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Finite element analysis on mechanical behavior of flange reinforced connections between wide-flange specially shaped composite columns and steel beams

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Abstract. A parametric model for steel beam to wide-flange specially shaped composite column flange reinforced connection is analyzed by ABAQUS with varying parameters. The results are in good agreement with the experimental ones and the reliability of the calculation method is verified. Then the influence of the geometric parameters of the reinforcing plate on the stiffness, bearing capacity, plastic zone and ductility of the joints is analyzed. The results show that the triangle reinforcing plate can achieve the same effect as the trapezoidal reinforcing plate. The length of the reinforcing plate is 1 to 1.2 times that of the steel beam, the width may be 1/4 to 1/3 height of steel beam, and the thickness may be 1.2 times the steel beam flange thickness.

1. Introduction

Rectangular steel pipe concrete column is often used for the steel structure residential building. The integrity of interior space and applicability is destroyed by fairly large section of columns and prominence on the wall. The combined special-shaped columns composed of rectangular steel tubes can solve this problem by the L-type, T-type and crisscross type. However, the width of the section of the special-shaped columns is limited by the width of the walls, so the connection form of the joints needs to consider many factors.

At present, the connecting node of the rectangular steel tube concrete column and the steel beam is more used by the inner partition node and the outer septum plate node. Xue et al.[1] used the inner partition plate for the concrete-filled rectangular steel tubular special-shaped column joints, and conducted an experimental study on its seismic performance. The seismic performance of the outer spaced plate joints of crisscross type and T-type combined special-shaped columns was tested [2]. Chen et al.[3] connected the concrete filled steel tubular column to the steel beam, and proposed the outer rib ring plate joints. The joints were tested and analyzed. Zhou et al.[4] adopted such joints in the concrete-filled square steel tubular special-shaped columns structure and studied them.

A new flange strengthened node welding reinforcement on both sides of the upper and lower flange ends of the beam is proposed [5]. The experimental research is carried out by the researcher. The strengthening measures can make the bending moment of the beam end directly pass to the end column web plate through flange reinforcement, so as to reduce the stress and deformation of the steel tube wall. Based on this test, the influence of different parameters of flange stiffeners on the performance of joints is analyzed, and the type of nodes is optimized and improved, and reasonable values are identified to guide engineering applications.



2. Comparison between finite element analysis and test

On the basis of the experiment, the experiment of the model simulation of node with finite element analysis (FEA) is established (shown in Figure 1). Material constitutive model use the material of the test. The connection between steel tube column and steel beam is bonded by the tie in ABAQUS. The contact relationship between the steel column and the concrete inside the column is established. The load is the same as that of the test, adding several cycles to the specimen depending on the situation.

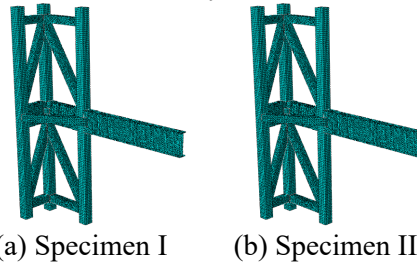


Figure 1. The finite element model of specimen.

After the numerical analysis is completed, the load-displacement hysteretic curve and the skeleton curve in the plane direction at the loading point are derived, and the curves are compared with those obtained in the test (shown in Figures 2 and 3).

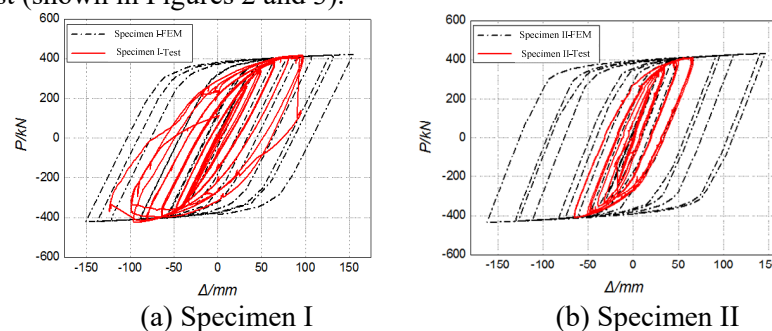


Figure 2. Finite element analysis and test hysteretic curve.

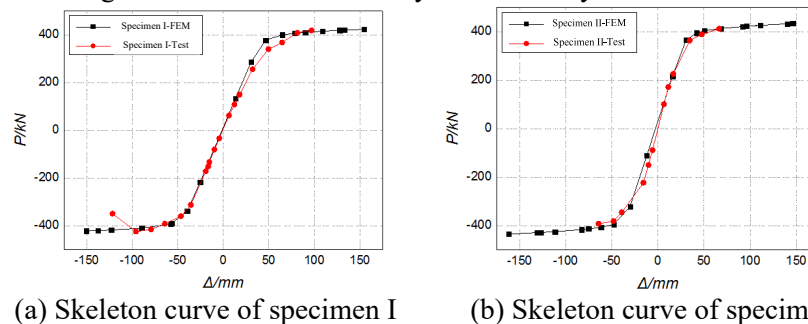


Figure 3. Finite element analysis and test skeleton curve.

The results show that the hysteretic curves have good symmetry in the numerical simulation, however, there are some asymmetries in the test curves. The numerical simulation results are basically consistent with the experimental results, the hysteretic loops in the test have some residual deformation, and the numerical results have no residual deformation. When the load reaches the peak point, the bearing capacity of the numerical simulation is basically consistent with the test value. The hysteretic loop is not as full as the result of the FEA. The skeleton curves of the joint test is basically the same as the FEA. In the FEA, the component can increase several cycles more than the test, therefore, the FEA has a longer displacement section and the ductility is better than the test.

3. Improvement of flange reinforced plate form and connection position

The test results show that the joint performance of the two different size specimens have similarities and differences. On the basis of the flange reinforced plate in the test, the improvement on the node is

proposed (shown in Figure 4). Firstly, the trapezoid reinforced plate (Test) is changed to a triangular reinforced plate (E-I), and then the position of the reinforced plate is changed, and the flange side connection (E-II) is changed into the flange connection. The load displacement curve at the end of the beam is drawn (shown in Figure 5).

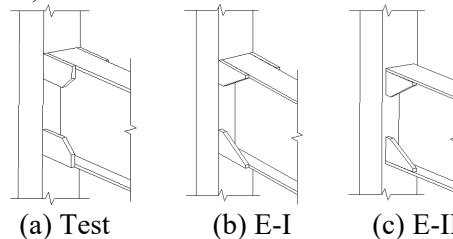


Figure 4. Improvement of flange stiffening plate.

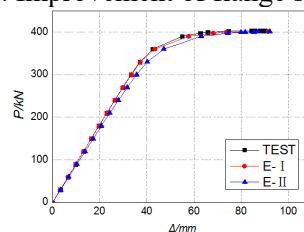


Figure 5. Load-displacement curves of joints.

The load-displacement curves of the Test and E-I joints are basically coincided and the displacement extension section of E-II joint is slightly larger than other joints. The ultimate bearing capacity of the three joints is basically the same.

4. The effect of the geometric parameters of the reinforced plate on the joints

In this section, the length, width and thickness of the flange reinforced plate are changed, and the effect of these parameters on the performance of the new type beam column connection joint is analyzed. The reasonable value of the above parameters is found out. The reinforced plate is shown in Figure 6.

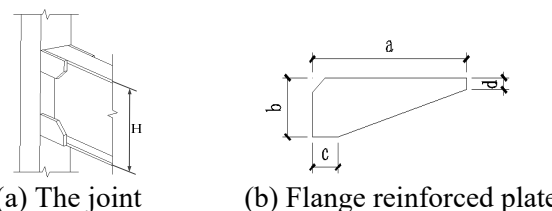


Figure 6. The joint and flange reinforced plate.

4.1 The effect of the length of the flange reinforced plate

In the analysis of the effect of the reinforced plate length on the performance of the joint, five specimens are used for comparative analysis. The various parameters of the specimen are shown in Table 1. By computation, the hysteretic and skeleton curves of the specimens are shown in Figures 7 and 8, and other results are shown in Table 2.

Table 1. The specimen changed length sizes of reinforced plate

Specimen No.	Plate length a (mm)	Plate width b (mm)	Plate thickness t (mm)	c (mm)	d (mm)
BASE	0.5H	H/4	1.5T _f	50	20
L-1	0.75H	H/4	1.5T _f	50	20
L-2	H	H/4	1.5T _f	50	20
L-3	1.2H	H/4	1.5T _f	50	20
L-4	1.5H	H/4	1.5T _f	50	20

Note: H is the height of steel beam section and T_f is the flange thickness of steel beam (in Figure 8).

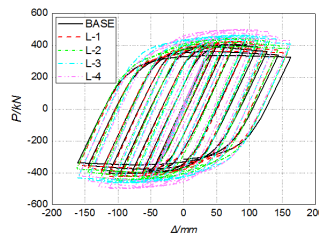


Figure 7. Hysteretic curves of specimens.

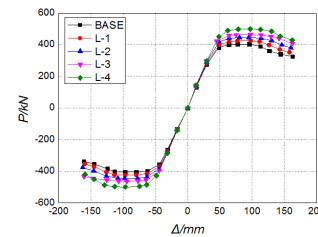


Figure 8. Skeleton curves of specimens.

Table 2. The computing results of reinforced plates with different length

Specimen No.	Loading direction	Ultimate bearing capacity (kN)	Yield displacement Δ_y (mm)	Failure displacement Δ_u (mm)	Ductility coefficient μ	$\bar{\mu}$
BASE	Negative	-404.92	-44.01	-145.31	3.30	3.15
	Positive	404.95	48.15	144.0	2.99	
L-1	Negative	-424.58	-44.01	-145.49	3.31	3.12
	Positive	424.79	48.68	142.84	2.93	
L-2	Negative	-446.20	-44.01	-162.93	3.70	3.5
	Positive	445.90	48.68	160.14	3.29	
L-3	Negative	-463.92	-44.01	-161.0	3.66	3.64
	Positive	463.73	44.98	162.59	3.61	
L-4	Negative	-499.95	-48.42	-159.27	3.29	3.32
	Positive	499.84	48.37	162.26	3.35	

Note: The ductility coefficient is the ratio of failure displacement to yield displacement.

The results show that the hysteretic curves of the five specimens are full of spindle shape, showing good energy dissipation capacity, and the length of reinforced plate has great effect on the new type of joints. With the increase of the length of the reinforced plate, the ultimate bearing capacity is increasing from 405 to the 500kN. All the specimens have good deformation capacity. The ductility coefficient of the specimen is slightly larger when the length of the reinforced plate is 1 to 1.2 times height of the beam, and the deformability is slightly better than that of other specimens.

4.2 The effect of width of the flange reinforced plate

In the analysis of the effect of the reinforced plate width on the performance of the joint, four specimens are used for comparative analysis. The various parameters of the specimen are shown in Table 3. By computation, the hysteretic and skeleton curves of the specimens are shown in Figures 9 and 10, and other results are shown in Table 4.

Table 3. The specimen changed width sizes of reinforced plate

Specimen No.	Plate length a (mm)	Plate width b (mm)	Plate thickness t (mm)	c (mm)	d (mm)
BASE	0.5H	H/4	1.5T _f	50	20
W-1	0.5H	H/3	1.5T _f	50	20
W-2	0.5H	H/5	1.5T _f	50	20
W-3	0.5H	H/8	1.5T _f	50	20

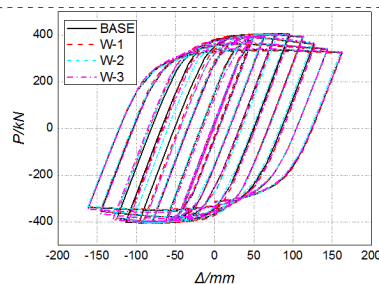


Figure 9. Hysteretic curves of specimens.

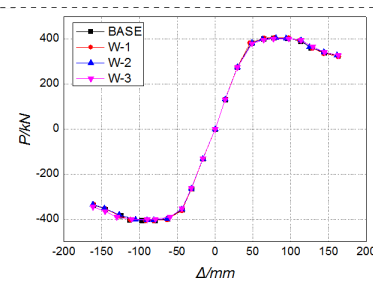


Figure 10. Skeleton curves of specimens.

Table 4. The computing results of reinforced plates with different width

Specimen No.	Loading direction	Ultimate bearing capacity(kN)	Yield displacement Δ_y (mm)	Failure displacement Δ_u (mm)	Ductility coefficient μ	$\bar{\mu}$
BASE	Negative	-404.92	-44.01	-145.31	3.30	3.15
	Positive	404.95	48.15	144.0	2.99	
W-1	Negative	-405.46	-44.01	-146.23	3.32	3.17
	Positive	405.58	47.26	142.5	3.02	
W-2	Negative	-404.21	-44.01	-146.44	3.33	3.14
	Positive	404.07	48.68	143.81	2.95	
W-3	Negative	-400.42	-44.01	-145.61	3.31	3.13
	Positive	400.82	48.71	143.5	2.95	

The results show that the hysteretic curves of the four specimens are full of spindle shape, showing good energy dissipation capacity, and the effect of the width of reinforced plate on the new type of joints is not particularly obvious. When the width is $H/3$, $H/4$ and $H/5$, the ultimate bearing capacity of the specimen is 404.95, 405.58 and 404.07kN respectively. Only when the width is $H/8$, the bearing capacity is slightly lower than that of the others, and the value is 400.82kN. The four specimens have good deformation capacity. The ductility coefficient of the specimens is not very different.

4.3 The effect of the thickness of the flange reinforced plate

In the analysis of the effect of the reinforced plate thickness on the performance of the joint, five specimens are used for comparative analysis. The various parameters of the specimens are shown in table 5. By the computation, the hysteretic and skeleton curves of the specimens are shown in figures 11 and 12, and other results are shown in table 6.

Table 5. The specimen changed thickness sizes of reinforced plate

Specimen No.	Plate length a (mm)	Plate width b (mm)	Plate thickness t(mm)	c(mm)	d(mm)
BASE	0.5H	H/4	$1.5T_f$	50	20
T-1	0.5H	H/4	$1.2T_f$	50	20
T-2	0.5H	H/4	T_f	50	20
T-3	0.5H	H/4	$0.8T_f$	50	20
T-4	0.5H	H/4	$0.5T_f$	50	20

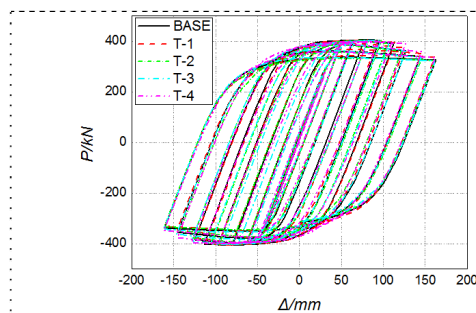


Figure 11. Hysteretic curves of specimens.

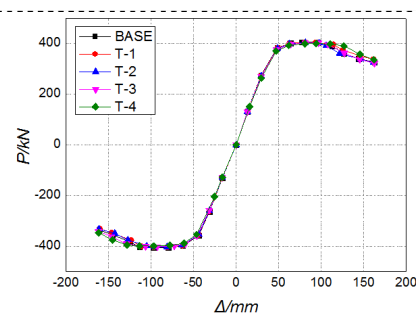


Figure 12. Skeleton curves of specimens.

Table 6. The computing results of reinforced plates with different thickness

Specimen No.	Loading direction	Ultimate bearing capacity(kN)	Yield displacement Δ_y (mm)	Failure displacement Δ_u (mm)	Ductility coefficient μ	$\bar{\mu}$
BASE	Negative	-404.92	-44.01	-145.31	3.30	3.15
	Positive	404.95	48.15	144.0	2.99	
T-1	Negative	-403.82	-44.01	-146.29	3.32	3.16
	Positive	404.19	48.68	145.62	2.99	

T-2	Negative	-402.78	-44.01	-142.68	3.24	3.12
	Positive	403.08	48.68	145.5	2.99	
T-3	Negative	-402.28	-46.32	-146.5	3.16	3.11
	Positive	401.86	47.37	145.0	3.06	
T-4	Negative	-399.57	-46.57	-148.5	3.19	3.15
	Positive	399.52	46.97	145.51	3.10	

The results show that the hysteretic curves of the five specimens are full of spindle shape, showing good energy dissipation capacity, and the effect of the thickness of reinforced plate on the new type of joints is not particularly obvious. With the decrease of the thickness of the reinforced plate, the ultimate bearing capacity of the specimen is decreasing from 405 to the 399.52kN, and the reduction is very small. All the specimens have good deformation capacity. It is known that the ductility coefficient of the specimen is slightly larger when the thickness of the reinforced plate is 1.2 times thickness of the steel beam flange, and the deformability is slightly better than that of other specimens.

5. Conclusions

The joint performance is basically no difference when the flange reinforced plate is changed from trapezoidal to triangular plate. It is found that the performance of the flange reinforced plate welded on the flange side of the beam is not significantly different from those the welded inside the flange of the beam. When the cross section of the column limb is the same width as the steel beam, it will be a good solution to weld the reinforced plate into the flange of the steel beam. Increasing flange reinforced plate length can significantly improve the bearing capacity of the joints. The ductility of the joints is improved by changing the triangular into arc reinforced plate. The arc type plate can be used when the reinforced plate is adopted. The length of the reinforced plate is preferable 1 to 1.2 times the height of the steel beam, the width is desirable for 1/4 to 1/3 of the steel beam height, and the thickness is advisable for 1.2 times the thickness of the steel beam flange.

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