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REDUCING THE EFFECT OF EARTHQUAKE ON RESIDENTIAL BUILDING BY USING BASE ISOLATION WITH LEAD RUBBER BEARING (LRB) DAMPER

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ABSTRACT

This research explores the use of a rubber pad to modify the base isolation system to absorb energy from ground shaking. The numerical analysis was conducted on a building in Dhaka, for seismic zone 2. The building was first analyzed without a base isolator, then remodeled and analyzed with a Lead Rubber Bearing (LRB) isolator. The paper provides a detailed comparison of the time periods studied in both cases and presents the findings. The analysis involves using the acceleration-time history of three earthquakes, namely El-Centro, Sylmar Earthquake, and Petrolia Earthquake, to perform time history seismic analysis. From the findings, it is found that the LRB isolator significantly increases the time period, and decreases the story drift, base shear, and acceleration of the shaking. In this research, a focus was placed on creating an LRB isolator that adhered to the BNBC 2020 guidelines. Additionally, the experimental building underwent a parametric study in various seismic zones and loading cases, all following the Bangladesh National Building Code (BNBC) 2020.

Keywords: *Earthquake; Base-isolation; Lead Rubber Bearing; ETABS; BNBC 2020.*

1. INTRODUCTION

Structural engineers are researching earthquake-resistant designs to ensure stability and durability. Mitigation methods include controlling vibrations and fortifying the base against lateral loads, both related to the concept of "damping".

Damping is the process of dissipating energy to prevent vibratory motion such as mechanical oscillations. Structures must attain stability after an imposed load (wind, seismic). There are multiple options to increase the damping of a structure such as; base isolations, dampers, bracings, and tuned mass dampers. Additionally, dampers are of many kinds like friction dampers, tuned liquid dampers, LRB dampers, etc. Tuned liquid column dampers were first introduced by Fumitoshi Sakai [1]. Tuned liquid column dampers or TLCD are found effective in suppressing maximum displacement due to the wind load and Balendra et al. suggested that the opening ratios of the columns of the dampers are responsible for the effectiveness according to the heights of the buildings [2]. Base Isolation is another advancement in seismic-resistant construction. The adoption of this method keeps skyscrapers floated on a system (ball bearings, springs, padded cylinders) that absorbs sudden loads [3]. Tajirian proposed a design guideline of base isolation for structures and stated that it may help to avoid expensive retrofitting [5].

Among all the seismic mitigation methods, base isolation to increase damping is more effective and economical. Base isolation is a technique used to protect buildings from earthquake damage. It involves separating the building's foundation from the structure above it using devices made of multiple layers of rubber and lead. The lead layers provide dampening, and the rubber layers provide flexibility. This technique increases the building's resilience and reduces the risk of casualties during earthquakes.

The base isolation system was developed by Skinner, Robinson, and McVerry in 1993, and later extended by Naiem and Kelly in 1999. The system is based on a principle that aims to reduce the responsiveness of a building, allowing the ground to move below it without transmitting motion to the structure. In isolated structures, displacements are often large, and measures are taken to release the earthquake energy. This lengthens the structure's inherent duration of vibration, resulting in significantly reduced reactions. For the research, we used a rubber isolator with a lead core known as the Lead Rubber Bearing Isolator or LRB Damper. This passive elastomeric isolator is discussed in detail in the paper.

2. METHODOLOGY

2.1 Design Data of Existing Building

The investigation will be carried out on an existing G+8-story building, The specifications of the building and design method of Base isolation by using an LRB damper are discussed in this chapter.

Table 1. Software and Code.

Sr. No.	Title	Description
1.	The software used for the analysis	ETABS v 16.2.1
3.	Code Provisions as per	BNBC 2020
		ASCE
		Types of analysis performed time history analysis.

Table 2: Building Details.

Dimensions	12.5 m * 19 m
Type of building	Residential (Plan Regular structure)
Total Height	31.5 m (3.05 each storey)
Wall thickness	125 mm
Interior beam	300mm X 510mm
Exterior beam	300mm X 610mm
Slab thickness	150 mm

Table 3. Gravity Loads.

S.N.	Title	Description
1.	Dead load (slab)	(3.75kN/m^2)
2.	Live load	2 kN/m^2
3.	Floor finish load	1.5 kN/m^2
4.	Fix. Partition Wall	6.75 kN/m
5.	Wall load	3.5 kN/m
6.	Parapet load	3.0 kN/m

Table 4. Materials Specification

Sr. No.	Material Type	Description	Value	Unit
1.	Steel	Mass per unit volume	749.047	Kg/m^3
		Modulus of Elasticity, E	200,000	MPa
		Poisson's Ratio, U	0.3	-
		Shear Modulus, G	76030.8	MPa
		Minimum Yield Strength	414	MPa
		Minimum Tensile Strength	621	MPa
2.	Concrete	Mass per unit volume	2402.77	Kg/m^3
		Modulus of Elasticity, E	24855.58	MPa
		Poisson's Ratio, U	0.2	-
		Shear Modulus, G	10356.49	MPa
		Compressive Strength, fc'	27.6	MPa
3.	Rebar	Mass per unit volume	7849.047	Kg/m^3
		Modulus of Elasticity, E	199948	MPa
		Poisson's Ratio, U	0.3	-
		Shear Modulus, G	76030.8	MPa

2.2 ETABS Models

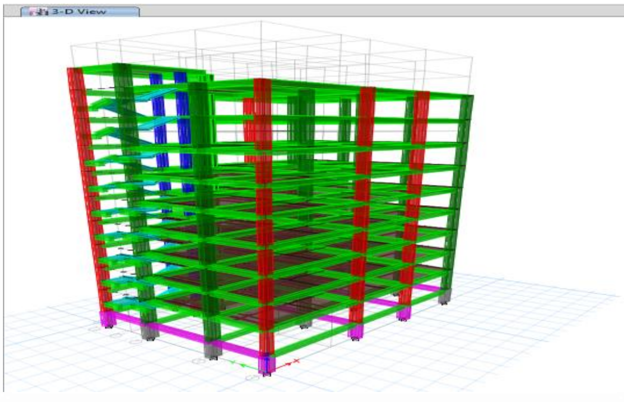

Figure 1. 3-D view of Structure (Fixed Base)

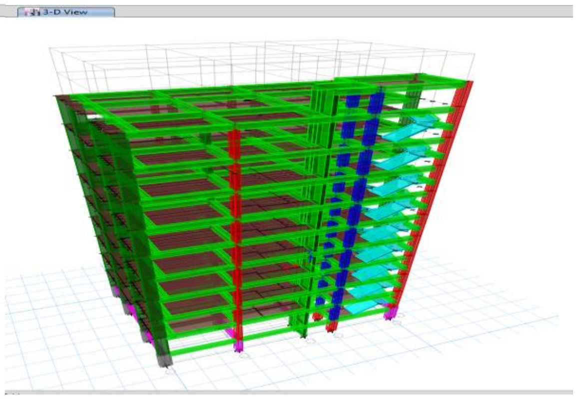

Figure 2. 3-D view of Structure (LRB Base)

3. THEORY AND NUMERICAL ANALYSIS

3.1 Calculation of Various Design Parameters

Zone factor:
For Uttara, Dhaka zone II (BNBC 2020),
Soil Type: SD, Z = 0.20
Importance factor. I = 1
Response reduction factor. R=5
Calculation of period:

$$T_{ax} = 0.09 \times h/d^{0.5}$$
$$= 0.09 \times 31.5/12^{0.5}$$
$$= 0.80\ sec$$

$$T_{ay} = 0.09 \times h/d^{0.5}$$
$$= 0.09 \times 31.5/19^{0.5}$$
$$= 0.65\ sec$$

Average acceleration coefficient For Hard Soil:

$$S_{a/g} = 1/T$$
$$= 1/0.8$$
$$= 1.25$$

Damping percentage = 5%
Factor =1.00
Horizontal seismic coefficient:

$$A_h = Z \times I \times S_a / 2 \times R \times g$$
$$= 0.2 \times 1 \times 1.25 / 2 \times 5$$
$$= 0.025$$

Load on the structure =28830 KN
Base shear

$$= V \times b$$
$$= 28830 \times 0.014$$
$$= 403.64\ kN$$

$$V = 2/3 \times I \times C_s / R \times Z \times W$$
$$= 2/3 \times 1 \times 0.09/5 \times 0.20 \times 28830$$
$$= 69.192\ kN$$

$$C_s = SDS \times 1/R$$
$$= 0.45 \times 1/5$$
$$=0.09$$

3.2 Design of LRB

Seismic Zone Factor (Z): Zone 2
Seismic Coefficient Ca: 0.36
Seismic Coefficient Cv (CVD): 0.54
To get the properties of the isolator its design is carried out as shown below.
Maximum compression load = 4250 KN
Size of column = 300 mm X 900 mm
By applying various loading combinations, the static period is Increased on software, and for safety precautionary the designed time period is 2 sec.

3.2.1 The steps are as follows

1. Calculate design displacement:
Design Time Period, $T_D = 2.013$ sec
All values are mentioned above and put in the formula we get, $D_D = 0.268$ m

2. Effective stiffness (Keff)

$$= 4250/9.81 \times (2 \times \pi/2)^2$$
$$= 4275.83\ kN/m$$

3. The energy dissipated per energy cycle

$$W_d = 2 \times \pi \times K_{ef} \times D_d$$
$$= 2 \times 3.1416 \times 4275.83 \times 0.268 \times 0.05$$
$$= 359.82 kN - m$$

4. Force at design displacement

$$Q = W_D / 4 \times D_D$$
$$= 359.82/4 \times 0.268$$
$$= 335.66\ kN$$

5. Stiffness in rubber

$$K_2 = K_{ef} - (Q/D_D)$$
$$= 4275.83 - (335.66/0.268)$$
$$= 3023.36\ kN/m$$

6. Yield displacement, (Dγ)

$$D_y = Q / K_1 - K_2$$

As we have, K1=10K2

$$= 3356/(9 \times 3023.36)$$
$$= 0.0123\ m$$

7. Recalculation of Q to QR

$$QR = W_D / 4 \times (D_D - D_y)$$
$$= 359.82 / 4 \times (0.268 - 0.0123)$$
$$= 351.80\ kN$$

8. Area and Diameter of Lead Plug: The yield strength of lead is around 10 MPa

$APB = QR / 10 \times 10^3$

$= 351.80 / 10^4$

Here,

$\pi \times d^2/4$

$= 0.0351\ mm^2$

$d = 211.4\ mm$

9. Revising rubber stiffness Keff to Keff(R)

$K_{eff}(R) = K_{eff} - QR/D_D$

$= 4275.83 - 351.80/0.268$

$= 2963.15\ kN/m$

The total thickness of rubber layer

Where γ = 100 % (max. shear strain of rubber)

$= 0.268/1$

$= 0.268\ m$

10. Area of bearing

$A_{LRB} = K_{eff}(R) \times t_y/G$

$= 2963.15 \times 0.268/(0.7 \times 1000)$

$= 1.15\ m^2$

Where the Shear Modulus is 0.7 MPa

Diameter of bearing, D = 1210 mm

11. Shape Factor $S = (1/2.4) \times (f_y/f_H)$

Where fv is the vertical frequency and fH is the horizontal frequency. Also

$t = Q \times LRB/4 \times S$

$= 1210/(4 \times 8.336)$

$= 36.31\ mm$

Number of rubber layers

$= t_y/t$

$= 0.268/0.0363$

$= 7.4$

Provide 40 mm thick 8 rubber layers

12. Dimensions of lead rubber bearing

Let, the thickness of shim plates = 3 mm

No. of shim plates = (8-1) = 7

As Standard,

End plate thickness varies between 19.05 mm to 38.1 mm

Adopt the thickness of the end plate as 25 mm

Total height of LRB

$= (8 \times 40) + (7 \times 3) + (2 \times 25)$

$= 391\ mm$

$= 0.391\ m$

The diameter of the rubber layer

$\emptyset = N \times t$

$= 8 \times 40 = 0.32\ m$

The area of the rubber layer

$A = \pi \times \emptyset \times 2/4$

$= 0.083\ m^2$

13. Compression Modulus, Ec:

$$Ec = 6 \times GS_2 \left(1 - \left(6GS_2/K\right)\right)$$

Where, K= Bulk modulus = 2000 MPa

G= Shear modulus = 0.7 MPa

Ec= 248.96 x 10^3 kN/m^2

Horizontal stiffness

$$K_H = G \times ALR \times B_{LRB}/t_y$$

$= 0.7 \times 10^3 \times 1.15/0.268$

$= 1565.75\ N/mm$

Vertical stiffness

$K_v = E_c \times A_{LRB}/t_y$

$= 248.96 \times 10^3 \times 1.15/0.268$

$= 1565500\ N/mm$

End plate size = $450mm \times 1200mm \times 25mm$

Table 5. Isolator Parameters to be used in the subjected structure below the Interior column

Property	**Values**	**Unit**
Rational Inertia, I	0.013	
U1 Effective Stiffness	1565500	N/mm
U2 & U3 Effective Stiffness	1565.75	N/mm
U2 & U3 Effective -Damping	249.5	N-s/mm
U2 & U3 Distance from End J	0.002	mm
U2 & U3 Stiffness	15658	N/mm

3.2.2 Geometric Properties of Isolator

Table 6. LRB Design Parameters

Details	**Internal**	**External**	**Corner**
Edge of the Bearing	25 mm	25 mm	25 mm
Total height of the bearing	392 mm	320 mm	300 mm
Number of rubber layers	8	6	6
The thickness of individual layers	25 mm	20 mm	15 mm
Diameter of lead core	211.4. mm	140 mm	140 mm
Number of steel plates	7	5	5
Thickness of steel plates	3 mm	2.8 mm	2.8 mm
The top and bottom cover plates, t	25 mm	25 mm	25 mm

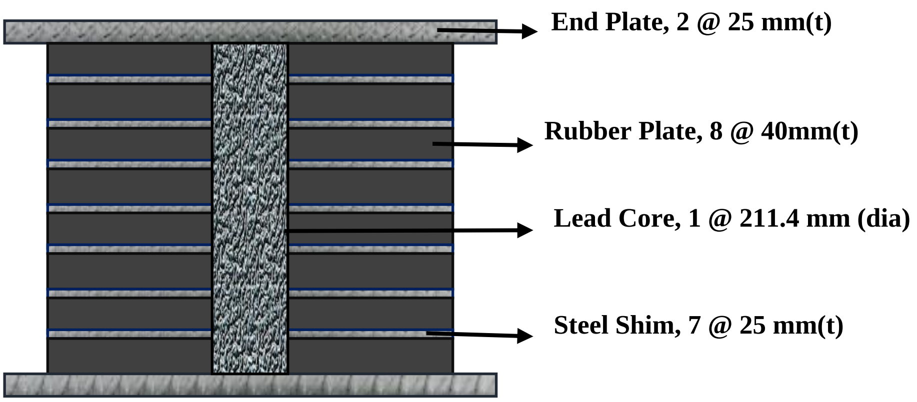

Figure 3. Lead-Rubber Isolator Details

4. ILLUSTRATIONS

The results from time history analysis for three earthquakes—El Centro, Petrolia, and Sylmar—demonstrates the significant impact of using Lead Rubber Bearing (LRB) base isolation in reducing seismic response. Across all cases, the LRB dampers led to a substantial reduction in displacement, acceleration, and base shear compared to the fixed base models.

For the El Centro Earthquake, displacement was reduced by 45.95%, acceleration by 38%, and base shear by 70.2%. Similarly, for the Petrolia Earthquake, displacement decreased by 32.67%, acceleration by 38.62%, and base shear by 70.6%. The Sylmar Earthquake, which showed the largest displacements and forces, saw even more pronounced reductions with LRB isolation, including a 66.47% reduction in displacement, a 69.37% reduction in base shear, and a 69.4% reduction in acceleration.

Table 7. Comparison of Analytic Parameter

Name of Earthquake	Parameter	Fixed Base	LRB Damper
El Centro Earthquake	Displacement (mm)	265.68	143.52
	Acceleration (m/sec^2)	5.039	3.125
	Base Shear (KN)	4930.99	1469.35
1992 Petrolia Earthquakes	Displacement (mm)	198.3	133.52
	Acceleration(m/sec^2)	8.310	5.101
	Base Shear (KN)	5397.71	1585.69
1971 Sylmar Earthquake	Displacement (mm)	1089.52	365.21
	Acceleration (m/sec^2)	10.252	3.141
	Base Shear (KN)	9837.87	917.96

4.1 El Centro Earthquake, California

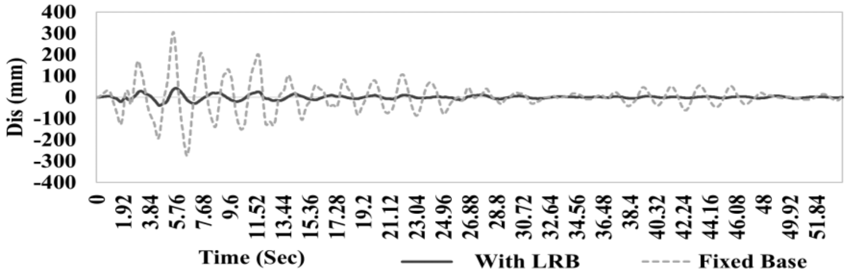

Figure 4. Fixed VS LRB (displacement)

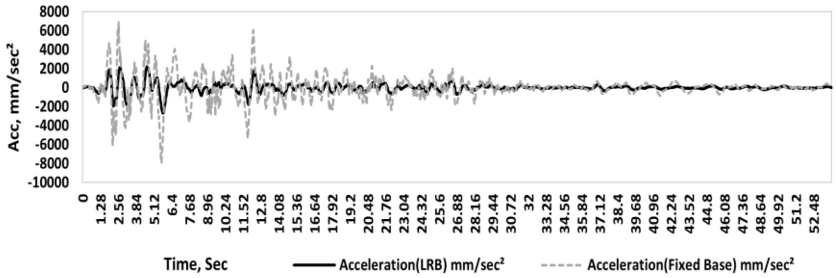

Figure 5. Fixed VS LRB (acceleration)

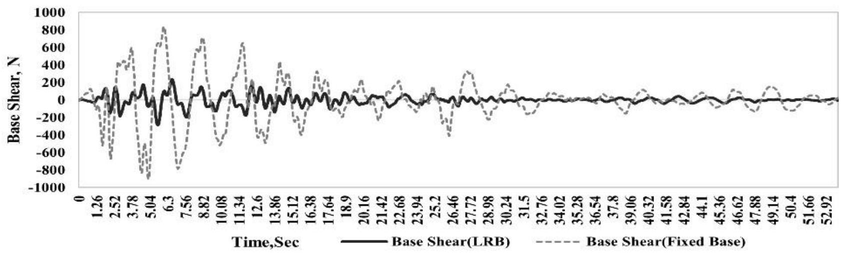

Figure 6. Fixed VS LRB (base shear)

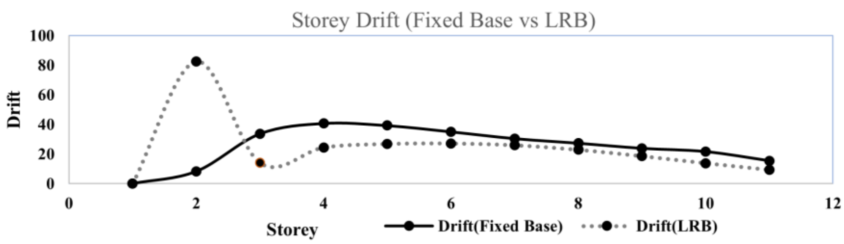

Figure 7. Fixed VS LRB (storey drift)

The time history analysis for the El Centro Earthquake evaluated the performance of Lead Rubber Bearing (LRB) base isolation compared to a fixed base model. The results indicate a 42.73% reduction in displacement and a 37.98% decrease in acceleration with LRB isolation. Additionally, the top story displacement was reduced by 47.71%. These findings suggest that increasing damper stiffness significantly reduces story displacement, enhancing the overall seismic performance of the structure.

4.2 1992 Petrolia Earthquake

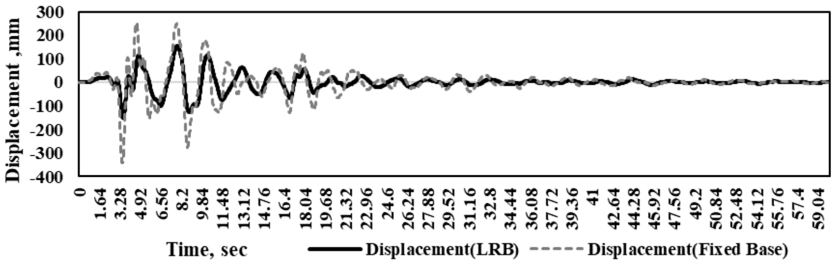

Figure 8. Fixed VS LRB (displacement)

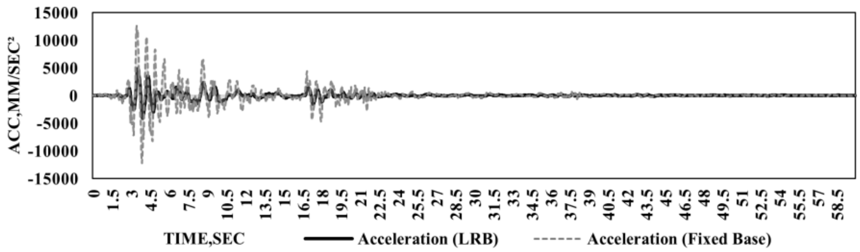

Figure 9. Fixed VS LRB (acceleration)

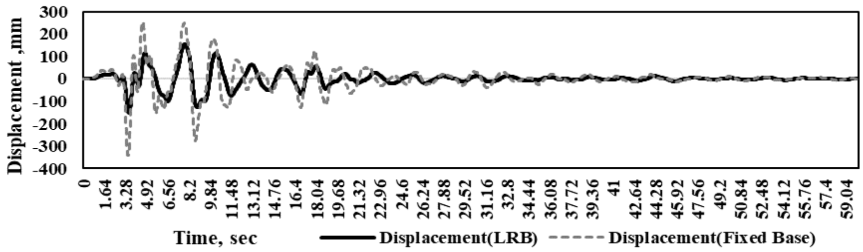

Figure 10. Fixed VS LRB (base shear)

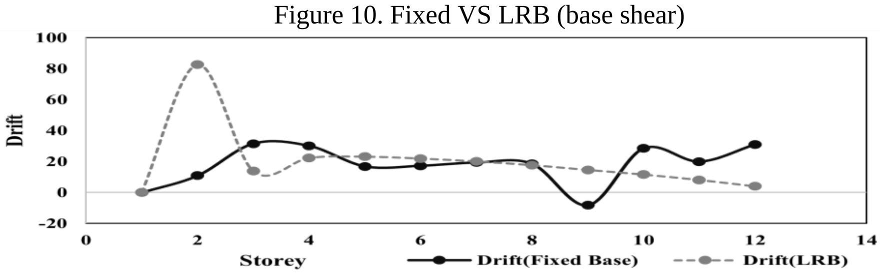

Figure 11. Fixed VS LRB (storey drift)

The time history analysis for the Petrolia Earthquake demonstrates that implementing LRB base isolation led to a 32.67% reduction in displacement, a 38.62% decrease in acceleration, and a 40.68% reduction in top story displacement compared to a fixed base model. These results underscore the effectiveness of increased damper stiffness in reducing overall structural response, particularly in minimizing story displacement during seismic events.

4.3 1971 Sylmar Earthquake

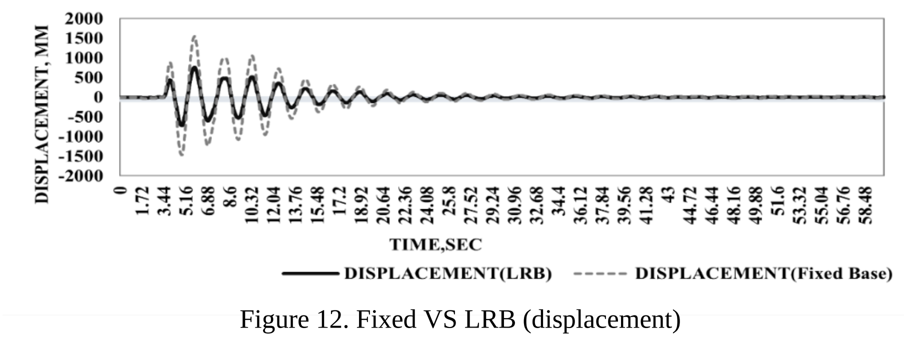

Figure 12. Fixed VS LRB (displacement)

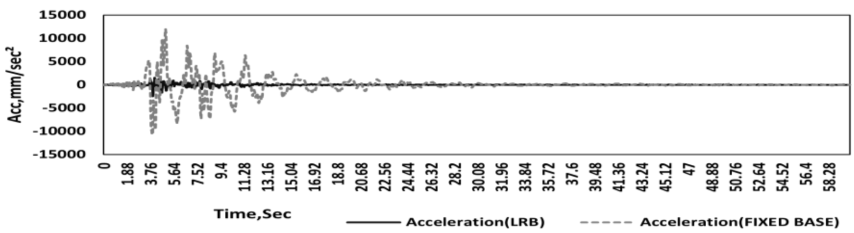

Figure 13. Fixed VS LRB (acceleration)

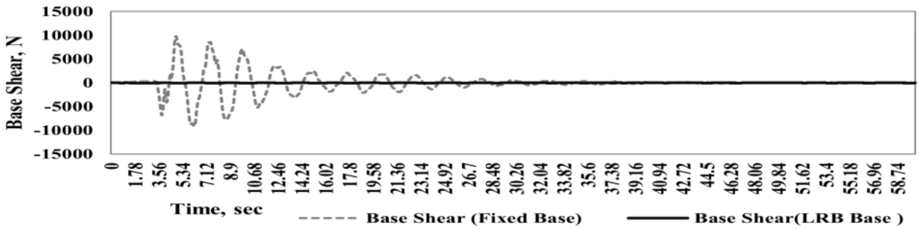

Figure 14. Fixed VS LRB (base shear)

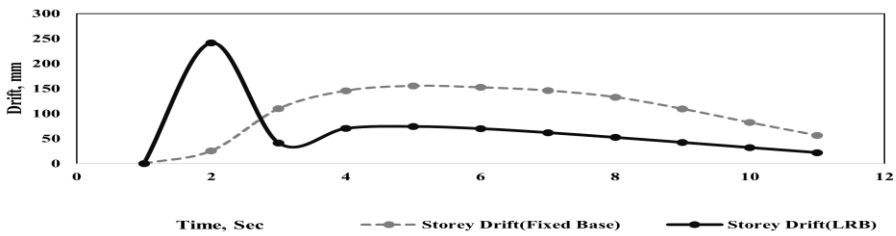

Figure 15. Fixed VS LRB (storey drift)

The results of the time history analysis for the Sylmar Earthquake reveal that the displacement of 1089.52 mm was reduced by 33.52%, while acceleration decreased by 30.64%, and the story displacement at the top floor was reduced by 61.25% in the LRB base-isolated model. These findings indicate a clear correlation between increased damper stiffness and reduced story displacement. However, to ensure the structure's resilience against the Sylmar Earthquake, further optimization of the damper design is necessary to enhance performance under such high seismic demands.

5. CONCLUSION

This research highlights the effectiveness of Lead Rubber Bearing (LRB) base isolation in reducing earthquake-induced impacts on residential buildings. Time history analysis of three earthquakes—El Centro, Petrolia, and Sylmar—shows that LRB isolators significantly decrease displacement, base shear, and acceleration compared to a fixed base model. The reduction in story drift enhances structural resilience. Adhering to BNBC 2020, the study confirms LRB isolation as a practical and economical solution for improving seismic safety in Dhaka's buildings. Further optimization is recommended for stronger earthquakes, as seen in the Sylmar case.

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