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Analysis of Seismic Behavior of the Ring-stiffeners Bird-Beak SHS Joint

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Abstract. This paper studied bird-beak square hollow T-joint and ring-stiffened bird-beak square hollow T-joints, and the finite element model of the joint were established with ABAQUS, to analyze the enhancing effect of the joint bearing capacity when each parameter changes, and analyzed the seismic performance of the joint under cyclic axial loading, including its ultimate bearing capability, hysteretic behavior, deformation performance and failure modes. Some inclusions provide reference for engineering design.

1. Introduction

With the increasing industrialization of hollow steel section and emergence of new processing design, the application scope and market demand of steel tube structure is expanding day by day, and the form of steel tube joint is also increasing. The intersecting joint of steel tube truss structure is welded by the chord (main tube) and the brace (branch tube) in a positive form, while a new joint is achieved by rotating the chord and brace through 45°about their longitudinal axes, called bird-beak joint [1]. The bird-beak joint fall into two types: one is called diamond bird-beak joint, as shown in Figure 1; another is called square bird-beak joint, which achieved by rotating the chord through 45°about their longitudinal axes only, as shown in Figure 2.

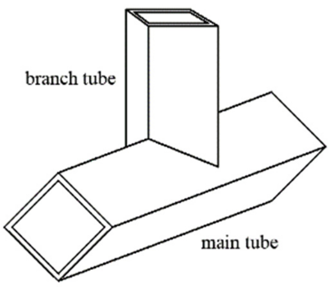

Figure 1. Diamond bird-beak joint

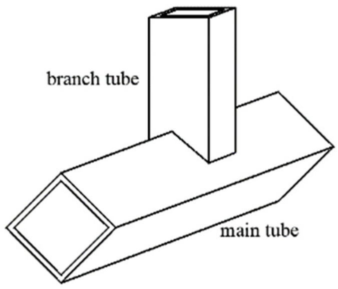

Figure 2. square bird-beak joint

In order to improve the ultimate carrying capacity of the joint, the connection area of the main tube and branch tube can be reinforced. There are a lot of research [2~6] on reinforced steel tube joint, in contrast, the method of the internal ring-stiffeners reinforcement can not only greatly improve the strength of the joint, but also does not affect the aesthetics of the building, is a better method, so this paper will adopt this method, to analyze the effect of the internal ring-stiffeners on the mechanical performance of the joint.

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2. Establishment of finite element model

2.1. Geometrical parameters of joint

According to the *HHS Structure Connection Design Guide*, the symbol for geometrical parameter of the ring-stiffeners reinforced bird-beak joint and its meaning are shown in Figure 3: the spacing of the ring-stiffeners is *d*, the thickness is *t*, and the width is *w*.

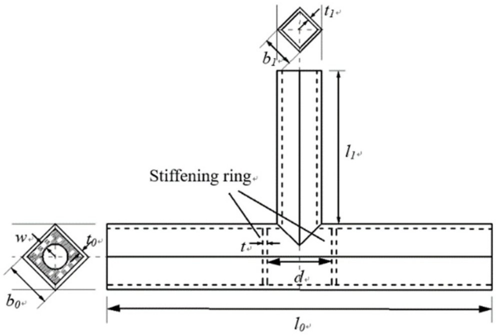

Figure 3. Geometry of the ring-stiffeners reinforced joint

2.2. Finite element modeling points

The impact of the weld is not considered when modeling, the connection between the parts of main tube, branch tube and ring-stiffener is stimulated by the binding constrains. The steel tube of the joint is assumed to be thin plate, and regard the neutral plane of the steel tube as the analysis surface. The connection area where the main tube and the branch tube is the key part of the analysis, so the mesh of this part is refined, setting the seed spacing of encryption area as 6mm, the spacing of other part as 12mm, the divided joint model is shown in Figure 4.

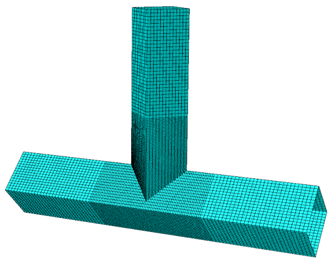

Figure 4. Mesh generation of the joint

2.3. Material properties and boundary conditions

The steel type in this paper is Q345, and its thickness is less than 15mm, according to the relevant regulations, the yield strength of this steel is 345Mpa, and the ultimate tensile strength is 470Mpa. The cyclic loading that the branch tube bearing is stimulated by displacement loading, constrains all displacements at the branch end except the axial displacement and all displacements at ends of the main tube, and the calculation sketch of boundary condition is shown in Figure 5.

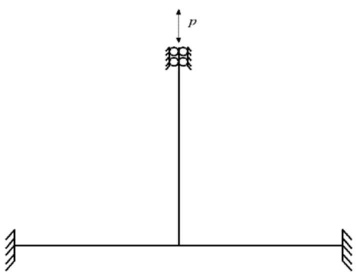

Figure 5. Boundary condition

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2.4. Finite element model validation

The test piece T40-D1 that experimented by Wu Zhenyu [7] and Chen Peng was selected as the verification object, the section size of the main tube is 100mm×100mm ($b_0 \times h_0$), the length is 700mm, and the thickness is 2.73mm, the section size of the branch tube is 40mm×40mm ($b_1 \times h_1$), the length is 343mm, the thickness is 1.74mm. The material properties of the steel tube used in the experiment are shown in Table 1.

Table 1. Experimental Steel Mechanical Performance

Types	σ_y/MPa	σ_u/MPa	μ	E/MPa
Main tube	344.3	410.1	0.261	203500
Branch tube	366.3	451.9	0.269	200000

The hysteresis curve resulting from the experiment and finite element simulation is shown in Figure 6. It can be seen that the hysteresis curve obtained by finite element simulation is basically the same as the shape, size and fullness of the hysteresis curve obtained by the experiment, although there are a little differences, but in generally, the carrying capacity of the test piece obtained by the finite element calculation is close to the experimental result, the difference is within 5% and within the scope of engineering error, indicating that the modeling method used in this paper is reasonable and effective, and can be used in the following text.

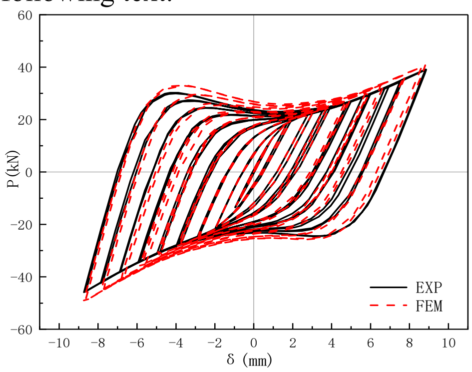

Figure 6. Hysteresis curve of the experiment and the finite element

3. Effect of the stiffening ring parameter on the bearing capacity of joint

This section made a single-factor variable analysis of geometric parameters of the stiffening rings (including the spacing and thickness), and analyzed the enhancing effect of the joint bearing capacity when each parameter changes, so as to find out the most reasonable and economical way to set the stiffening rings. A displacement load of 20mm is applied downward along by the branch tube to simulate the axial fore that each test piece bearing, to study the mechanical properties of the bird-beak square tube joint under axial pressure load.

3.1. Effect of the spacing of stiffening ring on the ultimate bearing capacity

According to the results of finite element analysis, we can get the relationship curve between the spacing of stiffening ring and the enhancement of joint carrying capacity, as shown in Figure 7. As shown in Figure 7, the improvement effect on the carrying capacity of the joint is divided into two stages as the spacing increasing.

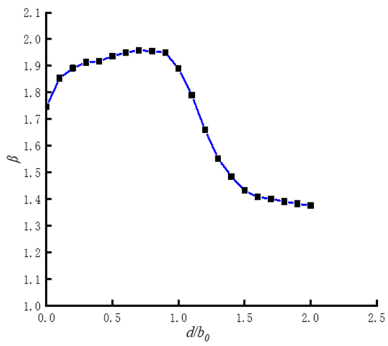

Figure 7. Relationship curve for the spacing of stiffening ring and enhanced multiple

The first stage is the rising stage, while the spacing of the stiffening ring between 0 and $0.9b_0$, at this stage, with the increase of spacing, the increase in the ultimate carrying capacity of joint becomes more and more significant. In the whole range of this stage, the effect of the stiffening ring on the joint carrying capacity is significant, so it is recommended to set the s stiffening ring with the spacing in this range. The second stage is the decrease stage, while the spacing of the stiffening ring between $0.9b_0$ and $2b_0$, at this stage, with the increase of the spacing of the stiffening ring, the increase in the ultimate carrying capacity of joint gradually decline, it can be seen that although the ultimate carrying capacity of the joint has been improved, but the effect is not obvious, so it is not recommended to set the stiffening ring with the spacing in this range. To sum up, when using the method of setting a stiffening ring to improve the carrying capacity of joint, the spacing of the stiffening ring is suggested be 0 to $0.9b_0$ symmetry, while the ultimate carrying capacity of the reinforced joint can reach 1.7 to 1.9 times than the unreinforced joint.

3.2. Effect of the thickness of stiffening ring on the ultimate bearing capacity

According to the results of finite element analysis, we can get the relationship curve between the thickness of stiffening ring and the enhancement of joint carrying capacity, as shown in Figure 8. As can be seen from the figure, the curve also can be divided into two stages.

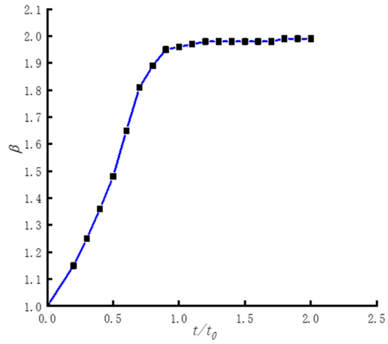

Figure 8. Relationship curve for the thickness of stiffening ring and enhanced multiple

The first stage is the rising stage, while the thickness of the stiffening ring is 0 to t_0, at this stage, with the increase of the thickness of the stiffening ring, the multiple of the increase in the ultimate carrying capacity of joint gradually increase, when the thickness is t_0, the ultimate carrying capacity of joint reaches the peak, which is 1.9 times than the unreinforced joint, so it is recommended to set the stiffening ring with the thickness between $0.7t_0$ to t_0. The second stage is the gentle stage, while the spacing of the stiffening ring between t_0 and $2t_0$, at this stage, with the increase of the thickness of the stiffening ring, the ultimate carrying capacity of the reinforced node is always maintained at about 1.9 times than the unreinforced. So when using the method of setting a stiffening ring to improve the carrying capacity of joint, the thickness of the stiffening ring is suggested be t_0, while the ultimate carrying capacity of the reinforced node can reach 1.9 times than the unreinforced joint.

4. Comparative analysis of the hysteretic behavior of reinforced joints and normal joints

4.1. Geometrical parameter of the joint

The main parameters of the joint are as follows: ratio of the double length to the width of the main tube: $\alpha=2l_0/b$; ratio of the width of the branch tube to the width of the main tube: $\beta=b_1/b_0$; ratio of the width to the double thickness of the main tube: $\gamma=b_0/2t_0$; ratio of the thickness of the branch tube to thickness of the main tube: $\tau=t_1/t_0$.

Table 2. Geometrical parameter of the joints

Number	α	β	γ	τ
T1	12	0.8	15	1
T2	12	0.6	15	1
T3	12	0.8	20	1
T4	12	0.8	15	0.9

4.2. Loading system

According the *Specification for seismic test of buildings* [8] （JGJ101-96）, this paper has presented displacement loading control method along the branch axial direction. two times per level of circulation for the 25%, 50%, 75% of yield displacement before yield, three times per level of circulation for the 1 x, 2 x, 3 times of yield displacement after yield, then switch to two times per level of circulation for the 4 x, 5 times of yield displacement, until the test piece is destroyed. The loading system is shown in Figure 9.

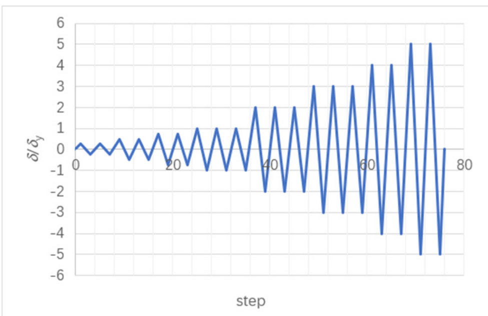

Figure 9. The reciprocating loading system

4.3. Hysteresis behavior

The hysteresis curve was represented by the relationship between the displacement u at the end of the branch and the reciprocating loading P, the hysteresis curve of the 4 groups of joints is shown in Figure 10 to 13. It can be seen that for two kinds of joints, the hysteresis curve of the reinforced joint with stiffener ring is fuller than the hysteresis curve of the normal joint that with the same parameters, which indicates that the energy dissipation capacity and seismic performance of joints have been improved after the reinforcement of the stiffening ring.

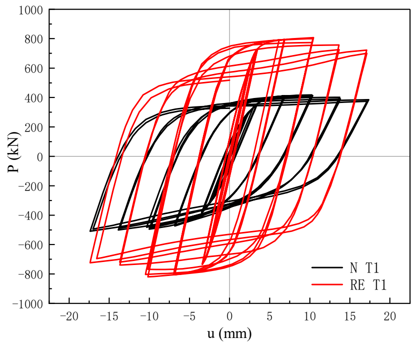

Figure 10. Hysteresis curve of the T1 joints

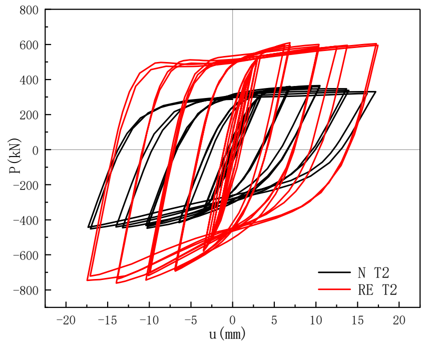

Figure 11. Hysteresis curve of the T2 joints

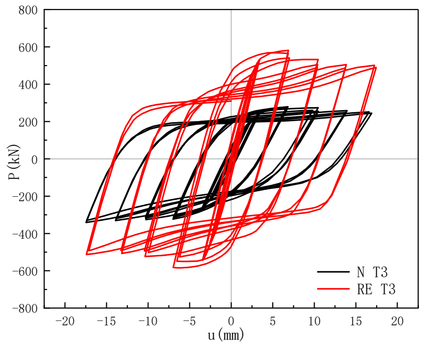

Figure 12. Hysteresis curve of the T3 joints

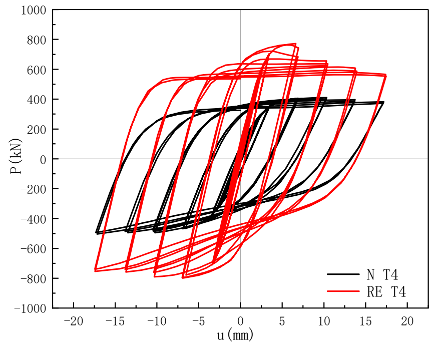

Figure 13. Hysteresis curve of the T4 joints

4.4. Skeleton curve and energy dissipation coefficient

The skeleton curve of each joint model is shown in Figure 14, and it can be clearly seen from the figure that, under the premise that other parameters are the same, the initial stiffness and the ultimate carrying capacity of reinforced joint are greater than the unreinforced joint with the same size, indicating that the reinforced method with the stiffening ring can effectively improve the carrying capacity and deformation capacity of the joint under the action of reciprocating load.

The relationship curve between the energy dissipation coefficient and the displacement of each joint model is shown in Figure 15, which shows that the energy dissipation coefficient of each group of reinforced nodes is basically larger than that of the unreinforced joint, indicating that the reinforced method with the stiffening ring can effectively improve the energy dissipating capacity of joint.

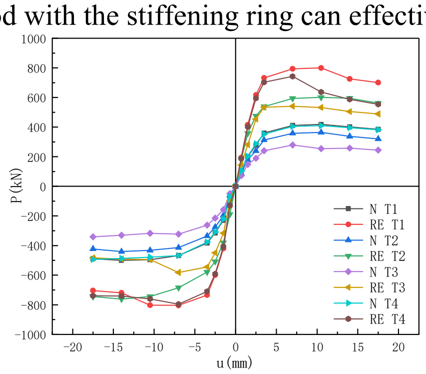

Figure 14. Skeleton curve of joints

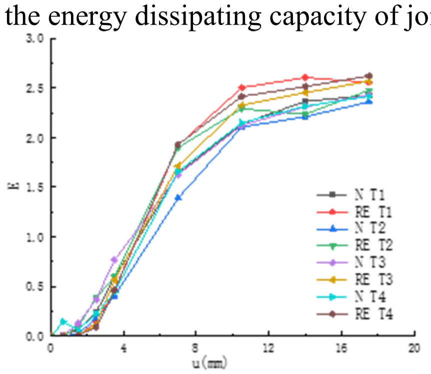

Figure 15. Relationship curve between the energy dissipation coefficient and the displacement

Acknowledgments

This paper used the finite element method to study the effect of the parameter of the stiffening ring on the bearing capacity of joint, further analyzed the difference of hysteresis performance between the normal node and the reinforced node, the main conclusion are:

(1) When the parameter of stiffening ring changes, the carrying capacity of the reinforced joint also changes, wherein, when the spacing stiffening rings changes, the impact on the joint's carrying performance is greater. When the stiffening ring is set symmetrically with the branch axis in the main tube, the spacing is suggested be $0.5b_0$ to $0.9b_0$, the thickness is suggested be same as the thickness of main tube.

(2) The carrying performance of reinforced joint with reasonable parameter of the stiffening ring is significantly improved compared to the unreinforced joint, the stiffening ring can effectively bear the load that form branch, the hysteresis curve of reinforced joint is more full, its ultimate carrying capacity and energy dissipation coefficient are greater than the unreinforced joint, the stiffening ring can effectively reinforce the seismic capacity of the joint.

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