Performance Analysis of LRB and HDRB Base Isolators for Low-rise and mid-rise steel frames

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Performance Analysis of LRB and HDRB Base Isolators for Low-rise and mid-rise steel frames

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ABSTRACT: The enhancement of seismic performance is the main concern of owners and designers in the use of elastomeric bearings for the performance criteria. The LRB (Lead Rubber Bearing) and the HDRB (High Damping Rubber Bearing) are widely used as a part of the base isolation systems (BISs). This paper discusses and investigates the difference between them for their seismic performance and their effects for deduction of structural weight and material usage for the low-rise and mid-rise structures. The results show that the HDRB has better seismic performance in conjunction with its efficiency for weight deduction which conducts the projects for an economic design. Conclusion of paper shows clear vision to design engineers for future selection between LRB an HDRB BISs.

1 INTRODUCTION

1.1 *Description*

Many seismic resistant structural designs procedures and technologies have been developed over the years in attempt to mitigate the effects of earthquakes on buildings and potentially vulnerable contents. The base isolation systems (BISs) are a relatively evolving technology of this kind. BISs are more commonly between the top of the footings/pedestals and the superstructure. The seismic isolation consists essentially of the installation of devices, which decouple the structure and/or its contents from potentially damaging earthquake induced ground or support motions. This decoupling is achieved by increasing the flexibility of structure, together with providing appropriate damping.

Basically, the seismic isolation devices differ from the conventional seismic design approaches. During these years, uncertainty to select a proper system is appeared. In the conventional approaches, it is accepted that considerable earthquake forces and energy will be transmitted to the structure from the ground. In the seismic isolation, however the fundamental aim is to substantially reduce the transmission of the earthquake forces and energy into the structure. Therefore, the seismic isolation is an innovative seismic resistant design approach aimed at protecting structures against damage from the earthquake by limiting the earthquake attack rather than resisting it. Although it is a relatively recent technology, the seismic isolation has been well evaluated and reviewed, there are few comparative studies on performances of various types of BISs for the critical design parameters. In the most of countries, which are located in high seismic risk regions, rehabilitation and seismic upgrading is now as a part of their program. The number of low-rise and mid-rise buildings for the rehabilitation or new projects is numerous so, the main concern of owners and designers in the use of elastomeric bearings for the performance criteria about their types, behavior, performance in conjunction with costs. Two famous BISs introduced as the rubber bearing (RB) or high damps rubber bearing (HDRB) and lead rubber bearing (LRB), systems are investigated.

To evaluate performances of two mentioned BISs and suitable earthquake-resistance design of the performance analysis for variations in building height and types of BISs in conjunction with the deduction of structural weight to show the efficiency of devices is required.

Therefore, a comparative study on performances of mentioned BISs for low-rise and mid-rise building as the core of interests for rehabilitation and new projects in different countries is accomplished in this paper.

A set of analyses performed for design of sample frames with 5, 10 and 15 stories. The elements of frames have been designed based on AISC code. For a consistent and proper design condition a sort of nonlinear pushover analyses carried out to make confidence on their behavior in different lateral loads scenarios for the final consequence. During the sort of push over analyses, iterative analysis performed to find the minimum sections based on codes as the common practice that engineers normally have concern about it. Performance analyses based on the performance levels mentioned in FEMA 356 code (US Federal Emergency Management Agency) have been carried out using three different earthquake records with different frequency contents. All analyses performed for LRB and HDRB separately to find their efficiency in this paper. Efficiency is the level of performance in conjunction of deducted weight of structural element as the basis for economic design.

1.2 *Base isolator behavior*

A variety of the seismic isolation and energy-dissipation devices has been developed all over the world. The components in BISs are specially designed, distinct from the structural member, and installed at the base of the structure. Basically, BISs increase flexibility and thus natural period of the structure. If the frequency is decreased beyond the earthquake frequency content, the possibility of resonance and the seismic acceleration response is reduced. Energy dissipation or Damping is one of the important features. However, the increased period and consequent increased flexibility also affects the horizontal seismic displacement of the structure. These excessive displacements are counteracted by the introduction of increased damping and/or energy-dissipation. Because of these characteristics of BISs, they can attenuate the harmful horizontal acceleration transmitted to the superstructure and reduce the sectional force of the substructure. Various systems have used as RBs (elastomeric bearings) with and without lead plugs, damping being provided either by the use of high-loss rubber or neoprene materials in the construction of bearings or by auxiliary viscous dampers.

1.3 *The RB (HDRB) system*

These bearings are fully developed as commercial products whose main application has been for bridges and buildings. The RB system consists of alternating layers of rubber and steel with the rubber being vulcanized to the steel plates for the horizontal flexibility and the vertical stiffness. The dominant feature of this device is the parallel action of spring and dashpot (Fig. 1). The equation of motion is stated as :

$$M\ddot{x}_b(t) + C_b\dot{x}_b(t) + K_b x_b(t) + \sum_{n=1}^{N} m_n a_n = -M\ddot{x}_g(t) \qquad (1)$$

Where, C_b and K_b are damping and stiffness coefficients of the RB system, respectively. The high-loss rubber has use for this device with high damping value and it calls as high damping rubber bearing (HDRB).

1.4 *The LRB system*

A lead-plug insert in the core of RBs. It provides hysteretic energy-dissipation; therefore, the damping required for a successful seismic isolation system can be incorporated in a single compact component with the RB system. Thus, one device is able to support the structure vertically, to provide the horizontal flexibility together with the restoring force, and to provide the required hysteretic damping. To determine properties of the LRB system, the bilinear model of characteristic curve is used. The effective stiffness coefficient, K_{eff}, is obtained with reference to shear force versus displacement hysteresis loop (Fig. 2). In general, the concept of this effective value is a gross approximation, but it works surprisingly well.

The equation of motion, which uses the effective and equivalent values, is stated as:

$$M\ddot{x}_b(t) + C_{eq}\dot{x}_b(t) + K_{eff}x_b(t) + \sum_{n=1}^{N} m_n a_n = -M\ddot{x}_g(t) \qquad (2)$$

Where, C_{eq} is the equivalent linear damping coefficient given by Eq. (3) and ξ_{eq} is the equivalent linear damping ratio given by Eq. (4), respectively.

$$C_{eq} = 2\xi_{eq}\sqrt{MK_{eff}} \qquad (3)$$

$$\xi_{eq} = \Delta E/(2\pi K_{eff}D_D^2) \qquad (4)$$

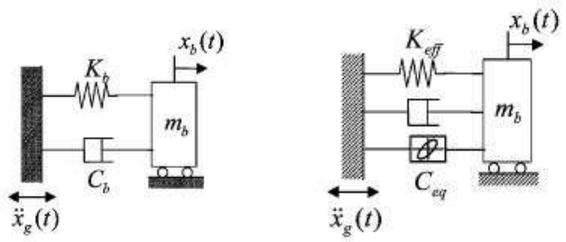


Fig 1. RB/HDRB model LRB model

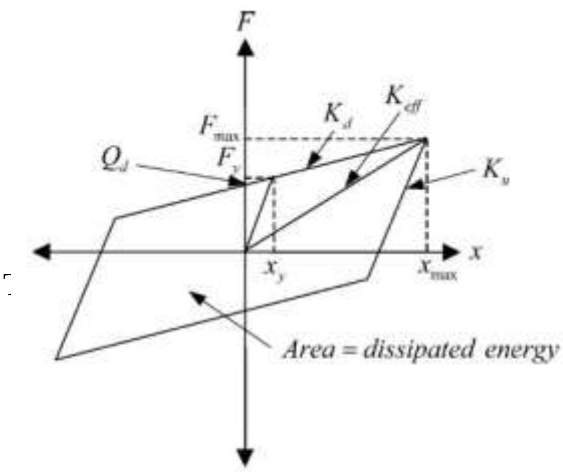


Fig. 2. Characteristic of LRB system

2 SENSITIVITY ANALYSIS

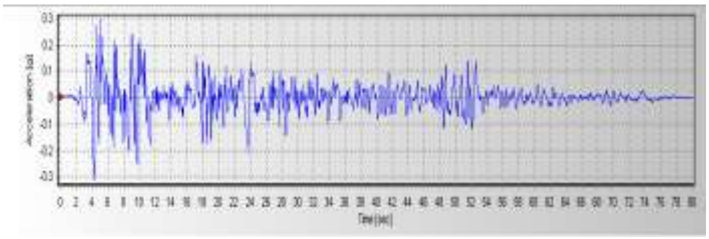
2.1 *Model description and assumptions*

For the performance analysis of two BIS models, three different models of steel frames have been considered (Table 1). For the low-rise to mid-rise models the 5, 10 and 15 stories, building have been analyzed. Performance analysis and pushover analysis were carried out to find the number of plastic hinges and the performance level of each model for different type of base isolators.

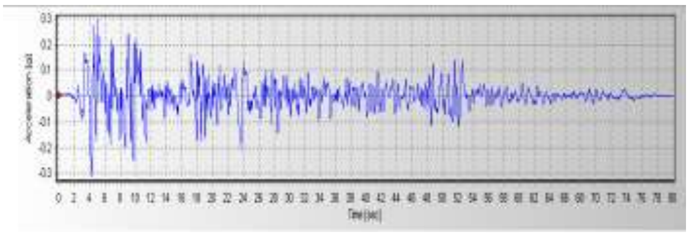
Table 1. Specification of Models

Description	Model 1	Model 2	Model 3
Fixed Base Models	5F	10F	15F
Isolated Base Model	5I	10I	15I
Columns shape	Rectangular	Rectangular	Rectangular
Connections	Fixed	Fixed	Fixed
Design Code	FEMA 357	FEMA 357	FEMA 357
Software	SAP2000	SAP2000	SAP2000
Height of stories	3m	3m	3m
Length of spans	5m	5m	5m
Structural system	Steel frame	Steel frame	Steel frame

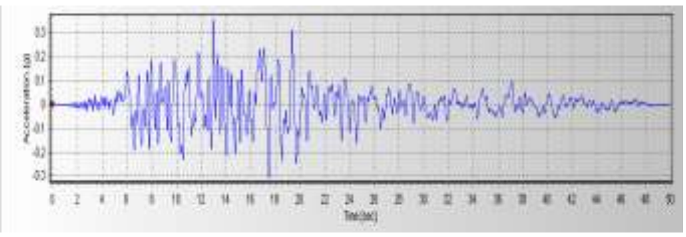
For the performance analysis on variations in the design parameters of BISs, a number of different earthquake excitations are used (Fig. 3).



Cape Mendocino Earthquake record, 1992



El Centro Earthquake record, 1940



Northridge Earthquake record, 1994

Fig. 3 Time histories of different earthquakes

Among several major earthquake excitations, El CENTRO (1940), CAPE MENDOCINO (1992) and NORTHRIDGE (1994) earthquakes are used as the ground acceleration. These earthquake records have a variety of peak ground acceleration (PGA) and cover various forms of the frequency range. The El Centro time history is typical of those to be expected on the ground of moderate flexibility during a major earthquake. It must also be recognized that occasionally earthquakes give their strongest excitation at long periods

The finite element analysis software, SAP2000 has been used for both Static nonlinear Pushover Analysis (SNPA) and Nonlinear Time History Analysis (NTHA).

SNPA is used to check the behavior and find the different structural levels of performance based on FEMA 357. Three levels of plastic behavior introduced as IO (Immediate Occupancy), LS (Life Safety), and CP (Collapse Prevention) are the basis in FEMA (Fig. 4).

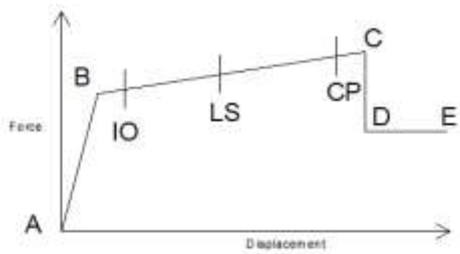


Fig. 4. FEMA Force-Displacement relation

This is an essential analysis to find the proper level of structural strength for all models with different stories and for both fixed and BISs.

The parameters for the LRB have been selected from Robinson Company in New Zealand and HDRB from FIP Company in Italy (Table 2). The designed values for BISs will show the similar conditions for behavior for both.

Table 2. Specification of BISs for 5, 10 &15 stories Bld.

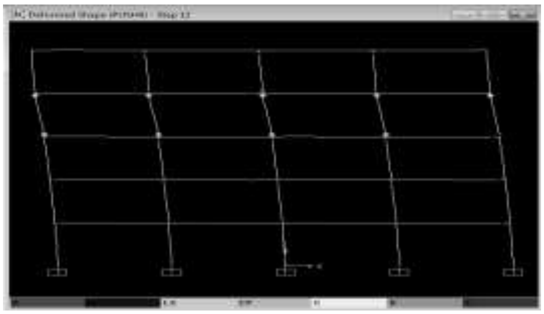
Parameter	No. of Stories	LRB	HDRB
Stiffness	5	464.4 KN/m	725.64 KN/m
Fy	5	341.65 MPa	127.07 MPa
Effective Stiffness	5	2322 KN/m	3628.2 KN/m
Stiffness	10	808.6 KN/m	1468 KN/m
Fy	10	630 MPa	175.6 MPa
Effective Stiffness	10	4043.1 KN/m	7339.8 KN/m
Stiffness	15	99.53KN/m	725.64 KN/m
Fy	15	94.13 MPa	127.07 MPa
Effective Stiffness	15	497.67 KN/m	3628.2 KN/m

2.2 *Static Nonlinear Pushover Analysis*

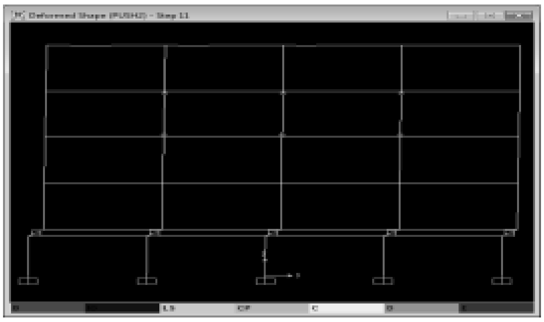
All models have been designed based on codes and a sort of iterative SNPA have been carried out for each model with and without BISs to check their confidence and consistent assumption and proper section properties during different steps of incremental loading. This analysis will show the IO and LS conditions for the frames in the same steps of loading. In addition different Scenarios of SNPA have been considered to show the consistency in behavior Table 3 and Fig. 5.

Table 3. Different scenarios for pushover analysis

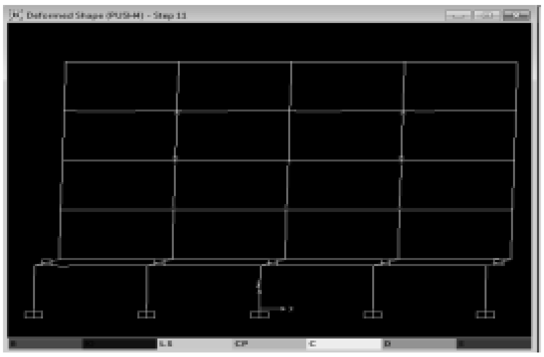
Scenario	Description
Push 1	Gravity load SNPA
Push 2	Lateral loading linear distribution based on seismic codes
Push 3	Lateral loading uniform distribution
Push 4	Lateral loading distribution based on 1st mode of vibration



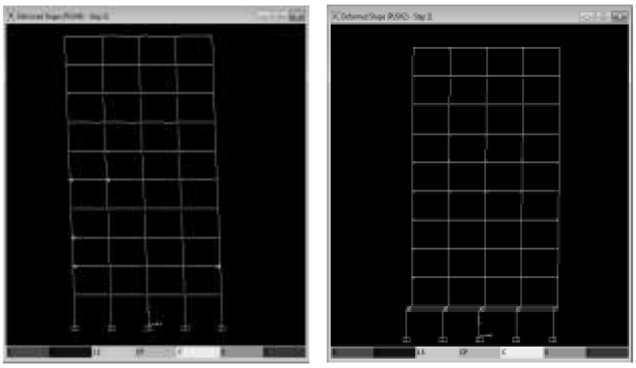
a. Final step-Push 4, 5 stories Bld.



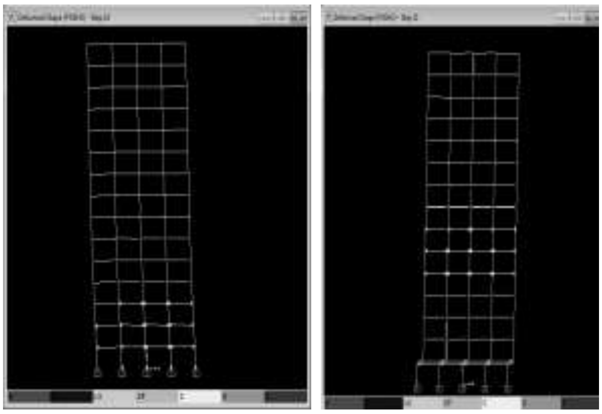
b. Final step-Push 3, LRB – BISs, 5 stories Bld.



c. Final step-Push 3,HDRB –BISs, 5 stories Bld.



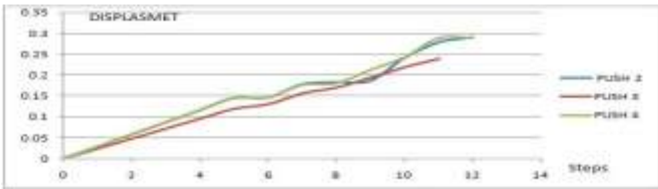
d. Final Step-Push 3, fix and BISs, 10th stories



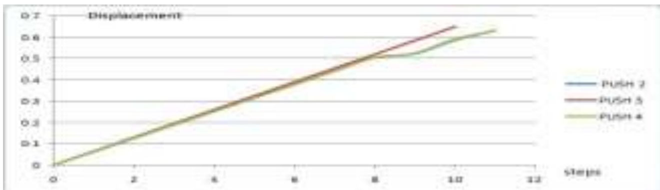
e. Final step-Push2, 15th stories bld., BISs& fixed base

Fig. 5a-e: SNPA scenario for investigated frame.

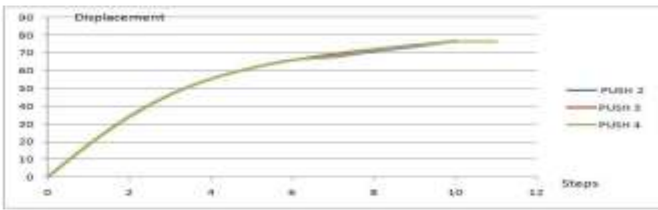
Results for the displacement of all scenarios show confidence for the structural design of frames based on codes for static design for further nonlinear analysis as the target of this research (Fig. 6).



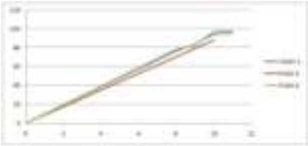
1a



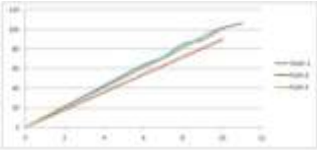
2a



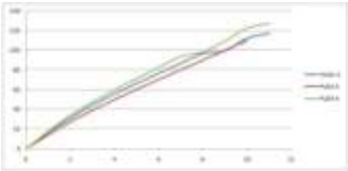
3a



1b



2b



3b

Fig. 6: Displacement of frames for different scenarios of push over analysis, “a” for 5 & “b” for 10 stories, and “1=Fix, 2=LRB and 3= HDRB”

2.3 *Nonlinear Time History Analysis*

Nonlinear time history analysis has been conducted for the 3 different assumed earthquake records and for the different condition of FEMA description for performance has been used as the index for comparison. Each earthquake record was calibrated for the important thresholds.

The first threshold as the termination point for calculation is the seismic acceleration which causes CP condition. Second threshold for termination of calculation is the acceleration equal to g (=9.81m/sec^2). All other conditions between these 2 thresholds have been investigated to find the performance of the two types of BISs.

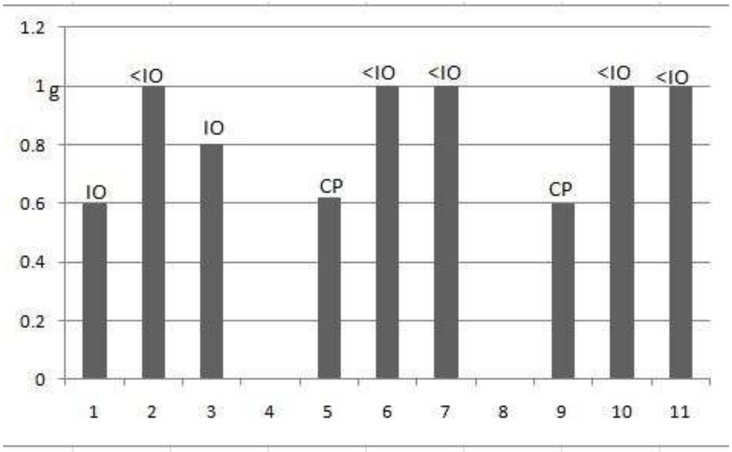
The acceleration have been increased from 0.35g and terminated on 1g.

In fact the use of 3 different records is for simulating different frequency content and possibility of occurrence of different modes.

Termination of iterations for all models was based on the thresholds achieving in one of the analysis sort for specific record. For example for the fixed base model with 5 stories, the Cape Mendocino records show the IO condition at 0.6g however, CP condition for the El Centro earthquake. So, the analyses were terminated and investigation was not conducted beyond this level for the mentioned record. Different frequency content of the assumed earthquakes shows a good interpretation of structural behavior. The results of analysis for summarized in the figure 7, 8 and 9 for different records.

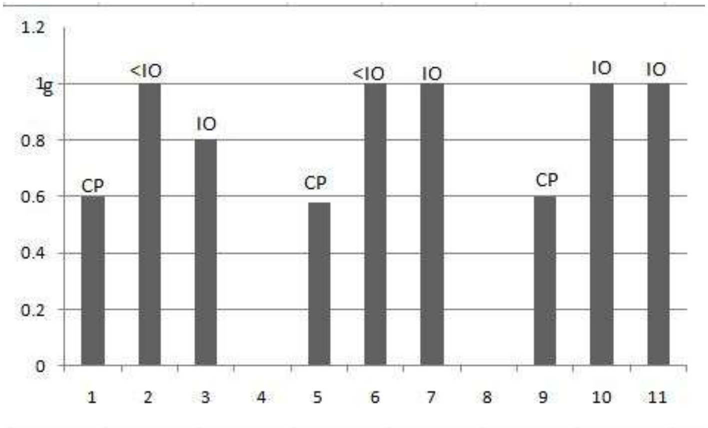
2.4 *Effect of BISs on weight of structural elements*

As an important index for the engineers that engaged with design affairs are about the difference between BISs systems. For the iterative SNPA the minimum weight of structural elements were designed. The weight of structure in different models shows that HDRB will be more efficient than LRB. For the low rise buildings exceptionally economic and for mid rise the results are approximately the same (Fig 10).



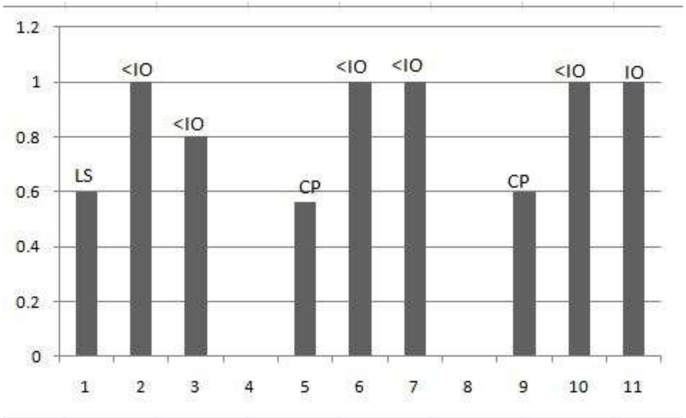
Fix LRB HDRB Fix LRB HDRB Fix LRB HDRB
5 Stories 10 Stories 15 Stories

Fig. 7: Seismic Performance of Cape Mendocino Earthquake



Fix LRB HDRB Fix LRB HDRB Fix LRB HDRB
5 Stories 10 Stories 15 Stories

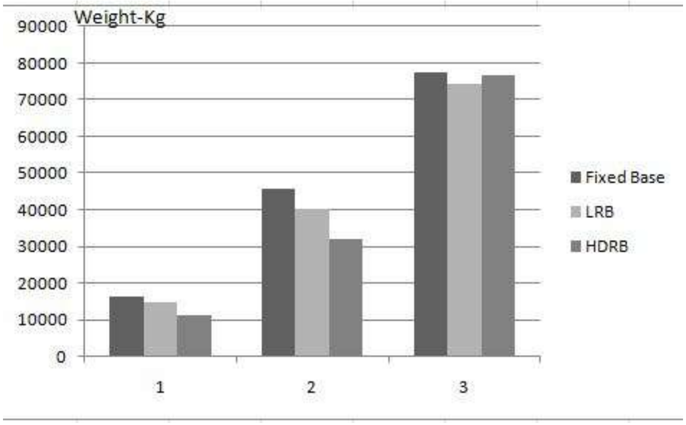
Fig. 8: Seismic Performance of El Centro Earthquake



Fix LRB HDRB Fix LRB HDRB Fix LRB HDRB
5 Stories 10 Stories 15 Stories

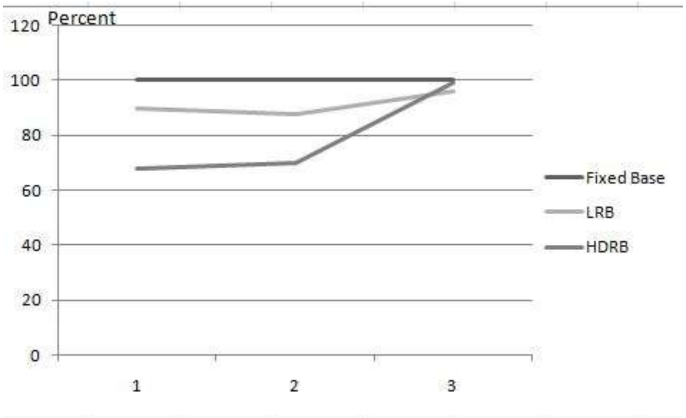
Fig. 9: Seismic Performance of Northridge Earthquake

The deducted percentage of weight for the low rise building significantly shows the efficiency of HDRB but for both LRB and HDRB the deducted weight for mid rise model are less than five percent and their performance are the same (Fig. 11).



5 Stories 10 Stories 15Stories

Fig. 10: Weight of sample structures in different models



1=5 Stories 2=10 Stories 3=15Stories

Fig. 11: Deducted Percent for the weight of structure in compare with fixed base as the index (100%)

3 CONCLUSION

Comprehensive performance analyses of LRB and HDRB BISs has been investigated. Within the range of the parametric study of this paper, three recent examples of application of seismic isolation to building frames for the 5, 10 and 15 stories as a sample of low rise and mid rise buildings were investigated. The results show:

- LRB shows a good Performance in all low rise and midrise cases.
- HDRB for the midrise buildings shows better performance in compare with low rise frame.
- Although the HDRB has less performance for low rise buildings for different earthquake records, the peak ground acceleration for its performance is equal to 0.8g and based on seismicity in most countries such as Iran, Pakistan, USA and Europe it would have enough confidence.
- HDRB significantly deduct the weight of structures in compare with LRB and it is very economic.
- General survey on both performance and deduction of weight shows that HDRB is more efficient than LRB.
- Deduction of weight in mid rise frame in compare with fixed base building is not significant and both systems are not economic for these frames.

4 ACKNOWLEDGEMENT

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