Analysis of Seismic Performance of Steel Moment Connection with Welded Haunch and Cover Plate

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Abstract: In this study, a new connection joint of cover-plate-haunch connection was brought forward on the basis of improving haunch connection and cover plate connection. This kind of connection joint not only overcomes the shortcomings that bilateral haunch connections affect the flatness of floor and the interior appearance, but also strengthens the connection performance. ABAQUS finite element software is used to study node stress, plastic zone distribution, ultimate bearing capacity and hysteretic behavior. The result of new model is compared with past model. The results indicate that the new connection can effectively reduce stress concentration on butt weld of the joint, make the plastic hinge away from the connection and lower the possibility of brittle fracture. The ultimate bearing capacity of new connection can be increased 23% than normal connection, equivalent viscous damping coefficient and ductility factor is respectively 0.321 and 4.06, therefore the new connection is theoretically feasible and practical in application as well as excellent performance in earthquakes and the ideal energy dissipation.

Key words: Cover-plate-haunch connection, ductility factor, energy dissipation, equivalent viscous damping coefficient, haunch connection, hysteretic behavior, plastic hinge

INTRODUCTION

1994 Northridge earthquake happened in the California of USA and 1995 Kobe earthquake happened in Japan, great amounts of rigid connections of steel frame damaged. The most common form of damage occurred in the interface of the welding zone between beam and column flange. Post-earthquake many researchers (Chen et al., 2006) about the traditional nodes were carried out by domestic and foreign scholars and the design concept of make the plastic hinge away from the connection was presented (Wang, 2006). It could improved stress states on connection of welding seam base on the plastic hinge shift away from the surface of column and also avoided serious brittle fracturing in the welding zone. (Yu et al., 2006) gives the experimental study on full-scale steel beam-to-column moment connections. It is worth mentioning two methods to make the plastic hinge away from the connection. One is base on reinforced joints, such as set up cover plate, slab used as stiffening rib in beam flange of joint, enlarge the section of beam flange and so on. The other one is using reduced beam section connection, which is weakening partial of the beam flange or web, such as dog-bone connections and using long slot bore in beam web. By more than decade research (Sun et al., 2010), have demonstrated that those change can improve the seismic performance of steel connections in different ways. (Sun et al., 2010) analyses the seismic consideration and fracture-resistant of beam-to-column web rigid connections for steel moment frames. (Lin et al., 2003) gives the theorem proving based on the extension rule. (Mahin, 1998) shows the lessons from damage to steel buildings during the northridge earthquake. There have two forms for haunch connection: unilateral haunch and bilateral haunch of the beam-column connection. Unilateral haunch connection could relief weld stress concentration at haunch side of flange, while stress at the other side of beam flange is larger than normal connection. The main reasons of this phenomenon are that neutral axis move to haunch side of unilateral haunch connection. So it will result brittle fractures easily at non-haunch side of flange. We could realize relocation of plastic hinge in bilateral haunch connection, which can reduce weld stress focus and better than unilateral haunch connection, as well as a good seismic behavior was shown. However, in practical engineering, some steel frame have high requirement, haunch in upper side of beam lead to floor unevenness and visage will be affected. Three connection models were created in this paper: normal connection, unilateral haunch connection, the connection with cover plate on top flange and haunch on lower flange. All models using box column and H-beam. And using finite element software ABAQUS to discuss node stress, plastic zone distribution, ultimate bearing capacity and hysteretic behavior in this study.

METHODOLOGY

Establish finite element model:
Geometry model: According to the suggestions in Literature (Yu and Qian, 2006), we should prefer to use
weld ladder cover plate on top flange and haunch on lower flange to analysis beam-column connection of steel frame. We created three connection models in this paper: normal box column-H beam connection (BASE specimen), haunch on lower flange connection (SP specimen), cover plate on top flange and haunch on lower flange connection (WH specimen). Comparison and analysis will be made to the last specimen and the other two specimens. The geometries of analysis utilized in this research consisted of HW300 00 6 box column connected to HM220 50 0. The length of beam is 1800 mm and column high is 3000 mm. Model shape and geometry size as shown in Fig. 1.

Material properties: All members using Q345 steel, The elastic modulus and Poisson’s ratio are assumed as $E = 220,000$ MPa and $n = 0.3$. Von Mises yield criterion by used and multiple alignment equivalent strengthen stress-strain curve as shown in Fig. 2. Material defect and the effect of weld residual stress were not considered during analysis.

Mesh generation and loading law: Figure 3 shows the stress-strain curve of Q345 steel. The models are analyzed using ABAQUS, as shown in Fig. 4. The finite element model utilized in this study is reduced integration element C3D8R. The element is defined by eight nodes having three degrees of freedom at each node. The upper end of column is hinge and applied 100 MPa pressure on it. The bottom of column is consolidation to bear upper pressure. During the process of analysis, loading procedure divided into uniaxial loading (impose 0.03 radian vertical displacement at the end of beam) and cyclic loading. Cyclic loading displacement curve apply on the free end of beam as shown in Fig. 5.
THE RESULT OF FINITE ELEMENT ANALYSE

Node stress: For whole analysis the stress distribution of connections, the Von Mises stress distribution along the three stress path (Path 1 to Path 3) of beam top flange and 50 mm away from column under on 0.03 radian vertical displacement imposed at the free end of beam were analyzed and compared.

Figure 6 showed Von Mises stress distribution of beam web along the distance of 50 mm away from column flange. In Fig. 6, web stress of each specimen present small at the middle and large at the ends. The stress of BASE specimen is symmetric distribution along the direction of web and neutral axis located at middle of web. The web stress at haunch side of SP specimen is smaller than BASE specimen. The maximum stress appeared at the other side of haunch flange and the stress value higher than the edge of haunch side obviously. The minimum stress value of SP specimen located at 9.3 mm offset from the central of the beam web. It indicates that neutral axis of web shift down after haunch. The web stress in cover plate side of WH is slightly larger than the stress in haunch side. It is not obvious that the neutral axis of web to shift down and almost locate at the median of web.

The Von Mises stress distribution along width direction of beam upper flange in the joint (Path 1) shown as Fig. 7. In actual engineering, we usually assume that the stress is uniform distribution along beam flange. However, in Fig. 7, we can observe that stress distribution of beam flange is uneven and the shape is similar to “W”, the stress values are higher at the ends and the central of flange than other area. The maximum Mises stress value occurs at the ends of flange, which is explained by the effect of different flange width in contact region of beam-column. Further observation in Fig. 7, the stress of different points in upper flange of BASE and SP specimen is larger than yield stress of steel. Due to the neutral axis of web to shift down after haunch, the stress of different
points in upper flange of SP specimen was slightly larger than those in BASE. The results indicate that beam flange at tension side even in a more insecure situation after haunch. However, the stress of upper flange in elastic stage during the whole loading process when cover plate at upper flange in SP specimen. The results indicate that cover plate in upper flange of SP specimen can effectively decrease stress value in weld zone of connection.

Figure 8 showed Von Mises stress distribution along width direction of beam upper flange in the joint (Path 2). Obviously, we can observe that the stress value was high in the medium and low in the ends along width direction of each specimen. The stress value of flange was in elastic state during the whole loading process except for middle part in flange of BASE specimen, while the flange of WH specimen entered the plastic state.

Figure 9 showed Von Mises stress distribution along length direction of beam upper flange (Path 3). We can observe stress is monotonically decreasing along length direction of beam flange in BASE and SP and stress curve of haunch connection had a horizontal line around the end of haunch plate, which is explained by stiffness difference of flange at the end of haunch plate. Stress peak present to beam flange near weld region for BASE and SP, while stress maximum shift out from the cover plate region of flange when cover plate on the upper flange of haunch connection. So it can ease the stress concentration near weld.

The appearance and development of the plastic hinges:

In order to get the moir interferometry images and the Von Mises stress distribution, we imposed 0.03 radian vertical displacement at the end of beam. The moir interferometry images showed in Fig. 10. All specimens are local yield. Firstly, for normal connection, plastic deformation appeared in the ends of flange near weld. With loading displacement increasing, plastic region extending toward the central and upper flange and lower flange on the beam-to-column connections reach plastic yield. Then plastic region was extending toward the central of web from in junction of flange with web. Finally, plastic hinge formed at the node junction of beam-to-column, as showed in (Fig. 10a).

During the whole loading process of haunch connection, the region of beam flange from weld to the end of haunch was in elastic state. Plasticity deformation area formed firstly at bottom flange near the external end of haunch where the maximum stress value appeared. With the loading displacement is increasing, plastic region extending toward the central of web from in junction of flange with web. However, stress in upper flange slightly larger than those in normal connection.
Plastic deformation of the bottom flange of cover-plate-haunch connection is the same as haunch connection. For upper flange, the coverage area with cover plate was in elastic state where stiffness increased. Firstly, plasticity deformation area formed at top flange near the external end of cover plate. Then, with the load is increasing, plastic region extending toward the ends of flange and the central of web. Finally, plastic hinge formed at the top flange and the bottom near Path 2. So cover-plate-haunch connection could be controlled the plastic hinge position on beam effectively.

**Hysteretic behavior:** Figure 11 showed load-displacement hysteretic loops at free end of beam. With cyclic displacement increasing, all specimen share the almost same shape and curve slope decreases continuously until attain the extreme limit loading. The beam-to-column connections form has great effect on hysteretic loops, in which the hysteretic loops of cover-plate-haunch connection is the plumpest, haunch connection is the second and normal connection is the poorest. The results indicate that cover-plate-haunch connection with best energy dissipation ability than other two connections.

According to the requirements of Specifying of Testing Methods for Earthquake Resistant Building, energy dissipation coefficient and equivalent viscous damping coefficient are the key factors to affect the anti-earthquake performance of a building. The more the hysteretic curve is full, the larger the energy dissipation coefficient and equivalent viscous damping coefficient, as well the better energy dissipation capacity of specimen was shown and the better the seismic behavior. Energy dissipation capacity is defined by the difference between the absorbed energy under loading and released energy under unloading after one control cycle. Ductility performance is defined by the ratio of maximum deformation in certain load to limit deformation in elastic stage. Table 1 showed the ultimate bearing capacity, equivalent viscous damping coefficient and ductility factor of the members. The results indicate that the ultimate bearing capacity of haunch connection can be increased 12% than normal connection and cover-plate-haunch connection can be increased 23%. The equivalent viscous damping coefficient of normal connection is 0.261 and ductility factor is smaller than 4, which means energy dissipation capacity is lower. Therefore, it has poor seismic performance. The equivalent viscous damping coefficient of haunch connection is 0.298 and ductility factor is close to 4, so its seismic performance is good. The equivalent viscous damping coefficient of cover-plate-haunch connection is the largest among three
members and ductility factor is larger than 4 which have excellent performance in earthquakes and the ideal ductility.

CONCLUSION

- The triaxial stress condition was complicated on butt weld of normal connection, sensitive to welding defect and result brittle fractures easily. It had obvious effect to decrease the stress of bottom flange at the welding seam for haunch connection, while that inability to top flange. Cover-plate-haunch connection can effectively decrease the stress at the welding seam, reduce stress focus and avoid to brittle fractures.
- The stiffness increased at the joint for cover-plate-haunch connection, which makes the stress of beam section at weld zone less than other area. So non-welded region yielded first and achieve the goal of outer moving of plastic hinge.
- The ultimate bearing capacity of cover-plate-haunch connection can be increased 23% than normal connection, equivalent viscous damping coefficient and ductility factor is respectively 0.321 and 4.06, larger than normal connection and haunch connection, the hysteretic loops is plump, so it has excellent performance in earthquakes and the ideal ductility.

REFERENCES