{10} \times 1.971 * 10^{-3}} - w = 0$$

Where: R--resistance of structure or structure, S--effect of action, F-- concentrated load, w--deflection.

Using the mean one-time second-order moment method, calculated by Matlab software. The reliability index of the bridge before corrosion is 6.85, and that of the bridge after corrosion is 5.79. The reliability index meets the requirements of the code[3]. It can be seen that corrosion has a great impact on the reliability of simple supported girder Bridges with corrugated webs and steel bottom plates. Corrosion reduces reliability index by 15.5% compared to non-corroded bridges.

5 CONCLUSION

1. Galvanic corrosion occurs through inclusion and bridge in corrosive environment, and corrosion products overflow from the bottom of the corrosion products arch out of the inclusion due to volume expansion, thus forming a point corrosion pit, that is, non-uniform corrosion.
2. Through the comparison of stress cloud map before and after corrosion, it is found that the non-uniform corrosion has a great influence on the stress of steel bottom plate in the span of simple supported beam. The stress of the bottom steel bottom plate of the span under non-uniform corrosion increased by 18.2% compared with the non-corrosion.
3. Through the calculation of the reliability index of the simply-supported beam bridge before and after corrosion, it is concluded that the corrosion has a great influence on the reliability of the new steel-mixed simply-supported beam bridge. Corrosion reduces reliability index by 15.5% compared to non-corroded bridges.

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