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To cite this article: X Xiao et al 2018 IOP Conf. Ser.: Earth Environ. Sci. 153 032015

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Seismic Energy Dissipation Analysis Of Y And K Type Composite Eccentrically Braced Steel Frames

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Abstract: In order to study the seismic behavior of eccentrically braced frames with different braces, nonlinear finite element analysis of two eccentrically braced frames with Y and K shapes is carried out by using the software ABAQUS. Q235 steel is used in the K and Y shaped energy dissipation section and support in composite steel frames, and the other components are composed of Q345 and Q460 grade steel respectively. The analysis results show that both of them have good energy dissipation under the low cyclic loading; Under the same amount of steel., with the steel grade increases for the frame beam and column, the energy dissipation capacity of Y and K shape has greatly improved, the energy dissipation capacity of link beam Y shape frame is better than that in K shape frame; the overall energy consumption ability of Y shape frame is also better than that of K shape frame, and Y shape frames have many advantages such as easy repair after the earthquake, , save steel, and high economic benefit.

1. Introduction
The eccentrically braced frame structure not only has the seismic energy dissipation capacity of the frame structure, but also has the stiffness and strength of the centre braced frame structure system, so it is a good lateral force resisting system. Design for steel structures must meet the requirement that building has enough rigidity under small earthquakes [1]. Under the rare earthquake, it can dissipate the energy generated by the earthquake action by the way of plastic deformation of the energy dissipation section, and avoid plasticity of other beams, columns and brace members [2]. Beams and columns of the frames should be elastic basically, and the steel with high strength can be used to reduce the size of the section. It can not only meet the requirements of seismic performance, but also save materials, and it has very good economic benefits. Steel composite eccentrically braced frame is such a frame structure system which combines the advantages of eccentric brace with good seismic performance and high bearing capacity of steel. It is an efficient seismic steel structure system [3]. In the steel composite eccentrically braced frame, the steel with low yield strength and good deformation performance is often used in the eccentrically braced energy dissipation section. The energy dissipation is mainly concentrated in the energy dissipating beam, and prevent structure from damages [4].

Dubina and et al [5] have made an experimental research on energy dissipation for K eccentrically braced coupling beam structure with the bolt connected high strength steel. The test indicated that this structure can not only change the plastic deformation capacity of the components of the energy dissipation section, but also save materials. Ardesthir [6] used the finite element software to simulate 68 frames with different length.

Energy dissipation section and with or without stiffeners under the cyclic loading, and analysed the the energy dissipation capacity, the influence of the length of the energy dissipation segment stiffening rib spacing and thickness, web thickness ratio and the loading on the hysteretic ability.
Wang Feng [7] studied seismic performance of high strength steel composite Y-shape eccentrically braced steel frame by the low cyclic loading experiment of the three layer structure of a 1:2 scale, He found that most of seismic energy dissipation by the link the elastoplastic deformation with lower yield strength in Y-shape eccentrically braced. Duan [8] combined the high strength steel K-eccentrically braced steel frame link beam with low yield point steel and other components by using the high strength steel segment retained, the cyclic loading, the failure of specimens from EBSF, residual deformation is small, is conducive to rehabilitating the dual lateral force resisting system.

Therefore, it is of great significance and value to carry out systematic research and theoretical analysis on the steel composite eccentrically braced structure system. In this paper, the seismic performance of two kinds of K and Y-shaped steel composite frames is analyzed. The energy dissipation capacity of the two different structural components is discussed. Comparing the seismic energy dissipation characteristics of the two braced frames with the same steel volume, an optimal seismic energy dissipation frame structure is proposed, which provides a reference for practical engineering application.

2. Verification of FE method
In order to verify the validity of the finite element method to analyze the energy dissipation of the composite eccentrically braced frame the Y - shaped eccentric bracing frame in the literature [9] is selected. The applicability of the finite element model is verified from the properties of steel, boundary conditions and loading methods. The mechanical properties of steel are shown in Table 1. The Y-shaped eccentrically braced steel frame model is a two-story single-span shear type, as shown in Fig. 1. The span of the frame is 1.9m. The frame beam, column, and brace are the I-shaped section. The detailed size is shown in Table 2.

![Figure 1 Y shaped EBF verification model](image)

![Figure 2 Analysis curves and test curves](image)

| Steel   | E/MPa   | σy/MPa | σu/MPa | ν   |
|---------|---------|--------|--------|-----|
| Q235B   | 206000  | 235    | 375    | 0.2 |

| Part    | Secondary section   |
|---------|---------------------|
| Beam    | 150×150×7×10        |
| Column  | 150×150×7×10        |
| Brace   | 100×100×6×8         |
| Lind-beam | 200×100×5.5×8   |

Without considering the vertical load, the loading point at top point, with low cyclic loading. The energy dissipation section is connected rigidly with the frame beam, column and brace connection. The result of the finite element simulation is compared with the test, as shown in Figure 2.
From figure 2, the hysteresis curves of finite element simulation are good agreement with the experimental results. They are all shuttle filled and coincide. Therefore, the finite element analysis method can be used to analyze the seismic performance of eccentrically braced structures. At the same time, the hysteresis loop of the elastic phase is basically straight. With the increase of loading, the enveloping area increases and the energy dissipation capacity is enhanced. It shows that the Y shaped eccentrically braced frame has good energy dissipation capacity.

3. Energy dissipation analysis of two brace frames

3.1. Model design

In order to study the influence of different steel combinations on the energy dissipation of eccentrically braced frames, two single span three-story Y and K EBF are designed. The specific size is shown in Figure 3. The steel combination of different components is shown in Table 3. The size specification of the frame section is shown in Table 4.

| Model numbers | YZ₀/KZ₀ | YZ₁/KZ₁ | YZ₂/KZ₂ | YZ₃/KZ₃ |
|---------------|---------|---------|---------|---------|
| Link-beam     | Q235B   | Q235B   | Q235B   | Q345    |
| Beam column   | Q235B   | Q345    | Q460C   | Q460C   |

Table 3 Steel combinations of Y and K- shaped EBF

| Part         | Sizes        |
|--------------|--------------|
| Beam         | 400×200×20×16|
| Column       | 400×400×20×16|
| Brace        | 200×200×20×16|
| Link-beam    | 600×200×16×12|

Table 4 Cross section size of Y and K- shaped

3.2. Model element and boundary condition

The model uses the solid element, and all elements used the 8 node hexahedral one-time reduced integral hourglass control element(C3D8R) in griding the structures. The frame beams, columns and braces are all connected by tie. The bottom of the column is used to simulate the condition of the fixed ends by restricting all degrees of freedom. The coupling columns are in the range of beam height to a point, as the loading point of horizontal reciprocating load, as shown in Figure 3. The full degree of freedom at the bottom of the column is connected to the ground rigid, and the initial defect of the material and the influence of the welding residual stress are not taken into account.

3.3. Loading approach

In order to control the force at the time of loading, the simulation can be better convergent, and the
displacement control is adopted in the cyclic loading. The application of horizontal loads is referred to "code for seismic test of buildings" (JGJ/T 101-2015), and the loading rules is shown in Figure 4.

3.4. Failure criterion

The eccentrically braced steel structure is an ideal seismic energy dissipation structure. The whole structure reaches the ultimate state of bearing capacity. Before the energy dissipation section, all other members should be in the elastic state [10]. The following phenomenon occurs, the component is destroyed, and the simulation [11] is stopped.

1. Any beam and column member except the energy dissipating beam enters the plastic stage.
2. Any equivalent stress in link beam reach or exceed the ultimate strength of steel.

According to this failure criterion, the ultimate stress of Y and K eccentrically braced beams under cyclic loading is 236Mpa, which exceeds the ultimate strength of the steel and enters the plastic stage, and the calculation terminated. The Y and K-shaped eccentrically braced frames comply with the stress failure criteria as shown in Figure 5.

![Figure 5: Model failure stress](image)

4 Analysis of results

4.1. Hysteretic curve

Figure 6 is a hysteresis curve of Y and K shaped frame joints at top floor. The overall curve is relatively full, the area of hysteresis loop is larger, and the energy dissipation capacity is strong. The YZ2 and YZ3 model joints have better energy dissipation capacity, and the energy dissipation capacity of the composite structure Y-shaped eccentric bracing is higher than that of the K-shaped eccentrically braced brace. With the increase of steel grade for column, the hysteretic curve of Y and K shape is more full, and the hysteretic performance has some extent improvement. It has a certain ductility and energy dissipation capacity, and its bearing capacity is improved.

Figure 7 is the hysteresis curve of energy dissipation section at top floor in structures. From the graph, though the number of cycles and the fullness of the 4 groups of models is different, the shapes of the hysteretic curves of the models are all shuttle shaped, showing a good hysteretic property, which indicates that this part has good yield deformation performance. The area enveloped by the Y shape brace combination hysteretic curve is larger than the K shape brace. The dissipated energy in the Y shape brace is larger than that in the K shape brace and the total energy consumption increases by 12.3% to 24.3%.
Figure 6: Hysteresis curve of joints at top floor

(a) $YZ_0$-$KZ_0$ Hysteresis Curve
(b) $YZ_1$-$KZ_1$ Hysteresis Curve
(c) $YZ_2$-$KZ_2$ Hysteresis Curve
(d) $YZ_3$-$KZ_3$ Hysteresis Curve
4.2 Energy dissipation analysis

Table 5 and Table 6 are the energy dissipation values of the components of each combination model. Although the steel grades of each frame are different, the energy consumption of the two types of brace is the most, the second energy consumption is joints, and the energy consumption of the beam and column is the smallest. Dissipation of the frame structure, and contribution of other components is less. The structural details, length, and the grade of steel will have a certain effect on the hysteresis performance of the frame structure. The overall energy consumption of the structure can be improved by changing the steel grade of the energy dissipation section from various frame combinations.

Table 5 Energy dissipation value of Y- shaped components

| Combination type | Total (kN·m) | Lind-beam (kN·m) | Joints (kN·m) | Brace (kN·m) | Beam (kN·m) | Column (kN·m) |
|------------------|--------------|------------------|---------------|--------------|-------------|--------------|
| YZ0              | 2645.28      | 1105.80          | 1065.00       | 343.07       | 67.18       | 64.25        |
| YZ1              | 2886.11      | 1229.22          | 1102.81       | 386.877      | 128.99      | 38.22        |
| YZ2              | 3147.99      | 1304.06          | 1203.4        | 399.28       | 139.12      | 102.13       |
| YZ3              | 2829.02      | 1270.24          | 973.66        | 351.25       | 136.27      | 97.60        |

Table 6 Energy dissipation value of K- shaped components

| Combination type | Total (kN·m) | Lind-beam (kN·m) | Joints (kN·m) | Brace (kN·m) | Beam (kN·m) | Column (kN·m) |
|------------------|--------------|------------------|---------------|--------------|-------------|--------------|
| KZ0              | 2095.93      | 1004.98          | 936.64        | 52.62        | 62.01       | 39.68        |
| KZ1              | 2424.05      | 1252.15          | 980.07        | 63.13        | 78.66       | 50.04        |
| KZ2              | 2563.29      | 1286.43          | 1095.24       | 62.46        | 68.58       | 50.58        |
| KZ3              | 2208.05      | 1060.86          | 956.21        | 51.42        | 96.4        | 43.16        |

Figure 8 is the energy dissipated by each cycle of joints at top floors in the combined models. It is known from the diagram that the YZ2 model accumulates the most energy of the cyclic dissipation, and the YZ3 model is the second one. Compared with the K-shaped brace model, the energy dissipation of the Y-shaped brace model is higher than that of the K-shaped brace under the same combination from 1% to 22%. Because of energy dissipation of structural failure, not only related to energy dissipation sections, but also the frame beam and column are involved in. Although the same load is used in the model, the energy dissipation energy and the ultimate energy dissipation coefficient are different between the models.
Figure 8 Joint accumulative energy dissipation

Figure 9 shows the energy of accumulative dissipation of the energy dissipation section of each model at top floors. It is known that the energy of the YZ2 energy dissipation section is the largest, the KZ0 is the smallest, and the graph trend is similar to the energy consumption pattern of the joints. The energy dissipation of Y-shaped braced frames is also better than that of K-shaped braced frames by 1% - 22%, so Y-shaped braced frame is a good seismic structure.

Figure 9 Link-beam accumulative energy dissipation

Energy consumption of energy of energy dissipation sections for Y-shaped accounted for the overall energy consumption of energy range from 41.3% to 44.9%, while for K-shaped accounted for the overall energy dissipation range from 47.9% to 50.1%. It can be indicated that Y-shaped braced frames have better energy consumption section, can consume the earthquake energy effectively through deformation, so Y-shaped braced frame is a kind of excellent frame structure.

5. Conclusion
Based on two three-story single-span eccentrically braced frame structure, 4 groups of Y-shaped eccentrically braced frames and K-eccentrically braced frame structure models are designed. The following important conclusions are obtained:

1) The hysteretic curves of K-shaped and Y-shaped eccentrically braced steel frames are similar, with a little difference, and all of them have a certain energy dissipation capacity. Two kinds of eccentric braces are mainly dissipated by the energy dissipation section. The energy dissipation capacity of combined model YZ2 is the best, and the energy dissipation capacity of KZ0 is the lowest.

2) Under the same load, the energy consumption of the K-shaped eccentrically braced steel frame is always below the Y-shaped eccentrically braced steel frame, which indicates that the energy dissipation section of the K-shaped brace frame is less than the Y-shaped eccentric brace frame, and the Y-shaped eccentrically braced energy dissipation section is independent of the frame beam and column, which can
effectively dissipate the seismic energy.

3) Two kinds of frames, the dissipative energy of the dissipative section account for more than forty percent, which can effectively dissipate the seismic energy through the yield deformation energy dissipation section.

In conclusion, YZ2 structure is recommended for the aseismic design of high strength steel composite steel frames. The first reason is that the seismic energy consumption is slightly higher than the other structures. The second reason is that the deformation of this structure is mainly in the energy dissipation section rather than on the frame beam, which is easy to replace and repair after earthquake. In the high-intensity seismic area the proposed combined Y-shaped eccentric bracing can be used as the structure of the frame.

Acknowledgement
The authors gratefully acknowledge the financial support provided by National Natural Science Foundation of China (Grant No. 51574151), Key Project of Hunan Provincial Education Department (Grant No. 15A163) and Research Initiation Funds of University of South China for the Returned Visiting Scholars (Grant No. 2016XQD47).

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