STUDY AND MODELLING OF DYNAMIC BEHAVIOUR OF STRUCTURES WITH ENERGY DISSIPATION DEVICES TYPE ADAS

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ABSTRACT:

To limit the human and material damage caused by an earthquake, we can use lots of devices that are able to absorb a part of the energy input by the earthquake in the structure. The energy dissipation devices type ADAS (Added Damping and Stiffness) can dissipate a part of seismic energy input to a structure by hysteretic contribution. This work consists in studying the effect of these devices on seismic response of a short period building under seismic loads with different dynamical characteristics, by analyzing how the important parameters such as the damper percentage of lateral stiffness and the seismic coefficient act in connection with the lateral stiffness of the building. The seismic response was studied in terms of absorbed energy and the inter story drift.

KEYWORDS: Paraseismic design, yielding dampers ADAS, non-linear models, near field, far field.

1. INTRODUCTION

Earthquakes come from the brutal and sudden release of energy and the building which receive this energy (E_I), have to dissipate it or distribute it some way. To achieve this goal, several vibration control systems have been invented, passive system, active system, semi-active system and hybrid system.
It was found from the research that the systems of the passive control of base isolation are not very effective against earthquakes in near field because the displacements of the base isolators are large enough for most slender structures. Therefore, to cover this limitation, we use the systems of passive control energy dissipation.
The energy dissipating devices represent one of the most effective mechanisms available for the dissipation of energy input in a structure during an earthquake.
The metallic dampers ADAS have some advantages: they do not require sophisticated technology to get produced, they can easily be integrated into structures, and they show a stable behavior under the effect of the earthquake, as well as environmental factors (temperature, humidity ...) which do not affect their performance. These dampers are usually mounted in a frame of a bracing system. After the earthquake, they can easily be replaced for the reinforcement of the structure for future earthquakes.
Tena Colunga A. (1997) [1] presented another different method, that analytical models determine the stiffness and the load-deformation curves of the ADAS device using the flexibility method. De la Llera (2004) [2] conducted experimental and parametric study on the supplemental copper dampers and proved that the efficiency of these devices depends on the soil conditions and flexibility of the primary structure, so it is concluded that supplemental copper dampers are a good alternative for drift reduction in a wide range of structural layouts. Alehashem S.M.S. (2008) [3] studied the behavior and the performance of steel structures equipped with ADAS and TADAS metallic dampers and compared with conventional earthquake-resisting steel structures. Abdollahzadeh G. (2011) [4] illustrated that the energy dissipation device significantly increases the resistance of the structure components to the dynamic loads and that they are effective in reducing the seismic response of the structures and in absorbing the hysteretic energy. Curadelli O. (2009) conducted a parametric study on the hysteretic damping systems. Lots of other researchers worked on the yielding dampers ADAS and proved that

the incorporation of these devices in a structure improve in a significant way its dynamical behavior under a seismic excitation.
The effect of an earthquake on a structure depends on its stiffness: a rigid low-rise building has a short natural period and a slender high-rise building has a longer natural period.
This work, studies the influence of the stiffness of the yielding dampers ADAS on the dynamical behavior of a building with short period for different combinations of damper stiffness; 25%, 50% and 75% respectively according to the total stiffness of the building.
In this research, we used ETABS program (*Extended Three Dimensional Analysis of Building Systems,* in its version 9.6) for the analysis.

2. DESCRIPTION OF THE ENERGY DISSIPATION SYSTEM

The ADAS device, its deformation and its hysteresis loop are shown in figure 1. The device chosen for this study is an ADAS 75_10, which means metal plates with height $h = 150mm$, basic width $b = 75mm$ and thickness $t = 10mm$
The limit of elasticity of the steel plates used for the ADAS is σ_y =2530 kg/cm^2, for a steel-E36. [2].

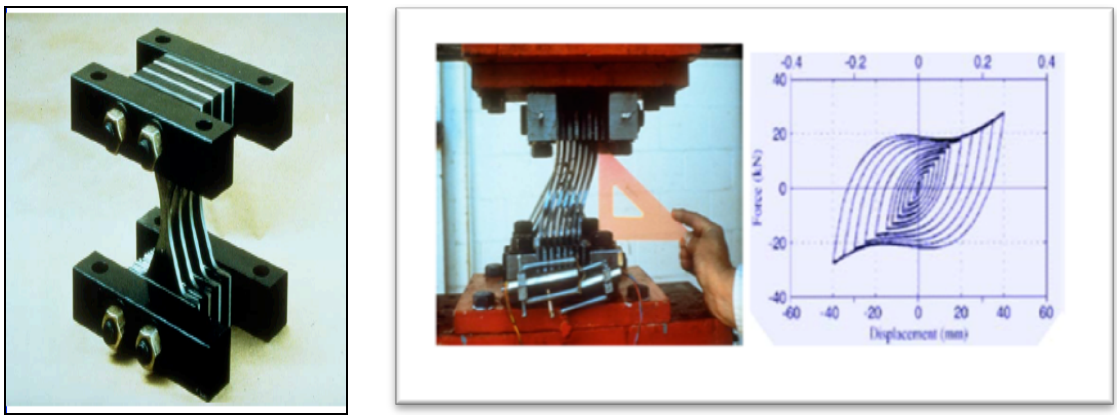


Figure 1. ADAS device, its deformation and its hysteresis loop [7]

The ADAS dampers are defined by the following parameters:

- The initial elastic stiffness: $K_{ADAS} = n\left(\frac{2Ebt^3}{3h^3}\right)$ (1)

- The yield force: $F_y = n\left(\frac{\sigma_y bt^2}{2h}\right)$ (2)

- The yield displacement: $\Delta_y = \left(\frac{3\sigma_y h^2}{4Et}\right)$ (3)

- The ductility ratio μ : $\mu = \frac{\Delta_u}{\Delta_y}$ (4)

Where n is the number of plates which compose the ADAS system, b is the width of the plates, h the height of the plates and E the elasticity modulus of steel.

3. EFFECTIVE STIFFNESS OF THE DAMPER

This work is based on the principle of the equivalent linearization; that represents one of the approximation techniques of structures analysis and which consists in replacing the nonlinear real system by an equivalent linear system. To simulate the seismic behavior of the ADAS devices, a bilinear behavior between shear force and relative displacement is reached. So, the shear force in the ADAS device is:

$$F_u = K_{eff} \cdot \Delta_u \tag{5}$$

Effective stiffness of an ADAS system is directly related to the maximum deformation reached, as shown in figure 2.

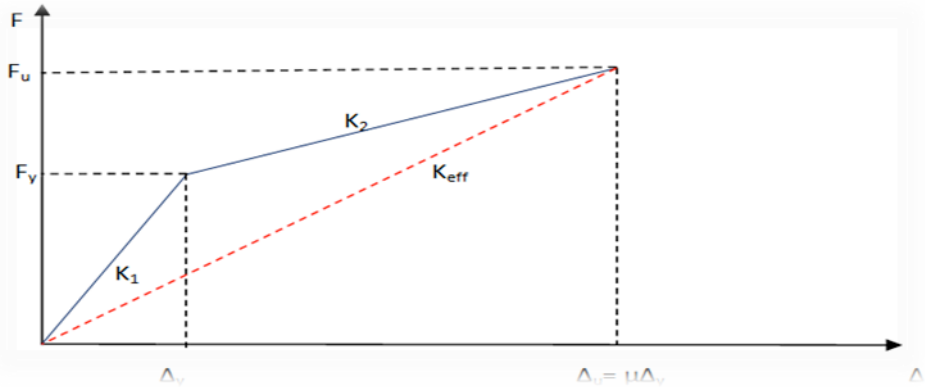


Figure 2. Stress-strain curve of a system with bilinear behavior [7]

According to the preceding figure, the effective stiffness of the damper is calculated as follows:

$$K_{eff} = \frac{K_1 + K_2(\mu - 1)}{\mu} \tag{6}$$

Where K_1 is the elastic stiffness of the dampers, K_2 its post-elastic stiffness, and μ its ductility ratio. [4]

4. ANALYTICAL MODELING

The structure used in this study is a metal building in four levels of rectangular form in plan 18 x 15 m² including three spans in each direction. The height of a floor is of 3 m. The frames are consisting of beams and joists IPE 330 and of columns HE240A. The wind-bracing is ensured by diagonals of the type rafter UPN160. Mixed floors with slab collaborating are made up with slab of 16.5 cm of thickness of the reinforced concrete resting on steel vat and posed on the girders,
In the direction of analyses (X), the dampers are placed on the edges frames; in the central span, assembled on wind-bracing of the rafter type. The dampers are placed in only one direction (X), as shown in figure 3.

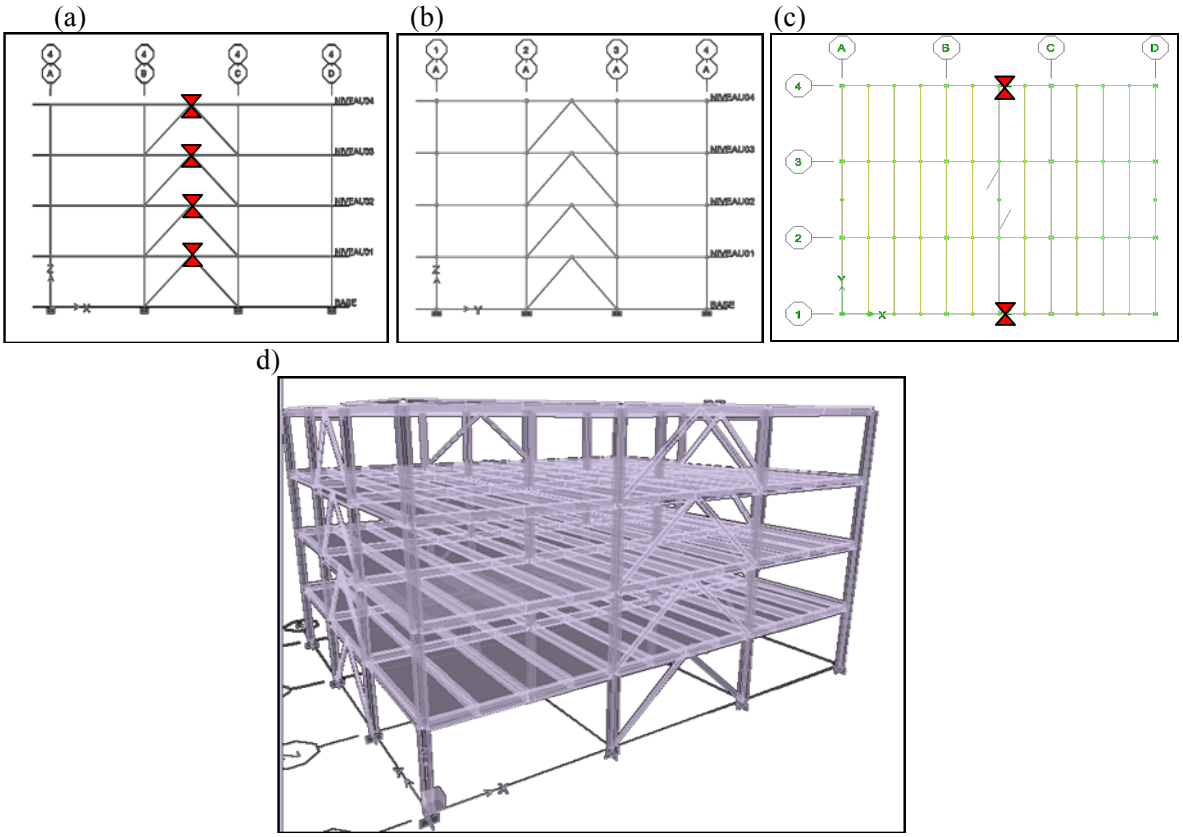


Figure 3. The studied structure: a) Elevation view in direction X, b) Elevation view in direction Y, c) Plan view with site of dampers (PZ), d) 3D view

5. SEISMIC LOADINGS

An analysis of the responses by two records is carried out and the considered records are the following: [8]
1. The component of El Centro of Imperial Valley earthquake (1979).
2. The component of YERMO of LANDERS earthquake (1992).
With a Peak Ground Acceleration (PGA) of 0.436 g and 0.151 g respectively. The accelerograms of these excitations are represented in figure 4 and figure 5, respectively.

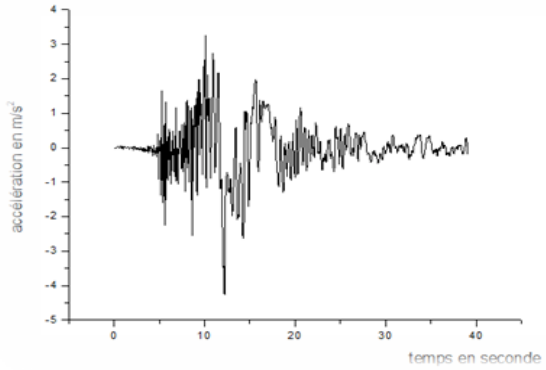


Figure 4. El Centro ground acceleration of Imperial Valley earthquake

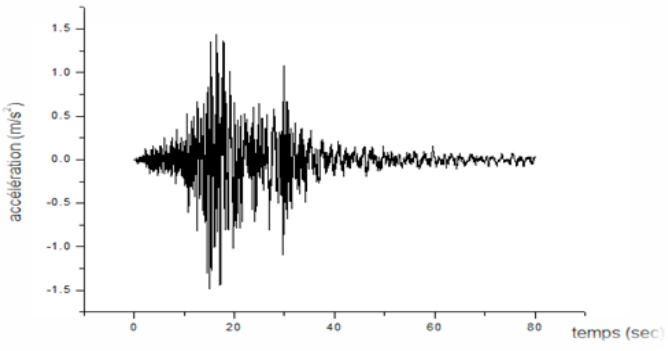


Figure 5. Yermo ground acceleration of Landers earthquake

The influence of the seismic source (far field, near field) and the response of the structure are studied while varying the seismic coefficient for values of $0.025C_s$, $0.050C_s$, $0.100C_s$, $0.150C_s$, $0.200C_s$ and C_s

The first design of the dampers is according to IBC2000 (International Building Code). [9]

The structure is divided into two stages; the dampers from each two successive levels have the same characteristics.

Table 1. Parameters of the two devices ADAS

Parameters of the devices		ADAS stiffness (%)		
		25%	**50%**	**75%**
ADAS1	V_{adas}	31.6500544	63.3001088	94.9501631
	K_{eff}	1556.81527	3113.63053	4670.4458
	K_1	10736.657	21473.314	32209.971
	F_y	21.8276237	43.6552474	65.4828711
ADAS2	V_{adas}	21.7621952	43.5243904	65.2865856
	K_{eff}	1070.44738	2140.89476	3211.34214
	K_1	7382.39572	14764.7914	22147.1872
	F_y	15.0084105	30.016821	45.0252315

With: V_{adas} : The shearing action of the 1st level of the stage (KN)
K_{eff} : The effective stiffness of damper (KN.m)
K_1 : The elastic stiffness of damper (KN.m)
F_y : The yield force in the damper (KN)

6. RESULTS AND DISCUSSIONS

The seismic response was studied in terms of absorbed energy and the inter story drift.

6.1. Energies

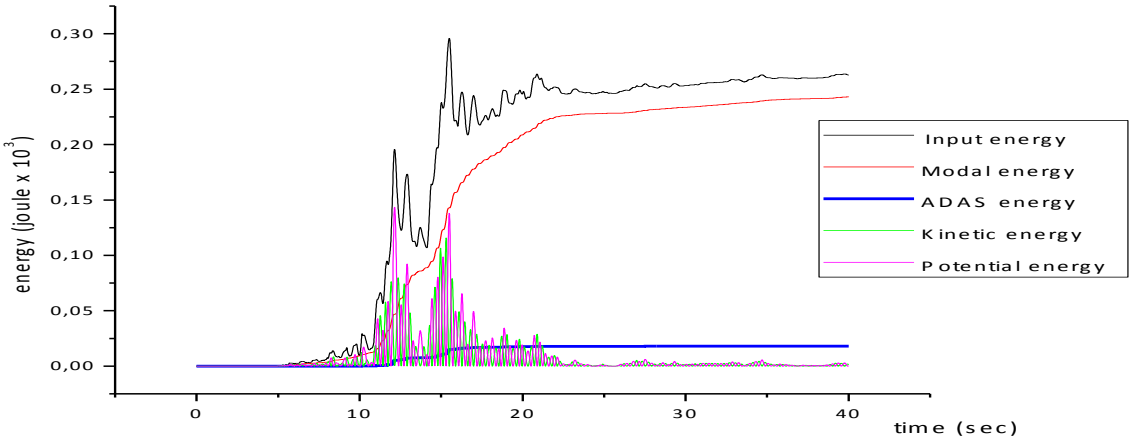
Generally, it is known that the input energy (E_I) disappears in a building in four manners, namely, the elastic deformation energy (E_S), the energy of the movement known as kinetic energy (E_K), the energy of modal damping of the structure (E_D) and the inelastic energy (E_H), also called the nonlinear behavior of energy or ductility. The equation of the energy balance is: [5]

$$E_I = E_S + E_K + E_D + E_H \tag{7}$$

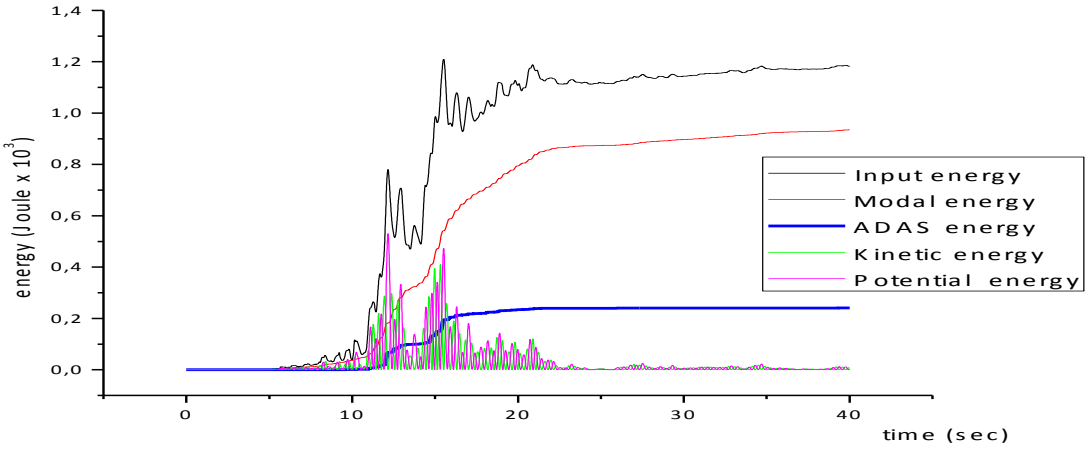
The cases where the devices used are of type ADAS ($E_H = E_{\text{ADAS}}$), the equation of the energy balance (7) becomes:

$$E_I = E_S + E_K + E_D + E_{ADAS} \tag{8}$$

(a)


0,30
0,25
0,20
0,15
0,10
0,05
0,00
energy (joule x 10^3)
0
10
20
30
40
time (sec)
Input energy
Modal energy
ADAS energy
Kinetic energy
Potential energy

(b)


1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
energy (Joule x 10^3)
0
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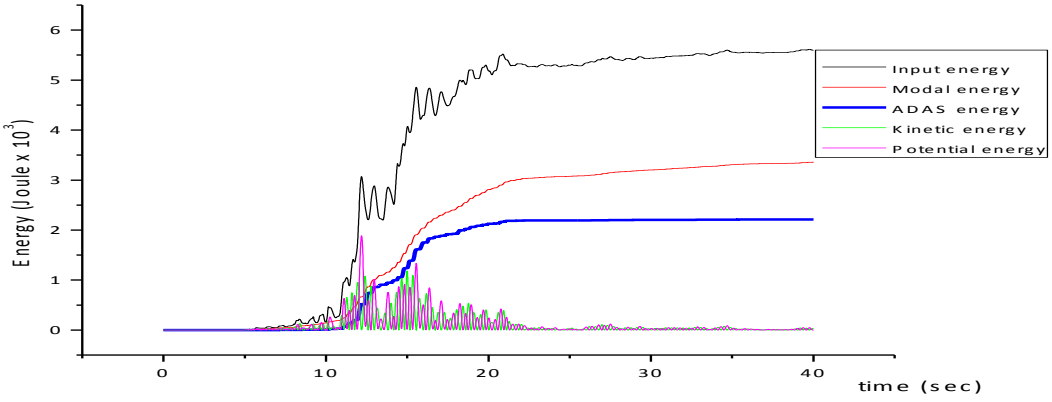
20
30
40
time (sec)
Input energy
Modal energy
ADAS energy
Kinetic energy
Potential energy

(c)


6
5
4
3
2
1
0
Energy (Joule x 10^3)
0
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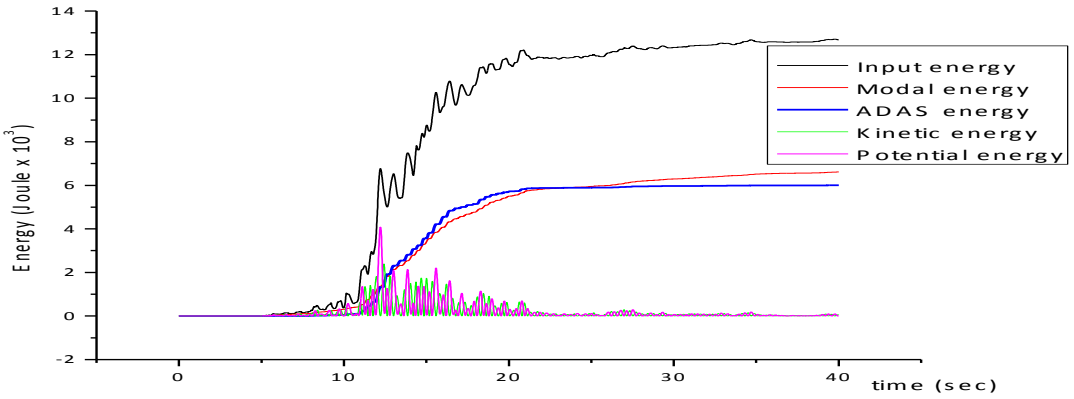
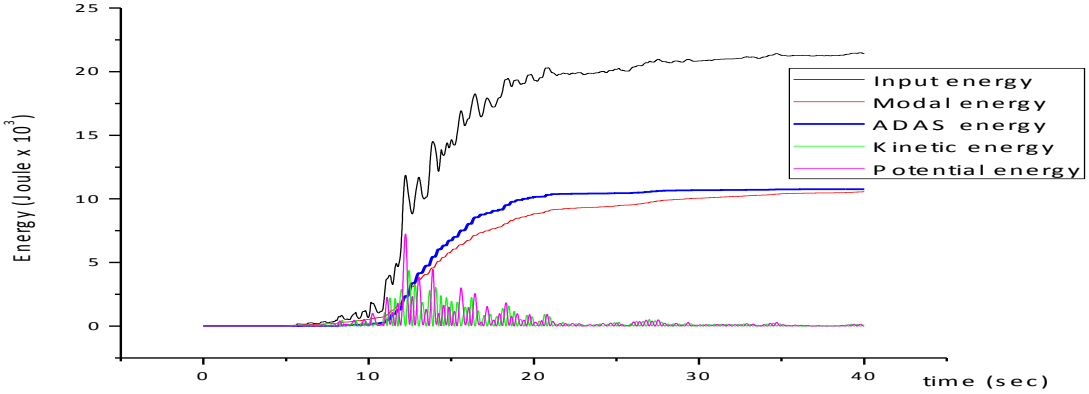
30
40
time (sec)
Input energy
Modal energy
ADAS energy
Kinetic energy
Potential energy

(d)



(e)



(f)

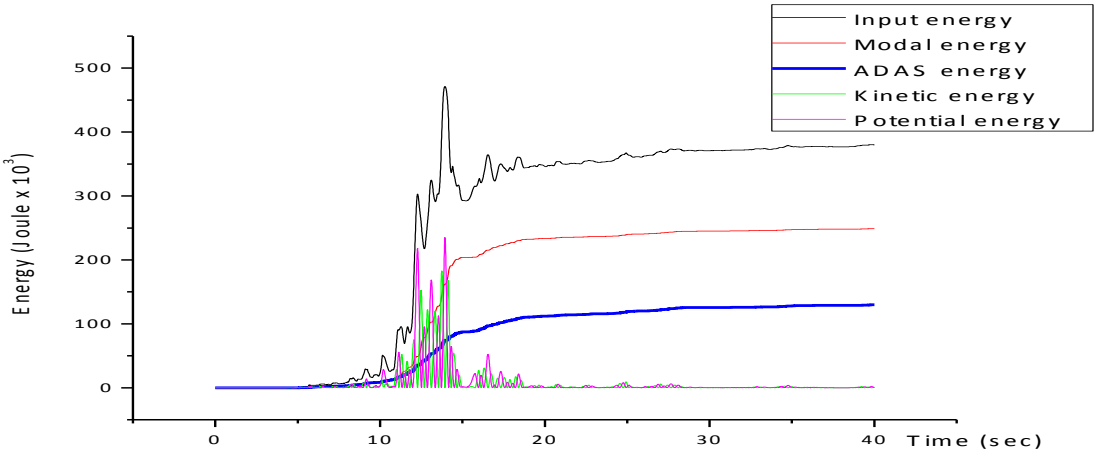


Figure 6. The dissipated energies under the seismic excitation of El Centro for the stiffness $K_{ADAS} = 25\% : a)0{,}025C_s _ b)0{,}05C_s _ c)0{,}100C_s _ d)0{,}150C_s _ e)0{,}200C_s _ f)C_s$

The results obtained are summarized in the following tables;

Table 2. Energies results for the various seismic coefficients under the seismic excitation of El Centro for the three combinations of stiffness.

	Seismic coefficient	Seismic Energy input Joule x10^3	Energy dissipated by				Total of dissipated energy (%)	Remaining Energy (%)
			modal damping		ADAS			
			Joule x10^3	(%)	Joule x10^3	(%)		
K_{ADAS}=25%	0.025Cs	0.04334	0.04282	99.07	0.0003633	0.84	99.91	0.09
	0.050Cs	0.1744	0.1686	96.67	0.005617	03.22	99.89	0.11
	0.100Cs	0.7182	0.6385	88.90	0.07903	11	99.90	0.10
	0.150Cs	01.678	01.344	80.1	0.3325	19.81	99.91	0.09
	0.200Cs	03.096	02.24	72.35	0.835	27.55	99.90	0.10
	Cs	90.32	44.25	49	46.01	50.94	99.94	0.06
K_{ADAS}=50%	0.025Cs	0.04431	0.04370	98.62	0.000267	0.60	99.22	0.78
	0.050Cs	0.1773	0.1718	96.90	0.004169	02.35	99.25	0.75
	0.100Cs	0.7100	0.6448	90.81	0.06063	08.54	99.35	0.65
	0.150Cs	01.602	01.328	82.89	0.2666	16.64	99.53	0.47
	0.200Cs	02.865	02.143	74.79	0.7133	24.89	99.68	0.32
	Cs	85.56	30.24	35.34	55.29	64.62	99.96	0.04
K_{ADAS}=75%	0.025Cs	0.02738	0.02593	94.70	0.0000832	0.30	95	05
	0.050Cs	0.1098	0.1031	93.90	0.001322	01.20	95.10	04.90
	0.100Cs	0.4441	0.4033	90.81	0.02061	04.64	95.45	04.55
	0.150Cs	01.017	0.8768	86.21	0.1003	09.86	96.07	03.93
	0.200Cs	01.855	01.493	80.48	0.3013	16.24	96.72	03.28
	Cs	77,71	24.36	31.34	53.32	68.61	99.95	0.05

Table 3. Energies results for the various seismic coefficients under the seismic excitation of Landers for the three combinations of stiffness.

	Seismic coefficient	Energy Seismic input Joule x10^3	Energy dissipated by				Total of dissipated energy (%)	Remaining energy (%)
			modal damping		ADAS			
			Joule x10^3	(%)	Joule x10^3	(%)		
K_{ADAS}=25%	0.025Cs	0.04334	0.04282	99.07	0.0003633	0.84	99.91	0.09
	0.050Cs	0.1744	0.1686	96.67	0.005617	03.22	99.89	0.11
	0.100Cs	0.7182	0.6385	88.90	0.07903	11	99.90	0.10
	0.150Cs	01.678	01.344	80.1	0.3325	19.81	99.91	0.09
	0.200Cs	03.096	02.24	72.35	0.835	27.55	99.90	0.10
	Cs	90.32	44.25	49	46.01	50.94	99.94	0.06
K_{ADAS}=50%	0.025Cs	0.04431	0.04370	98.62	0.0002673	0.60	99.22	0.78
	0.050Cs	0.1773	0.1718	96.90	0.004169	02.35	99.25	0.75
	0.100Cs	0.7100	0.6448	90.81	0.06063	08.54	99.35	0.65
	0.150Cs	01.602	01.328	82.89	0.2666	16.64	99.53	0.47
	0.200Cs	02.865	02.143	74.79	0.7133	24.89	99.68	0.32
	Cs	85.56	30.24	35.34	55.29	64.62	99.96	0.04

K_{ADAS}=75%	0.025Cs	0.02738	0.02593	94.70	0.0000832	0.30	95	05
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	0.100Cs	0.4441	0.4033	90.81	0.02061	04.64	95.45	04.55
	0.150Cs	01.017	0.8768	86.21	0.1003	09.86	96.07	03.93
	0.200Cs	01.855	01.493	80.48	0.3013	16.24	96.72	03.28
	Cs	77.71	24.36	31.34	53.32	68.61	99.95	0.05

A comparative study of the three percentages of side rigidity of the dampers ADAS (25%, 50% then 75%) enabled us to deduce that:

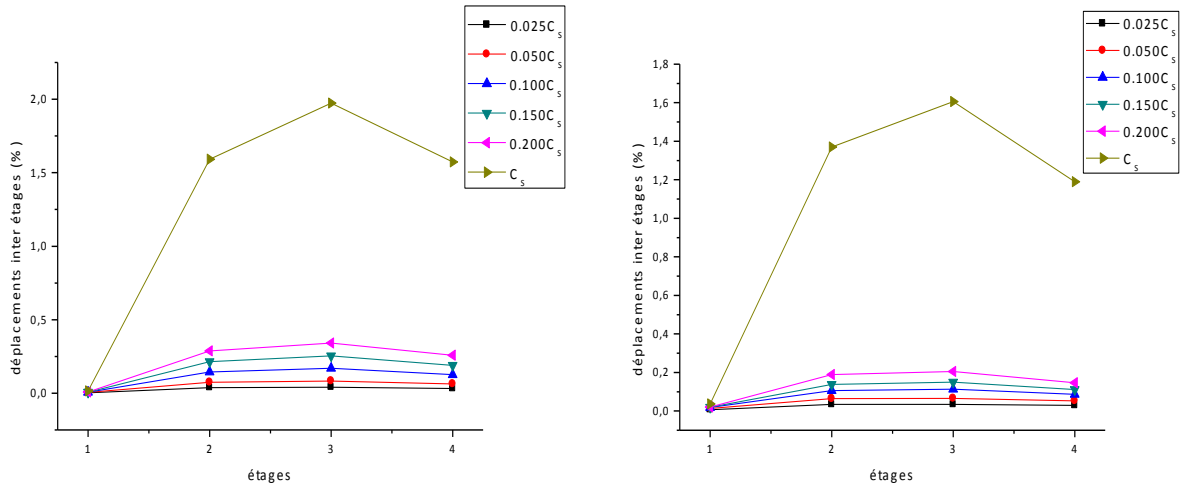
- The energy dissipated by the ADAS becomes increasingly high and the modal damping energy decreases.
- The mechanical energy (energies potential and kinetic) increases.
- The input seismic energy remains almost invariable.

A comparative study of the various seismic coefficients enabled us to deduce that in agreement with the increase from the seismic coefficient, we note:

- An increase in the input seismic energy, in the energy of modal damping and in the energy dissipated by the system of energy dissipation.
- A reduction of the difference between the energy of the modal damping and the one dissipated by the dampers.

6.2. Inter-Story Drift

The results represented in figure 7 shows that inter-story displacements are generally increasing with the increase of seismic coefficient.



(a) (b)

Figure 7. Displacements inter floors under the seismic excitation of El Centro

$(a): K_{ADAS} = 25\%$ $(b): K_{ADAS} = 75\%$

The inter-story displacement for the high seismic coefficients exceeds that the unit value. These values can be explained by the effect of the proximity to the epicenter on the plates which make up the ADAS devices and which have a low vertical stiffness. These factors lead to large displacements of the structure.

7. CONCLUSION

We can conclude that the energy dissipation devices (ADAS) are effective for this building type. They are more effective when they are more rigid and when the structures are subjected to average or high seismic excitations. The ADAS devices are effective for the structures built in areas of low or moderate seismic coefficients (far field). By cons, in areas that have significant seismic coefficients (near field), where the vertical acceleration is large, these systems become a choice to avoid.

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