Nonlinear Finite Element Simulation on Seismic Behaviour of Steel Frame-Central Brace with Ring Damper

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Abstract. The central brace combined with a ring damper is used as lateral resistant to improve the lateral stiffness and seismic performance of steel frame. In order to reveal the working mechanism of the new system, three nonlinear finite element models: steel frame with central brace, steel frame with eccentric brace, and steel frame infill central brace with steel ring damper, were established. The results indicate that compared with other two structural systems, the steel frame infill central brace with steel ring damper has the best bearing capacity, energy dissipation ability and seismic behaviour.

1. Introduction
Using of the brace system could increase the lateral stiffness of steel frames dramatically, and reduce the seismic demands on steel frames. Previous researches show that different brace systems have different effects on the performance and energy consumption of steel frames. Chong ping Bai [¹-⁴] carried out finite element simulation analysis on steel frames with various supporting system, such as “X-shaped” and “herringbone type”. It was found that the supporting steel frame structure can reduce the interlayer displacement, but the support rods are easily destabilized under compression. Jie Leng etc. [⁵-⁹] conducted a cyclic loading test on the self-repairing support steel frame. The results indicated that the structure had residential deformation after loading and a poor permanent in energy dissipation. In order to study the reinforcement brace system, a new type of supporting brace system for steel frame was produced. Based on that, an analysis model using ABAQUS software was established to study it’s lateral resistant and energy dissipation ability.

2. Steel Frame--Central Brace with Ring Damper
The calculating example is based on a 6-storey frame-brace structure. A horizontal composite steel frame in the central area was selected as the research object (Figure 1). Based on that, a steel frame--central brace with ring damper (SBRD) was simplified for analysis (Figure 2).
3. Nonlinear Finite Element Analysis
In order to compare the seismic behavior of steel frame with central brace, steel frame with eccentric brace and SBRD, the same frame element type, mesh division, boundary conditions and loading methods are adopted.
3.1. Finite Element Models Establishment
In order to simulate the Steel Frame-central brace with ring damper accurately, S4R shell unit is adopted in beam and column, C3D8R hexahedron solid unit is adopted in brace and ring damper. Specimens were selected according to ASTM-A370-05 for material properties. The beams and columns are made by Q345B steel, while the braces and ring dampers are made by Q235B steel. Material mechanical properties data is shown in Table 1.

Table 1. Mechanical Properties of Materials

|                      | fy [MPa] | fu [MPa] | E [GPa] |
|----------------------|----------|----------|---------|
| Steel frame(Q345)    | 300      | 460.5    | 204     |
| Brace and damper (Q235) | 200      | 336.2    | 203     |

*fy is the yield strength.
*fu is the ultimate strength.
*E is the elastic modulus.

To ensure the accuracy and efficiency of calculation, structural meshing is adopted in all elements, as shown in Figure 3.

![Figure 3. Meshing Grid](image)

To meet the requirements of nodal rigidity and seism, the braces are articulated connect to beams and columns, and beams and columns are connected by bolt and weld. Ring dampers are bolted to braces to transfer the shear (Figure. 4).

![Figure 4. Interaction](image)
The boundary conditions are set as follows: all bottom nodes of the brace and column are fixed completely. A lateral constraint is arranged in the middle of the beams and columns web to prevent the out-of-plane overturning of the steel frame. In order to avoid the stress concentration and local buckling at the loading point, the beam-column section is coupled to the hinged joint, on which lateral displacement is applied. The boundary conditions and load arrangement are shown in Figure. 5.

![Figure 5. Boundary Conditions](image)

The monotonic load and cyclic loading scheme are controlled by displacement and the load step increases 2mm each stage. Each stage of the load moves only once. The load-displacement performance and hysteretic behaviour are recorded under the loading scheme.

### 3.2. Finite Element Results

The displacements of three structures increase with the increase of monotonic load (Figure 6). The steel frame with a central support has a desirable initial stiffness in the initial elastic stage (Table 2). In the elastic-plastic stage, although the stiffness of each structure decreases gradually. The ultimate bearing capacity of SBRD is 915.2kN and the ultimate displacement is about 310mm. It has satisfactory bearing capacity and strong deformation ability under lateral loads.

![Figure 6. Comparison of Three Load-Displacement Curves](image)

### Table 2. Comparison of Bearing Capacity and Initial Stiffness

| Model                        | Bearing capacity | Initial Stiffness |
|------------------------------|------------------|-------------------|
| SBRD                         | 915.2KN          | 22.4KN/mm         |
| Steel Frame with Central Brace| 976.0KN          | 50.8KN/mm         |
| Steel Frame with Eccentric Brace | 874.2KN       | 37.8KN/mm         |
Three hysteresis curves of three structures under the cyclic loads are listed in Figure 7 respectively. Two of them are all shuttle shape, while the SBRD hysteresis curve is much plumper showing that it has better deformation performance and energy dissipation ability.

![Figure 7. Hysteresis Curves of Three Models](image)

The Stress nephograms of three structures are shown in Figure 8-10. It indicates that the forces in steel frame with central brace and SBRD are mainly applies on the joints, beams and braces. The SBRD delays compression buckling of braces through deformation of the ring damper to realize better energy dissipation performance. The forces in the steel structure with eccentrically brace are mainly applies on the joints, beams and energy-consuming beams. Once the energy-consuming beams are damaged in the loading procedure, it may cause premature failure of the structure.

![Figure 8. SBRD](image)
4. Conclusion

According to the performance of three structural models under monotonic loads and cyclic loads, conclusions can be drawn as follows:

1. The SBRD has the best deformation ability under the monotonic loads, and thus has better performance under large deformation conditions. Also the SBRD has desirable lateral stiffness and bearing capacity.

2. The SBRD has the best seismic behaviour under cyclic loads. It dissipates the energy through a ring damper.

3. SBRD could not only delay the buckling of the brace, but also avoid the structural damage caused by the failure of energy-consuming beams.
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