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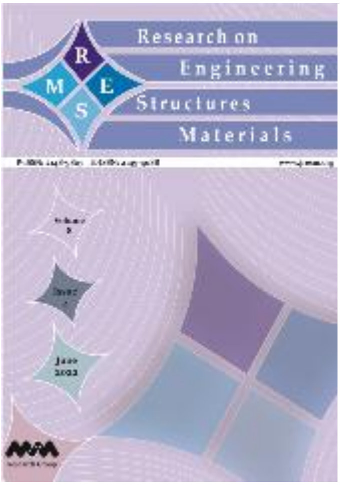

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Research Article

Performance analysis of lead rubber bearing isolation system for low, medium and high- rise RC buildings

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Abstract

Earthquakes are the most vulnerable natural hazard which causes damage to both structure and human life. Even though advanced technologies have invented some degree of predictability in terms of probabilistic measures the main challenge for the structural engineers is to design earthquake-resistant structures. The use of base isolation solutions allows a building to withstand potentially devastating seismic impacts by allowing for flexibility in between building and the foundation. The concept of base isolation system had been suggested in last few decades and getting well established in countries like US, Japan and Turkey. Properly designed and detailed building with base isolation has shown very good performance in past earthquakes and the demand of base isolation has increased. The main focus of this study is to understand the performance and efficacy of base isolation in regular multi-storey RC framed structures with varying heights using lead rubber bearing by response spectrum analysis and pushover analysis. The software used was ETABS 2018 followed by IS 1893(Part 1):2016 and ASCE 7-16 under most credible earthquake. Performance of lead rubber bearing in G+5, G+15 and G+25 storey building models was examined and compared with the fixed base buildings. All the models showed better performance with isolators than the fixed base models. However, the effectiveness of base isolators is more prominent in medium and high-rise buildings.

1. Introduction

The major challenge faced by all Structural Engineers is to provide sufficient strength and stiffness to buildings for resisting lateral loads such as seismic loads and wind loads. Looking at the Indian code particularly, design philosophy evolves around earthquake intensity, with design- based earthquakes having a 10% chance in a 250-year return time and most credible earthquakes having a 2% chance in a 250-year return period. The seismic philosophy in the Indian code requires that the structure have a minimum strength to withstand structural and non-structural contents during earthquakes with intensities less than design- based earthquakes. It is always preferred to design under most credible earthquake if the location is highly prone to earthquake. To make the structure safe base isolation systems are used which reflects the energy from the earthquake before it is transferred to the structure. There are different types of base isolators used in the past few decades. Base isolators are generally categorized into two groups, namely, Sliding system and Elastomeric bearing system. Sliding system uses sliding elements between base and foundation of the building. It is again subdivided into Resilient friction system and Friction pendulum system (Jiying et al. 2021; Yongbo et al. 2021). Whereas Elastomeric bearing system is formed of thin layers of synthetic rubber sandwiched together between steel plates. It is classified into natural rubber bearing, low damping rubber bearing, lead plug bearing and high damping rubber bearing.

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The analysis and design of various base isolation systems were performed to investigate the dynamic characteristics of buildings under ground motions in terms of long period ground motions, epicentral distance effect, beyond design base earthquakes, etc (Sunita et al. 2016; Shoma et al. 2018; Ahmad et al. 2019; Antonello et al. 2019; Mahdi et al. 2020; Feiyan et al. 2021; Jara et al 2021). Some of the studies on natural rubber bearing and lead rubber bearing (Keri et al. 2005; Gordon et al. 2007; Sharbatdar et al. 2011; Young et al. 2016; Parham et al. 2018; Seunghyun et al. 2018) revealed that the inter-storey drift, base shear and top acceleration of base isolated structures are reduced satisfactorily. A few studies were carried out on base isolated irregular buildings and observed effective in resisting the effects of earthquakes (Donato et al. 2016; Fayaz et al. 2018). Base isolation technique could be implemented for retrofitting soft-storey buildings (Fabio et al. 2018). New base isolation systems were developed for low and high-rise buildings and investigated for their seismic performance under different earthquake loadings. From various studies on base isolation systems for buildings' safety against ground movement, in this study, lead rubber bearing is used which is cost effective and commonly used compared to other type of isolators. This study mainly focuses on the behaviour of lead rubber bearing as base isolation system in low, medium and high- rise RC building which is located in high seismic zone V.

2. Methodology

For finding the performance and efficacy analysis of base isolation technology in RC buildings, G+5, G+15 and G+25 storey buildings are analyzed and compared the performance of buildings with increase in stories. The flowchart below shows the different stages of the work. Figure 1 below shows the flow chart representing the methodology of this entire study.

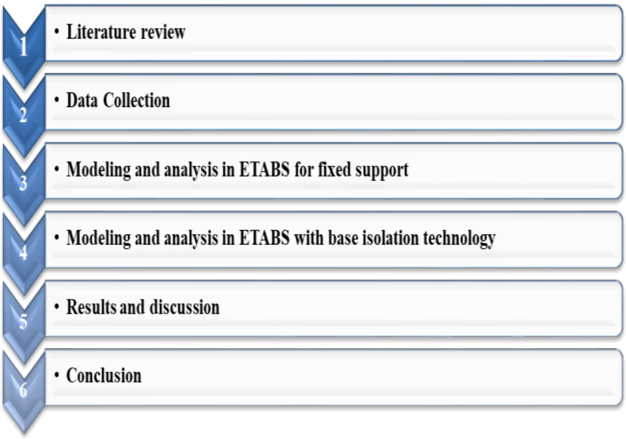


Fig.1 Methodology

3. Specifications

Table 1 shows the specifications of the building models considered in the study. The materials and member sizes were taken to suit the requirements of a G+5, G+15 and G+25 storey RC buildings. The parameters for the seismic analysis were obtained from IS 1893 (2016).

Table 1. Specifications

Sl.No.	Description	Values
1	Materials	M30, Fe500
2	No. of storeys	G+5, G+15, G+25
3	Plan size	81m x 28.5 m
4	Size of beam	Primary beam: 450 mm x 650 mm Secondary beam: 250 mm x 450 mm
5	Size of column	750 mm x 750 mm
6	Floor height	3.5 m
7	Slab thickness	150 mm
8	Seismic zone	V
9	Types of analysis	Response spectrum analysis, Pushover analysis
10	Zone factor(Z)	0.36
11	Reduction factor (R)	Fixed =3, base isolator =1
12	Importance factor (I)	Fixed =1.5, base isolator =1
13	Type of Soil	Type II- Medium Soil

Table 2. shows the live load specification of the building obtained from IS 875:2015 (Part 2) which is applied to the building model.

Table 2. Live load specifications

Sl. No.	Live load	Values
1	LL1(> 3 kN/m^2)	Corridor =4 kN/m^2 Staircase =4 kN/m^2
2	LL2(≤ 3 kN/m^2)	Office Room=3 kN/m^2 Laboratories =3 kN/m^2 Bathroom/Toilet =2 kN/ m^2 X-Ray room/Operating room =3 kN/ m^2 Wards/bedrooms =2 kN/ m^2
3	LL3(Terrace floor)	1.5 kN/ m^2

4. Modeling and Analysis

Modeling and analysis were done in ETABS 2018 as per IS 1893(Part 1):2016 and ASCE 7-16 under most credible earthquake. The analysis used were Response spectrum analysis and push over analysis.

Response spectrum analysis is widely recommended for the analysis and design of buildings against lateral loads due to earthquakes. This method of analysis gives the quantity of lateral loads acting at each floor level of the buildings when they are subjected to earthquakes. This method includes higher modes of vibrations in the analysis and therefore powerful method to understand the seismic behaviour of buildings.

In the present study response spectrum as specified in IS 1893:2016 was used to analyse (Figure 2) the behaviour of three different types of buildings i.e. low-rise, mid-rise and high-rise structures with lead rubber base isolation.

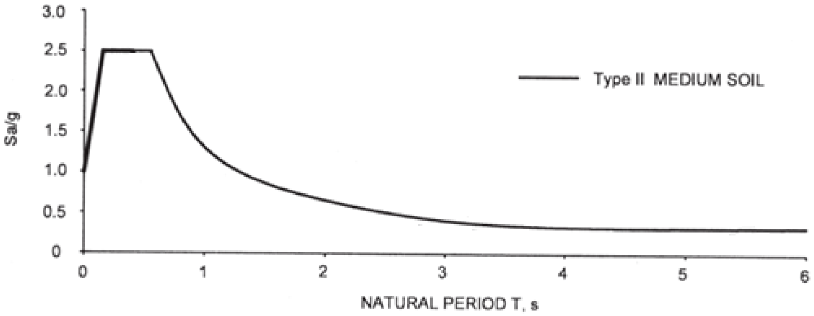


Fig. 2 Response Spectrum (IS 1893:2016)

The parameters considered in this study are displacement, base shear and time period.

- Displacement: It is the distance from which the structural element such as beams, columns and frame moves from its original position. While comparing the displacement with fixed base and base isolator, it gives a clear image how the isolator performs.
- Base Shear: Base shear is the maximum lateral load acting at the base of the building under ground motion due to earthquakes. The percentage reduction in base shear helps to study the performance of base isolation in structure.
- Time Period: When a building is subjected to ground shaking in the case of an earthquake, its time period is its natural period of oscillation.
- Drift: The sideways deflection of the upper floor in relation to the sideways deflection of the lower floor for a particular story is known as building story drift. It's also known as the lateral or sideways displacement of two neighboring stories.

Push over analysis is a simple technique for estimating the strength capacity and global and local damage level of a building in the post-elastic range of behaviour. The procedure to carry out the pushover analysis is explained in the seismic guidelines ATC-40, 1996, FEMA-356, 2000, etc. Modal pattern was used for pushover analysis which combines response from pushover analysis in multiple modes. It can estimate the magnitude and distribution of force demands in the first and higher modes including inelastic response. Automatic hinges were used in this study for assigning hinges to structural elements. P-M2-M3 hinges were assigned to columns and flexural M3 hinges to beams.

From the pushover analysis the different performance levels of buildings can be obtained. Buildings performance levels that are commonly used is shown below,

- Operational: This performance level gives an idea that the building can be used after the earthquake event since the deformations in the buildings are minor.
- Immediate Occupancy: There occurs very limited structural damage and damage to life is negligible. The components retain almost all pre-earthquake characteristics.
- Life Safety: This level ensures the life safety of the occupants from structural or non-structural building components damages.
- Structural Stability: This stage shows the partial or total collapse of the building which reveals the inability of the lateral load resisting elements.

4.1 Fixed Base Building

Modeling and analysis were done in ETABS 2018 followed by IS 1893(Part 1):2016 and ASCE 7-16 under most credible earthquake. The regular plan considered was with 81 x

28.5m plan with floor height of 3.5m. The analysis used were Response spectrum analysis and push over analysis. Building structures are classified into three types namely low-rise (<20 m), mid-rise (20 m to 50 m) and high-rise (>50 m) with respect to the height of the structures (IS 875 (Part 3), 2015). In this study, buildings are designed for all the categories mentioned under the seismic and non-seismic loading conditions. The height of low-rise structure is 19.5m and the height of mid-rise structure is 48.5m and the number of stories in low and mid-rise structure is five and fifteen. High-rise structure consists of 25 stories with a total height of 81.5m. The materials and member sizes were taken to suit the requirements of a G+5, G+15 and G+25 storey RC buildings. Figure 3 represents the plan of RC building for G+5, G+15 and G+25.

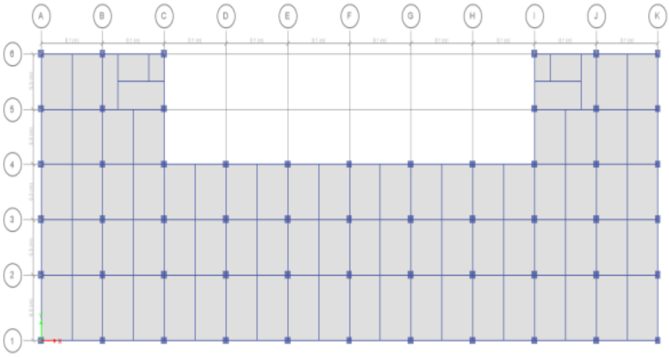


Fig. 3 Plan of RC building

4.2 Lead Rubber Bearing Isolation Device

Figure 4 and 5 show a typical model of lead rubber bearing with different parts mentioned. Rubber and lead layers are arranged in a definite pattern to obtain a lead rubber bearing which will strain first before the building components when it is installed in a building, thereby protection of building is ensured.

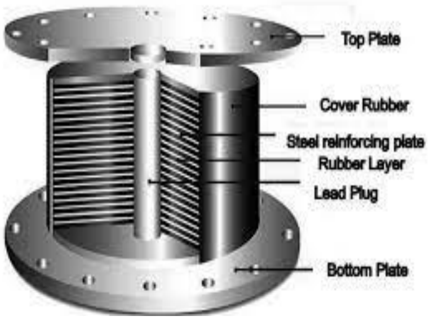


Fig.4 Lead rubber bearing-Typical

4.3 Design of Lead Rubber Bearing

The design of lead rubber bearing is done by using the following steps.

Step 1 (Isolation system force-displacement behavior)

Q_d (System characteristic strength) is found by the available data. (1)

$Q_d = \pi D_L^2 \sigma_{YL}/4$

Where D_L =Lead core diameter (Assumed as 4.5inch)

σ_{YL}= Effective yield stress of lead

lower bound= 1.45-1.75

upper bound = 1.35x(1.45-1.75)

D_B= Bonded rubber diameter (3-6times D_L)

K_d (System post-elastic stiffness)

$K_d = G f_L \pi (D_B^2 - D_L^2)/4T_r$

G= lower bound= 60-75

upper bound = 75x1.1x1.1 (2)

f_L= effect of lead core (ranges from 1.1-1.2)

T_r= less than or equal to D_L

Y=Yield displacement (0.25-1)

Step 2 Equivalent lateral force procedures (MCE)

In this method maximum displacement (D_M) is assumed and then found by iteration method

$D_M = g S_{M1} T_M / 4\pi^2 B_M$

Where, (3)

S_{M1} = 0.36 x 1 x 1.36/1 = 0.49

S_{MS} = 0.36 x 1 x 2.5 = 0.9

The effective stiffness and damping in bilinear model is shown in Figure 6.

Effective stiffness k_M

$k_M = K_{d,total} + Q_{d,total} / D_M$ (4)

Effective period T_M

$T_M = 2\pi\sqrt{W/k_M g}$ (5)

Effective damping β_M. The yield displacement *Y* is assumed to be 0.6inch

$B_M = 4Q_{d,total}(D_M - Y)/2\pi k_M D_M^2$ (6)

Damping coefficient B_M can be interpolated from Table 17.5-1(ASCE 7-16).

Table 3 and 4 gives the design details and dimensions of the lead rubber bearing under study and are used as input for the modelling and analysis using ETABS.

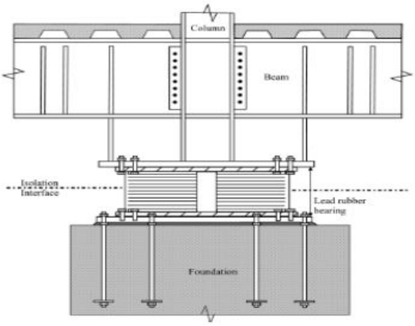


Fig. 5 Detailing of isolation system at column

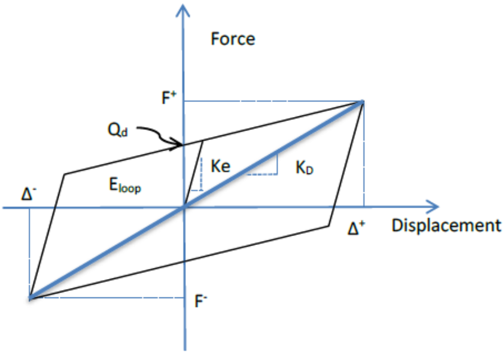


Fig. 6 Effective stiffness and damping in bilinear model

Table 3. Lead rubber bearing dimensions

	G+5	G+15	G+25	Units
N	56	56	56	-
W	77692	220520	363349	kN
D_L	115	130	140	mm
D_B	575	650	700	mm
T_r	115	130	140	mm
Y	15	15	15	mm
σ_{YL}	9.9	12	13.7	N/mm^2
G	413.7	517.1	551.6	kN/m^2

Table 4. ETABS input

ETABS input	G+5	G+15	G+25
Effective Stiffness (U1), kN/m	943060	719860	520335
Effective Stiffness (U2&U3), kN/m	943.06	719.86	520.33
Effective damping (U2&U3), kN-s/m	350	350	350
Post elastic stiffness (U2&U3), kN/m	49912	38993	27112
Yield strength (U2&U3), kN	5744.5	6933.0	11836.3

4.4 Building with Base Isolator

To make the structure safe, base isolation techniques are used which prevents the deformation to the buildings during earthquakes. The main aim of isolators is to reduce the vibration to the super structure. The present study deals with the performance and efficacy of base isolation in low rise, mid-rise and high- rise building. For that G+5, G+15 and G+25 storey buildings were considered with lead rubber bearing device. Figure 7 represents the closer view of base isolator attached between base and the ground.

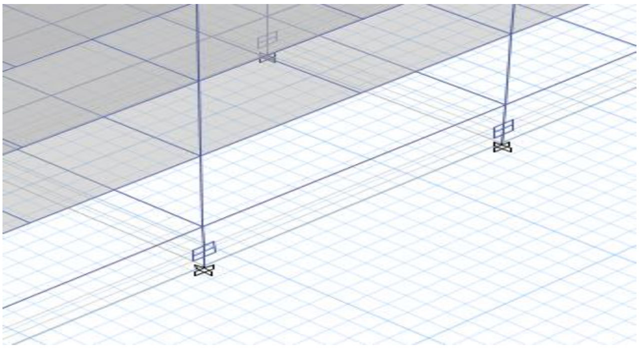


Fig. 7 Closer view of base isolator

5. Results and Discussion

Analysis was done using response spectrum method and the pushover analysis on G+5, G+15 and G+ 25 storey buildings with and without base isolators. Base responses for fundamental time period, first-storey displacement, base shear, and maximum inter-storey drift ratio are given in Table 5, 6, 7 and 8, respectively.

Figures 8, 9 and 10 are the graphical representation for displacement and Figures 11, 12 and 13 are the graphical representation for drift for G+5, G+15 and G+25, respectively. The bar chart comparison for Base shear and Time period for G+5, G+15 and G+25 are represented by Figures 14 and 15, respectively. The provision of base isolators in the buildings made them more flexible which is witnessed from increased fundamental time period of the buildings. The maximum inter-storey drift ratio of the base isolated buildings is considerably reduced and it is very effective in G+15 storey building.

Table 5. Fundamental time period

Building Type	Time period (sec)		
	Fixed base	Base isolated	Increase
G+5	0.949	2.789	2.94 times
G+15	3.387	6.283	1.86 times
G+25	4.816	9.894	2.05 times

Table 6. First-storey displacement

Storey	Displacement (mm)		
	Fixed base	Base isolated	Increase
G+5	16.95	127.11	7.49 times
G+15	19.64	678.46	34.55 times
G+25	20.35	1248.38	61.36 times

Table 7. Base shear

Building Type	Base Shear (kN)		
	Fixed base	Base isolated	Decrease
G+5	31308.86	6595.42	4.75 times
G+15	45811.47	20972.63	2.18 times
G+25	52660.67	36290.18	1.45 times

Table 8. Maximum Inter-storey drift ratio

Building Type	Maximum Inter-storey Drift Ratio		
	Fixed base	Base isolated	Decrease
G+5	0.0107	0.0047	2.27 times
G+15	0.0171	0.0033	5.18 times
G+25	0.0222	0.0118	1.88 times

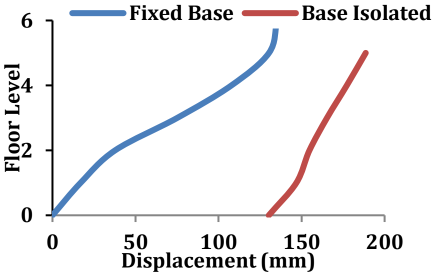


Fig. 8 Displacement for G+5

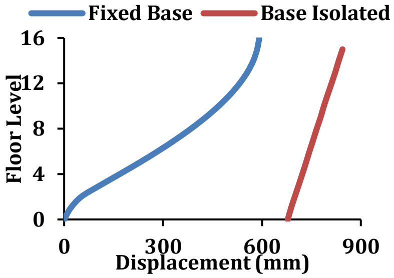


Fig. 9 Displacement for G+15

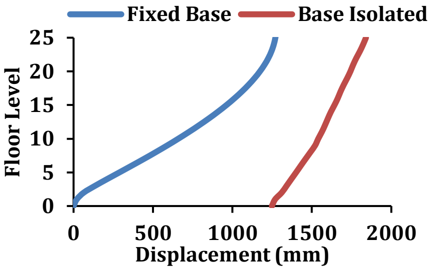


Fig. 10Displacement for G+25

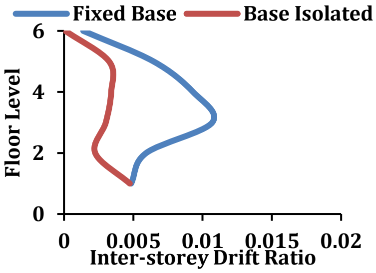


Fig. 11 Inter-storey Drift Ratio for G+5

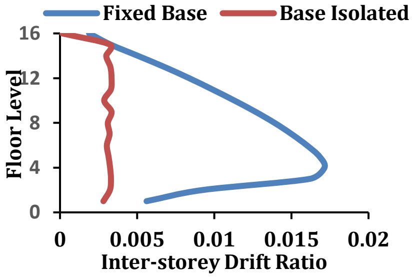


Fig. 12 Inter-storey Drift Ratio for G+15

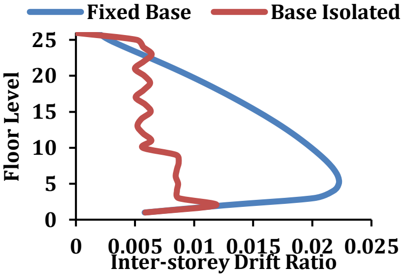


Fig. 13 Inter-storey Drift Ratio for G+25

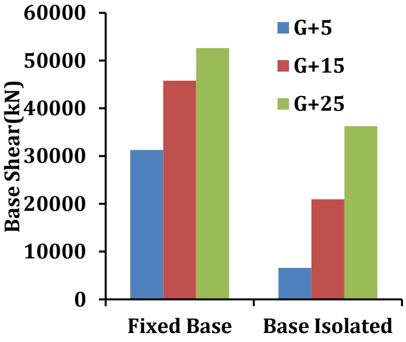


Fig. 14 Base shear

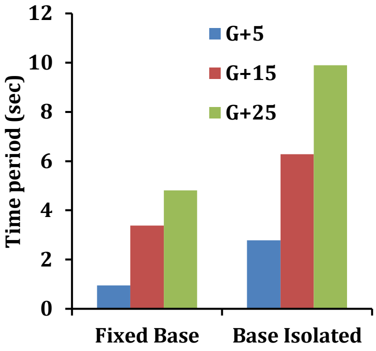


Fig. 15 Time period

Pushover analysis was done to identify the yield capacity and ductility ratio of base isolators compared to fixed structures. Capacity curves were obtained after pushover analysis for both fixed base and base isolator. Figures 16,17 and 18 represent the capacity curve along X direction for G+5, G+15 and G+25 storey buildings, respectively with and without base isolators. It can be seen that the ductility capacity of the base isolated structure has been improved especially in medium and high-rise structures. This behaviour may be due to the flexibility contribution by base isolator.

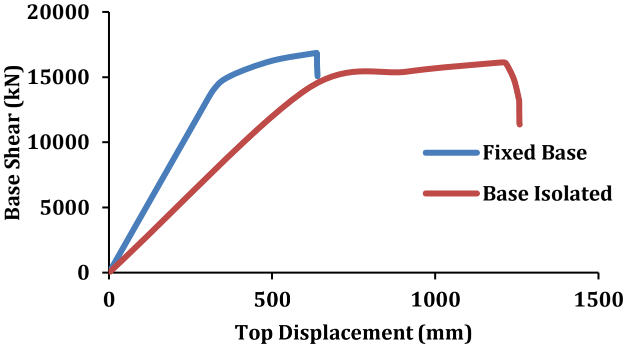


Fig. 18 Capacity Curve for G+5

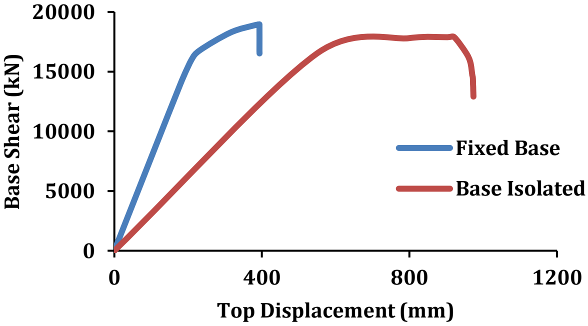


Fig. 17 Capacity Curve for G+15

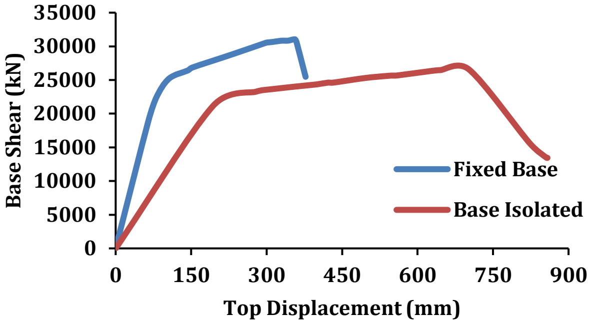


Fig.16 Capacity Curve for G+25

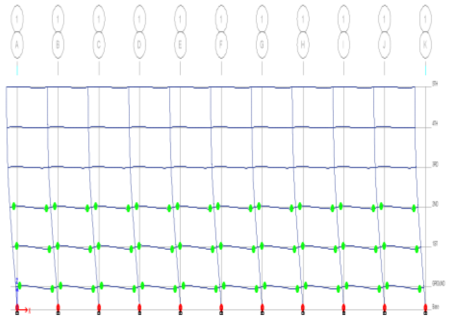
Hinge formation represents the performance level of the structure such as immediate occupancy, life safety and collapse prevention. Details of hinge formation for last step are shown in Table 9. It is observed that no hinges are formed in the buildings with base isolators beyond LS level and this type of behaviour is required and expected for seismic resistant structures. In G+5 storey FB building model, 81% , 16 % and 3 % of total hinges were formed in A-IO, IO-LS and beyond CP damage levels, respectively; whereas in G+5 storey BI building model 85% and 15 % of total hinges were formed in A-IO and IO-LS damage levels, respectively. In G+15 and G+25 storey BI building models, 100 % of total hinges were formed within A-IO level and, in G+15 and G+25 storey FB building models a few hinges were observed in beyond CP level. Hinge formation analysis shows that the base isolation is very effective in G+15-BI and G+25-BI building models when IO level is considered for design. However, when LS is considered for design, base isolation is effective in all the three models under study.

Table 9. Details of hinge formation

	A-IO	IO-LS	LS-CP	>CP	Total
G+5-FB	2984	576	0	112	3672
G+5-BI	3320	576	0	0	3896
G+15-FB	9776	0	0	16	9792
G+15-BI	10016	0	0	0	10016
G+25-FB	15910	0	0	2	15912
G+25-BI	16136	0	0	0	16136

From the above table it is very clear that number of hinges were limited within immediate occupancy for structure with base isolator whereas structure without base isolator exceeds collapse prevention. Typical hinge formation in G+5 is shown in Figure19 and Figure20 for with and without base isolator.

The displacement ductility factor is one of the key outputs of the pushover analysis. Higher the ductility factor higher the capacity of the structure. Table 10 represents the displacement ductility factor for G+5, G+15 and G+25. It can be seen that the ductility factor is very much improved in the G+15 and G+25 buildings with base isolator.



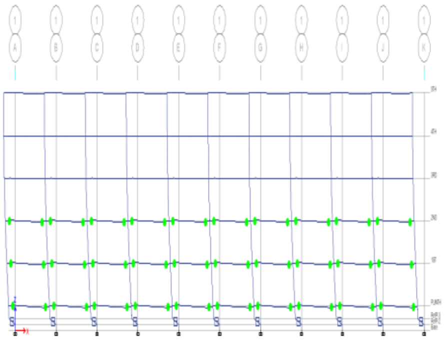


Fig. 19Hinge formation in fixed base

Fig. 20 Hinge formation in base isolator

Table 10. Displacement ductility factor

	G+5		G+15		G+25	
	FB	BI	FB	BI	FB	BI
Ultimate displacement (mm)	377	858	394	12910	639	11384
Yield displacement (mm)	106	193	209	548	320	605
Displacement ductility factor	3.6	4.4	1.9	23.6	1.99	18.8
Ductility improvement	0.8		21.7		18.8	

6. Conclusion

In this paper, performance analysis of lead rubber bearing isolation system for low, medium and high- rise RC buildings using response spectrum analysis and pushover analysis was performed. For understanding the performance of lead rubber bearing, parameters used were, fundamental time period, base shear, first storey displacement and inert-storey drift ratio from response spectrum analysis. Capacity curves and hinge formation were plotted from pushover analysis to study the parameters such as shear capacity and displacement ductility factor. As there is no Indian code describing the design procedures for base isolators, in this project ASCE-7-16 procedure was modified according to Indian standards and done the analysis and following were concluded.

- In base isolation, modal periods are increased more than 40% in G+5, G+15 and G+25 structures, increasing the building's reaction time during earthquake. For G+5 modal period got increased by 65%, G+15 it got increased by 46% and finally G+25 modal period increased by 51%.
- From the response spectrum analysis results, there is a significant reduction in the base shear after incorporating base isolation in the buildings in the order of 1.45 to 4.75 times. Therefore, it is very clear that use of base isolation has a large influence which is very efficient in earthquake prone areas.
- The inter-storey drift ratio of the buildings is significantly reduced, nearly 2 to 5 times after the installation of base isolation device.

- Pushover analysis was done to understand the efficacy of all the three models and concluded that model with base isolation showed a large percentage increase in yield displacement and ductility ratio compared to model without base isolation. It can be seen that the ductility factor is improved significantly in the medium and high-rise buildings with base isolator (nearly 19 to 22 times).
- It is observed that no hinges are formed in the buildings with base isolators beyond life safety level and this type of behavior is required and expected for seismic resistant structures. Hinge formation analysis shows that the base isolation is very effective in G+15-BI and G+25-BI building models when immediate occupancy level is considered for design. However, when life safety is considered for design, base isolation is effective in all the three models under study.
- Performance of lead rubber bearing of G+5, G+15 and G+25 was also understood after the analysis. All three models showed same level of performance with isolators. But still for more safety it is suggested that if storey height is more than G+15 and the location is very prone to earthquake other technologies such as shear wall and dampers can also be added.
- It is concluded that using lead rubber bearing as a base isolation system improves structural stability and protects the building from adverse effects of lateral loads due to earthquakes.

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