J-Researchers

JOURNAL OF CIVIL ENGINEERING RESEARCHERS

Seismic Response Assessment of high rise RC building with Lead Rubber bearing base isolator on different soil types

Faramarz Noruzi[a,*], Ahmad Hasanpour[a], Sahand Saeedian[a]

[a] *Islamic Azad University ,Chaloos, Iran*

Abstract

In this paper, the effect of base isolator on the seismic response demands of 12 story reinforced concrete buildings with moment resistant frame which are designed for soil types II and III according to fourth edition of Iran seismic code (2800) is investigated. The nonlinear time-history analysis is carried out on two buildings with different soil types in two states with and without base isolator under 7 near field earthquakes which are scaled for two performance levels of life safety and collapse prevention. The seismic responses with respects to base shears and inter-story drifts are compared according to the installation of LRB isolation systems in the frame building. The main function of the base LRB isolator is to extend the period of structural vibration by increasing lateral flexibility in the frame structure, and thus ground accelerations transferred into the superstructure can dramatically decrease. Therefore, Base isolation system is able to achieve notable mitigation in the base shear. In addition, they make a significant contribution to reducing inter-story drifts distributed over the upper floors.

Keywords: Base isolator; reinforced concrete; time-history; ETABS2015; lead-rubber bearing (LRB)

1. Introduction

Base isolation has been used as one of the most wildly accepted seismic protection systems that should substantially dissociate a superstructure from its substructure resting on a shaking ground, thereby sustainably preserving entire structures against earthquake forces as well as inside non-structural integrities. Base isolation devices can operate very effectively against near-fault (NF) ground motions with large velocity pulses and permanent ground displacements.

The most common base isolation devices used over many years by engineers are lead-rubber bearing

[*] Corresponding author. Tel.: +989111283877; e-mail: faramarz.norouzi46@yahoo.com

(LRB) isolators which combine isolation function and energy dissipation in a single compact unit [1,2]. Such LRB isolator devices provide vertical load support, horizontal flexibility, supplemental damping, and centering force to the structure from earthquake attack. In addition, they require minimal cost for installation and maintenance as compared to other passive vibration control devices [3,4]. The LRB isolator typically consists of laminated rubber layers with a lead core plug down its center as illustrated in Figure 1.

The typical LRB isolator has considerable maximum shear strains corresponding to between 125% and 200% because reinforcing steel plates have little effect on the shear stiffness. The energy dissipation generated by the yielding of the lead core achieves an equivalent viscous damping coefficient up to approximately 30%, and effectively reduces the horizontal displacement.

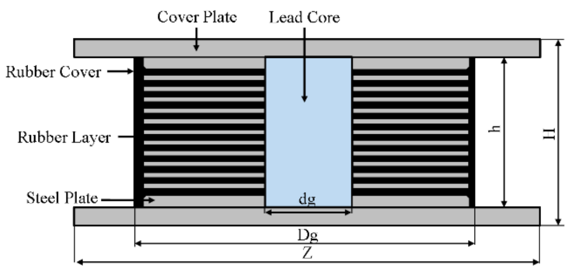


Figure 1. Components of lead-rubber bearing isolator

The LRB isolators with hardening behavior were developed for low to mid-rise buildings located in the moderate seismicity area, and besides, the behavior of the base-isolated building was accurately predicted by nonlinear dynamic analyses performed with relatively long-period ground motions. Most recently, some researchers have been starting to evaluate seismic performance and capacity for the base-isolated multi-story building structure subjected to several NF ground motions [5-7]. Many studies in the literature focused on the performance of buildings protected by isolators, made of rubber (elastomeric bearings with or without lead cores) [8-10].

This study is intended to mainly investigate seismic capacity and performance of 15 story reinforced concrete moment resistant building which is designed for soil types II and III according to fourth edition of standard 2800 and analyzed under nonlinear near field time-history analysis for two performance levels of life safety and collapse prevention.

Finally, statistical investigation based on analysis results should be conducted in order to fairly verify the effectiveness of the LRB base isolation system in the multi-story building structure.

2. LRB isolator device

The LRB isolator model used for this study which is actually applied in construction is chosen from code 523 entitled "Guidelines for the design and implementation of seismic isolation systems in buildings" [11]. Force-displacement responses for LRB isolator can be modeled with bilinear hysteretic loops. The bilinear hysteretic loops are defined by three key parameters: elastic stiffness (K_e), post yielding stiffness (K_P) and specific strength (Q). The idealized bilinear model based on experimental data is shown in Figure 2.

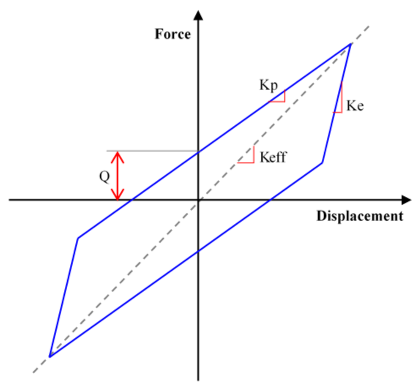


Figure 2. The idealized bilinear model for Isolator device

The horizontal effective stiffness for isolation is defined as [19]:

$$K_{eff} = \frac{(W = P_{DL+LL})}{g} \times \left(\frac{2\pi}{T_D}\right)^2 \quad (1)$$

In which T_D is the fundamental period of the isolated structure equal to 716/4 seconds that is three times more than the fundamental period of the not isolated structure (structures with fixed base). P_{DL+LL} is the support axial force under gravity loads in the structural model with fixed base. The amount of design displacement according to code 523:

$$D_D = \frac{g}{4\pi^2} \times \frac{A \times B \times T_D}{B_D} \leq 0.3m \quad (2)$$

In which A×B is design spectral acceleration and for soil types II and III is equal to 0.338, 0.508 according to fourth edition of standard 2800. The effective damping ratio (ξ_{eff}) is equal to 10%. The damping coefficient (BD) for isolator device with $\xi_{eff} = 10\%$ according to code 523 is equal to 1.2. The maximum relative shear deformation γ_{max} is equal to 150%. The specific strength (Q) is determined as:

$$Q = \frac{\pi}{2} K_{eff} \times \xi_{eff} \times D_D \quad (3)$$

The post yielding stiffness (K_P) is determined as:

$$K_P = K_{eff} - \frac{Q}{D_D} \quad (4)$$

The elastic stiffness (K_e) can be defined about 6.5 to 10 times of K_P. The vertical stiffness of LRB isolator is equal to:

$$K_V = K_{eff} \times \left[\frac{E \times (1 + 2kS^2)}{G} \geq 400\right] \quad (5)$$

In which, E and G are the elastic modulus and the shear modulus of lead core equal to 4.45 and 1.06 respectively. The shape factor (S) is equal to 20. k is the correction factor, which is in the range of 0.15 to 0.5 and it is equal to 0.45 in this study.

3. Building models and design

In this paper, 12 story 3D concrete frames with 3m story height and constant plan of 3 and 4 spans in two directions is selected. The lateral resistant system is moment resistant frames with moderate ductility. The buildings are located in Tehran with high seismicity on the soil types of II and III. The building floor is joist with Polystyrene block. The ACI 318-08 [12] is used for designing the Reinforced Concrete (RC) elements. The chosen loading codes are sixth issue of Iran regulations [13] and the fourth edition of Iran seismic code (Standard 2800) [14]. According to soil types II and III and also two states considering and not considering isolator device, 4 models are created which are named "II-Fix, II-Isolator, III-Fix, III-isolator". Design and nonlinear analysis is performed in finite element software of ETABS2015 [15].

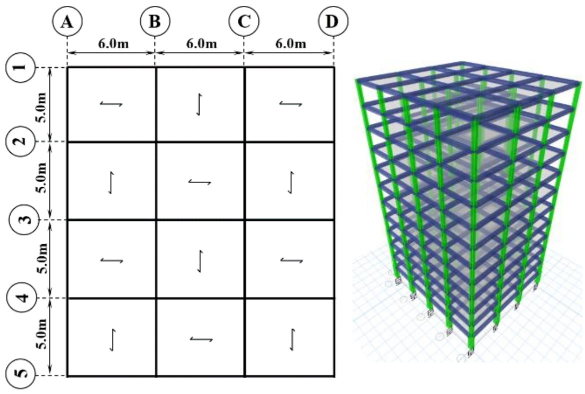


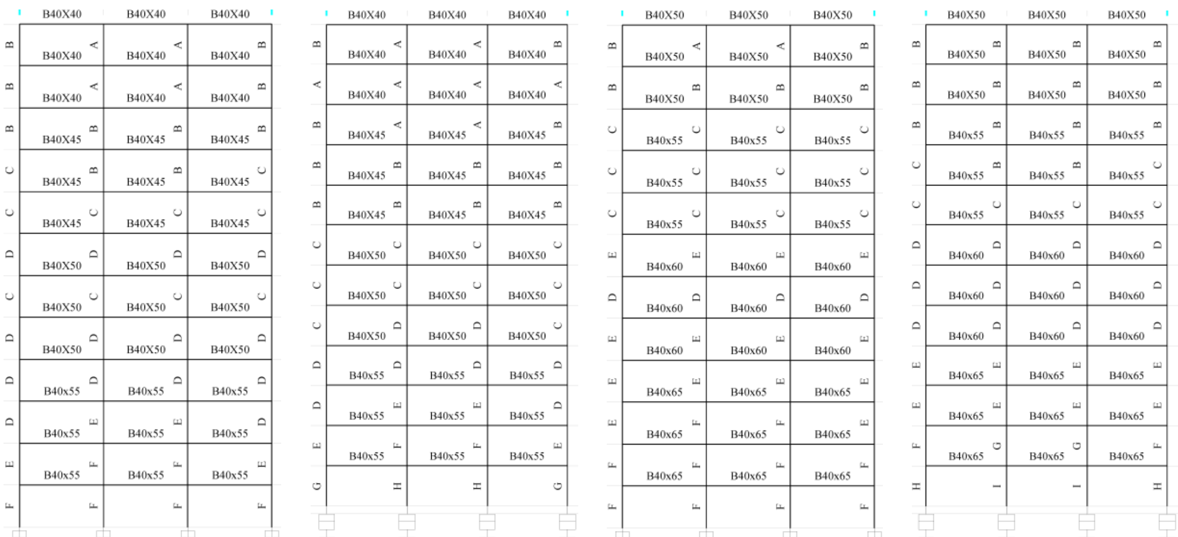
Figure 3. Typical plan of the building model and finite element model of 12 story RC building

compressive strength of 21 MPa $(f_c = 21\ MPa)$ and elasticity modulus of 22912.9 MP $(E_c = 22912.9\ MPa)$ and steel reinforcement with yielding stress equal to 400 MPa $(f_y = 400\ MPa)$. For nonlinear analysis, the plastic hinges are defined and allocated to elements in order to explain the nonlinearity properties of material and elements. According to section 4-3-1-4-6 of guideline 360 [16], the modelling parameters and acceptance criteria for each section and element are defined. All of the beams and columns are flexural control.

According to large displacements of LRB isolator, the applied acceleration to lower stories of RC buildings is larger than fixed base. So the column sections in the first 3 stories equipped with LRB isolator are larger than the fixed base. In return, by increasing the story number, the applied seismic loads in buildings equipped with LRB decreased significantly, so that the column sections become smaller. The designed sections of columns for middle frame of axis 3 for different soil types are shown in Figure 4. Also according to Figure 5, the amount of designed flexural reinforcement for beams in models equipped with LRB in the first 3 stories are larger than the fixed base specially in the first floor, this increases more than 2 times of fixed base. However, the flexural reinforcement percentage of beams in models with LRB isolator decreases around 20% from the fourth story to roof story.

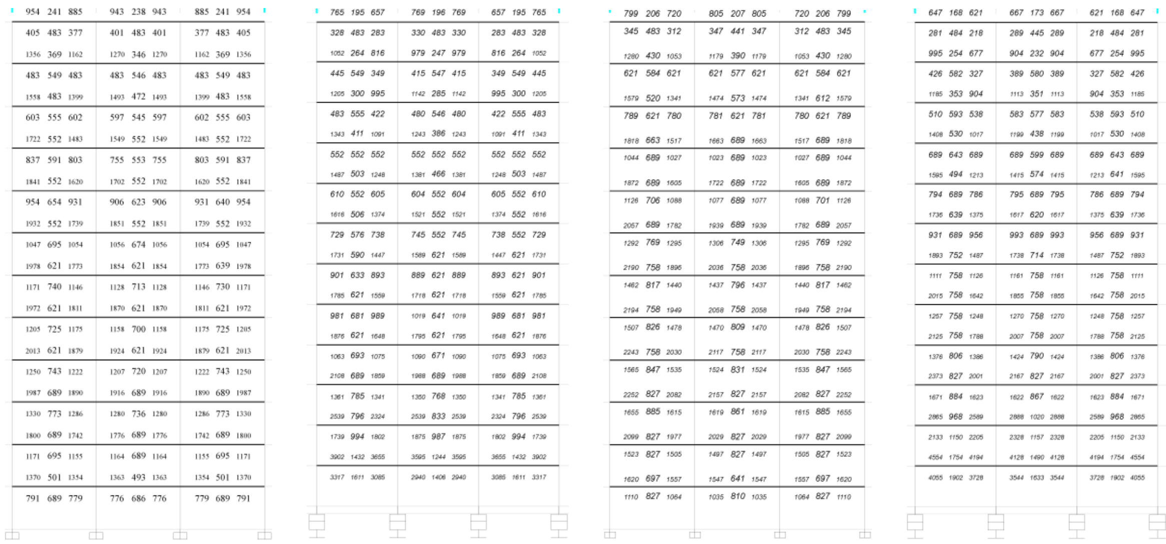
Table 1
Columns names and characteristics

Column section	Dimension (mm)	Reinforcement
A	40×40	8Φ20
B	40×40	12Φ20
C	45×45	16Φ20
D	50×50	20Φ20
E	55×55	24Φ20
F	60×60	24Φ22
G	65×65	24Φ25
H	70×70	24Φ28
I	75×75	26Φ28



(II-Fix) (II-Isolator) (III-Fix) (III-Isolator)

Figure 4. The designed sections of columns and beams for axis 3 of models



(II-Fix) (II-Isolator) (III-Fix) (III-Isolator)

Figure 5. The designed area of flexural reinforcement of beams for axis 3 of models

4. Nonlinear time-history analysis

In this section, the seismic behaviour of RC buildings in two states with and without isolator device (LRB) under the near field seismic ground motion is discussed. In the velocity records of near field seismic ground motion, the main pulses have larger period and intensity compared to far field ground motion. The near field earthquakes are influenced by fault mechanism and are identified by distinct waves that determine the structural response.

The studied models are analysed by nonlinear time-history method in two performance levels of life safety (LS) and collapse prevention (CP). In the LS performance level, low or repairable structural and non-structural damage is expected for moderate earthquake excitations (10% probability of occurrence in 50 years). Also in CP performance level, irreparable or hardly repairable structural and non-structural damage without any collapse is expected for major earthquake excitations (2% probability of occurrence in 50 years). The standard design spectrum with 2% probability of occurrence in 50 years for Tehran is extracted from seismic studies that is carried out for a specific construction project in the region of Niyavaran with the number record of 10071406 [17]. The standard design spectrums in different performance levels for soil types II and III is shown in Figure 6.

The selected earthquakes have similar characteristics such as: magnitudes 4.5 to 8 Richter scale, the shear wave velocity according to the site soil type is equal 600 to 1200 ft/s and the maximum range of selected acceleration records are between 0.2g-2g.

According to fourth edition of Iran seismic code (2800), the selected acceleration records for 3D analysis should be scaled by the following method: a) each acceleration record should be scaled to its maximum amount. This means that the maximum acceleration should be equal to gravity acceleration. b) the acceleration spectrum of each scaled acceleration record is determined by considering 5% damping ratio. c) each acceleration record should be scaled in such that for each period in the range of 0.2T-1.5T, the average amount of spectrums should not exceed more than 10 percent of 1.3 times standard design spectrum. T is the fundamental period of buildings. The characteristic of 7 earthquakes is shown in Table 2. Figure 7 presents the standard design spectrum with elastic acceleration response spectrums of chosen 7 earthquakes and their average amount in scaled modes in performance levels for RC buildings designed for different soil types.

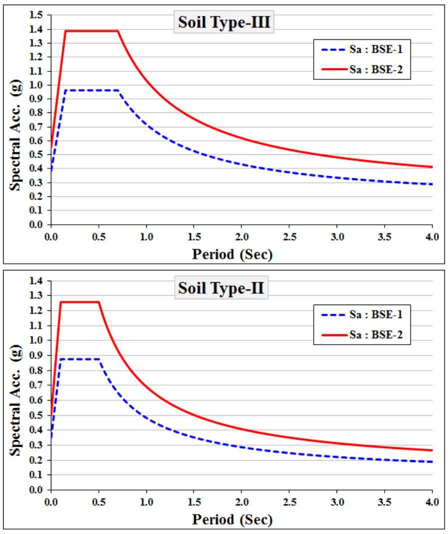


Figure 6. Standard design spectra for soil types II and III in various performance levels

Table 2
Selected earthquakes details

EQ. NO	Year	Earthquake	Recording Station	PGA (g)	Vp (cm/s)	Site Class	distance (Km)
1	1987	Whittier Narrows	90079 Doweney-Birchdale/180	0.299	37.8	D	56.8
2	1989	Loma Prieta WVC	CDMG 58235 Saratoga-W Valley Coll.	0.332	62.5	D	23.7
3	1990	Manjil, Iran	BHRC 99999 Abhar	0.496	43.78	D	40.43
4	1987	New Zealand A-MAT	99999 Matahina Dam	0.293	21.07	D	24.23
5	1981	Westmorland	5169Westmorland Fire Sta/90	0.496	34.4	D	35.6
6	1966	Park FieldTMB	CDMG 1438 Temblor pre-1969	0.357	21.5	D	26.1
7	1987	Tabas DAY	9102 Dayhook	0.406	26.5	D	27.0

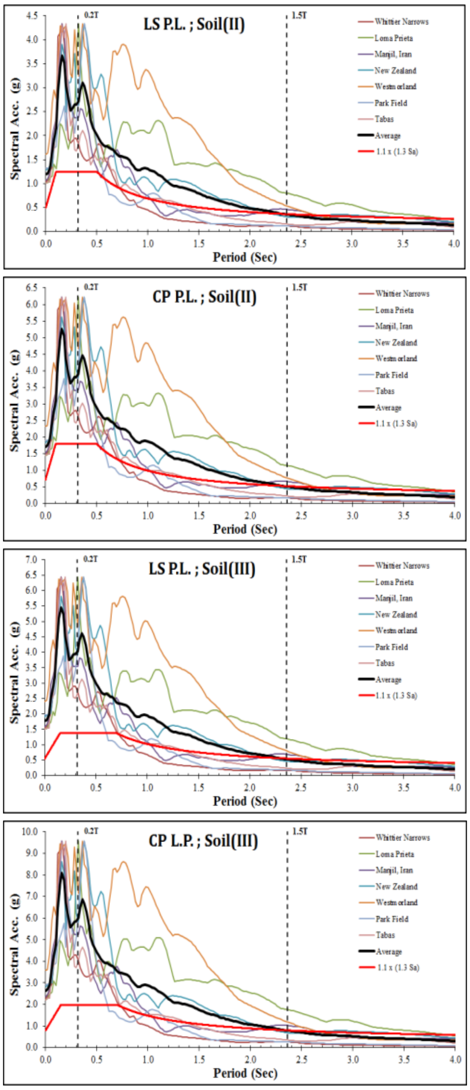


Figure 7. Comparison between average of scaled acceleration record of various spectra and standard design spectra in various performance levels

5. Result and discussion

Figure 8 illustrates the comparison of deformed shapes of RC buildings with and without the LRB isolator for the average of 7 earthquakes in two performance levels of LS and CP. It should be noticed that the allowable maximum drift according to table C1-2 of FEMA356 for LS and CP performance levels are 2% and 4% respectively [18].

The inter story drift of RC buildings in original case have completely non-uniform distribution along the height of structure. So that the inter story drift increases from base to fifth story and decreases after the fifth story. But in the case of using LRB isolator, the inter story drift have completely uniform distribution in all stories except first story. The maximum and minimum inter story drift in the original case for soil type II in LS and CP performance levels are equal to (1.56%, 0.47%) and (2.66%, 0.8%) respectively that the maximum inter story drift for LS and CP performance levels are 3.32 and 3.33 times of minimum inter story drift respectively. Also, the maximum and minimum inter story drift in the original case for soil type III in LS and CP performance levels are (1.78%, 0.54%) and (2.97%, 0.87%) respectively that the maximum inter story drift for LS and CP performance levels are 3.30 and 3.41 times of minimum inter story drift respectively. So it is expected that plastic behaviour characteristics of RC buildings which determines its hysteretic behaviour against incoming seismic forces have non uniform distribution along the height of buildings. Such that middle stories which have maximum deformations play the most important role in the plastic behaviour of buildings, however other stories have less effect in dissipating applied seismic energy. The RC buildings in original case because of not having a reasonable lateral resisting system do not present a uniform hysteretic behaviour against the applied seismic energy so that the buildings are not able to use all of its plastic capacity in order to dissipate the applied seismic energy. However, as it clears from the figures in case of using LRB isolator, the non-uniform distribution of inter story drift after a significant decrease along the height become substantially uniform.

Another important point is the effective reduction of maximum inter story drift in the case of using LRB isolator rather than the original case. So that the maximum inter story drift for soil type II in original case and equipped with LRB isolator in LS performance level are 1.56% and 0.59% respectively, and in CP performance level these amounts are equal to 2.66% and 1.03% respectively. The decrease of maximum inter story drift for soil type II in the case of equipped with LRB isolator compared to original case is 62.2% and 61.3% in LS and CP performance levels. Also the maximum inter story drift for soil type III in original case and equipped with LRB isolator in LS performance level are 1.78% and 0.7% respectively, and in CP performance level these amounts are equal to 2.97% and 1.15% respectively. The decrease of maximum inter story drift for soil type III in the case of equipped with LRB isolator compared to original case is 60.7% and 61.3% in LS and CP performance levels. It is found that the RC buildings equipped with LRB isolator act like a smart system in such that by increasing the strength and lateral stiffness of original buildings, not only make uniform the drift distribution along the height, but also decrease the maximum inter story drift significantly more than 60 percent. It is obvious that the LRB isolator have the ability to be highly compatible in terms of structural performance levels in any particular seismic level like moderate seismic level (LS performance level) and severe seismic level (CP performance level).

6. Conclusion

In this study, by designing two 12 story buildings in two states with and without LRB isolator on two different soils type II and III, seismic performance assessment of models under the near field earthquakes in LS and CP performance levels is presented. The extracted results are as follows:

- The high rise buildings designed on both soils type, in the first three stories have larger column sections and beam flexural reinforcement than the original case with fixed base. And this becomes inverse from fourth story to roof story.
- The high rise RC buildings with moment resisting frame are not able to present a uniform hysteretic

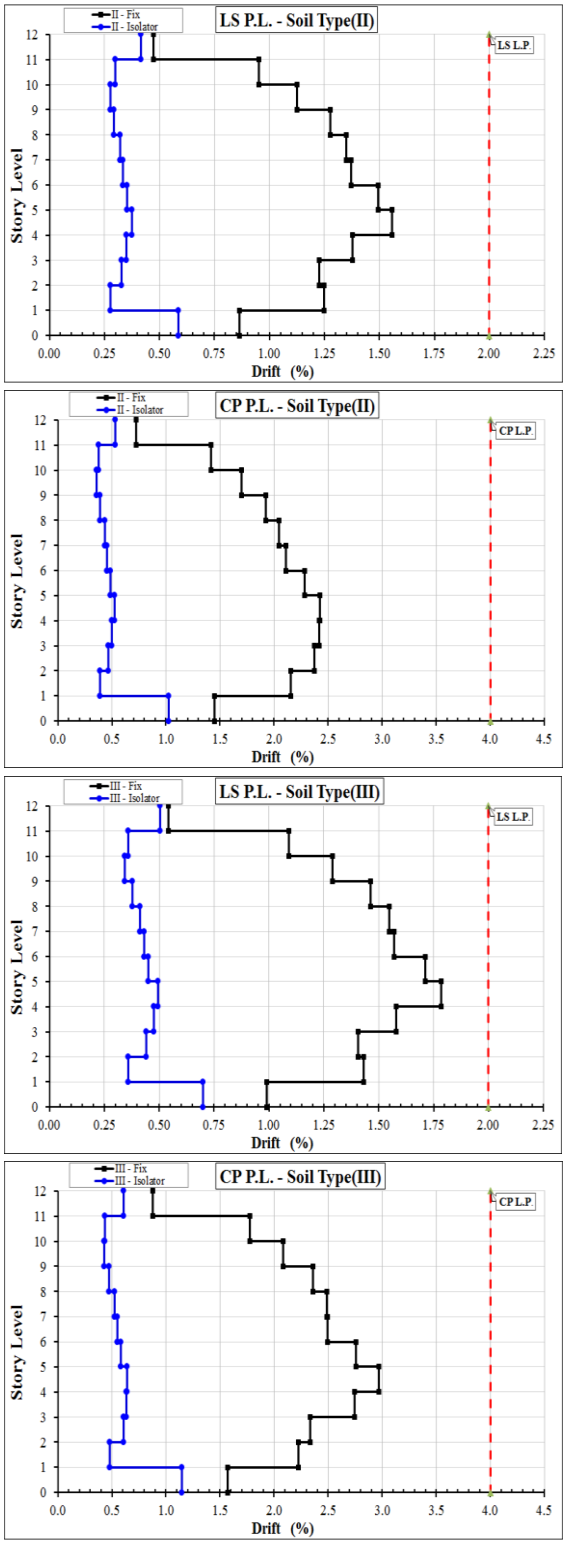


Figure 8. Comparison of average inter story drift for models in LS and CP performance levels

behavior along the height of buildings, so the entire nonlinear capacity of buildings is not used in dissipating of applied seismic energy. In contrary, in case of using LRB isolator, just the first story experiences large drift because of large displacements of base isolator and significant applied acceleration to the first floor, but the drift distribution along the height of building from the second story to roof story decreases and changes uniformly.

- The RC buildings equipped with LRB isolator because of having a ductile system with high damping ratio to absorb large earthquake movements, by increasing the flexibility, not only make uniform the displacement distribution but also decrease the maximum inter story drift significantly up to 60%. the LRB isolator have the ability to be highly compatible in terms of structural performance levels in any particular seismic level like moderate seismic level (LS performance level) and severe seismic level (CP performance level).

References

[1] S.L. Ahmadi, I.G. Tadjbakhsh, "A comparative study of performances of various base isolation systems, Part 1: Shear beam structures". J. Earthq. Eng. Struct. Dyn., 18, 11–32, 1989.
[2] C. Chen, K. Yeh, F. Liu, "Adaptive fuzzy sliding model control for seismically excited bridges with lead rubber bearing isolation". Int. J. Uncertain. Fuzz., 17, 705–727, 2009.
[3] G.J. Lee-Glauser, G. Ahmadi, L.G. Horta, "Integrated passive/active vibration absorber for multistory buildings". ASCE J. Struct. Eng., 123, 499–504, 1997.
[4] L. Su, G. Ahmadi, I.G. Tadjbakhsh, "Comparative study of base isolation systems". ASCE J. Eng. Mech., 115, 1976–1992, 1989.
[5] J.F. Hall, T.H. Heaton, M.W. Halling, D.J. Wald, "Near-source ground motion and its effects on flexible buildings". Earthq. Spectra., 11, 569–605, 1995
[6] P.B. Rao, R.S. Jangid, "Performance of sliding systems under near-fault motions". Nucl. Eng. Des., 203, 259–272, 2001.
[7] J. Shen, M. Tsai, K. Chang, G.C. Lee, "Performance of a seismically isolated bridge under near-fault earthquake ground motions". ASCE J. Struct. Eng., 130, 861–868, 2004.
[8] R.S. Jangid, J.M. Kelly, "Base isolation for near-fault motions". Earthq. Eng. Struct. Dyn., 30, 691–707, 2001.
[9] A. Rodriguez-Marek, "Near-Fault Seismic Site Response". Ph.D. Thesis, Civil Engineering, University of California, Berkeley, CA, USA, 2000.
[10] C.P. Providakis, "Effect of LRB isolators and supplemental viscous dampers on seismic isolated buildings under near-fault excitations". Eng. Struct., 30, 1187–1198, 2008.
[11] Publication No. 523, Iranian design and implementation guidance of seismic isolation systems in buildings, department of strategic supervision, technical and operational office, 1389.
[12] ACI Standard (ACI 318-08), American Concrete Institute, Building Code Requirements for Structural Concrete and Commentary, Edition January 2008.
[13] Sixth issue, Design loads for buildings, Iranian National Building Regulations, 1392.
[14] Standard 2800, the Iranian Code of Practice for Seismic Resistant Design of Buildings, Ministry of Housing and Urban Development, fourth edition, 1392.
[15] ETABS2015 (version 15.2.2); Computers and Structures, Inc.; Berkeley, CA 94704, 2015.
[16] Publication No. 360, Seismic Retrofitting Guidelines of existing buildings, Management and Planning Organization: Department of Technical Affairs to develop technical standards and Earthquake Risk Reduction, 1385.
[17] https://services6.tehran.ir/urbanmodule?portalid=6
[18] FEMA 356, Prestandard and Commentary for Seismic Rehabilitation of Buildings. Prepared by the American Society of Civil Engineers for the Federal Emergency Management Agency (Report No. FEMA-356), Washington, D.C. 2000.
[19] Bagherinejad, K., Hosseini, S., & Charkhtab, S. (2017). Cost Viability of a Base Isolation System for the Seismic Protection of mid-rise reinforced concrete moment frames. Journal Of Civil Engineering Researchers, 1(1), 1-7.