Experiment and Finite-element-method Analysis of Steel Frame Joints Transferring Forces Outside Box Columns

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Abstract: Based on experimental results of two steel frame joints transferring forces outside box columns and two simple joints without inner diaphragms, by widely used finite-element-method program ANSYS, these two types of steel frame joints and traditional joints with inner diaphragms were modeled in this paper. By comparing their load-displacement curves, distributions of Von-Mises stresses and stresses path，effectiveness of the adding force-transforming plates was proofed. The carrying capacities of joints transferring forces outside box columns by adding force-transforming plates are much greater than those of joints without inner diaphragms, and are close to those of traditional joints. The adding force-transforming plates can effectively reduce the stresses of panel zone and change the way of transmitting stresses, and the brittle fracture near the butt weld with high stresses can be avoided.
Keywords: beam-column joint; force-transforming plate; stress; carrying capacity; experiment; finite-element-method.

1. Introduction

For twenty years, more and more beam-column joints' retrofitting and strengthening methods have been proposed to avoid brittle failure of panel zone [1-2]. As the key part of the beam-column connection in the structural steel frame, its performances influence the integral responses of the whole frame under loading [3-5]. Inner diaphragms are set at beam-column connections of traditional steel frame joints, they can ensure sufficient stiffness, yielding strength and ultimate carrying capacity [6-8]. A joint transferring forces outside box column by adding force-transforming plates is present in this paper [9]. By finite-element-method program ANSYS and some experiments, we found that, different from traditional joints, adding force-transforming plates of this new joint can effectively reduce stresses of panel zone and change the way of transmitting stresses.

2. Experimental models

2.1 Joints

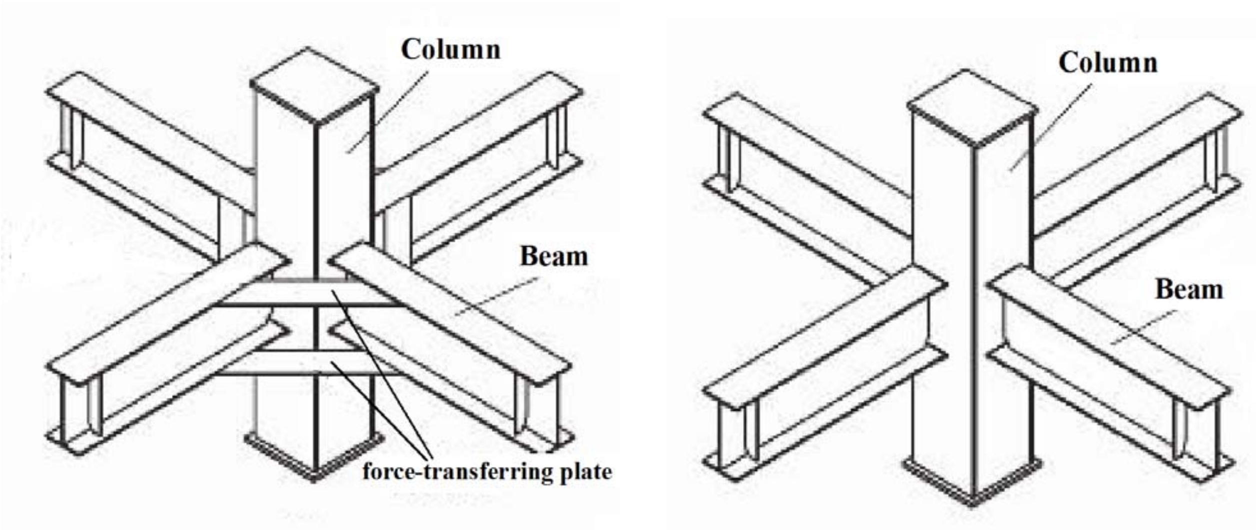
In this experiment, two steel frame joints transferring forces outside box columns and two joints without inner diaphragms were designed [10]. Details of the joints transferring beams' forces outside box columns, joints without inner diaphragms and traditional joints with inner diaphragms in columns at the beam-column connection are shown in Figure 1. Figure 2 shows detail of a force-transforming plate welded between the beams. Thickness, width and lengths of force-transforming plate are indicated by a, b, c and d. For each specimen, the column length is 2 m, the length of each beam is 1.5m. The section size of steel column is W200×200×8, and the section size of each steel beam is H250×125×6×9. The material of steel specimens is Q345B, Poisson's ratio ν =0.3. Joints are all made by welding. The other parameters are shown in Table 1.

2.2 Loading in experiment

During experiments, a vertical force was applied at the top of the column of the joint by a 100t hoisting jack. The joint was put in a 200t counter-force apparatus. At the ends of four beams, concentrated loads were applied upward by 50t hoisting jacks [11], at the same time and with same load values, some experiment pictures are shown in Figure 3.

Table1 Parameters of specimens (in mm)

Specimens		Column section size	Beam section size	Force-transforming plate			
				a	b	c	d
ST-1	Joints transferring forces outside box columns	W200×200×8	H250×125×6×9	9.00	125.00	374.07	124.00
ST-2							
SJ-1							
SJ-2	Traditional joint with inner diaphragms	W200×200×8	H250×125×6×9	none			
ST-3	Joints without inner diaphragms	W200×200×8	H250×125×6×9	none			
ST-4							
SJ-3							



(a) Joints transferring beams' forces outside box columns ST-1, ST-2, SJ-1

(b) Joints without inner diaphragms ST-3, ST-4, SJ-3 and traditional joint with inner diaphragms SJ-2

Fig.1 Conformation of specimens

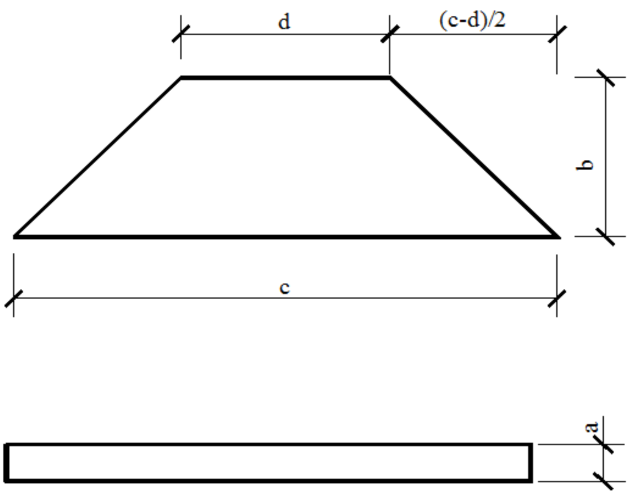


Fig.2 Sizes of adding plate to transfer forces

(a) A joint under loading (b) Loading at end of a beam

Fig.3 Loading of experiment

3. Creation of Finite Element Models

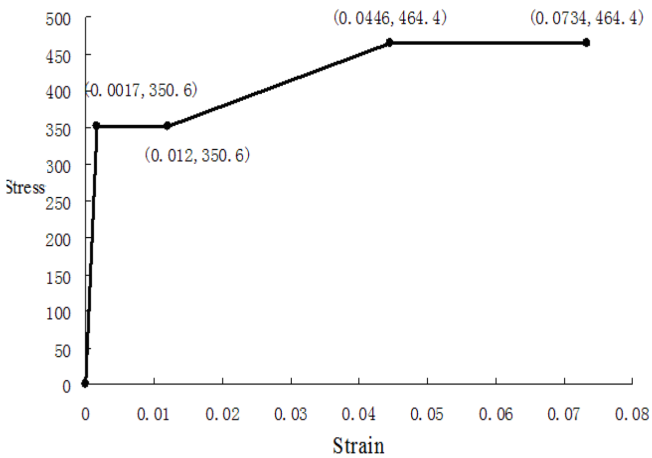
Steel frame joints transferring forces outside box columns，joints without inner diaphragms and traditional joints with inner diaphragms were modeled by finite-element-method program ANSYS.

3.1 Model design

A typical stress-strain curve was obtained by tension test, under SHT41006 electric-fluid servo compression machine, as shown in Figure 4.

Three models SJ-1, SJ-2 and SJ-3 were created by ANSYS. The material of steel joints is Q345B, with its Poisson's ratio 0.3. The sizes of model SJ-1 are same as those of ST-1, and the sizes of SJ-2, SJ-3 are same as ST-3, but different with those of the joint SJ-3, SJ-2 is a traditional joint with two inner plates of 9mm thickness to transfer forces of beam flanges. SJ-3 has no inner diaphragms in column.

In this ANSYS analysis, material nonlinearity and geometric nonlinearity are considered, and the model of Multilinear Isotropic is selected, and the yielding criterion to choose Von-Mises criterion [12].

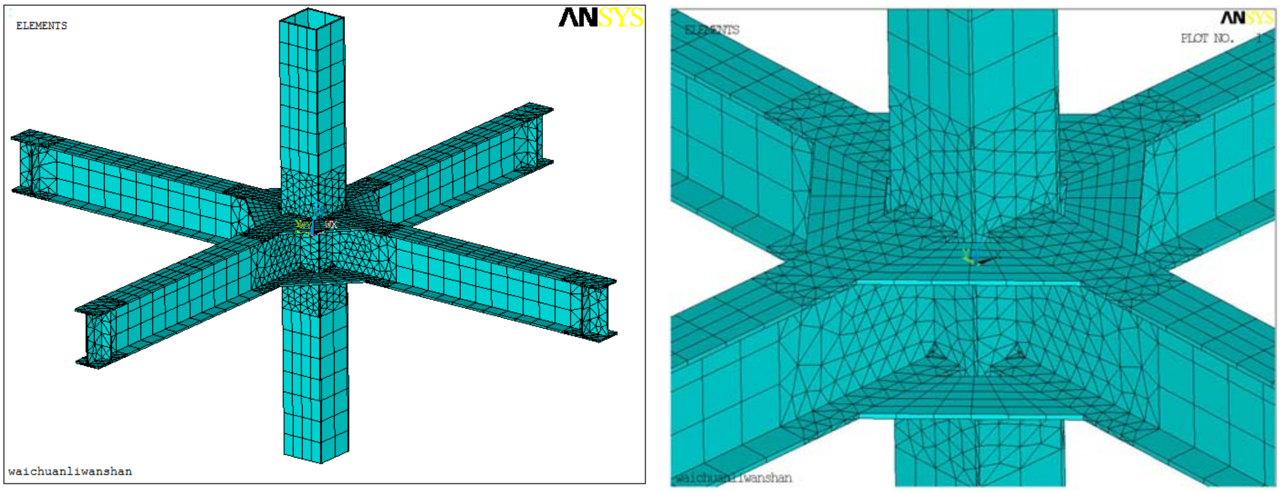


(a) An electric-fluid servo compression machine (b) Stress-strain curve

Fig.4 Stress-strain curve and universal testing machine

3.2 Model discretization

Focusing on the performance of panel zone, smaller elements of the centre part and bigger elements far away from the panel zone were created [13], SOLID45 with 8 nodes was used for beam-column elements which are far away from the panel zone, high-precision SOLID95 with 20 nodes was used for beam-column elements and the force-transforming plates, as shown in Figure 5.



(a) Finite element netting of a joint with force-transforming plates (b) Finite element netting at centre

Fig.5 Finite element discretization of a joint

3.3 Constraints and loading

To simulate actual situation in engineering, constraints along three directions x, y, z are set at bottom of the column, constraints of two directions x, y are set at top of the column. At the top of the column vertical load is applied to simulate the axial loading from upper-structure, and at the ends of four steel beams concentrated loads were applied. Slowly loading of 60 sub-steps is used to simulate static performance of specimens.

4. Results of experiment and Finite-Element-Method Analysis

4.1 Analysis of experimental results

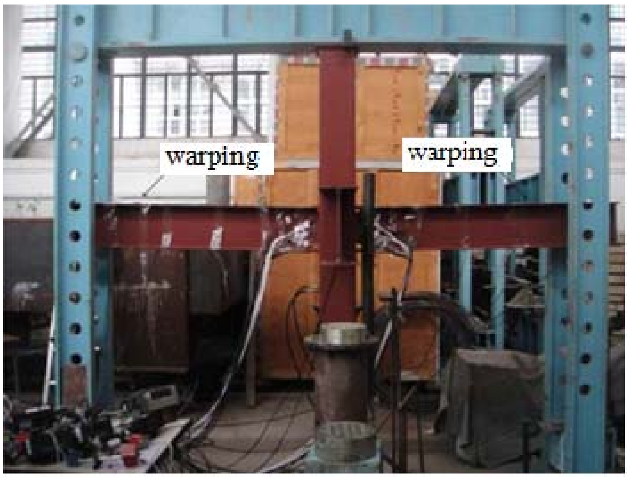
A constant load of 200kN was applied at the top of the column of the joint being tested, four forces were applied at the ends of four beams at same time and with same increasing values.

For joints without inner diaphragms, ST-3, ST-4 experimental yield loads are 18.7kN and 17.9kN, and yield load of joint SJ-3 is 17.2kN, about 8.0% and 4.1% less than experimental results. For joints transferring forces outside box columns, ST-1, ST-2 experimental yield loads are 30.0kN and 28.9kN, and yield load of joint SJ-1 is 30.9kN, about 3% and 6.9% greater than experimental results.

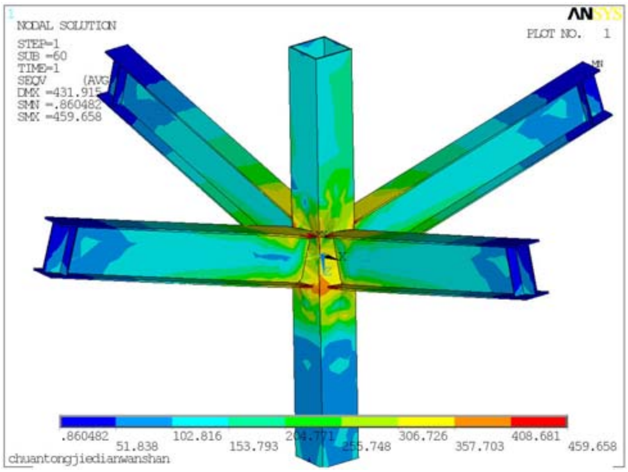
Failure modes of joints by experiment and finite element method are shown in Figure 6 and Figure 7.

As shown in Figure 6, when the load of beam was increased 18.7kN in the experiment, the joint without inner diaphragms ST-3 was yielded and its deformation increased rapidly. Add greater load on the beam, greater stresses were produced at the beam-column connection, and bulging of the column and the warping deformation of beam took place. The same phenomenon occurred in the finite element analysis.

As shown in Figure 7, as for joint transferring forces outside box columns, when the load of beam was increased up to 30kN in the experiment, the joint ST-3 was yielded. Add greater load on the beam, force-transforming plates had serious deformations, but the bulging of the column and the warping deformation of beam didn't took place, it shows that it can effectively reduces the stress of panel zone and changes the way of transmitting stresses by adding force-transforming plates. The same phenomenon occurred in the finite element analysis.

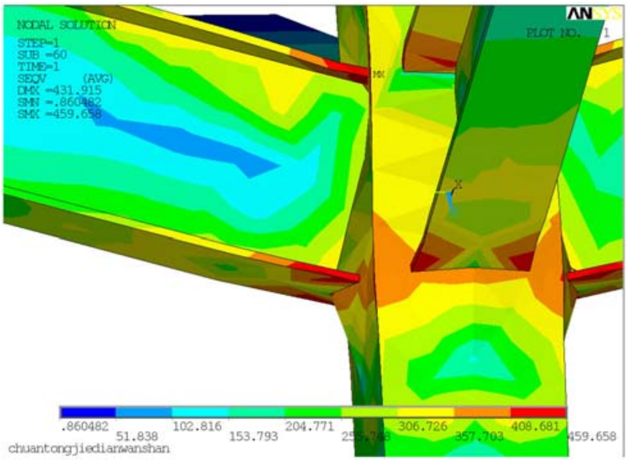


(a) Warping in the experiment



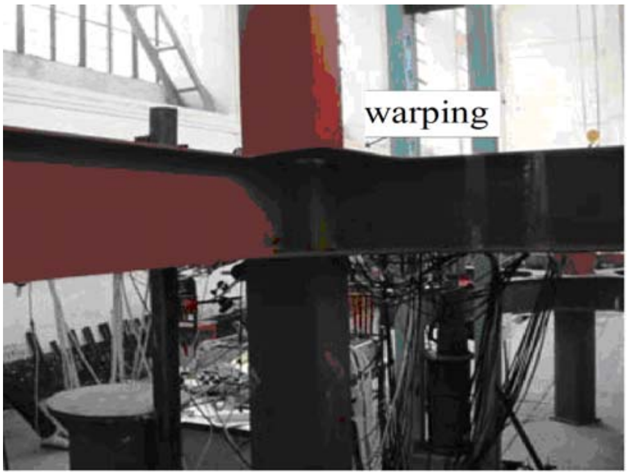
(b) Warping in simulative calculation

(c) Bulging of the column

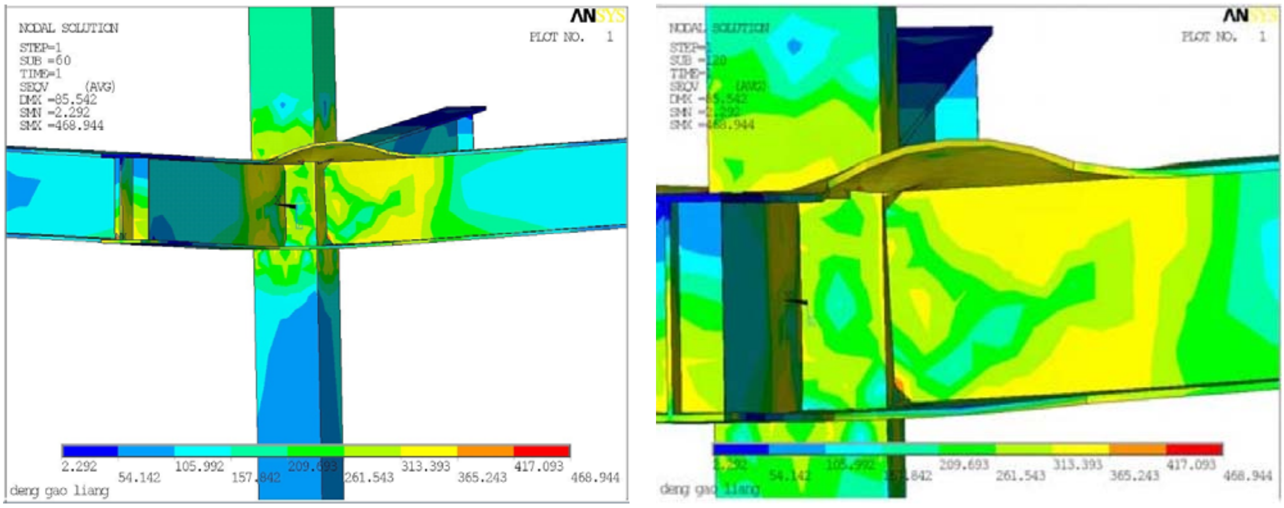


(d) Bulging of the column

Fig.6 Failures by experiment ST-3 and by finite element analysis of specimens SJ-3



(a) Deformation of force-transforming plates in the experiment of ST-1



(b) Deformation of force-transforming plates in finite-element-method analysis of SJ-1

Fig.7 Comparison of failures by experiment and by finite-element-method analysis

4.2 Results of finite-element-method analysis

4.2.1 Load-displacement curves

Taking beam as reference points on the flange of the central axis, by widely used finite-element-method program ANSYS, a joint transferring forces outside box columns, joint without inner diaphragms and traditional joint were analyzed. The load-displacement curves are shown in Figure 8.

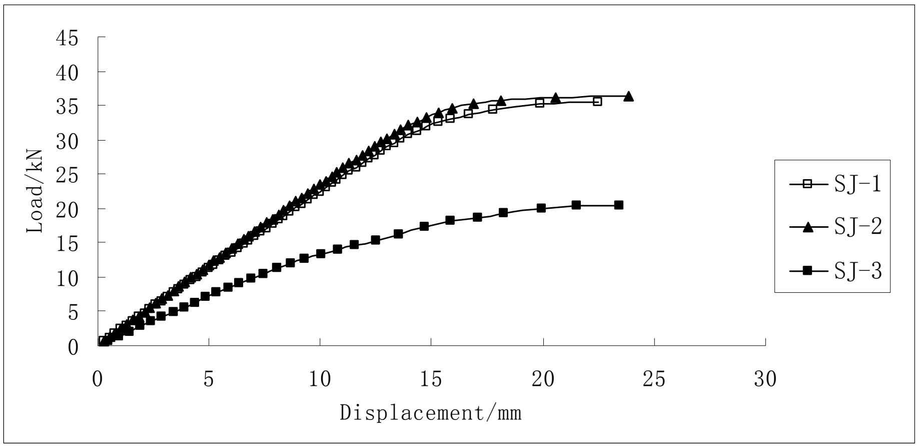
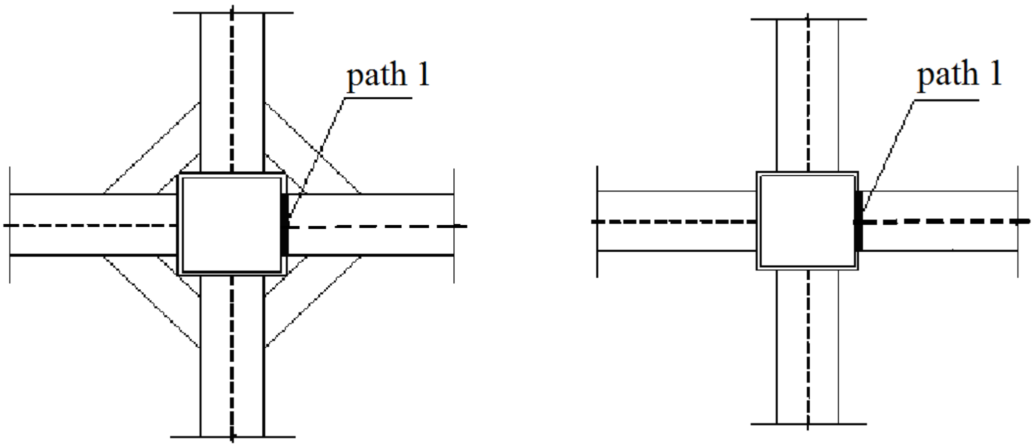


Fig.8 Load-displacement curves of SJ-1, SJ-2, SJ-3

As shown by the load-displacement curves of SJ-1, SJ-2 and SJ-3, when the load of beam was increased to 17.2kN, joint without inner diaphragms was yielded and its deformation increased rapidly. While under the same load, joint transferring forces outside box columns and traditional joint were still in the elastic-plastic state. Comparing with joint without inner diaphragms, we find that yielding capacity, stiffness, ultimate carrying capacity of traditional joint and joint transferring forces outside box columns have greatly increased. The yielding capacity of joint transferring forces outside box columns was 30.9kN, and 79.7% greater than that of specimen SJ-3. The yielding capacity of traditional joint was 31.7kN, and 84.3% greater than that of specimen SJ-3. Ultimate carrying capacity of specimen SJ-3 was only 20.3kN. SJ-1 was a specimen which joint transferring forces outside box columns by adding force-transforming plates, it was 35.5kN of the ultimate carrying capacity, about 74.9% greater than that of joint without inner diaphragms. And it was very close to that of traditional joint, which was 36.4kN.

4.2.2 Analysis of Von-Mises stresses

In order to analyze the Von-Mises stresses of panel zone, we took the beam-column connection position as Von-Mises stresses of the path 1(see Figure 9). We got stresses' distribution as shown in Figure 10.



(a)Path of joints transferring forces outside box columns

(b) Path of joints without inner diaphragms and traditional joints

Fig.9 Path of joints

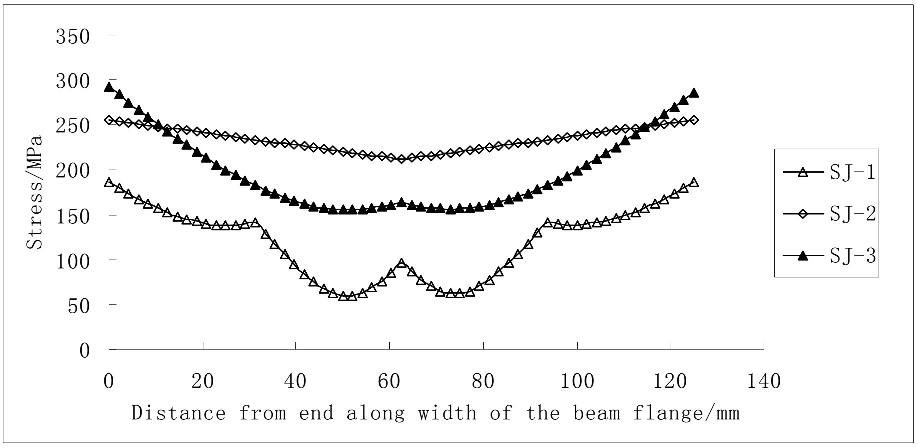


Fig.10 Distribution of Von-Mises stresses of the path 1

As shown in Figure 7, stresses were evenly distributed for traditional joint, with its maximum stress was 255.3MPa. But stresses of joint without inner diaphragms were distributed unevenly, with its maximum stress was 292.4MPa, comparing to the specimen SJ-2, and maximum stress of specimen SJ-3 was increased by 14.5%. For joint transferring forces outside box columns by adding force-transforming plates, stresses of beam-column connections have been greatly decreased, with its maximum stress was only 186.5MPa, about 26.9% less than that of traditional joint, and 36.2% less than that of joint without inner diaphragms. The stress of midpoint of beam's top flange was 95.7MPa, only 0.45 times the stress of specimen SJ-2, and 0.59 times the stress of SJ-2. So the stresses of beam-column connections can be greatly decreased by adding force-transforming plates, and the inner diaphragms is no longer the only way to transfer stresses. Transferring force outside columns can be realized.

5. Conclusions

In this paper, two joints transferring forces outside box columns and two joints without inner diaphragms had been experimented. Combined with calculation by widely used finite-element-method program ANSYS, we have some conclusions as following:

1) By experiment, yield loads of joints without inner diaphragms were 18.7kN and 17.9kN, but yield loads of joints transferring forces outside box columns yield load were 30.0kN and 28.9kN.

2) Calculation by finite-element-method of joint transferring forces outside box columns, ultimate carrying capacity is 35.5kN, 74.9% greater than that of joint without inner diaphragms. And it was very close to that of traditional joint, which was 36.4kN.

3) For joint transferring forces outside box columns, the stresses of beam-column connections can be greatly decreased by adding force-transforming plates, and the inner diaphragms is no longer the only way to transfer stresses. Transferring force outside columns can be realized. Joints with force-transforming plates can be used to the practical engineering.

6. Acknowledgements

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7. References

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