Proceedings of IOE Graduate Conference, 2019-Summer
Peer Reviewed
Year: 2019 Month: May Volume: 6
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Comparison of Effectiveness of Base Isolation System Using Lead Plug Bearing in Different Shaped RC Frame Building Structure

Bishal Ratna Tamrakar [a], Gokarna Bahadur Motra [b]

[a] *Department of Civil Engineering, Thapathali Campus, IOE, Tribhuvan University, Nepal*
Corresponding Email: [a] tamrakarbsal@gmail.com

Abstract
Base isolation is an anti-seismic design strategy that can reduce the effect of earthquake ground motion by uncoupling the superstructure from the foundation. The structure can be decoupled from the horizontal components of the ground motion by interposing structural elements with low horizontal stiffness between the foundation and superstructure. This research described the applicability of base isolation system for reinforced concrete structure using Lead Plug Bearing (LPB) as a passive control [1].
The linear model Time History Analysis of three different shaped RC frame buildings was performed by using ETABS software for fixed base and isolated base system. Analysis illustrated that the building responses like base shear, roof acceleration and relative displacement between base and roof of the structure decreased while the fundamental time period of the structure increased. The effect of base isolation also depends upon the types of soil.

Keywords
Base Isolation, Lead Plug Bearing, Time History Analysis

1. Introduction

Base Isolation is one of the most effective passive control methods to reduce vibrations transmitted from ground to the structure. The base isolator protects structures from earthquake forces by deflecting and absorbing seismic energy. The seismic energy is deflected by making the base of the building flexible in lateral direction, thereby increasing the fundamental time period of the structure. Since the isolator behaves non-linear response to the earthquake excitation and exhibits hysteretic behavior, much of the input seismic energy to the isolators is lost in the hysteresis loop [2].

The lead plug bearing is a more recent innovation which was first introduced and used in New Zealand in the late 1970s. Therefore, they are also referred as N-Z system. LPB system provides the combined features of vertical load support, horizontal flexibility, restoring force and damping on a single unit. To provide an additional means of energy dissipation, a central lead core is added which deforms plastically under shear deformation, enhancing the energy dissipation capabilities compares to the low-damping natural rubber bearing.

Building geometry and configuration plays vital role in seismic resistant design of a building. The regularity of a building can significantly affect its performance during a strong earthquake. Buildings with irregular geometry respond differently against seismic action. A building may be classified as a regular or an irregular structure. Regular structures have no significant physical discontinuities in plan or vertical configuration or in their lateral force resisting systems, whereas irregular structures have significant physical discontinuities in configuration or in their lateral force resisting system. They may have either vertical irregularity or plan irregularity or both.

2. Objectives

The study is carried out with following objectives of work.

- To determine the behavior of the structure with base isolation using lead plug bearing (LPB).
- To evaluate the effectiveness of Lead Plug Bearings in reducing the earthquake response in

multi storied RC frame building structure.

- To compare different types - regular (rectangular) shaped and irregular shaped buildings with LPB and fixed base system.

3. Methodology

3.1 Modelling in ETABS

The 3D model of three different shaped reinforced concrete buildings were built in finite element software ETABS 2015. Different material properties and section properties has been assigned.

Sailent Features of the buildings

Shape of Building:Square, L-Shaped and C-Shaped
Size of Building (L x B) :15m x 12m
Inter-story Height of Building :3m
Column Size:500mm x 500mm
Beam Size:400mm x 500mm
Depth of Slab:127mm
Staircase Waist Slab Depth:127mm
Number of Story:Five Story + Staircase Cover

Defining Material Properties

The properties of different materials that have been used in the analysis model are described in brief as follows:

- For M20 Concrete
  Modulus of Elasticity (E) = 22360.68 MPa
  Specific Weight Density (γ) $=25KN/m^3$
  Poisson's Ratio (η)=0.2
  Modulus of Rigidity (G) =9316.95 MPa
- For Steel Rebar (Fe500)
  Modulus of Elasticity (E) =200,000 MPa
  Specific Weight Density(γ) =76.97 KN/m^3

Model Built-up

After defining the section properties of beam, column and slab, the frame structure 3D model was built by assigning the various sections. Three different shaped buildings model were built with fixed base. Beam and columns were assigned by line element while slab was defined as a thin shell element of 5" thickness.

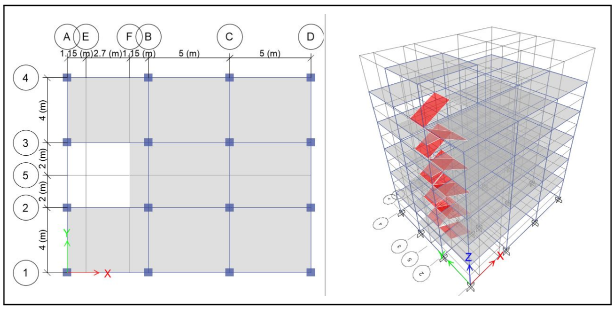

Figure 1: Rectangular Building

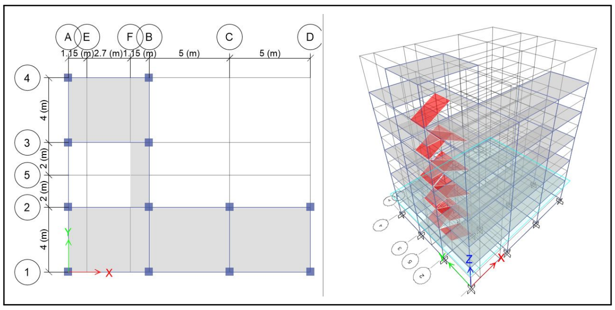

Figure 2: L Shaped Building

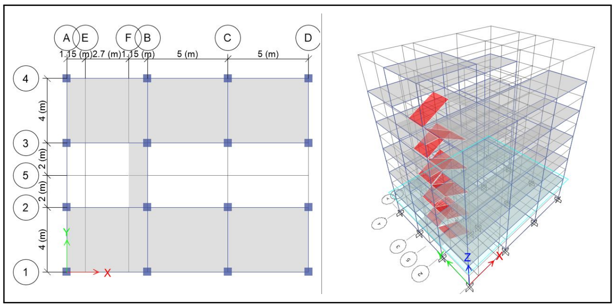

Figure 3: C Shaped Building

Analysis of Fixed Base Model

Linear Static analysis of three different models in two different soil conditions was carried out for fixed base. The vertical loafs under each column were taken for the design of Lead Plug Bearing (LPB). The vertical loads were grouped into three categories and three types of LPB were designed depending upon the vertical loads.

3.2 Design of Lead Plug Bearing

For the design of LPB, base isolated time period of 2sec was taken. The design parameter of LPB like effective stiffness, post yield stiffness, yield strength

and yield displacement were calculated for three different shaped buildings having two soil conditions. The geometric properties of LPB (Group 1, Group 2 and Group 3) were calculated. A sample design calculation of LPB for rectangular building in Hard Soil is shown below
S_a/g= 0.350
S_a= 3.434 m/s^2
Vertical Load(W)= 968.00 KN
Isolation Time Period(T_D)= 2.00 sec
Effective Stiffness(K_{eff})= 973.88 KN/m
Effective Damping Ratio (ξ_{eff}) = 15 %
S_d= 0.348 m
Energy Dissipation (W_D) = 111.084 KNm
Yield Strength(Q_D)= 79.83 KN
Post Yield Stiffness(K_d)= 744.42 KN/m
Initial Stiffness (K_u) = 7,444.16 KN/m
Yield Displacement (D_Y)= 0.0119 m
F_y= 88.70 KN
Q= 82.66 KN
Post Yield Stiffness Ratio= 0.10

Geometric Design

Material Properties
E= 4450 KN/m^2
ε_b= 500 %
G= 1060 KN/m^2
Modification Factor (k)= 0.57
Design Shear Strain (γ_{max}) = 50 %
Effective Damping Ratio(ξ_{eff}) = 15 %
Yield Strength of Lead Core (f_{py}) = 8820 KN/m^2
Allowable Normal Stress(σ_c) = 7840 KN
Yield Strength of Steel Plates (F_y) = 274000 KN/m^2
Shear Yield Strength of Steel Plates (F_s) = 164400 KN/m^2
Lead Plug Area (A_p) = Q_D/f_{py}
= 0.0091 m^2
Diameter of Lead Plug (d_P) = 0.107 m
Assume Diameter as d_P = 0.110 m
Total Height of Rubber Layer H = $S_d/(\gamma_{max}$) = 0.696 m
Select Shape Factor such that $E(1+2kS^2)/G >$ 400 S
> 9.0940938
Use S= 10
Compression Modulus of Rubber-Steel Composite (E_C) = 511750 KN/m^2
Effective Area A_0 of the bearing based on the allowable normal stress under vertical load case:
$\sigma_c = P_{DL+LL}/A_0 \leq 7840$
A_0= 0.12 m^2
Effective area A_1 from the shear strain condition for the vertical load case γ_{DL+LL} = 6S x $P_{DL+LL}/(E_c\ A_1)$ $\leq \varepsilon_b/3$
A_1= 0.07 m^2
K_d is related to K_r by
$K_d = K_r(1+12A_p/A_0)$
K_r = 396.04 KN/m
Area of the rubber layer, A = 0.260 m^2
Diameter, d = 0.58 m
A_{re} = 0.073 m^2
A = max (A_0,A_1,A_2) = 0.12 m^2
d = 0.40 m
Adopt d = 0.50 m
A = 0.196 m^2
Single Layer Rubber thickness: t = 0.0125 m = 1.25 cm
Number of Layers: N = 55.661805
Use N = 56 Nos.
Steel Plate Thickness,t_s > 2 mm
> 0.65 mm
Use t_s = 2.5 mm
Total height of the isolator, h = 88.577257 cm
Cover Plate Thickness = 0.025 m
Diameter of Cover Plate, D = 60 cm

Table 1: Rectangular Building in Hard Soil

	LPB1	LPB2	LPB3
Time Period,T(sec)	2	2	2
Effective Damping(ξ_{eff})	15%	15%	15%
Axial Load on Isolator, W_i(KN)	968.00	1540.77	2299.46
Effective Stiffness,K_{eff} (KN/m)	973.88	1550.13	2313.43
Post Elastic Stiffness,K_d (KN/m)	744.42	1184.89	1768.34
Yield Strength, Q_D(KN)	79.83	127.06	189.63
Yield Displacement, D_Y (m)	0.0119	0.0119	0.0119
Diameter of Rubber (mm)	500.00	550.00	650.00
Total Height of the bearing (mm)	885.77	873.27	853.27
Number of rubber Layers	56	51	43
Each rubber layer Thickness (mm)	12.50	13.75	16.25
Diamter of Lead Core (mm)	110.00	140.00	170.00

Table 2: Rectangular Building in Soft Soil

	LPB1	LPB2	LPB3
Time Period,T(sec)	2	2	2
Effective Damping (ξ_{eff})	15%	15%	15%
Axial Load on Isolator, W_i(KN)	968.00	1540.77	2299.46
Effective Stiffness,K_{eff} (KN/m)	973.88	1550.13	2313.43
Post Elastic Stiffness,K_d (KN/m)	744.42	1184.89	1768.34
Yield Strength, Q_D(KN)	133.31	212.19	316.68
Yield Displacement, D_Y (m)	0.0199	0.0199	0.0199
Diameter of Rubber (mm)	500.00	550.00	650.00
Total Height of the bearing (mm)	1444.44	1424.44	1391.94
Number of rubber Layers	93	85	72
Each rubber layer Thickness (mm)	12.50	13.75	16.25
Diamter of Lead Core (mm)	140.00	180.00	220.00

Table 4: L Shaped Building in Soft Soil

	LPB1	LPB2	LPB3
Time Period,T(sec)	2	2	2
Effective Damping (ξ_{eff})	15%	15%	15%
Axial Load on Isolator, W_i(KN)	929.20	1650.87	1996.81
Effective Stiffness,K_{eff} (KN/m)	934.85	1660.90	2008.94
Post Elastic Stiffness,K_d (KN/m)	714.58	1269.56	1535.59
Yield Strength, Q_D(KN)	127.97	227.36	275.00
Yield Displacement, D_Y (m)	0.0199	0.0199	0.0199
Diameter of Rubber (mm)	400.00	550.00	600.00
Total Height of the bearing (mm)	1504.44	1424.44	1406.94
Number of rubber Layers	117	85	78
Each rubber layer Thickness (mm)	10.00	13.75	15.00
Diamter of Lead Core (mm)	140.00	190.00	200.00

Table 3: L Shaped Building in Hard Soil

	LPB1	LPB2	LPB3
Time Period,T(sec)	2	2	2
Effective Damping (ξ_{eff})	15%	15%	15%
Axial Load on Isolator, W_i(KN)	929.20	1650.87	1996.81
Effective Stiffness,K_{eff} (KN/m)	934.85	1660.90	2008.94
Post Elastic Stiffness,K_d (KN/m)	714.58	1269.56	1535.59
Yield Strength, Q_D(KN)	76.63	136.14	164.67
Yield Displacement, D_Y (m)	0.0119	0.0119	0.0119
Diameter of Rubber (mm)	500.00	550.00	650.00
Total Height of the bearing (mm)	885.77	873.27	853.27
Number of rubber Layers	56	51	43
Each rubber layer Thickness (mm)	12.50	13.75	16.25
Diamter of Lead Core (mm)	110.00	140.00	170.00

Table 5: C Shaped Building in Hard Soil

	LPB1	LPB2	LPB3
Time Period,T(sec)	2	2	2
Effective Damping(ξ_{eff})	15%	15%	15%
Axial Load on Isolator, W_i(KN)	957.16	1535.88	2027.48
Effective Stiffness,K_{eff} (KN/m)	962.98	1545.21	2039.80
Post Elastic Stiffness,K_d (KN/m)	736.08	1181.13	1559.18
Yield Strength, Q_D(KN)	78.93	136.66	167.20
Yield Displacement, D_Y (m)	0.0119	0.0119	0.0119
Diameter of Rubber (mm)	400.00	550.00	650.00
Total Height of the bearing (mm)	920.77	873.27	863.27
Number of rubber Layers	70	51	47
Each rubber layer Thickness (mm)	10.00	13.75	15.00
Diamter of Lead Core (mm)	110.00	140.00	160.00

Table 6: C Shaped Building in Soft Soil

	LPB1	LPB2	LPB3
Time Period,T(sec)	2	2	2
Effective Damping (ξ_{eff})	15%	15%	15%
Axial Load on Isolator, W_i(KN)	957.16	1535.88	2027.48
Effective Stiffness,K_{eff} (KN/m)	962.98	1545.21	2039.80
Post Elastic Stiffness,K_d (KN/m)	736.08	1181.13	1559.18
Yield Strength, Q_D(KN)	78.93	136.66	167.20
Yield Displacement, D_Y (m)	0.0199	0.0199	0.0199
Diameter of Rubber (mm)	400.00	550.00	600.00
Total Height of the bearing (mm)	1504.44	1424.44	1406.94
Number of rubber Layers	117	85	78
Each rubber layer Thickness (mm)	10.00	13.75	15.00
Diamter of Lead Core (mm)	140.00	180.00	200.00

3.3 Assigning LPB in Model

In the model, the rubber isolator has been assigned by selecting the rubber isolator as link type and other properties like effective stiffness, effective damping and nonlinear properties has been assigned. The boundary condition of the isolator has been selected in such a way that the isolator is fixed in vertical direction since it has very high vertical stiffness whereas the isolator has degree of freedom in two horizontal directions.

3.4 Defining Time History Function

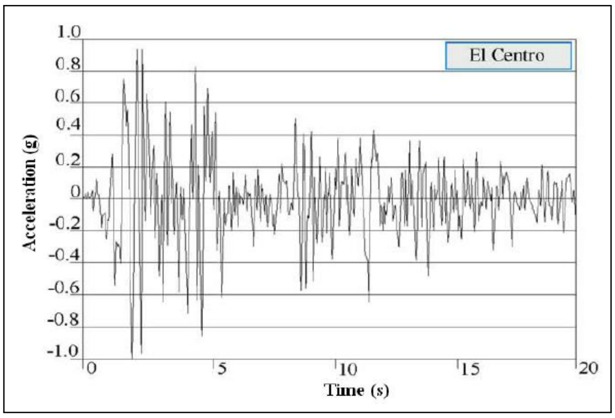

Figure 4: Time History Record of ElCentro Earthquake

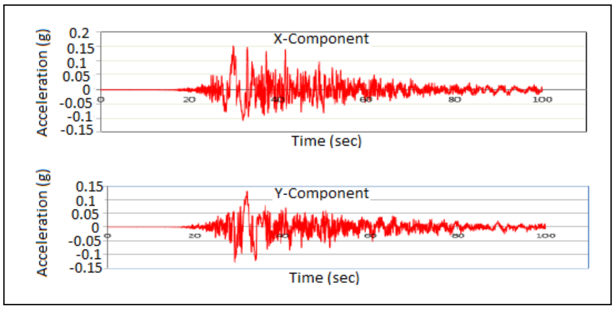

Figure 5: Time History Record of Gorkha Earthquake

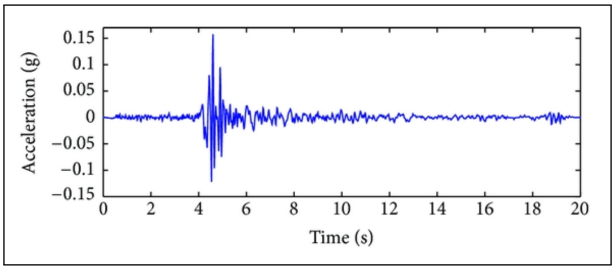

Figure 6: Time History Record of Northridge Earthquake

The time history records of Imperial Valley-02 (EL Centro, array-09), Gorkha earthquake and Northridge earthquake has been applied as an excitation force in the model.

3.5 Spectral Matching Method

Time domain method was chosen for spectral matching, target response spectrum was set to Indian Standard and reference acceleration time history was chosen as per required time history functions. The uniform unit was set for both functions and the time history was matched.

3.6 Linear Modal Time History Analysis

The Linear modal time history analysis or mode superposition method is often preferred over direct integration approach because it has more flexibility and a better control over the step-by-step time integration of each modal equation. Linear modal time history analysis was performed to analyse the modal.

4. Result and Discussion

In the present study, Time History Analysis of three different shaped buildings was carried out for three different earthquake motions.

The results of time history analysis were interpreted to investigate the effectiveness of lead plug bearing to minimize the base shear, story drift, roof acceleration and displacement. The different shaped buildings were analyzed with fixed base and base isolated conditions in different conditions.

The comparison chart shows that base isolation decreases the base shear of the building for all structure. However, the base isolation is more effective in hard soil than in soft soil. Further, the decrease in value of base shear in C-Shaped building in hard soil is more in comparison to others.

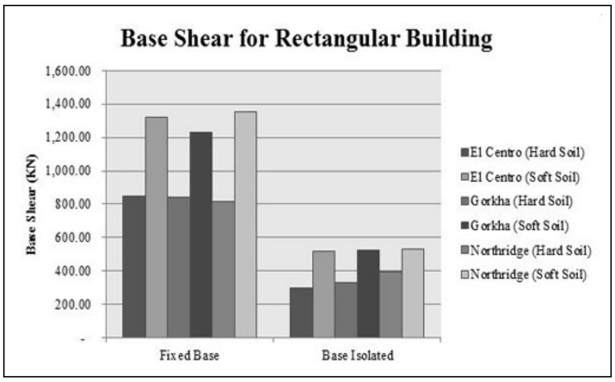

Figure 7: Base Shear of Rectangular Building

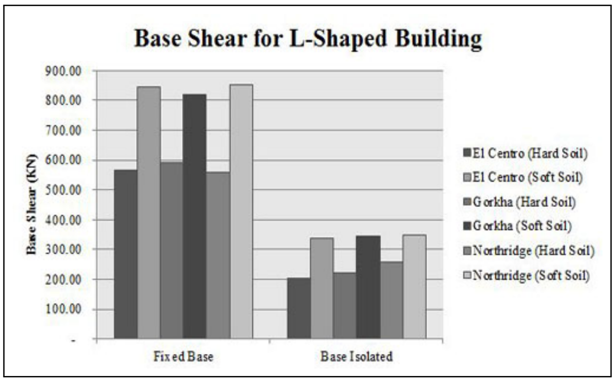

Figure 8: Base Shear of L-shaped Building

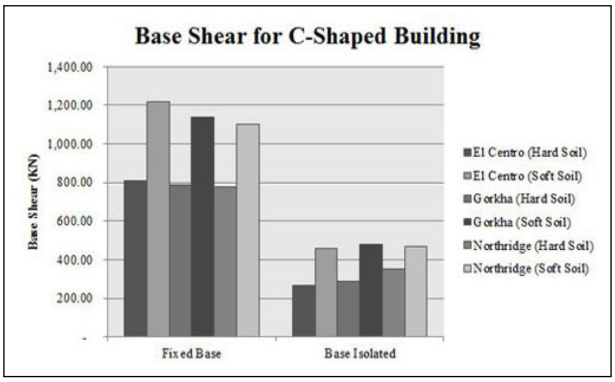

Figure 9: Base Shear of C-shaped Building

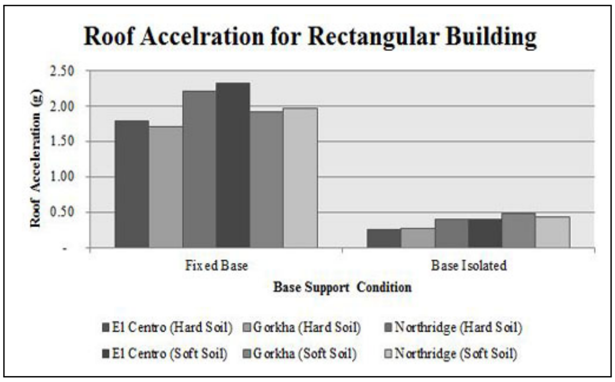

Figure 10: Roof Acceleration of Rect. Building

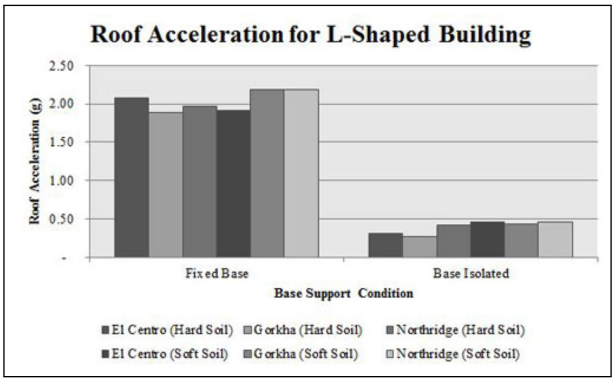

Figure 11: Roof Acceleration of L-shaped Building

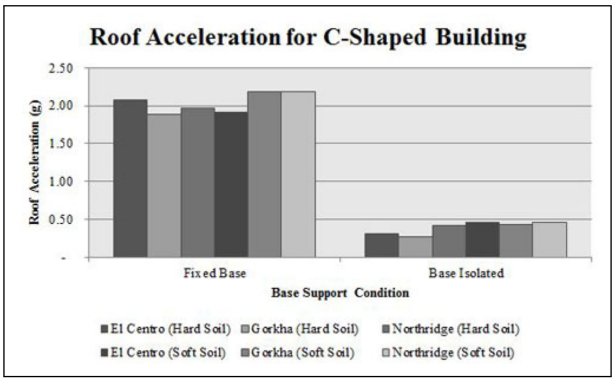

Figure 12: Roof Acceleration of C-shaped Building

Table 7: Comparison of Roof Displacement

Earthquake	Soil Condition	Building Shape	Fixed Base	Base Isolated	% Decreased
ElCentro	Hard Soil	Rectangular	11.9	4.5	62.18%
		L-Shaped	15.8	4.5	71.52%
		C-Shaped	13.0	4.7	63.85%
	Soft Soil	Rectangular	18.2	7.2	60.44%
		L-Shaped	18.1	9.4	48.07%
		C-Shaped	18.6	8.3	55.38%
Gorkha	Hard Soil	Rectangular	11.8	3.9	66.95%
		L-Shaped	11.6	3.6	68.97%
		C-Shaped	12.2	4.2	65.57%
	Soft Soil	Rectangular	18.1	6.4	64.64%
		L-Shaped	22.4	7.9	64.73%
		C-Shaped	18.3	8.5	53.55%
Northridge	Hard Soil	Rectangular	15.0	5.3	64.67%
		L-Shaped	11.9	4.7	60.50%
		C-Shaped	15.7	4.8	69.43%
	Soft Soil	Rectangular	17.7	7.0	60.45%
		L-Shaped	20.7	6.5	68.60%
		C-Shaped	23.5	7.3	68.94%

Table 8: Comparison of Story Drift

Earthquake	Soil Condition	Building Shape	Fixed Base	Base Isolated
ElCentro	Hard Soil	Rectangular	0.00127	0.00067
		L-Shaped	0.00140	0.00070
		C-Shaped	0.00123	0.00067
	Soft Soil	Rectangular	0.00180	0.00103
		L-Shaped	0.00173	0.00137
		C-Shaped	0.00177	0.00123
Gorkha	Hard Soil	Rectangular	0.00110	0.00043
		L-Shaped	0.00103	0.00033
		C-Shaped	0.00120	0.00043
	Soft Soil	Rectangular	0.00173	0.00080
		L-Shaped	0.00207	0.00143
		C-Shaped	0.00170	0.00123
Northridge	Hard Soil	Rectangular	0.00130	0.00073
		L-Shaped	0.00100	0.00063
		C-Shaped	0.00137	0.00067
	Soft Soil	Rectangular	0.00167	0.00093
		L-Shaped	0.00190	0.00090
		C-Shaped	0.00217	0.00100

5. Conclusion

The analysis of three different shaped RC frame building with fixed base and base isolation has been done. The effectiveness of LPB in the buildings using different earthquake excitation under various soil conditions has been discussed. The following conclusions can be drawn from the analysis:

1. The base shear, roof acceleration, story drift and relative roof displacement of the structure reduce significantly while the time period increases with the introduction of LPB as a base isolation as compared to fixed base.

2. Base shear of regular building is higher than irregular one.

3. The results show that the base isolation is more effective for hard soil compared to that for soft soil.

4. From above analysis, it can be concluded that the isolation system performs well in the sense of reducing structural responses as compared to the fixed base system. The roof accelerations, base shear as well as relative roof displacement were all effectively reduced by adoption of Lead Plug Bearing isolator systems.

References

[1] Tei-Chieh Wu. Design of base isolation system for buildings. 2001.

[2] T.K. Dutta. *Seismic analysis of Structures*. John Wiley & Sons (Asia) Pte Ltd, 2nd edition, 2010.

[3] A. K. Jain. *Reinforced Concrete: Limit State Designl*. Nem Chand & Bros, 7th edition, 2012.

[4] A. K. Chopra. *Dynamics of Structure Theory and Applications Earthquake Engineering*. Prentice Hall International, 1st edition, 1995.

[5] R.W. Clough and J. Penzien. *Dynamics of Structure*. McGraw Hill Publication, 2nd edition, 1993.

[6] S. Anilduke and A. Kheddikar. Comparison of building for seismic response by using base isolation. 2015.

[7] R. Jumy and S. Sabu. Seismic response of base isolated irregular buildings. 2017.

[8] S. Patel and J. Abbas. Effect of base isolation on seismic performance of rc irregular buildings. 2017.