Experimental Behavior of the Seismic Filled Accordion Metallic Dampers, FAMD

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ABSTRACT :

In recent years, in conjunction with developments of supplemental passive energy absorption devices , the idea of buckling of thin-walled tube and the use of this property as an accordion metallic damper (AMD) as a valid seismic energy absorption damper was entertained throughout the scientific world. Extremely good behavior for seismic damping has been resulted and shown for the AMD's.
For the purpose of improvements on AMD's , filled accordion metallic dampers (FAMD) are introduced and analytically and experimentally investigated in this paper. First analytical studies have lunched on FAMD's for identification of their behavior under axial cyclic loads. After specifying the preliminary material properties, a series of AMD's and FAMD's filled by polymeric foam were subjected to dynamic tension and compression. Based on the results obtained, using the appropriate filling inside the AMD's is a suitable technique for the purpose of improvement some of important specification such as the number of cycle before failure, amount of dissipated energy, plastic tension and pressure capacity and the effect of interaction between foam and accordion thin walled tubes plays a major role for this purpose specially in low capacity AMD's.
This paper will provide the analytical and experimental investigations as well as promising results obtained during testing for potential use in seismic resistant construction.

KEYWORDS: Filled accordion metallic damper, Polymeric foam, Experimental study

1. INTRODUCTION

During the last decades, many researches have been concerned about the development of supplemental passive energy absorption devices especially hysteretic metallic dampers. In this regards, many different type of these devices have been developed for different purposes with different capacities and potentials.
Thin-walled tubes are considered to be the most common shape and probably the oldest shape utilized in impact energy absorption. Plastic energy can be dissipated in thin-walled metallic tubes in several modes of deformation, including: inversion, splitting, lateral indentation, lateral flattening and axial crushing. From the point of view of energy absorption capacity it was found that axial crushing of circular tubes provide one of the best devices. An axially crushed circular tube can undergo one or more of three distinct deformation modes: Euler buckling, concertina mode of deformation, and diamond mode. Using accordion thin-walled tubes has been suggested by Motamedi and Nateghi-A as a hysteretic metallic damper [Motamedi and Nateghi-A., 2004]. This damper utilizes the capability of accordion thin-walled tubes for excitation of axisymmetric concertina buckling mode as a damping mechanism which in turn increases the amount of the energy absorption under axial cyclic loading. many investigators have also studied the inclusion of different fillers to improve the performance of energy absorption systems. Research in to the collapse of thin-walled sections filled with foam fillers was first investigated by Thornton. Low-density polymeric foams as filler inside different energy absorption devices reported by Thornton, Lampinen and Jeryan, and Reid et al. Lampinen and Jeryan experimentally studied the behavior of foam-filled tubes. They concluded that foam plays a major role in the stability of deformation of tubular struts. Reid et al. investigated the collapse of foam-filled thin-walled metal tubes under quasi-static and dynamic conditions and concluded that the mean crushing load and the collapse folding length were dependent upon the foam density. The influence of high-density foam or pine wood filler on

the mode of collapse of quasi-statically and dynamically crushed non-circular metal tubes has been investigated by Reddy and Al-Hassani. Hanssen et al. carried out quasi-static experimental investigations on aluminum foam-filled square extrusions and concluded only properly bonded foam produces specific energy higher than non-bonded foam filled extrusions. There are many experimental and analytical studies about using the fillers inside circular and noncircular tubes as energy absorption devices that some of them described. However all of these researches only apply to impact load and the behavior of these systems under axial cyclic loading as a structural damper focused in this study. The objective of this paper is to introduce of FAMD's (Fig.1) and comparison the characteristics of AMD's and FAMD's filled by an especial polymeric foam in order to validate the effect of foam filling on the behavior of AMD's. Section and common geometry parameters of FAMD's have been shown in Fig. 2. In this fig: L, length of tube, D, diameter of tube, T, wall thickness, r, radius of wrinkles plate and n, are the number of corrugates along the tube.

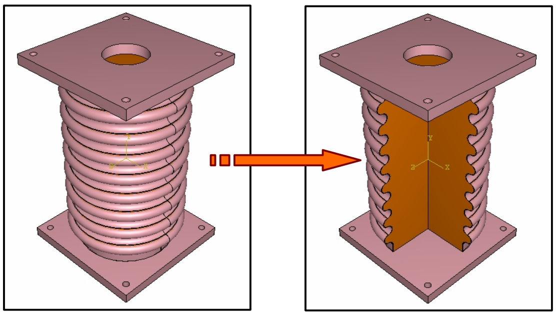


Figure 1. Filled Accordion Metallic Damper, FAMD

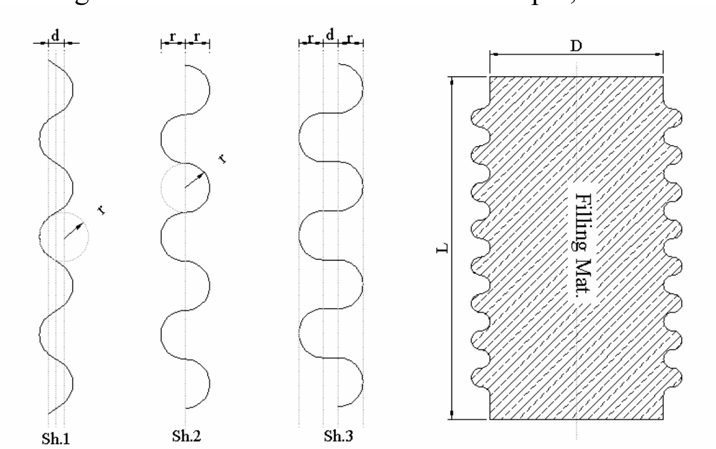


Figure 2. Section and geometric parameters of Filled Accordion Dampers, FAMD

2. POLYMERIC FOAMS AND ANALYTICAL STUDIES

Analytical studies based on finite element method and nonlinear dynamic analysis was performed in order to determination of the approximate preliminary specifications of different polymers for potential use as filler inside FAMD's. for this purpose analytical models of AMD and FAMD's with different fillers have been developed and based on result obtained, an especial flexible polyurethane foam choose as filler inside FAMD in this research. The analytical models of AMD and FAMD is shown in Fig. 3.
There are two predominant types of foams used: polymer and metal foams. Polymer foams are commonly made by blowing gas bubbles into a liquid monomer or hot polymer. These bubbles are allowed to grow and stabilize before the polymer solidifies. This material has relatively low density, high efficiency, and good mold ability for greater design flexibility. Rigid friable polyurethane foams is unrecoverable, such that it can only withstand a single impact but semi-rigid and flexible polyurethane foams are recoverable and suitable for withstand against cyclic loading.

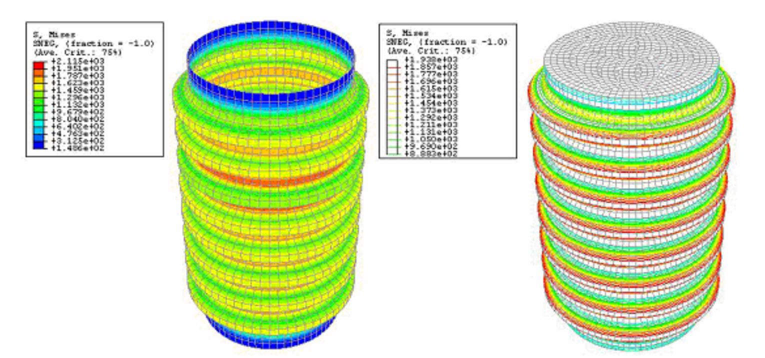


Figure 3. Analytical finite element model of AMD and FAMD

3. EXPERIMENTAL STUDIES

Experimental studies have been conducted on a series of AMD's and FAMD's specimens in odder to investigate and compare the cyclic behavior of FAMD's and AMD's. The specimens have been tested under quasi static axial cyclic loading by tension and compression hydraulic actuator in the laboratory of International Institute of Earthquake Engineering and Seismology.

3.1. Specimens and Test Setup

Forming method based on punching is used for manufacturing the accordion thin-walled tubes and A304 stainless steel by 2100 Kg/cm2 of yielding stress, 5000 Kg/cm2 of ultimate stress and 70% total elongation is used as their materials. Two plates with appropriate dimension are welded to ends of the each tube. Specimens sandblasted, cleared by an Aston bath and filled by polyurethane foam compound that designed for this purpose. Geometric parameters of specimens are shown in Table 3.1. Dynamic universal actuator used for cyclic tests on the specimens. The welded end plates of tubes are bolted to the connecter that designed for this purpose and its arm would be fastened to each grip in the actuator. In this condition specimens suffer only axially deformation without any rotation at the ends. The hydraulic actuator, connector plate and tests setup is shown in Fig. 4. Loading regime for tests is illustrated in Table 3.2 . It is displacement control and amplitude of excitation is gradually increased by frequency of 0.1 HZ . Low frequency of loading was selecting for more possibility of observation the behavior of specimens during the tests.

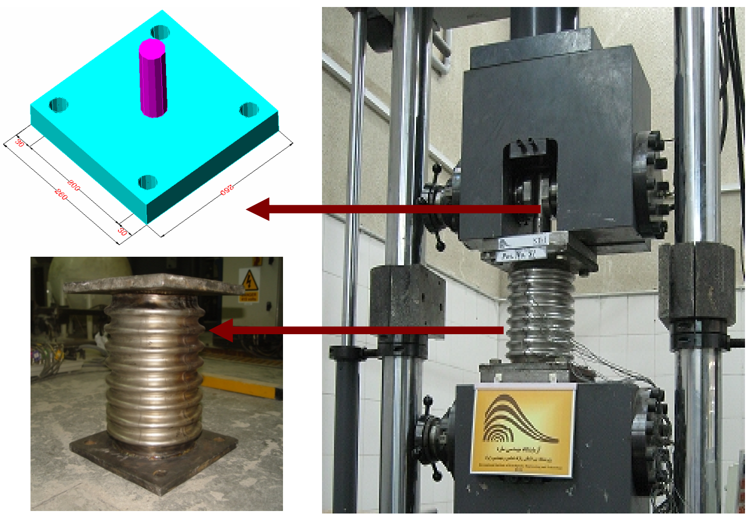


Figure 4. Test setup for axial loading of specimens without any rotation at ends

Table 3.1 Geometric parameters of specimens using for experimental studies

Test No.	Specimen No.	S.h	D (mm)	L (mm)	T (mm)	n (mm)	r (mm)	s (mm)	d (mm)	Filling (Sure. A)
PT-1	P1	2	150	256	2	8	8	13	-	50
PT-1*	P1	2	150	256	2	8	8	13	-	empty
PT-2	P2	3	158	152	0.6	10	4	-	8	40
PT-2*	P2	3	158	152	0.6	10	4	-	8	empty

Table 3.2 characteristics of axial loading regime using for cyclic test of specimens

Test No.	Signal	A_n (n):*Max Amplitude-mm (No of cycle)*								Freq.
		n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8	
PT-1	$A_n\,Sin(\omega t)$	2(2)	5(2)	10(3)	15(3)	20(3)	25(3)	30(3)	35(∞)	0.1 Hz
PT-2	$A_n\,Sin(\omega t)$	50(10)	60(10)	70(10)	80(10)	90(∞)	-	-	-	0.1 Hz

3.2. Results

Axial cyclic loading applied to filled and empty specimens. Hysteretic behavior of Specimen No. P1 is shown in Fig. 5. Specimen No. P1 as a high capacity specimen (wall thickness=2 mm) suffered 22 cycles before failure at the empty state and 28 cycles in the filled state. The hysteretic loops show the amount of dissipated energy in cycle deformation compared for filled and empty specimen. No of suffered cycles increased but the amount of dissipated energy remained constant to some extent for filled specimen in comparison to empty specimen. Hysteretic behavior of Specimen No. P2 is shown in Fig. 6. Specimen No. P2 as a low capacity specimen (wall thickness=0.6 mm) suffered about 71 complete cycles in a stable status without any tearing or collapse in both of filled and empty state. As shown in Fig. 6 The area under hysteretic loops that shows the amount of dissipated energy in cycle deformation increased for filled Specimen No.P2 in comparison to empty specimen but the number of suffered cycles before failure remained constant.

Dissipated energy of Specimens No.P2 (filled and empty) is shown and compared in Fig.7. As shown in Fig using polyurethane foam as filling inside accordion metallic damper lead to increasing about 100% dissipated energy in different amplitude axial deformation. This increasing in amount of dissipated energy is due to interaction effects between foam and thin-walled accordion tubes and the effect of foam inside damper in preventing contact of corrugates (concentration of deformation).

Compression and tension capacity of specimens No.P2 (filled and empty) is shown and compared in Fig.8. As shown in Fig.8, compression and tension capacity of empty damper increased significantly by using polyurethane foam as filler inside the damper. Mainly interaction effects between foam and thin-walled accordion tubes play a major rule in increasing of plastic compression and tension capacity of damper and capacity of FAMD is more than algebraic sum of foam capacity and accordion thin-walled tube.

Commonly, in elastic analysis, hysteretic damping substitute by an equivalent damping. Equivalent hysteretic damping is derived by Equation 3.1.

$$\xi = \frac{E_h}{4\pi E_s} \tag{3.1}$$

Where E_H is dissipated energy in a cycle, E_s is elastic energy and ξ is equivalent hysteretic damping. Equivalent damping in a fully reversed sinusoidal cycle in specimens No. P2 (filled and empty) is shown and compared in Fig.9. As illustrate in fig.9 although dissipated energy increase in filled specimen but its hysteretic equivalent damping reduced.

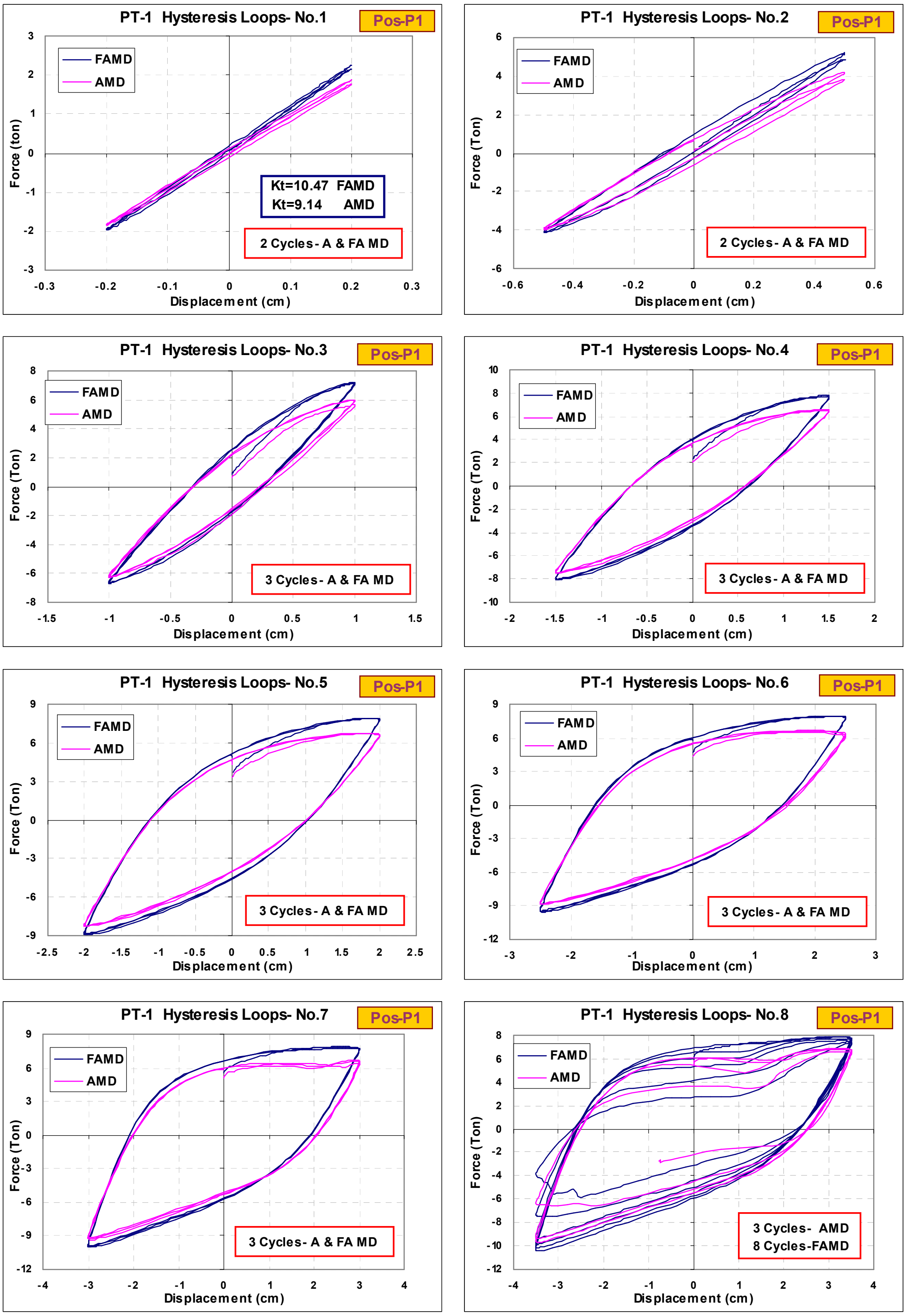


Figure 5. Force-Displacement hysteretic behavior of specimens No. P1

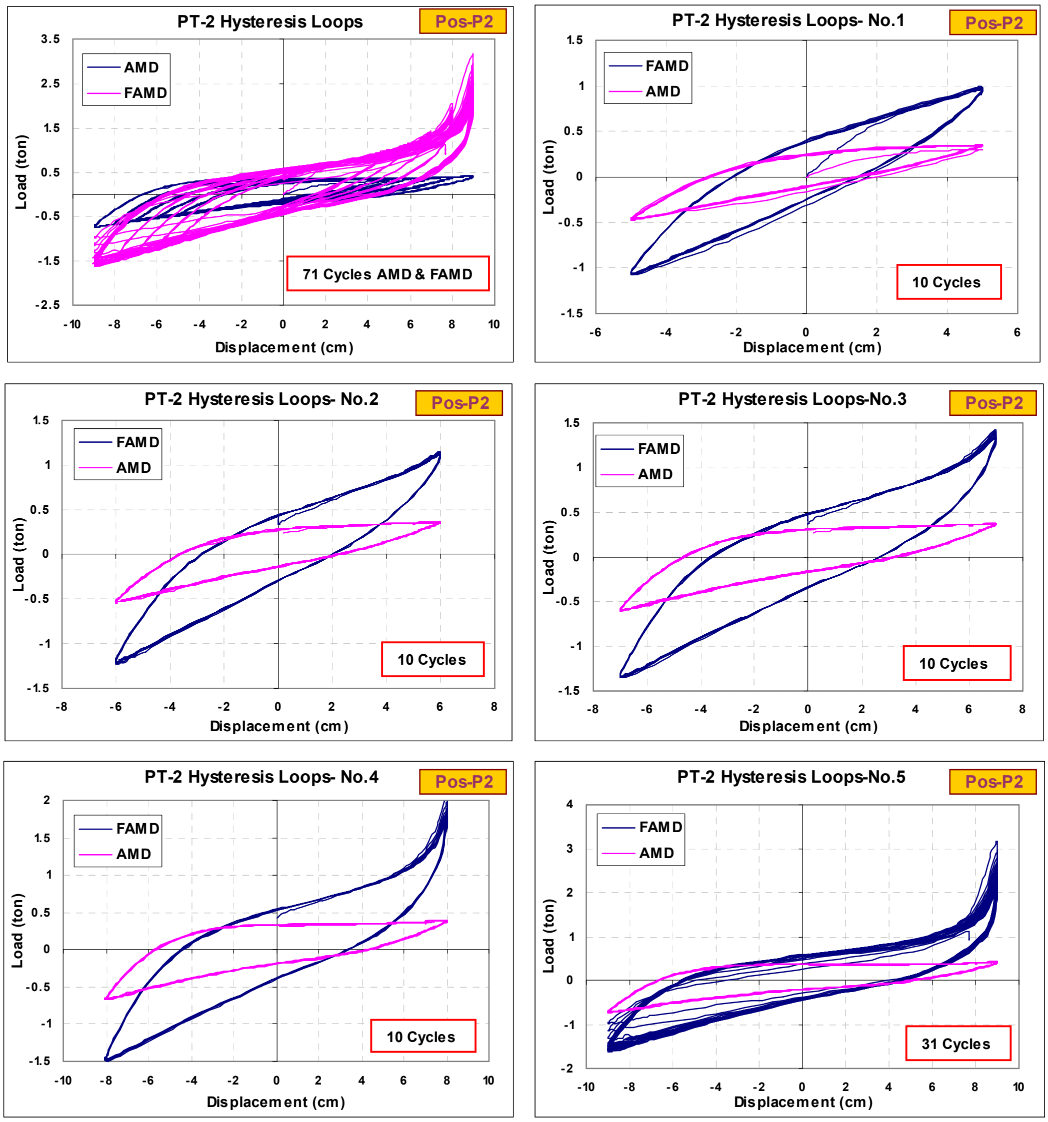


Figure 6. Force-Displacement hysteretic behavior of specimens No. P2

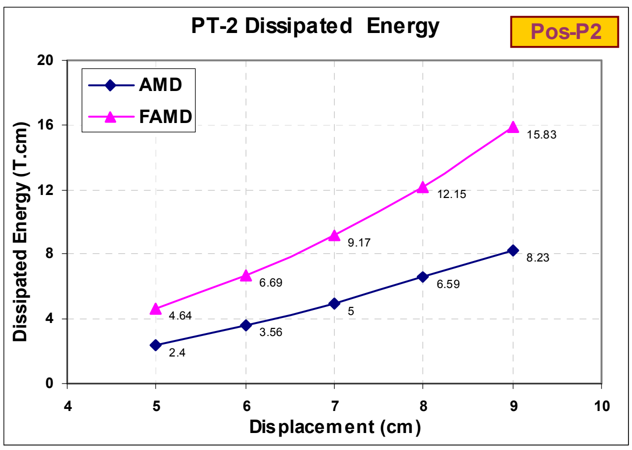
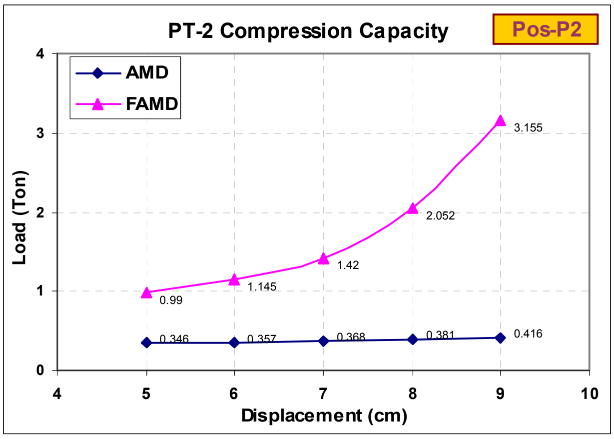


Figure 7. Dissipated energy in a fully reversed cycle specimen No. P2



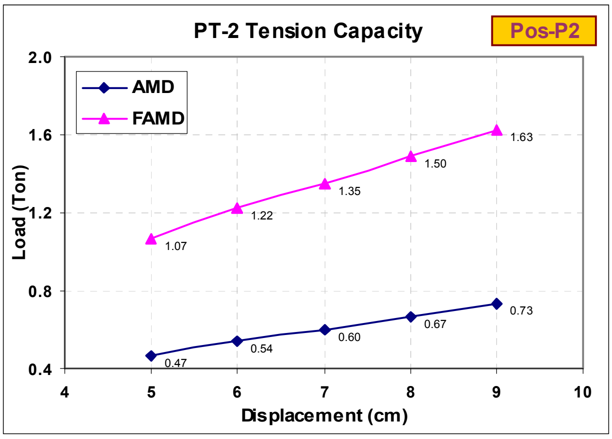


Figure 8. Compression and Tension capacity curve of specimen No. P2

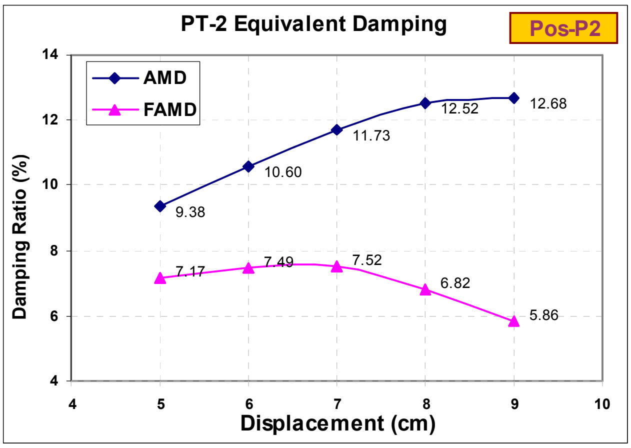


Figure 9. Equivalent damping in a fully reversed cycle specimen No. P2

4. CONCLUSIONS

- Based on experimental results, using polyurethane foam as filler inside Accordion Metallic Dampers help to control buckling mode of dampers under axial cyclic loading and prevent contact of corrugates (concentration of deformation between corrugates), consequently will increase number of cycle before failure of damper. this effect is more significant for high capacity dampers (wall thickness=2 mm)

- Interaction effects between foam and thin-walled accordion tubes play a major rule for improvement some of damper characteristics such as amount of dissipated energy, compression and tension capacity. This effect is more significant for low capacity dampers (wall thickness=0.6 mm)

- Effects of foam filling of damper, although increase amount of dissipated energy but because of sharp increasing of compression and tension capacity, hysteretic equivalent damping decrease in low capacity specimen.

- Amount of dissipated energy, compression and tension capacity of filled damper by polyurethane foam are more than algebraic sum amount of dissipated energy, compression and tension capacity of foam and AMD separately.

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