Behavior and Performance of Structures Equipped With ADAS & TADAS Dampers (a Comparison with Conventional Structures)

Seyed Masoud Sajjadi Alehashem[1], Ali Keyhani[2], and Hassan Pourmohammad[3]

[1]*Research Scholar, Dept. of Civil Engineering, Shahrood University of Technology, Shahrood, IRAN.*
[2]*Asst. Prof., Dept. of Civil Engineering, Shahrood University of Technology, Shahrood, IRAN.*
[3]*Asst. Prof., Dept. of Civil Engineering, Islamic Azad University, Karaj Campus, Karaj, IRAN.*
Email: m_sajjadi_a@Yahoo.com, m_sajjadi_a@Hotmail.com

ABSTRACT :

Metallic dampers such as Added Damping and Stiffness (ADAS) and Triangular Added Damping and Stiffness (TADAS) are among energy dissipating devices that have been using in design of the new generations of earthquake-resisting buildings. In this paper, the behavior and performance of steel structures equipped with ADAS and TADAS metallic dampers are investigated and compared with conventional earthquake-resisting steel structures such as CBF, CHEVRON and EBF systems. For this purpose, ground acceleration records of the El Centro, Hachinohe, San Fernando, and Taft earthquakes are used as the disturbing ground motion in a series of numerical simulations of a multi-story steel building. The numerical simulations were carried out by using DRAIN-2DX program and the nonlinear dynamical behavior of the different systems was compared with each other. Results show suitable behavior of systems equipped with ADAS and TADAS metallic dampers and main damages are occurred in dampers keeping main structure safe.

KEYWORDS: metallic dampers, seismic behavior, nonlinear analysis, energy dissipation

1. INTRODUCTION

New systems for designing earthquake-resisting structures are mainly based on dissipating energy by various devices. These systems are classified into following groups [3]:
a) Base isolation systems, b) Active and semi-active systems, c) Passive systems
Among passive energy dissipation systems, metallic dampers have some advantages: no complicated technology is needed to manufacture them, they can easily be integrated in structures, and they show stable behavior in earthquakes and no environmental (temperature, humidity, etc.) factors affect their performance. These dampers, increase damping and stiffness of structures and increase energy dissipation capacity in them. Adding metallic dampers to the structures can cause concentration of energy dissipation in the dampers. After earthquakes, dampers can easily be replaced for strengthening structure for future earthquakes.

Using steel plates for absorbing and dissipating energy was first used exclusively in nuclear installation [1]. Kelly et al. 1972, tested X-shaped energy dissipaters in a 3-storey building on the earthquake simulator at the University of California at Berkeley [4]. Whittaker et al. 1989, at University of California at Berkeley, conducted a more elaborated test [7]. Xia et al. 1992, studied various aspects of X-shaped (ADAS) dampers by numerical simulations [8]. Tsai et al. 1993, have conducted some numerical and laboratory tests on TADAS dampers [5]. Considering the promising outlook in using these dampers, in this paper behavior of structures equipped with metallic ADAS and TADAS dampers are compared with conventional steel structures including CBF, CHEVRON, and EBF systems from the performance and behavior point of view.

2. ANALYTICAL MODEL

One of most effective mechanisms for dissipating input energy to the structure during an earthquake is non-elastic deformation of metals. During earthquakes, the inter-story drifts cause movement of the upper end of ADAS & TADAS dampers relative to the lower end. This causes yielding of metallic plates of the damper and as a result, the energy is dissipated. Fig (1) and Fig (2) shows the behavior of ADAS and TADAS dampers during earthquake.

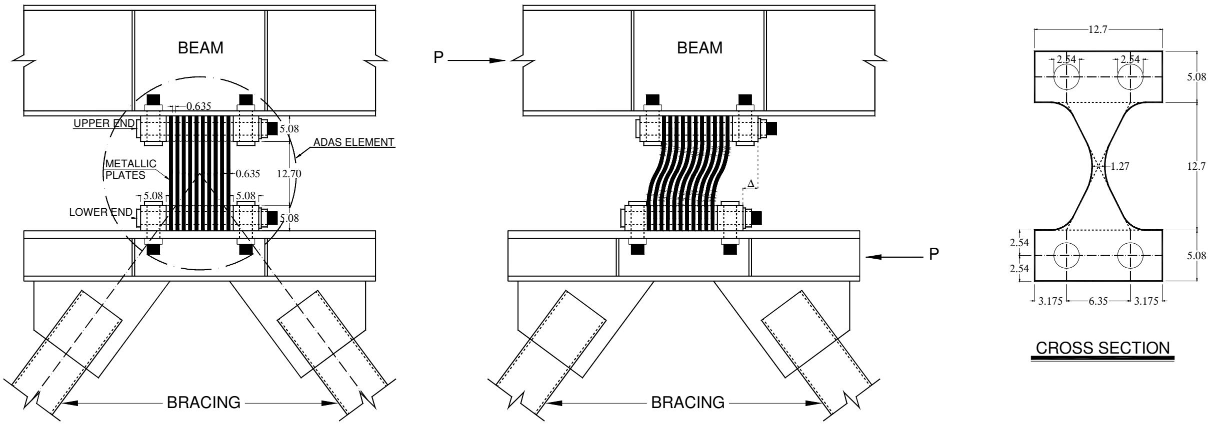

Figure 1. The behavior of ADAS damper during earthquake (all dimensions in centimeter)

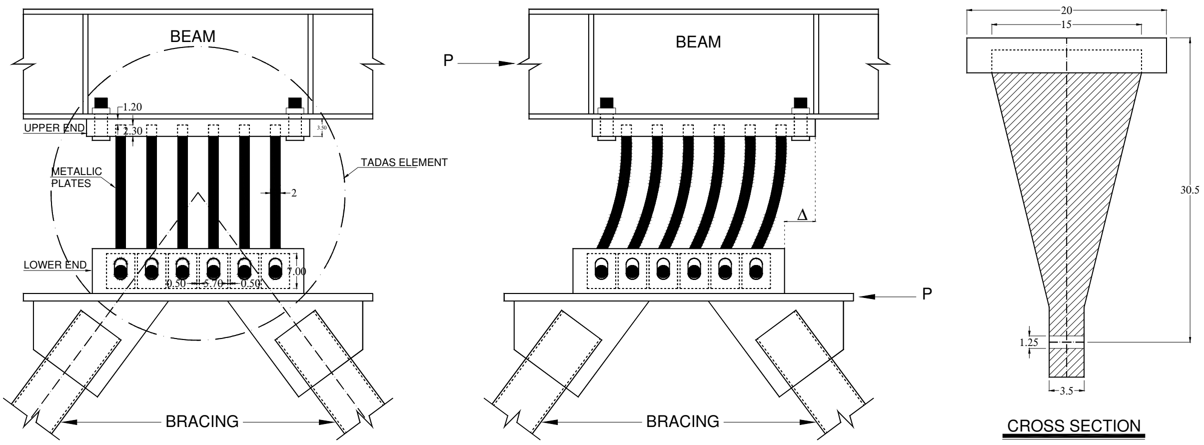

Figure 2. The behavior of TADAS damper during earthquake (all dimensions in centimeter)

The load-deformation curve in shear of the ADAS & TADAS dampers can be idealized as an elastic-perfectly plastic curve (Fig (3-a)), or as a bilinear one with strain hardening (Fig (3-b)) [7]. In this paper, a bilinear curve (with strain hardening of 3%) is used.

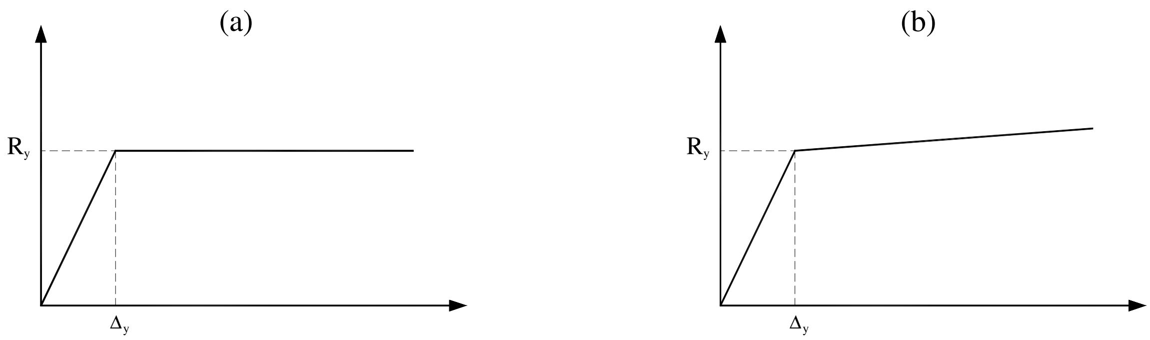

Figure 3. Proposed load-deformation for ADAS & TADAS dampers
a) Elastic-perfectly plastic curve, b) Bilinear curve with strain hardening

For comparing different systems, a ten-story building is selected. The studied building is a steel frame with symmetrical plane, 5m span, and 3.2m story height. The plans of all stories are same and loading of all frames are similar. Bracings are set in outside frames of building and in each frame two spans are braced. In designing EBF system, short link (shear link) with e=60cm is used and considering designing codes, bracing spans are chosen such that gravitational loads is not placed on link beams. In dynamic analysis of the structures by DRAIN-2DX, the analysis is carried on a single frame (outer frame) which is equipped with one of the earthquake resisting systems. For designing systems equipped with ADAS & TADAS dampers, first a moment resistant frame is designed. This frame is designed for the minimal base shear force [8] that is recommended by UBC97 [6] considerations.

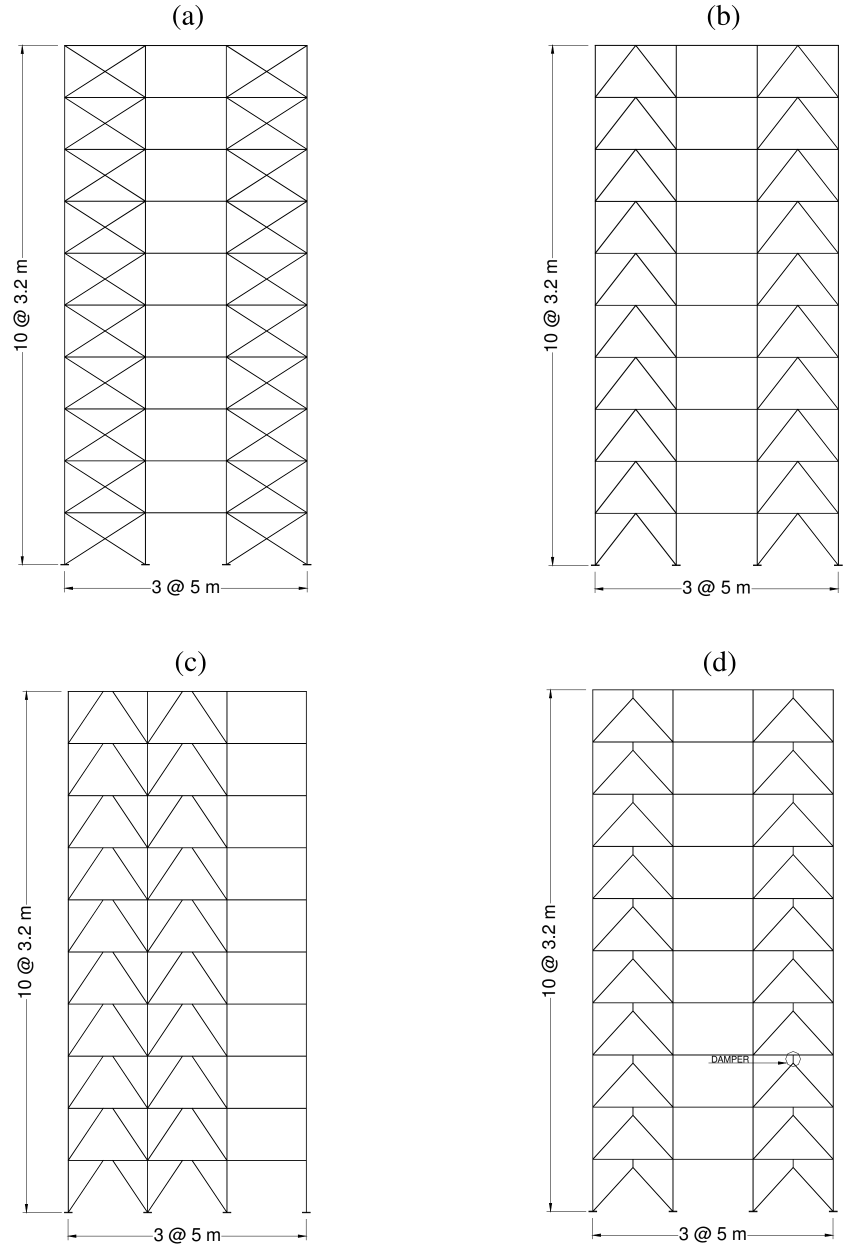

Figure 4. Type of studied single frame
a) CBF, b) CHEVRON, c) EBF, d) ADAS & TADAS

For designing ADAS dampers, specification of ADAS dampers tested by Whittaker et al. 1989[7], are used and for TADAS, specifications of TADAS dampers tested by Tsai et al. 1993[5], are used. Specifications of dampers are presented in table (1).

Table 1. Specifications of used dampers

<table>
<tr><td rowspan="2">Type of Damper</td><td colspan="7">Specification</td></tr>
<tr><td>h (cm)</td><td>$b_{top\&bot}$ (cm)</td><td>b_{middle} (cm)</td><td>t (cm)</td><td>Δ_y (cm)</td><td>P_y (kg)</td><td>K_{damper} (kg/cm)</td></tr>
<tr><td>ADAS</td><td>12.7</td><td>6.35</td><td>1.27</td><td>0.64</td><td>0.2794</td><td>305.8</td><td>1094</td></tr>
<tr><td rowspan="2">Type of Damper</td><td colspan="7">Specification</td></tr>
<tr><td>h (cm)</td><td>b (cm)</td><td>t (cm)</td><td>Gap (cm)</td><td>Δ_y (cm)</td><td>P_y (kg)</td><td>K_{damper} (kg/cm)</td></tr>
<tr><td>TADAS</td><td>30.5</td><td>15</td><td>2</td><td>1.3</td><td>0.548</td><td>988</td><td>1802</td></tr>
</table>

Different design parameters of dampers are chosen considering Xia et al. 1992 [8], recommendations. For this purpose, we used $\frac{B}{D}=3$ and SR=3, where:

$$\frac{B}{D}=\frac{K_b}{K_d} \tag{2.1}$$

In this relation, K_b is lateral stiffness of bracing members and K_d is elastic stiffness of ADAS damper. The value of K_d is calculated from equation (2).

$$K_d=\frac{P_y}{\Delta_y} \tag{2.2}$$

In which P_y is yielding force, Δ_y is yielding deformation of ADAS damper. Lateral stiffness of ADAS Element (consisting ADAS damper and bracings) is calculated from equation (3).

$$K_a=\frac{K_b.K_d}{K_b+K_d} \tag{2.3}$$

SR coefficient is the ratio of horizontal stiffness of ADAS damper element to the stiffness of building storey without applying ADAS Element (K_f).

$$SR=\frac{k_a}{K_f} \tag{2.4}$$

3. DYNAMIC NON- LINEAR TIME HISTORY ANALYSIS

During strong and mediocre earthquakes, structures go into plastic range. Therefore, we have to use a nonlinear analysis. For this purpose, numerically simulations were carried out by DRAIN-2DX software [2]. Beams and columns were modeled as beam-column element with a strain hardening of 3%. Bracings are considered as a truss-element that have capability of yielding in tension and buckling in compression and have a strain hardening of 3%. For modeling ADAS and TADAS dampers, we used an equivalent prismatic beam [5]. Existing gap in the connection of TADAS damper to chevron bracing modeled as simple connection element with gap. The mass of structure concentrated in the joints and distributed loads on the beams are applied as fixed end moments in end joints of beams. Other parameters are chosen as it was suggested in DRAIN-2DX software manual [2]. For numerical simulations, accelerograms related to horizontal component of the Elcentro (PGA=0.35g), Hachinohe (PGA=0.19g), San Fernando (PGA=1.17g) and Taft (PGA=0.19g) are used. Response spectra of these earthquakes with damping ratio of ξ=2% is shown in Fig (5).

Assessment of structure period is an important factor in analyzing flexibility and ductile behavior of it. In addition, designers always try to avoid structural periods close to dominant period of the exiting force. To this end, first mode periods of different systems are shown in Table (2). Considering this table, it could be found that periods of the systems equipped with ADAS & TADAS dampers are higher that other systems and CHEVRON system has the smallest period among all.

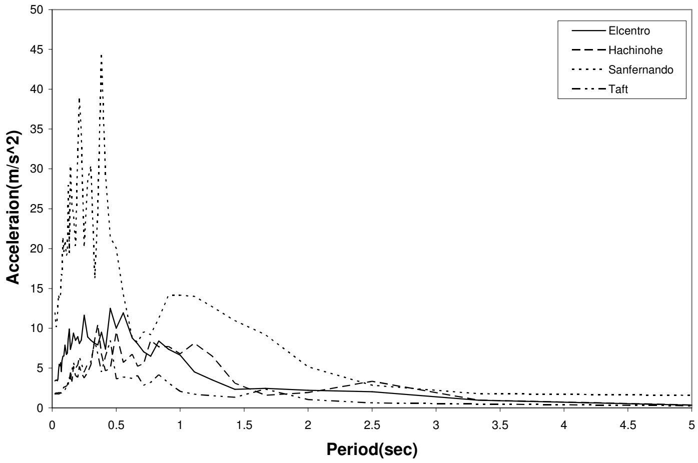

Figure 5. Response spectra of different earthquakes with damping ratio of ξ =2%

Table 2. First mode periods of different systems

System	ADAS	TADAS	CBF	EBF	CHEVRON
First mode period (Sec)	1.39	1.23	1.06	1.05	0.96

Induced base shear force in the structures is one of the important parameters, which can be used in comparing different structural systems. A high induced base shear force indicates that the structural system is susceptible to risk. Maximum induced base shear force calculated from numerical simulation for different systems due to Elcentro, Hachinohe, San Fernando, and Taft accelerograms is shown respectively in Fig (6).

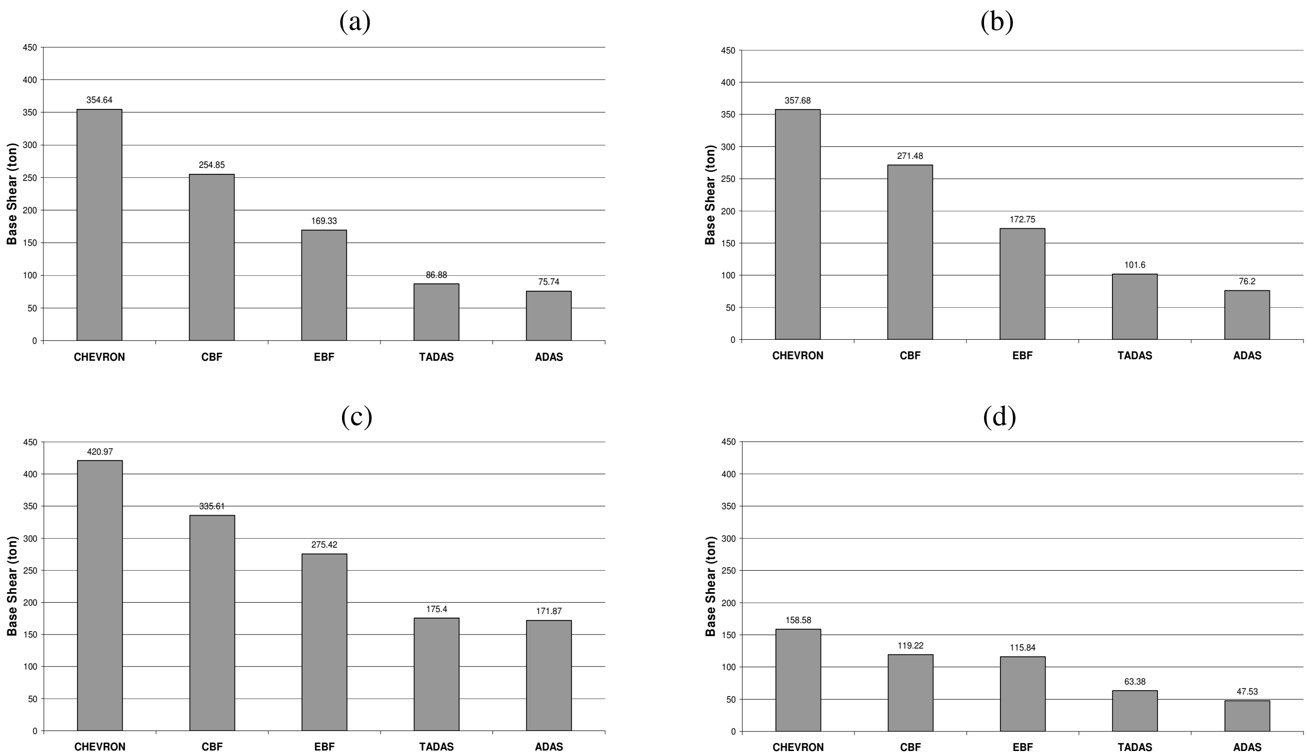

Figure 6. Maximum induced base shear force of different systems
a) Elcentro, b) Hachinohe, c) San Fernando, d) Taft

It is seen that in Elcentro earthquake, induced base shear force of systems equipped with ADAS and TADAS dampers is lesser compared to EBF, CBF and CHEVRON systems (about 50% , 66% and 76% respectively). The induced base shear force of CHEVRON system is higher than other systems. Furthermore, induced base shear force of system equipped with ADAS damper is 13% lesser than system with TADAS dampers. In Hachinohe earthquake, induced base shear force of the system equipped with ADAS damper is lesser that other systems and is 25% lesser compared with system equipped with TADAS damper, 56% lesser compared with EBF system, 72% lesser compared with CBF systems and 78% lesser compared with CHEVRON systems. Fig (6-c) shows induced base shear force in San Fernando Earthquake, we can see that the induced base shear force of systems equipped with ADAS & TADAS is approximately equal but is 36% lesser compared with EBF system, 48% lesser compared with CBF system and 58% lesser compared with CHVRON system. In Fig (5-d) we can see in Taft earth quake, induced base shear force of system equipped with ADAS is the lowest and is 25% lesser compared with TADAS equipped system, 59% lesser compared with EBF system and 60% compared with CBF system and 70% lesser compared with CHEVRON system. Due to this earthquake, base shear forces of EBF and CBF systems are approximately equal.
In Fig (7) maximum relative storey displacement (Drift) of Different systems for Elcontro, Hachinohe, San Fernando, and Taft accelograms are shown.

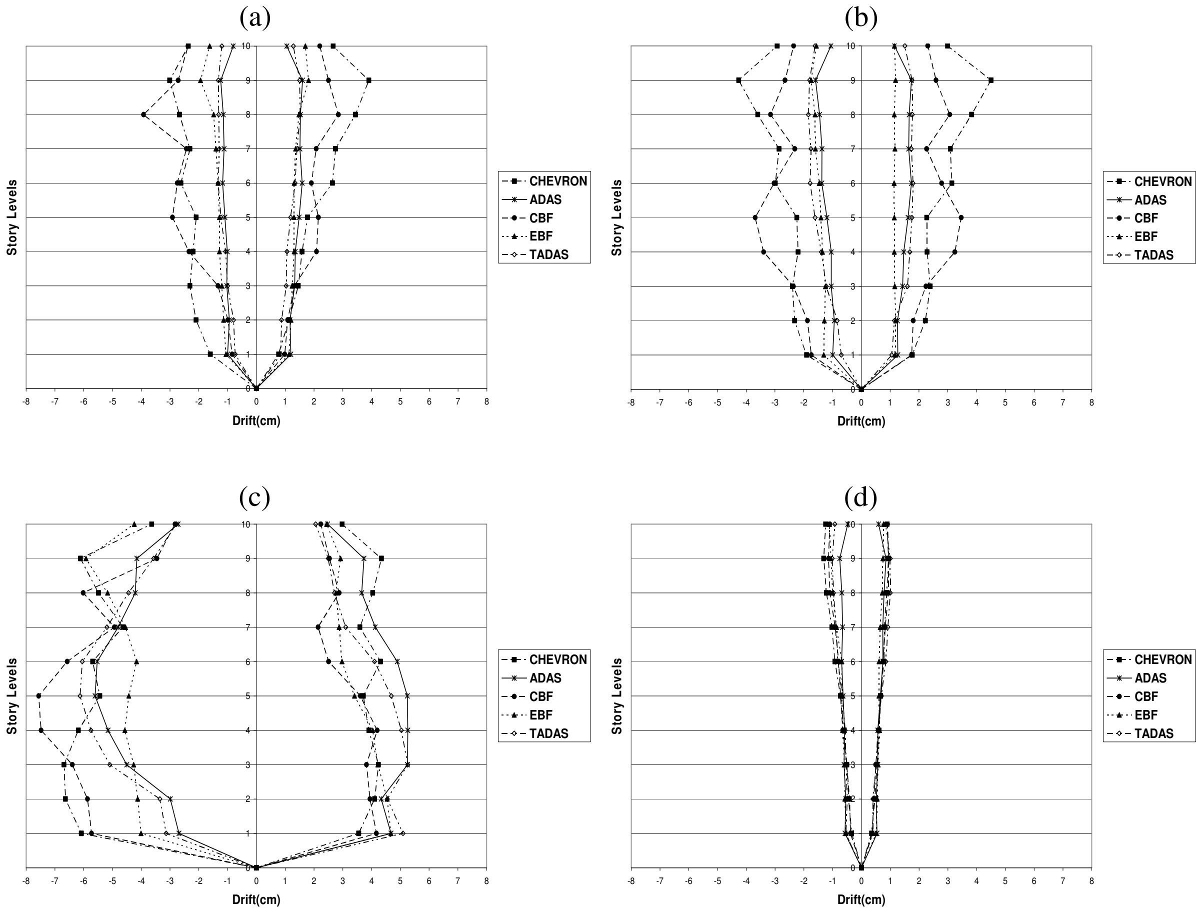

Figure 7. Maximum drift of different systems; a) Elcentro, b) Hachinohe, c) San Fernando, d) Taft

Systems equipped with ADAS and TADAS and EBF system have the same drift in all stories. This fact minimizes non-structural damages during earthquake. Furthermore relative plastic displacement is limited to (Drift < 0.02H=6.4cm) as requested by UBC97. From Fig (7-d), it can be understood that all systems under San Fernando earthquake has high relative displacements, but the limitation of relative plastic displacement of UBC97 (Drift<0.02 H= 6.4cm) is only achieved by systems equipped with ADAS &TADAS dampers and in EBF systems. Considering the fact that San Fernando earthquake with PGA = 1.17g is a very strong earthquake and the probability for the building to face this kind of earthquake is very low. However, systems equipped with

ADAS and TADAS and EBF systems showed that even during this strong earthquake, they satisfy the limitations imposed by UBC97 for relative displacement.
Acceleration of stories is an index of the comfort of inhabitants especially from psychic point of view. To this point, the acceleration of roof for different systems in the accelerogerams of Elcentero, Hachinohe, San Fernando, and Taft earthquakes are analyzed. The maximum amount of acceleration for different systems is shown in table (3). As it is seen, the maximum acceleration of the roof for the system equipped with ADAS damper in Elcentro, Hachinohe and Taft earthquakes are surprisingly lower than other systems (near 50% of CBF and CHEVRON systems). Furthermore, the system equipped with TADAS dampers and EBF systems have lower acceleration in comparison with CBF and CHEVRON systems. Maximum roof acceleration of systems equipped with ADAS damper and CBF system under San Fernando earthquake is lower than other systems and peak roof acceleration of EBF systems and TADAS equipped systems are almost equal.

Table 3. The maximum amount of acceleration for different systems

System	**Maximum Acceleration** (m/sec^2)			
	Elcentro	Hachinohe	San Fernando	Taft
ADAS	5.7	3.9	11.2	2.6
TADAS	6.7	5.3	12.6	3.0
EBF	6.7	5.4	13.5	4.0
CBF	10.3	9.0	11.4	5.2
CHEVRON	13.1	13.1	17.1	5.9

4. CONCLUSION

• First mode period of the systems equipped with ADAS & TADAS dampers are 1.39s and 1.23s respectively that is higher than periods of EBF, CBF and CHEVRON systems.

• The induced base shear force of the systems equipped with ADAS and TADAS under Elcentro, Hachinohe and Taft earthquakes shows approximately 50% decrease comparing with EBF systems, 60% comparing with CBF system and 70% comparing with CHEVRON systems. As for San Fernando earthquake, the induced base shear force of the systems equipped with ADAS and TADAS shows approximately 36% decrease comparing with EBF systems, 48% comparing with CBF system and 58% comparing with CHEVRON systems.

• Drift for systems equipped with ADAS and TADAS dampers and EBF systems in the height of the building is almost uniform. Under San Fernando earthquake which is a strong earthquake, Drift in the systems equipped with ADAS and TADAS dampers is in the allowable range of UBC97 (Drift < 0.02 H= 6.4cm). The same is not true for CBF and CHEVRON systems. Drift of all systems under other earthquakes is in the allowable range of UBC97 code.

• Roof acceleration of the systems equipped with ADAS and TADAS dampers is lower in comparison with other systems. This shows high comfort level of these systems in comparison with other systems.

REFERENCES

[1] Kelly, J.M., Skinner, R.I. and Heine, A.J. (1972). Mechanisms of Energy Absorption in Special Devices for Use in Earthquake Resistant Structures, *Bulletin of N.Z. Society for Earthquake Engineering* **5:3,**.

[2] Parkash, V., Powell, G.H. and Filippou, F.C. (1992). DRAIN-2DX a General Purpose Computer Program for Static and Dynamic Analysis of Inelastic Plane Structure, *Report No. UCB/SEMM-92/29*, Earthquake Engineering Research Center, University of California, Berkeley.

[3] Soong T.T., Dargush G.F. (1997). Passive Energy Dissipation Systems in Structural Engineering, Wiley, Chichester, England.

[4] Stiemer, S.F. and Godden, W.G. and Kelly, J.M. (1981). Experimental Behavior of Spatial Piping System with Steel Energy Absorbers Subjected to a Simulated Differential Seismic Input, *Report No. UCB/EERC-81/09*, Earthquake Engineering Research Center, University of California, Berkeley, CA.

[5] Tsai, K.C., Chen, H.W., Hong, C.P., and Su, Y.F. (1993). Design of Steel Triangular Plate Energy Absorbers for Seismic-Resistant Construction, *Journal of Earthquake Spectra* **9:3,** 505-528.

[6] Uniform Building Code (UBC), (1997).

[7] Whittaker, A., Bertero, V., Alonso, J., and Thompson C. (1989). Earthquake Simulator Testing of Steel Plate Added Damping and Stiffness Elements, *Report No. UCB/EERC-89/02*, Earthquake Engineering Research Center, University of California, Berkeley.

[8] Xia, C. and Hanson, R.D. (1992). Influence of ADAS Element Parameters on Building Seismic Response, *Journal of Structural Engineering* **118:7,** 1903-1918.