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Simulation Analysis on Hysteretic Performance of Cross-type Rigid Node for Steel Frame Based on Abaqus

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Abstract

In order to study the cross-type rigid steel frame node hysteretic behavior of components, the axial compression ratio, H type steel column web thickness, girder section and stiffener as design parameters, 8 steel frame cross-type rigid joints and a T-type rigid joint are designed. Based on simplified mechanical model and constitutive relations of material, using ABAQUS software the corresponding finite element model is established and the hysteretic performance analysis is carried out. Through comparison between given T-type node test results and analysis results, both are in good agreement, thus the rationality of the finite element model established in this paper is verified. Simulation analysis of cross-type node is developed in further, load -displacement hysteretic curve of nodes, skeleton curve, envelope figure and the stress nephogram are extracted and comparative analysis is conducted, influence regularity of four parameters on the seismic behavior of the joints is obtained. The corresponding design suggestion for the axial compression ratio and column web and flange thickness ratio is proposed, design limit value of axial compression ratio of column should be taken as 0.5 and limit value of column web and flange thickness ratio is taken as 0.75,and these can provide reference for actual engineering design.

Keywords: *Cross-type Rigid Connections, Hysteretic Behavior, Abaqus software, Finite Element Analysis, Design Suggestions*

1. Introduction

Steel structure is applied widely in civil engineering structure with the advantages of light weight, high strength, good ductility, excellent seismic performance, flexible layout. In recent years, with combination between steel frame and concrete composite slab to make more and more application in high-rise buildings for steel structure, it has become the main building structure system. As everyone knows, the steel structure has certain particularity, mechanics performance of the steel frame node directly affects the safety and applicability of steel structure, and thus it is a key to the design of steel structure for ensuring the structure node with good seismic ability. Many scholars have carried out the experimental study and theoretical analysis of the node in different forms, through the opening in the web of the beam the weakening type node hysteretic performance analysis was carried out by Xi'an University Of Architecture and Technology Liu Yan *et al.* [1], the node that beam web is reduced has good plastic deformation ability and can effectively reduce the stress of beam flange. Design

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and research institute of Wuhan University of Technology Dai Shaobin *et al.* [2] carried out tests and nonlinear finite element analysis on the flange weakening type rigid joints under low cyclic loading, and results show that the flange weakening type rigid connection has a large connection stiffness and ideal energy dissipation, the weld strength at beam flange is the main factor for affecting the flange weakening type rigid connection joints. Test analysis on mechanical performance of beam web opening connection was performed for steel frame by Harbin Institute of Technology Wang Xiuli *et al.* [3], and discussed the hysteretic behavior of beam column joints domain, using ABAQUS finite element program to explore different influence of plastic hinge position on the structural ductility. The adoption of this kind of node can reduce the possibility of brittle failure of the connection welding, and effectively control plastic hinge position, so as to improve the overall ductility of frame structure. Chen Hong of Tsinghua University performed nonlinear finite element analysis on steel frame beam-column joints of 4 kinds of structural forms, by comparison simulation and test results were in good agreement, finally the improved node form was given [4]. Some scholars have carried out analysis on mechanical effect of floor and wall to rigid node, after the combined effect was considered stiffness and bearing capacity of node improved, hysteretic behavior and seismic capacity were improved [5-7]. Tsinghua University Shi [8] has carried out analysis on mechanical performance of semi-rigid node of end plate connection for steel frame, and mechanical performance of semi-rigid node of end plate connection node was explored. The results showed that the characteristics of flush end plate connections was more close to the hinged joints, and bearing capacity and stiffness decreased by approximately 50%, while the extended end plate was exerted with stiffening rib, it can make the nodes obtain good mechanical properties. Wihittaker *et al.* [9] carried out research on quasi static test of T-type rigid node, T-type node moment rotation curve was acquired, based on the test seismic design method is put forward, so the conclusion has certain limitation.

Though there was some study on different nodes, feasible design proposal is less on the actual project, the numerical analysis on hysteretic performance of cross-type rigid joints for steel frame has not been reported based on the axial compression ratio, column web thickness, section forms of beam and stiffening rib. Therefore, this article uses large-scale finite element software ABAQUS [10, 11] to carry out hysteretic performance analysis on 8 groups of cross-type rigid node and 1 T-type joint for steel frame, and the effect of different parameters on the mechanical performance is investigated, seismic performance index for the specimen stiffness degradation, energy dissipation capacity, bearing ability and ductility is explored, some suggestions on the design of the actual engineering are put forward, these can provides the theory basis for the design of this kind of node, and lay a foundation for carrying out seismic performance test of steel concrete composite structure node in further.

2. The Design of Simulation Specimens

In order to investigate the influence of axial compression ratio, web thickness of H-type steel column, sectional forms of beams and stiffening rib four parameters on seismic behavior of this kind of joints, based on code for design of steel structure (GB50017-2012) 8 groups cross-type rigid welding joints were designed under the control of different parameters, and the specific parameters of the specimens were shown in Table 1.

The specimen JD-2 was selected as the standard sample, sectional size of the column with a height of 3000mm is 400mm × 300mm × 10mm × 16mm and section size of H-type beam with a length of 1500mm is 300mm × 200mm × 8mm × 12mm. variable parameters of specimens included axial compression ratio, web thickness of H-type steel column, sectional form of girder and stiffening rib. The axial compression ratio was 0.2, 0.4 and0.6

respectively, and web thickness of H-type steel column was 10mm, 12mm and 14mm respectively. The section forms of beam were taken as H-type steel, round steel tube and square steel tube. Stiffening ribs with a size of 368mm × 145mm × 12mm were set in intersection position between beam and column. 3D geometry models of some specimens were shown in Figure1. At the same time the author designed a set of T-type rigid joint which number was named for EERC-PN, the specific data were listed in Table 2. The size and sectional form were exactly the same as test node in reference [9], and it was used to validate the correctness of the finite element model. To be consistent with the original data, inch was used as unit of length and ksi was used as unit of the yield strength and elastic modulus.

Table 1. The Main Parameters of Specimens

Specimens	The axial compression ratio	The web thickness of column	The sectional forms of beams	The stiffening rib
JD-1	0.2	10 mm	H-type steel 300mm×200mm×8mm×12mm	No stiffeners
JD-2	0.4	10 mm	H-type steel 300mm×200mm×8mm×12mm	No stiffeners
JD-3	0.6	10 mm	H-type steel 300mm×200mm×8mm×12mm	No stiffeners
JD-4	0.4	12mm	H-type steel 300mm×200mm×8mm×12mm	No stiffeners
JD-5	0.4	14 mm	H-type steel 300mm×200mm×8mm×12mm	No stiffeners
JD-6	0.4	10 mm	Circular steel tube 203mm×12mm	No stiffeners
JD-7	0.4	10 mm	square steel tubes 158 mm×12mm	No stiffeners
JD-8	0.4	10 mm	H-type steel 300mm×200mm×8mm×12mm	stiffeners

Table 2. The Size of EERC-PN Specimen and Mechanical Properties

EERC-PN Specimen	Height of section	Width of section	Thickness of web	Thickness of flange	Yield stress		Modulus of elasticity
					web	flange	
Column	15.22	15.65	0.83	1.31	49.50	50.00	29500
Beam	29.65	10.45	0.52	0.67	55.70	50.3	

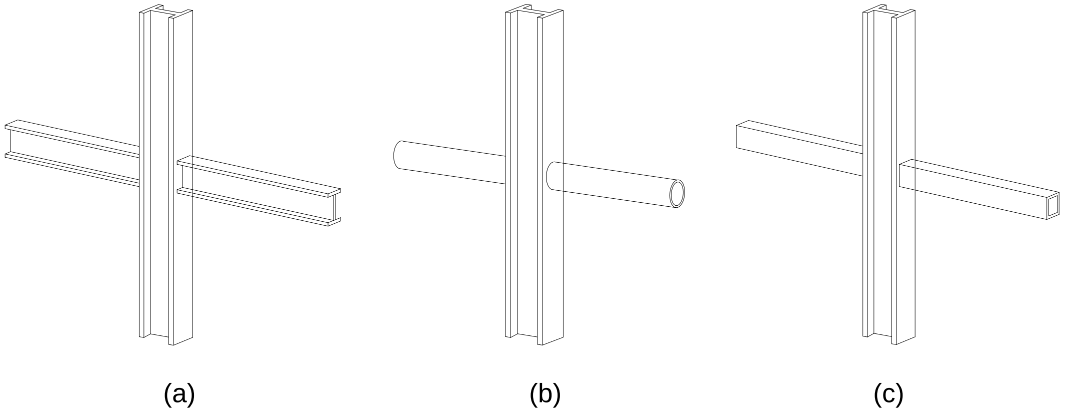


Figure 1. Three-dimensional Geometry Entity Models of Specimens

3. Finite Element Analysis based on ABAQUS Software

3.1. The Process of Computer Software Analysis

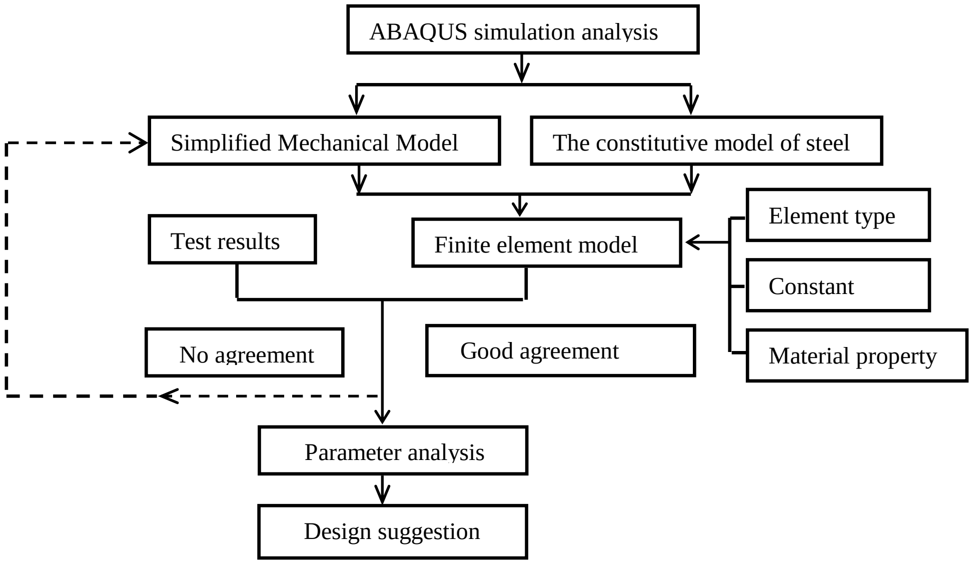


Figure 2. The Process of Computer Software Analysis

The process of computer software analysis is listed in Figure 2, we can acquire simulation solution instead of test by computer, it not only can save a lot of money, but also can carry out some analysis test can not achieve.

3.2. Simplified Mechanical Model

The node is formed at intersection position of frame beam and column, and force is more complex at node. Both ends of column are the hinged supports and a constant axial force is applied at the top of the column. Frame beams at both ends form free ends, and cyclic loading is applied. Simplified models of cross-type and T type nodes are shown in Figure3 and Figure4 respectively.

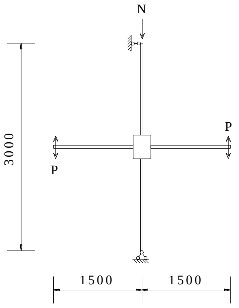


Figure 3. Cross-type Node

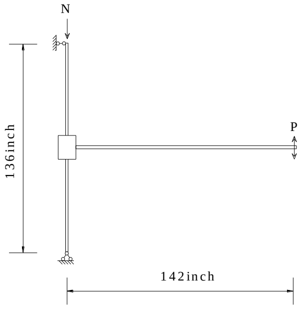


Figure 4. T-type Node

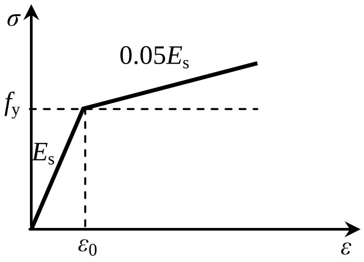


Figure 5. Stress-strain Curve

3.3. The Constitutive Model of Steel

Members are made of Q345 grade steel and the mechanical property index of steel is shown in Table3. Considering the displacement is large during node hysteretic analysis, steel will enter the strengthening phase after steel yields, so the stress increases with the increase of strain, the bilinear kinematic hardening model is adopted as the constitutive model for steel, and slope of strengthening stage is for 0.05Es. The simplified stress-strain relationship curve is shown in Figure 5. Specific physical meaning of parameters is listed in Table 3.

Table 3. The Mechanical Property Index of Steel

Material	E_s /MPa	Poisson's ratio	f_y /MPa	f_u /MPa
Steel	2.1×10^5	0.3	345	450
Bottom plate	2.1×10^6	0.3	---	---

3.4. Finite Element Model

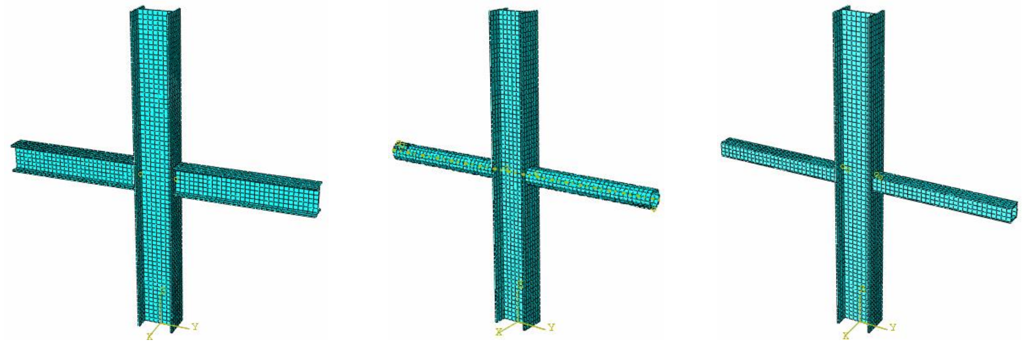

(a) (b) (c)

Figure 6. Finite Element Models of Specimens

ABAQUS [10] is one of the most powerful finite element analysis software, which has a powerful function of calculation and simulation capabilities widely. The hysteretic nonlinear finite element analysis was carried out using ABAQUS software, the H-type steel column, H-type steel beam, round steel tube, square tube, stiffener and plate were simulated by adopting three-dimensional entity unit C3D8R with 8 nodes linear reduced integral function. Beam, column and the plate component were created in the assembly module, and each component is assembled together. Therefore, combined with the characteristics of node model in this paper, grid was meshed by swept mesh Division [11] technique, hexahedral elements which were relatively easy for convergence were gotten. Finite element model was shown in Figure 6 after grid was meshed for node consisting of beam of different sectional forms.

Combined with the force characteristics of node under the actual circumstances, pseudo static loading mode was adopted. The loading scheme was shown in Figure 7, δ was the loading displacement, N was loading cycles. Finite element models after constraint are shown in Figure 8and Figure 9.

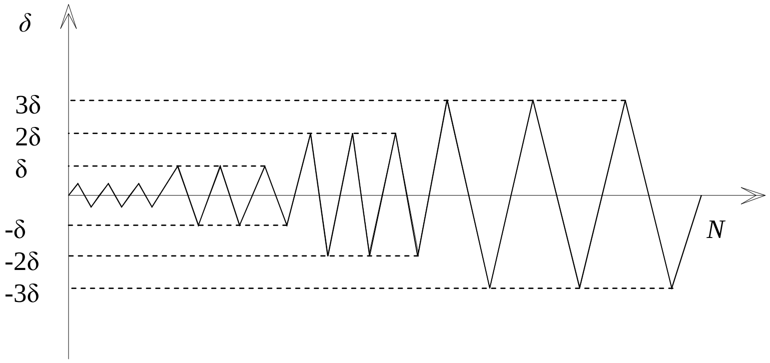


Figure 7. Cyclic Loading Schemes

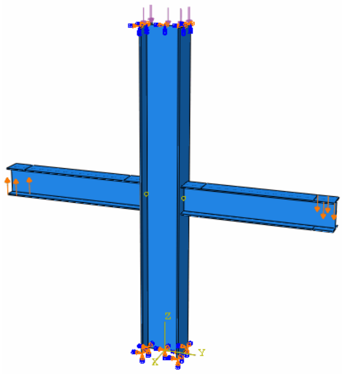


Figure 8. FEM for Cross-type Rigid Node

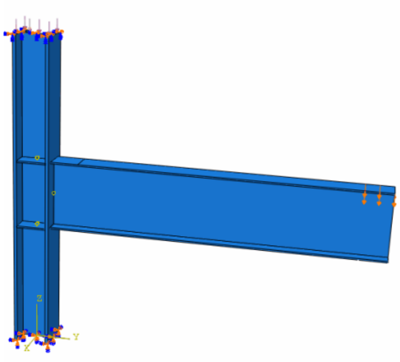
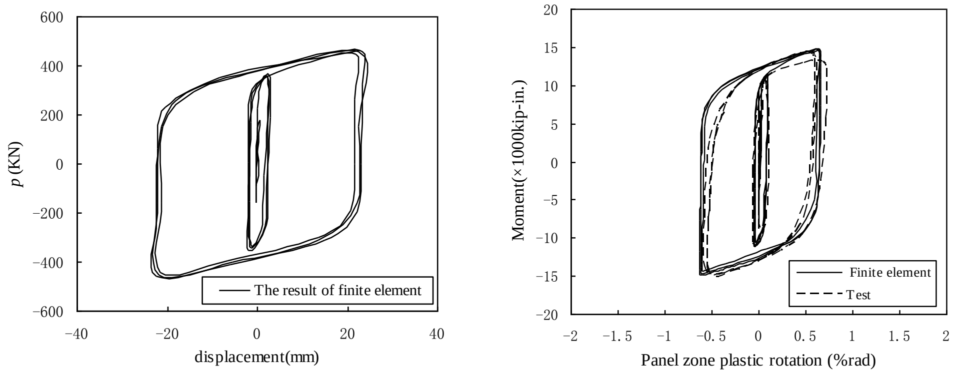


Figure 9. FEM for EERC-PN1specimen

4. Analysis and Comparison on the Results of Simulation

4.1. The Validation of Finite Element Model

Foreign scholars Wihittaker *et al.* [9] carried out test analysis of T-type rigid node, and load- displacement hysteretic curve was obtained and transferred into moment-rotation hysteresis curve shown in Figure 10(b). Nonlinear simulation analysis of EERC-PN1 node finite element model was carried out by ABAQUS software, and component parameters and loading plan were the same as test, load-displacement hysteretic curve of EERC-PN was extracted as shown in Figure 10 (a). Its moment-rotation hysteresis curve was shown in Figure 10 (b). Through contrast we can see that both are in good agreement, therefore the method establishing finite element model is correct, which laid a foundation for developing hysteretic numerical analysis of cross-type node in further.

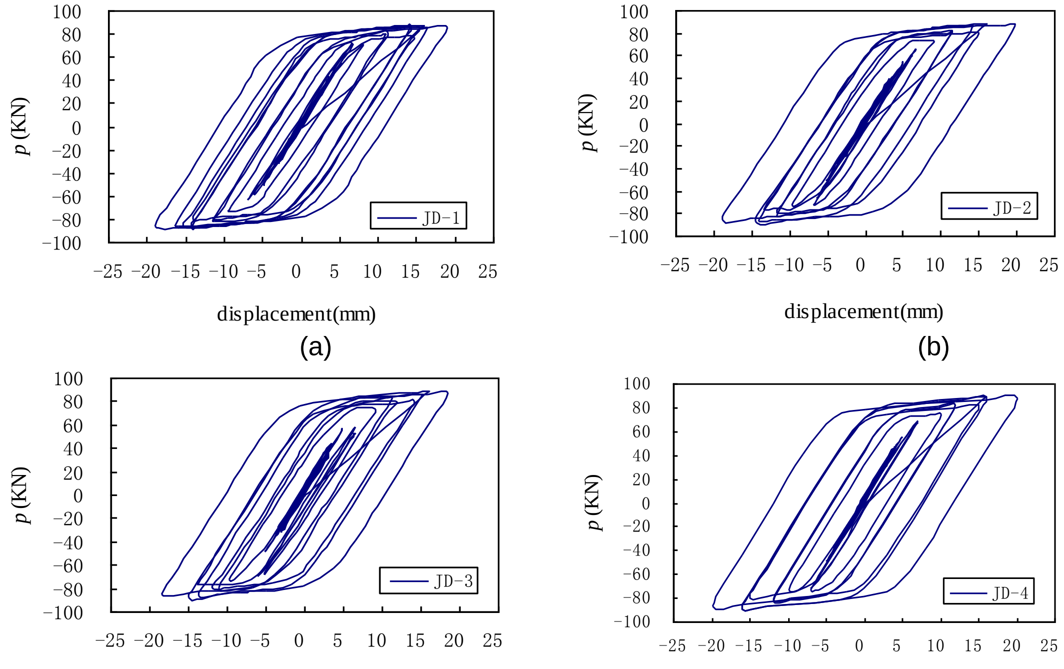


(a) (b)

Figure 10. (a)The FEM Result of EERC-PN Specimen (b) The Comparison between FEM and Test Results

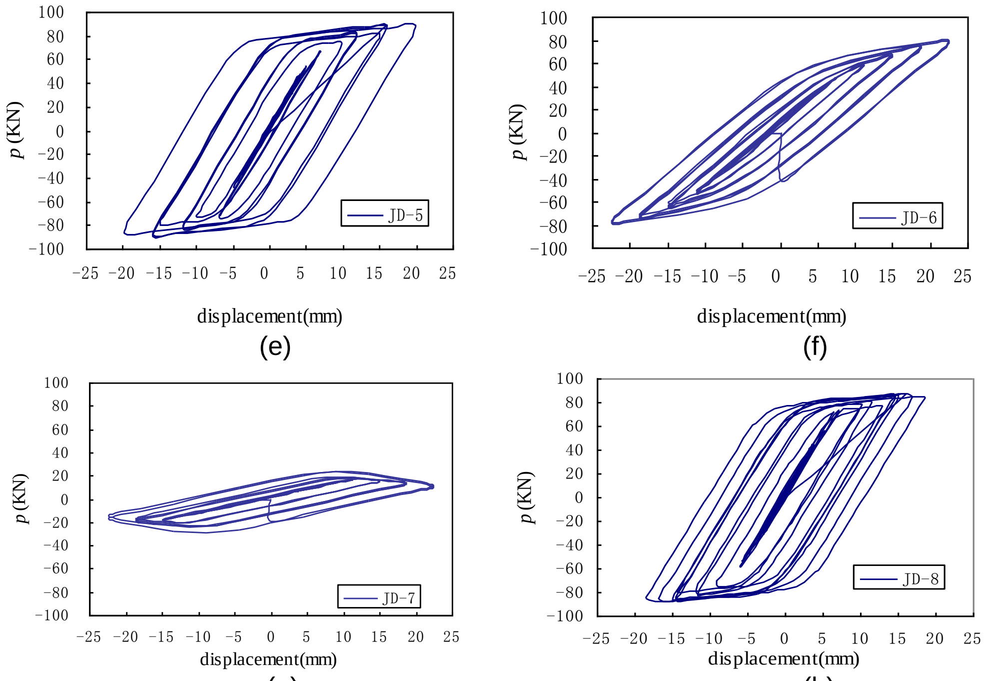
4.2. Hysteretic Curves and Analysis on Eight Groups of Specimens

Based on the verification analysis process, the hysteretic analysis on 8groups JD specimens was carried out using ABAQUS software, and load-displacement hysteretic curve data were extracted by the visualization module, then the load-displacement hysteretic curves were drawn using Excel software, all are shown in Figure 11. Envelope figure contrast extracted from different specimens is shown in Figure 12.



(a) (b)

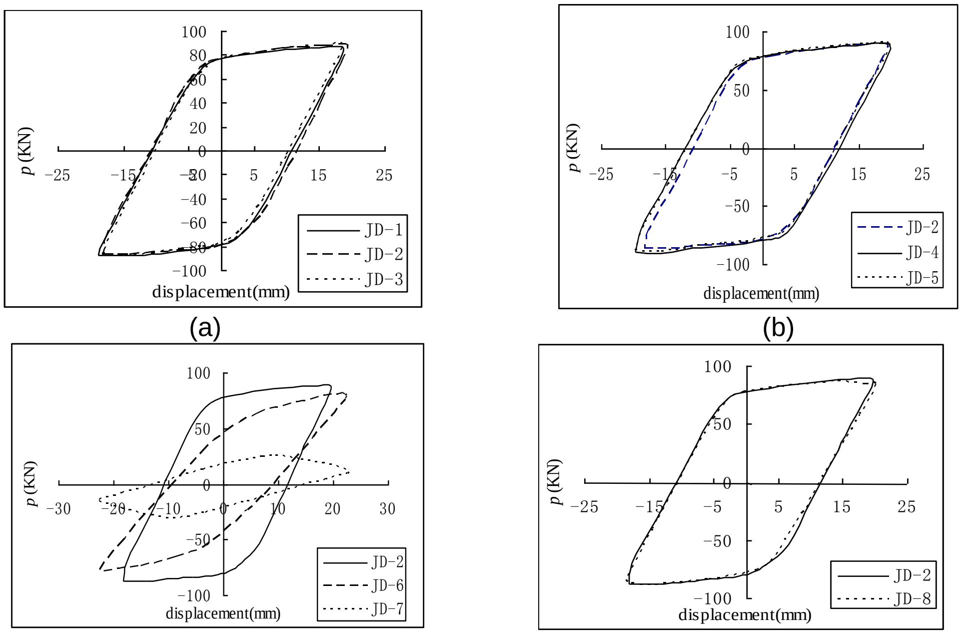
(c) (d)



(e) (f)

(g) (h)

Figure 11. The Load-displacement Hysteretic Curves



(a) (b)

(c) (d)

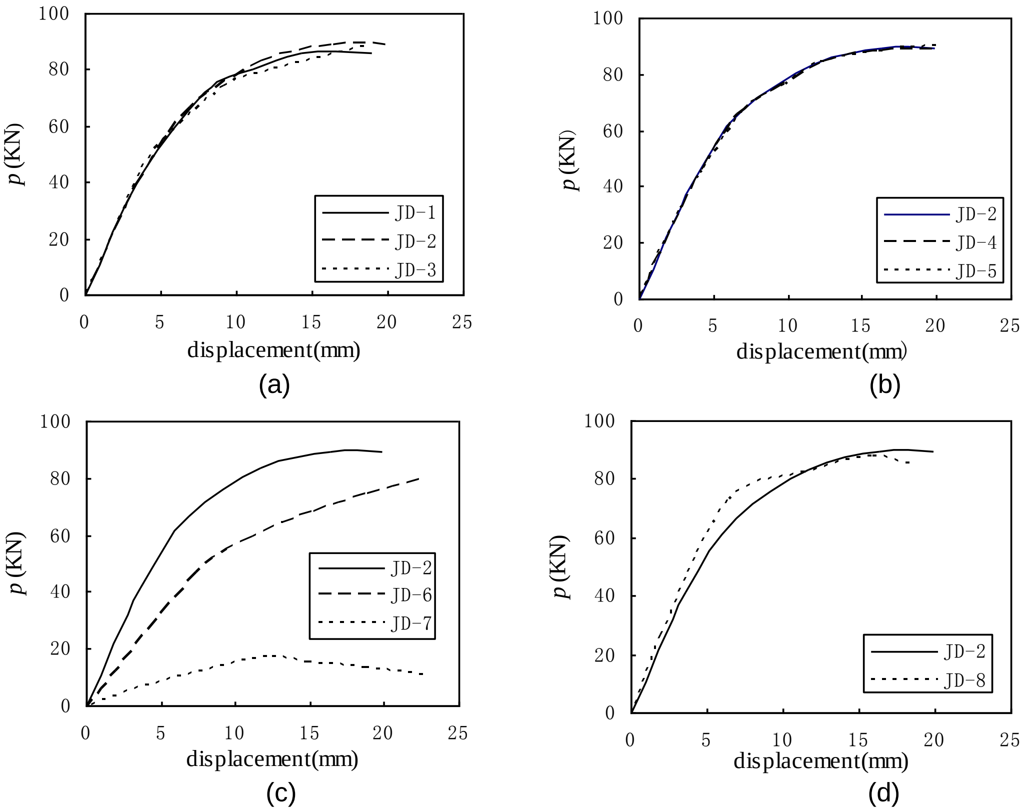
Figure 12. (a) Envelope under Different Axial Compression Ratio, (b) Envelope under Different Webs of Column, (c) Envelope under Different Sections of Beam, (d) Envelope under Different Stiffening Ribs

The load-displacement hysteretic curves of 8 groups of specimens are shown in Figure 11, we can see that the hysteretic curves are plump and show good plastic behavior. Envelope charts of specimen JD-1, JD-2 and JD-3 are compared as shown Figure 12 (a), and the envelope area is 3501.4KN·mm, 3681.5 KN·mm and 3376.2KN·mm respectively. Envelope charts of specimen JD-2, JD-4 and JD-5 are compared as shown Figure 12 (b), and the envelope area is 3681.5 KN·mm, 3956.5 KN·mm and 3898.3 KN·mm respectively. Envelope charts of specimen JD-2, JD-6 and JD-7 are compared as shown Figure 12 (c), and the envelope area is 3681.5 KN·mm, 2324.1 KN·mm and 1161.3 KN·mm respectively. Envelope charts of specimen JD-2 and JD-8 are compared as shown Figure 12 (d), the envelope area was 3681.5 KN·mm and 3702.9 KN·mm respectively. It can be seen from Figure 10 specimen JD-1, JD-5 and JD-8 have good energy dissipation capacity, specimen JD-6 and JD-7 envelope area is small, so the energy dissipation capacity is relatively poor. From Figure 10 and Figure 11 the following conclusions are drawn:

When axial compression ratio is from 0.2 to 0.4, with the increase of axial load ratio, area of envelope diagram increases and energy dissipation capacity of node also increases. While the axial compression ratio is from 0.4 to 0.6, with the increase of axial load ratio, area of envelope diagram decreases, the energy dissipation capacity of node reduces. With the increase of the web thickness of column, hysteretic loop becomes more full, the energy dissipation capacity and ductility of node increases, but the web thickness is too thick, the hysteretic loop envelope area decreases, energy dissipation capacity of node decreased slightly. Nodes of different section forms of beam are analyzed, when the section forms of beam is H-type steel the node has the most full hysteretic loop, the largest envelope area, the strongest energy dissipation capacity, the maximum ductility and bearing force. When the section forms of beam are for steel tubes, all indexes decrease in comparison with H-type steel beam. While the section forms of beam are for square steel tube, bearing capacity of node is the lowest, energy dissipation capacity and the ductility are the worst. Hysteretic loop of node set stiffening rib is more full, envelope area and ductility increases.

4.3. Skeleton Curves

Skeleton curves of specimens are formed by maximum value connections at hysteresis loop, skeleton curves of 8 specimens and comparison are shown in Figure 13. The comparison of skeleton curves of specimens JD-1, JD-2 and JD-3 is shown in Figure 13 (a), JD-1, JD-2 and JD-3 axial compression ratios are 0.2, 0.4 and 0.6, with the increase of axial load ratio bearing capacity of node increases firstly, then decreased, while initial rigidity of joint does not change obviously. The comparison of skeleton curves of JD-2, JD-4 and JD-5 is shown in Figure 13 (b), when web and flange thickness ratio of the column is from 0.625to 0.750, bearing capacity and initial stiffness of the joint does not change significantly with the increase of column web thickness. When web and flange thickness ratio of the column is from0.750 to 0.875, bearing capacity and initial stiffness of the joint decrease slightly with the increase of the column web thickness. Overall, column web thickness has little effect on this kind of node, mainly because the bearing capacity and stiffness of “strong column and weak beam” type of nodes is mainly controlled by steel beam. he comparison of skeleton curves of JD-2, JD-6 and JD-7 is shown in Figure 13 (c), the influence of the sectional forms of beam on bearing capacity and initial stiffness of the joint is very large. When the sectional forms of beam is for H-type steel, bearing capacity and initial stiffness of the joint are the highest. When the sectional forms of beam is for circular pipe, all indexes decreases in comparison with H-type beam. While the sectional forms of beam is for square steel tubes, the carrying capacity and the initial stiffness of node are the lowest. The comparison of skeleton curves of JD-2 and JD-8 is shown in Figure 13 (d), stiffener can improve initial rigidity of joint and yield capacity of node increases significantly.



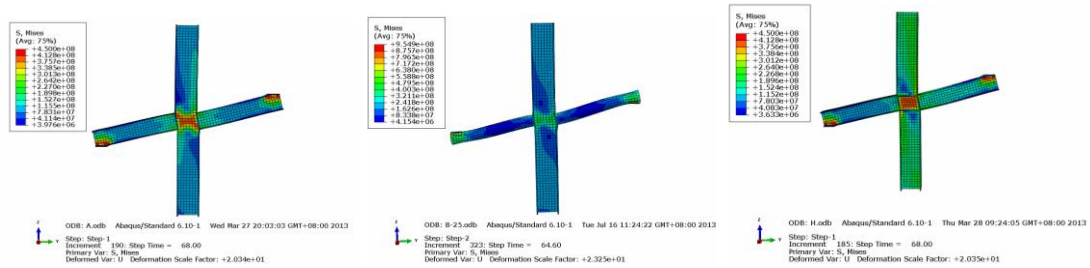
(a) (b)

(c) (d)

Figure 13. The Comparison of Skeleton Curves

4.4. Stress Analysis

Through Visualization module of ABAQUS software, stress nephograms of specimens are shown in Figure 14. We can see from Figure 14 (a) maximum stress of the node happened at interaction position of beam flange and column (the maximum bending moment), and σmax is 413.94MPa. The material has entered the yield stage, so it is the easiest for interaction position of beam flange and column to failure. The maximum stress of all specimens is shown in Table 4, it can be seen from Table 4 with the increase of axial load ratio, the maximum stress value of beam column connections increases firstly and then decreases. With the increase of column web thickness, the maximum stress value decreases. The maximum stress is significantly lower for JD-8 node at connection position of beam and column, it is only 285.33 MPa, and so transverse stiffener can effectively reduce the stress at the connection. For specimen JD-6 JD-7 node, the maximum stress reaches ultimate strength of steel, and node failures, therefore seismic performance of the node consisting of circular steel tube or square steel tubes is poor.



(a) (b) (c)

Figure 14. (a) JD-1 Stress Nephogram, (b) JD-6 Stress Nephogram, (c) JD-8 Stress Nephogram

Table 4. Stress Value at the Interaction Position of the Flange of Beam and Column

Specimen	JD-1	JD-2	JD-3	JD-4	JD-5	JD-6	JD-7	JD-8
Stress /MPa	413.9	416.8	405.8	411.1	396.3	450.0	450.0	285.3

5. Recommendations for Project Design

By Nonlinear Numerical Analysis of steel frame cross-type rigid nodes, the following 4 pieces of suggestions are put forward:

(1) During analysis axial force and strength of materials is the standard value, but in practical steel structure design engineering the design value of axial compression ratio is adopted, the conversion relationship between the standard value and the design value is shown in (1).Through analysis we can know that the joints of beam and column sectional forms for H-type steel, when axial compression ratio of joint column is less than 0.4, their bearing capacity, energy dissipation capacity increase with the increase of axial compression ratio. When the axial compression ratio is from 0.4 to 0.6, the joint bearing capacity, energy dissipation capacity decrease with the increase of axial compression ratio, but the ductility don’t decreases obviously. Therefore the axial compression ratio 0.4 is seismic bearing capacity limit of this kind of node. Through equation (1) conversion the design value of axial compression ratio corresponding to axial compression ratio 0.4 is 0.53, so as to ensure the node to meet the requirements of seismic load, design limit value of axial compression ratio of column should be suggested for 0.5.

$$\frac{N}{f_y A} \approx \frac{1.2N_k}{\frac{f_{yk}}{1.1}A} = \frac{1.2\times 1.1N_k}{f_{yk}A} = 1.32\frac{N_k}{f_{yk}A}. \qquad \textbf{(1)}$$

(2) When sectional form of steel beam is H-type steel for steel frame cross-type rigid node, hysteretic curves of this kind of nodes are full under cyclic loading and good seismic performance, and far better than that sectional forms of round steel and square steel tube, so H-type sectional form which beam and column adopt is good during design. In Code for design of steel structure at position of compression and tensile flange of beam, the corresponding provisions are given for column web thickness t_w and column flange thickness t_c [12], while under the action of the earthquake, the beam ends of steel frame will experience

tension and compression process repeatly [13], so the thickness of column web and flange at node position should remain unchanged and avoid welding in node domain of column.

(3) The web and flange thickness ratio of the column should not be too large, when the ratio is less than 0.75, with the increasing of ratio load-carrying capacity of the node does not change significantly, but energy dissipation capacity for the node increases. When the ratio is greater than 0.75, the joint bearing capacity and energy dissipation capacity decrease with the increasing of ratio, so thickness ratio limit value of the column flange and web is taken as 0.75.

(4) The specimens arranging transverse stiffener is stronger for bearing capacity, under the same displacement compared with specimen without transverse stiffeners, node stress is smaller, so the seismic behavior of the joints can be improved through transverse stiffeners at the nodes. But the joint shearing strength should meet the requirements of (2), the physical meaning of (2) is shown in literature [14].

$$\frac{M_{\mathrm{b1}} + M_{\mathrm{b2}}}{V_{\mathrm{p}}} \leq \frac{4}{3} f_v \, . \tag{2}$$

Transverse stiffeners should be able to transfer concentrated force which coming from beam flange. In order to enhance the shear capacity, inclined stiffener can be set in the node domain, and inclined stiffener should send shearing force except node domain can bear shearing force.

6. Conclusions

Simulation analysis on seismic performance of steel frame cross-type rigid nodes was carried out by using finite element ABAQUS software, and the following four conclusions are obtained through analysis and comparison of finite element results.

(1) Axial compression ratio, web thickness of H-type steel column, sectional form of girder and stiffener were taken as parameters, 8 steel frame cross-type rigid node and 1 T-type rigid node were designed, and simplified mechanical model and material constitutive relation were given, based on these finite element model were established.

(2) Simulation analysis of T-type rigid node was carried out, by comparison the finite element results were in good agreement with the experimental results, so the rationality of the finite element model is established, these can lay foundation for carrying out seismic performance analysis of steel frame cross-type rigid joints in further.

(3) Simulation analysis was carried out for cross-type nodes, and load-displacement hysteretic curves were obtained. Skeleton curves, envelope figure and stress nephogram were extracted and compared, at last influence law on seismic behavior of this kind of joint was gotten for Axial compression ratio, web thickness H-type steel column, different sectional forms of beam and stiffening rib.

(4) Through comparison and analysis, the corresponding design suggestions are proposed for the axial compression ratio, thickness ratio of column web and flange, design limit value of axial compression ratio of column should be 0.5, and limit value of the column web and flange thickness ratio is taken as 0.75. When the sectional form is for H-type steel, the seismic performance is very good, and H-type steel is much better than the steel tube section, the transverse stiffener can improve the seismic behavior of the joints.

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References

[1] Y. Liu and C. Guo, "Steel Structure", vol. 21, no. 3, **(2006)**, pp. 66-68.
[2] S. Dai, J. Huang and J. Zhu, "J. of Huazhong University of Science and Technology", vol. 22, no. 3, **(2005)**, pp. 18-20.
[3] X. Wang, S. Shen, Z. Duan and Q. Li, "Engineering Mechanics", vol. 23, no. 6, **(2006)**, pp. 65-76.
[4] H. Chen, Y. Shi, Y. Wang and D. Zhao, "Industrial construction", vol. 31, no. 5, **(2001)**, pp. 56-58.
[5] Y. Shi, M. Wang, Y. Wang and Ga. ng Shi, "Civil Architecture and Environmental Engineering", vol. 32, no. 3, **(2010)**, pp. 1-7.
[6] H. Hou, Q. Canxing and G. Li, "Steel Structure", vol. 25, no. 4, **(2010)**, pp. 25-28.
[7] H. Liu, X. Longjun, Q. Zhang and S. Li, "Journal of Harbin Institute of Technology", vol. 44, no. 2, **(2012)**. pp. 28-32.
[8] Y. Shi, M. Wang, Y. Wang and G. Shi, "Engineering Mechanics", vol. 28, no. 9, **(2011)**, pp. 21-58.
[9] J. Jin, "Seismic performance of steel reduced beam section moment frame buildings", Dissertation for Doctor Degree at the University of Central Florida Orlando, Florida, **(2002)**.
[10] Y. Wang and C. Fu, "ABAQUS structural engineering analysis and examples", China Building Industry Press, Beijing, **(2010)**.
[11] Y. Shi and Y. Zhou, "ABAQUS finite element analysis examples", Mechanical Industry Press, Beijing, **(2006)**.
[12] GB50017-2003, Code for Design of Steel Structure, China Building Industry Press, Beijing, **(2003)**.
[13] GB50023-2010.Code for Design of Seismic Building, China Building Industry Press, Beijing, **(2010)**.
[14] S. Zhong and G. Bai, "Analysis and design on beam-column node in high-rise buildings combined structure Frame", China Communications Press, Beijing,**(2006)**.

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