

Seismic Behaviors of the Composite Central Brace with Steel Ring Damper

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Abstract. Using ring damper in the center brace could solve premature buckling and decrease residual deformation of the central brace. A design method for Composite Steel Ring Brace system was proposed based on current design codes. A nonlinear finite element model was established to study seismic behaviors of the ring damper by use of ABAQUS software. The results indicate that ring damper has ample initial stiffness, bearing capacity, better deformation performance and energy dissipation ability in the control displacement range.

Introduction

The brace can significantly improve the lateral stiffness of steel frame. Pure steel brace has the characteristics of easy buckling instability and weak energy dissipation performance, which cannot meet the seismic requirements. In order to resolve the problem mentioned above, Jun xian Zhao^[1-4] have conducted researches on various types of brace system, and the research results can improve the buckling of supports to a certain extent, but the residual deformation is still large after the earthquake. Canadian scholar Robert^[5-6] settled the problem of large post-earthquake deformation by conducting tensile test on a new type of self-reduction energy-consuming brace with dual characteristics of self-reduction and energy consumption. This kind of brace has high requirements on prestressed bars, which is difficult to realize in real practice. In order to make up the shortcomings of the traditional braces, a composite central brace with steel ring damper (CBRD) is produced. The existence of the ring damper could improve the seismic performance of the brace. Based on the current design specifications, a design method for CBRD system is put forward, which enlarge the use of the central brace.

Design of CBRD system

The calculating example is based on a 6-storey frame-brace structure. The total lateral force is calculated by using the bottom shear method. The lateral force of selected frame is evaluated by 1/3 of the total lateral force, the interlayer shear force is calculated by the sum of force of above layers and (Table 1).

Table 1. Interlayer Shear Force

Number of layers / i	1	2	3	4	5	6
interlayer shear V_i /KN	1112.9	1058.8	951.6	793.3	577.2	321.1

The brace of the combined ring is equivalent to the central herringbone system, which is assumed to bear all the lateral shear. Consider the angular relationship between the shear force between layers and the equivalent brace, the maximum axial force of the bottom layer is calculated to be 1043.3 KN.

Ring damper design

Based the simplified force analysis Figure 1, the bearing capacity of the ring damper is calculated by the axial force caused by the interlayer shear force to meet the requirements of deformation.

Through the plastic hinge P_i bending moment equilibrium conditions, the thickness of the ring is 12 mm, and its overhanging plates length is 180 mm. The inner and outer radius of the ring damper is set as 99mm and 105mm respectively.

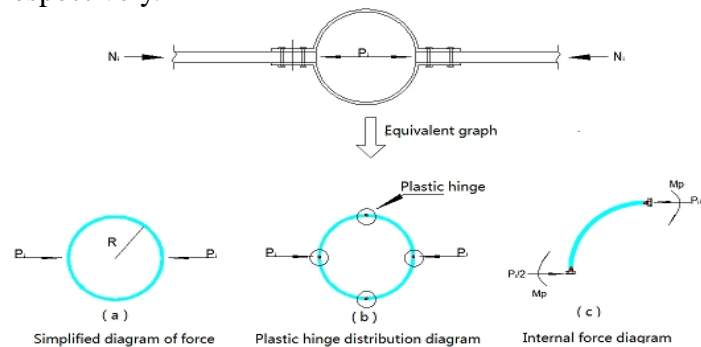


Fig.1 Ring Damper Simplified Diagram of Force

According to Zahra Andalib^[7] studies' on the bearing capacity and energy dissipation performance of a composite steel damper, the ring damper is actually difficult to realize it's the ideal state, thus there is an error between theoretical value and real value. A adjustment factor should be considered, and the calculation formula for the bearing capacity of the ring in the elastic range and the plastic range (Equation 1,2) is proposed.

$$K_1 = l_i^2 / 3t_i R_i \quad P_i = K_1 \pi t_i^2 l_i f_y / R_i \quad (1)$$

$$K_2 = l_i^2 / 2t_i R_i \quad P_i = K_2 \pi t_i^2 l_i f_y / R_i \quad (2)$$

Where,

K_1 ----- Elastic section composite ring bearing capacity adjustment factor;

K_2 ----- Plastic section composite ring bearing capacity adjustment factor;

l_i ----- The length of the i composite ring;

t_i ----- The thickness of the i composite ring;

R_i ----- The radius of the i composite ring.

The compression bearing capacity of the ring damper is 121.7 KN, which is close to the design value of the theoretical ultimate bearing capacity of 117.2 KN. the calculation error is about 3%.

Connection design of brace rod

As shown in figure2, Using groove butt joint design could achieve connection of inner sleeve. According to the specifications of steel structure for high-rise buildings (JGJ99-2015)^[8], the dimension of the section are calculated as 90mm and 120mm respectively. Based on the "Code for Design of Steel Structures"^[9](GB50017-2017), the connection design of the brace bar was carried out. The ring damper is bolted to the brace. The diameter of the bolt is 22.8mm according to the shear capacity design of the bolt. The bolts of the brace are arranged along the length of the supporting rods, with 90mm space. The End bolts are 24mm distance from the edge. The cover plate is welded to the upper port of the lower brace. The butt weld is E43 electrode, the fillet weld is E50 electrode, the welding leg size is 6mm, and the weld strength is designed to meet the specification requirements.

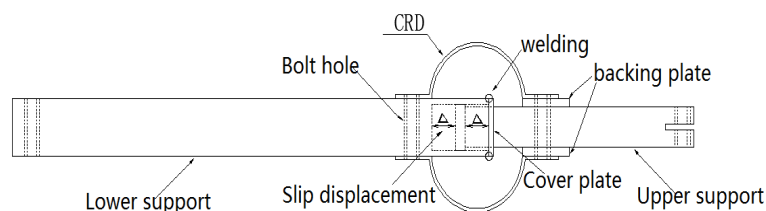


Fig.2 Inner Sleeve Connection

Finite Element Analysis

Finite Element Modeling

In order to simulate the ring damper accurately, the element C3D8R hexahedron solid unit is

adopted, as shown in figure3. Q235B grade steel is applied for the ring damper. The yield stress and elastic modulus are respectively 197Mpa and 203Gpa. In the model, the method of "face to face hard contact" is used to simulate the contact situation of the two plates.

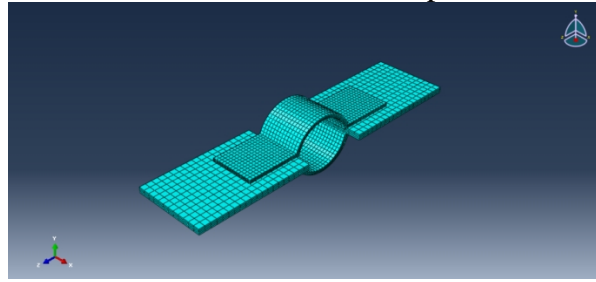


Fig.3 Ring Damper Finite Element Model

Finite element analysis

Behavior under monotonic loading

As shown in Figure4-5, the ring damper were experienced elastic, yield and elastic-plastic under tension and compression. The simulation results were compared with that of Yun Zhou^[10-11] and Ji Liu (Table 2). The Bearing capacity under tension is 10 times higher than that under compression. Whereas the stiffness is almost the same.

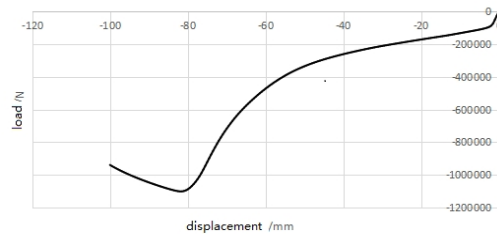


Figure.4 The Curve under the Tensile Load

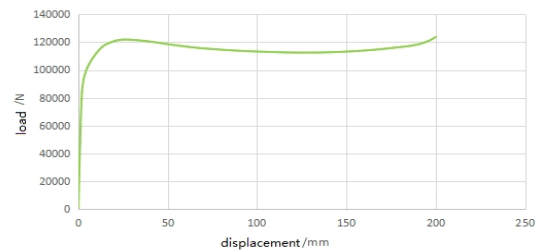


Figure.5 The Curve under the Compress Load

Table 2 .Comparison of Bearing Capacity and Stiffness

Loading mode	Bearing capacity	Stiffness
Ring damper	121.7KN	48.3KN/mm
Flat plate damper ^[10]	18.9KN	1.2KN/mm
Double ring damper ^[11]	50.4KN	4.8KN/mm

Seismic behavior

As shown in Figure 6, the hysteretic curve has good performance within the range of 30mm. The energy dissipation of the ring damper is mainly caused by plastic hinges in the range of 30mm displacement. The plastic hinges mainly appears at the top and sides of the ring damper.

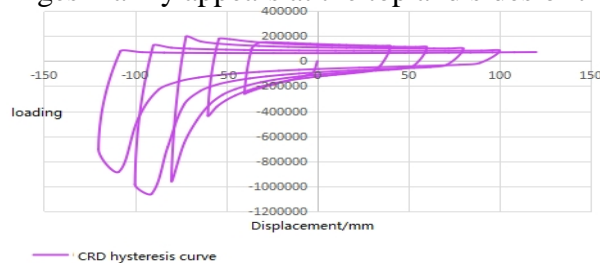


Fig.6 Hysteretic Curve

Conclusions

1. The ring damper is designed by use of conjunction of bolt and weld to meet the initial rigidity and seismic demands.

3. The ring damper can be used as an energy dissipation component for central braces. It absorbs the earthquake energy and avoid the premature buckling of the brace.

3. The ring damper reaches the ultimate bearing capacity through forms of multi-plastic hinges, and

shows good seismic performance within the 30mm ranges.

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