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A Study on Dynamic Response of High-Rise Buildings using Lead Rubber Bearing Isolator

S. Mallikarjun[1] and A. Shruthi[2]
[1]PG Scholar, CVR College of Engineering/Civil Engg. Department, Hyderabad, India
Email: droptomallikarjun@gmail.com
[2]Asst. Professor, CVR College of Engineering/Civil Engg. Department, Hyderabad, India
Email: shruthiarikeri95@gmail.com

Abstract: **Seismic devastation can result in significant fatalities as well as economic damage to structures and individuals living in seismic danger zones. As shown by prior catastrophic disasters, each earthquake leaves a substantial amount of destruction in its wake. To reduce the detrimental effects of seismic activity on buildings without causing the entire structure to collapse, these structures must be seismically safeguarded. To maintain these RC structures and improve their performance during a seismic event, a variety of seismic retrofitting methods are now being employed. Base isolation is one of the most effective strategies for mitigating the effects of seismic risks.**

This study uses linear and non-linear dynamic analysis as defined by IS Codal to investigate the seismic behavior of a structure with a fixed base and a structure with base isolation. Using the ETABS software, the impacts of various types of base isolator systems are taken into account in the modelling of RC structures for symmetric and asymmetric plan configurations of both G+7 and G+10 storey heights. Many parameters, such as storey drift, base shear, Storey displacement, and time period, are compared for isolated base and fixed base scenarios.

Index Terms: **Base isolator, Lead Rubber bearing (LRB), Storey drift, Base shear, Time period, Storey displacement.**

I. INTRODUCTION

Earthquakes are the most unanticipated and fatal of all natural calamities, and it is quite difficult to protect a large number of assets and lives from them. To cater these concerns, it is essential to assess the seismic performance of the built environment using various analytical techniques, which ensure that structures can withstand numerous mild earthquakes and provide sufficient caution when encountered to big earthquakes. Thus, the greatest number of lives possible can be saved. There are a number of recommendations that have been updated on this issue all around the world. The seismic performance of a building is influenced by its stiffness, lateral strength, ductility, and simple and regular configurations. Plan and elevation of buildings with regular, evenly distributed geometry, mass, and stiffness endure considerably less damage than buildings with uneven layouts.

The process of protecting a structure from earthquake damage by providing some reasonable support that isolates it from trembling ground is appealing, and several techniques have been proposed to achieve this goal. Despite the fact that some of the older suggestions date back hundreds of years, base isolation has only recently become a feasible earthquake-resistant design technique. It's a passive control device that's put between the building's foundation and base. High damping rubber bearing (HDRB), Elastomeric rubber bearing (ERB), Lead rubber bearing (LRB), and Friction pendulum system (FPS) are some of the base isolation systems that must be placed under the superstructure. Despite the fact that bearings are a tiny component of a structure, their importance is inversely related to their size. This is typically the case since only this section of the structure transmits and absorbs the whole weight of the structure as well as the energy exerted by seismic waves. The many factors within the design should be given a high priority since any misbehavior in its performance due to bad design will result in the collapse of the entire structure.

Lead rubber bearing

Seismic isolation bearings include lead rubber bearings (LRB), which are similar to high damping rubber bearings. It has a central lead core and is made up of many layers of elastomeric material and vulcanized reinforced steel plates. The rubber used to make lead rubber bearings is typically natural rubber, with a shore hardness ranging from 45 to 55, making it more flexible than an elastomeric bearing pad.

In 1975, New Zealand created lead rubber bearings. Layers of steel plates, rubber layers, and a lead core are the three basic components of equipment. Vertical rigidity is provided by the steel layers, while lateral flexibility is provided by the rubber layers. The component that will provide extra rigidity to the isolators and adequate damping to the system is the lead core.

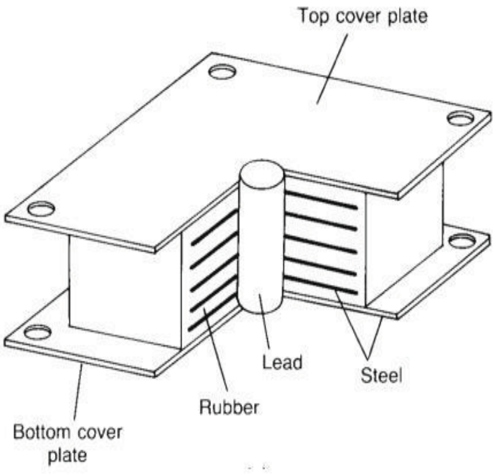

Figure 1. Components of Lead Rubber Bearing

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A. Objective of the study

1. To demonstrate the impact of base isolators on the response of Symmetric and Asymmetric Buildings.
2. To compare the behavior of a base isolated structure to the conventional structure (G+10 & G+7) storey during a seismic activity.
3. To study the seismic requirements of regular and irregular R.C buildings for both regular and base isolated structure using ETABS by performing the Linear and Non-linear time history analysis.

B. Procedure adopted

A high-rise RCC building subjected to seismic activity is investigated in this study utilising both linear and non-linear time history analysis. The structures studied are RC conventional moment resistant space frames with G+10 and G+7 storeys of height that are located in Zone III seismic zones. Using the ETABS software, the research considers two major factors based on the support conditions: a building with a permanent base and a building with a Lead Rubber Bearing (LRB). The structure is proposed to be evaluated as per seismic code IS-1893:2016 with the assistance of the ETABS software.

II. LITERATURE REVIEW

Eknath et al evaluated the building structure with and without Lead rubber bearing isolators and compared the results using time history analysis using software 2016. A case study was done using G+10 building structure as test model. This paper concluded that the time period of structure increased approximately twice after providing the base isolator and also the maximum storey displacement and storey drift were observed to be increased.[1]

Balachandran et al analysed G+3 and G+20 storey RC building with fixed base and base isolators (LRB) using ETABS software considering EI-Centro time history data. It was observed that base isolation increases the time period of the building and base shear reduced.[2]

Sahoo et al studied comparative analysis of various RC framed structures with fixed base and isolated base lead rubber bearing isolator. This base isolation study along with seismic analysis is done in equivalent static method using E-TABS software considering G+10 and G+15 structures as test model with fixed base and base isolation. This study revealed that there is an increase in time period, storey drift and storey displacement. The lateral earthquake load, storey share, storey stiffness found to be reduced.[3]

Swapnil et al studied the effectiveness of base isolation using lead rubber bearing (LRB) over conventional construction. Modeling and analysis of G+6 rigid joint plane is done in ETABS software using base isolator. It is concluded that with the use of isolator, there is a reduction in story shear, base shear and storey drift. Modal displacements and natural periods are increased which reduces earthquakes forces on the shaking.[4]

Ambasta et al studied the comparative behavior of fixed base and isolated G+8 storied building for high intensity earthquakes. Lead rubber bearing (LBR) is used as isolator. Results showed that the variation in maximum displacement of stories in base isolated model is very low while compared with fixed base mode. Storey overturning moment and storey shear force fount to be reduced.[5]

Madhuri et al studied comparative study of fixed base and base isolation structures. Lead bearing rubber (LRB) is used as base isolator. Response spectrum method and time history analysis method are used for the analysis and is done through a computer software ETABS. Results showed that storey shear, base shear and storey drift reduced, point displacement and mode periods are increased in both the methods of analysis. Time history analysis was found much efficient in providing results when compared to response spectrum method.[6]

B.R.Anirudha et al had done a comparative study between the fixed base and base isolators for different parameters. Work lead rubber bearing, and friction pendulum isolators are used for asymmetric building plan. They have concluded that the fundamental time period for base model is observed that there is a decrease in acceleration, storey sear and displacement of base isolators was increased.[7]

Gowardhan et al. used high damper rubber bearing (HDRB) as isolator and non- linear time history analysis is performed using Sap2000 version14. This study showed that the base isolation system reduced the base shear force, storey drifts and storey acceleration also increase in storey displacements and time period is observed.[8]

III. METHODOLOGY

The building's dynamic analysis is done utilizing the linear and non-linear time history analytic methods that correlate to seismic zone III.

The following is an example of structural modelling with LRB.

1) ETABS software is used to create a 3-D model of a symmetrical and unsymmetrical (L-shape, T-shape) G+10 and G+7 storey building structure.
2) The ‘Define Material Properties' is used to define material properties. The desired grade of concrete and steel is chosen according to Indian IS standards IS 456:2000 and IS 800:2007 respectively.
3) ‘Define sectional properties’ is used to assign the dimensions of Frame sections.
4) Enter the dimensions of a beam, then the design type ‘Beam' (M3 design only) and the Rebar material to be considered.
5) Enter the dimensions of the column in the similar way, and by clicking on the modify/show Rebar command, choose the design type as ‘Column' (p-m2-m3 design).
6) By selecting the slab material from the ‘Define Slabs sections' command, the slab property can be defined. The slab thickness has to be entered, and the modelling type is set to ‘membrane.’
7) After the material properties and section properties have been specified, the section properties are given to the building model by utilizing the tools available to design beams, columns, and slab panels.

8) The ‘Define- Diaphragm' option is used to define a rigid and Flexible type of diaphragm.
9) The response spectrum and time history functions for the study's targeted seismic zones are defined.
10) Load patterns such as Dead load, Live load, Seismic loads, Response spectrum, and Time history load patterns are defined by selecting the required load type from the ‘Define Load patterns' command.
11) Load cases are defined by selecting the relevant load case type from the ‘Define - Load case' command. The terms "dead load," "live load," "seismic static loads," "response spectrum," and "time history" are all used to describe load scenarios.
12) Add default design load combinations from ‘Define - Load combinations,' where ETABS produces load combinations for the different loads defined by the user based on Indian design codes.
Add default design load combinations from ‘Define Load combinations,' where ETABS produces load combinations for the different loads defined by the user based on Indian design codes.
13) Calculate and assign the exterior and internal wall loads operating on the structure.
14) Assign the slab panels to the floor completion load and the live load.
15) ETABS calculates the self-weight of frame components automatically and adds it by default when section attributes are provided.
16) Define the term "mass source"
17) Define isolator properties using the 'Link properties' option. Select the required link type, in our instance rubber isolator and high damping rubber, by defining sectional characteristics and link properties. Fill in the appropriate high damping rubber values.
18) Now, using the main menu, define spring properties,
19) Define spring properties point springs
The spring is then assigned to the supports. Assign springs to the joints.
20) Analyze and run the model.

The Plan configuration consists of

1. Model 1- G+10 Building Rectangular plan
2. Model 2- G+7 Building Rectangular plan
3. Model 3- G+10 Building L-shaped plan Asymmetry,
4. Model 4- G+7 Building L-shaped plan Asymmetry,
5. Model 5- G+10 Building T-shaped plan Asymmetry
6. Model 6- G+7 Building T-shaped plan Asymmetry

Rubber bearings were simulated in ETABS using hysteretic isolator linkages. At the foundation level, an isolator link is assigned to each column as a single joint member to connect the superstructure to the ground. Rubber with a lot of dampening as a rubber isolator link, bearing links were used. The Link/Support Property in ETABS determines how link elements behave. Mechanical activity in six directions is represented by directional attributes U1, U2, U3, R1, R2, and R3. Axial deformation (U1) has solely linear qualities, while shear deformations (U2, U3) have both linear and nonlinear features. Also, the tensional deformation (R) around U1 is merely linear. Rotations above U2 and U3 are solely linear (R2 & R3). The isolator linkages' internal deformations are believed to be independent of one another.

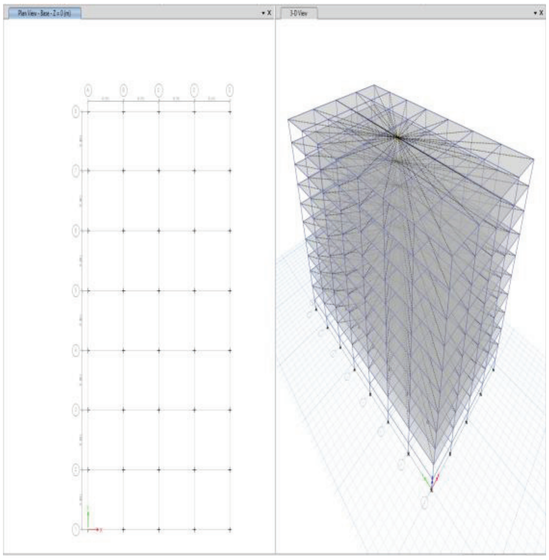

Figure 2. Plan and Isometric view of Model-1 with LRB G+10

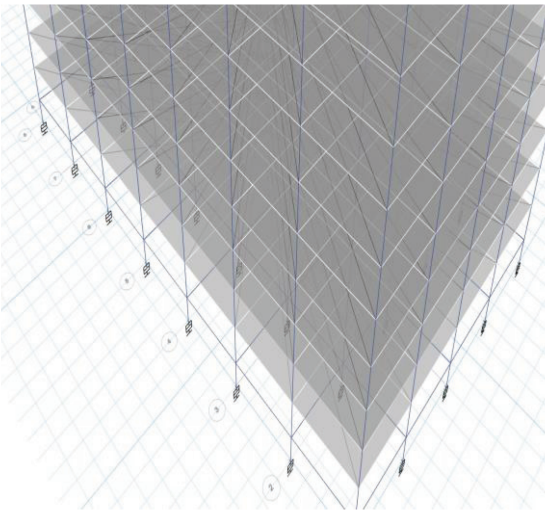

Figure 3. LRB Isolator installed at the fixed supports

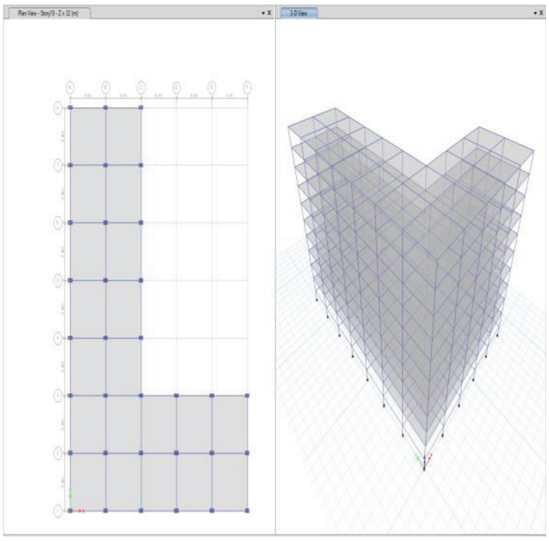

Figure 4. Plan and Isometric view of Model-3 with LRB G+10

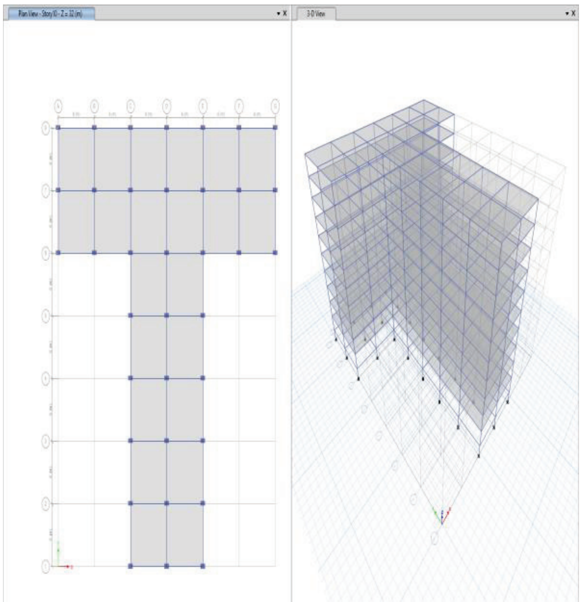

Figure 5. Plan and Isometric view of Model-5 with LRB G+10

III. SPECIMEN CALCULATIONS

Assumed Preliminary Data Required for the Analysis of the Frame

TABLE I.
PRELIMINARY DATA

Type of structure	Ordinary Moment Resisting Frame
Materials	M30, Fe-500
Size of Beams	300x450 mm
Size of Columns	450x750 mm
Depth of slab	150 mm
Wall load Internal & External	11.14KN/m, 5.57KN/m
Seismic zone	III
Zone Factor	0.16
Response Reduction Factor	3

Design of Lead Rubber Bearing

Assume design time period, T_D = 2.5sec (Kelly,1986)

Maximum vertical load on individual column,

w = 4011kN (For G+10 building)

a) **Effective stiffness, K_{eff}** $= \frac{W}{g} X \left(\frac{2\pi}{T_D}\right)^2$ **kN/m**

$$=\frac{4011}{9.81} X \left(\frac{2x3.11}{2.5}\right)^2$$

=2582.637kn/m

b) **Design Displacement, Dd=** $\frac{gC_{VD}T_D}{4\pi^2 B_D}$**, m**

Seismic coefficient C_{VD}= 0.54 (UBC 97, Vol -2, Table 16- R, For zone-3 & S_D)

$$=\frac{9.81*0.54*2.5}{4*3.11^2*1}$$

= 0.33546 m

c) **Energy dissipated per cycle, W_D = $2\pi keffD_D^2\beta eff$ kN-m**

Effective damping, βeff = 5% (5% damping is considered for the LRB)

= 2*0.311*2582.637*0.335462*1

= 91.306 kN-m

d) **Characteristic Strength, Q =** $\frac{W_D}{4D_D}$**, kn**

$$=\frac{91.306}{4*0.3354}$$

=68.0450 kN

e) **Pre-Yield Rubber, K2 = K_{eff} -** $\frac{Q}{D_D}$ **, KN/m**

$$= 2582.63 - \frac{68.045012}{0.33546}$$

= 2379.7972 kN/m

Post – Yield stiffness, k_1 = $10k_2$ (Kelly,1986)

= 23797.97 kN/m

f) **Yield Displacement (Distance from END -J), D_Y =** $\frac{Q}{K_1-K_2}$**, m**

$$=\frac{68.045012}{23797.972-2379.7972}$$

= 0.003177 m

g) **Recalculation of Force Q TO Q_R**

$$=\frac{W_D}{4*D_D-D_Y}, \text{kN}$$

$$=\frac{91.306002}{4*(0.3354618-0.003177)}$$

= 68.69559 KN

h) **Area of lead plug required, A_{PB} =** $\frac{Q_R}{Yield\ strength\ of\ lead}$

Yield strength of lead = 10MN/m2 (Mayes and Naeim,2000)

$$=\frac{68.69559}{10*10^3} = 0.0068696 \text{ m}$$

Diameter of lead plug required,

d = 0.0935232m

i) Recalculation of rubber stiffness K_{eff} to $k_{eff(R)}$

$$= K_{eff} - \frac{Q_R}{D_D}$$

$$= 2582.637 - \frac{68.69559}{0.3354618}$$

= 2377.8578 KN/m

j) Total thickness of rubber, $t_r = \frac{D_D}{\gamma}$**, m**

Maximum shear strain of rubber, γ = 100%

$$= \frac{0.3354618}{1}$$

= 0.3354618m

k) Shape factor, $s = \frac{1}{2.4} x \frac{f_v}{f_h}$

Horizontal time period = 2sec (Kelly ,1986)

Horizontal frequency, f_h = 0.5h_z

Vertical frequency, f_v = 10h_z (Kelly,1986)

S = 8.3333

l) Area of bearing, $A_{LRB} = \frac{K_{eff\,(R)} X t_r}{G}$**,m²**

$$= \frac{2377.8578 \; x \; 0.3354618}{0.7 x 1000}$$

= 1.13954

Diameter of bearing = 1.204538m

m) Single layer rubber thickness, $t = \frac{\emptyset_{LRB}}{4S}$

$$= \frac{1.204538}{4 * 8.333} = 36mm$$

Number of rubber layers, N = 9.2832

Thickness of shim plates = 2.8mm (Kelly ,1986)

No. of shim plates, n = N-1

= 10-1

= 8.2832

End plates thickness is between 19mm to 38mm, choose 25mm

n) Compression modulus, $E_c = 6GS^2 \left(1 - \frac{6GS^2}{K}\right)$

Bulk modulus, K = 249131.94kN/m²

o) Vertical stiffness, $k_v = \frac{Ec * ALRB}{t_r}$

$$= \frac{249131.94 * 1.1395434}{0.3354618}$$

= 846286.21kN/m

p) Yield strength, $F_y = Q + K_2 * D_Y$, KN

= 68.04502+ 2379.7972*0.003177

= 75.60556KN

Input values of LRB in ETABS

For G+10 Regular Building

U1 Effective Stiffness = 846286.211kN/m

U2 & U3 Eff. Stiffness = 2582.637032kN-m

U2 & U3 Eff. Damping = 0.05

U2 & U3 Distance from End-J = 0.0031m

U2 & U3 non-linear Stiffness= 2379.797194kN/m

U2 & U3 Yield Strength = 75.6055688KN

For G+7 Regular Building

Support reaction: 2940KN

U1 Effective Stiffness = 620314.5002kN/m

U2 & U3 Eff Stiffness = 1893.032379kN-m

U2 & U3 Effective Damping = 0.05

U2 & U3 Distance from End-J = 0.00317m

U2 & U3 non-linear Stiffness =1744.353964kN/m

U2 & U3 Yield Strength = 55.41769441KN

V. RESULTS OBTAINED FROM ETABS SOFTWARE:

Time period(sec):

TABLE II.
TIME PERIOD FOR SYMMETRIC BUILDING

	G+10 TIME PERIOD (Sec)		G+7 TIME PERIOD (Sec)	
	FNA	LDI	FNA	LDI
Fixed	1.913	2.01	1.471	1.471
LRB	3.233	3.23	2.514	2.70
% Change	69%	61%	71%	84%

TABLE III.
TIME PERIOD FOR UNSYMMETRIC BUILDING

UNSYMMETRIC BUILDING TIME PERIOD (Sec)			
		FIXED	LRB
G+10 L SHAPE	FNA	2.08	2.883
	LDI	2.08	2.883
G+7 L SHAPE	FNA	1.704	2.37
	LDI	1.704	2.37
G+10 T SHAPE	FNA	2.031	2.91
	LDI	2.031	2.1
G+10 L SHAPE	FNA	1.445	2.46
	LDI	1.445	2.46

Max storey Displacement(mm)

Story displacement is the lateral displacement of the story relative to the base

TABLE IV.
MAXIMUM STORY DISPLACEMENT

Base Type	Symmetric Plan		Asymmetric Plan			
	G+10	G+7	G+10	G+7	G+10	G+7
	Rectangular	Rectangular	L-shape	T-shape	L-shape	T-shape
Fixed	26.12	19.125	29.622	27.19	20.18	14.50
LRB	21.04	21.25	26.45	25.84	21.15	16.61

Storey Drift rato

Story drift is the relative displacement of one-story relative to the other.

TABLE V.
STORY DRIFT

Base Type	Symmetric Plan		Asymmetric Plan			
	G+10	G+7	G+10	G+7	G+10	G+7
	Rectangular	Rectangular	L-shape	T-shape	L-shape	T-shape
Fixed	0.00156	0.00205	0.0018	0.00125	0.00155	0.000897
LRB	0.00146	0.00085	0.00121	0.00127	0.001057	0.000848

Base shear(KN):

Base shear is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity

TABLE VI.
BASE SHEAR

BASE SHEAR (kN)			
		FIXED	LRB
G+10 L SHAPE	FNA	-861.22	-552.35
	LDI	-932.53	-682.34
G+7 L SHAPE	FNA	-800.33	-556.13
	LDI	-814.76	-599.22
G+10 T SHAPE	FNA	-1141.31	-614.47
	LDI	-1139.66	-775.98
G+7 T SHAPE	FNA	-1165.88	-469.35
	LDI	-1155.03	-586.83
G+10 Regular	FNA	-1040.53	-692.80
	LDI	-1111.99	-954.27
G+7 Regular	FNA	-1074.34	-723.42
	LDI	-1083.82	-757.24

VI. CONCLUSIONS

1. The study's goal to introduce the base isolation approach for symmetric and asymmetric structures utilising the ETABS package is achieved.
2. For both L-shaped and T-shaped buildings, the magnitude of base shear, Max storey displacement, storey drift, and storey shear has been shown to decrease with the installation of the Lead Rubber Bearing (LRB).
3. The effect of the base isolator is observed to enhance the time period for both G+7 and G+10 storey asymmetric structures, indicating that the performance of the base isolated structure is superior to the structure without any isolation.
4. When analysing a G+7 structure utilising the Non-linear FNA method, LRB revealed a higher contribution.
5. LRB had a larger impact in lowering the Base shear for both Linear and Non-Linear analysis for a G+10 L-shaped and T-shaped structure.
6. The different parameters considered for evaluating the structures responses are found to be satisfactory in comparative studies made from conventional and isolated (G+10, G+7) storied buildings subjected to Linear and Non-linear analysis, proving that the base isolation technique is flexible to adopt for highly seismic areas.
7. The contribution of LRB is found to be more effective in asymmetric buildings, whereas it is found to be less effective in symmetric structures.

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