Analysis of Seismic Performance of the New Self-centering Buckling Restrained Brace

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Abstract. A new structure of self-centering buckling restrained brace was proposed. The finite element model was established by ABAQUS software. The mechanical failure mechanism of this kind of self-centering buckling restrained brace was studied. The influence of the parameters such as the area of self-centering reinforcement and the sectional area of core tube on its hysteretic performance and self-centering ability was analyzed. The results show that with the increase of the area of the reset reinforcement, the hysteretic curve of the brace is more pinched, and the self-centering ability is increased by 46%; it was suggested that the weakening degree of the cross-sectional area of the core tube should not exceed 50%.

1. Introduction

The buckling restrained brace mainly uses the plastic deformation of the core material to dissipate seismic energy. Compared with ordinary braces, it has energy dissipation behavior during tension and compression, which can fully dissipate seismic energy and effectively protect the main structure [1]. However, due to the low stiffness of the energy-consuming core material after yielding, it will cause a large residual deformation after the earthquake, which makes it difficult to repair the structure. Research shows that when the residual deformation is greater than 0.5%, the repair cost of the structure will exceed the reconstruction cost [2].

Therefore, scholars at home and abroad have studied a kind of BRB which can dissipate seismic energy and reduce residual deformation. Christopoulos et al. [3-4] carried out an experimental study on the self-centering buckling restrained braced frame model. The results show that: its residual deformation can be controlled very small. However, the maximum elastic strain of aramid fiber reinforced bar is relatively small, and anchoring is difficult. Miller et al. [5] proposed a kind of self-centering buckling restrained brace using shape memory alloy (SMA) as reduction reinforcement. The research results show that the reset performance of the brace is good, but the disadvantage is that SMA is greatly affected by temperature and expensive. Liu Lu et al. [6] proposed a new type of self-centering buckling restrained brace with prestressed steel strand as the reset reinforcement. The research results show that this kind of brace has good reset capacity and energy dissipation capacity, but its structure is complex and the construction is difficult.
To sum up, the self-centering buckling restrained braces proposed at present are either relatively complex in structure, or the cost of restoring bars is high, the elastic deformation capacity is poor or the anchoring is difficult. Therefore, a new type of self-centering buckling restrained brace (SCBRB) with relatively simple structure and low cost is proposed in this paper.

2. Structure of new self-centering buckling restrained brace

Fig.1 shows the schematic diagram of new SCBRB, which is composed of BRB and SC. The buckling restrained brace consists of core tube, inner restraint tube, outer restraint tube, left force transmitting plate, left cross plate, right force transmitting plate and right cross plate. At the left end, the cross plate is welded with the force transmitting plate, and the force transmitting plate, core tube and inner restraint tube 1 are welded; at the right end, the cross plate and the force transmitting plate are welded with the outer restraint tube 2. The core tube is located between the inner tube and the outer tube. It mainly bears the axial force. Its left end is connected with the inner tube and its right end is connected with the outer tube. This can make the inner tube and the outer tube transfer the external load for the core tube. A new type of SCBRB, as shown in Fig.1 can be formed by adding reset bars, left end plate and right end plate to the BRB.

3. Establishment of finite element model

Considering Bauschinger effect of steel, bilinear follow-up strengthening model (kinematical) is adopted in the constitutive model. T3D2 bar element is used for self-centering reinforcement of SCBRB, and C3D8R element is used for the rest.

The contact mode of self-centering buckling restrained brace is face-to-face contact, the normal direction of contact surface is "hard contact", and the tangential direction is set as no friction. The steel tube is connected with the force transfer plate, the force transfer plate and the cross plate by welding. The welding method is realized by binding restraint mode.

The new type of self-centering buckling restrained brace requires that the restoring bar is always in the elastic stage when it is loaded. As the steel strand is used as the restoring bar, its elastic deformation is only 1%. Therefore, the loading system should be carried out according to the following requirements:

The elastic deformation of the reset reinforcement is

$$\varepsilon_e = \frac{F_0}{EA} = \frac{70.2 \times 10^3}{140 \times 1.95 \times 10^5} = 0.257\%$$

Therefore, in the subsequent loading, the available elastic deformation is 0.743%, so the maximum loading displacement in this paper is:

$$\Delta l_{\text{max}} = \varepsilon l = 0.743 \times 10^{-2} \times 1400 = 10.5\text{mm}$$

Therefore, the maximum loading displacement is 10.5 mm, and the increment of each stage is 1.5 mm.
4. Stress mechanism analysis

A finite element model of a new type of self-centering buckling restrained brace with a length of 1400mm, a diameter of 90mm, an area of 810mm$^2$, a diameter of 12.7mm, and a prestressing force of 190kN is established. The model is used to analyze the bearing mechanism of the brace. The stress state of the brace is analyzed when the axial displacement is 1.5mm, -4.5mm, 7.5mm, -10.5mm.

4.1. When the axial displacement is 1.5mm

Fig. 2 shows the stress nephogram and hysteresis curve of the support when the axial displacement is 1.5mm. It can be seen from the figure that at this time, the core pipe has not yet yielded, and its large strain is concentrated near the opening. In the curve diagram, the energy dissipation coefficient of the brace is 0.015, and the energy consumption capacity is relatively weak. This is because the core material pipe has not yielded energy consumption, but the reset reinforcement has elongation, which basically achieves complete reset.

4.2. When the axial displacement is -4.5mm

Fig. 3 shows the stress nephogram and hysteresis curve of the support when the axial displacement is -4.5mm. It can be seen from the figure that at this time, the core material pipe has partially yielded at the opening section, and the stress nephogram shows that the area of the hysteretic curve of the support increases, the energy dissipation coefficient is 0.802, the energy dissipation capacity is enhanced, the ratio of residual deformation to maximum deformation is 10%, and the reset performance is good, which is due to the energy consumption of the core material pipe after yielding under compression. The increase of the force makes the restraint tube break off the end plate, and the break off of the end plate drives the extension of the reset bar, so the support has the reset ability.

4.3. When the axial displacement is 7.5mm

Fig. 4 shows the stress nephogram and hysteresis curve of the brace when the axial displacement is 7.5mm. It can be seen from the figure that the core tube has basically entered the yield state at the opening, and is still in the elastic state at both ends, which indicates that the opening can achieve fixed-point yield. The area of the hysteretic curve of the brace continues to increase, the energy dissipation coefficient is 0.805, the energy consumption capacity continues to increase, the ratio of the residual deformation to maximum deformation is 6.5%, and the reset capacity is good. The curve shows obvious flag shaped characteristics.

4.4. When the axial displacement is -10.5mm

Fig. 5 shows the stress nephogram and hysteretic curve of the bearing when the axial displacement is -10.5mm. It can be seen from the figure that the core tube has entered the yield state at the opening, and the pressure buckling at the opening indicates that the core tube is the main stress component. The
energy dissipation coefficient of the brace is 0.719, and the energy dissipation performance is good. The ratio of residual deformation to maximum deformation was 6.28%, and the reduction ability was good. This is because the core tube is compressed and yielding, and the self-centering reinforcement is extended, so that the bracket has the ability of resetting.

![Graph showing energy dissipation and deformation](image)

**Fig 4** when the axial displacement is 7.5mm  **Fig 5** when the axial displacement is -10.5m

5. Analysis of influencing factors

5.1. Model parameter design

In order to study the influence of various parameters on the performance of self-centering buckling restrained brace, five models were established by changing the area of reset reinforcement and cross-section area of core, and the specific parameters are shown in Table 1.

| Model   | Diameter of reset bar (mm) | Cross section area of core tube (mm²) |
|---------|---------------------------|-------------------------------------|
| SCBRB1  | 15.2                      | 1080                                |
| SCBRB2  | 12.7                      | 1080                                |
| SCBRB3  | 9.5                       | 1080                                |
| SCBRB4  | 12.7                      | 810                                 |
| SCBRB5  | 12.7                      | 540                                 |

5.2. The influence of the area of reset reinforcement

SCBRB1, SCBRB2 and SCBRB3 are selected to study the effect of the area of the reset bar on the performance of the SCBRB. Fig.6 shows the effect of the area of the rebars on the hysteretic curve of the BRBs. It can be seen from the figure that the yield force of the support is basically the same, because the initial prestress remains unchanged; with the increase of the area of the reset reinforcement, the maximum bearing capacity of the brace is from 710kN to 1140kN, This is mainly due to the increase of the area of the reset reinforcement, which increases the stiffness of the brace.

Fig. 7 and Fig. 8 show the influence of the area of the reset bar on the energy dissipation and reset performance of the brace. It can be seen from the figure that with the increase of the area of the reset reinforcement, the energy dissipation coefficient of the brace decreases by 37%; the ratio of the residual deformation to the maximum deformation decreases by 46%, indicating that the energy dissipation capacity of the brace is weakened, and the reset capacity is enhanced. This is mainly because the total energy consumption of the brace is certain, and the increase of the area of the reset reinforcement increases the output of the brace, increasing the load of each loading step The elastic potential energy area leads to the weakening of the energy dissipation performance of the brace.
To sum up, the larger the area of reset reinforcement is, the larger the bearing capacity of the brace is; the energy consumption capacity is weakened; and the reset capacity is enhanced. How to balance the reset capacity and energy consumption capacity of the brace needs to be determined according to the owner's requirements and structural requirements.

5.3. Influence of cross section area of core tube
SCBRB 2, SCBRB 4 and SCBRB 5 were selected to study the influence of the weakening degree of core tube section on the performance of SCBRB. Fig. 9 shows the effect of the cross-sectional area of the core tube on the hysteretic curve of the self-centering buckling restrained brace. It can be seen from the figure that with the increase of section weakening degree, the bearing capacity of the brace decreases from 1025 kN to 870 kN, which is mainly due to the reduction of the cross-section area of the core tube, which reduces the stiffness of the support, thus reducing the bearing capacity of the brace.

Fig. 10 shows the influence of the cross-sectional area of the core tube on the energy dissipation capacity of the support. It can be seen from the figure that when the weakening degree of the core tube area is 25%, the energy dissipation coefficient of the support is the largest. This is because the opening of the core tube can achieve the fixed-point yield, so that the brace can yield energy consumption in advance, with an increase of 60% compared with that without weakening.

Fig. 11 shows the influence of the area of the core material tube on the reset performance. It can be seen from the figure that the ratio of residual deformation to maximum deformation decreases with the increase of the weakening degree of the cross section. This is mainly because the initial prestress is unchanged, while the area of the core pipe decreases, which leads to the decrease of the yield strength of the core pipe, and the reset ability is enhanced by 95%.
To sum up, with the increase of cross-section weakening degree, the bearing capacity of the brace decreases, and the reduction capacity increases, and the enhancement range reaches 95% compared with that without weakening. When the weakening degree of the section is 50%, the energy consumption capacity of the support is decreased, and the tension and compression are extremely unbalanced. Therefore, it is suggested that the section weakening degree of the core material pipe should not exceed 50%.

6. Conclusion

Through the numerical simulation and analysis of the new type of self-centering buckling restrained brace, the stress mechanism of the brace is studied. The influence of the area of the reset reinforcement and the area of the core tube on its bearing capacity, hysteretic energy dissipation and reset performance is analyzed.

(1) The structure of the new self-centering buckling restrained brace is reasonable. The energy dissipation capacity and reset energy of the brace are relatively good.

(2) Other factors remain unchanged. With the increase of the area of the reset reinforcement, although the energy consumption capacity decreases by 37%, the residual deformation of the support decreases, the hysteretic curve is more pinched, and the reset capacity increases by 46%; it is suggested that the cross-section weakening degree of the core pipe should not exceed 50%.

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