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ANALYTICAL STUDY OF USING ACCORDION METALLIC DAMPERS FOR SEISMIC RETROFITTING OF BUILDINGS

M. Motamedi[1] and F. Nateghi-A.[2]

ABSTRACT

The application of hysteretic metallic dampers as an energy absorber system has been developed in seismic zones because of suitable efficiency, non sensitivity against temperature and environmental factors, certain and stable behavior, and desirable strength. Analytical and experimental studies have been conducted using Accordion Metallic Damper (AcMD) as a hysteretic device in the past research. In this paper, in order to evaluate the seismic behavior of buildings retrofitted by Accordion Metallic Dampers, three buildings with different number of floors have been selected. These buildings are poor against the lateral loads, and AcMDs are designed for retrofitting them. Secondly, the seismic behavior of those buildings is compared with and without damper in both conditions. Inelastic time history analysis has been used for these studies. Analytical results show that Accordion Metallic Dampers reduce the seismic vulnerability and dynamic response of the buildings. Also they reduce the damage indices severely. It seems using this kind of dampers is suitable for retrofitting the buildings, especially in tall buildings and in high risk zone.

Introduction

Nowadays, using energy absorber systems is a very common method for controlling the vibration of structures and there are many kinds of devices that are suggested and tested for this reason. X plate (Whittaker and Bertero, 1989) and V plate devices (Tsai and Chen, 1993) are two initial hysteretic metallic dampers that have been developed and are available in markets to be used for seismic retrofitting and earthquake resistant construction. These devises are related to displacement in the structure and absorb and dissipate a large amount of entrance energy by a yielding mechanism in a high volume of material due to cyclic deformation in plastic strain rate so that they can reduce the seismic response of the structure. Although hysteretic metallic dampers have been studied by many researchers (Soong and Dargush, 1997), it seems more investigation is required because of some difficulties in fabrication, installation and application of the device in the structure. One of the current methods in retrofitting the existing structures is using the energy absorbers (Hanson, 1993). Application of hysteretic metallic dampers as an energy absorber has been developed in seismic zones because of suitable efficiency, non sensitivity against temperature and environmental factors, certain and stable behavior, and desirable strength (Motamedi, 2002).

[1]Assistant Professor, Dept. of Civil Engineering, Islamic Azad University, South Tehran Branch, Tehran, Iran
[2]Professor, Dept. of Structural Engineering, Int. Institute of Earthquake Engineering & Seismology, Tehran, Iran

Accordion Metallic Damper (AcMD)

Thin-walled tubes have been used for absorbing the impact energy in mechanical and transportation systems for several years. Study of behaviour and deformation mechanism of these systems refers to the past. Reid (1993) studied the behaviour of straight thin-walled tubes under pressure axial force. Thin-walled tubes under axial pressure are considered one of the best methods for absorbing the energy because of the large deformation capacity and long crippling length. But these systems deform and absorb energy only in impact. Thin-walled tubes are suitable as an energy dissipater in the structure during an earthquake, provided that a suitable inelastic buckling mode could occur. Study of behavior of axially crushed corrugated tubes under impact load was conducted by Singace and El-Sobky (1997).

Using accordion thin-walled tubes has been suggested by Motamedi (2004) as a hysteretic metallic damper. This author showed that accordion thin-walled tubes would have suitable capacity of energy dissipation in cyclic axial deformation mechanism by experimental studies on a series of corrugated expansion joints which were available in market (Motamedi and Nateghi-A., 2006).

Fig. 1 shows the test setup for the experimental studies of an Accordion Metallic Dampers (AcMD). Thin-walled tube deformation would occur only in the longitudinal axis of the tubes. In this mechanism, stress and strain in the tube's wall will increase by increasing the axial force and deflection and the first plastic hinge as a narrow ring will appear on the top and bottom of the corrugates. By increasing the axial load, the yielded rings grow and cover the entire tube gradually. This mechanism will repeat in the next cycles. Hysteretic behavior of the AcMD based on experimental studies is shown in Fig. 2. The amount of energy absorption depends on the volume of the yielded materials. Analytical study of application of AcMDs in seismic retrofitting the buildings needs more investigation, which is conducted and explained in this paper.

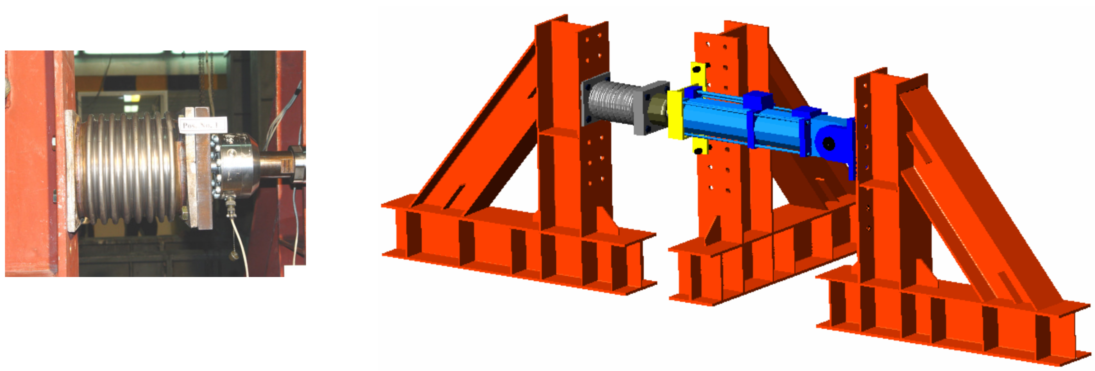

Figure 1. A test setup for experimental studies of Accordion Metallic Dampers (Motamedi, 2005).

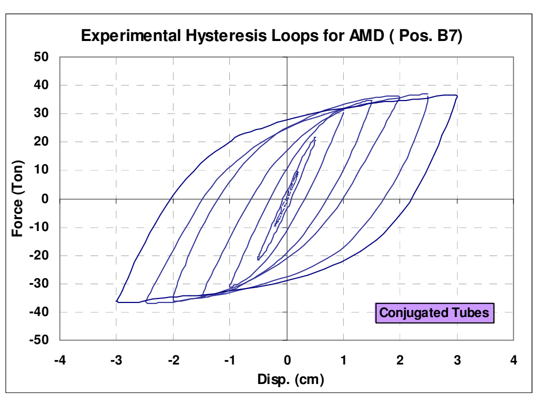

Figure 2. Hysteretic behavior of Accordion Metallic Damper (AcMD) based on experimental studies.

Fig. 3 illustrates the idea for using the Accordion Metallic Dampers in a building for seismic retrofitting.

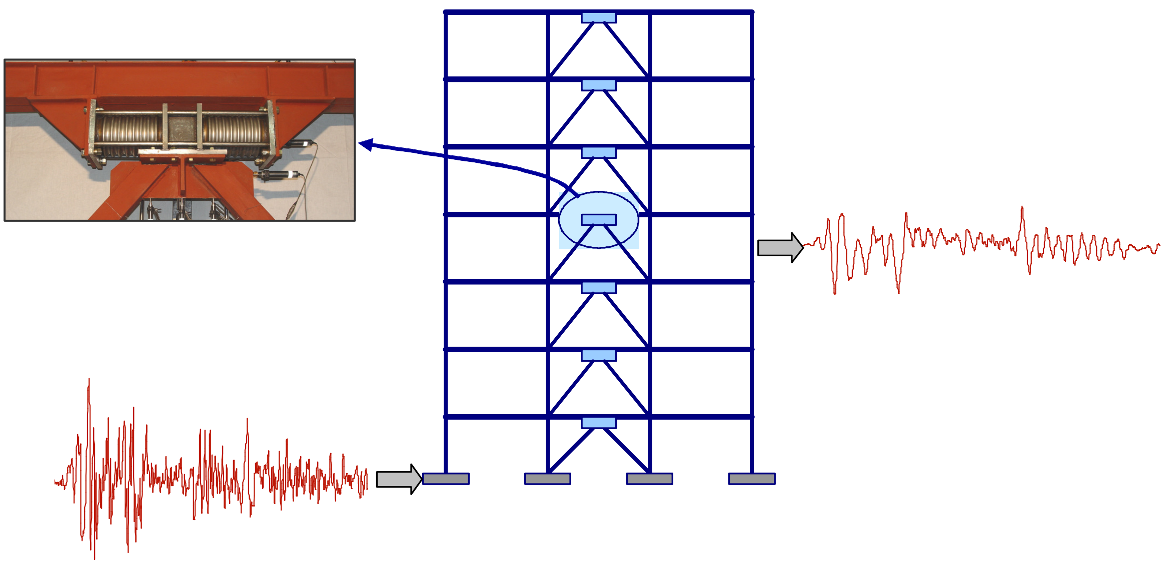

Figure 3. Illustration of installation the Accordion Metallic Dampers in a building and the idea for using them for seismic retrofitting.

Case Studies

In order to study the behavior of the retrofitted buildings by Accordion Metallic Dampers, three steel structure buildings with a different number of stories (5, 10 & 15) are used. The lateral resistant system is a moment resisting frame. The assumptions for designing and retrofitting are the same and are adapted to Iranian codes construction by reducing the base shear forces by 30%. Therefore, these buildings are seismically vulnerable and require retrofitting. AcMD are designed for retrofitting, based on the NEHRP 2000 method (NEHRP 2000). Analytical studies are done by a finite elements method program using the nonlinear dynamic analysis option (Ramirez, 2000). Each building has been analyzed in two conditions with and without damper due to Tabas (1978), Northridge (1994) & Elcentro (1940) records which are normalized to 0.2, 0.35, 0.5, 0.7 and 0.9 PGA.

Buildings Description

Fig. 4 shows the uniform plan for these 3 typical buildings. The elevation view, of both bare frame and frame retrofitted by dampers are shown in Fig. 5.

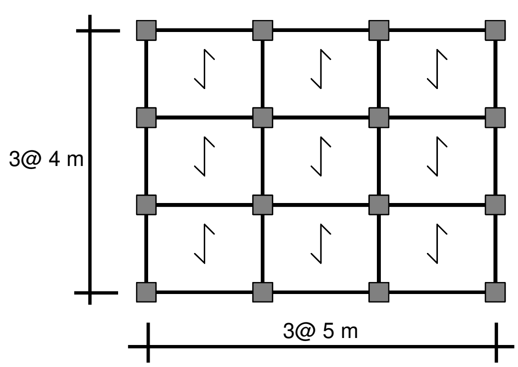

Figure 4. Plan of the case studies buildings.

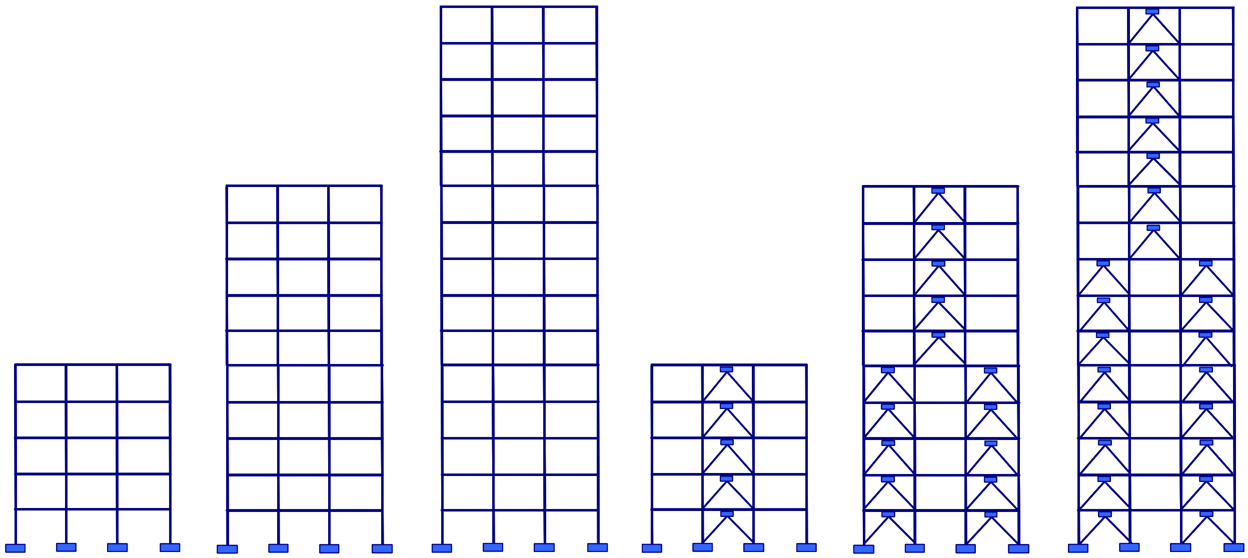

Figure 5. The elevation of 5 story, 10 story and 15 story case studies buildings (Bare frames & retrofitted frames by dampers).

Structural elements are designed based on Iranian national building codes, which are listed in Table 1.

Table 1. Mechanical characteristics of structural elements in case studies buildings.

	15 Story Building			10 Story Building			5 Story Building		
Story No.	**Column (Box)**		**Beam**	**Column (Box)**		**Beam**	**Column (Box)**		**Beam**
	Mid	**Edge**		**Mid**	**Edge**		**Mid**	**Edge**	
1	320X20	260X20	2IPE300	260X20	200X20	IPE360	200X20	140X20	IPE330
2	320X20	260X20	2IPE300	260X20	200X20	IPE360	200X20	140X20	IPE330
3	300X20	240X20	2IPE300	220X20	200X20	IPE330	160X20	140X20	IPE300
4	300X20	240X20	2IPE300	220X20	200X20	IPE330	160X20	140X20	IPE300
5	260X20	220X20	2IPE300	200X20	180X20	IPE330	160X20	140X20	IPE300
6	260X20	220X20	2IPE300	200X20	180X20	IPE330			
7	240X20	200X20	2IPE300	180X20	160X20	IPE330			
8	240X20	200X20	2IPE300	180X20	160X20	IPE330			
9	220X20	180X20	2IPE270	140X20	140X20	IPE300			
10	220X20	180X20	2IPE270	140X20	140X20	IPE300			
11	200X20	160X20	2IPE270						
12	200X20	160X20	2IPE270						
13	160X20	160X20	IPE300						
14	160X20	160X20	IPE300						
15	160X20	160X20	IPE300						

Designing the AcMDs

Accordion Metallic Dampers are designed for upgrading the buildings based on the SR method (Motamedi, 2005). Mechanical characteristics of designed AcMDs for seismic retrofitting of the case studies buildings are listed in table 2.

Table 2. Mechanical characteristics of designed AcMDs for seismic retrofitting of the case studies buildings.

Story	15 Story Building				10 Story Building				5 Story Building			
No.	Brace	K	Fy	AMD	Brace	K	Fy	AMD	Brace	K	Fy	AMD
1	2L150X15	75	23	Pos. 11	2L120X10	40	12	Pos. 1	2L100X10	40	12	Pos. 1
2	2L120X12	50	15	Pos. 10	2L120X8	30	9	Pos. 2	2L100X8	30	9	Pos. 2
3	2L100X14	45	14	Pos. 9	2L100X6	25	7.5	Pos. 5	2L100X6	20	6	Pos. 3
4	2L100X12	45	14	Pos. 9	2L100X6	25	7.5	Pos. 5	2L100X6	20	6	Pos. 3
5	2L100X10	35	11	Pos. 8	2L100X6	20	6	Pos. 3	2L100X6	20	6	Pos. 4
6	2L100X10	35	11	Pos. 8	2L100X10	40	12	Pos. 1				
7	2L100X8	30	9	Pos. 2	2L100X8	30	9	Pos. 2				
8	2L100X8	30	9	Pos. 2	2L100X8	30	9	Pos. 2				
9	2L100X14	45	14	Pos. 9	2L100X6	15	4.5	Pos. 6				
10	2L100X14	40	12	Pos. 1	2L100X6	15	4.5	Pos. 7				
11	2L100X10	35	11	Pos. 8								
12	2L100X10	35	11	Pos. 8								
13	2L100X6	20	6	Pos. 3								
14	2L100X6	20	6	Pos. 3								
15	2L100X6	20	6	Pos. 4								

Analytical Studies

Analytical studies were performed using a mathematical model of AcMD and a numerical integration method for nonlinear time history analysis by a computational program.

Analytical Results

Analytical results show that the periods of buildings before upgrading are 1.5, 2.37 and 3.11 seconds for the 5 story, 10 story and 15 story buildings, respectively. After adding AcMD system for retrofitting, the periods would decrease to 0.76, 1.15 and 1.58 seconds. Pushover analysis and nonlinear time history analysis have been performed in order to evaluate the effect of adding AcMD system to control the seismic responses of buildings.

Pushover Analysis

The effect of adding AcMD system to stiffness, bearing capacity and ductility is studied by pushover analysis.

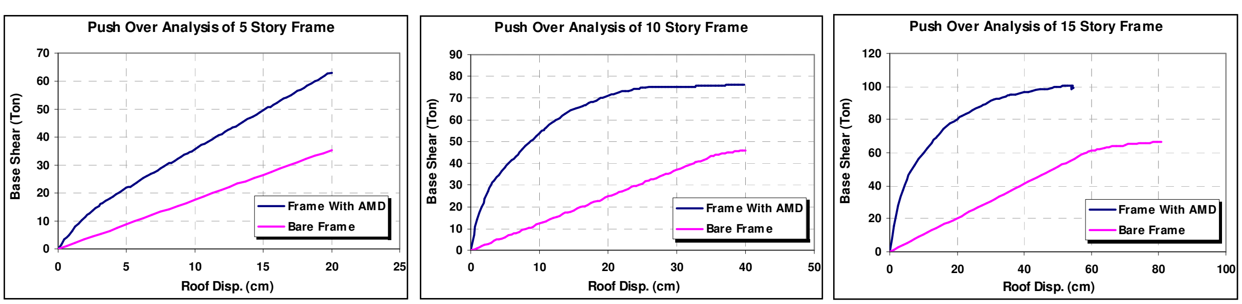

Figure 6. Pushover analytical results for case studies buildings (Bare frames & retrofitted frames by AcMDs).

Fig. 3 shows the pushover analysis results of three building structures, (5 story, 10 story and 15 story) in both condition bare frame and retrofitted frame. As this diagram shows, the lateral stiffness, bearing capacity and ductility increase by adding this system.

Nonlinear Dynamic Analysis

Time history response of roof displacements due to Tabas record is shown in Fig. 7. The effect of Accordion Metallic Dampers in response reduction could be seen, especially in taller buildings. The used record has been scaled to 0.7g .

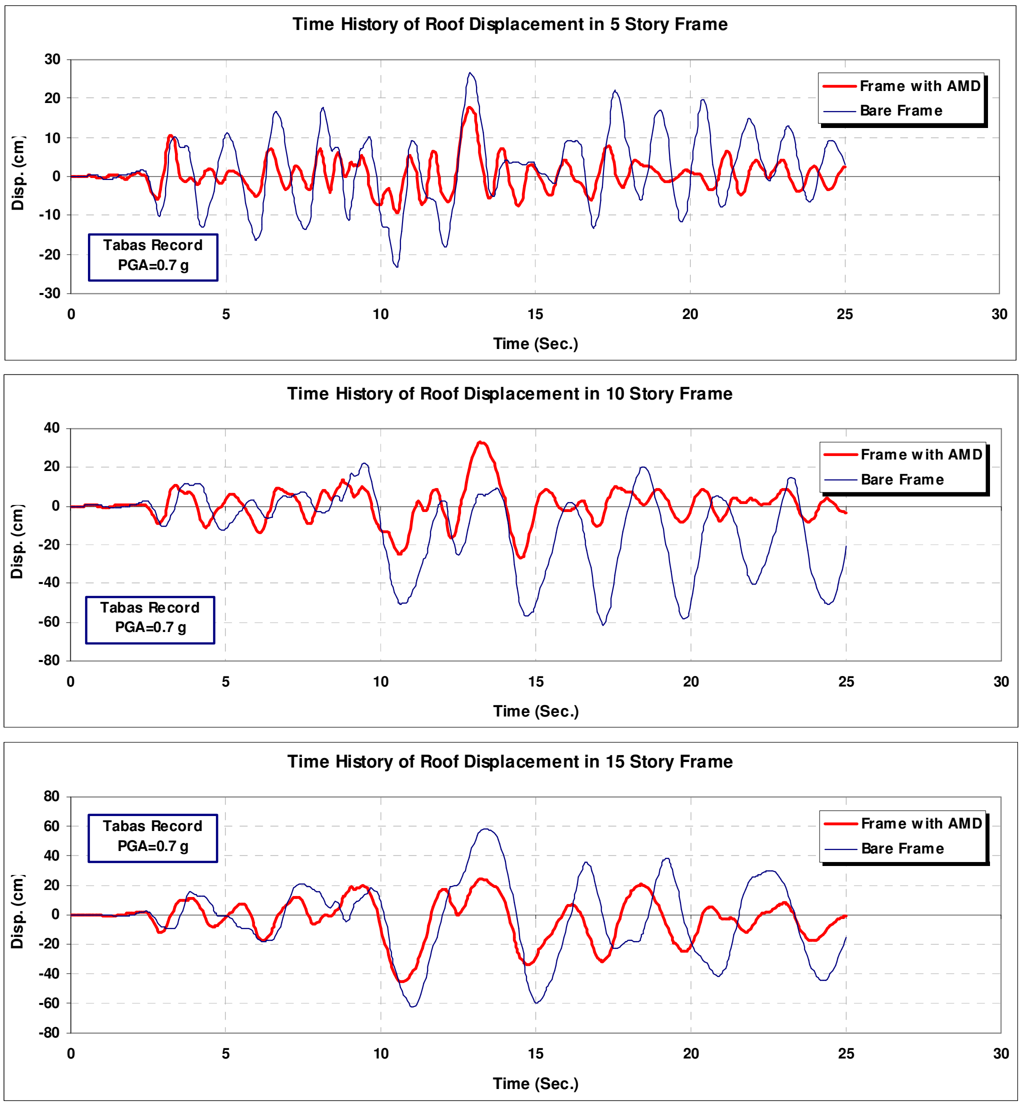

Figure 7. Time history responses of case studies buildings (Bare frames & retrofitted frames).

Fig. 8 shows the maximum displacements of a 10 story building with AcMDs in different PGA. Also, maximum story displacements of all case studies, bare frames and retrofitted buildings with AcMDs, are shown in Fig. 9. These nonlinear dynamic analyses have performed due to Tabas record scaled to 0.7g. As these diagrams show, adding the AcMD system decreases the amount of story displacements. There is up to 50% reduction in the responses.

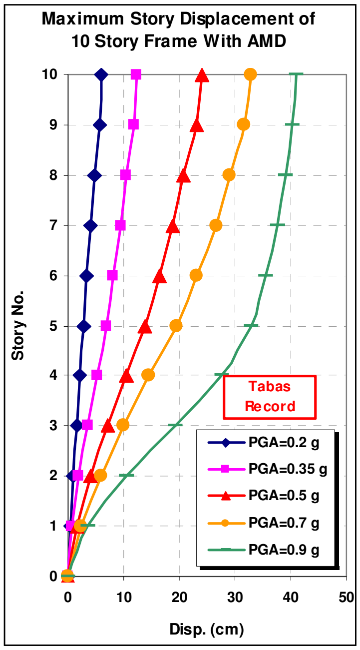

Figure 8. Maximum story displacements of 10 story retrofitted building with AcMDs in a nonlinear dynamic analysis due to Tabas record.

Fig. 10 illustrates plastic hinges distribution in the 15 story bare frame and retrofitted building by AcMDs in a time history analysis due to Northridge record (PGA=0.7 g). As this figure shows, adding AcMDs to the frame increases the number of plastic hinges and moves them down the structure. Fig. 11 shows hysteresis loops of AcMDs in different stories of the 15 story building in a time history analysis due to El-centro record (PGA=0.7g). These loops are fat enough which illustrate the large amount of energy dissipation by Accordion Metallic Dampers due to seismic excitation.

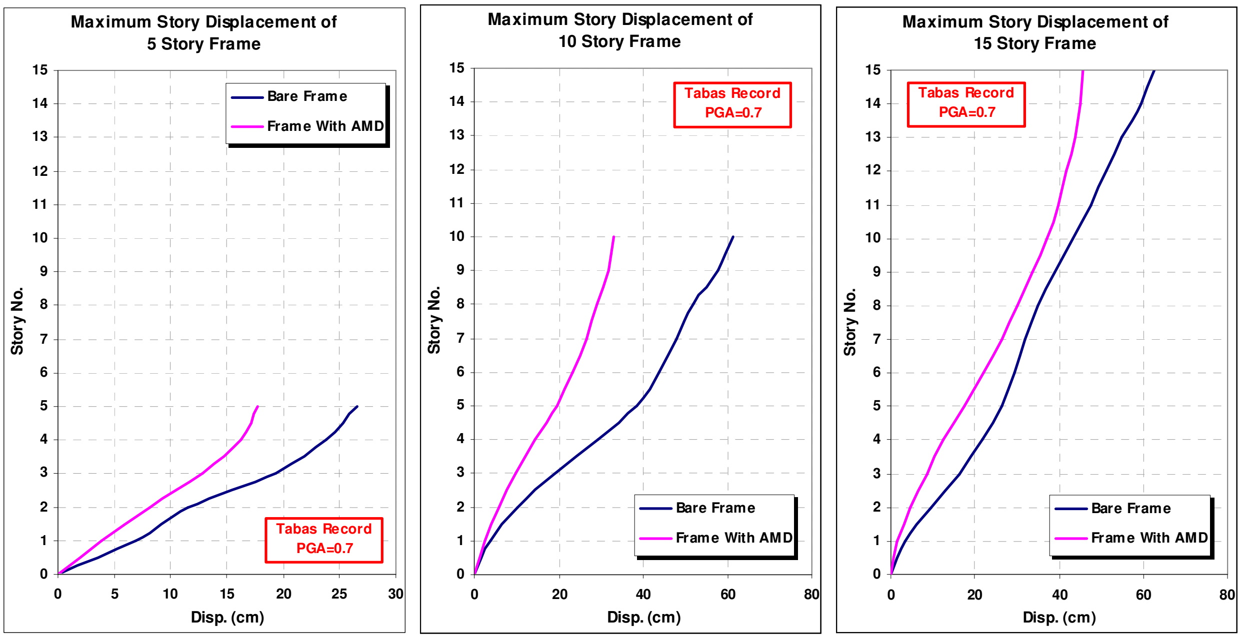

Figure 9. Maximum story displacements of case studies bare frames and retrofitted buildings with AcMDs in a nonlinear dynamic analysis due to Tabas record .

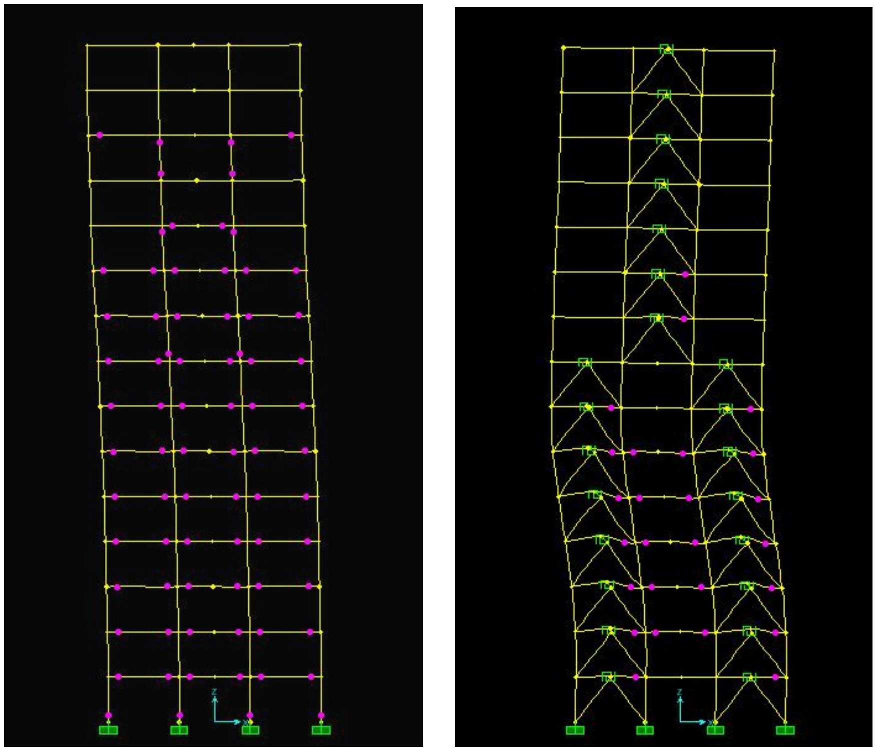

Figure 10. Plastic hinges distribution in 15 story bare frame and retrofitted building by AcMDs in a time history analysis due to Northridge record (PGA=0.7 g).

Conclusions

Experimental and analytical studies described in this paper, have shown that accordion metallic tubes have suitable capacity for energy dissipation and, in cyclic axial deformation mechanism, could be used as hysteretic metallic damper. Application of Accordion Metallic Dampers (AcMD) in retrofitting the weak buildings is investigated by analytical studies in this paper. The obtained results show that:

1- Accordion Metallic Damper (AcMD) could be used as hysteretic metallic damper for seismic retrofitting building structures.

2- Using AcMDs in a weak building would reduced the seismic responses and allows the structure to be in the elastic state and safer mode.

3- Reduction in story displacement is one of the important effects of Accordion Metallic Damper. Permanent displacement of each floor and maximum drifts are reduced severely. In lower PGA's, drifts may increase.

4- Capability of Accordion Metallic Damper is more evident in taller buildings.

5- The effect of Accordion Metallic Damper on damage indexes in high risk zones is more obvious than the other zones and it depends on frequency content in low risk zones. This effect is less important in low rise buildings.

6- The decreasing effect of hysteretic metallic damper on story displacement is more relevant in higher PGA's. This effect is higher in intermediate floors.

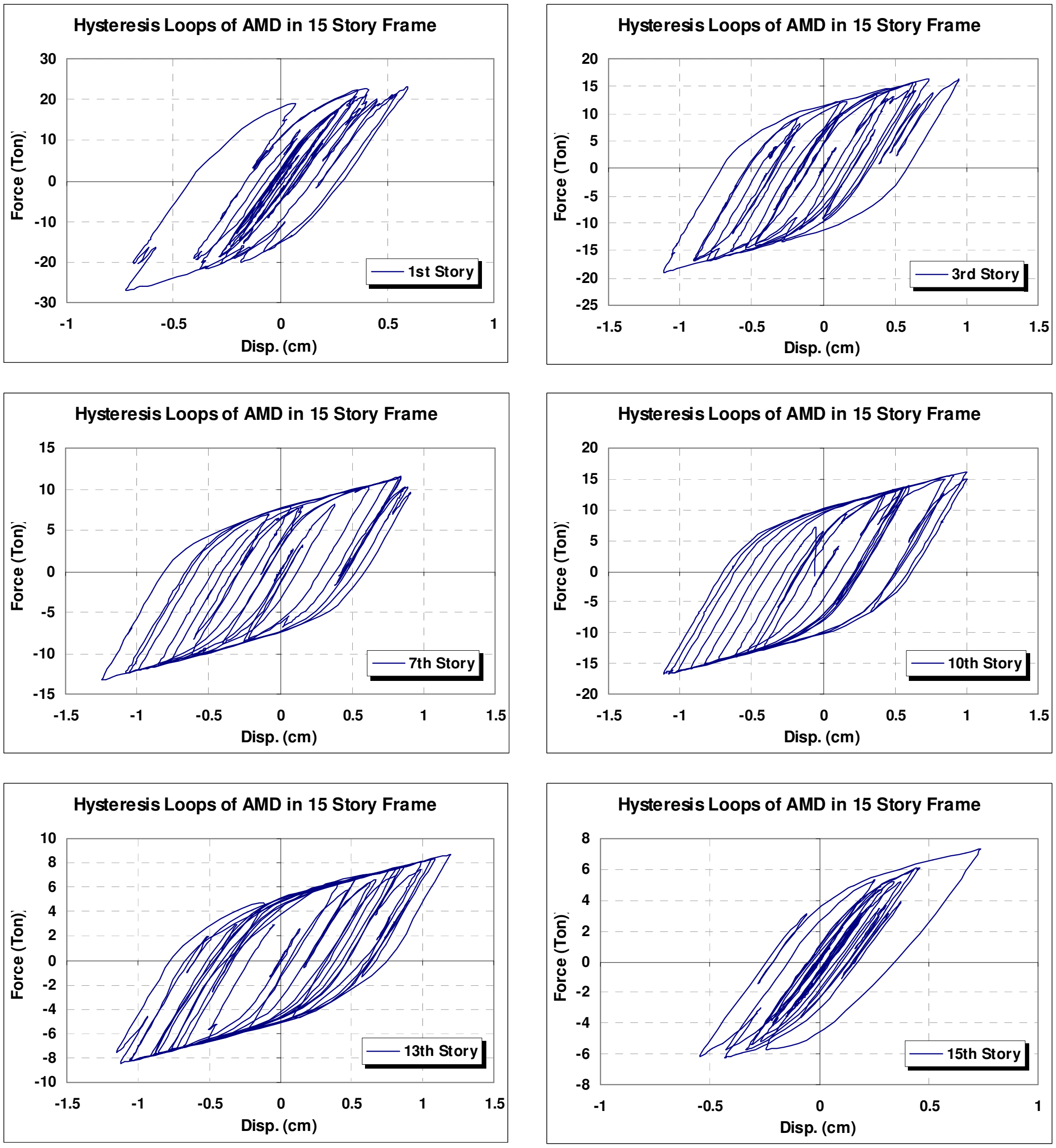

Figure 11. Analytical hysteresis loops of AcMDs in different stories of the 15 story building in a time history analysis due to El-centro record (PGA=0.7g).

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