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Research on Characteristics of New Energy Dissipation With Symmetrical Structure

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Abstract. Utilizing good energy consumption capacity of arc steel bar, a new energy dissipation with symmetrical structure was proposed in this article. On the base of collection experimental data of damper specimen under low cyclic reversed loading, finite element models were built by using ANSYS software, and influences of parameter change (Conduction rod diameter, Actuation plate thickness, Diameter of arc steel rod, Curved bars initial bending) on energy dissipation performance were analyzed. Some useful conclusions which can lay foundations for practical application were drawn.

1. Introduction
With the increasing of long span spatial structures (as reticulated shell), how to resist the wind load and seismic load effectively were more concerned by scholars. To dissipate energy by structural self stiffness which was unreasonable and will produce large deformation in structure was the original Seismic design concept. Now, energy dissipation devices are installed in structure to prevent Structural failure. There are many kinds of energy dissipation devices, which can be divided into friction damper, steel damper, viscoelastic damper and viscous damper according to the mechanism of energy dissipation. Seismic performances of frame structure with viscoelastic dampers were analyzed by Hu Wei-bin etc. [2]; The influences to Structural vibration control of a new friction damper were analyzed by Zhao Dong etc [3].

Steel damper has good application prospect for making full use of good hysteretic behavior after yielding of metallic materials. The characteristics of steel damper were widely researched by scholars worldwide, The impacts of buckling-restrained brace to seismic performances of double-layer cylindrical reticulated shells were analyzed by Wang Xiu-li etc [4]; A new steel rod damper was developed by Donatella etc on the base of Conical steel suspension rod damper developed by Tyler in 1978 [5]; Curved steel damper and curved steel bar damper were developed respectively by Wu Cheng-liang and Deng Xue-song, the performances of the two kinds of dampers were studied by experiments and finite element analysis; The performance of a new steel tube damper developed by Wen Ming which is suitable for reticulated shells and long-span structures were researched by experiment and finite element analysis [8]; on the base of literature [8], improvements were made and a New energy dissipation With Symmetrical Structure was developed, the performances of the improved damper were researched in this article, which lays a theoretical foundation for the application of this improved damper.

2. Structure and working principle of the new energy dissipation
The concrete structure of the new energy dissipation is shown in Fig 1.
1-base plate 2-chassis 3-arc steel bar 4-left action plate 5-sleeve 6-middle top plate 7-top plate 8-right action plate 9-top fixed plate 10-force transfer steel pipe 11-Left cabin 12-Conduction bar 13-middle Top plate Round hole 14-Right cabin 15-Top plate Round hole

**Fig. 1** cross section diagrammatic sketch of a new energy dissipation

It can be seen from the diagrammatic sketch that the force is transmitted to the arc steel bars by the right actuation plate, the conduction bar and the left actuation plate when axial tension and pressure is subjected, and the energy is dissipated by the elongation and shortening of the arc steel bars. Three arc steel bars with the same size and initial bending are arranged symmetrically on both sides of the left actuation plate, which ensure the damper has symmetrical tensile and compression stiffness on axial force. Lateral load can also be borne by hole wall support of middle top plate and top plate.

### 3. Experiment analysis and finite element model establishment of the new energy dissipation

In order to verify the actual energy dissipation capacities of the damper, three energy dissipation specimens with the same size were produced. The parameters of the three specimens is shown in Figure 2. Steel No. is Q345. The performances of the energy dissipation under the low-cycle reciprocating load were tested.

**Table 1** The main parameters of new energy dissipation

| Specimen number | arc steel bar diameter / mm | arc steel bar initial bending /% | Left actuation plate thickness / mm | Conduction rod diameter / mm |
|-----------------|-----------------------------|---------------------------------|------------------------------------|-----------------------------|
| A1, A2, A3       | 12                          | 25                              | 10                                 | 30                          |

**Fig. 2** physical drawing of new energy dissipation

The performances of the energy dissipation under the low-cycle reciprocating load were tested on the reflexive force loading frame, and the load object diagram is shown in Fig 3.
According to the requirements of 《Specificating of Testing Methods for Earthquake Resistant Building》 (JGJ 101-96) [9], Displacement loading method was applied to specimens A1, A2 and A3, loading schemes is shown in Table 2.

| Specimen number | Load step | Displacement / mm |
|-----------------|-----------|-------------------|
| A1              | 1         | ±0.5\(\Delta_y\), Pull and press once |
|                 | 2         | ±\(\Delta_y\), Pull and press once |
| A2              | 3         | ±2\(\Delta_y\), Pull and press three times |
| A3              | 4         | ±4\(\Delta_y\), Pull and press three times |
|                 | 5         | ±8\(\Delta_y\), Pull and press three times |
|                 | 6         | ±12\(\Delta_y\), Pull and press three times |
|                 | 7         | ±16\(\Delta_y\), Pull and press three times |

\(\Delta_y\) is the extremum of Elastic displacement

The testing data are close for the size of the three specimens are the same, and only the load-displacement curve of the specimen A1 is drawn in fig 4. It can be seen from the Fig that the hysteresis loop of load displacement curve is obviously spindle shape, which indicating that the plastic deformation ability of the specimen is relatively strong and the damper has good energy dissipation capacity.
From the energy dissipation structure, it can be seen that the main influencing factors to energy dissipation characteristics are diameter of conduction rod, thickness of actuation plate, diameter and curvature of arc steel bar. In order to analyze the effect of each parameters to the performances of the energy dissipation device, finite element model of the energy dissipation device was established.

Multi linear kinematic hardening elastoplastic material model MKIN which consider Basinger effect and adopt Mises yield criterion is chose for the constitutive relation of materials. Steel NO is Q345, Poisson's ratio is 0.3, material density is 7850 kg/m³, yield strength is 345 MPa, ultimate strength is 510MPa, material elastic modulus is 206 GPa. The performance curve of the material is shown in Fig5.

The finite element model established under ANSYS is shown in Figure 6. The same low cyclic loading as the test was applied to the model, and the getting hysteretic curve is shown in Fig7.
Compared between the results getting by experiment and finite element model calculation, the extreme point location is close, and the slope and shape of the whole curve are similar. It shows that the finite element model has high accuracy.

4. Parameter study to the characteristics of new energy dissipation

The good and bad of energy dissipation characteristics is embodied in ductility and Energy dissipation performance.

Ductility is an important indicator when evaluating the good and bad of seismic performances of structure or component, and ductility of structure or component is usually compared with ductility coefficient, and the maximum displacement ductility is focused usually. The maximum displacement ductility coefficient is the ratio of the limit displacement to the yield displacement, which is

\[ \mu = \frac{\Delta_u}{\Delta_y} \] (1)

General yield bending moment method is used to get the yield displacement for yield point of damper skeleton curve is not obvious. [10].

Energy dissipation performance is another important parameter of damper. The area of hysteresis loop \( S_{ABCD} \) shown in Fig 8 is equal to dissipated energy under repeated loads. Energy consumption coefficient is used usually to compare energy dissipation characteristics of different dampers. Calculation formula of Energy consumption coefficient is shown as follow:

\[ E = \frac{S_{(ARC + CAD)}}{S_{(OBE + ODF)}} \] (2)

In addition, the energy dissipation performance of damper can also be measured by the equivalent viscous damping coefficient \( H_e \) [12], which is calculated as

\[ H_e = \frac{S_{(ARC + CAD)}}{2\pi S_{(OBE + ODF)}} \] (3)

Various parameters (conduction rod diameter, actuating plate thickness, arc steel rod diameter and arc steel bar bending) of damper shown in Fig 6 were changed, and influence of parameter change to ductility coefficient and equivalent viscous damping coefficient were analyzed.

Parameter representation of damper is: \( HNQ-ax-bx-cx-dx \). ax is the diameter of the conduction rod, bx is the thickness of the actuation plate, cx is the diameter of the arc steel bar, and dx is the initial bending of the arc steel bar.

4.1. The influence of conduction rod diameter change to the characteristics of new energy dissipation

The basic parameter of the damper is: \( bx = 10 \text{ mm}, cx = 12 \text{ mm}, dx = 25\% \).

Diameter of Conduction rod is chosen respectively from 25mm, 30mm, 35mm, 38mm, 40mm and 45mm. The relationship between the ductility coefficient and the diameter of the conduction rod is shown in Fig 9. The relationship between the equivalent viscous damping coefficient and the diameter of the conduction rod is shown in Fig 10.
Fig. 9 Diagrams of ductility coefficient and different diameters of conduction rod

Fig. 10 Diagrams of equivalent viscous damping coefficient and different diameters of conduction rod

It can be seen from the figure that the ductility coefficient and the equivalent viscous damping coefficient are gently as a whole, which illustrate that the main function of conduction rod is Transmission load and has minor impact to the ductility and energy dissipation capacity of the damper.

4.2. The influence of actuating plate thickness change to the characteristics of new energy dissipation

The basic parameter of the damper is:
\[ ax = 28\text{mm}, \, cx = 12\text{mm}, \, dx = 25\% .\]

The thickness of actuation plate is chosen respectively from 8.5mm, 10mm, 12mm, 14mm, 16mm, 18mm .The relationship between the ductility coefficient and the thickness of the actuation plate is shown in Fig11 , The relationship between the equivalent viscous damping coefficient and the thickness of the actuation plate is shown in Fig12 .

Fig.11 Diagrams of ductility coefficient and different thickness of actuation plate
It can be seen from the figure that the ductility coefficient and the equivalent viscous damping coefficient are gently as a whole too, which illustrate that main function of actuation plate thickness is Transmission load and has minor impact to the ductility and energy dissipation capacity of the damper.

4.3. The influence of diameter variation of arc steel bar to the characteristic of new energy dissipation
The basic parameter of the damper is:
ax = 42mm, bx = 21mm, dx = 25%.

The diameter of the arc bar is chosen respectively from 8mm, 10mm, 12mm, 14mm, 16mm, 17mm. The relationship between the ductility coefficient and the diameter of arc bar is shown in Fig13. The relationship between equivalent viscous damping coefficient and the diameter of arc bar is shown in Fig14.

Fig. 13 Diagrams of ductility coefficient and the different diameter of arc bar

Fig. 14 Diagrams of equivalent viscous damping coefficient and different diameter of arc bar
It can be seen from Fig13, 14 that the ductility coefficient and the equivalent viscous damping coefficient are increasing with the increasing of the diameter of the arc steel bar, and the increasing range is slow when diameter of arc steel bar is more than 14 mm.

4.4. The influence of the initial bending variation of the arc steel bar to the characteristics of new energy dissipation

The basic parameter of the damper is:
ax = 33 mm, bx = 14 mm, cx = 12 mm,
The initial bending of the arc steel bar is changed from 10%~35%.

The relationship between the ductility coefficient and the initial bending of the arc steel bar is shown in Fig15. The relationship between the equivalent viscous damping coefficient and the initial bending of the arc steel bar is shown in Fig. 16.

From Fig. 15 and 16, it can be seen that the ductility coefficient and the equivalent viscous damping coefficient are gradually reduced with the increase of the initial bending of the arc steel bar, but the deformation capacity is relatively improved.

5. Conclusion
In this paper, a new type of steel pipe energy dissipation with symmetrical structure was proposed, and experiment and finite element parameters were analyzed. The following conclusions were drawn:

(1) the main function of conduction rod and the actuation plate is Transmission load and has minor impact to the ductility and energy dissipation capacity of the damper.

(2) arc steel bar is the main energy dissipation element. The energy dissipation characteristics is improved significantly with the increasing of the diameter of arc bar, and the promotion of the energy dissipation characteristics is not significant when diameter reach a certain value, and it has little significance to increase the diameter when considering economy and effect.
(3) The reason of ductility and energy dissipation capacity are better when the initial bending of curved steel bar is small is that the steel bar is stretched, and the characteristic of arc steel bar is not used. The intermediate value of arc steel bar can be chosen in practical application.

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