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Effectiveness of Base Isolation Technique and Influence of Isolator Characteristics on Response of a Base Isolated Building

Sunita Tolani[1], Dr. Ajay Sharma[2]
[1,2]*(Department of Structural Engineering, M.B.M. Engineering College, Jodhpur, Rajasthan, India)*

ABSTRACT: *This study concerns with the seismic response comparison of a fixed base building with a base isolated building and parametric study of a base isolated building. The structural system considered for analysis is a three storey reinforced concrete building, which is idealized as a shear type building with one lateral degree of freedom at each floor level. The isolation systems considered for this study are Laminated Rubber bearing (LRB), Lead Rubber Bearing (N-Z bearing) and Friction Pendulum System (FPS). The response of fixed base building and of base isolated building is compared in terms of maximum top floor acceleration, inter-storey drift, maximum floor displacements and base shear. For parametric study important isolation system parameters considered are: (i) isolation time period, isolator damping for LRB; (ii) isolator yield strength, isolation time period, isolator damping for N-Z bearing and (iii) isolation time period, friction coefficient for FPS. It is found that base isolation technique is very effective in reducing seismic response of structure and isolation system parameters significantly influence the earthquake response of a base isolated structure.*

Keywords: *Base isolation, Laminated Rubber Bearing, N-Z Bearing, Friction Pendulum System, top floor acceleration, drift, maximum floor displacement, base shear.*

I. INTRODUCTION

Base Isolation is a very effective way for controlling seismic response of civil engineering structures. This technique is based on the principle that it is more efficient to reduce seismic demand on a structure rather than increasing its earthquake resistance capacity. The main idea behind the Base Isolation is based on minimizing the earthquake induced forces transferred to the superstructure. The earthquake energy is prevented from entering the structure by decoupling the later from the ground motion, thereby reducing both the ductility demand and inter-storey drifts. This uncoupling is done by interposing the structural elements with low horizontal stiffness between foundation and superstructure which reduce the fundamental frequency of structural vibration to a lower value than the predominant energy containing frequencies of earthquake ground motions and it also provides a means of energy dissipation which reduces the transmitted acceleration to the superstructure. In this way, the Base Isolation provides seismic protection to the structure and its non-structural components. The two most common types of isolation bearings are Spring-Like Isolation Bearing (Elastomeric bearing with or without lead core) and Sliding-Type Isolation Bearing. The former with lesser horizontal stiffness help in reducing seismic forces by increasing the fundamental period of structure. Sliding type isolation is based on the principal of sliding friction between two surfaces. This method is very successful for protecting the structures even against very severe earthquakes. In recent years this technology has emerged as a practical and economic alternative to conventional seismic design. This method is being used in new and existing (as retrofit) structures, both important and civilian, in different types of structures and in different countries.

In the past several researchers have done experimental study to demonstrate effectiveness of base isolation technique. R.S. Jangid and P. Bhasker Rao carried out an experimental shake table study for the response comparison of isolated and non-isolated structure. The response of isolated structure was compared with non-isolated structure and it was found that the isolation devices are effective in reducing the seismic response of the structure. The influence of isolator characteristics on the seismic response of multi-story base-isolated structure was investigated by Matsagar and Jangid .

This study is done for two objectives: The first objective of this study is to show effectiveness of base isolation technique and second is to study the influence of isolator parameters on response of an isolated structure. The structural system considered for analysis is a three storey reinforced concrete building, which is idealized as a shear type building with one lateral degree of freedom at each floor. The building is first analyzed for fixed-base case and then for base-isolated condition considering three types of bearing Laminated Rubber Bearing (LRB), Lead Rubber Bearing (N-Z system) and Friction Pendulum System (FPS). The responses of fixed base building and of base isolated building both subjected to three different earthquake ground motions are found out by non-linear time history analysis using Matlab software.

II. MATHEMATICAL MODELING

Basic Properties of the Building

The building considered for investigation is shown in figure 1. It is a three storey reinforced concrete building which is regular in plan and elevation. Plan dimensions are 15mx15m with three equal spans in each direction and all storey heights are 3m. Beam sizes are 300X450mm, column sizes are 450X450mm, slab thickness 200mm, Grade of concrete is M25.

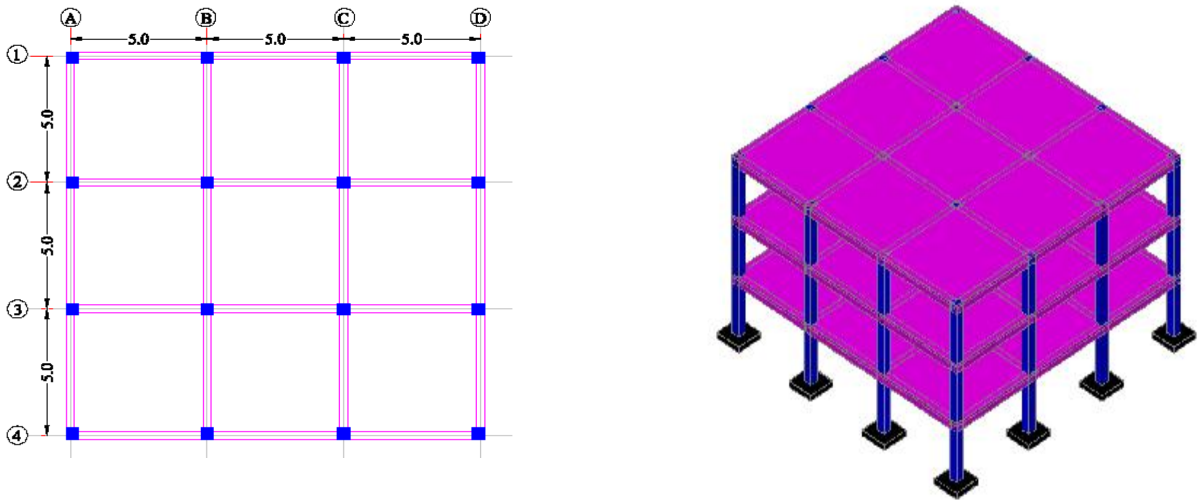


Figure 1: Plan and 3-D View of Sample building.

Structural Model

The structure is idealized as a three storey shear type building as shown in figure 2 and 3. The building is modeled as 3-DOF system for fixed base condition and as 4-DOF system for base isolated condition. The structure is modeled using one lateral degree of freedom at each floor. The damping of superstructure is assumed as Rayleigh's mass and stiffness proportional damping for that critical damping is considered as ξ=5% in all modes. For base isolated building the isolation system may consist of elastomeric system (with or without Lead Core) or friction pendulum system.

Assumptions

The various assumptions made for modeling of building are:

1. The system is subjected to single horizontal component of the earthquake ground motion.
2. The total mass of the structure is concentrated at the levels of the floors.
3. The slabs and girders on the floors are infinitely rigid as compared to the columns.
4. The columns are inextensible and weightless providing the lateral stiffness.
5. The effects of soil-structure interaction are not taken into consideration.

In addition to this for base isolated building we assume that the superstructure is considered to remain within the elastic limit during the earthquake excitation. This is a reasonable assumption as the isolation attempts to reduce the earthquake response in such a way that the structure remains within the elastic range.

Equations of Motion

The equations of motion for fixed base condition under earthquake ground acceleration can be expressed in matrix form as:

$$[M_s]\{\ddot{x}_s\} + [C_s]\{\dot{x}_s\} + [K_s]\{x_s\} = -[M_s]\{R\}(\ddot{x}_g) \quad (1)$$

The equations of motion for the superstructure for isolated base condition under earthquake ground acceleration are expressed in the matrix form as

$$[M_s]\{\ddot{x}_s\} + [C_s]\{\dot{x}_s\} + [K_s]\{x_s\} = -[M_s]\{R\}(\ddot{x}_b + \ddot{x}_g) \quad (2)$$

Where

n = superstructure degree of freedom.

r = no. of components of input ground motion.

[M_s], [C_s] and [K_s] are the superstructure mass, damping and stiffness matrices of order n x n,
{ x_s } is the floor displacement vector relative to the base of size nx1
{ $\dot{x}_s$} is the velocity vector relative to the base of size n x 1
{ $\ddot{x}_s$} is the acceleration vector relative to the base of size n x 1
$\ddot{x}_b$ is the vector of base acceleration relative to ground size r x 1
$\ddot{x}_g$ is the ground acceleration vector of size r x 1
{R} = influence coefficient vector of order n x r, having '1' for element corresponding to degree of freedom in the direction of applied ground motion and '0' for other degree of freedom.
r = 1 because single horizontal component of ground motion is considered. So in this case $\{R\} = \{1\ 1\ 1\}^T$

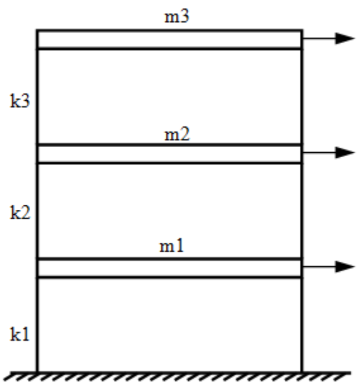


Figure 2: Model of fixed base building.

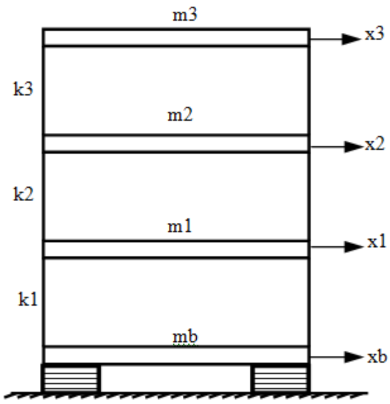


Figure 3: Model of Base Isolated building.

The equations of motion for the base are as follows:

$$m_b \ddot{x}_b + F_b - k_1 x_1 - c_1 \dot{x}_1 = - m_b \ddot{x}_g \quad (3)$$

Where
m_b = base mass.
F_b = restoring force developed in the isolation system.
k_1 = storey stiffness of the first floor.
c_1 = first storey damping.
The restoring force F_b depends upon the type of isolation system considered and it is described as follows for different systems:

Laminated Rubber Bearing(LRB)
The Laminated Rubber Bearing represents the most commonly used elastomeric isolation system. The basic components of LRB are steel and rubber plates, built through vulcanization process in alternate layers. The dominant feature of this bearing is parallel action of linear spring and damping. Generally, it is characterized with high damping capacity, horizontal flexibility and high vertical stiffness. The relatively low shear stiffness in the horizontal plane is provided by the rubber, and the high vertical stiffness is provided by steel shims to control bouncing effect on the structure due to vertical vibration caused by the earthquake. The steel shims also help to confine the rubber from bulging out. This system is modeled with linear force deformation behavior and viscous damping. The restoring force is expressed by

$$F_b = c_b \dot{x}_b + k_b x_b \quad (4)$$

Where c_b and k_b are damping and stiffness of bearing respectively.
The stiffness and damping of the LRB system is designed to provide the specific values of the two parameters namely the period of isolation (T_b) and the damping ratio (ξ_b) expressed as:

$$T_b = \frac{2\pi}{\omega_b} \quad \text{and} \quad \omega_b = \sqrt{\frac{k_b}{M}} \quad (5)$$

$$2\,\xi_b\,\omega_b = \frac{c_b}{M} \quad (6)$$

Where $M = m_b + \sum_{j=0}^{n} m_j$ is the total mass of base isolated structure and m_j is mass of the jth floor of the superstructure.

Lead-Rubber Bearing (N-Z Bearing)
These bearings are similar to the laminated rubber bearing but a central lead core is used to provide an additional means of energy dissipation and initial rigidity against minor earthquakes and winds. The energy absorbing capacity provided by the lead core reduces the lateral displacement of the isolator. The lead rubber bearings also provide an additional hysteretic damping through the yielding of lead core. The hysteretic loop of a bearing is generally modeled by bilinear force deformation behavior. The restoring force is expressed by:

$$F_b = c_b \dot{x}_b + \alpha k_b x_b + (1 - \alpha) F_y Z \quad (7)$$

Where F_y is the yield strength of the bearing; α is an index which represents the ratio of post to pre-yielding stiffness; k_b is the initial stiffness of the bearing; c_b is the viscous damping of the bearing; and Z is the non-dimensional hysteretic displacement component.
The Lead-Rubber bearings are generally designed to specified values of three parameters namely: the isolation period (T_b), the damping ratio (ξ_b) and the normalized yield strength (F_0). The parameters T_b and ξ_b are obtained from Eqs. (5) and (6), respectively based on the post-yield stiffness of the bearing. The parameter F_0 is defined as:

$$F_0 = \frac{F_v}{M\,g} \quad (8)$$

Where g is the acceleration due to gravity.

Friction Pendulum System (FPS)
This device is a sliding isolation device. The sliding systems exhibit excellent performance under a variety of severe earthquake loading and are very effective in reducing the large levels of the superstructure acceleration. These isolators are characterized by their insensitivity to the frequency content of earthquake excitation, because of the tendency of sliding system to reduce and spread the earthquake energy over a wide range of frequencies. There is another advantage of sliding isolation systems over conventional rubber bearings. Due to development of the frictional force at the base, it is proportional to mass of the structure, and the centre of mass and centre of resistance of the sliding support coincides. Consequently, the torsion effects produced by the asymmetric building are diminished. The concept of sliding bearings is combined with the concept of a pendulum type response, resulting in a conceptually interesting seismic isolation system known as a friction pendulum system (FPS).
The concept of sliding bearing is marked by sliding of an articulated slider on spherical concave chrome surface. The slider is faced with a bearing material which when in contact with the polished chrome surface results in development of friction force while concave surface produces restoring force. The system is activated only when the earthquake forces overcome the static value of friction and coefficient of friction depends upon the velocity attained. The FPS develops a lateral force equal to the combination of the mobilized frictional force, and the restoring force that develops because of the rising of the structure along the spherical concave surface. The restoring force for the friction pendulum system is expressed by

$$F_b = k_b x_b + F_x \quad (9)$$

Where k_b is the bearing stiffness provided by virtue of inward gravity action at the concave surface and F_x is the frictional force in the sliding system.
The stiffness k_b of the system is designed in such a way to provide specific value of time period (T_b) expressed as:

$$T_b = 2\pi \sqrt{\frac{k_b}{M}} \quad (10)$$

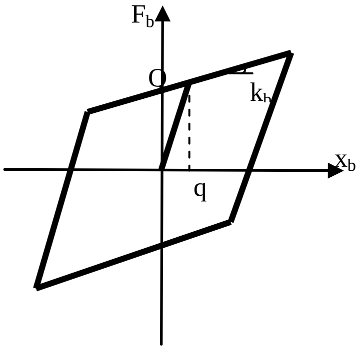
Where $M = m_b + \sum_{j=0}^{n} m_j$ is the total mass of base isolated structure and m_j is mass of the jth floor of the superstructure.
The limiting frictional force in the bearing is given by,

$$F_s = \mu M g, \quad (11)$$

where μ = friction coefficient of the FPS.
Depending upon the magnitude of the frictional force, F_x the system will be in stick or slip conditions. If $F_x < F_s$, then it will be in non-sliding (stick) phase and if $F_x > F_s$, then it will be in sliding (slip) phase.

Thus the modeling of FPS requires the specification of two parameters, namely the isolation period (T_b) and the friction coefficient (μ).

Bi-linear hysteresis model for Lead Rubber bearing (N-Z system) and friction pendulum system (FPS)



As explained above Laminated Rubber bearing (LRB) exhibits Linear force deformation behavior and N-Z system and FPS exhibit non-linear force deformation behavior. The non-linear force-deformation behavior of the isolation system is modeled through the bi-linear hysteresis loop characterized by three parameters namely: (i) characteristic strength (Q), (ii) post-yield stiffness (k_b) and (iii) yield displacement (q) as shown in figure 4. The bi-linear model is selected because this model can be used for all isolation systems used in practice. The characteristic strength Q is related to the yield strength of the lead core in the N-Z bearing and friction coefficient of the sliding type isolation system. The characteristic strength Q is normalized by the weight of the building, W=M g.

Figure 4: Bi-Linear Hysteretic Model

The non-dimensional hysteretic displacement component (Z) can be expressed by following non-linear first order differential equation [Nagarajaiah et al.]

$$q\,\dot{Z} = A\,\dot{x}_b - Z^2\,[\,\gamma\ \mathrm{sign}(\dot{x}_b\,Z) + \beta]\ \dot{x}_b \qquad (12)$$

where A, γ and β are dimensionless quantities that control the shape of hysteresis loop.This hysteretic model can account for the variation of coefficient of friction with velocity for sliding system and in case of elastomeric bearing it can account for the change in energy absorption capacity due to variation of axial force in case of elastomeric bearing.For a sliding bearing, the mobilized forces can be expressed as

$$F = \mu\,W\,Z \qquad (13)$$

For N-Z bearing mobilized forces can be expressed as

$$F = \alpha\,k_b\,x_b + (1-\alpha)\,F_y\,Z \qquad (14)$$

Solution of Equations: The equations of motion can be solved by Newmark's constant average acceleration method. The differential equation governing the behavior of nonlinear isolation elements can be solved by using the semi-impicit Runge-Kutta method.

III. INTERPRETATIONS & DISCUSSIONS

Response Comparison of Fixed Base Building and Base Isolated Building

The first objective of this study is to compare the performance of fixed base building and base isolated building. The responses of fixed base building and of base isolated building isolated by Laminated Rubber Bearing, subjected to selected earthquake ground motions are found out by non-linear time history analysis. The selected earthquake ground motions are El Centro (1940) Earthquake (N-S component); Kobe (1995) Earthquake; Sylmar (1971) Earthquake. The fixed base building fundamental time period is 0.3 sec., the value of bearing stiffness is so designed to provide increased time period T_b = 2 sec. Isolator damping considered is 10% of critical.

Tables 1, 2, 3 show response comparison of fixed base and base isolated building. It shows maximum absolute displacements of all the three floors. In case of fixed base building these displacements are relative to ground and for base isolated building these displacements are relative to base slab. It is clear from this data that in case of base isolated structure the superstructure above base slab acts as rigid, drift values are also very much reduced. This reduction in inter-storey drift ensures safety on non-structural components of building. When we compare base shears of both buildings, it is very less for base isolated building in comparison to fixed base building which clearly indicates reduction of earthquake induced forces in building by using base isolation technique.

Table 1: Response comparison of fixed base and base isolated building Subjected to El Centro(1940) Earthquake

Response quantity	Fixed base building	Base isolated building
Max. abs. displacement of 1st floor slab relative to base (mm)	7.8	1.7
Max. abs. displacement of 2nd floor slab relative to base (mm)	13.6	2.8
Max. abs. displacement of 3rd floor slab relative to base (mm)	16.7	3.2
Max. first storey drift(mm)	7.8	1.7
Max. second storey drift(mm)	6	1.1
Max. third storey drift(mm)	3.1	0.5
Max. Base Shear (KN)	4778	1025

Table 2: Response comparison of fixed base and base isolated building Subjected to Kobe(1995) Earthquake

Response quantity	Fixed base building	Base isolated building
Max. abs. displacement of 1st floor slab relative to base (mm)	20	4.7
Max. abs. displacement of 2nd floor slab relative to base (mm)	34	7.7
Max. abs. displacement of 3rd floor slab relative to base (mm)	41	9
Max. first storey drift(mm)	20	4.7
Max. second storey drift(mm)	15	3
Max. third storey drift(mm)	7	1.3
Max. Base Shear (KN)	12950	2846

Table 3: Response comparison of fixed base and base isolated building Subjected to Sylmar(1971) Earthquake

Response quantity	Fixed base building	Base isolated building
Max. abs. displacement of 1st floor slab relative to base (mm)	28	6.9
Max. abs. displacement of 2nd floor slab relative to base (mm)	48	11.2
Max. abs. displacement of 3rd floor slab relative to base (mm)	58	13.1
Max. first storey drift(mm)	28	6.9
Max. second storey drift(mm)	21	4.4
Max. third storey drift(mm)	10	1.9
Max. Base Shear (KN)	17817	4174

For the base isolated structure absolute acceleration is a response quantity of interest because it is directly proportional to the forces exerted in the superstructure due to earthquake ground motion. Top floor absolute accelerations for fixed base building and base isolated building are plotted against time to study the effectiveness of base isolation technique. Figure5 clearly indicates that the superstructure acceleration of the isolated structures is relatively less in comparison to that of non-isolated system. In figure 6 the top floor displacement of fixed base building relative to ground and top floor displacement of base isolated building relative to base slab are plotted. It is clear from figures that top floor relative displacement is very much reduced in case of base isolated building.

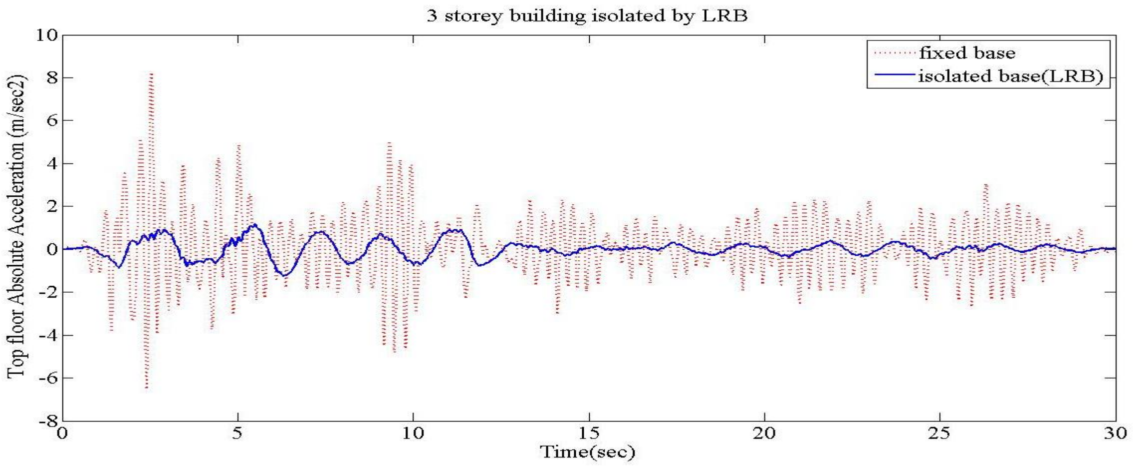
Influence of Isolator System Parameters on the Response of Isolated Structure

The second objective of this study is to investigate the influence of isolator characteristics on the response of isolated structure under the variation of isolator parameters. These parameters are: (a) Isolation time period and isolator damping for Laminated Rubber Bearing; (b) Yield strength, isolation time period and isolator damping for Lead Rubber Bearing (N-Z system) and (c) Isolation time period and friction coefficient for friction type isolation system.

Figure 7 shows the variation of the top floor absolute acceleration and isolator displacement against the isolator damping ratio. The variations are plotted for different values of isolator time period (T_b= 1.5, 2, 2.5, 3 sec) of the LRB system. It is observed from the figures that the increase in the period of isolation increases the bearing displacement but decreases the superstructure acceleration. Further, increase in isolator damping decreases both the bearing displacement and the superstructure acceleration. However, variation in superstructure acceleration between 20 to 25% isolator damping ratio is not significant.

The parameters for the N-Z system are the period of base isolation (T_b), the damping ratio of the bearing (ζ_b) and the yield strength level of bearing (F_0). The other parameters of the N-Z bearing are the yield displacement level of the bearing (q), and parameters of hysteresis loop of the bearing such as A, β and γ as shown in equation (12). These parameters are held constant and values taken are q=20mm, A=1, β=γ=0.5. Figure 8 shows the variation of the isolator displacement and top floor absolute acceleration against the isolator damping ratio. Variations are plotted for different values of isolator time period of the NZ system (i.e. T_b= 1.5, 2, 2.5, 3 sec). It is observed from the figures that the increase in the period of isolation increases the bearing displacement but decreases the superstructure acceleration. Further, increase in isolator damping decreases both the bearing displacement and the superstructure acceleration. Figure 9 shows the variation of the top floor absolute acceleration and isolator displacement respectively against Normalized Yield Strength (F_0) of isolator. Variations are plotted for different combinations of isolator time period (i.e. T_b=1.5 and 2 sec) and damping ratio (i.e. ζ_b=.05 and 0.1) of the NZ system. It is observed from the figures that the increase in the Normalized Yield Strength (F_0) of the bearing decreases the bearing displacement but increases the superstructure acceleration.

(a)



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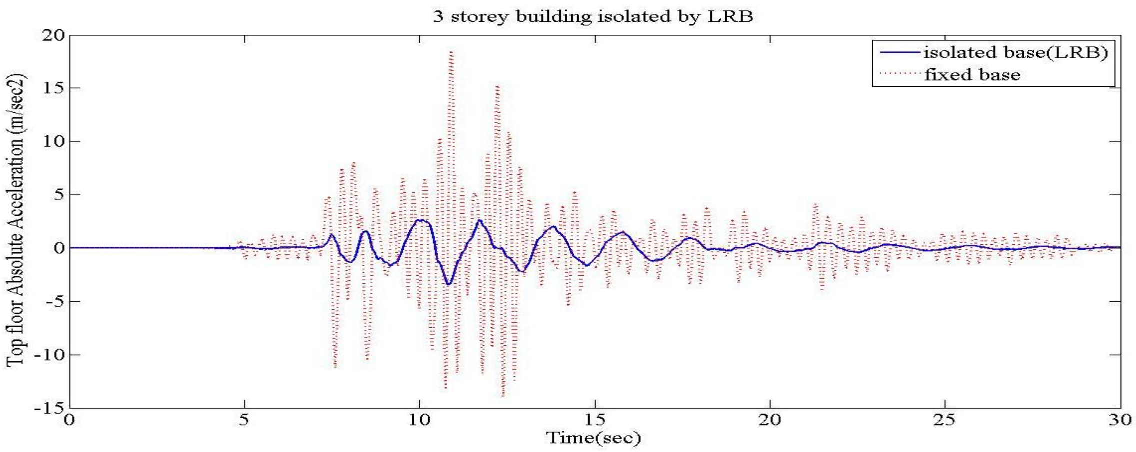

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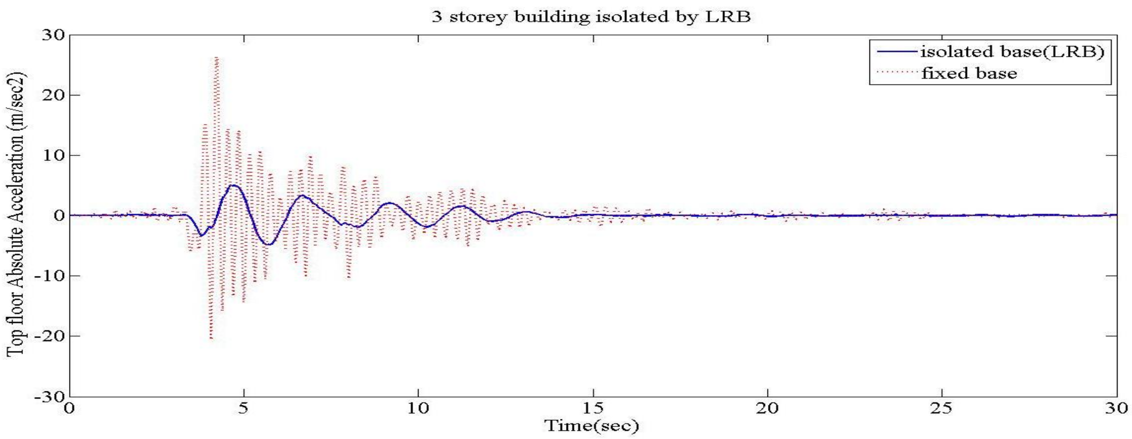
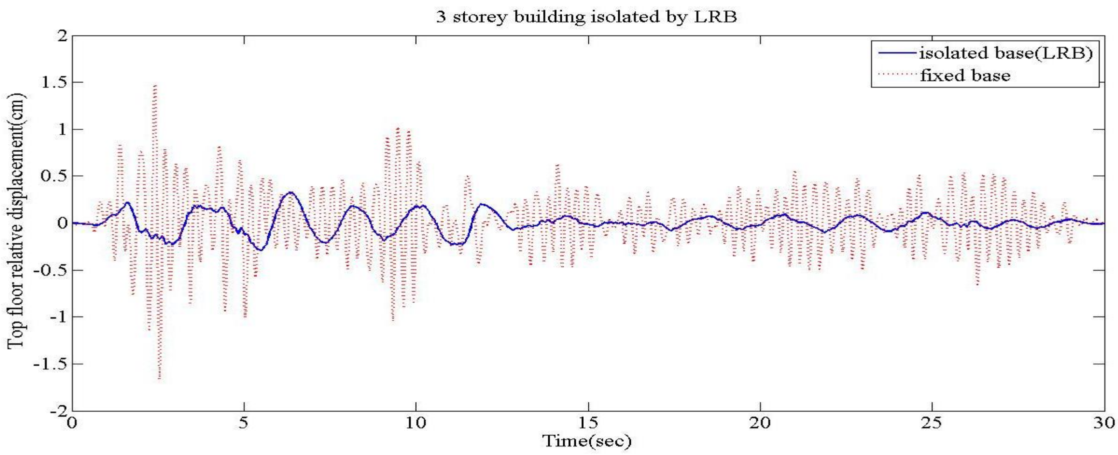


Figure 5: top floor absolute acceleration for fixed base building and for base isolated building isolated by laminated Rubber bearing(T_b 2 sec, ζ_b 10%), Subjected to (a) El Centro (1940) Earthquake, (b) Kobe (1995) Earthquake,(c) Sylmar(1971) Earthquake

(a)



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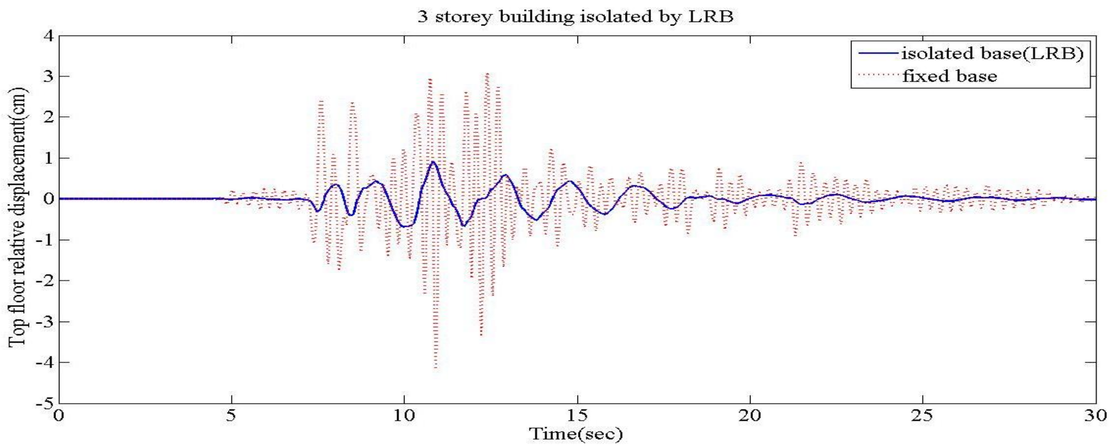

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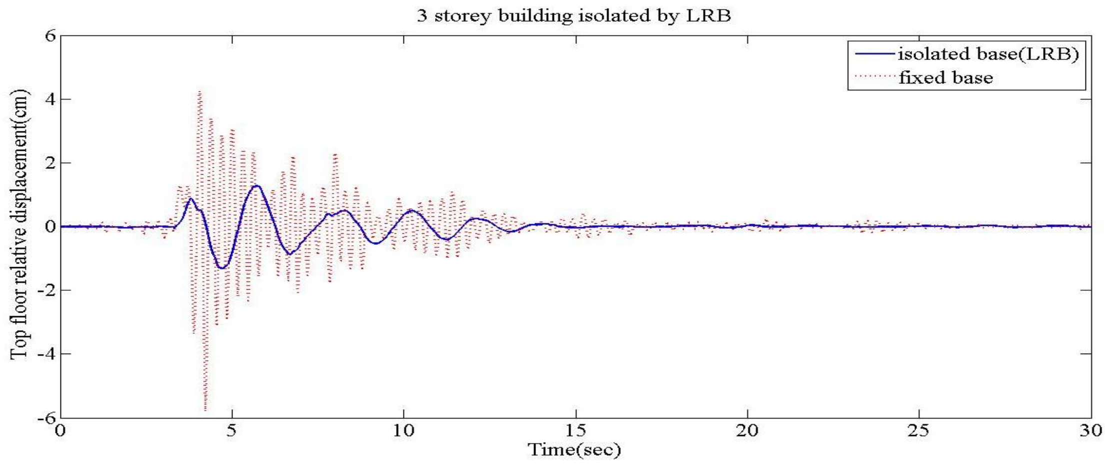
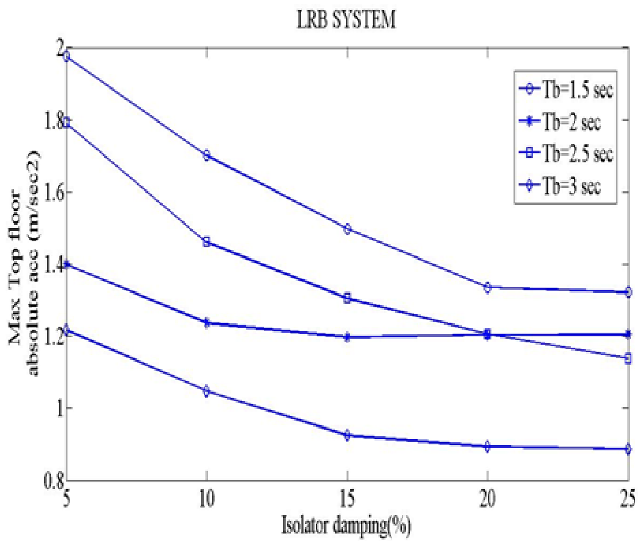


Figure 6: top floor relative displacement for fixed base building and for base isolated building isolated by laminated Rubber bearing (T_b 2 sec, ζ_b 10%), Subjected to (a) El Centro (1940) Earthquake, (b) Kobe (1995) Earthquake,(c) Sylmar(1971) Earthquake



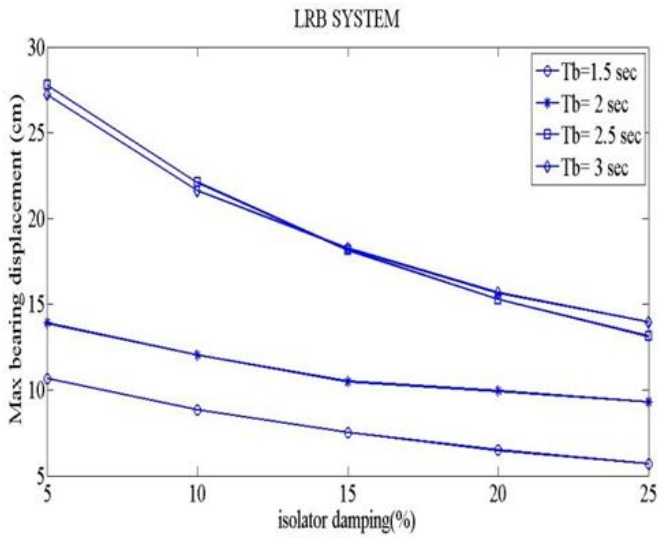
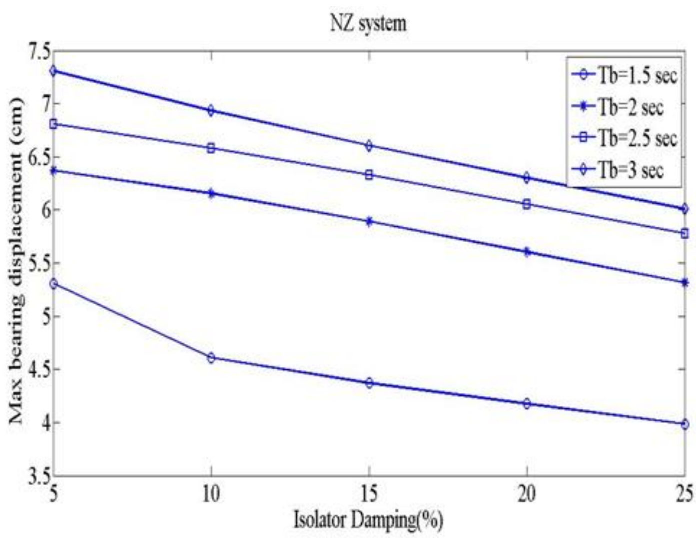


Figure 7: Effect of isolation time period and bearing damping ratio on top floor absolute acceleration and max. bearing displacement for building isolated by LRB, Subjected to El Centro (1940) Earthquake



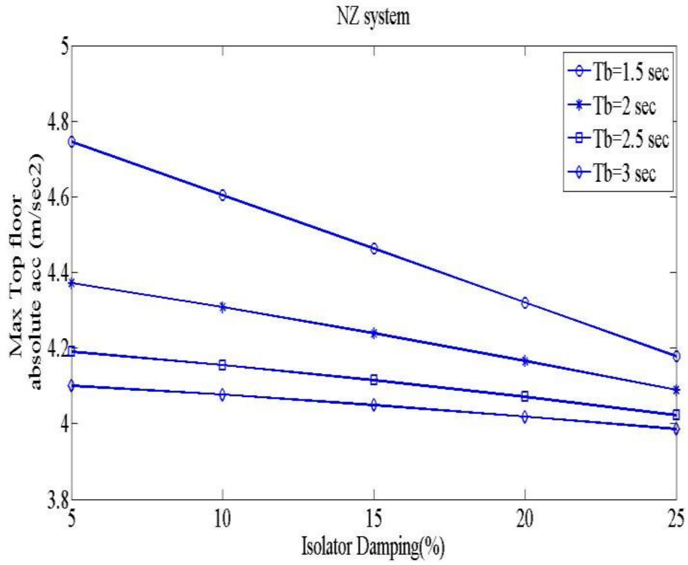


Figure 8: Effect of isolation time period and bearing damping ratio on top floor absolute acceleration and max. bearing displacement for building isolated by NZ bearing (F_0=.05), Subjected to El Centro (1940) Earthquake

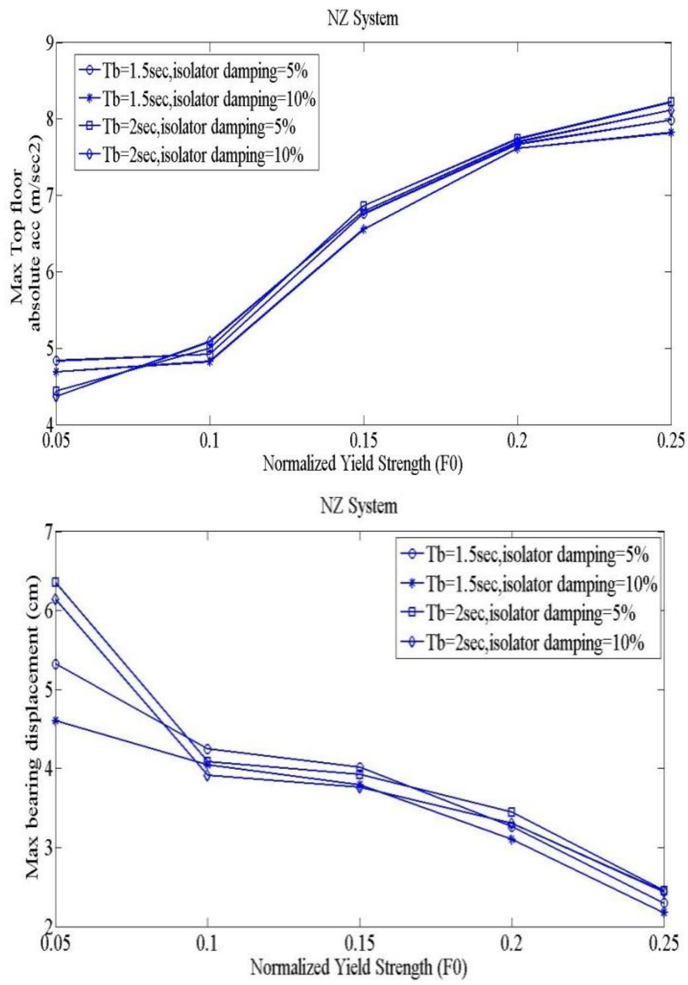
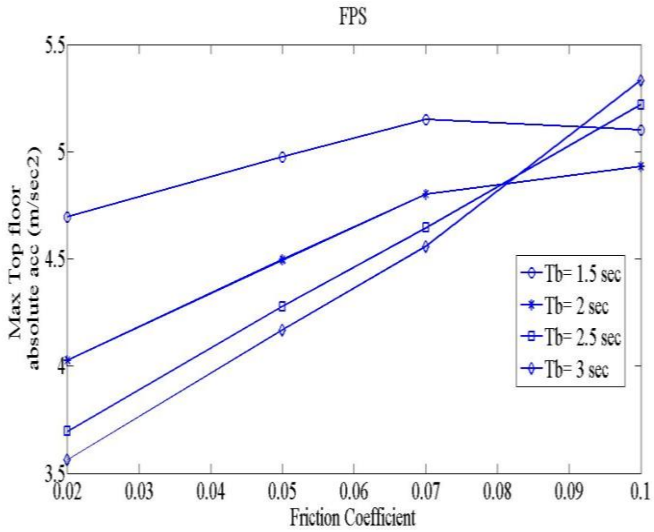


Figure 9: Effect of Normalized Yield Strength on top floor absolute acceleration and max. bearing displacement for building isolated by NZ bearing, Subjected to El Centro (1940) Earthquake



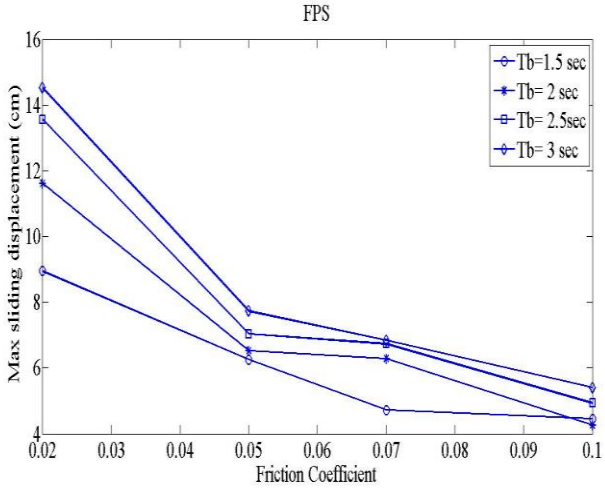


Figure 10: Effect of isolation time period(T_b) and Friction Coefficient (μ) on top floor absolute acceleration and max. bearing displacement for building isolated by FPS, Subjected to El Centro (1940) Earthquake

Figure 10 shows the variation of the top floor absolute acceleration and isolator displacement respectively against the friction coefficient (μ). Variations are plotted for different values of isolator time period (i.e. T_b =1.5, 2, 2.5, 3 sec) of the FPS. It is observed from the figures that the increase in the friction coefficient (μ) decreases the bearing displacement but increases the superstructure acceleration and increase in the period of isolation increases the bearing displacement but decreases the superstructure acceleration.

If we compare the performance of these three types of isolation systems we observe that the LRB provides maximum reduction in the superstructure acceleration but isolator displacement is more as compared to N-Z system and FPS. On the other hand, the N-Z system and FPS require minimum bearing displacement for reasonable reduction in response.

IV. CONCLUSIONS

This study yielded following results:

1. Top floor absolute acceleration, inter-storey drift and base shear are very less in base isolated building in comparison to corresponding response of fixed base building which indicates reduction of earthquake induced forces in structure and ensures safety of structural and nonstructural components of the building.
2. In Base isolated building having LRB system,

(i) Increase in the period of isolation increases the bearing displacement but decreases the superstructure acceleration.

(ii) Increase in isolator damping decreases both the bearing displacement and the superstructure acceleration.

3. In Base isolated building having NZ System,

(i) Increase in the period of isolation increases the bearing displacement but decreases the superstructure acceleration. However, the response is not much influenced by isolation period.
(ii) Increase in isolator damping decreases both the bearing displacement and the superstructure acceleration.
(iii) Increase in the Normalized Yield Strength (F_0) decreases the bearing displacement but increases the superstructure acceleration.
4. In Base isolated building having FPS,
(i) Increase in the friction coefficient (μ) decreases the bearing displacement but increases the superstructure acceleration.
(ii) Increase in the period of isolation increases the bearing displacement but decreases the superstructure acceleration.

REFERENCES

[1]. Kelly JM and Naeim F. "Design of Seismic Isolated Structures- From Theory to Practice", John Wiley & Sons, Inc, 1999
[2]. Kelly JM, "Base Isolation: Origin and Development", A paper submitted in National Information Services for Earthquake Engineering (NISEE), University of California, Berkeley, 1998.
[3]. Jangid RS, Datta TK, "Seismic behavior of base-isolated building: a state-of-the-art review", structures and buildings 1995; 110(2) 186-203.
[4]. Stanton J, M.EERI and Roeder C, M.EERI. "Advantages and Limitations of Seismic Isolation", Earthquake Spectra, vol. 7, No. 2, 1991.
[5]. Panchal VR and Jangid RS, "Variable friction pendulum system for seismic isolation of liquid storage tanks", 2008.
[6]. Pranesh M and Sinha R. " VFPI: an isolation device for aseismic design", 2000.
[7]. Panchal VR and Jangid RS, "Seismic Isolation of Bridge Using Variable Curvature Friction Pendulum System", 2008.
[8]. Bhasker Rao P and Jangid RS, "Experimental Study of Base-Isolated Structures", 2001.
[9]. Nagarajaiah S, Reinhorn AM, Constantinou MC. "Nonlinear dynamic analysis of 3d-base-isolated structures". J. of Str. Engg., 1991a; ASCE, 117(7), 2035-2054.
[10]. Narasimhan S, Nagarajaiah S, Johnson EA, Gavin HP. "Smart Base Isolated Benchmark Building, Part I: Problem Definition". J. of Struct. Control 2002; 00:1-6.
[11]. Jangid RS. "Parametric Study of Base-Isolated Structures". Advances in structural Engineering, 5(2) 2002.
[12]. Matsagar VA and Jangid RS, "Influence of isolator characteristics on the response of base-isolated structures", 2004.
[13]. Jangid RS, "Optimum lead-rubber isolation bearing for near-fault motions",Eng.Struct., 29: 2503-2513, 2007
[14]. Matsagar VA and Jangid RS, "Base Isolation for Seismic Retrofitting of Structures", 2008.
[15]. Shrimali MK and Jangid RS, "Seismic analysis of base isolated liquid storage tanks", 2002.