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Influence of the Shape of Slit of a Circular Hollow Steel Damper on its Energy Dissipation Capacity

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Abstract. This research studies the effect that the shape of slits of a circular hollow steel (CHS) damper has on its EDC, whose computation is raised in a hysteresis diagram obtained from a tridimensional non-linear dynamic element finite analysis in Abaqus. A cyclic displacement protocol attending international normative is used to induce cyclic displacement in the upper part of the device while the bottom part is considered fully restrained. The model considers the presence of large deformations in the device as a result of the yielding in the material. Only one configuration for the geometry (predefined thickness and external diameter) the CHS is analyzed, but a total of 5 different shapes for the slits are considered (horizontal, vertical, circular, square and triangular shapes). All the slits configuration presents the same void area in order to obtain a fair comparison. A-36 steel is used for the damper as present good ductility characteristics. Finally, the performance of each CHS damper configuration is analyzed from the characteristics of their hysteresis diagram, the stress distribution through the damper and their EDC. It was concluded that the model with circular slits was the one that presented the highest dissipation capacity, since this type of groove favors the distribution of stresses in its contour, unlike the others whose vertices generate stress concentrators.

Keywords: Circular Hollow Steel Damper, Hysteretic Behavior, Energy Dissipation.

1. Introduction

The creation of new devices for the control of vibrations has increased in recent decades, the need to preserve the lives of people who are inside buildings and its structural components, has encouraged the constant improvement of instruments used to accomplish this goal.

Seismic energy dissipation systems can be divided mainly into two large groups, active control systems and passive dissipation systems, the main difference between these types of systems is that unlike active type, passive systems do not require an external energy source, which makes them more attractive when selecting one of these alternatives for the application, there are other types of classifications of these systems such as hybrid or semi-active control systems but these are essentially a combination of those mentioned previously and both require, to a lesser extent compared to active systems, an external power source to operate at full capacity [1].

Among the passive control systems are metal heatsinks, this type of dampers works by the principle of inelastic deformation in metals, this group of dampers have been widely used due to their ease of manufacture, low production cost, low maintenance and the Materials familiarity with the world of engineering [2].

In metallic dampers, the dissipation capacity is characterized by the hysteresis curve, which is formed by relating the displacements or loads applied by the seismic movement and the resulting forces due to that excitation, the dissipated energy is represented by the area under the curve of hysteresis curve, the objective of the design process of this type of dampers is to obtain uniform hysteresis curves with large amplitudes, which represents a greater dissipation of energy.

In the present work, a type of metallic damper known as VPD (Vertical pipe Damper) or CHS (circular hollow Steel damper) is used.

This device consists of a tubular section of steel installed vertically, whose lower end is fixed and allowing displacement in Its top, this damper has the advantage that it can dissipate energy in two directions [3].

The model dimensions were established considering the effective size proposed by Abebe [4] in which the effective size is established when calculating the maximum bending and shear stresses considering the heatsink as a fixed beam and applying the Von Mises criterion that relates those stresses. Figure 1 shows a simplification of the stress distribution present in the damper model.

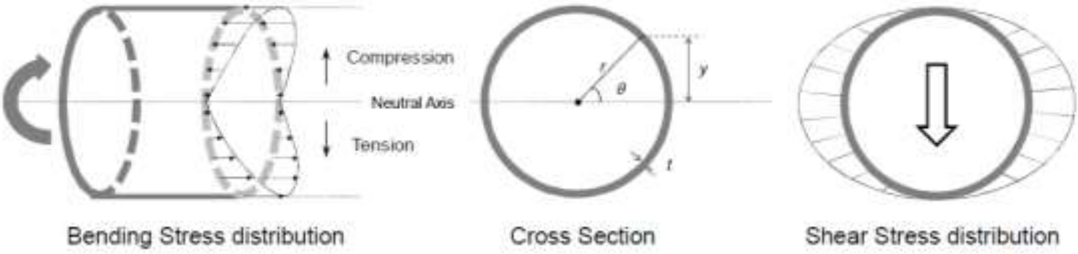

Figure 1. Stress distribution in CHS [4]

In the case of bending stress, the magnitude of the stress is given by:

$$\sigma_\theta = \frac{My}{I}. \tag{1}$$

Where $M, y\ and\ I$, represent, respectively, the bending moment, the distance of the point in analysis to the neutral axis and the moment of inertia.

From the figure we obtain $y = r\sin\theta$, taking into account the value of the moment of inertia for a circular section as $I = \pi r^3 t$ we can obtain the expression of the maximum bending stress by substituting the value of θ for $\pi/2$, then

$$\sigma_{max} = \frac{M}{\pi r^2 t}. \tag{2}$$

Similarly, for shear stress

$$\tau_\theta = \frac{Mr^2}{hI}\cos\theta\,. \tag{3}$$

Where h represents half the height of the cylinder, Substituting the value of the moment of inertia and knowing that the highest value of $\cos\theta$ occurs when $\theta = 0$ we obtain the formula that represents the maximum shear stress

$$\tau_{max} = \frac{M}{hrt\pi}. \tag{4}$$

Applying the von Mises criterion, which relates the uniaxial stress and the shear stress as

$$\sigma = \sqrt{3}\tau \,. \tag{5}$$

We obtain the effective size of the damper is given by the ratio

$$\frac{h}{r} = \sqrt{3} \,. \tag{6}$$

This article analyzes the influence of the slits in a circular metal damper on its energy dissipation capacity, the process is developed by creating damper slits to subsequently subject it to a cyclical displacement protocol, each of the models It has the same amount of material to make a proper comparison, in the end the performance of each one of the models is analyzed and it is determined which configuration of the slits provides greater dissipation capacity.

2. Materials and methods

2.1 Geometry and mesh

Figure 2 presents the geometry and mesh of the damper model with circular slits, the general dimensions such as height, diameter and thickness are the same in all models, the slits have different shapes, but the amount of material in all models it is the same to guarantee an adequate comparison. The size of the slits was selected randomly, to represent a percentage of the volume, for the present study a volume ratio of 17% was used, that is, the introduction of the slits represents a decrease of 17% in the volume of the cylindrical model without slits. The thickness of the damper of 5 mm and the circular slits have a diameter of 20 mm, the dimensions of the other slits were determined by matching the corresponding area.

Figure 2. CHS mesh and geometric characteristics.

The analysis of the dissipation capacity of each of the models has been carried out using the Abaqus finite element software, the model has been created using the Shell element with an S4R mesh element, with a global element size of 2 mm. The loading protocol used follows the model proposed in FEMA 461 [5] in section I where the recommendations for quasi-static analysis with controlled deformation cycles are presented, this analysis is used for when you want to determine the dynamic response and the hysterical behavior of structural components in a building.

2.2 Loading protocol and mechanical properties

For the analysis of the dynamic response of the damper, 10 cycles of increased displacements with a maximum amplitude of 20 mm have been used, the specimens are made of steel, the plasticity values are entered into the finite element program in true stress and strain values. Figure 3 presents the loading protocol and the stress and deformation relation both nominal or engineering (Eng) as well as the true stresses and deformations (True) introduced to Abaqus.

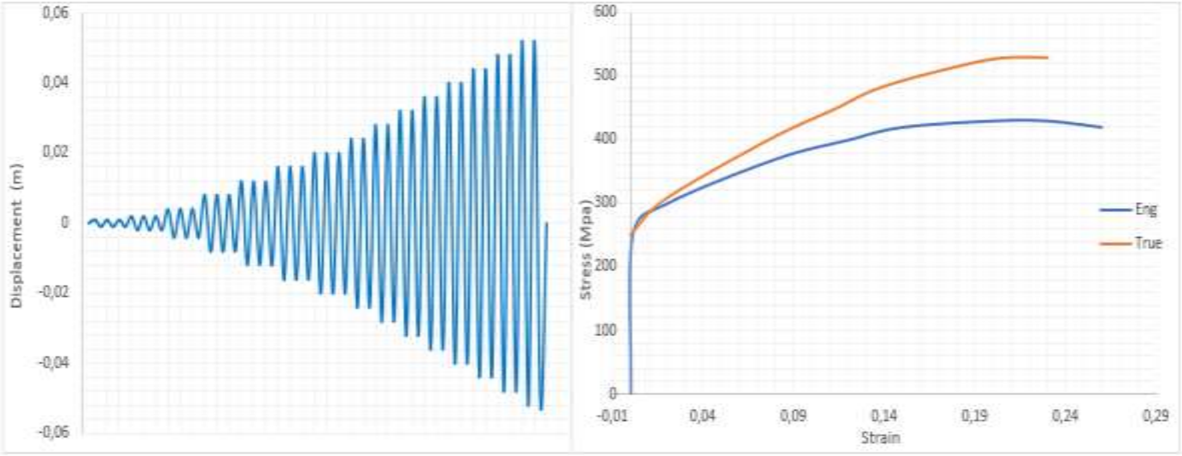

Figure 3. a). loading protocol b). Stress vs Strain curve.

The geometries of each of the models, the loading protocol and the mechanical properties of the material were inserted into the finite element software. The results are presented using the hysteresis curves of each of the models and the energy dissipated due to plastic deformation.

2.3 Boundary conditions

The damper is considered fixed in its bottom side, that is, both the translations and the rotations in that part are restricted, in the upper part all the rotations have been restricted and only translations in the direction of the applied displacement are allowed, which corresponds to axis X.

3. Results

3.1 Stress Distribution

For each of the damper variations, the distribution of stresses was presented, both in its deformed and in its undeformed form, the hysteresis curve produced by the application of the loading protocol and finally the energy dissipated as a result of the plastic deformation of each model.

Figure 4 presents the stress distribution produced in the model with circular slits, the deformation suffered by the damper can be seen on the left and compared with its original shape, it can be seen how much of the specimen has stresses greater than 472 MPa, the circular grooves allow a uniform stress distribution in the device, finally on the right side of the image the stress distribution is presented in the plane perpendicular to the direction of the load where it is possible to observe an important region of material that presents less stress, the deformation in this area can be seen in the same way.

Figure 4. CHS stress deformation and distribution with circular slits

In the case of the square-shaped slits, a decrease in the areas within the range of maximum stresses is evident, in the middle area of the device there is a reduction in the stresses greater than the model with circular slits, this because It is in the vertices of the squares that the stresses are concentrated, as can be seen in Figure 5.

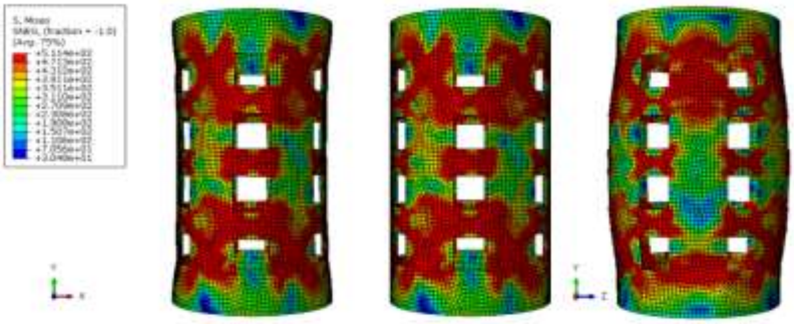

Figure 5. CHS stress deformation and distribution with square slits

Figure 6 presents the results obtained from the model with triangular slits, although in the yx plane the stress distribution shows more focus compared to the previous model, in the yz plane larger regions are observed where the stresses are lower compared to their circular and square counterparts.

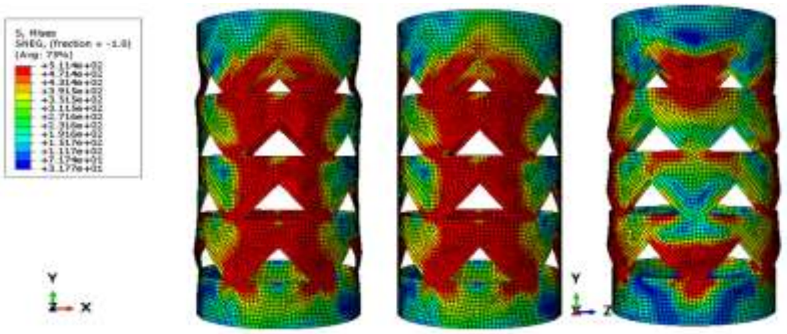

Figure 6. CHS stress deformation and distribution with triangular slits

Regarding the difference between the deformed and deformed shape, visually the three previous cases present appreciable differences in their two configurations, the models with circular and square slits present a similar deformation in the plane perpendicular to the direction of the load, although in the specimen of triangular slits also presents a deformation in this plane, it is less pronounced than in the previous ones. In Figure 7 it is possible to observe the behavior presented by the specimen of horizontal or rectangular slits, it is interesting that its deformed shape does not differ greatly from the deformed one as the plane parallel to the direction of the load can be seen, observing the plane perpendicular to the load, a shape is also observed without major disturbances and even this area presents less stress than previous models.

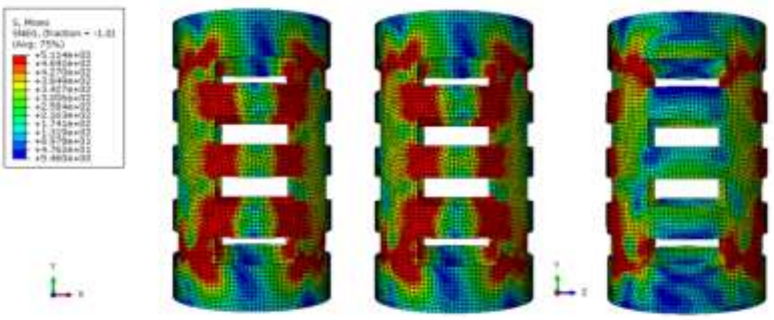

Figure 7. CHS stress deformation and distribution with horizontal slits

Finally, Figure 8 presents the effects of the application of displacements in the vertical slits model, it can be seen that this configuration suffered greater deformations, both in the planes parallel and perpendicular to the direction of the load, this configuration does not allow a uniform distribution of stresses and in advance, it can be affirmed that this type of slits is not suitable for the damper being analyzed in this study.

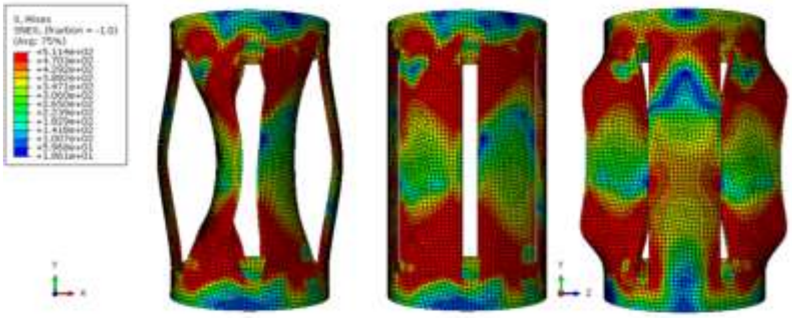

Figure 8. CHS stress deformation and distribution with vertical slits

3.2 Hysteretic behavior

As mentioned above, the hysteresis curve represents the dissipation capacity of the seismic energy dissipation device, the hysteresis curve is the ratio of the applied load in the form of displacement and the resulting forces resulting from said application. The energy produced by the damper is obtained by calculating the area under the curve of the hysteresis cycles, in general, the energy dissipated as a result of the plastic deformation experienced by the device is expressed by means of the equation

$$E_p = \oint F * du \tag{7}$$

where F and u represent, respectively, the forces and displacements suffered by the damper. Taking into account that metal dampers are devices that after fulfilling their function must be replaced in the structure, it is required that during their phase of operation they can absorb as much energy as possible. In the hysteresis curve, this behavior is represented by large, uniform curves. The hysteresis curves obtained from the application of the loading protocol to the circular damper are presented in Figure 9, it can be seen that the models that presented the highest stresses are those that obtained the highest hysteresis cycles and therefore a greater energy dissipation capacity.

As it had concluded in the previous section, the damper model with vertical slits was the one that presented less stable hysteresis cycles, therefore, as mentioned, it is the least suitable configuration for the analyzed device.

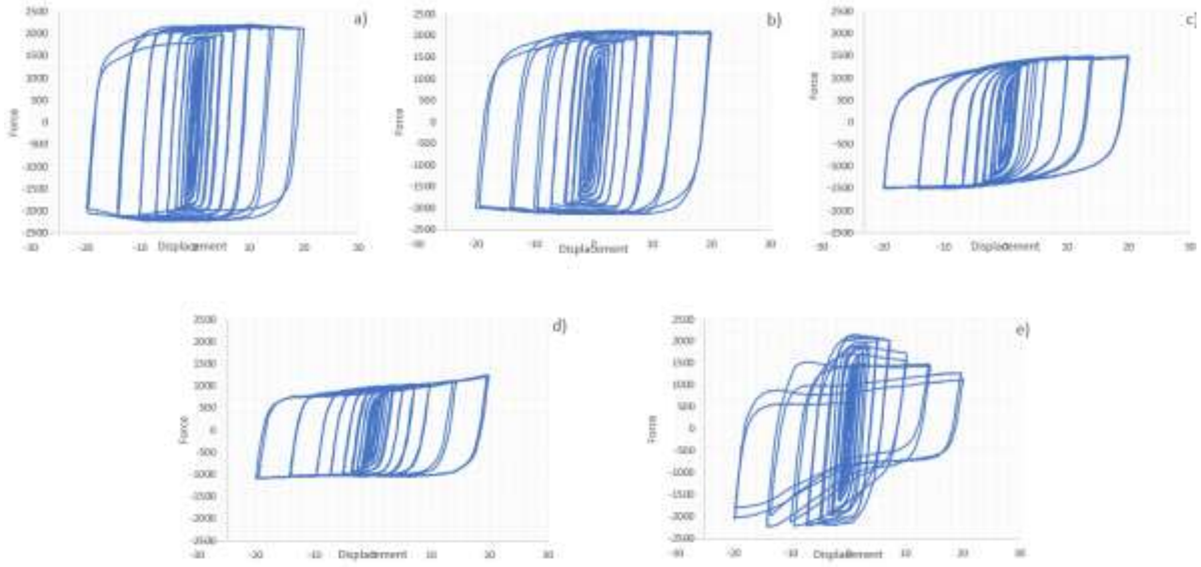

Figure 9. Hysterical behavior of dampers a) circular b) squares c) triangular d) horizontal e) vertical.

It can be seen that the hysteresis curves corresponding to the models with circular, square, triangular and horizontal slits have a stable shape, however, the reaction forces reached by the last two are less, so their dissipation capacity of energy is lower. The hysteresis curve corresponding to the vertical slotted damper is quite unstable and although it reaches forces of greater magnitude than those of its triangular and horizontal counterparts, its instability condition is not desired for this type of application.

Table 1 allows comparing the reactions and the amount of energy accumulated during the application of the load cycles, as mentioned, those devices that obtained the greatest stress concentration zones and stable hysteresis curves were the ones with the highest dissipation capacity.

Table 1. Maximum force and energy obtained by the models

	Circular	**Square**	**Triangular**	**Horizontal**	**Vertical**
Max Force (N)	2206.35	2120.21	1505.8	1234.69	2137.13
Energy (J)	53476.6	45053.6	40423.7	23731.3	19745.9

Figure 10 presents the energy dissipated during the operating cycles of each of the damper models used, as evidenced in Table 1, the models with circular and square slits presented greater dissipation capacity.

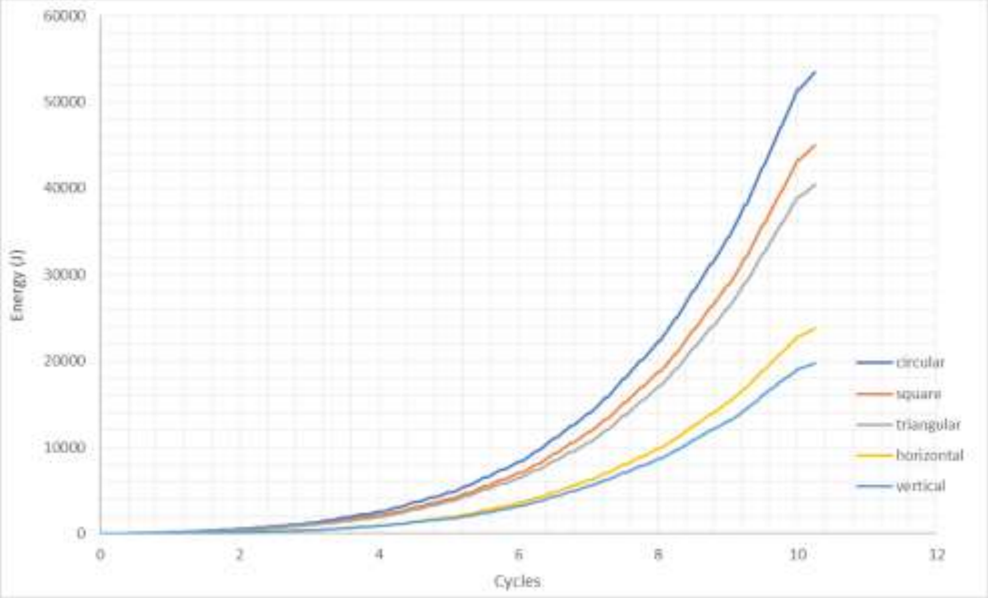

Figure 10. Comparison of the energy dissipated by the devices.

4. Conclusions

The hysterical behavior and the energy dissipation capacity due to plastic deformation were obtained from a CHS type damper model, which was made with 5 different types of slits. As a result, it was found that the grooves that most favored energy dissipation were circular and square ones.

The device with circular slits presented greater energy dissipation, its hysteretic behavior was stable during load cycles, the square grooved specimen also presented stable hysteresis cycles, but due to the concentration of stresses focused on the vertices of the squares, it had a lower dissipation capacity compared to its similar circular slits which had larger areas where maximum stresses occur.

The damper models with triangular, horizontal and vertical slits presented lower performance, it is interesting to observe that all analyzed models presented significant deformations with respect to their initial state, however, the specimen with horizontal slits was the one that suffered fewer deformations.

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