Low Cycle Response Analysis of Welded Aluminum Alloy Box Castellated Beam

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Abstract. Welding aluminum alloy 6061-T6 aluminum alloy material is more and more widely used in construction engineering due to its light weight and high strength characteristics. Welding aluminum alloy box Castellated beam has great application value due to its unique section characteristics, in order to obtain more low cycle response curve of welding aluminum alloy box Castellated beam. In this paper, the constitutive relationship of domestic 6061-T6 aluminum alloy was obtained by laboratory test, and the finite element results were verified by low-cycle cycle test and full-scale test. ANSYS software is used to simulate the mechanical response of four welded aluminum alloy box Castellated beams under low cyclic load. The numerical results show that the hysteretic curves of aluminum alloy specimens are full, the pinching phenomenon is not obvious, and the welded aluminum alloy box Castellated beam shows strong overall stability. The seismic performance of welded aluminum alloy box Castellated beam is mainly controlled by expansion ratio, web height to thickness ratio and flange width to thickness ratio.

Keywords. Welding aluminum alloy, box type Castellated beam, bearing capacity, hysteretic loop, impact parameters.

1. Introduction
Because of its light weight, high strength and corrosion resistance, aluminum alloy is used more and more in construction engineering. On the basis of aluminum alloy box beam, the section form of box castellated beam is innovated. More and more attention has been paid to welded aluminum alloy box castellated beam due to its excellent characteristics [1-4]. At present, there are few researches on welded aluminum alloy box castellated beam, so it is necessary to make clear its seismic performance. Through the finite element software ANSYS, the low cycle response of welded aluminum alloy box castellated beam is carried out on the basis of constitutive relation data and test verification.

2. Finite Element Model Verification
2.1. Constitutive Test of Domestic 6061-T6 Aluminum Alloy
In the Mechanical Laboratory of Xi’an Technology University, 6 groups of tensile tests were carried out by DNS300 tensile testing machine (as shown in figure 1), and the tensile data of aluminum alloy was obtained, as shown in figure 2.
The tensile test data is shown in figure 3, and the Constitutive test of domestic 6061-T6 aluminum alloy is shown in figure 4.

2.2. Low Cycle Test
Based on the tensile test data, the finite element numerical simulation was carried out, and the results of the finite element numerical simulation were compared with the low cycle laboratory test. The test site is shown in figure 5 and figure 6.

2.3. Viscoplastic Follow-up Reinforcement Model
Based on the nonlinear analysis module of ANSYS, a finite element model including the Chaboche follow-up reinforcement model of the viscoplastic theory is established. The section parameters of the finite element model are shown in table 1. The finite element model is shown in figure 7.
Table 1. Model section parameters (mm).

| Model | Web thickness | Web height | Flange width | Flange thickness | Component length |
|-------|---------------|------------|--------------|------------------|------------------|
| SJ-1  | 7             | 286        | 120          | 7                | 980              |
| SJ-2  | 7             | 286        | 120          | 7                | 890              |
| SJ-3  | 7             | 330        | 120          | 7                | 890              |
| SJ-4  | 7             | 330        | 120          | 7                | 890              |

Figure 7. Finite element model.

2.4. Boundary Conditions and Loading System
The model is fixed by cantilever, and the flange position is fixed at one end of the beam in UX, UY, UZ directions. The loading system of the low-cycle test refers to the loading of box beams in *Hysteresis and Anti-seismic Design of Steel Structure* [4]. The system, combined with Wang Yuanqing [5] aluminum alloy material low-cycle loading content, set the loading to 5mm as a level, and load a total of 64 levels, as shown in figure 8.

Figure 8. Finite element cyclic loading system.

3. Finite Element Simulation Results
There are two stages in the deformation of the whole structure. The first stage is the fully elastic stage. In this process, with the increase of load, the deflection of the component will change linearly. In this stage, once the load is removed, the structure will return to the original state, without any plastic deformation and damage of the internal metallic bond. As the load continues to increase, the equivalent strain of more and more positions inside the specimen exceeds the elastic yield limit. As the load increases, the component enters the plastic phase, and the part entering the plastic region can no longer provide additional rigidity. The specific performance is that the elastic modulus keeps decreasing, and the ratio of load displacement curve keeps decreasing. In this process, the deformation of the plastic part produced by the sample has not been recovered, and then the load of the sample is unloaded. The unloading speed of the sample is the same as the loading speed. Through the first circle of the hysteresis curve, it can be seen that the slope of the curve in the unloading process is exactly the
same as that in the loading process, but when the load returns to the "0" position, the structure does not return to the initial position, a residual strain of 1.5 mm is generated, and then reversed loading and unloading are carried out. As the load continues to cycle, the yield bearing capacity and ultimate bearing capacity of the component continue to decrease, and the load of the specimen with the same deflection continues to decrease [6].

Taking SJ-1 as an example, the finite element calculation is carried out for different plastic strengthening criteria, and different results are compared.

The elastic-plastic strain reinforcement is not considered, but the nonlinear and follow-up reinforcement are added to the constitutive relationship, and the large strain is opened, and the same loading conditions are used, the results are shown in figure 9. It can be seen that as the structure enters the elastic-plastic state, the deflection of the beam end increases continuously, and the bearing capacity of the structure no longer increases. At this time, the hysteretic curve presents a special regular change state like ratchet.

![Figure 9. SJ-1 load displacement finite element results (BKin).](image)

In consideration of Bauschinger effect, the Chaboche subsequent reinforcement model is used to increase the strain plasticity of the constitutive relationship, and the large strain is opened, and the same loading conditions are used, the results are shown in figure 10. It can be seen from figure 10 that the bearing capacity of the structure itself decreases with the increase of the end deflection of the component, which is due to the damage in the plastic strain area at the end of the structure. When the alternating load is continuously loaded, the damage is continuously accumulated, resulting in the continuous reduction of the bearing capacity of the structure [7].

![Figure 10. Simulation results of end displacement of SJ-1 finite element specimen.](image)

4. Comparative Analysis of Finite Element Simulation Results of Hysteretic Curve

The Chaboche subsequent reinforcement model considering Bauschinger effect is used to simulate the constitutive relationship and low cycle test. The hysteretic curve of SJ-1 is shown in figure 10, and the skeleton curve is shown in figure 11. From figure 10, it can be seen that with the increase of loading displacement, the maximum bearing limit of the structure appears continuous underground sliding.
During the whole low cycle, the end deformation of the component is larger and larger, but the whole weld position does not appear serious tearing phenomenon.

![Figure 11. SJ-1 skeleton curve.](image)

Compared with SJ-1, the whole change of SJ-2 is not obvious, and the whole hysteresis curve shows shuttle shape. As the loading process goes on, the whole hysteresis loop becomes fuller and fuller without pinching. SJ-2 hysteresis curve and skeleton curve are shown in figure 12 and figure 13.

![Figure 12. Simulation results of end displacement of SJ-2 finite element specimen.](image)

![Figure 13. SJ-2 skeleton curve.](image)

According to figure 12 and figure 13, it can be found that the hysteresis curve of SJ-2 is fuller than that of SJ-1, indicating that the ductility and energy consumption capacity of SJ-1 is stronger than that of SJ-2. SJ-3 hysteresis curve and skeleton curve are shown in figure 14 and figure 15 [8].

![Figure 14. Simulation results of end displacement of SJ-3 finite element specimen.](image)

![Figure 15. SJ-3 skeleton curve.](image)

Observing SJ-3, it is found that there are some differences between SJ-2 and SJ-3, because the section height of SJ-3 is higher, and the deflection of SJ-3 is smaller under the same load [9]. Compared with SJ-2 whose expansion ratio is 1.3 times, the whole hysteresis curve is “thin and long”. And the difference between most of the hysteresis loops is small, which means that the buckling and
failure of the fixed end of the whole specimen is less than SJ-2. SJ-4 hysteresis curve and skeleton curve are shown in figure 16 and figure 17.

![Image](image_url)

**Figure 16.** SJ-4 finite element specimen end displacement simulation results.

**Figure 17.** SJ-4 skeleton curve

Stiffness degradation is the characteristic feature of metal structure, and it is the macroscopic embodiment of Bauschinger effect (caused by forward loading during metal plastic processing, plastic strain strengthening causes metal material to show plastic strain softening in the subsequent reverse loading process, which is the phenomenon of lower yield limit). Through the skeleton curve, we can see the change of the rigidity matrix of the test piece, and the rigidity of the test piece is decreasing.

Energy consumption performance is an important index to evaluate the seismic performance of structures. The energy consumption performance can be obtained by the hysteretic curve of components or structures, and can simulate the occurrence of structural components under earthquake. By observing the hysteretic curve and skeleton curve, we can predict whether the seismic performance of the structure meets the requirements. Through the graphic analysis of finite element simulation [10], it is found that the pinch linearity of aluminum alloy structure is not obvious, and the hysteretic curve of aluminum alloy box castellated beam is relatively full, which has a certain energy consumption capacity. However, the ultimate strain of aluminum alloy is worse than that of steel, so when the strain amplitude is large, the energy dissipation capacity of aluminum alloy will be greatly reduced, and the attenuation degree is not more than 34%.

5. Conclusion
In this paper, the finite element model of different sizes of the specimen is used to simulate the low cycle loading, and the Bauschinger effect is considered.

1. The hysteretic curves of SJ-1 and SJ-2 are full, showing great seismic performance. As the load-carrying capacity of the periodic load superposition component decreases gradually, the hysteretic curve presents a "shuttle" shape as a whole.

2. Compared with SJ-1, SJ-3 and SJ-4 hysteretic curves have stronger flexural rigidity, and the whole hysteretic loop shows a "narrow and high" shape. With the increase of loading times, the ultimate load of the whole specimen decreases significantly.

3. Through four groups of skeleton curves, the welded aluminum alloy box castellated beam shows good seismic performance, full shape of hysteresis loop, and the whole hysteresis curve has no obvious pinch polymerization phenomenon.

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