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COMPARATIVE STUDY OF EIGHT METALLIC YIELDING DAMPERS

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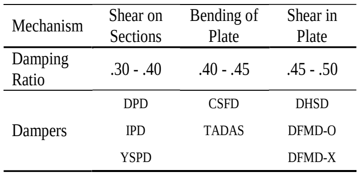
Graphical abstract



Mechanism	Shear on Sections	Bending of Plate	Shear in Plate
Damping Ratio	.30 - .40	.40 - .45	.45 - .50
Dampers	DPD IPD YSPD	CSFD TADAS	DHSD DFMD-O DFMD-X

Abstract

The seismic resistance of structures can be enhanced by using passive energy dissipation devices in order to dissipate earthquake energy. One of these devices is metallic yielding dampers which is low-cost, but highly-efficient. This paper aims to compare four key variables among eight metallic yielding dampers. Theses four parameters are equivalent viscose damping ratio, large load to weight, ductility and cumulative displacement. The dampers were selected based on the availability of the experimental data in the literature. As the first step of the methodology eight particular dampers with its load-displacement curve were carefully chosen to study. Three dissimilar last loops of force-displacement hysteresis were selected and drawn for each damper. Then the above mentioned parameters were calculated and compared to get results and draw conclusion. The outcomes reveal the relationship of the four studied parameters with each other. The results show there is a relationship between the mechanisms of energy dissipation with the specific range of equivalent viscous damping ratio in the studied metallic dampers.

Keywords: Damper, passive, energy dissipation, metallic, equivalent viscous damping ratio

1.0 INTRODUCTION

Generally structural control can be classified into three main categories: active control, passive control and semi-active control. Active and semi-active controls have a control system to modify the motions of structure. These systems need an external energy supply. Passive control systems effectively reduce the input energy of earthquake to the system, and increase the damping of the system as well. These occur by using either isolation system devices or dissipating devices. The main objective of passive control is to absorb as much of the input energy as possible, to protect the main members from structural damages. Simplicity, ease of installation and replacement, low initial cost and maintenance, free of external power source are the advantages of passive control over the other control systems.

Passive devices utilize different mechanisms to dissipate seismic energy such as, yielding of metals, deformation of viscoelastic materials and fluid orificing. The most effective and economical mechanism is the yielding of metal in dissipative devices. This mechanism was suggested for the first time in the early 1970s [1]. A variety of variables are considered in study of the metallic yielding dampers including strength and stiffness of damper, cumulative displacement, total absorbed energy, the weight of damper, equivalent viscous damping ratio, fatigue strength, deformation capacity ratio, dissipated energy to weight ratio, large force to weight ratio and construction cost.

A large number of researches have been conducted about dissipative devices, and also possible damage of its failure in different aspects during last decades [1-12]. In this comparative study, eight yielding metallic dampers have been selected from the relevant literature. Three last dissimilar hysteresis loops of the dampers have been chosen based on the available experimental data. Then, four important variables, equivalent viscous damping ratio, large force to weight, ductility and cumulative displacement have been calculated and discussed in order to make comparison. This study and its results may help engineers to give a wider view, to choose suitable metallic damper for their structures.

2.0 METALIC YIELDING DAMPERS

2.1 TADAS Damper

A steel Triangular-plate Added Damping and Stiffness (TADAS) device is developed to withstand earthquake forces. This device consists of several triangular plates welded to a common base plate as shown in Figure 1(a). Experimental results indicate that TADAS can sustain a large number of yielding reversals without any stiffness or strength degradation. Figure 1(b) illustrates the force-displacement hysteresis of the specimen 2B2 obtained from the experimental investigation [2]. The device was made of steel material (ASTM A36) with 8 plates, 36 mm thickness and 304 mm height.

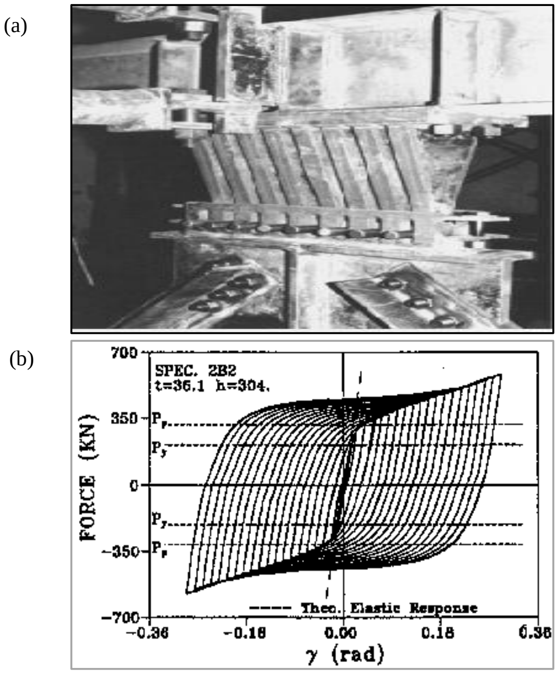


Figure 1 TADAS Damper [(a) Specimen 2B2, (b) Force-Displacement Hysteresis]

2.2 Cast Steel Yielding Brace

The cast steel Yielding Brace System (YBS) is a hysteretic damper that was developed at the university of Toronto to enhance the seismic performance of braced frames [3]. In this system, shown in Figure 2(a), cast steel connector dissipates seismic energy through inelastic flexural yielding triangular fingers. This device prevents the tensile yielding and inelastic buckling of traditional braces. YBS provides a symmetrical hysteresis with increased energy dissipation. Figure 2(b) shows the force-deflection response of a prototype with 10 plates, 34 mm thickness and 250 mm height.

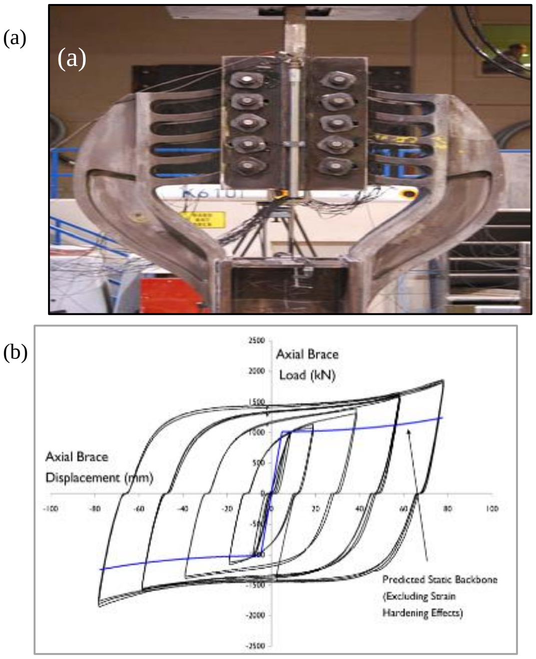


Figure 2 Cast Steel Yielding Brace [(a) YBS-01, (b) Force-Displacement Hysteresis]

2.3 Dual-Pipe Damper and Infilled-Pipe Damper

Two passive earthquake energy dissipative devices, dual-pipe damper (DPD) and Infilled-Pipe damper (IPD), were introduced and investigated by Maleki [4, 5]. DPD is made of two pipes welded at selected locations and withstand shear load as shown in Figure 3(a). The mechanism of energy dissipation is flexural of pipe body. However, tension forms at large displacement in the device, leading to increased stiffness and strength. The result of experiments shows better performance in comparison with the single pipe dampers, which were previously studied [6]. Cyclic quasi-static tests were performed on four specimens of DPD. The result exhibits acceptable ductility, energy absorption and stable hysteresis loops in all specimens. Figure 3(b) illustrates the obtained force-displacement relationships for specimen M1L100. The length, diameter and thickness of pipes are 100 mm, 140 mm and 5.1 mm, respectively.

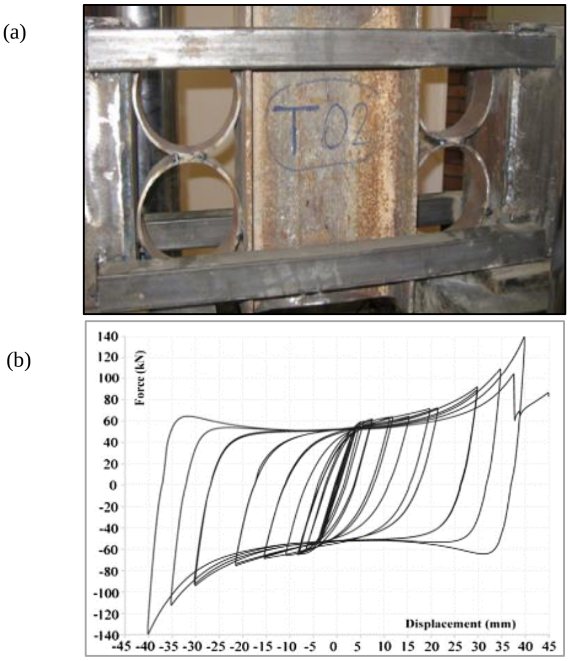


Figure 3 Dual-Pipe Damper [(a) Specimen M1L100, (b) Force-Displacement Hysteresis]

Infilled-Pipe Damper (IPD) consists of two welded pipes which have two smaller pipes inside them. The spaces between the pipes are filled with metals such as lead or zinc Figure 4(a). The device was loaded in shear. The energy absorption mechanism in the device is the plastification of the outer pipes, the inner pipes, infilled metals, and the friction between metals. Quasi-static cyclic tests were performed on a series of specimens to investigate energy dissipation capability. Figure 4(b) shows the obtained force-displacement hysteresis diagram for the specimen DP-220-I-140-1, filled with lead. The diameter, length and thickness for main pipe are 220 mm, 100 mm and 9.2 mm, and for inner pipe are 142 mm, 100 mm, 6.5 mm, respectively.

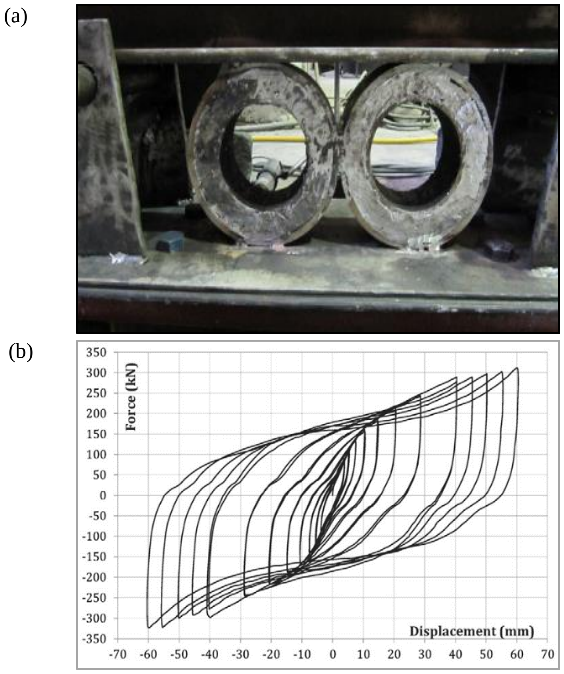


Figure 4 Infilled-Pipe Damper [(a) Specimen DP-220-I-140-1, (b) Force-Displacement Hysteresis]

2.4 Yielding Shear Panel Device

The Yielding Shear Panel Device (YSPD) dissipates energy through plastic shear deformation of a thin steel plate welded inside a square hollow section (SHS), as shown in Figure 5(a). A series of tests, monotonic and cyclic, have been conducted to verify the performance of the damper [7]. The results showed that the device has the ability to dissipate energy along with stable behavior. Two important variables which influence the performance of the device are plate slenderness and in-plane rigidity of the restraining SHS. Figure 5(b) illustrates the hysteresis of the specimen 100-2C, with SHS of 100×100×4 and plate slenderness of 49.5, which have been used for this comparative study.

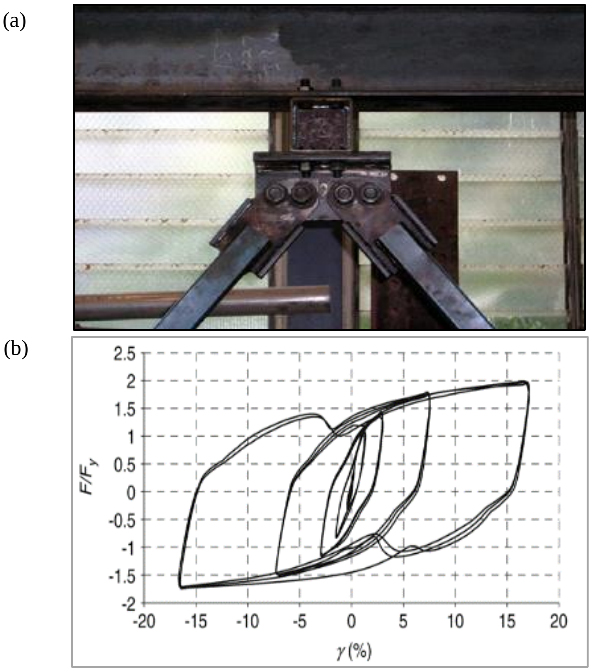
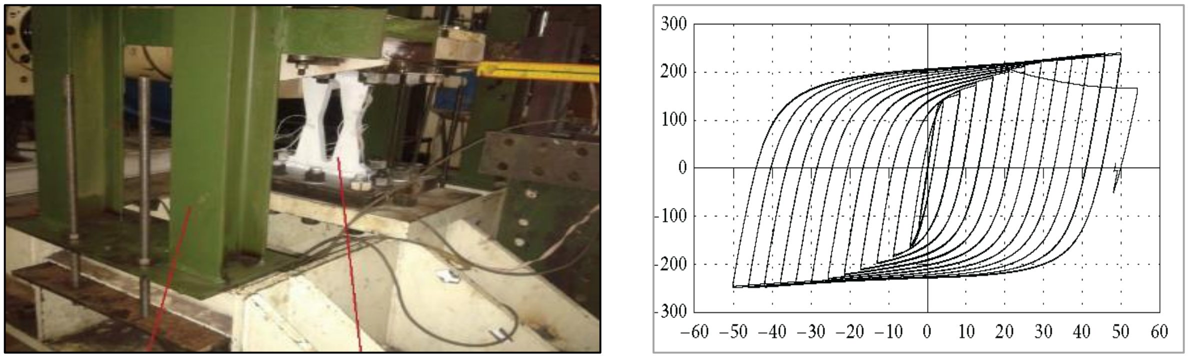


Figure 5 Yielding Shear Panel Device [(a) Specimen 100-2C, (b) Force-Displacement Hysteresis]

2.5 Hysteretic Steel Damper (HSD)

These types of steel dampers are fabricated from mild steel plate with different geometrical shapes on the side part, as shown in Figure 6(a). The shapes can be straight, concave or convex. The performance of this device has been verified experimentally by several quasi-static cyclic tests [8]. The specimen with convex-shape showed stable hysteretic behavior with desirable energy dissipation capabilities and ductility factor. Figure 6(b) illustrates the load-deformation relation of the specimen DHSD-4, with width, height and thickness of 210 mm, 300 mm and 20 mm, respectively.

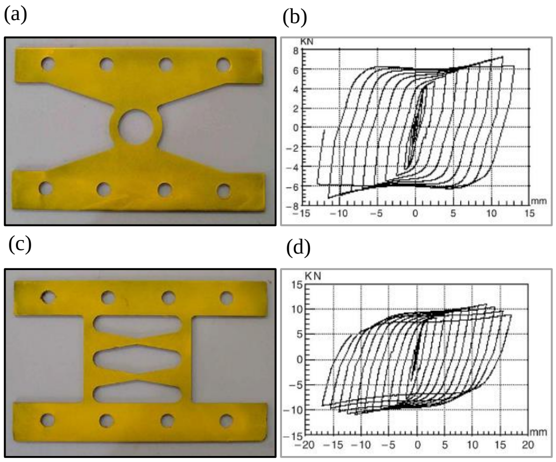


(a) (b)

Figure 6 Hysteretic Steel Damper [(a) Specimen DHSD-4, (b) Force-Displacement Hysteresis]

2.6 Dual Function Metallic Dampers

A type of dissipative device as metallic damper was presented by Li and Li [9]. This damper provides additional structural stiffness along with good seismic energy dissipation capabilities. Therefore, they were named as dual function metallic dampers (DFMD). Quasi – static and shaking table tests carried out on the dampers in order to study effects of this device on behavior of the structures. The dampers made of mild steel plate with two specific geometric shapes on it, single round-hole (DFMD-O) and double X-shaped (DFMD-X), as shown in Figures 7(a)-(c). The width, length and thickness of the plate are 180 mm, 228 mm and 2mm, respectively. Figures 7(b)-(d) show the hysteretic response of the DFMD-O and DFMD-X, respectively.



[(a) Specimen DFMD-O, (b) Hysteresis of DFMD-O, (c) Specimen DFMD-X, (d)Hysteresis of DFMD-X]

Figure 7 Dual Function Metallic Damper

3.0 COMPARISON AND DISCUSSIONS

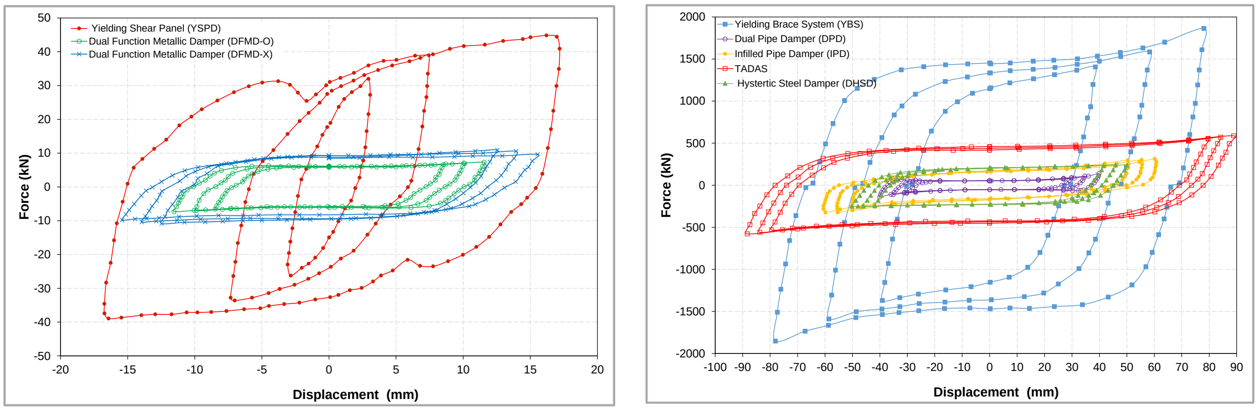
The last three completed dissimilar hysteresis loops of the introduced dampers, just before failure, were selected to draw in one diagram, to calculate the enclosed area of each, and to determine four parameters as equivalent viscous damping ratio, large force to weight, ductility and cumulative displacement t. Figures 8(a)-(b) demonstrate the three last loops of each damper, which have been selected and drawn separately.

3.1 Equivalent Viscose Damping Ratio

To have an indication of the energy dissipation capability of the dampers, it is useful to calculate equivalent viscose damping ratios. Since these two factors are directly proportional to each other. Equivalent Viscose damping ratio can be calculated by following formula [13];

$$\xi_{eq} = \frac{1}{4\pi}\frac{E_D}{E_{S_0}} \qquad (1)$$

where E_D is dissipated energy of each loop of hysteresis, which is equal to its enclosed area. E_{So} is strain energy equal to $k.u_0^2/2$, where k is stiffness and u_0 is deformation as determined from experiment. For each presented damper, damping ratio, dissipated energy and strain energy were calculated for every three loops of the hysteresis before the failure. The results are tabulated and shown below in Table 1.



(a) (b)

Figure 8 Last three hysteresis of [(a) YBS, DPD, IPD, TADAS, DHSD, (b) YSPD, DFMD-O, DFMD-X]

Table 1 Dissipated energy, Strain Energy and Damping ratio of three end hysteresis loops of dampers

Dampers	Third Last Cycle			Second Last Cycle			Last Cycle			ξ_{av}
	E_d	E_s	ξ	E_d	E_s	ξ	E_d	E_s	ξ	
DPD	6887	1369	0.40	7869	1898	0.33	9734	2790	0.28	0.31
IPD	30957	7447	0.33	36289	8365	0.35	36843	9397	0.31	0.33
YSPD	179	42	0.34	179	42	0.34	623	144	0.44	0.37
YBS	142438	27067	0.42	216027	46165	0.37	403292	72758	0.44	0.41
TADAS	115558	21866	0.42	131909	24026	0.44	143449	26110	0.44	0.43
DFMD-X	384	68	0.45	435	74	0.47	436	74	0.47	0.46
DFMD-O	169	28	0.48	205	35	0.47	253	42	0.48	0.48
DHSD	30899	4858	0.51	35040	5507	0.51	38864	5965	0.52	0.51

As an interesting approach, it seems there is a good relation between the type of dissipation mechanism of dampers with the equivalent viscous damping ratio. In other words, a range of damping ratio can be assigned to the particular type of dissipation mechanism. Therefore, metallic yielding dampers, in terms of their dissipation mechanism, can be classified based on a range of damping ratios. This approach is summarized in Table 2

Table 2 Dampers classification

Mechanism	Shear on Sections	Bending of Plate	Shear in Plate
Damping Ratio	.30 - .40	.40 - .45	.45 - .50
Dampers	DPD IPD YSPD	CSFD TADAS	DHSD DFMD-O DFMD-X

3.2 Large Force to Weight Ratio

As mentioned before, one of the valuable factors in study of metallic yielding damper is ratio of maximum force obtained from hysteresis of experiment to weight of the dissipater element in the device. This ratio can be considered as an index of material efficiency in fabrication and performance of a damper. This index indicates the amount of maximum force which can be experienced with unit weight of absorber element in the related damper. Therefore, the higher index shows better material of the damper. This ratio is calculated based on the available data of the dampers and arranged in Table 3. The result indicates the DHSD, YSPD, DEMD-X and DPD have greater maximum force to weight ratio. It can be concluded that the shape of the absorber element and the configuration of elements in damper has a great influence on this ratio.

Table 3 Max Force to Weight ratio of the dampers

Dampers	Max. Force (kN)	Weight of absorber Element (kg)	Max. Force to weight ratio
IPD	312.7	57.7	5.4
TADAS	587.4	45.9	12.8
DFMD-O	7.3	0.5	14.7
DPD	140.3	7.0	19.9
DFMD-X	10.9	0.5	22.0
YSPD	32.0	1.4	22.6
DHSD	240.5	6.9	35.0

Table 4 Ductility and Cumulative Displacement of The Dampers

Dampers	D_u (mm)	D_y (mm)	μ_c (= D_u/D_y)	Cumulative Displacement (mm)
YSPD	17	2	8.5	330
DHSD	50	2.6	19.2	340
DFMD-O	15.5	0.9	17.2	353
DFMD-X	15.4	0.9	17.1	353.3
DPD	42	2.1	20.0	1100
YBS	78	9	8.7	1888
IPD	22	0.79	27.8	1905
TADAS	88	4	22.0	3636

3.3 Ductility and Cumulative Displacements

The ductility of a damper is the ratio of ultimate displacement to yielding displacement. It indicates the capability of plastic deformation of the damper without fracture. The ductility of the dampers are calculated based on the available data, as presented in Table 4. Based on the results, it seems that there is no relation between ductility and the mechanism of energy dissipation in dampers. The other important factor for the dampers is cumulative efficiency in the device. However, this ratio is independent of the energy dissipation capacity displacement which expresses the total displacements, experienced by a damper in the hysteresis. The cumulative displacements of the studied dampers are also tabulated in Table 4. As shown in this table, the cumulative displacement has relation with the damper shape and energy dissipation mechanism. The mechanism of plate bending shows the most cumulative displacement. Moreover, no relationship has been observed between ductility and cumulative displacement.

4.0 CONCLUSION

The comparative study has shown that there is a correlation between equivalent damping ratio, or energy dissipation capacity, and the mechanism of energy dissipation used in a damper. In other words, each particular mechanism can be classified under specific range of equivalent damping ratio. In this study, the dissipation mechanisms were shear in plane, bending in plane and shear in structural sections, which can be assigned to the range of equivalent damping ratio as .45-.50, .40-45., .30-.40, respectively. Large force to weight ratio is completely independent of the equivalent damping ratio, and it depends highly on the shape and configuration of the damper. In terms of ductility, there is no evidence of having relation with the dissipation mechanism and shape of dampers. Cumulative displacement shows a relation with dissipation mechanism and the shape of the damper. Last but not least, ductility and cumulative displacement are not coextensive.

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