Design and Test of a Prototype of Hysteretic Damper Device with Steel Plates Bending Yielding

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LISBOA 2012

SUMMARY:
This paper describes the design and presents the results of a laboratory testing of a hysteretic damper devise made up bending steel plates. This work is limited to testing the device in a load frame subjected to alternating tension and compression cycles, under different levels of displacements. The hysteretic diagrams obtained from the tests, their corresponding maximum and minimum values are analyzed to get the design envelope. The results correspond to different hysteretic load-deformation loops of the dissipative plates of energy device, the dissipated energy and stiffness degradation are also included; these results demonstrate the great capacity of dissipation that has the prototype.

Keywords: Hysteretic damper, cycling test, energy dissipation, seismic control.

1. INTRODUCTION

The structural response during an earthquake event is not only a function of the seismic intensity; it also depends on different factors like: The natural periods of the soil and the structure, the structural configuration, the dynamic structural properties, etc.

The actual construction codes, take as acceptable that the seismic energy induced to the structure, could be dissipated inside the inelastic behavior range of their materials. As consequence, is desirable that plastic joints be formed during the seismic action, to avoid structural generalized damage or collapse. Never the less, the creation of plastic joints depends on great deformations and their ductility.

An alternative to the seismic resistance design are the seismic control devices which has the objective to control the structural displacements, through modifying the dynamic properties of the building (Cahís, 2000)

When the kinetic energy induced by the earthquake is dissipated in a safe way, the deformations in the structure are significantly reduced and also the possibility of damage. The classification of seismic control systems consists in four groups: Passive control systems, Active control systems, Hybrid control systems and Semi-active Control Systems.

In this work, a seismic control system is presented. The devise can be classified as a hysteretic damper (Passive control systems), which performance is based in their capability of develop stable hysteretic cycles. The steel is the material used for this their construction, due to their ductility and availability.

Some research (Nakashima et al., 1996) have demonstrated that for dissipate the seismic energy, through seismic dampers, in an efficient way, is preferable to start in low displacement ranges. Therefore it´s needed that the geometry of each damper allows a uniform material´s yielding, near to elasto-plastic model behavior, within small interstory drifts.

The background of this work is a research that took place in the Engineering Faculty of the Universidad Autonoma del Estado de México (Alonso et al., 2007), which consisted on the design and test of three dissipation plates, working in bending, submitted to alternate load cycles of tension and compression.

The main reasons to choice steel as the device material are the well defined linear behavior and their great ductility. Also the plates working at bending were selected to ensure the material´s stable hysteretic cycles.

In this work the geometrical configuration of the dissipating plates were adjusted to the test equipment limitations. The system that allows the plates to behave as the supposed theoretical model was also designed.

2. DESIGN OF THE ENERGY DISSIPATOR DEVICE

The dissipations plates (figure 2.1) are to be proposed for work in bending as a simple supported beam. The prototype of hysteretic damper is projected to be installed in a brace element (figure 2.2). For this objective, the diagonal brace is fixed to the structure in the upper level; the other tip is connected with the dissipation plates. The connection is done in the middle part of the dissipation plates by the load plate, the other wing is connected with the under level by the restriction plates.
Under these perspectives of the functioning, the seismic control systems design is described further on.

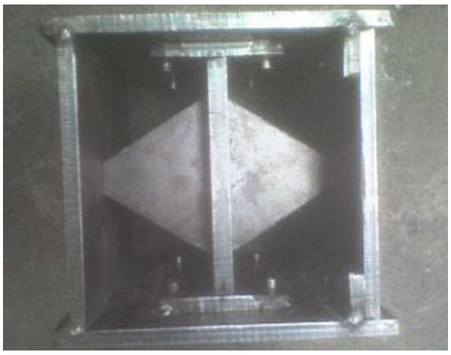

Figure 2.1. Dissipation plates

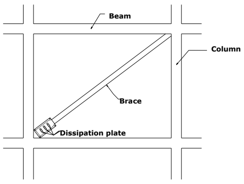

Figure 2.2. Damper device configuration

2.1. Design methodology.

- The dissipation plates were designed as simple beams supported in both ends with a punctual load at the center of the span.
- Based in the bending theory, the resistant moment in the plate section is reviewed. In the ends of the plates, the shear force is checked, and is obtained the force needed to reach the yield stress.
- The load and restriction plates were revised with the limit states of plastic flow and fracture in the whole section.
- The elements that helps to attach the whole device, and its connection with the test equipment. Were designed to reach the yielding load in the dissipation plates.

The yield and ultimate stress for the steel were determinate by tension test as fy = 548.9 MPa (5593.25 kg/cm2), fu=726.9 MPA (7412.5 25 kg/cm2) respectively.

2.2. Dissipation plates.

The final plate´s dimensions and properties were selected in accordance to the test equipment limitations. The final dimensions of the dissipation plates are shown in figures 2.3. The table 2.1 summarizes the calculation of inertia moment and elastic modulus in the middle section of the dissipation plates, as well as, moment, load and displacement reach at the yielding.

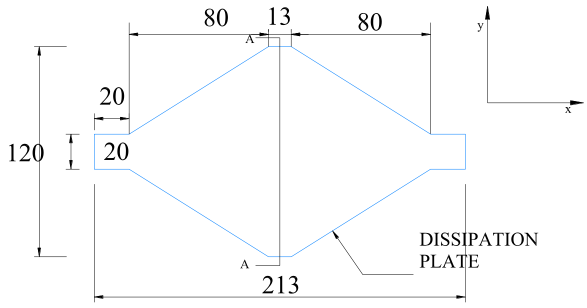

Figure 2.3.a Dissipation plate front view

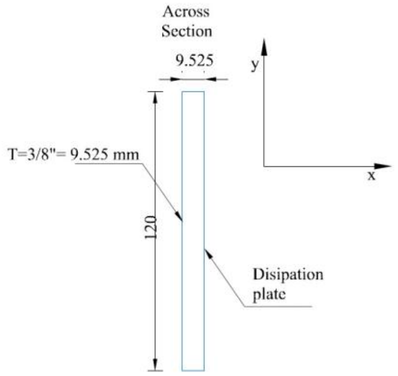

Figure 2.3.b Dissipation plate transversal section

Table 2.1. Yielding load, moment and displacement of dissipation plates

$I = \frac{bh^3}{12}$	$M_y = f_y \frac{1}{y_{máx}}$	$S = \frac{M}{\sigma}$	$P_y = \frac{4}{L}\sigma_y S$	$\Delta_y = \frac{P_y L^3}{48EI}$
0.8642 cm4	*995.27 N.m*	*1.81 cm3*	*22 062.3 N*	*1.50 mm*

2.3. Load plate.

In order to transmit the axial load in the brace, to the middle part of the dissipation plates, a load plate was designed, this plate was calculated to fix three dissipation plates as shown in figure 2.4 and their dimensions are: 15 x 16 x 1.27 cm, with holes of 1.0x12.0 cm, so that the dissipations plates can be passed through it. The assembly of load plate and the dissipation plates were obtained only by the passing the dissipation plates through the load plate, without any other connection.

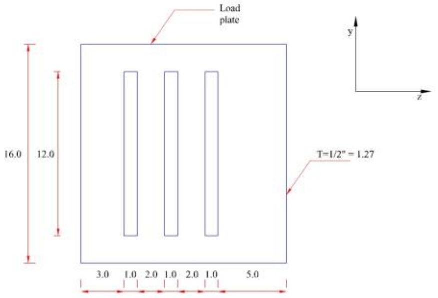

Figure 2.4.a Load plate dimensions

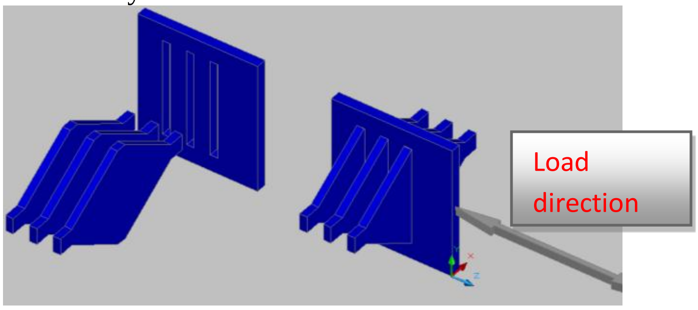

Figure 2.4.b.Plates assembly

2.4. Restriction plate.

To restrict movement of the ends of the dissipation plates, in order to achieve the behavior of a simply supported beam, it was proposed a plate called restriction plate; their dimensions and assembly with the other plates are shown in Figure 2.5.

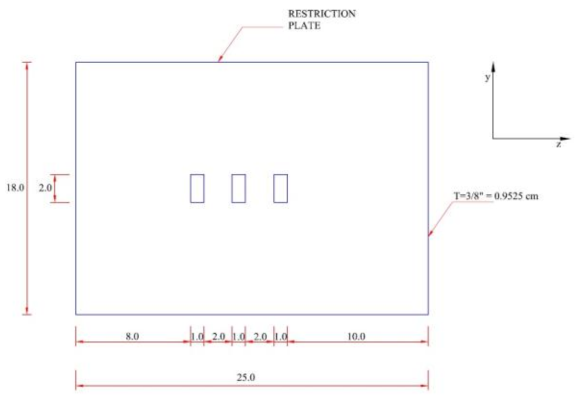

Figure 2.5.a. Restriction plate´s dimensions

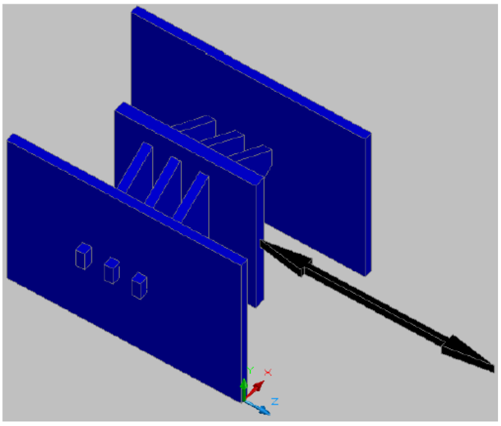

Figure 2.5.b Plates assembly

2.5. Sliding plates.

In the design of the load plate and restriction plates, the states of yield strength of the total area and fracture of the net section were considered. Additionally it is necessary to restrict the movement of the load plate, only in the axis of application of the forces, movement is allowed, for that purpose, the plates forming a slide mechanism (sliding plates) were constructed in both ends of the load plate . Chamfers were manufactured in both sides of the sliding plates (see Figure 2.6).

To fasten the sliding plate with the load plate, were fixed in advance with Allen screws flathead 6.40 mm (1/4 inch) diameter by 51.00 mm (2.00 inches) long, with the intention to avoid that in the welding process, the load plate does move out of their plain.

Finally, the lids are placed on the top and bottom of the device along with sliding guides, which are the complement of the chamfer, to prevent load plate from getting out of their axis of action (see Figure 2.7).

One of the side plates which restrict the movement of the dissipation plates, is not welded to any element, this to allow that the dissipation plates could be replaced after some use, i.e. an event to occur in which the device is subjected to extraordinary loads, in that case the dissipation plates can be replaced by new elements, without damaging the rest of the device (see Figure 2.8).

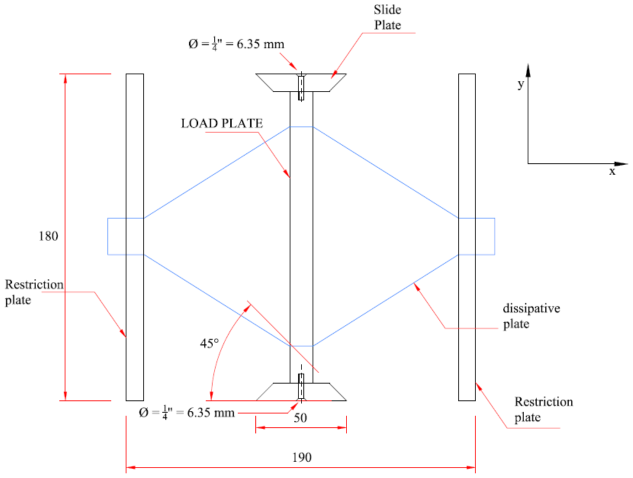

Figure 2.6. Slide mechanism (mm)

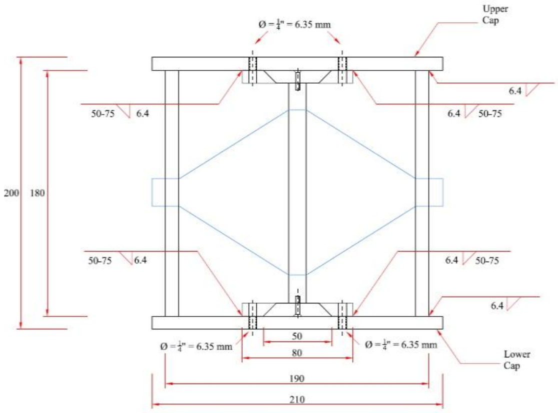

Figure 2.7.a Scheme of the device

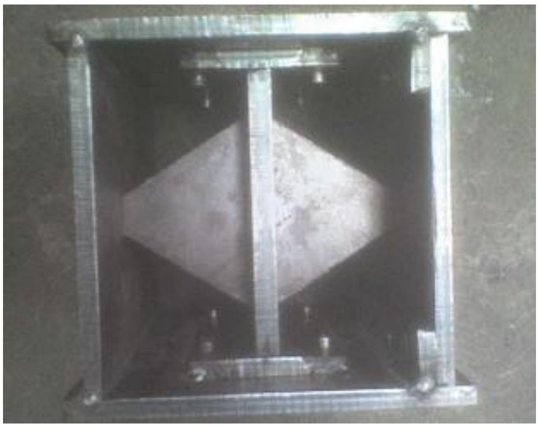

Figure 2.7.b Photograph of the device

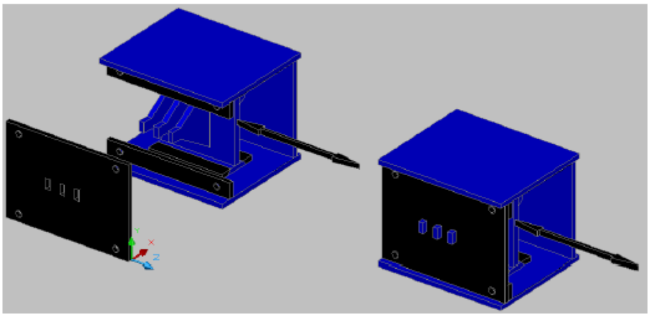

Figure 2.8.a Removable side plate´s device

Figure 2.8.b Photograph of the assembly

3. TEST OF THE ENERGY DISSIPATION DEVICE.

The test was performed in the lab of materials "Javier Barros Sierra", faculty of engineering of the Universidad Autónoma del Estado de México. The equipment used was the press Enerpac vlp-20013ze4s with 1961.33 kn (200 tons) load capacity. The pressure was measured with digital manometers connected to electrical transducers. A micrometer was used to control displacements.

Figure 3.1. Test of damper device**.**

3.1. Development of tests

Although the device has the ability to test three plates simultaneously, four assays were performed with a pair of plates each. Dissipation plates were tested for 6.0, 12.0, 15.0 and 21.0 mm of travel in each direction. Table 3.1 shows the maximum load values applied in each assay in the state of tension and compression. Figure 3.2 shows the plates before and after the test.

Table 3.1. Maximum load en each test

Test	Deformation (mm)	Tension (KN)	Compression (KN)
E-1	6	63.8	58.1
E-2	12	72.1	79.7
E-3	15	80.5	82.5
E-4	21	101.0	95.6

Figure 3.2.a Plates before the test

Figure 3.2.b Plates after the test

4. ANALYSIS OF EXPERIMENTAL RESULTS.

The test was controlled by displacement, for values of 6.0, 12.0, 15.0 and 21.0 mm. With the information obtained in the laboratory test were conducted stress-strain curves to characterize the behavior of the alternate, tension and compression forces.

The figure 4.1 shows the hysteretic behavior of each test. The table 4.1 presents the amount of energy dissipated, and the figure 4.2 plot the total energy dissipated against the displacement of the hysteretic loops.

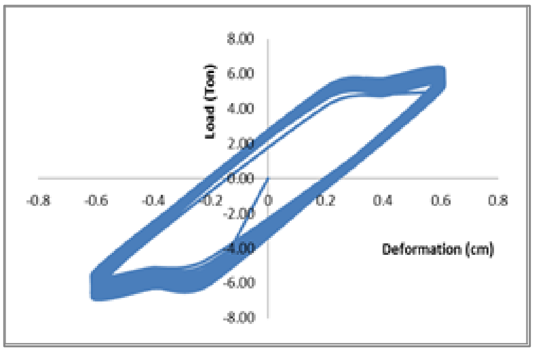

Figure 4.1.a Hysteretic loops E1 Test

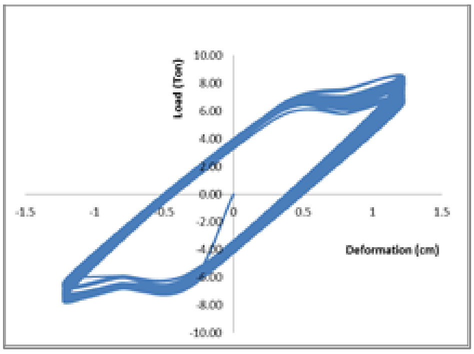

Figure 4.1.b Hysteretic loops E2 Test

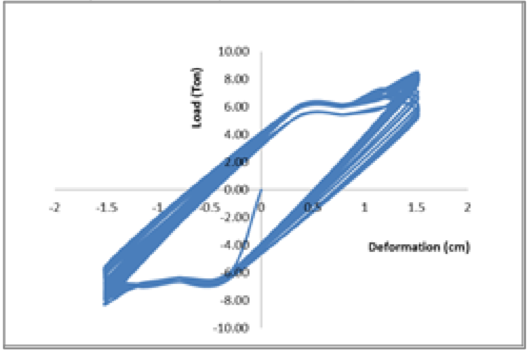

Figure 4.1.c Hysteretic loops E3 Test

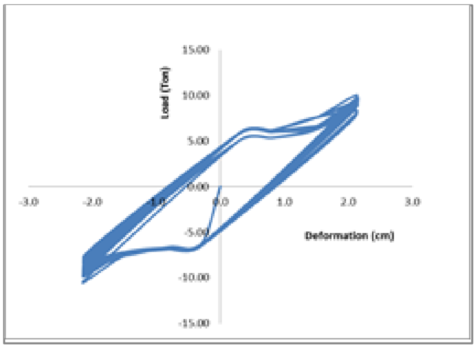

Figure 4.1.d Hysteretic loops E4 Test

Table 4.1. Values of the amount of energy dissipated for each of the assays of the plates

Test	Displacement (mm)	Dissipated energy per cycle (Ton.cm)	No. de cycles	Total dissipated energy (Ton.cm)
E1	6.0	8.30	132.0	1095.32
E2	12.0	19.71	64.0	1261.60
E3	15.0	25.93	41.0	1063.13
E4	21.0	42.27	32.0	1352.64

As shown in figure 4.2, the total dissipated energy does not have significant variations with the amplitude of the hysteresis loops and therefore may be considered as constant. This amount of energy is directly related to the geometry of the plate and the properties of the steel used.

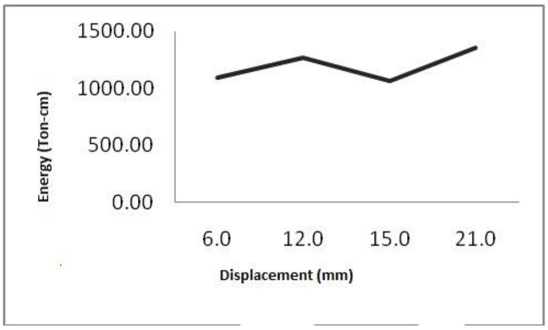

Figure 4.2. Total dissipated energy as function of displacement

The plates used for all assays have the same area and the same thickness; a pair of plates was used for each assay. And since it is considered that the total dissipated energy is constant, we can assume a minimum capacity of energy dissipation per unit area (see table 4.2).

Table 4.2. Mínimum dissipated energy per area unit

Dissipated energy (Ton.cm)	Total area of plates (cm2)	Dissipated energy per area unit (Ton.cm/cm2)
531.56	11.43	46.50

Figure 4.3 shows the force- displacement envelope for each of the assays performed, and the figure 4.4 presents the corresponding stiffness degradation curve.

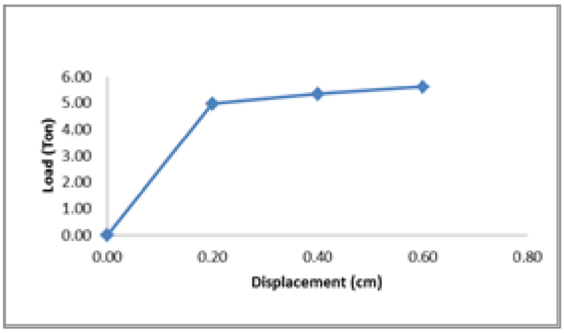

Figure 4.3.a Load displacement curve E1 Test

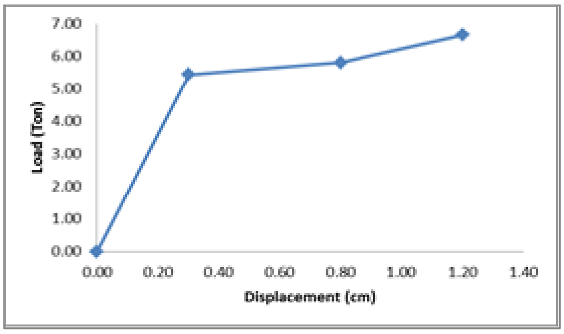

Figure **4.3.b** Load displacement curve E2 Test

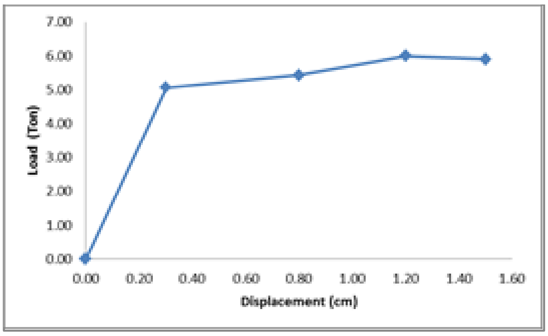

Figure 4.3.c Load displacement curve E3 Test

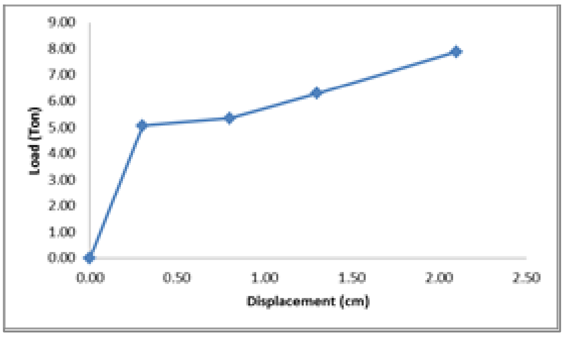

Figure **4.3.d** Load displacement curve E4 Test

As shown in the results, the number of cycles to reach the failure, of the energy dissipation plates, depends on the magnitude of displacement which they are undergone. To estimate the number of cycles to generate the fault in the dissipation plates, a linear regression was conducted.

Using the minimums squares method for estimating the regression coefficients, β = 580.09 and α = -11.99 were founded, in this way the proposed regression equation is presented in equation 1. Figure 4.5 plots this equation.

$$y = -11.99 + \left(\frac{580.09}{x}\right) \qquad (1)$$

where:
y= Number of cycles before showing the fracture
x= normalized displacement (Du/Dy)

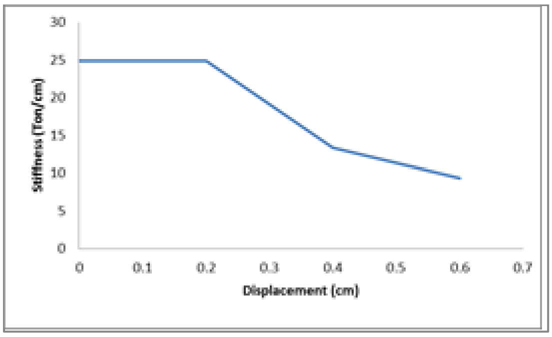

Figure **4.4.a** Stiffness degradation curve E1 Test

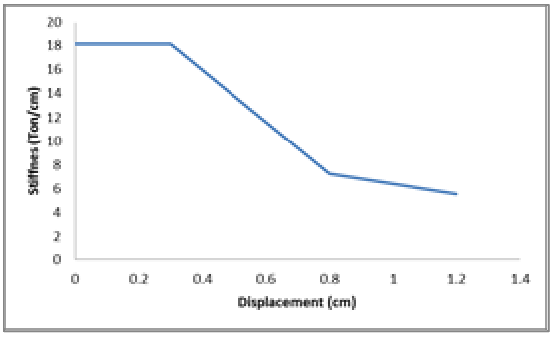

Figure **4.4.b** Stiffness degradation curve E2 Test

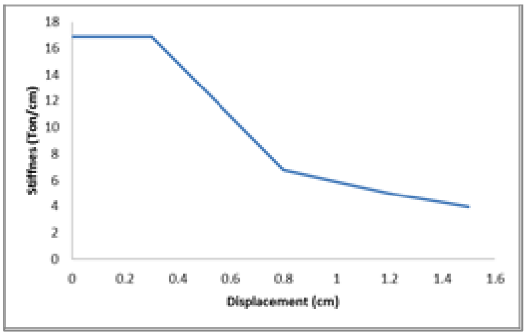

Figure **4.4.c** Stiffness degradation curve E3 Test

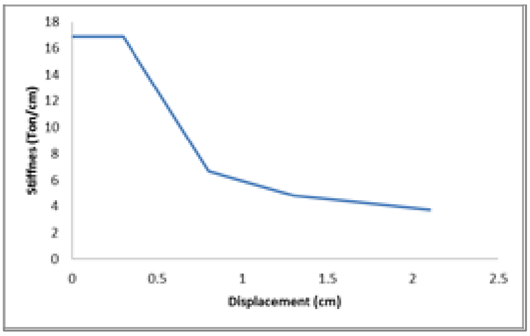

Figure **4.4.d** Stiffness degradation curve E4 Test

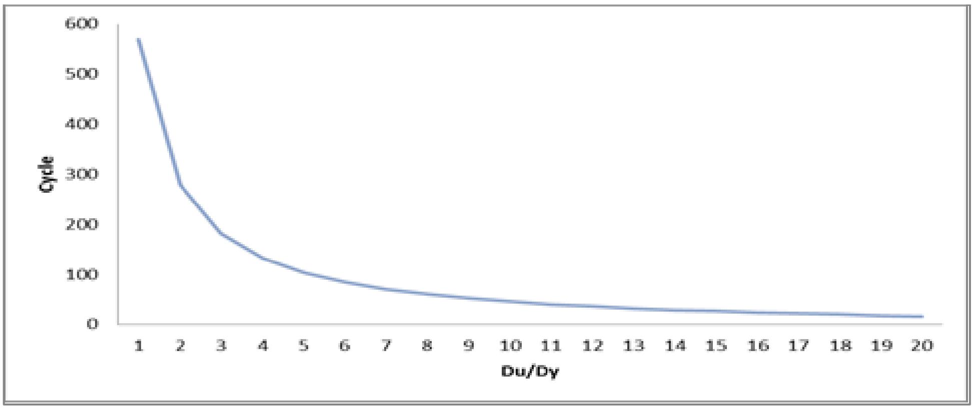

Figure 4.5. Equation 1 plot

5. CONCLUSIONS.

This study aimed, to build and test a seismic dissipation device was achieved successfully, as the results were consistent with theoretical.

The dimensions of the proposed model allows to properly integrating it with a system of bracing, The wide range of hysteresis loops shows the great ability to dissipate energy with the device.

Efficient behavior is observed, even for low levels of deformation and the hysteretic cycles shows no significant variation that express a primary deterioration or malfunction of the device, that modify the bending work of the plates and consequently come to modify the proposed objectives.

By analyzing the information from the experimental results can be seen that the amount of dissipated energy does not depend on the amplitude of displacement. As can be seen the dissipated energy is maintained constant and depends only on the geometry of the plate, so that the dissipated energy could be regarded as one of the design parameters.

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