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ANALYTIC STUDY OF FLOOR ISOLATION SYSTEM

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SUMMARY

This research shows effectiveness of using floor isolation system in order to reduce the response of structures in severe ground motions. It is known that the main part of mass is concentrated in the floor, so a suitable approach is to use appropriated isolation between the floor slab and structure. The study includes a comparison of building's response under the accelerograms from the El-Centro NS, Taft EW and San Fernando N16 earthquakes when it is considered with and without the isolation system, and is carried out for buildings. It is found that the proposed isolation system is effective, is construct able, and has the potential to become a suitable way to reduce structural earthquake damage in above buildings, although the isolation system is also suitable for absorbing earthquake energy.
KEY WORDS: passive control; mass isolation; floor isolation system

INTRODUCTION

It is very important, controlling the response of civil engineering structures to environmental loads such as strong earthquakes and high winds. Several efforts have been made to control the structures, by using passive as well as active control devices [1]. Among the available devices, the passive devices are one of the simplest and most reliable control devices. Its mechanism of mitigating the structural vibration is to transfer the vibration energy of the structures to devices, and the energy dissipates through them. Unlike seismic base isolation, however, passive devices can be effective against wind-induced motion as well as those due to earthquakes. Contrary to semi active and active systems, there is no need for an external supply of power [2].

Passive systems do not focus on the mass of structures (buildings), unlike usual passive systems, the system introduced in this paper focuses on the mass of structures as the main source of vibration. The

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source of earthquake force in the classical dynamic system subjected to earthquake ground motion is not ground acceleration alone and the mass id also the primary reason in generating excitation in the structure [3]. In fact, mass attracts the earthquake input energy in structure. So, controlling the vibration of the structure requires to isolation the mass, ideally isolation from the structure and not necessarily from the ground [4,5,6].

Introducing interruption in the stiffness of building (using a flexible layer) seems to be only practical means for vibration isolation in most cases because mass and lateral stiffness of structure are usually integrated. Isolation of mass without causing discontinuity in the lateral stiffness would be possible if mass and stiffness are not rigidly integrated. This concept suggests that isolation layer to be placed between the mass and lateral stiffness of a structural system.

Floor isolation system (FIS) is a kind of practical mass isolation system, as the main part of mass is concentrated in the floor; a suitable approach is to use an appropriated isolation between the floor slab and structure. In this paper, analytical and experimental study is carried out to show the effectiveness of floor isolation system.

FLOOR ISOLATION SYSTEM

A typical building with proposed floor isolation system (FIS) shown in figure 1. Modal periods of this building are different from the building without FIS (building with solid floor).

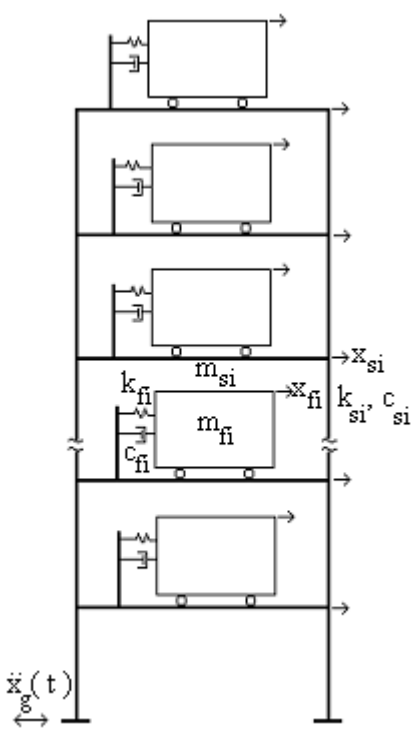


Figure1. Analytical model of multi story building with floor isolation system

The dynamics equilibrium equation of the system can be expressed in the matrix form as

$$[m]\{\ddot{x}\}+[c]\{\dot{x}\}+[k]\{x\}=[m]\{r\}\ddot{x}_g \tag{1}$$

Where [m], [c] and [k] are $2N \times 2N$ mass, damping and stiffness matrices of the system. Respectively, $\{\ddot{x}\}$, $\{\dot{x}\}$ and $\{x\}$ are $2N \times 1$ vector of nodal accelerations, velocities and displacements. Respectively, $\{r\}$ and $\ddot{x}_g$ are $2N \times 1$ vector of earthquake influence coefficients and ground acceleration. The system can be non-proportionally damped systems. The dynamic response of non-proportionally damped system can be obtained using the complex mode-superposition method [7]. In the complex mode-superposition method, equation (1) is transformed by using following state vector.

$$\{u\} = \begin{Bmatrix} \dot{x} \\ \ddot{x} \end{Bmatrix} \tag{2}$$

Using the vector equation (1) become to the following differential equation.

$$[A]\{\dot{u}\} + [B]\{u\} = -[D]\begin{Bmatrix} 0 \\ \{r\} \end{Bmatrix}\ddot{x}_g \tag{3}$$

Where, [A] and [B] can be obtained from the following equation.

$$[A] = \begin{bmatrix} [0] & [m] \\ [m] & [c] \end{bmatrix} \qquad [B] = \begin{bmatrix} -[m] & [0] \\ [0] & [k] \end{bmatrix} \qquad [D] = \begin{bmatrix} [0] & [0] \\ [0] & [m] \end{bmatrix} \tag{4}$$

For the solution of homogeneous part of equation (3), $\{u\}$ may be expressed in the following form:

$$\{u\} = \{\phi'\}e^{\lambda t} \tag{5}$$

To derive a response, equation (5) is substituted into equation (3), leading to

$$(\lambda[A]\{\phi'\} + [B]\{\phi'\})e^{\lambda t} = 0 \tag{6}$$

From equation (6) leading to the eigenvalue problem.

$$Det(\lambda[A] + [B]) = 0 \tag{7}$$

The solution of equation (7) is in complex conjugate Paris with following complex eigenvalues.

$$\lambda_j = -\beta_j + i\theta_j = -\xi_j\omega_j + i\omega_j\sqrt{1-\xi_j^2} \tag{8}$$

Where λ_j is the jth eigenvalue, ω_j and ξ_j are the jth natural frequency and damping ratio of the system in the jth mode, and i is the unit imaginary number ($i = \sqrt{-1}$). ω_j and ξ_j can be obtained in the following form.

$$\omega_j = \left|\lambda_j\right| = \sqrt{\beta_j^2 + \theta_j^2} \qquad \xi_j = \frac{\beta_j}{\left|\lambda_j\right|} = \frac{\beta_j}{\sqrt{\beta_j^2 + \theta_j^2}} \tag{9}$$

The rate of changes of period a building with floor isolation system is compared to a building without floor isolation system. A one-story building with and without floor isolation system is considered and parametric study is carried out. Where M is the total mass given by $M = m_f + m_s$ and m_s is the structural mass, and m_f is the floor mass. c_s and k_s are the structural damping and stiffness. c_f and k_f are the damping and stiffness of floor isolator.

The building with floor isolation system can be a Non-proportionally damped system. The eigenvalue equation of this building can be derived by the complex mode superposition method.

$$\lambda^4 + \left[\left(-2\sqrt{\frac{\beta}{\mu}}.\xi_f - 2\frac{\sqrt{\mu\beta}}{1-\mu}.\xi_f - 2\sqrt{\frac{1}{1-\mu}}.\xi_s\right)\omega_b\right]\lambda^3 + \left[\left(\frac{\mu+\beta}{\mu(1-\mu)} + 4\sqrt{\frac{\beta}{\mu(1-\mu)}}\xi_s\xi_f\right)\omega_b^2\right]\lambda^2$$
$$+\left[\left(-2\sqrt{\frac{1}{1-\mu}}\frac{\beta}{\mu}\xi_s - 2\sqrt{\frac{\beta}{\mu}}\frac{1}{1-\mu}\xi_f\right)\omega_b^3\right]\lambda + \frac{\beta}{\mu(1-\mu)}\omega_b^4 = 0 \tag{10}$$

Where λ is the eigenvalue, and ξ_s is the structural damping ratio, and ξ_f is the damping ratio of the floor isolator. μ, β and ω_f are the mass ratio, stiffness ratio and natural frequency of the building without FIS (building with solid floor) defined in following manner.

$$\mu = \frac{m_f}{M} \qquad \beta = \frac{k_f}{k_s} \qquad \omega_b^2 = \frac{M}{k_s} \tag{11}$$

The equation (10) is solved, and modal periods of building with FIS are derived with respect to period of building without FIS.

$$T_1 = C_1 T_b \qquad T_2 = C_2 T_b$$
(12)

Where T_1 and T_2 are periods of building with FIS, and T_b is the period of building without FIS. The values C_1 and C_2 for the $\xi_s = 0.02$ and $\xi_f = 0.2$ shown in table 1.

Table 1. The values C_1 and C_2 for the different μ and β

β	μ=0.5				μ=0.9			
	C_1	ζ_1	C_2	ζ_2	C_1	ζ_1	C_2	ζ_2
1	1.1376	0.0422	0.4395	0.2448	1.3480	0.0675	0.2226	0.4721
0.5	1.2904	0.0809	0.5480	0.2003	1.6338	0.1067	0.2597	0.3866
0.25	1.5966	0.1295	0.6263	0.1441	2.1037	0.1428	0.2852	0.2993
0.125	2.1173	0.1638	0.6679	0.1008	2.8276	0.1682	0.3001	0.2248
0.0625	2.9071	0.1820	0.6880	0.0737	3.8958	0.1832	0.3080	0.1673
0.0312	4.0541	0.1911	0.6977	0.0566	5.4376	0.1914	0.3121	0.1251
0.0156	5.6991	0.1956	0.7024	0.0454	7.6455	0.1956	0.3142	0.0946
0.0078	8.0329	0.1978	0.7048	0.0378	10.777	0.1978	0.3152	0.0728

For each mass ratio μ and stiffness ratio β, the values of T_1 and T_2 are varied. Table I indicates that the building with FIS in compare to the building without FIS, includes two sets periods, these two sets of periods are far from the higher region of acceleration, which is shown schematically in figure 2.

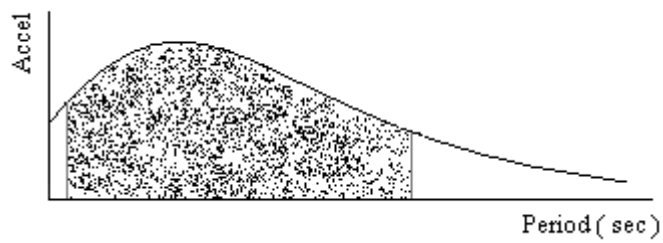


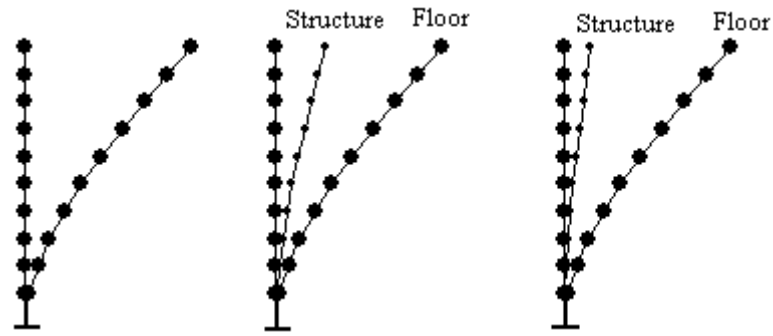
Figure 2. Schematic sketch of absolute acceleration spectrum

NUMERICAL STUDY

To investigate the effectiveness the building whit FIS, 5, 10 and 15 story buildings with and without FIS under records of the El-Centro NS, Taft EW and San Fernando N16 earthquakes are considered and analyzed by DRAIN-2DX program [8]. Above-mentioned buildings are designed based on Iranian code of practice for seismic design of buildings (standard No.2800) [9]. The dynamic analysis is carried by using the structural damping ratio ζ_s = 0.015, and the damping ratio of the floor isolator $\xi_f = 0.8$ for each story. The stiffness of floor isolator given by $k_f = m_f T_f$, and $T_f = 2$ and 3.0 sec. The result is shown only for 10-story building and normalized PGA=(0.35g and 1.0g) because of similarity of other earthquake result.

Periods and first mode shape

The periods of buildings with and without FIS are shown in table 2. It is observed from the table 2 that building with using floor isolation system include two sets periods which, first set includes the period higher than FIS periods (flexible part of the building), and second set includes very low periods (stiff part of the building). This subject is shown in figure 3.Therefore, by using floor isolation system far from the higher region of acceleration, and also the building include soft part and stiff part (idea of mass isolation) that low mass placed in stiff part.



(a) (b) (c)

Figure 3. The first mode shapes of buildings; (a) without FIS, (b) With FIS with $T_f = 2.0$ sec, (c) with FIS with $T_f = 3.0$ sec

Table 2. The periods of buildings with and without FIS

Mode	Period (sec)		
	Building without FIS	Building with FIS $T_f = 2.0$ Sec	Building with FIS $T_f = 3.0$ Sec
1	1.331	2.3895	3.2707
2	0.363	2.0311	3.0208
3	0.182	2.0079	3.0053
4	0.123	2.0036	3.0024
5	0.092	2.0020	3.0014
6	0.077	2.0014	3.0010
7	0.067	2.0011	3.0007
8	0.062	2.0009	3.0006
9	0.055	2.0007	3.0005
10	0.048	2.0006	3.0004
11	-	0.2491	0.2730
12	-	0.0799	0.0806
13	-	0.0406	0.0407
14	-	0.0275	0.0275
15	-	0.0206	0.0206
16	-	0.0172	0.0172
17	-	0.0149	0.0149
18	-	0.0138	0.0138
19	-	0.0124	0.0124
20	-	0.0107	0.0107

Maximum of structural response

Maximum displacement and drift of structure for 10-story building under records of the El-Centro NS, Taft EW and San Fernando N16 earthquakes with normalized PGA=0.35, 1.0g shown in figures 4 and 5. The following observation can be made from figures 4and 5.

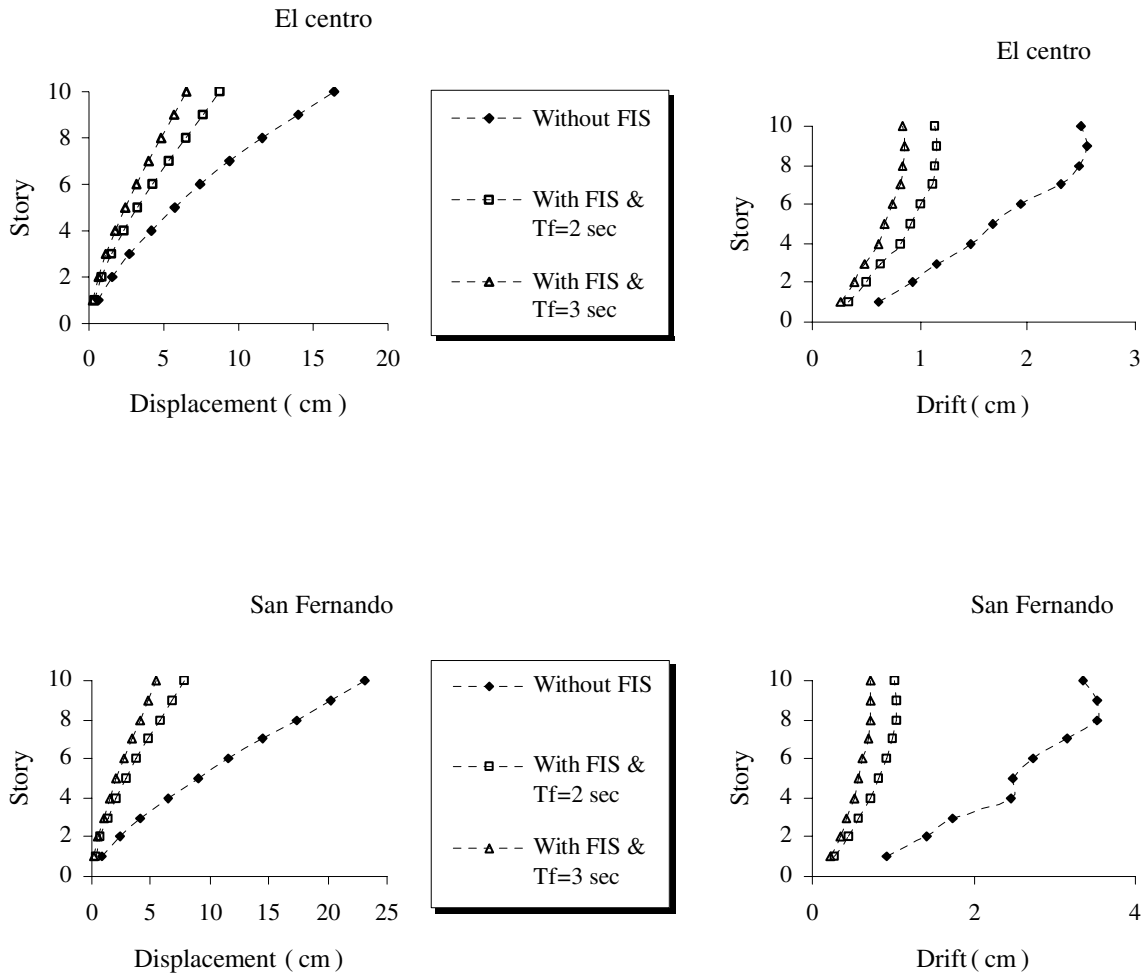
1- Reduction in maximum displacements and drifts of structures can be achieved whit FIS, especially for building with soft isolator.
2- By considering FIS in building the uniform story drift is observed which cause not to concentrate on specific story (damage not to concentrate on specific story).

Maximum drift of floor to structure

Maximum drift of floor to structure for 10-story building with normalized PGA= 0.35 shown in table 3. It was found that decreasing the stiffness of floor isolator increases the maximum drift of floor to structure. In the design of building by using FIS, drift of floor to structure must be limited, so to design the optimum isolator of floor.

Time history of energy

Time history of various energy for 10-story building under San Fernando N16 earthquake with normalized PGA=1.0g is shown in figure 6. Figure indicates that the floors isolator consume a significant portion of the total energy (input energy) thus the structure is protected.



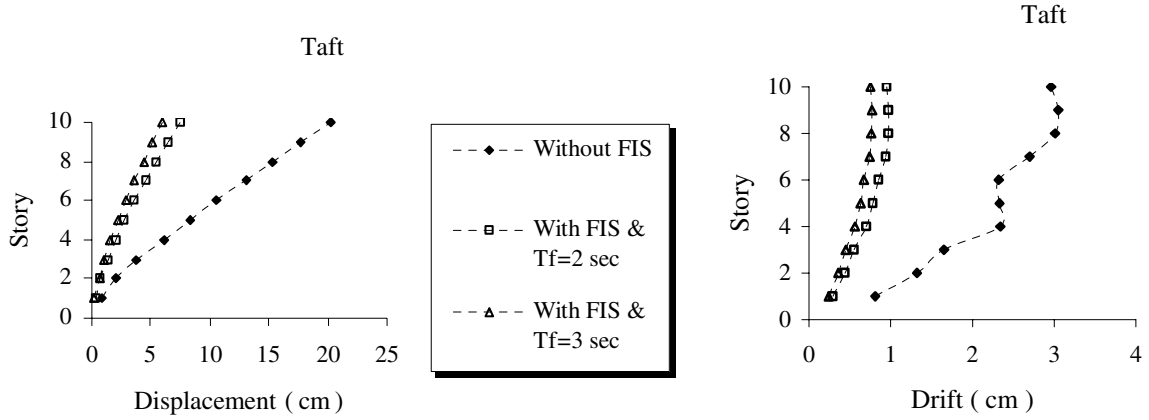
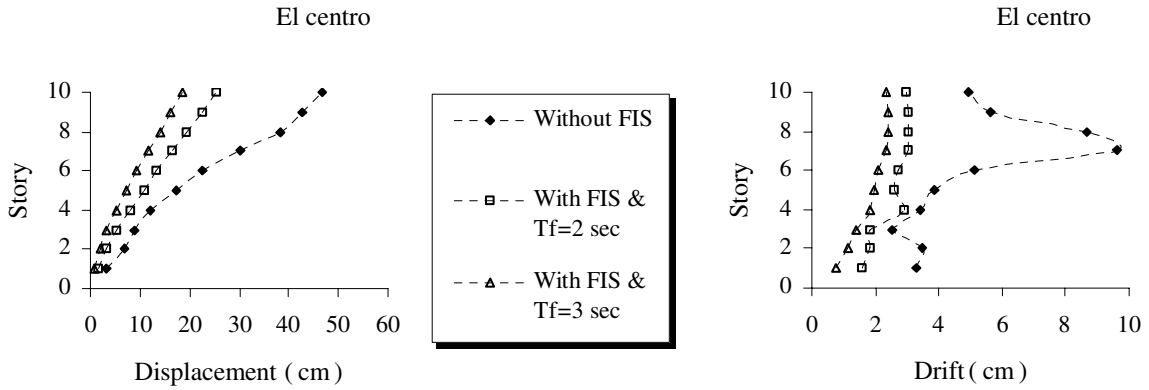
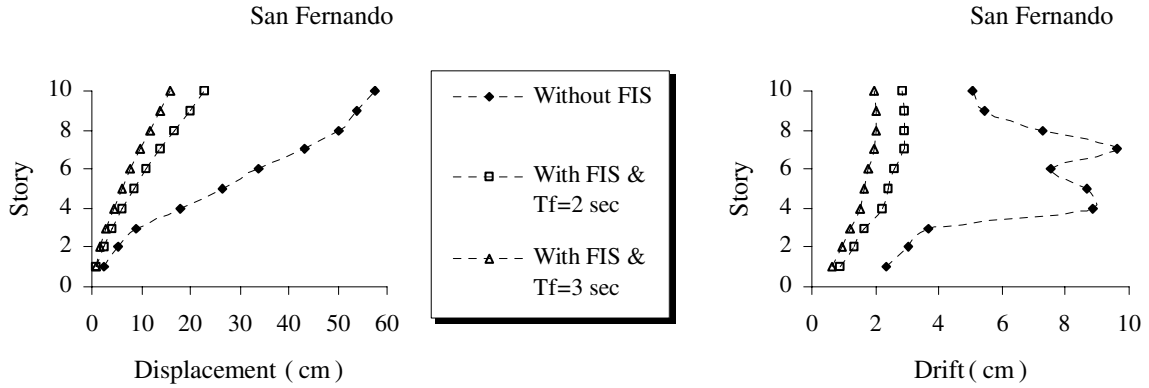


Figure 4. Maximum displacement and drift of structure for 10-story building
With Normalized PGA =0.35g





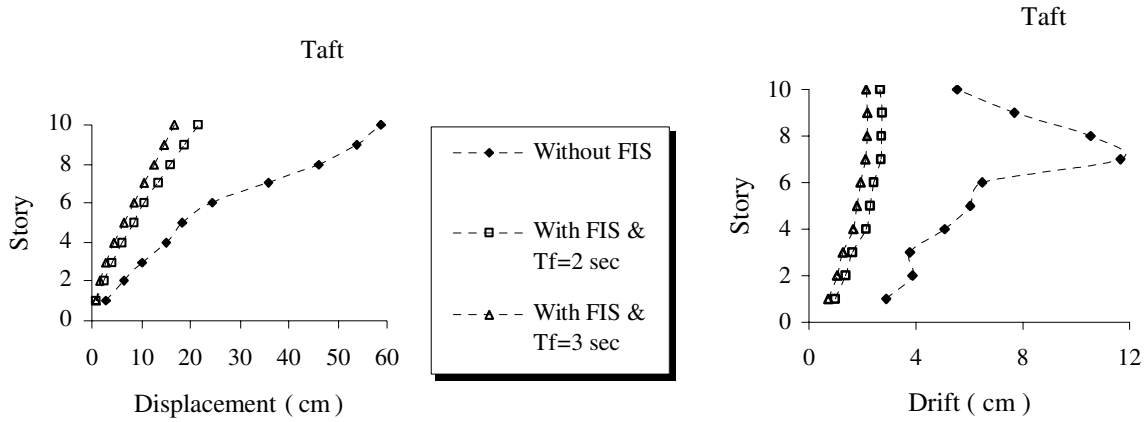
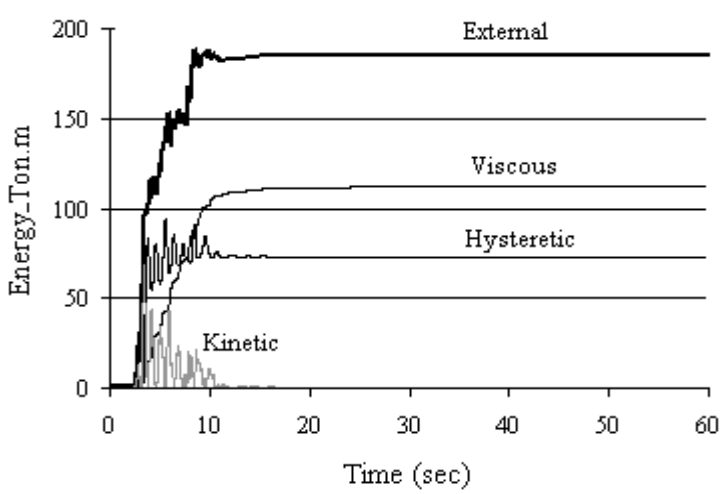


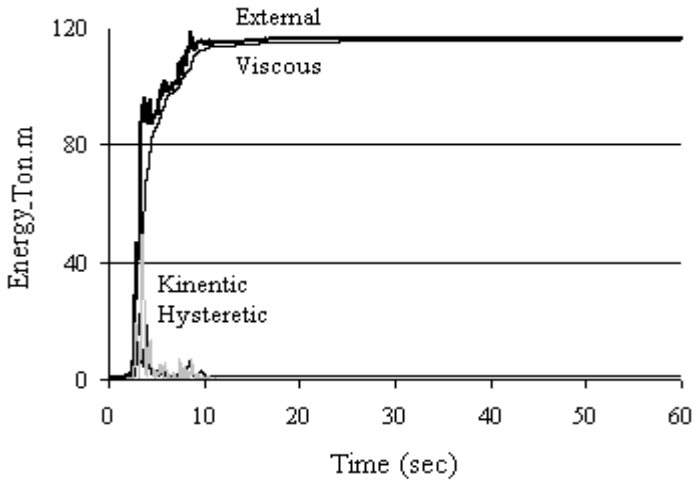
Figure 5. Maximum displacement and drift of structure for 10-story building
With Normalized PGA =1.0g

Table 3. The maximum drift of floor to structure for 10-story building
With Normalized PGA =0.35g

Story	Maximum drift of floor to structure with $T_f = 2.0$ sec (cm)			Maximum drift of floor to structure with $T_f = 3.0$ sec (cm)		
	El Centro	San Fernando	Taft	El Centro	San Fernando	Taft
1	4.96	4.84	5.3	5.72	6.70	7.3
2	5.04	4.85	5.3	5.78	6.71	7.3
3	5.16	4.85	5.3	5.85	6.73	7.3
4	5.34	4.87	5.4	5.97	6.79	7.3
5	5.59	4.93	5.4	6.13	6.89	7.4
6	5.92	5.06	5.6	6.34	7.04	7.5
7	6.36	5.31	5.8	6.67	7.27	7.7
8	6.89	5.66	6.2	7.07	7.56	8.0
9	7.51	6.10	6.7	7.54	7.90	8.4
10	8.20	6.60	6.4	8.04	8.31	8.9



(a) Without FIS



(b) FIS With $T_f = 2.0$ sec

Figure 6. Time history of energy under San Fernando N16 earthquake with normalized PGA=1.0g

CONCLUSION

This study resulted as the following:

1- Floor isolation system causes the building to be dividing into two parts, a soft and stiff part. The major mass of building is concentrated in the soft part in low acceleration and the minor mass of building is concentrated in the stiff part. Comparing to a building without floor isolation system the response of structure is decreased.

2- By considering FIS in building the uniform story drift is observed which cause not to concentrate on specific story (damage not to concentrate on specific story).

3- Using floor isolation system in building is also suitable for absorbing earthquake energy.

REFERENCES

1. Sarbjeet S., Datta T.K. "Sliding mode control of building frames under random ground motion." Journal of Earthquake Engineering 2003; 7: 73-95.
2. Soong T.T, Dargush G.F. " Passive Energy Dissipation System in Structural Engineering." John Wiley & Sons, New York, 1997
3. Clough R.W, Penzien J. " Dynamics of Structures." McGraw Hill, New York, 1993
4. Ziyaeifar M., Noguchi H. "Partial Mass Isolation in Tall building." Earthquake Engineering and Structural Dynamics, 1998; 27, 49-65.
5. Ziyaeifar M. "Method of Mass Isolation in Seismic Design of Structure." Proceeding of the 12th World Conference on Earthquake Engineering. Paper no 1411. New Zealand: 2000.
6. Ziyaeifar M. "Mass Isolation, concept and Techniques." Journal of European Association for Earthquake Engineering 2002; 2: 43-55, 2002
7. Chen H. C., Taylor R. L. "Solution of viscously damped linear systems using a set of load-dependent vectors." Report No. UCB/SEMM 88/16, University of California, Berkeley, ca, 1988.

8. Prakash V., Powell G.H., Campbell S. “DRAIN-2DX: Base program Description and user guide, V1.10. In structural engineering, mechanics and materials, Department of civil engineering, University of California: Berkeley: Report no. UCB/SEMM 93/17, 1993.
9. Iranian Code of Practice for Seismic Resistant Design of Building (Standard 2800), Second Edition, Building and Housing Research Center, BHRC-PN S 253.