# Study hollow on spring lead damper performance

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## INTRODUCTION

China is located at the junction of many crustal plates, which is an earthquake-prone country, and it is also one of the countries that suffer the most serious disasters in earthquakes. In the design and construction of nuclear reactors, site requirements are increasing, and how to mitigate the adverse effects of earthquakes is of Paramount importance. Since the Fukushima nuclear power plant incident, the international community pays more attention to the shock absorption and seismic isolation of nuclear reactors, and one of the key components of shock absorption and seismic isolation is the damper. In the field of earthquake resistance, many scholars have carried out extensive research on the damper (Zhou Y.2006).
In metal dampers, the energy-consuming metal commonly used is lead. Lead has the universal properties of metal, and will not cause fatigue during long-term placement and deformation leading to structural failure. In addition, due to its good flexibility, it can follow the deformation of the building well, so as to provide better supporting force and energy dissipation capacity at all times under external load, and finally has been widely used in the field of energy dissipation and shock absorption. However, lead has the characteristics of easy oxidation in the air and difficult to weld. In order to solve these problems, many studies have adopted the "synergistic action of multiple energy-consuming mechanisms" approach. The combined dampers have the advantages of large yield deformation displacement, consistent axial performance and remarkable energy dissipation effect(Lu Dehui, Zhou Yun,Deng Xuesong. 2013).

### *1.1 The subject of this paper*

Although there are many kinds of lead dampers with good extensibility and ultimate deformation ability, the problems of excessive additional stiffness, local buckling and insufficient bearing capacity will occur in most of the lead-core dampers used in practical engineering. Metal lead has good ductility and flexibility to provide a good deformation tracking ability. Besides, accumulation fatigue phenomenon will not appear because during the process of plastic deformation under room temperature conditions, recrystallization phenomenon will occur in theory. Although the literature proposes to introduce a hollow metal helical spring filled with lead core in parallel with the cylinder to increase the stability of the structure and provide vertical damping for the isolation support, in order to realize axial damping by using the low stiffness of the spring without affecting the low frequency characteristics of the isolator. However, the buffering performance of this kind of damper needs to be further studied(Wu S. 2022 ).

### *1.2 The purpose, content and significance of the research*

The purpose of this paper is to design and study the structure of the hollow spring lead damper, and determine its reasonable construction form; Through finite element numerical calculation to clarify the dynamic performance of the hollow spring lead damper, and explore the key design parameters of the hollow spring lead damper on its energy consumption.

Through finite element numerical calculation, the energy dissipation performance of two kinds of hollow spring lead dampers with different configurations is compared, and the reasonable structure is selected.

Through finite element numerical calculation, the influence of different structural parameters of the hollow spring lead damper on the damping characteristics of the damper is calculated, the influence rule is studied and the changing trend is given.

After the Fukushima nuclear power plant accident, the seismic requirements of nuclear power plants are generally raised. In order not to affect the design of existing reactors and improve their seismic capability, it is proposed to set a three-dimensional low-frequency seismic isolation layer between the reactor raft and the foundation to reduce the transmission of seismic movements to the superstructure of the reactor foundation. The isolation layer is mainly composed of isolators, dampers and limiters. The existing steel pipe lead damper and bellows lead core damper have large axial stiffness, which is not conducive to the low frequency of isolation layer. The hollow spring lead damper is a new type of metal displacement damper, which is characterized by low axial stiffness. If good damping characteristics can be obtained through reasonable design, it has great theoretical and practical application value for the low frequency of the vibration isolation layer of the reactor.

## PERFORMANCE ANALYSIS OF HOLLOW SPRING LEAD DAMPERS WITH DIFFERENT CONFIGURATIONS

Hollow spring lead damper of configuration A for lead core is the main energy consumption material, and steel as hollow spring material to provide restoring force, to ensure the cyclic capacity of the damper; Hollow spring lead damper of configuration B is used as the hollow spring material and the steel core provides support for the hollow spring, so as to avoid the fatigue failure of the lead core after multiple plastic deformation and not recovering the original state. Since the hollow spring lead dampers of two configurations have not been systematically calculated and analyzed after being proposed, two configurations of A and B with different sizes are calculated first to compare their energy consumption capacity. Then determine the specific configuration to be used, so as to facilitate the subsequent optimization calculation.

### *2.1 The exploration of hollow spring lead damper configuration A*

Hollow spring lead damper of configuration A is used as the hollow spring material and lead core for the hollow spring to provide plastic deformation energy. At the same time in the case of large deformation steel pipe will also participate in energy consumption. In order to verify whether this construction form is suitable for the actual needs of the project, ANSA is used for grid division and pre-processing in this paper, and ABAQUS software is used for finite element simulation calculation, which provides reference for the following calculation.

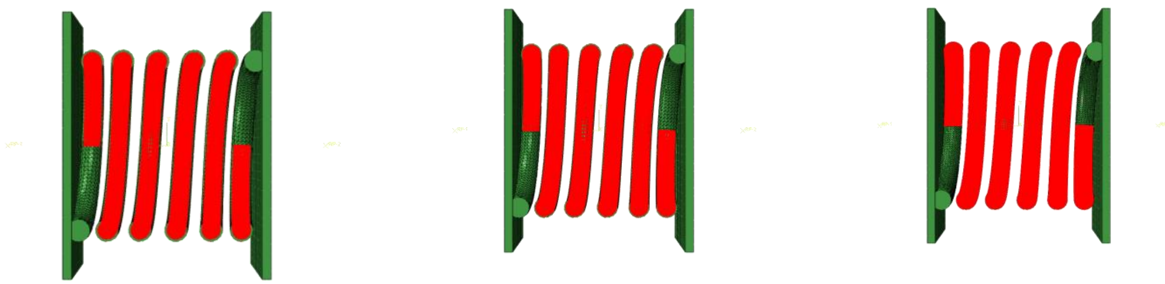
In order to study the influence of different structural forms of hollow spring lead dampers on mechanical properties, three kinds of hollow spring lead dampers with different envelope thickness of 5 mm steel envelope, 3 mm steel envelope and 1 mm steel envelope were designed. The specific geometric dimensions are shown in Table 1.1Configuration a Calculated geometric parameters (unit: mm).

Table 1.1Configuration a Calculated geometric parameters (unit: mm)

| No. | H1 | H2 | D3 | D4 | R1 | R2 | D1 |
|---|---|---|---|---|---|---|---|
| A1 | 460 | 420 | 390 | 440 | 20 | 25 | 220 |
| A2 | 460 | 420 | 390 | 440 | 22 | 25 | 220 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| A3 | 460 | 420 | 390 | 440 | 24 | 25 | 220 |

ANSA software is used for pre-processing and ABAQUS software is used for finite element simulation analysis of two different construction forms. Figure 1 Grid division diagram of Configuration A hollow spring lead damper (the red part is lead core)



(A1) 5mm (A2) 3mm (A3) 1mm

Figure 1 Grid division diagram of Configuration A hollow spring lead damper (the red part is lead core)

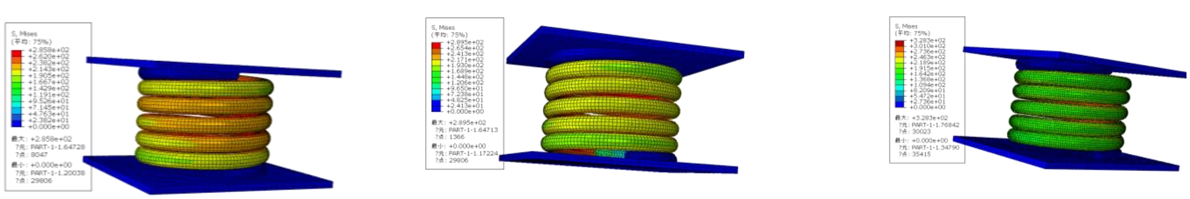
### *2.2 Performance analysis of the hollow spring lead damper of Configuration A*

In order to further study the influence of mechanical properties of the hollow spring lead damper of configuration A, our study will be conduct from the following aspects: stress distribution, plastic deformation distribution, hysteretic performance and energy dissipation mechanism of the hollow spring lead damper.

Figure 2 Stress distribution nephogram of a hollow spring lead damper of configuration A. It can be seen from the figure that the hollow spring lead damper has reasonable stress distribution, the steel envelope stress distribution is relatively average, and there is no stress concentration phenomenon.

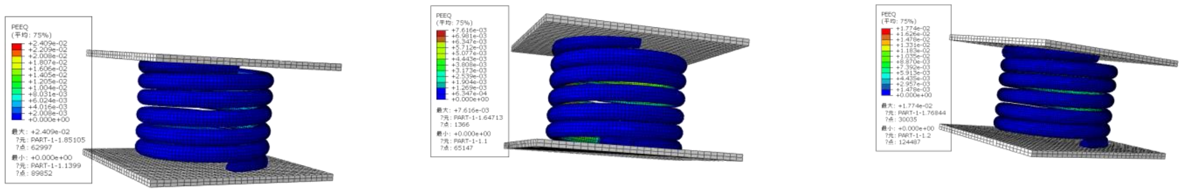
However, as it can be seen from FIG. 2.3 (a), (b) and (c), although there is a good stress distribution, the steel-enveloped hollow spring lead dampers do not show obvious plastic deformation. Therefore, the steel-enveloped hollow spring lead dampers mostly provide supporting capacity rather than energy dissipation capacity, indicating that they maintain the ultimate deformation capacity of the hollow spring lead dampers.

Figure 3 Plastic strain cloud diagram of a hollow spring lead damper of configuration A .However, it failed to give full play to the energy dissipation capacity of lead.



(a) 5mm steel envelope (b) 3mm steel envelope (c) 1mm steel envelope

Figure 2 Stress distribution nephogram of a hollow spring lead damper of configuration A

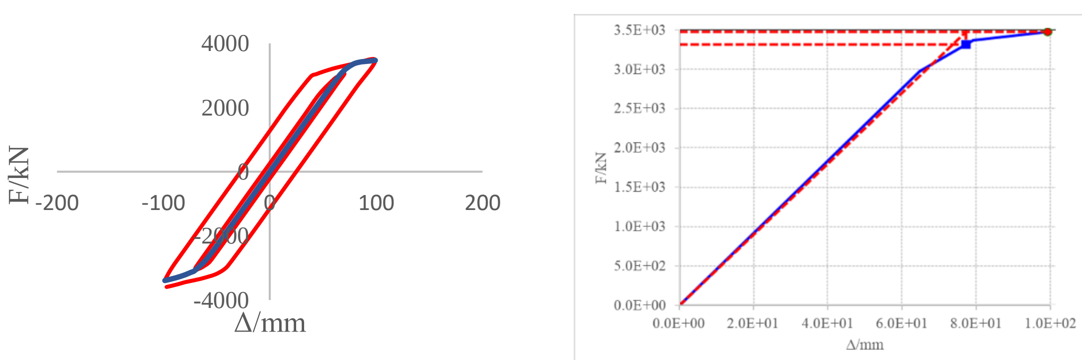


(a) 5mm steel envelope (b) 3mm steel envelope (c) 1mm steel envelope

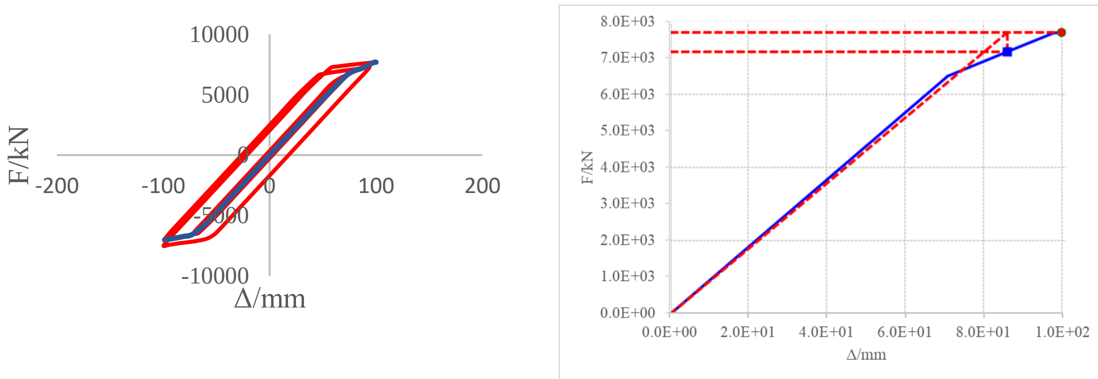
Figure 3 Plastic strain cloud diagram of a hollow spring lead damper of configuration A

### *2.3 Hysteretic performance calculation and analysis*

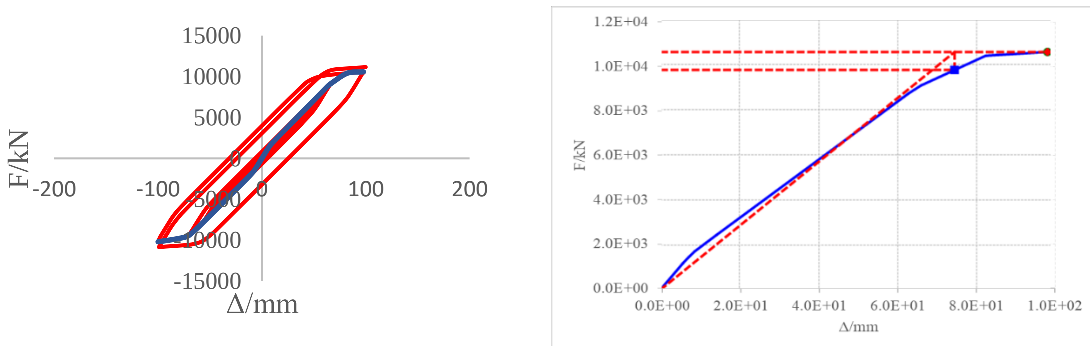
Under the earthquake, the hollow spring lead damper is subjected to reciprocating action, and the reciprocating axial compression deformation occurs. Its hysteretic curve reflects the mechanical properties of the model well. Figure 4 Configuration a Hysteretic curve and ductility curve of steel envelope of different thickness. Various parameters of the curve are analyzed in detail. Firstly, the line of each extreme point of the hysteretic mechanical characteristic curve is the skeleton curve of the model, which can reflect the trajectory of the maximum peak force reached by each cyclic loading, and is also an important basis for determining the feature points in the restoring force model.
It can be seen from the curve that the skeleton curve of the model is not clear, and it can be seen that the skeleton curve of 5mm steel envelope has obvious broken lines, indicating that its energy consumption is unstable. And the span of the hysteresis loop envelope on the horizontal axis is small, the energy consumption is relatively insufficient, while observing its ductility curve, the first half of the curve completely presents a linear state, until the subsequent steel plastic deformation after a more obvious relaxation section, it can calculate the ductility coefficient. Figure 5 Collection of mechanical characteristic curves. At the same time, the model also has the condition that the initial rigidity is too high, which will affect the work of the isolator. Although its equivalent hysteretic damping ratio can reach 0.25 or above due to the large longitudinal axis span of its energy dissipation area curve and the large energy dissipation area, it is not suitable for being a stable damper element.




(a) 1mm steel envelope

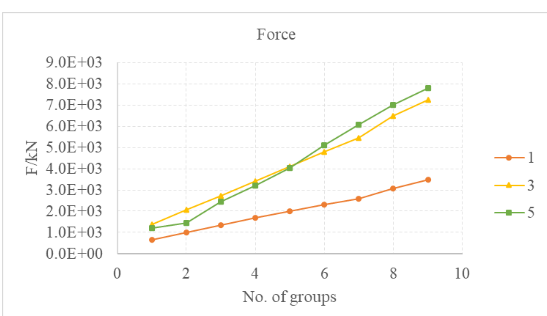



(b) 3mm steel envelope

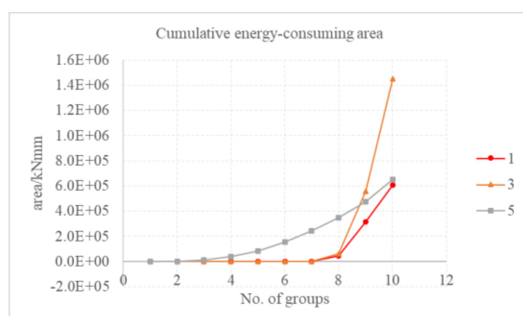



(c) 5mm steel envelope

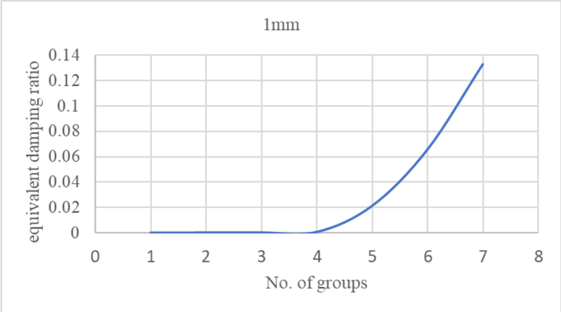
Figure 4 Configuration a Hysteretic curve and ductility curve of steel envelope of different thickness



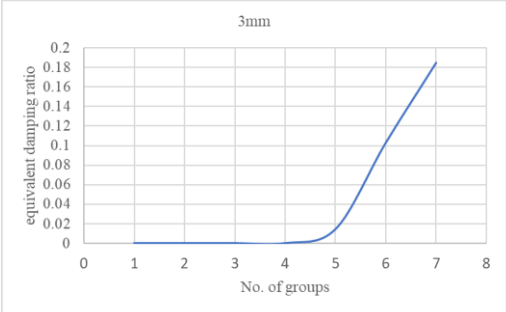

(a) Peak hysteretic Force curve of configuration



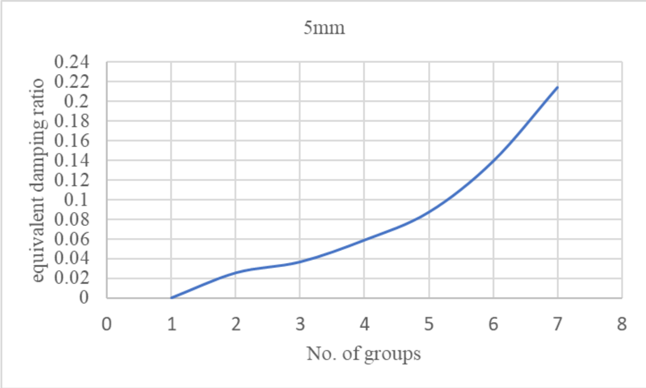

(b) Cumulative energy dissipation area




(c) 1mm steel envelope




(d) 3mm steel envelope




(e)5mm steel envelope

Figure 5 Collection of mechanical characteristic curves

### *2.4 Model design of hollow spring lead damper configuration B*

The lead material of configuration B is used as the hollow spring material and the steel core provides the restoring force for the hollow spring. At the same time, the steel pipe will also participate in the energy consumption in the case of large deformation. ANSA was used for meshing and pre-processing and ABAQUS software was used for finite element simulation calculation to compare with the above configuration A.
In order to study the influence of different construction forms on the mechanical properties of hollow spring lead dampers, three kinds of hollow spring lead dampers with different envelope thicknesses of 20 mm lead, 15 mm lead and 10 mm lead were designed. The specific geometry of the damper is shown in Table 2.2 Configuration b Calculated geometric parameters (unit: mm).

Table 2.2 Configuration b Calculated geometric parameters (unit: mm)

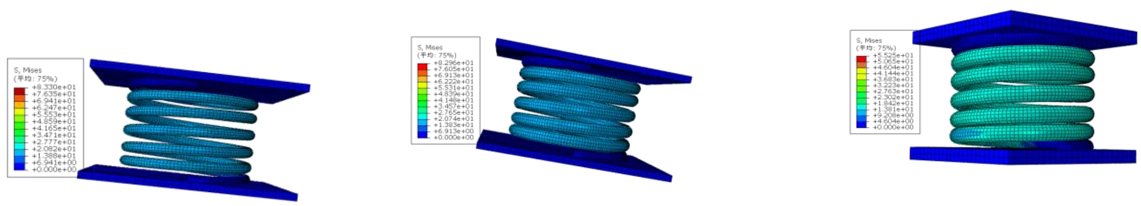
| No. | H1 | H2 | D3 | D4 | R1 | R2 | D1 |
|---|---|---|---|---|---|---|---|
| B0 | 460 | 420 | 390 | 440 | 5 | 25 | 220 |
| B1 | 460 | 420 | 390 | 430 | 5 | 20 | 220 |
| B2 | 460 | 420 | 390 | 420 | 5 | 15 | 220 |

***2.5 Performance analysis of hollow spring lead damperof Configuration B***

In order to further study the influence of mechanical properties of the hollow spring lead damper of configuration B, the study will be conducted from the following aspects: stress distribution, plastic deformation distribution, hysteretic performance and energy dissipation mechanism of the hollow spring lead damper.

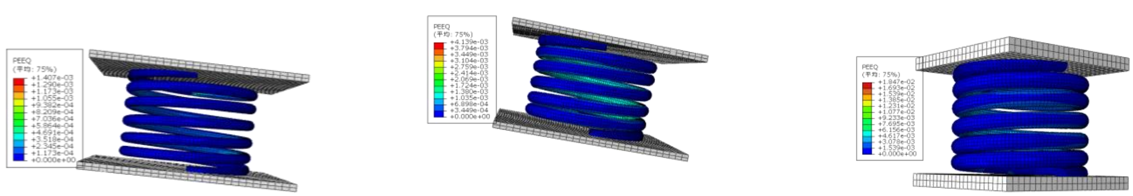
Figure 6 Stress distribution cloud diagram of a hollow spring lead damper of configuration B.As it can be seen from the figure, the force distribution of the hollow spring lead damper is reasonable, the force distribution of the steel envelope is relatively average, and there is no stress concentration phenomenon.

However, it also can be seen from Figure 7 Plastic strain cloud diagram of a hollow spring lead damper of configuration B that with the increase of lead envelope, the stress distribution of this model becomes more balanced, and obvious plastic deformation occurs in the inner side of the lead spring, indicating that this configuration has a good energy dissipation capacity.



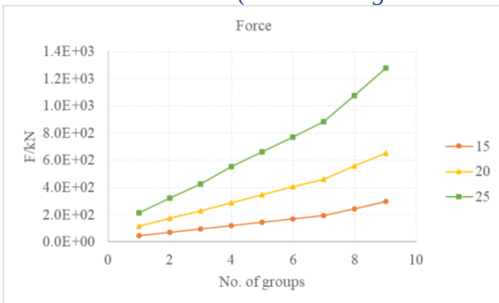
(a) 10 mm lead envelope (b) 15 mm lead envelope (c) 20 mm lead envelope

Figure 6 Stress distribution cloud diagram of a hollow spring lead damper of configuration B

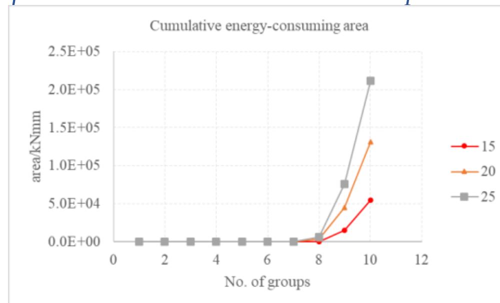


(a) 10 mm lead envelope (b) 15 mm lead envelope (c) 20 mm lead envelope

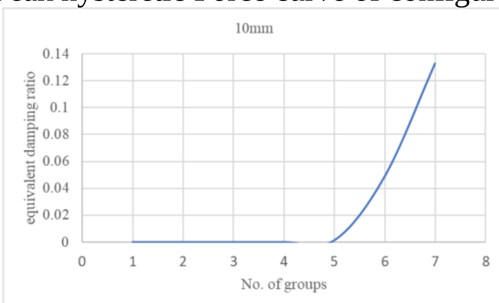
Figure 7 Plastic strain cloud diagram of a hollow spring lead damper of configuration BFigure 8 Configuration b hysteresis curve and ductility curve



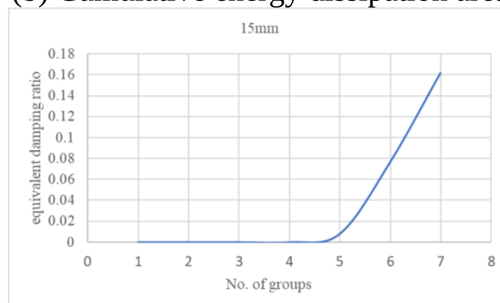

(a) Peak hysteretic Force curve of configuration




(b) Cumulative energy dissipation area

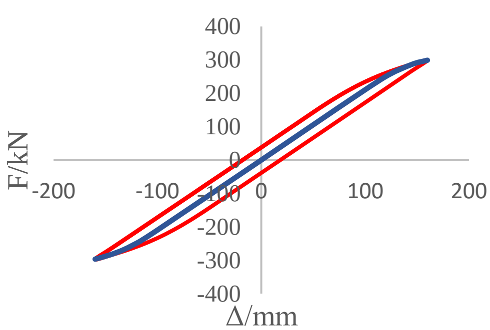


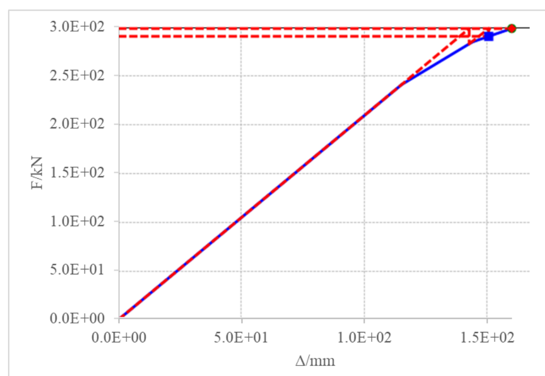

(c) 10 mm lead envelope



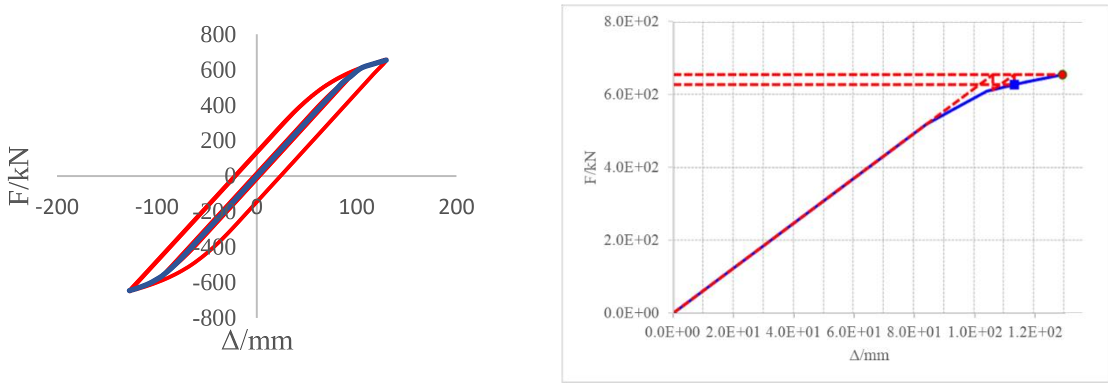

(d) 15 mm lead envelope

As it can be seen from the figure that the hysteretic curve of the hollow spring lead damper of configuration B is smooth, and the skeleton curve has no inflection point. Moreover, it can be seen from the hysteretic peak force curve and cumulative energy dissipation area curve that its energy dissipation capacity increases with the increase of loading, and the upward trend always exists without obvious attenuation. It can be concluded that configuration B has stable working performance and strong energy dissipation capacity.

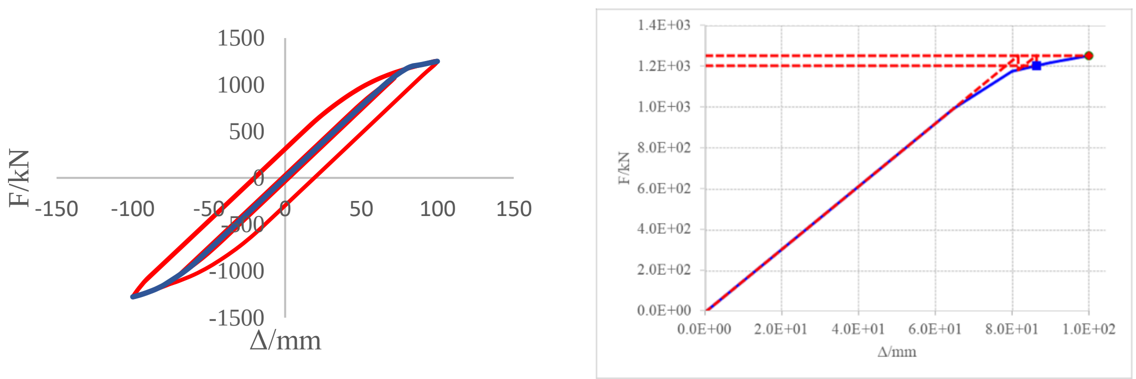



(a) 10 mm lead envelope

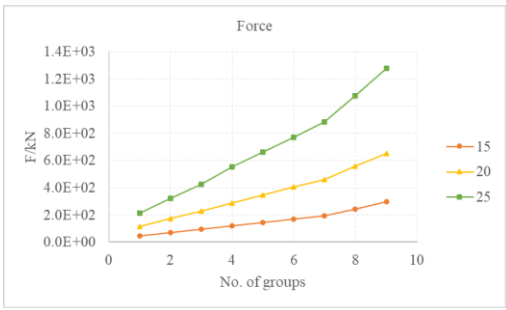



(b) 15 mm lead envelope

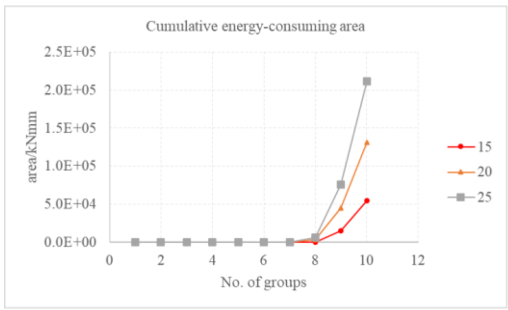



(c) 20 mm lead envelope

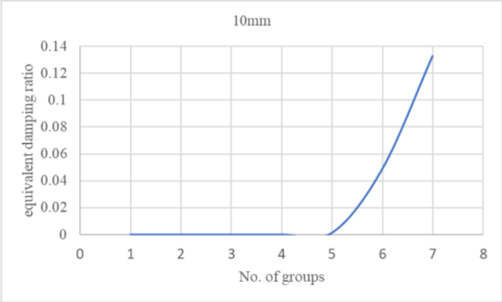
Figure 8 Configuration b hysteresis curve and ductility curve



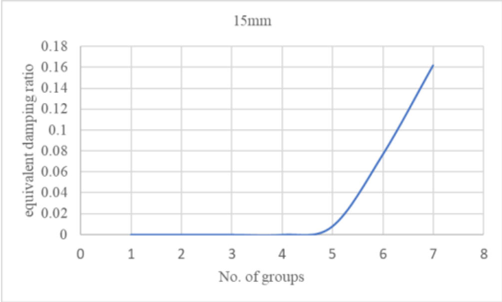

(a) Peak hysteretic Force curve of configuration




(b) Cumulative energy dissipation area




(c) 10 mm lead envelope




(d) 15 mm lead envelope

Figure 9 Collection of mechanical characteristic curves

## CONCLUSION

In this paper, ANSA software is used to pre-process the anticipated two types of hollow spring lead dampers, and then ABAQUS software is used to conduct finite element simulation analysis of the hollow spring lead dampers, and a detailed calculation is also carried out. The stress, strain distribution contour cloud map, plastic strain and hysteresis curve are analyzed completely, and the following conclusions can be obtained:

（1）The hollow spring lead damper of configuration a has a good stress change trend, can provide good supporting force and stiffness, and has a good energy storage capacity.

（2）Although the hollow spring lead damper of configuration A has plastic deformation, its plastic deformation is not obvious and unstable, and it can not bear the main function of energy consumption, and not complete the basic task of energy dissipation capacity well. At the same time, due to its ductility curve, it indicates that this model does not have good energy consumption.

（3）The hollow spring lead damper of configuration A provides too high additional stiffness, which will greatly weaken the function of the vibration isolators working together, it , and affect the effect of shock absorption and earthquake resistance.

（4）The steel core of the hollow spring lead damper of configuration B can avoid the local buckling of the hollow spring in advance, and maintain a good deformation capacity, but also improve the bearing capacity and energy dissipation capacity.

（5）The special spring configuration of the hollow spring lead damper of configuration B significantly improves the deformation ability of the damper, and has a good deformation ability in the axial direction, which can delay the local buckling of the damper.

（6）Hollow spring lead damper of the configuration B has good deformation and ductility ability, and its ultimate deformation ability is also large, and the damping mechanism is clear.

（7）The energy dissipation curve of hollow spring lead damper of configuration B is full, there are obvious plastic strain and energy dissipation ring, and the energy dissipation performance is relatively good.

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