Finite element analysis of beam web holes Node

Tonglin Li [a], Wanli Pu, Bin Li

School of Architecture and Civil Engineering Southwest Petroleum University, Chendu 610000, China

[a]449599268@qq.com

Abstract

In the survey found that many times after earthquake damage, caused mainly due to steel frame is due to earthquake damage caused by beam-column joints brittle failure;in view of the damage, there is a kind of design idea is to improve the stress of the joints, so as to prevent the occurrence of brittle failure of beam column joints;In this paper, ABAQUS is used to analyze the seismic performance of the structure of the web, which is based on the finite element analysis of the steel frame center support system.

Keywords

ABAQUS Beam-column joints damage Hysteresis curve Node bearing capacity Node stress distribution

1. Introduction

Steel structure with its obvious advantages in all kinds of engineering to get more and more applications[1],But the steel frame structure in seismic zone needs to have good ductility in order to meet the requirements of seismic design[2-3]. Northridge in the United States and Japan's Kobe earthquake have caused varying degrees of beam-column joints brittle, and therefore the mechanical properties and structure of domestic and international seismic performance of beam-column connection nodes caused widespread concern, and more theoretical analysis and experimental research, made a lot of achievements。Based seismic design principles of strong column weak beam, we use a node on beam web form openings weakened。And using ABAQUS to establish three-dimensional finite element model of node, and in the main endpoint applied cyclic load and static concentrated load, a comparative analysis of girder web openings and opening on the mechanical properties of the structure are affected, on the other hand comparative analysis of the different flange width thickness ratio, girder shear span ratio on the web open pass nodes hysteretic performance and the node bearing the impact force, the stress distribution in the joint. The results show that a reasonable web openings node configuration, you can change the beam section stress distribution node near the location of the plastic hinge beam by beam portion offset achieve effective control of the plastic hinge purpose; With this same failure mode node node configuration enables the transition from brittle fracture to local buckling beam damage, reducing the possibility of brittle fracture nodes, greatly improve the seismic performance of steel frames.

2. The establishment of finite element model

2.1 Model dimensions and material properties

Adopted ABAQUS modeling, calculation model shown in Figure 1, the node finite element model shown in Figure 2.The main components of the structure: the main girder, the secondary beam, the stiffening rib, and the shear connectors, which are welded on the steel beam, which does not consider the residual stress caused by welding; Girder abdominal open hole and the girder flange welding stud, stud embedded into the concrete inside to play a role in shear. Geometric model size: Steel Column dimensions450×300×10×16, the secondary beam cross-sectional dimensions of 400×150×6×10, the main beam sectional dimensions are grouped according to the actual situation contrast, concrete slab thickness of 120mm.The steel beam column and the stiffening rib are simulated by solid homogeneous element. The "plastic damage modulus" of the concrete is considered. The steel is made of Q235 steel, the elastic modulus 2.1e11Pa, Poisson's ratio is 0.3, the yield stress is 2.35e8, Steel using ideal elastic model.

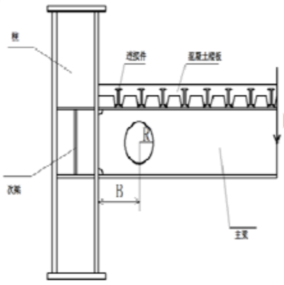


Figure 1 node model diagram

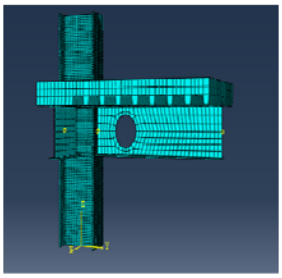


Figure 2 node finite element model

2.2 The boundary conditions and the connection processing model

Node model with low cyclic loading and static loading concentrated load in two ways, both ends of the steel columns of the fixed end, One end of the main beam did not use loading full section by way tie full section at one end of the main beam is coupled to a central point loading. In the stud welding on surface, reinforced upper main beam and secondary beams and studs are embedded into the concrete through Embedded. For consider concrete slab restraints web hole structure, the main beam is perforated at one end; According to the recommended value Xiuli et al. [4] studied the opening hole when considering the combined effect of the position of paper selected R = 140mm(5.51in), B = 380mm(14.96in), on the basis of the finite element simulation.

3. Effect of flange thickness ratio of node performance

3.1 Flange thickness ratio of the web openings hysteretic behavior of nodes

After a lot of studies have found that the flange thickness ratio not only have an impact on hysteretic behavior of beam web holes nodes, but also have a certain influence on bearing capacity and load point displacement structure. Hysteretic behavior of the structure mainly refers to the structure of the reaction force and load point displacement curves were analyzed, it reflects the structures under cyclic loads stiffness, ductility and energy dissipation capacity. The full degree of hysteretic curve is a comprehensive performance of its seismic performance. In this paper, the node model is divided into five groups, including W-1 is unopened Node, k-1, K-2, K-3, K-4 respectively different flange width thickness ratio of the open hole node model. Under cyclic loading displacement, through hysteretic curve analysis structure can reflect the influence of the flange thickness ratio of the seismic performance of structures. The hysteretic curve of the load point can be obtained by the coupling point load curve of the main beam, so as to analyze the seismic performance of the structure. Curve shown in Figure 3, the main beam cross section parameters in Table 1.

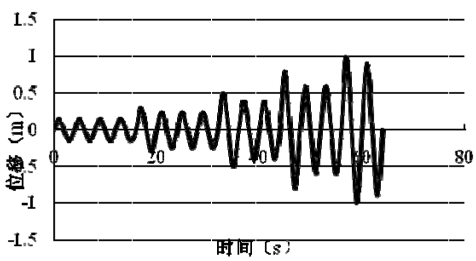


Figure 3 load displacement curve

For members W-1, K-1, K-2, K-3, K-4 were loaded calculated to obtain as shown in Figure 4 hysteresis curve。The unopened pass nodes and pass nodes were compared, and it was obvious that k-1 hysteresis curves more full, the curve of the envelope is relatively large, with better energy dissipation capacity, and therefore steel web node hole seismic performance is better than not opening some of them.K-1 flange thickness of 10mm, K-2 flange thickness is 8mm, but k-1 lag back curve envelope area and K-2 lag back curve envelope area difference, which shows the flange thickness, the lag structure of the back has little impact on performance. By comparing the K-1, K-2, K-3 and K-4, we can get that the width of the K-4 is the largest, and the envelope of the K-4 is the largest.

Table 1 node model sectional dimension

Grouping	Main Beam section size (mm)	Web thickness ratio h0/tw	Flange thickness ratio b1/t_f
W-1	400×150×6×10	66.7	7.2
K-1	400×150×6×10	66.7	7.2
K-2	400×150×6×8	66.7	9
K-3	400×180×6×8	66.7	10.9
K-4	400×200×6×8	66.7	12

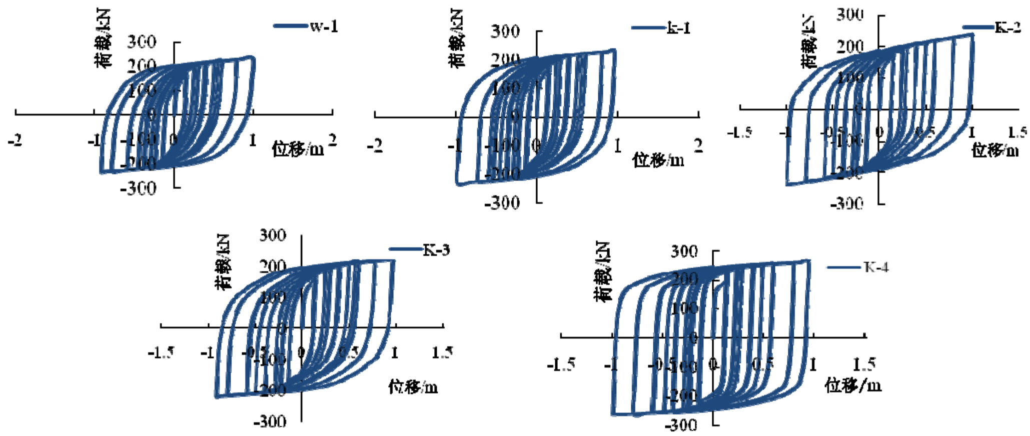


Figure 4. Load point hysteresis curve

In summary, the hysteretic behavior of beam web holes Node stronger than unopened Node hysteretic behavior, but for opening Node, flange generous better than the hysteretic behavior of the larger structure to main beam web opening Kong Youli to improve seismic performance.

3.2 Effect of flange width ratio on the bearing capacity of the joint

The static concentrated load is applied to the main beam under different conditions of the five groups, and the maximum load of the beam is 200kN, and the width of the main beam flange is changed under the same conditions. As shown in Figure 5, the load carrying capacity curve of different flange and heavy load ratio can be seen from the change trend of the curve, and the bearing capacity of the beam column joint is enhanced with the increase of the flange width ratio.

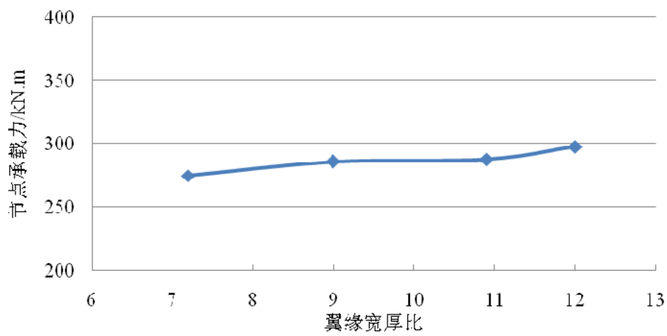


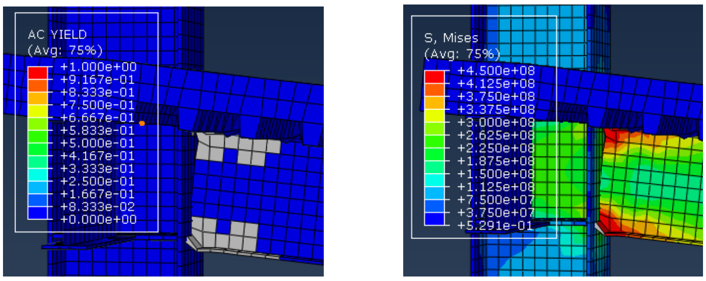
Fig. 5 the load carrying capacity curve of different flange ratio of different flange

Table 2 yield load and yield displacement and joint load bearing capacity of different flange ratio

Node number	W-1	K-1	K-2	K-3	K-4
Yield load	160kN	178.7kN	180.2kN	186.1kN	192.8kN
Yield displacement	29.64mm	37.21mm	38.1mm	42.32mm	50.12mm
Node Carrying Capacity	275kN·m	286kN·m	288 kN·m	298 kN·m	308 kN·m

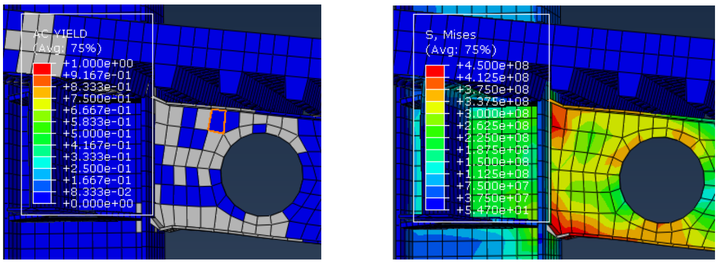
To sum up: Hole-type nodes compared with non-opening type node, opening type node main beam endpoint larger displacement, improve the ductility of the main beam. And, with the increase of the thickness ratio of the flange, the effect of the opening hole of the web on the ductility of the beam is better.

3.3 Effect of flange width on the stress distribution of the joint



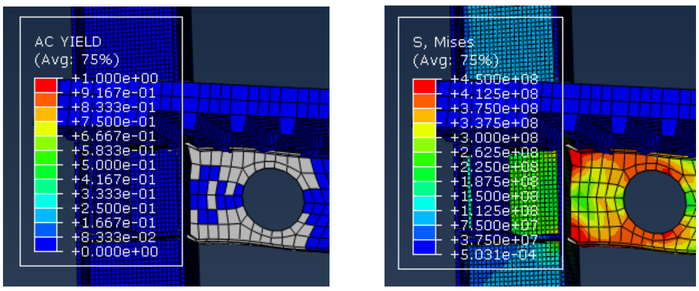
(a) (b)

W-1



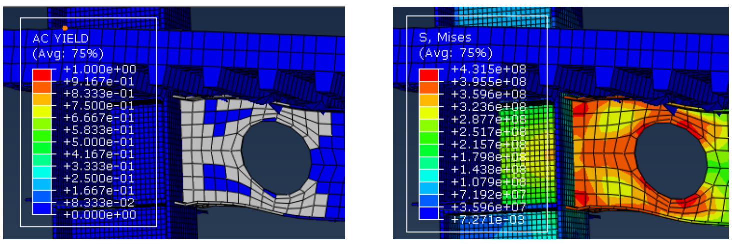
(a) (b)

K-1



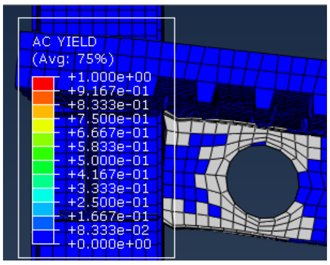
(a) (b)

K-2

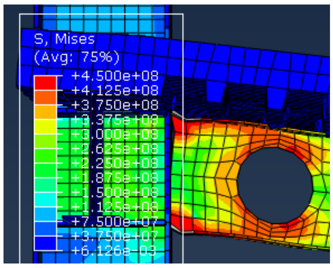


(a) (b)

K-3



(a)



(b)

K-4

a-- yield cover area figure b -- stress change image

Fig. 6 yield and stress changes of the joint.

The static concentrated load of the direction of the main beam is applied to the 200kN direction, and the yield and stress changes of the joint are shown in Figure 6.From each group node yield cloud model, we can see that the area of the lower flange plate greater than the yield on flange plate, visible concrete slab on top flange has some restraints. From Figure 4 W-1, we can see appeared unopened pass at the nodes of the severe damage to the trend and the node yield area coverage rate is larger. The nodes of K-1 and K-2 also appear in the yield state, while the upper and lower flange of the open hole is also provided with the yield. The lower flange of the upper and lower flange reduces the stress at the joint, but the yield area around K-2 is less than K-1.Therefore, with the increase of the width and thickness of the flange, the effect of the first yield is better than that of the hole.

4. Main beam shear span ratio on node performance

4.1 Main beam size selection

Through the research, it is found that the shear span ratio is an important factor affecting the failure mode and the bearing capacity of the steel frame structure. On the one hand, when the shear span ratio is different, the failure forms of the main girder of the main girder and the lower flange of the main girder are different, and the ductility of the main girder is not the same as the [9]. On the other hand, the shear span ratio is also affected by the formation of plastic hinges at the joints. In the research of the impact of the main girder span on the bearing capacity, the node number is LK-1600-W, LK-1800, LK-1600, LK-2200, LK-2600, the column cross section and the main beam section are 450 * 10 * 300 * 16, 400 * 200 * 6 * 8,Retention opening position B = 380mm, R = 140 unchanged, main beam length were taken 1.6m (unopened), 1.6m (hole), 1.8m, 2.2m, 2.6m.So the main girder shear span ratio are 3.85, 4.33, 3.85, 5.29 and 6.25, respectively, to the main girder of the end point of the static load 200kN (L for the beam end point to the effective length of the beam, H is the main beam section height).

4.2 Effect of shear span ratio on hysteretic behavior

Hysteresis curve reactions are seismic performance under cyclic loads, hysteretic curve more full description of the seismic performance of the structure, the stronger ability to resist earthquakes stronger. In the four groups, the main girder of the main beam is applied to the low cycle repeated load, and the hysteretic curve of the structure under the load is obtained, From the curve, it can be seen that the hysteresis curve of LK-1800 is more full than LK-1600, and the envelope of the curve is relatively large;LK-2200 compared with LK-1800, hysteresis curve horizontal development, along with increasing shear span ratio, although there is no load continues to increase, a substantial increase in displacement at the endpoint. At this point, the hole has been the yield and reach the ultimate bearing capacity of the state, deformation increases faster. From LK-2600 we can know that although the load at the end point is no longer increasing, the displacement of the end point is still increasing, and the hysteretic curve continues to be horizontal, and the development of LK-2200 is similar. Still it showed that with the increase of shear span ratio, the hysteresis curve is plumper, showed significantly better openings.

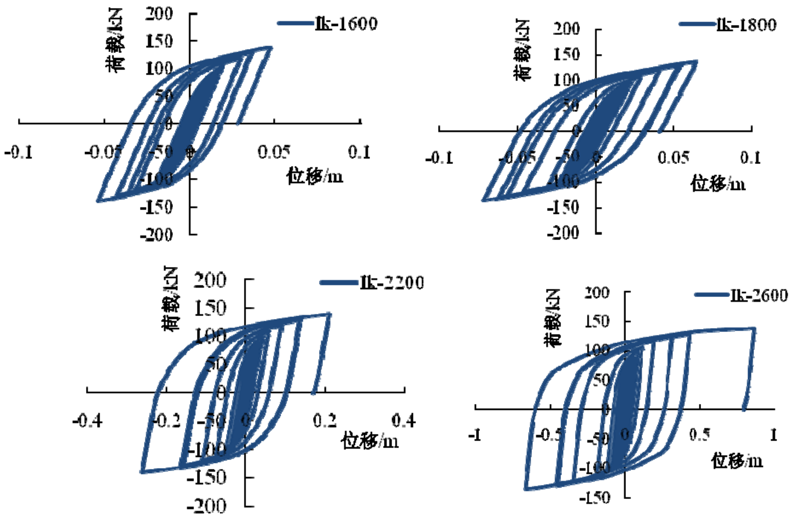


Figure 7. Load point hysteresis curve

4.3 Effect of shear span ratio on the bearing capacity of the joint

At the end of the main girder, the load is applied to the static load of 200KN, and the load direction is downward. When the beam column joints occur at the joints, the bearing capacity curves of different shear span ratios are obtained as shown in Figure 8.On the one hand, in Figure 8, we can clearly see that with the increase of the shear span ratio, the bearing capacity of the joints is increasing. All this shows that with the increase of beam span, the girder of open hole is beneficial to improve the bearing capacity of the node.

From table 4 data we can get opening in beam web nodes pass structure carrying capacity is larger than the beam unopened pass structure of node capacity. When the span of the beam is small,When the span of the beam is small, the web hole bearing force is not very significant increase; But with the increase of the main span, girder webs were opening is conducive to beam column joints of bearing capacity increase.

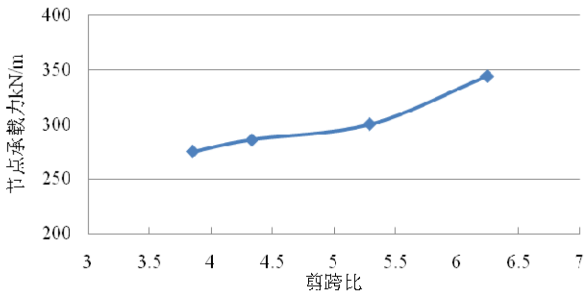


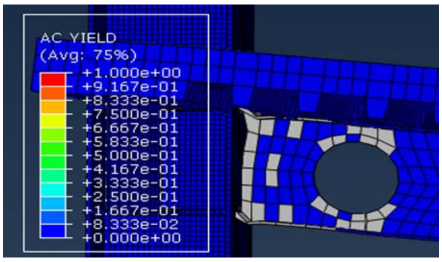
Fig. 8 the load carrying capacity curve of different shear span ratio

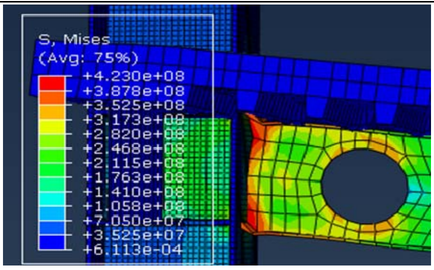
4.4 Shear span ratio influence on stress distribution node

The load of 200kN was applied to four kinds of the main girder of the web. The stress distribution and the yield of the joint are analyzed in Figure 9.In the comparative analysis of LK-1800 and LK-1600, we can see that both the stress at the joint of the joint is almost close, and the yield area is almost the same; But the difference is that LK-1800 occurs first in the hole and yield, and node at the upper and lower flange at the same time to enter the state of yield. In the contrast analysis of LK-1800 and LK-2200, we can find that although both of them have the same yield at the opening, it is obvious that when the load is added to 150KN, the latter has already yielded at the joint and at the opening of the hole; It mainly shows that the displacement of the main beam is accelerated, and the surrounding of the open hole is in the yield of the nodes. Stress at node LK-2600 has reached the limit state, the upper and lower flange plates and the connection point of the column were destroyed phenomenon.

Table 4 the yield load and yield load of the nodes in different shear span ratio

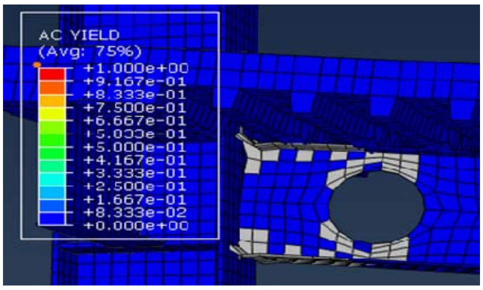
Node number	LK-1600-W	LK-1600	LK-1800	Lk-2200	Lk-2600
Yield load	172kN	178.7kN	166.7kN	156.7kN	152.7kN
Yield displacement	29.64mm	37.21mm	47.31mm	64.83mm	107.6mm
Node bearing capacity	275kN·m	286kN·m	300kN·m	344kN·m	397kN·m

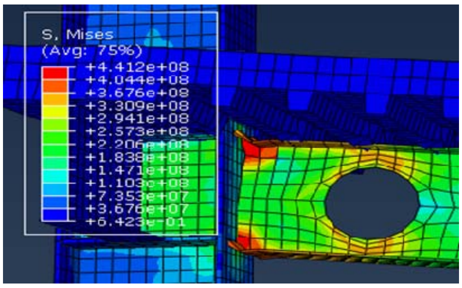




(a) (b)

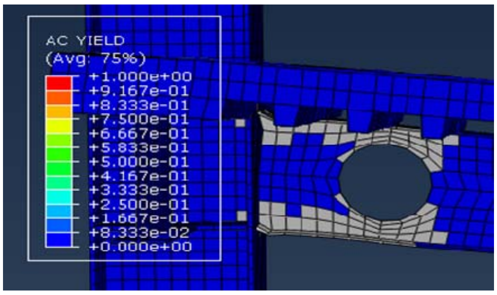
LK-1600

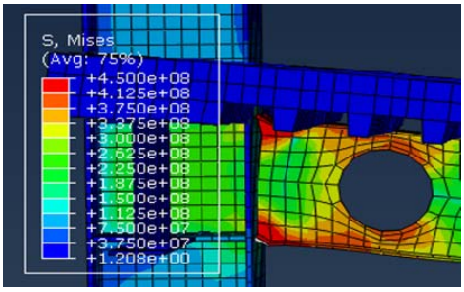




(a) (b)

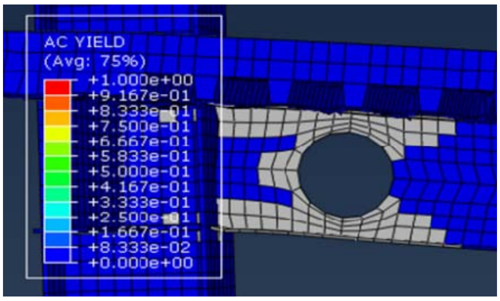
LK-1800

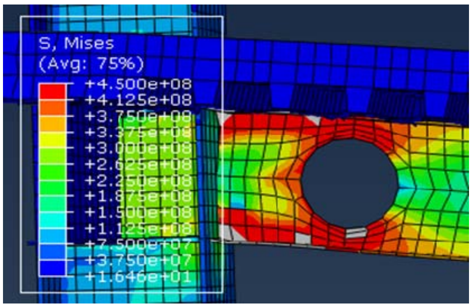




(a) (b)

LK-2200





(a) (b)

LK-2600

a -- yield cover area figure b -- stress change image

Figure 9 Node stress distribution

5. Conclusions

Finite element analysis of steel frame joints by ABAQUS on the beam web opening can be obtained by the following three points:(1)By applying five kinds of finite element models under different working conditions, we can find the hysteretic behavior of the flange on the structure. First web openings nodes hysteretic curves than the non-opening type of more full, and secondly for the open-cell node, the flange generous as possible, and the stronger the seismic performance than the hysteretic behavior of the larger structure.

Through the main five finite element model under different conditions of static load applied to the beam endpoint to discover, in the case of reducing the main beam flange thickness and widening the width of the flange plate, only the main beam of the bearing capacity of not It will be reduced, but also will improve the bearing capacity and ductility web openings emperor beam, which is conducive to the seismic performance of the structure.

With the increase of the length of the main girder, the hysteretic behavior of the loading point is better. At the same time, the displacement of the main girder is improved slightly, the ductility of the structure is improved, and the bearing capacity of the joint is improved, and the seismic effect is better. With the increase of shear span ratio, the effect is more obvious. Through the analysis of the stress of the joints and the yield state of the hole, we can see that with the increase of the shear span ratio of the main girder, the phenomenon of the opening hole is more obvious.

References

[1] Shi Zhiyu, Lu Lingyi. A test research of structural dam age detection by using model strain energy [J]. Journal of Southeast University, 1999, 29(2)：134-138. (in Chinese)

[2] K / M J T. Improved dam age identification method based on modal inform ationIJI . Journal of Sound and Vibration 2002, 252(2)：223-238.

[3] Kim Jeong—Tae, Ryu Yeon·Sun, Cho Hyun—Man, Stubbs Norris. Damage identification in beam —type structures: frequency. based method vs mode—shape—based method 〖J] Engineering Structures. 2003. 25：57～67. [4] Xiuli Wang. Experimental study on mechanical properties of the joints of the steel frame beam with web openings [J] Engineering Mechanics. 2006, 23(6)70-75

[5] Qiang Gu. Hysteretic behavior and seismic design of steel structures [B] China Architecture& Building Press, 2009, 1(165)

[6] Bo Li, Qinshan Yang.Analysis model of the joints of a beam with a circular hole.[J]Journal of Beijing Jiaotong University,2009,33(4)101-103

[7]Xinshen Xu.Analysis on seismic performance of a beam web steel frame considering combined effect [D].Thesis of master degree thesis. Beijing: Beijing Jiaotong University, 2007