SEISMIC ASSESSMENT DEMAND OF ISOLATED BUILDINGS

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ABSTRACT

Nowadays, the system of seismic isolation of structures is well known; it is possible that we can offer high security and protection from damage to the structure during the earthquake than an embedded system. The technology of the seismic isolation makes possible to convert weak and vulnerable buildings to resistant and insensitive buildings to earthquake by reducing the transfer of the effect of the ground motion to the building without interruption of its functional operations.

This work aims to clarify the nonlinear static behavior of the structures with and without the seismic isolation system and the influence of these systems in the mitigation of seismic risk and seismic demands.

The objective of the first stage is to evaluate the seismic demands of concrete buildings with and without the isolation systems by the capacity spectrum method of the ATC40 (approach in damping). In the second stage, a comparative study was made in order to quantify the influence of the isolators on the seismic demands.

INTRODUCTION

Modern buildings contain extremely sensitive and costly equipments that have become vital. In addition, hospitals, communications and emergency centers, police stations and fire stations must be operational when needed most, immediately after an earthquake. The above mention fact spurs a question of - how to protect the important buildings? A simple logical answer to the question is - can the buildings be detached from the ground in such a way that the earthquake motions does not transferred to the building, or at the least greatly reduced ? This simple logic is feasible in the form of seismic base isolation of the buildings.

Seismic isolation consist essentially the installation of mechanisms which decouples the buildings, and/or its content, from partially damaging earthquake induces ground or support motions. This decoupling is achieved by increasing the flexibility of the system, together with providing appropriate damping to resist the amplitude of the motion caused by the earthquake. The advantage of seismic isolation includes the ability to significantly reduce structural and non-structural damage, to enhance the safety of the building contents, and to reduce seismic design forces. This potential benefits are greatest for stiff structures fixed rigidly to the ground such as low and medium rise building, nuclear power plants, bridges etc.

DESIGN OF ISOLATORS

A practical seismic isolation system should meet the following requirements.

1. Sufficient horizontal flexibility to increase the structural period and spectral demands, except for very soft soil sites.
2. Sufficient energy dissipation capacity to limit the displacement across the isolators to a practical level.
3. Adequate rigidity to make the isolated buildings not much different from fixed base buildings under general service loading.

Based on above mentioned requirements and codal procedures, as per IBC 2000, Lead Rubber Bearing (LRB) was designed. As per IBC 2000 formulations, the effective stiffness to provide lateral stability was calculated. The properties like damping, hardness, modulus of rigidity, modulus of elasticity and poisons ratio, for rubbers were considered from Section 1623 of IBC 2000.

Building under consideration here requires different size of isolators, as gravity loads acting on all the columns are varied in magnitude. However, to maintain uniformity and ease of designing, same size of isolators are advisable for all the column of the building.

The basic equations of stiffness for LRB are as follows [IBC 2000]:

The effective horizontal stiffness of the isolator is:

$$K_{eff} = \frac{w}{g}\left(\frac{2\pi}{T_D}\right)^2 \tag{1}$$

The design displacement D_D is:

$$D_D = \left(\frac{g}{4\pi^2}\right)\left(\frac{S_D T_D}{B_B}\right) \tag{2}$$

The short term yield force Q_D is:

$$Q_D = \frac{W_D}{4D_D} = \frac{\pi}{2} K_{eff}\,\xi_{eff}\,D_D \tag{3}$$

The post-yield horizontal stiffness K_D is:

$$K_D = K_{eff} - \frac{Q_D}{D_D} \tag{4}$$

The detail calculations of base isolators are omitted here, and only final design parameters are listed (table 1), to avoid much of mathematical formulations, calculations and space.

Table 1. Parameters of LRB isolation system

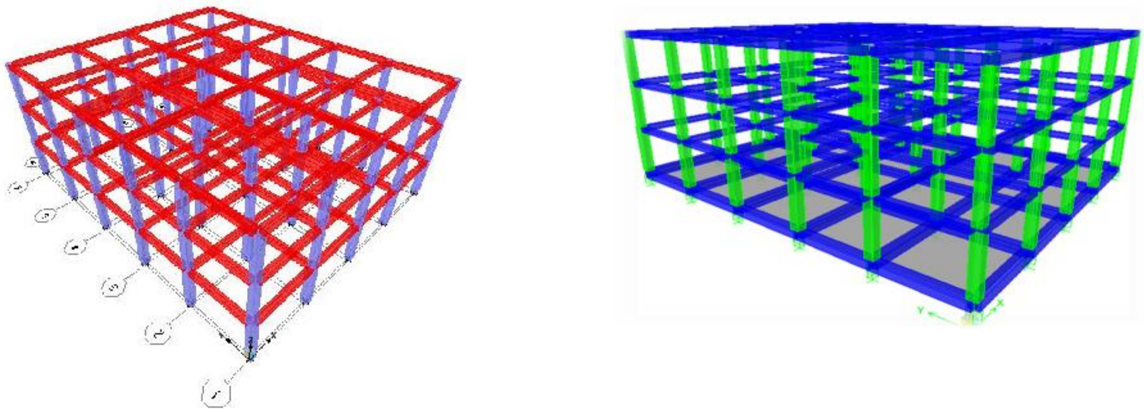
	W(kN)	K_{eff}(kN/m)	D(mm)	W_d(kN)	Q_d(kN)	K_d(kN/m)	K_u(kN/m)	D_y(mm)	F_y(kN)
A	195.08	124.85	165	2.13	3.23	105.25	1052.50	3.41	3.59
B	282.76	180.97	165	3.09	4.69	152.55	1525.55	3.41	5.21
C	298.87	191.28	165	3.27	4.96	161.25	1612.46	3.41	5.51
D	406.54	260.19	165	4.45	6.74	219.34	2193.36	3.41	7.49
E	285.53	182.74	165	3.12	4.73	154.05	1540.51	3.41	5.26
F	390.29	249.79	165	4.27	6.47	210.57	2105.69	3.41	7.19
G	343.60	219.90	165	3.76	5.70	185.38	1853.79	3.41	6.33

ETABS 9.07 supports the facility of modeling base isolator in the form of a link with appropriate properties to be defined. Initially fixed supports of building were detached and links were provided at all the supports of columns at base. The properties of the links were provided from the calculations of base isolator design.

MODELING OF BUILDING AND ANALYSIS

A medium height building of G+2 has been selected to understand the analysis and design of base isolators. Building chosen is symmetrical and regular in geometry, to reduce computation efforts. Figure1 show the 3D view of G+2 fixed and isolated buildings. The building is symmetric with respect to both the horizontal directions. It has 19.6 m of length in Y-direction and 12.4 m of width in X-direction. The height is 3m; the thickness of the floor is 15cm on all stories.

As mentioned earlier, the advantage of base isolation is lengthening of a time period for base isolated building compared to fixed base building. Therefore initially fixed base building was modeled in ETABS 9.07. For fixed base building, the translations and rotations of all columns node at base were suppressed. A free vibration analysis was carried out for Eigen-vector solution. The fundamental time period and mode shapes of the building were obtained.



(a) Fixed base building. (b) Base isolated building.

Figure 1. General view of the analyzed buildings (fixed base and isolated base).

To provide more information about the performance of the structures, plastic hinge patterns are investigated. The nonlinear behavior of beams and columns was modeled with plastic hinges at the elements ends (concentrated plasticity model) of M3 type and of PM2M3 type, respectively [ATC-40].

RESULTS AND DISCUSSIONS

The base shear for fixed base building and base isolated building was obtained. The base shear value for fix base building is 1814.81 kN. The base shear for base isolated building with LRB system is 2628.2 kN. It has been observed that the base shear values for base isolated building is more compared to fixed base building as shown in figure 2. This is because of the distribution of mass and stiffness which gives the fundamental time period more than 1 sec.

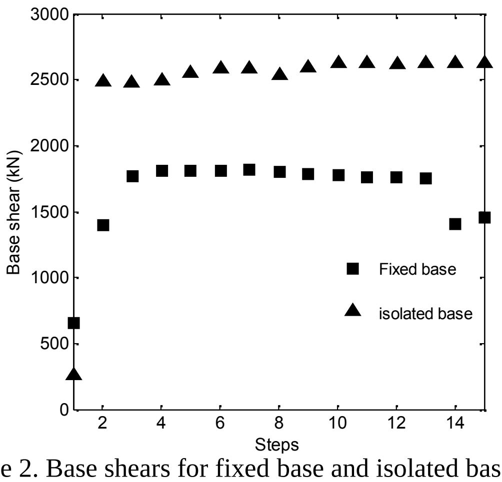
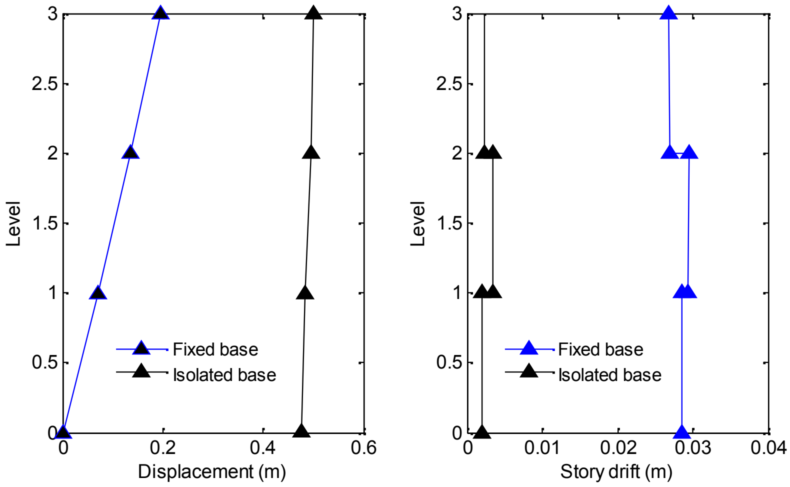


Figure 2. Base shears for fixed base and isolated base buildings.

The displacements and story drift for fixed base and base isolated building were obtained and compared with each other. It has been observed that the displacement at roof of base isolated building is less compared to fixed base building. However because of flexibility at base the displacement at base is higher in base isolated building compared to fixed base building. This can also be well understood by calculating the story drift for fixed base and base isolated building. It has been observed that the story drift in base isolated building is less compared to fixed base building. The figure 3 below shows the displacement and the story drift for base isolated building with LRB system compared with fixed base building.

For the fixed structure shown in Figure 4 (a), plastic hinge formation starts with column ends at the first floor with Immediate Occupancy (IO) label and the hinges propagates with Life Safety (LS) at the first floor and Immediate Occupancy (IO) at second floor. Then it will propagate to whole structure. In Figure 4 (b), the structure with rubber bearing as seismic isolation also will start plastic hinge formation at the first floor but it started slowly with Immediate Occupancy (IO) label and the propagation of plastic hinge is slow. It shows that there are significant differences in hinge pattern. This also can demonstrate the effectiveness of the seismic isolation system on structure.



(a) Absolute displacement. (b) Story drift.

Figure 3. Absolute displacement and storey drift of fixed base and base isolated buildings.

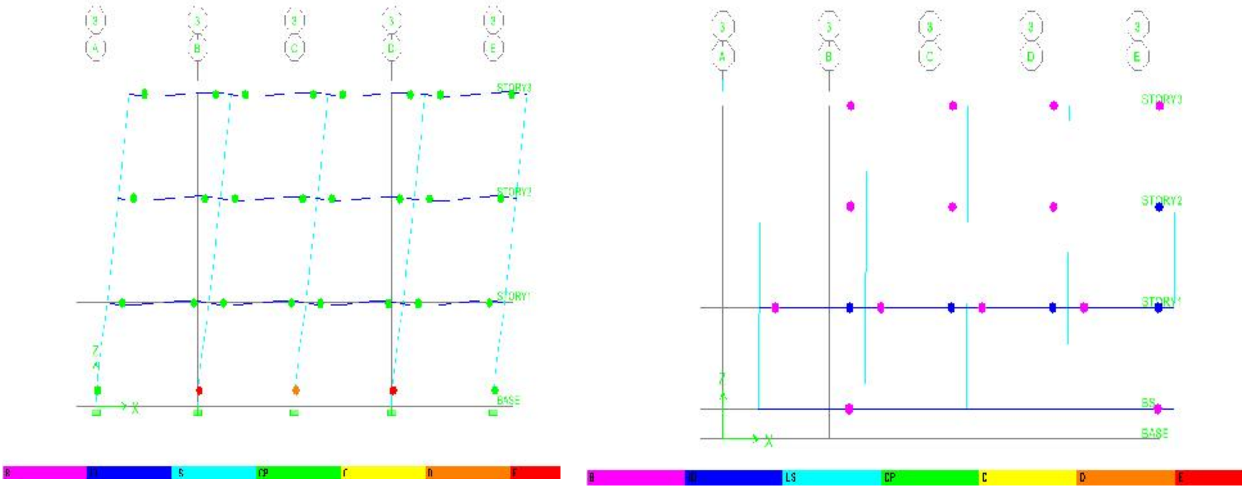


Figure 4. Plastic hinge distribution of fixed base and base isolated buildings.

The intersection of the capacity spectrum with appropriate demand spectrum in the capacity spectrum method represents the performance point. This method based on the iterative evaluation permit to determine the maximal displacement and acceleration of the structure (tables 2 and 3, and figure 5).

Table 2. CSM results of fixed base building

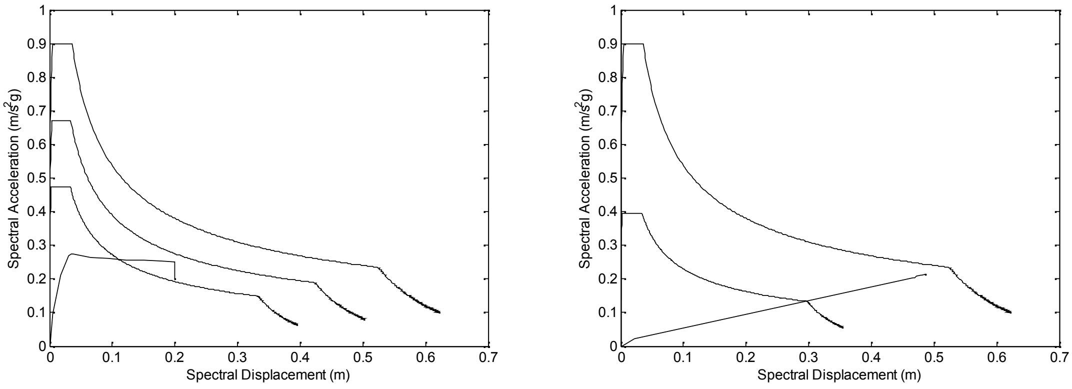
Iteration number	Acceleration spectral (m/s^2 g))	Displacement Spectral (m)	ξ_{eff} (%)
1	0.27	0.055	10.86
2	0.275	0.042	15.16
3	0.252	0.17	25.66
4	0.26	0.09	18.48
5	0.258	0.135	23.18
6	0.26	0.1	19.72
7	0.258	0.12	21.69
8	0.258	0.11	20.59
9	0.258	0.11	20.59

Table 3. CSM results of base isolated building.

N^{bre} d'iteration	Acceleration spectral (m/s^2 g)	Displacement Spectral (m)	ξ_{eff} (%)
1	0.128	0.28	0.286
2	0.135	0.295	0.284
3	0.135	0.295	0.2842

In this application, we changed the design of the structure by integrating isolators. According of pushover and CSM analyses, it was found displacement and damping in base isolated structure greater than those found in fixed structure, and acceleration was less important. So, we found a reduction of seismic demands which makes the performance level of the structure as an advantageous (figure 5) and we can explain these values as follows:

- Increasing of displacement (0.185 m) represents the displacement of the isolation system.
- The difference between the accelerations (-0.123 m/s2 g) represents the reduction in terms of solicitation provided by the earthquake.
- The isolated structure dissipates an important energy (7.65 % of difference) due to the presence of the isolation system.



(a) Fixed base.

(b) Isolated base.

Figure 5. Performance point evaluation of fixed base and base isolated buildings

CONCLUSIONS

The following conclusions were drawn out of the present work of comparison of fixed base building to base isolated building.

- The fundamental time period of fixed base building was 0.47 sec.
- The fundamental time period of base isolated building with LRB system was 1.05 sec.
- The time period for base isolated buildings are approximately 2.23 times higher compared to the fixed base building, which is the first objective of base isolation system called "Period Shift".

- The base shear value for fixed base building was as low as 1814.81 kN, while for base isolated building with LRB system was more than 2628.2 kN.
- The base shear value for fixed base building is approximately 1.52 times lower compared to base isolated building. The increase in base shear is due to higher time period (0.58 sec.) for the building undertaken.
- The story drift of fixed base building was found higher compared to base isolated building.

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