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Study on Seismic Behavior of Steel Frame Beam End Flange Expanded Airfoil Joints

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Abstract: In this paper, the numerical analysis of the expanded airfoil joints is carried out. The three-dimensional non-linear finite element analysis of the expanded airfoil joints under cyclic loads is carried out by using ansys finite element software. The effects of the initial position, width and length of the enlarged flange on the stress of the joints, the distribution of plastic hinges, the failure mode of the specimens and the ultimate load are systematically discussed. The location of plastic hinges is predicted and the recommended reference values for the selection of parameters of wing enlargement are given.

Keywords: Widen width; Limit load; Maximum plastic rotation angle

1. Introduction

1.1. Parametric analysis of flange expanded airfoil joints at beam end

China's steel structure started relatively late. With the enhancement of national economic strength and the need of social development, steel structure has made relatively rapid development in the past ten years, and has initially formed a number of powerful leading enterprises such as Angang and Baosteel. The quality of plate, section steel, steel pipe and coated steel plate used in steel structure has also been greatly improved. A number of new steel products, such as refractory steel, ultra-thin hot rolled H-beam, have been successfully developed and applied in various projects. The more important projects are: Pudong International Airport, Capital International Airport, Shanghai Jinmao Building, Shenzhen Saige Building, Dalian World Trade Center, Wuhu Yangtze River Bridge, Shanghai Lupu Bridge, Shanghai Baosteel Large Steel Rolling Workshop, Jiangnan Shipyard Warehouse, Yangtze River Transmission Tower, Qingdao Yizhong Stadium, Yiwu City Stadium, etc. Changsha Long-distance Bus Station and so on, these buildings have become a symbol of China's scientific and technological progress, and have had a certain impact at home and abroad. In recent years, steel structure is gradually applied in civil housing, and began to develop.

China is one of the countries most severely affected by earthquakes in the world. Since the 20th century, about one third of all earthquakes with magnitude 7 or above on the mainland of the world have occurred in China, especially the Wenchuan Earthquake (Fig. 1.1), which occurred at 1428 hours (Beijing time) on May 12, 2008. Grade 8.0, with more than 100,000 km2 in severely affected areas and nearly 50 million people affected. When the earthquake happened, the casualties were mainly due to the collapse of buildings and projects and secondary disasters after the earthquake. Because of the difference of earthquake intensity and the quality of buildings, the damage degree is not the same. Shear inclined cracks or X-shaped welds appear in most of the multi-storey brick-concrete buildings. The seismic damage of reinforced concrete frame structures occurs mostly at the end of columns (strong beams and weak columns) and joints, horizontal cracks at the end of columns, oblique cracks at the end of columns and joints. For cracks or cross cracks, the seismic damage of frame beams is relatively light, which is basically manifested by vertical bending cracks or shear inclined cracks at the end of the beams, while the workshop or space grid of steel structures have withstood the test in the earthquake and are basically intact. Steel structure has high strength, good ductility and easy fabrication. It is widely used in large-span, high-rise, heavy-load and light-weight structures, and it is an economical and effective structural form. In recent years, with the rapid growth of iron and steel production in China, steel structure has been widely used, and the application of steel structure in large-scale landmark buildings has become a trend.

For a long time, rigid connections between beams and columns of steel frames have been considered to have good seismic performance. Under strong earthquake, the ductility of joints based on materials can ensure the plastic deformation of structures, produce plastic hinges in beams rather than columns, and dissipate seismic transmission through the formation and rotation of plastic zones. The design idea of the so-called "strong column, weak beam, strong joint and weak member" is that the joints are protected from damage and the integrity of the structure is guaranteed to avoid collapse. But in 1994 Beiling Earthquake and 1995 Osaka-Shenzhen Earthquake in Japan, the performance of steel frame beam-column rigid connections overturned the traditional view. Large-scale brittle failure of connections has occurred, and the degree of failure varies from small cracks to complete fracture of column sections. The most common failure modes occur in the weld zone at the intersection of beam and column flanges, brittle fracture occurs in many connections, and even the bearing capacity is lost. The most common damage in Beiling earthquake occurs in the welded joints or adjacent parts between the lower flange of the beam and the flange of the column. Therefore, taking necessary measures to improve the performance of beam-column rigid joints is not only of great theoretical significance, but also of great engineering application value. The test results of repairing joints before and after the Beiling earthquake show that early cracks similar to field cracks have been observed in all the tests, and the characteristic curves of the tests are the same as those of previous tests. The average plastic rotation capacity of beams is 0.05 arc, which is the target value of 0.0 arc determined by SAC after research. 1/6 shows that the joint performance of steel frame before Beiling earthquake is very poor, which is consistent with the connection failure in the earthquake, and contrary to the design intention of assuming that steel frame can develop great ductility.

A series of specimens were derived by selecting the main parameters of flange section shape change of beam end flange expanded airfoil joints (WFS-A series). The effects of flange plate length and width parameters on the bearing capacity of the joints and the seismic performance of the joints were studied, and the stress distribution characteristics of the joints were analyzed when the flange expansion parameters changed. The influence of load-carrying capacity, energy dissipation, ductility, the law of plastic hinge formation and development, the distribution and location of plastic hinge, hysteretic performance and so on are discussed. The range of flange parameters in the design of expanded airfoil joints is also given.The parameters range of enlarged airfoil joint is shown in Table 1, and the values of the parameters are shown in Table 2. The enlarged parameters of beam flange are shown in Figure 1.

Table 1. Extended airfoil joint parameter range

Parameter range	l_a	l_b	c
America FEMA-350(2000)[21] Parameter Range of Beam-column Joints with Circular Arc Weakening	$(0.50\sim0.75)b_f$	$(0.65\sim0.85)h_b$	$(0.20\sim0.25)b_f$
Chen Chengzhi et al. suggested parameters range for expanded airfoil joint:	$(0.60\sim0.8)b_f$	$(0.30\sim0.45)h_b$	$(0.30\sim0.5)b_f$
literature [7] Recommended parameters range for expanded airfoil joints:	$(0.50\sim0.75)b_f$	$(0.65\sim0.85)h_b/2$	$(0.20\sim0.25)b_f$
The parameters range of expanded airfoil joints are obtained in this paper.	$(0.33\sim0.93)b_f$	$(0.65\sim0.85)h_b/2$	$(0.13\sim0.33)b_f$

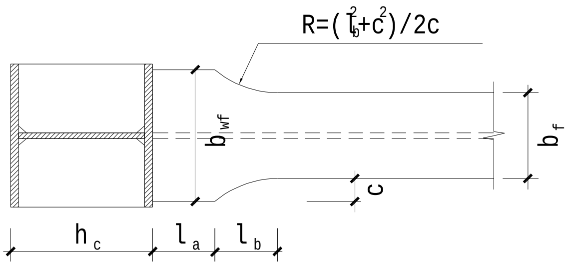


Figure 1. Girder flange enlargement parameters

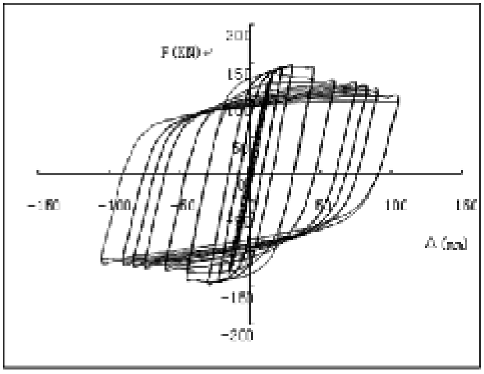
Table 2. Dimensions of wing enlargement parameters for WFS-A group specimens

Specimen number	la (mm)	la /bf	lb(mm)	lb /hb	c (mm)	c/bf
WFS-A1	50	0.33	90	0.30	40	0.27
WFS-A2	80	0.53	90	0.30	40	0.27
WFS-A3	110	0.73	90	0.30	40	0.27
WFS-A4	140	0.93	90	0.30	40	0.27

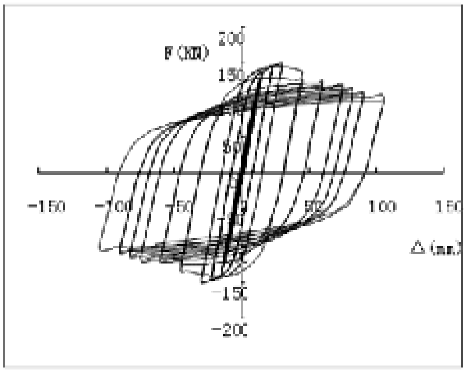
In the table, the section sizes of columns and beams are HW250 x 250 x 9 x 14 and HN300 x 150 x 6.5 x 9 respectively, while those of WFS-A group only change the length of flange extended La segment in order to keep the flange expanded width C unchanged.

2. Hysteretic Curve of Each Specimen in WFS-A Group

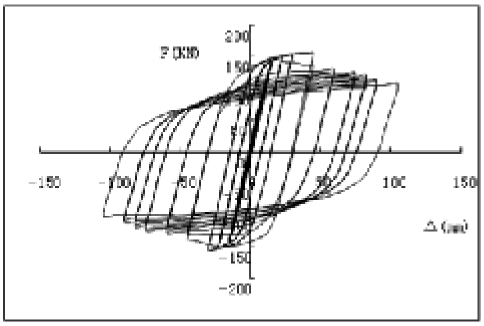
The finite element analysis of WFS-A group specimens under cyclic loading is carried out, and the hysteretic curves of the specimens under cyclic loading are obtained as shown in Figure 2.



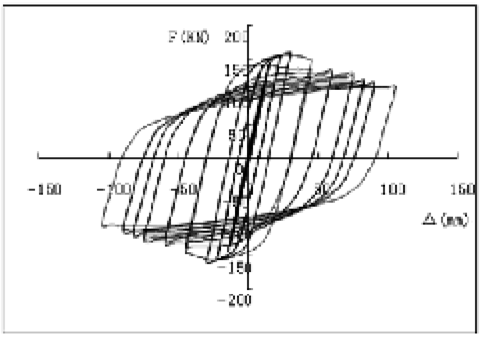
(a) Expanded wing joint(WFS-A1)



(b) Expanded wing joint(WFS-A2)



(c) Expanded wing joint(WFS-A3)



(d) Expanded wing joint(WFS-A4)

Figure 2. Hysteresis curves of WFS-A group specimens

It can be seen that the hysteretic curves of the specimens under cyclic loads are full shuttle-shaped, without pinching phenomenon, with large hysteretic area and good energy dissipation capacity. When the enlarged wing length changes, the shorter the enlarged wing length, the smaller the bearing capacity and the better the hysteretic performance.

3. Skeleton Curves of Each Specimen in WFS-A Group

The skeleton curves of each specimen in WFS-A group are shown in Figure 3.

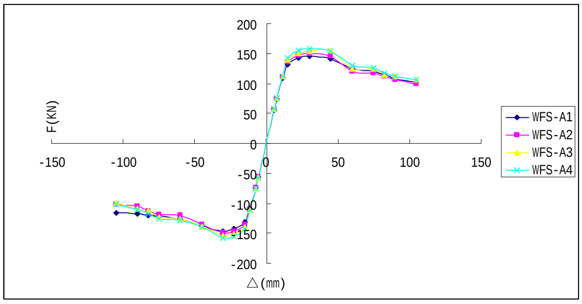


Figure 3. Skeleton curves of WFS-A series specimens

The skeleton curves of WFS-A specimens show good plastic deformation ability, which can transfer the plastic hinge from the weld at the root of beam-column connection to the outer region; the skeleton curves of WFS-A1 are in the inner side and WFS-A4 are in the outer side, indicating that the yield load of the specimens increases with the length of the enlarged wing section. Load and ultimate load increase accordingly.

4. Conclusion

When the hysteretic area of WFS-A series joints is relatively large, the joint has good energy dissipation capacity, and the skeleton curves show good plastic deformation ability, which can transfer the plastic hinge from the weld at the root of beam-column connection to the outer region. But when the enlarged wing length is too long, the distance between the plastic hinge and the cylindrical surface increases, which leads to the excessive bending moment at the beam end of the cylindrical surface, which makes the stress develop faster and the stress value larger, which is unfavorable to the stress on the weld. Therefore, the enlarged wing length should not be too large, and the enlarged wing should not be too small, otherwise the plastic hinge can not be removed. Because of the intersection of beam and column, according to the results of the finite element analysis of the joint specimens, it is suggested that the width of the flange of the beam be doubled by la.

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References

[1] Jong Won Park, In Kyu Hwang. Experimental Investigation Section Connections of Reduced Beam Section by Use of Web Openings. Engineering Journal. 2003.

[2] Subhash C, Goel S.L. Steel Moment Frames with Ductile Girder Web Opening. Engineering Journal.1997

[3] Ralph M., Richard C.J.A., James E. Partridge Proprietary Slotted Beam Connection Design. Modern Steel Construction.1997, 3, 28-33

[4] FEMA-350, Recommended Seismic Design Criteria for New Steel Moment-frame Buildings. 2000.

[5] Kim T. Cover-Plate and Flange-Plate Steel Moment-Resisting Connections. Structural Engineering.2002, 128(4), 474-482

[6] Kim T. Experimental Evaluation of Plate-Reinforced Steel Moment- Resisting Connections. Structural Engineering.2002, 128(4), 483-491

[7] Cheng Chihchen, Shuan Weichen, Ming Darchung, Ming Chihlin. Cyclic Behaviors of Unreinforced and Rib-reinforced Moment Connections. Journal of Constructional Steel Research.2005, 61, 1-21

[8] Hadikusumo B.H.W., Steve R. Capturing Safety Knowledge Using Design-for-safety-process tool. Journal of Construction Engineering and Management. 2004, 130(2), 281-289.

[9] Cai Yiyan. Beam-to-column Connection Design of Steel Frame Considering Plastic Hinge Displacement. Architectural structure. 2004, 34(2), 39