BUILDING WITH LOCAL ISOLATION SYSTEM: THEORETICALLY AND PRACTICALITY

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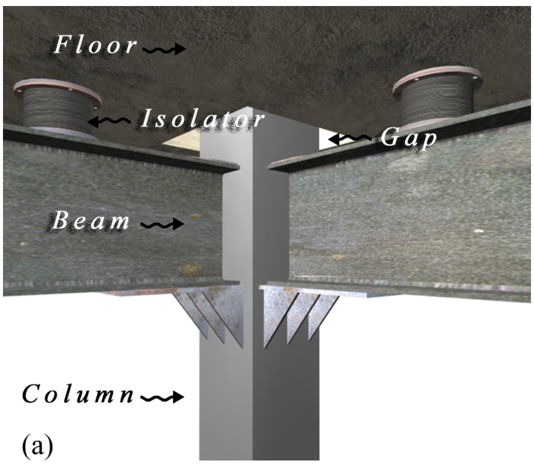
ABSTRACT :

Mass isolation is a method of structural vibration control against environmental loads such as strong earthquakes. Buildings with local isolation systems are a practical method of mass isolation. The major challenge for putting these buildings into practice is special isolators that are economical justification and have good performance. In this paper, the concept and efficiency of these buildings at seismic response reduction is examined and then structural details of these buildings are investigated; then a new isolator is proposed for these buildings.

KEYWORDS: structural control, local isolation, mass isolation, floor isolation

1. Introduction

Three methods for isolation are "base isolation", "mass isolation", and "partial mass isolation" [Ziyaeifar, et al. 1998, 2000, and 2002]. In base isolation method, the structural seismic response is reduced by using a flexible layer under the structure (between structure and ground) [see, for example, Skinner et al. 1993, and Naeim et al. 1999]. In the base isolation method actually, structure stiffness is isolated from ground that may cause some problems such as instability in large displacement, rocking motion of structure, periodic shift of structure and effectiveness wind motion and not using them in tall buildings. The structural mass as the main source of vibration absorbs earthquake input energy in the structure. So, controlling the vibration of the structure requires isolation of mass, from the structure and not necessarily from the ground. Mass isolation can be a suitable approach for this target. Such buildings with floor isolation systems (FIS) are a practical method of mass isolation. This causes the building with FIS to be divided into a soft part and a stiff part. The major mass of the building is concentrated in the soft part during low acceleration and the minor mass is concentrated in the stiff part [Pourmohammad, et al. 2004, 2006]. Hence equipping buildings with floor isolation can be an effective method of reducing structural seismic response. The construction of a building with FIS requires the main structure (columns and beams) be constructed first. Isolators are then placed on the beams and finally the floor slab is constructed on the isolators (figure1). If a part of mass has been isolated, this is called "partial mass isolation".



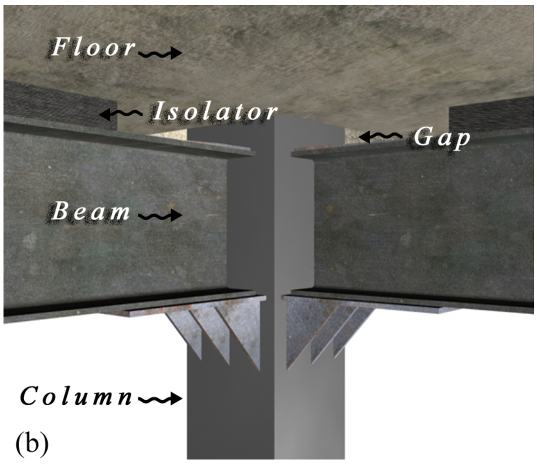
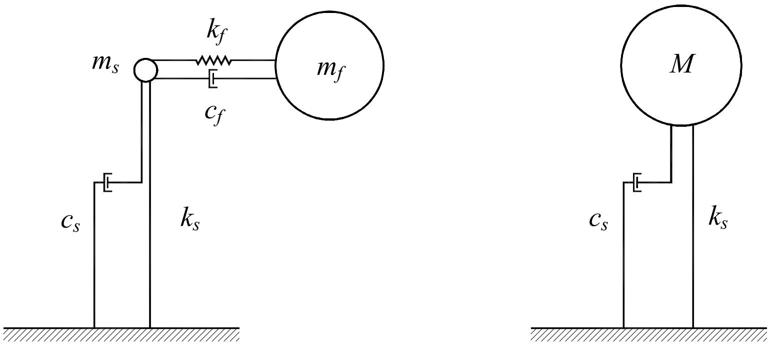


Figure 1 A proposed general model of FIS

Floor isolation systems (FIS) have been applied to many types of construction, such as Power Plants, Industrial Structures and Vibration-sensitive Rooms [see, for example, Fuller, et al 2002, Yaghoubian, et al. 1991, and Sabbagh, et al. 2004]. The target of this isolation is to control the response of the floor and/or the equipment on it. The FIS (local isolation system) presented in this paper controls the response of the main structure of a building as well as reducing floor acceleration.
Buildings with FIS such as multiple tuned mass dampers and secondary systems are known as non-classically damped systems. The available methods to dynamics analysis are complex and require time-consuming analyses. Furthermore, design and control methods work best for a building with a small number of degrees of freedom. To overcome this difficulty, a simplified method is proposed for the omitted, unnecessary degrees of freedom [Pourmohammad, 2006].The proposed method uses a much smaller number of degrees of freedom, the advantages of the standard mode-superposition method, and a simple model of mass damping and stiffness matrices.
There are many challenges for putting such buildings into practice as a controlling system. For example, many appropriate isolators are needed. These isolators must have economical justification and have to be satisfactory performance. Isolators designed for floor of multiple stories buildings should be light weight and have low lateral stiffness to resist earthquake input. Manufacture procedure of currently available elastomeric isolators are difficult and consequently, expensive. In this paper, after examining structural details of such buildings, an elastomeric isolator is presented, and a prototype constructed and tested, to put these buildings into practice.

2. BASIC PRINCIPLES OF FLOOR ISOLATION

Compare the periodic shift of a one-story shear building with FIS to one without isolation and their effectiveness in reducing the earthquake response. One-story shear buildings with and without FIS are shown in Figure 2. M is the total mass given by $M = m_f + m_s$; m_f is the floor mass; m_s is the structural mass; c_s and k_s are the structural damping and stiffness; c_f and k_f are the damping and stiffness of the floor system. μ is the mass ratio; β is the stiffness ratio; ξ_s is the structural damping ratio and ξ_f is the damping ratio of the floor system.



$$\mu = \frac{m_f}{m_t}$$

$$\beta = \frac{k_f}{k_s}$$

$$\xi_s = \frac{c_s}{2m_s\omega_s}$$

$$\xi_f = \frac{c_f}{2m_f\omega_f}$$

(a) (b)

Figure 2 Analytical models of one-story shear building (a) with FIS (b) without FIS

By considering the building with FIS to be a non-proportionally damped system, its complex eigenfunction can be written as:

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

where λ is the eigenvalue of the building with FIS and ω_b is the natural frequency of the building without

FIS. Eq. 1 is solved and the modal periods of the building with FIS (T_1, T_2) are derived for the periods of the building without FIS (T_b).

$$T_1 = C_1 T_b \qquad\qquad T_2 = C_2 T_b \tag{2}$$

Values for C_1, C_2, $\xi_s = 0.02$, and $\xi_f = 0.2$ are shown in Table 1. ξ_1 and ξ_2 are modal damping ratios for the building with FIS. For each μ and β, the values T_1 and T_2 are varied.

Table 1 indicates that the building with FIS in comparison with the building without FIS includes two sets of periods. These two sets are far from the region of higher acceleration, as shown schematically in Figure 3. Table 1 also shows that the first mode damping ratio is close to the damping ratio of the floor system. This causes the building with FIS to be divided into a soft part and a stiff part. The major mass of the building is concentrated in the soft part during low acceleration with the minor mass concentrated in the stiff part. Hence, equipping buildings with floor isolation can be an effective method of reducing structural seismic response.

Table 1 Values of C_1 and C_2 for different μ and β

β	$\mu = 0.90$				$\mu = 0.95$			
	C_1	ξ_1	C_2	ξ_2	C_1	ξ_1	C_2	ξ_2
0.001	30.126	0.1997	0.316	0.0390	30.835	0.1997	0.224	0.0476
0.002	21.231	0.1994	0.316	0.0468	21.813	0.1994	0.223	0.0589
0.003	17.343	0.1992	0.316	0.0528	17.818	0.1992	0.223	0.0677
0.004	15.025	0.1989	0.316	0.0579	15.431	0.1989	0.223	0.0750
0.005	13.445	0.1986	0.316	0.0623	13.813	0.1986	0.223	0.0815

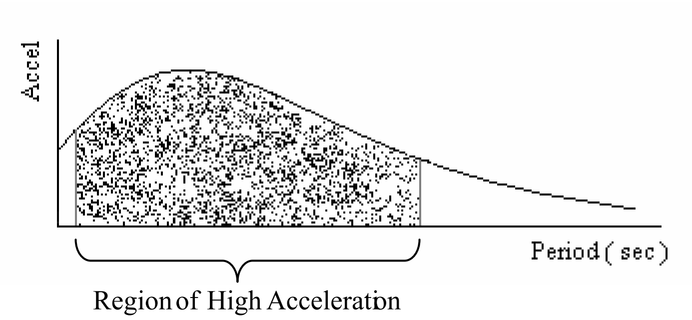


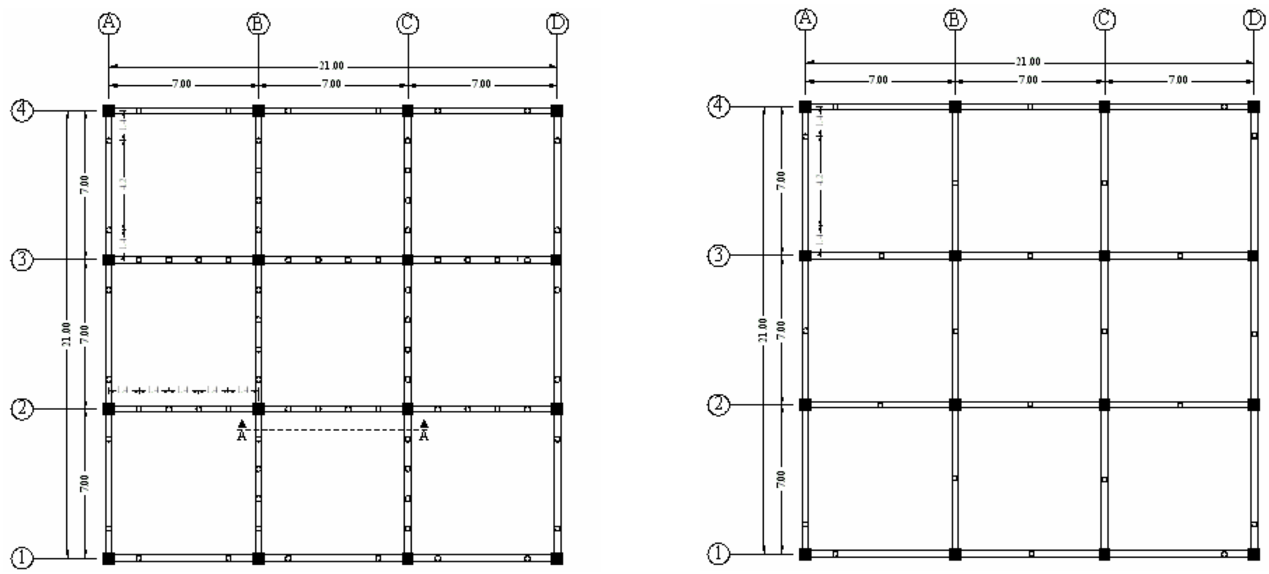
Figure 3. Schematic sketch of absolute acceleration spectrum

3. Challenges to Practical Applications

In this research, for evaluating practicality of buildings with floor isolated system, a regular 10-story is considered. In floor design of these buildings a two way flat slab system is used. One of most important factors for designing the flat slab is punching shear control this criteria depend on the number of isolators. For example two different cases of the locations of isolators on beams for each story are shown in figures 4. In case 2, comparing to case 1, lesser isolators are used. This is a more cost-effective and economical. In both cases, shear punching is checked using ACI code. There no necessities for using shear stiffeners in the slab. If lesser isolators shown in case 1 are used, a measure was taken for punching shear control.

More details for this building with larger scale are shown in figure 5. The horizontal distance between floors and main structure (columns) is one of main factors for designing these buildings systems. In economical design, performance of these buildings is assumed in two phases, first phase, is before pounding floors to columns and second phase is after pounding floors and slabs [Pourmohammad, 2006]. In second phase, impulsive effects of floors to columns are absorbed by stopper.

Structural details of floors are investigated, a two-way slab system can satisfy all the design factors and there is no need to design a new floor system. For practicality these buildings require so many isolators that are suitable performance and have economical justification. The available seismic rubber isolators have the lengthy processes of manufacturing result in a high price. In this paper a new rubber isolator is introduced that may solve this problem. Floors isolators are designed for light weight and low lateral stiffness against earthquake input, high vertical stiffness for the isolators must not be necessary. Because rocking is not a problem, like base isolation, and as demand displacement is lower than base isolation, the height of isolators can be much lower. Furthermore, large displacement and stability of these systems is not a concern because limited systems (columns) exist. If vertical isolation is needed, a 3-dimensional isolator can be applied.



(a) case 1 (b) case 2
Figure 4. Isolators locations on beams for each story

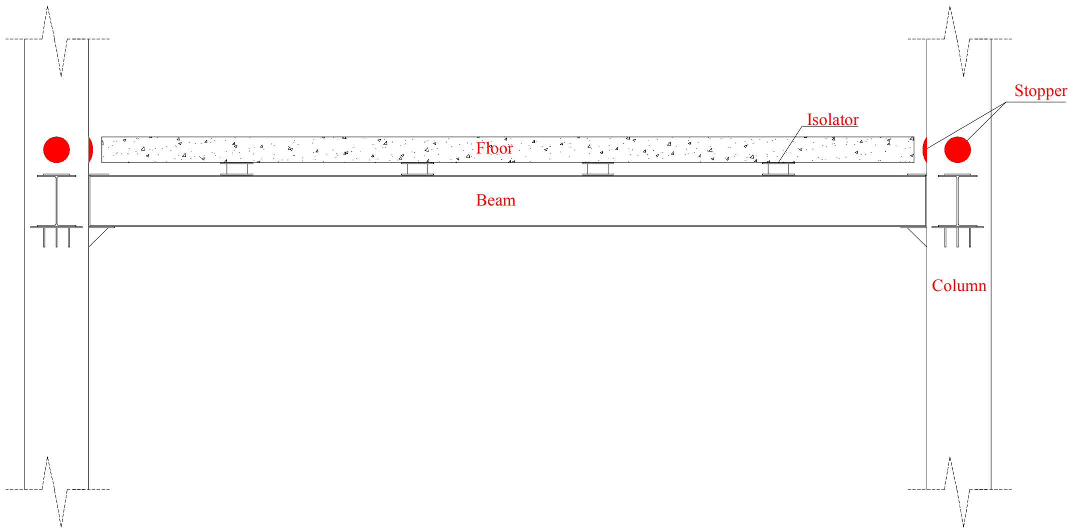
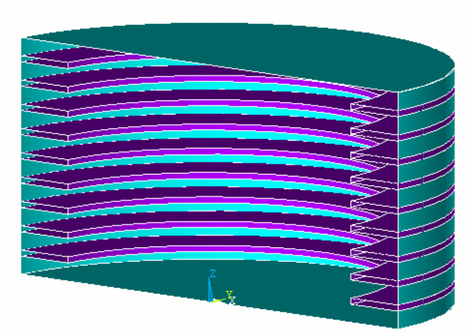


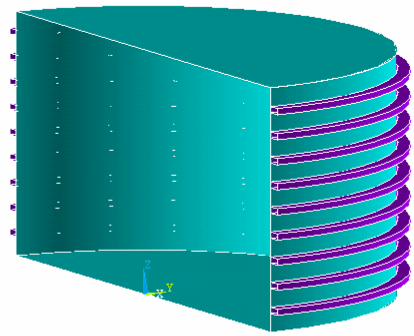
Figure 5. Cut view-(A-A)

4. Elastomeric Isolators with Steel Rings

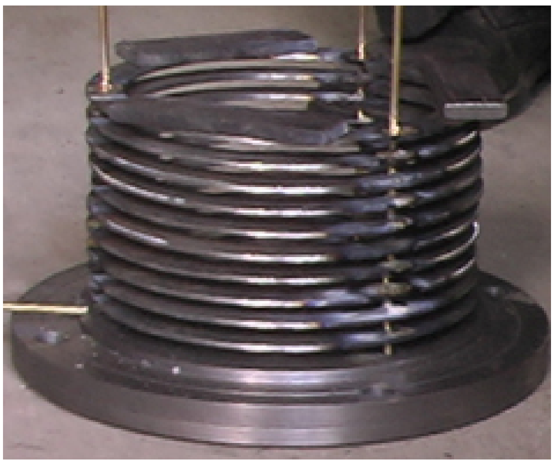
The state of hydrostatic pressure inside of elastomeric isolators is the key point in providing the high ratio of vertical to horizontal stiffness in such devices. In this study the state of hydrostatic pressure is provided by steel rings instead of steel shims used in classical elastomeric isolators. One advantage of this isolator is the possibility of adding new liquid materials to the core to increase damping.

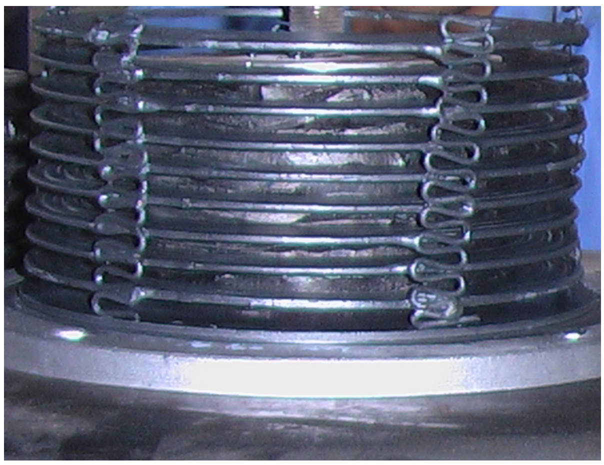
These isolators are categorized in to "isolators with inner steel rings" and "isolators with outer steel rings" (figure 5). According to the needed performance in design, one of them is chosen. Performance of these isolators is compared with classical elastomeric isolators (elastomeric isolator with steel shims) theoretically, numerically, and experimentally. The results shows suitable performance of these isolators in seismic isolators (especially in light weight isolating) and closeness of theoretical, numerical, and experimental results were seen [Pourmohammad, 2006].
One of the main advantages of these isolators is their simple and economical process manufacture. In this paper manufacturing procedure and experimental results of a prototype is presented. In manufacturing procedure, first of all, steel rings is produced as shown in figure 6-a, then the rings are placed into the mold, and now the mold and the rings within is put on the bottom plate, after that rubber compound is lead on the middle core by pressure increase until the rubber penetrates among the rings. The figure 6-b shows the space among the rings is filling with the rubber. For the last step of the manufacturing procedure, the upper steel plate will be put on the mold by a low rate of pressure.





a) Elastomeric isolators with inner steel rings b) Elastomeric isolators with outer steel rings
Figure 5 Proposed elastomeric isolators





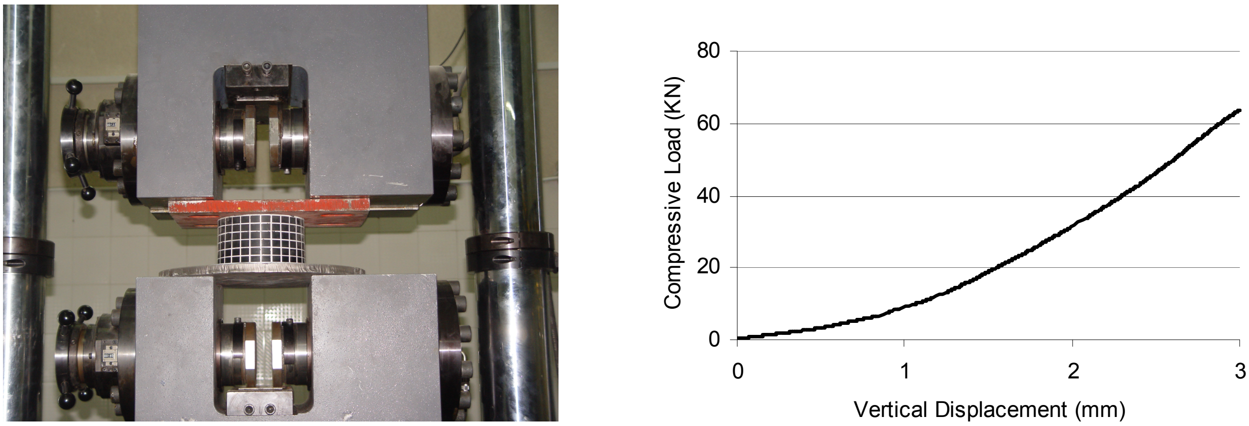
a) Inner steel rings with assembling plain bars b) Rubber penetrates among the rings with assembling meandering bars
Figure 6 Manufacturing procedure of proposed isolator

In this paper, two series of tests have been performed on isolators. First, prototype of isolator is loaded vertically and second loaded by vertical and shearing forces simultaneously.The test was performed using a vertical actuator for vertical load only. A prototype of the proposed isolator with vertical actuators is shown in Figure 7-a. The isolator was loaded to a vertical displacement of 3mm at a steady rate; the length of time to apply the maximum load was 30sec.The vertical force-displacement curve is shown in figure 7-b. The figure is shown that the vertical stiffness resulted from the test is close to design vertical stiffness.

This prototype was examined under the vertical load 64kN, with shear displacement amplitudes ±10, ±20, ±30, ±40, ±50, ±60, ±70, and ±80mm in three loading cycles for each shear displacement range. For vertical and shear loading, test set up no. 2 that is shown in figure 8 is used. Details for test set up no. 2 are as follows:

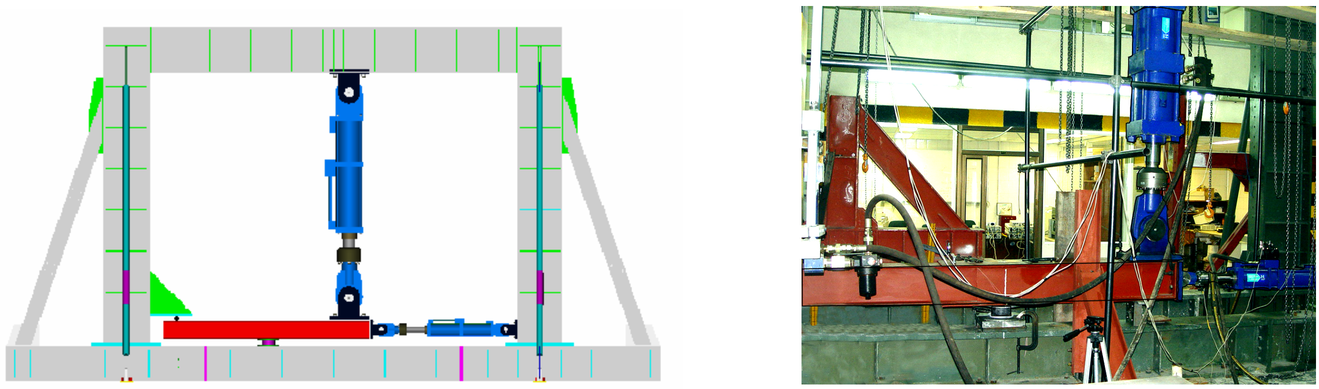
1- A main frame that a horizontal actuator, for applying shear loading: a vertical actuator for applying vertical loading and a horizontal beam for transferring vertical and shear loading to prototype isolator are attached to it.
2- A horizontal actuator
3- A vertical actuator

The horizontal beam that is attached to prototype isolator, act lever-like. The end part of beam is rolling support. The prototype isolator is another support of beam. Vertical loading is applied of the other end of beam by the vertical actuator. So the vertical load to isolator prototype is the resultant, vertical actuator load and rolling support reaction.



a) Test set up 1 b) Vertical load-displacement relation actuator

Figure 7 Vertical loading test

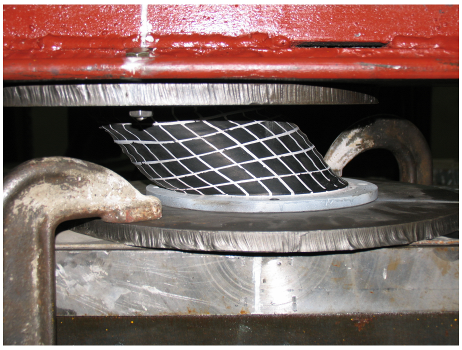


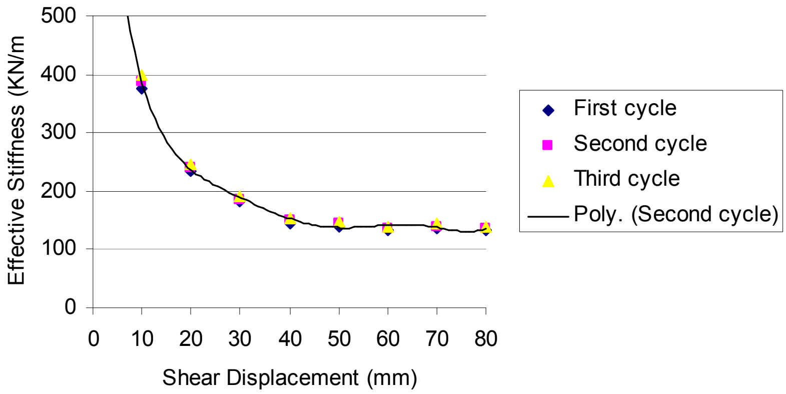
a) Schematic model b) constructed model

Figure 8 Test set up 2

The shear effective stiffness-displacement is shown in figure 9-b.It is seen in figure 9-b that the shear stiffness resulted from the test is close to designed shear stiffness and is not dependent on number of loading cycles. Also deformation shape of the isolator in shear displacement with amplitude 80mm is shown in figure 9-b. There is no lock of quality is seen in it.

The shear effective damping Ratio of the isolator for different shear displacement amplitudes is shown in figure 10. The figure indicates that the damping ratio in small shear displacement amplitude is substantial (approximately %16). The reason is existence of assembling copper bars (assembling bars used to arrange inner steel rings with a constant displacement), this case seems to be a good devices to increase damping of isolators. But in large shear displacement amplitude the effect of these bars are virtually excluded from system. Also in larger shear displacement amplitude, the value of damping ratio (approximately %9.5) is rather substantial. This issue might be because of energy absorbing of steel rings in large deformations. Also the figure 9 indicates that the damping ratio of the isolator is not depended on the number of loading cycles.





a) Deformation shape in displacement 80mm b) Shear Effective Stiffness-displacement relation
Figure 9. shear loading

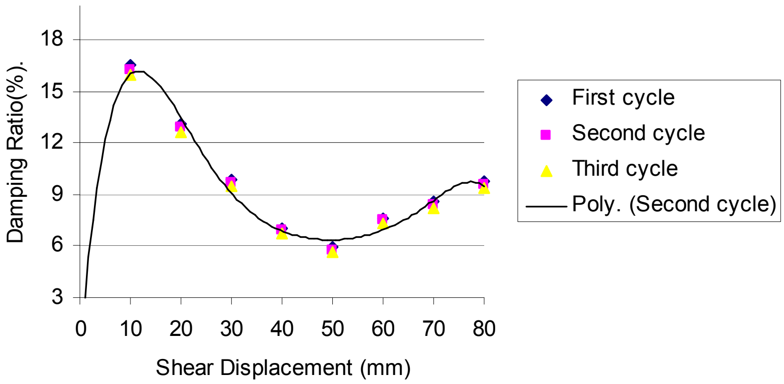


Figure 10 Shear effective damping ratio-displacement relation

5. Conclusions

The use of a floor isolation system (local isolation system) causes a building to be divided into a soft and a stiff part. The major mass of the building is concentrated in the soft part during low accelerations and the minor mass of the building is concentrated in stiff part. Thus, buildings with floor isolation can effectively reduce the structural seismic response. There are two main problems in putting the buildings with local isolation systems (the buildings with FIS) into practice as a controlling system. First, few isolators for optimum and economical design are needed. Second, a kind of isolator is needed that provides the demand performance and is cost effective. The first problem could be solved in designing procedure of floors system by choosing the number of optimum isolator and suitable floor system. In this paper for solving second problem, elastomeric isolator with steel rings is proposed. The experimental results show good performance of such isolators. Furthermore, these isolators considering simple procedure of manufacture are economically justified.

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