Finite Element Simulation of Steel Column Considering Corrosion Morphology

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Abstract—This paper carries out the three-dimensional scanning and eccentric compression bearing capacity test of a corroded steel column, which is obtained from the artificial accelerated corrosion test, and through the finite element software, establishes a finite element model considering the true corrosion morphology of the compressed flange and the web to study the effect of corrosion on the ultimate bearing capacity of steel column. The research result shows that the surface of rusted steel is rough, and the stress distribution is uneven. The maximum stress point is often occurred at the bottom of the rust pit, and there is stress concentration at the rust pit. Corrosion causes a significant reduction in the bearing capacity of the steel column. The numerical analysis method considering corrosion morphology can accurately predict the failure mode and ultimate bearing capacity of eccentric compression corroded steel column.

1. INTRODUCTION

At present, there are two main ways to consider corrosion in numerical simulation: one is to consider corrosion as a uniform thickness reduction or a local thickness reduction [1-3]; the other is to simulate pitting by means of manual digging [4-6]. Although the above two methods have certain accuracy for the prediction of the bearing performance of the component, they do not consider the effect of the true rusted rough surface. Some scholars have considered the surface morphology of corrosion when studying the mechanical properties of corroded steel plates [7-8], and the numerical analysis results can be very accurate. Therefore, it is necessary to establish a finite element model of the components considering corrosion morphology in the numerical simulation, and discuss the influence of corrosion surface morphology on the mechanical properties of the components.

In this paper, the corroded H-shaped steel column is taken as the research object. After three-dimensional scanning of the corroded steel column, the solid model of the corroded steel column was established using reverse engineering software, and then was imported to the ABAQUS software for simulation to study the bearing performance of the corroded H-shaped steel column.

2. 3D REVERSE RECONSTRUCTION OF CORRODED TEST PIECES

2.1. Source of Corroded Test Pieces

The corroded test pieces were obtained from the artificial accelerated corrosion test. The steel grade is Q345B and the model is HM200 × 150 [9]. The cross-sectional dimensions are shown in Fig. 1. After
the end of the corrosion test, a section of 1200mm was taken from the corroded test piece and the end was milled flat. The rust products on the surface of the test piece were removed by mechanical methods, and then the test piece was scanned in three dimensions.

Based on the acquired 3D scan data, the coordinate of the cross-section contour point can be obtained by using the layered slice method, and the remaining cross-sectional area could be obtained by coordinate calculation. The remaining cross-sectional area of each plate was extracted every 0.5mm along the length of the test piece, and the degree of rust was characterized by the cross-sectional area loss rate D. Table 1 lists the average cross-sectional area loss rate of compressed flanges Dcf, the average cross-sectional area loss rate of webs Dweb, and the average cross-sectional area loss rate of tensile flanges Dtf.

Table 1. Degree of Rust of Test Pieces

| No. | Rust Rate | Dcf(%) | Dweb(%) | Dtf(%) |
|-----|-----------|--------|---------|--------|
| PX2 | 21.59     | 19.30  | 17.84   |        |
| PX3 | 25.41     | 35.05  | 21.97   |        |

2.2. 3D Reverse Reconstruction

Since the stress level of the tension flange in compression-bending components with large eccentricity is often lower than that of the compression flange and the web, the degree of corrosion of the tension flange has no effect on the ultimate bearing capacity of the component. In order to reduce the calculation cost, the surface corrosion morphology of the tension flange was not considered. In the reverse engineering software, only three parts of the web and the compressed flange were reconstructed in three dimensions.

2.3. Establishment of Finite Element Model

The 3D solid model was imported into the pre-processing software and divided by using free meshing technology. The unit type was C3D4 and the approximate size was 2mm. After element division and element quality inspection, the data were exchanged into the finite element software ABAQUS. The part that does not take into account the morphology of the rusted surface was built with S4R shell elements. The part that does not consider the morphology of the rusted surface was built with S4R shell elements, and the thickness of the shell elements was reduced by the average section loss rate. As shown in Fig. 2a, the shell element and the solid element formed a shell-solid coupling to obtain a finite element model of a corroded steel column, as shown in Fig. 2b, and the total number of elements was more than 2 million. The finite element model has well restored the rust characteristics of the test piece, and this technique can be used to establish the finite element model of rusted components.

The mechanical properties of the materials in the model are derived from the tensile test data of the uncorroded steel of the research group. It is assumed that the steel is an ideal elastoplastic model with an elastic modulus of 206 GPa, a yield strength of 362 MPa, and a Poisson's ratio of 0.3. The boundary conditions and loading direction of the finite element model are consistent with the test. The loading point is located at the center of the compressed flange. The loading mode is displacement loading.
3. **FINITE ELEMENT ANALYSIS**

3.1. **Stress Cloud**

Taking the PX3 model as an example, Fig. 3 shows the stress contours of the compressed flanges and webs in the elastic and elastoplastic phases, and the cross-sectional area loss rates along the length direction. It can be seen from the Fig. 3a that the uneven distribution of stress occurs in the elastic stage. The areas with greater stress are distributed in places with severe corrosion, such as the bottom of the pit; as the load increases, the pit bottom occurs the yield stress first, and then plastic deformation occurs and gradually expands; the stress contour of the web becomes slick due to the influence of the corrosion morphology, and the web also has the phenomenon of stress concentration, Fig. 3e; The compression flange and web have a higher cross-sectional area loss rate in the range of 0mm ~ 400mm, so the stress is relatively high, and plastic deformation is concentrated in this area and eventually causes damage.

3.2. **Comparison of Destruction Patterns**

The comparison between the failure mode of the finite element simulation and the test failure mode is shown in Fig. 4. It can be seen that the failure modes of the two are more consistent. The out-of-plane displacement meter of the PX2 test specimen shows that the PX2 specimen has a certain torsional
deformation, and the PX2 finite element model has a more significant torsional deformation than the test. The overall deformation of the PX3 test specimen is very small, and the flange and web intersection lines remain straight. The reason for the difference between the buckling position of the PX3 model and the PX3 test specimen is that the welding residual stress at the end plate reduces the local stability of the nearby plate, resulting in local buckling at the ends, while the effects of welding residual stresses at the ends have not been taken into account in the finite element simulation, and buckling occurs at the most severely corroded sections (about 200mm).

![Figure 4. Comparison of failure modes between FEA and test](image)

3.3. Correlation Curve

According to the curve bifurcation method [10], the load-strain curves of the strain gauges symmetrically arranged on both sides of the plate should basically coincide at the initial stage of loading; When the plate is locally buckling, the plate appears bulge, and the compressive strain on the convex side develops to the tensile strain, while the compressive strain on the concave side continues to increase. Fig. 5 shows the load-strain curves of the PX2 and PX3 test specimens closest to the buckling wave peak. The S4-1 and S4-2 of the PX2 specimens are the flange strains across the mid-span compression, and S4-5 and S4-6 are the mid-point strain across the mid-section web; S7-3 and S7-4 of the PX3 test specimen are the strain at the flange at a distance of 150mm from the lower end plate, and S7-5 and s7-6 represent the midpoint strain of the web at 150mm from the end plate at the bottom.

From the load-strain curve of the test specimen, after the strain at the compression flange of PX2 reaches the limit load, the strain at the S4-2 measuring point develops toward the tensile strain and the S4-1 measuring point continues to maintain compressive strain. According to the curve bifurcation method, Elastic-plastic buckling occurred in the compressed flange of PX2 span. Similarly, according to the strain curve, it can be judged that the buckling deformation of the PX2 span mid web appears in the load drop section; the compressed flange and web at the S7 section of the PX3 specimen have locally buckled.
Figure 5. Load-strain curves of specimens: (a) compression flange of PX2; (b) web of PX2; (c) compression flange of PX3; (d) web of PX3.

Figure 6. Load-strain curves of FEMs: (a) compression flange of PX2; (b) web of PX2; (c) compression flange of PX3; (d) web of PX3.

Figure 7. Comparison of load-displacement curves between FEA result and test result: (a) PX2; (b) PX3.
The comparison of the load-in-plane displacement curves of PX2 and PX3 is shown in Fig. 7. The displacement data comes from the in-plane displacement of the spanned flange. In the loading stage, the in-plane displacement of the finite element model is relatively small, because the ideal boundary conditions of the finite element model are different from the experimental boundary conditions, and there may be slippage between the test specimen and the support. Combining the strain curve, it can be seen that the failure mode of the PX2 finite element simulation is consistent with the test, and both are local-overall torsional related instability failures. After the PX3 test specimen reaches the ultimate load, the displacement in the plane has almost no increase, so the failure mode of the PX3 test specimen is local instability. However, the buckling position in the PX3 finite element simulation is farther away from the end than the test, so the overall bending deformation of the component is relatively large during the load drop stage, and the local buckling is the main failure mode. In general, the change trend of the load-in-plane displacement curve of the finite element simulation is in good agreement with the test.

3.4. Ultimate Bearing Capacity

Table 2 shows the comparison of the ultimate bearing capacity of the PX2 and PX3 test specimens with the finite element simulation, where FF is the ultimate bearing capacity of the finite element simulation, FT is the ultimate bearing capacity of the test specimen, and the difference between the finite element simulation results and the experimental results is \((FF-FT)/FT \times 100\%\). The ultimate bearing capacity of uncorroded test specimens is 660.95kN, the ultimate bearing capacity of the rusted specimen PX2 decreases by about 24%, and the ultimate bearing capacity of the PX3 decreases by about 32%, indicating that the influence of rust on the ultimate bearing capacity of the specimen is very significant.

The ultimate bearing capacity of the finite element simulation considering surface morphology is very close to the ultimate bearing capacity of the test, but the numerical simulation results are slightly larger. The main reasons are: (1) The residual stress of the rolled H-beam and the welding residual at the end plate are not considered. Stress; (2) mechanical properties of rusted steel is not considered.

| No. | FF (kN) | FT (kN) | \((FF-FT)/FT \times 100\%\) |
|-----|---------|---------|-----------------------------|
| PX2 | 21.59   | 19.30   | 17.84                       |
| PX3 | 25.41   | 35.05   | 21.97                       |

4. CONCLUSION

(1) Due to the rough surface caused by corrosion, the stress distribution is uneven at the initial stage of loading, and the maximum stress is distributed at the bottom of the rust pit in the severely rusted section, and there is a significant stress concentration effect at the rust pit. When the load gradually increases, the yield strength at the bottom of the rust pit will produce plastic strain and develop to the surroundings.

(2) Corrosion reduces the thickness of the plate. When the degree of corrosion is large, the buckled flange and the web will locally buckle. The greater the degree of corrosion, the lower the ultimate bearing capacity of the eccentrically compressed H-shaped steel column.

(3) The finite element model considering the true surface topography of corrosion can accurately predict the failure mode and ultimate bearing capacity of the component.

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