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EFFECT OF BASE ISOLATION ON DYNAMIC RESPONSE OF RC IRREGULAR BUILDINGS

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Abstract: Base isolation, widely used in critical facilities such as hospitals, airports, nuclear power plants, and bridges to reduce the horizontal acceleration transmitted to the superstructure. It effectively decouples the superstructure and the foundation during earthquakes. Base Isolation significantly reduces base shear forces, inter storey drifts. Analysis is carried out to investigate the dynamic response of 16–storey regular and irregular buildings using E-tabs. The analysis compared dynamic responses with and without base isolation using Lead Rubber Bearing (LRB) systems. The effectiveness of base isolation was demonstrated by comparing storey drift, lateral displacement, base shear, and time period between fixed base and isolated base structures. Results showed that while lateral storey displacements at the first storey were higher for isolated buildings compared to fixed base buildings, the top storey experienced less displacement. Vertical irregular buildings with base isolation performed better than regular buildings, while those without base isolation showed poor dynamic responses. Base isolation reduced base shear in both X and Y directions, stabilizing the structure during earthquakes. Relative storey drift values were lower for base isolated buildings, and time periods were increased by about 3.03 seconds for 16-storey buildings, helping to mitigate severe earthquake accelerations. Maximum storey displacements increased with building height, but story drift and base shear values were reduced in higher stories, enhancing structure safety and stability against earthquakes. Overall, base isolation increased the time period of high-rise buildings to mitigate severe accelerations during earthquakes.

Index Terms -base isolation, vertical irregularity, vibration period, drift, acceleration.

I. INTRODUCTION

Base isolation (BI), also known as seismic isolation, widely protects structures from earthquake effects. It is a technique mostly used in critical facilities requiring continuous operation even after severe earthquakes, such as hospitals, airports, nuclear power plants, and government buildings. BI is also utilized in highway engineering structures like bridges and viaducts. BI systems effectively decouple the superstructure and the foundation during earthquakes, resulting in significantly lower base shear forces and inter-story drifts. Effective reduction of inter-story drift in base isolation systems ensures minimal damage to facilities and human safety. The concept of base isolation systems has been suggested in recent decades, with technologies and knowledge maturing and becoming well-established. Seismic isolation systems are particularly effective for high stiffness, low-rise buildings, as they can change the building's characteristics from rigid to flexible. The increasing number of structures using base isolation reflects its acceptance as a proven technology in earthquake hazard mitigation. Base isolation, as an anti-seismic design strategy, reduces the effect of earthquake ground motion by uncoupling the superstructure from the foundation. Performance of base-isolated buildings during large-scale earthquakes has been excellent, as predicted, leading engineers to invest time and research into this topic, resulting in well-developed and established isolation system technologies in theory, design, and construction phases. Analysis is carried out to understand the effect of vertical irregularity of buildings on dynamic performance with four different geometric configurations.

II. OBJECTIVES OF STUDY

The following objectives are focused for the study on dynamic response of irregular 16 storey buildings with 4 different configurations.

1. Analyze and study the effectiveness of base isolation, using lead rubber bearings, on the dynamic response of regular and vertical irregular structures.

2. Perform a comparison between fixed base and base isolated 16-storey buildings, focusing on dynamic properties such as base shear, storey drift, time period, and storey displacement.

3. Compare the performance of five different cases of base isolated vertical irregular buildings with a fixed base regular building.

III. LITERATURE SURVEY

Many researchers have studied the response of base isolation on buildings during earthquakes. Few studies are reviewed in this chapter. Khan and Baig (2018) studied the effectiveness of the lead rubber isolator for G+15 storey RCC framed structure. Analysis is carried out using E-tabs software for Bhuj earthquake data. two cases were analyzed, the first one is for rigid jointed framed RCC structure and second is for structure isolated by lead rubber bearing (LRB).Siesmic zone is V for soil type III (loose density type). Seismic performance in terms of storey drift, lateral displacement of the structure, base shear, acceleration, time period and maximum bending moment of the fixed base structure were compared to that of isolated base structure. Chiranjeevi and Manjunatha (2017) analyzed the building on sloping ground. G+ 9 storey RCC building with ground slope angle varying from 0° to 30° is considered. for analysis with and without base isolation. Linear static analysis and the response spectrum analyses have been carried out as per IS: 1893 (part 1): 2002. The results were obtained in the form of top storey displacement, drift, base shear and time period. Satyanarayana and Gopal (2018) anlysed the effect of lead rubber bearing base isolator for symmetric and asymmetric low and high rise structures. The Base isolation system increase the flexibility at the base of the building and which helps in Energy Dissipation due to the horizontal seismic forces. Storey drift and storey shear also reduces in the base isolated buildings. From the time history Analysis Acceleration, velocity, displacements are low for base isolated structures. It make the structure rigid and stiffer. Jishuai et al. (2022) predicted the influence of SSI on reinforced concrete buildings by using neural networks. Liguo et al. (2022) proposed a new framework for tuned mass damper systems with SSI effects. Yulin et al. (2023) investigated the earthquake response of multi-span bridges by taking into account abutment–soil–foundation-structure interactions. Present study is aimed at analysis of vertical irregular tall buildings response with base isolation using Lead Rubber Bearing.

3.1 LEAD RUBBER BEARING

Lead plug rubber bearings has central core which enhances the rubber bearing vertical stiffness highly effective under vertical loads. The structure attains sufficient stiffness enabling control of acceleration and velocity within acceptable range during service loading. During an earthquake event, the rubber bearing yields transferring energy to the rubbers through displacements and absorbing through damping device within the rubber bearing. In addition to its performance benefits, the cost of these bearing is lower compared to implementing extra forces of stiffness control. The purpose of lead core plug rubber bearings is to address issues arising from service loads, offering a direct and economical solution.

IV METHODOLOGY

4.1 ANALYSIS OF BUILDINGS USING E TABS

The building is analysed by using ETABS2016 software for fixed base and rubber base of16 floors. Structure 1 is considered with Fixed base and the lead rubber is assigned to the bottom joints for structure-2.In case of rubber base buildings, 4 different configurations are considered with vertical irregularity of A/L ratio of 0.3,0.35,0.2 and 0.3.

Structure-1: Fixed Base Regular Building
Structure-2: Rubber Base Regular Building
Structure-3: Configuration C1- Rubber Base System with Decreasing the Floor Heights Along X- Direction. (Vertical irregular structure with A/L ratio= 0.30)
Structure-4: Configuration C2-Rubber Base System with Decreasing the Floor Heights Along Y- Direction(Vertical irregular structure with A/L ratio= 0.35)
Structure-5: Configuration C3- Rubber Base System with tower shape. (Vertical irregular structure with A/L ratio=0.2)
Structure-6: Configuration C4- Rubber Base System with Decreasing the length Along X-Direction. (Inverted T-Vertical irregular structure with A/L ratio=0.3)
A length of 40 m is considered along X direction and 24m is considered along Y-direction. The height of the building is 48 m.

4.2 Basic Properties of fixed base structure used for analysis

Table 3.1 shows the properties of fixed base structure with material properties, sectional properties, building details, and parameters used for response spectrum method of analysis.

Table 3.1. Basic Properties of fixed base Structure

Building Details:	Structure	RCC (SMRF)
	Structure Type	Plan Regular FRAME Structure
	Plan Dimension	40m x 24m
	Height of Building	G+15 (48m)
	Total No. of Storey	16
	Height of Each Storey	3m
	Height of Bottom Storey	3M
	Building Type	Public Building
Material Properties	Grade of Concrete	M40
	Grade of Steel	HYSD 550
Sectional Properties	Column Size	600mm x 400mm
	Beam Size	650 mm x 300mm
	Slab Thickness	150mm
Load Consideration		
Gravity Load	Dead Load	6 kN/m on COLUMN
		4.875 kN/m on BEAM
		3.75 kN/m2 on SLAB
	Live Load	4 kN/m2
Lateral Load for Response Spectrum Analysis	Seismic Zone	**V**
	Zone Factor	0.36
	Importance Factor	1
	Seismic Coefficient Cv	0.54
	Response Reduction Factor R	5 (OMRF)
	Site Type	III(SOFT)

Table 3.2 provides the properties used to estimate stiffness of rubber base structure and Table 3.3 gives the other properties of rubber base structure used in the analysis od isolated buildings with rubber base.

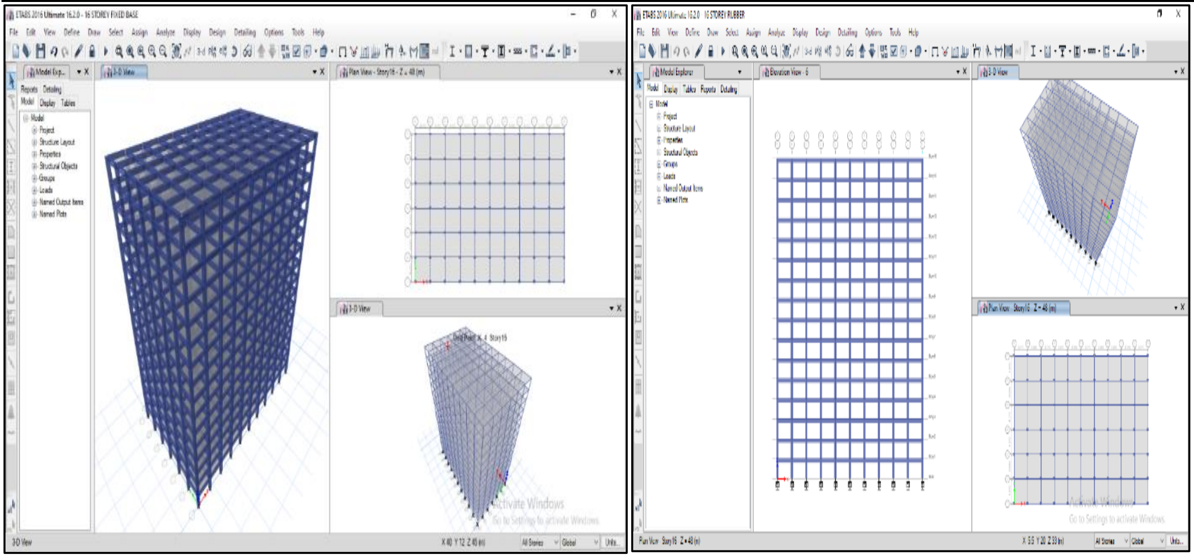
Table 3.2 - Basic Properties of stiffness of rubber base Structure

1	MAX.SUPPORT REACTION	**2600.883 KN**	Units
2	Calculate Design Displacement (D_D)		
	Assume Design Time Period T_D	2.5 sec	
	Seismic Coefficient Cv	0.54	
	Damping Coefficient (B_D or B_M)	1	
	Design Displacement (DD)	0.3358022	m
	Effective Stiffness (K_{eff})	800	kN/m
3	Damping (β_{eff})	5%	
	Energy dissipated per cycle (W_D)	59.23627	kN.m
4	Force at design displacement of characteristic strength (Q)	44.100572	KN
5	Stiffness in rubber (K_2)	1541.6522	kN/m
6	Yield Displacement (DY)	0.0031784	m
7	Recalculation of Q to QR	44.521984	KN

Analysis is carried out for the most seismically active region in India i.e. in zone V resting on soft soil (type III). The response reduction factor is 5 and importance factor is 1 as per IS 1893-2002. After the detailed study three types of load combinations are considered which gives maximum displacement, drift values and maximum base shear and overturning moments.

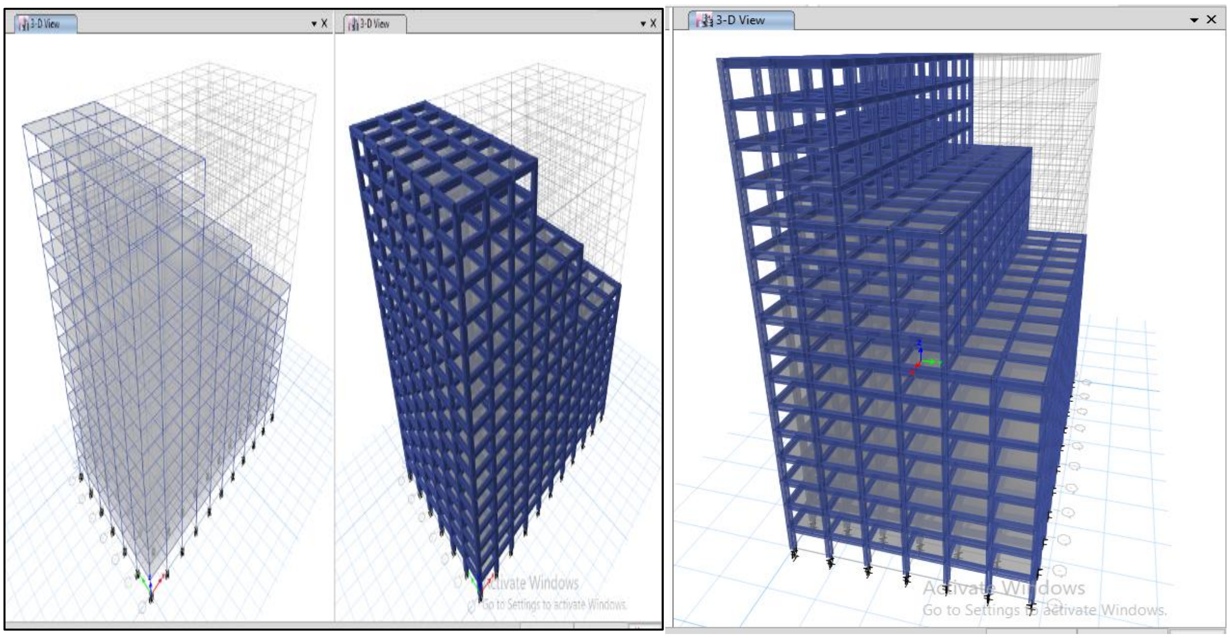
Table 3. 3. Basic Properties of rubber base Structure

<table>
<tr><td>Type of base isolator</td><td colspan="2">Lead rubber bearing isolator,</td></tr>
<tr><td rowspan="3">Placing Lead Rubber Bearing</td><td colspan="2">Base isolators are placed at 0.5m above base level.</td></tr>
<tr><td colspan="2">Isolators are provided above every footing</td></tr>
<tr><td colspan="2">Properties of LRB Calculated are mentioned in the below table</td></tr>
<tr><td rowspan="7"></td><td>Property Type</td><td>Response Spectrum Analysis</td></tr>
<tr><td>Effective Stiffness Keff (R)</td><td>800 kN/m</td></tr>
<tr><td>Horizontal Stiffness K_H</td><td>10731 kN/m</td></tr>
<tr><td>Vertical Stiffness K_V</td><td>1175418 kN/ m</td></tr>
<tr><td>Yield strength Q_R</td><td>34.7 kN</td></tr>
<tr><td>Post Yield Stiffness ratio</td><td>0.1</td></tr>
<tr><td>Damping</td><td>5%</td></tr>
</table>



(a) (b)

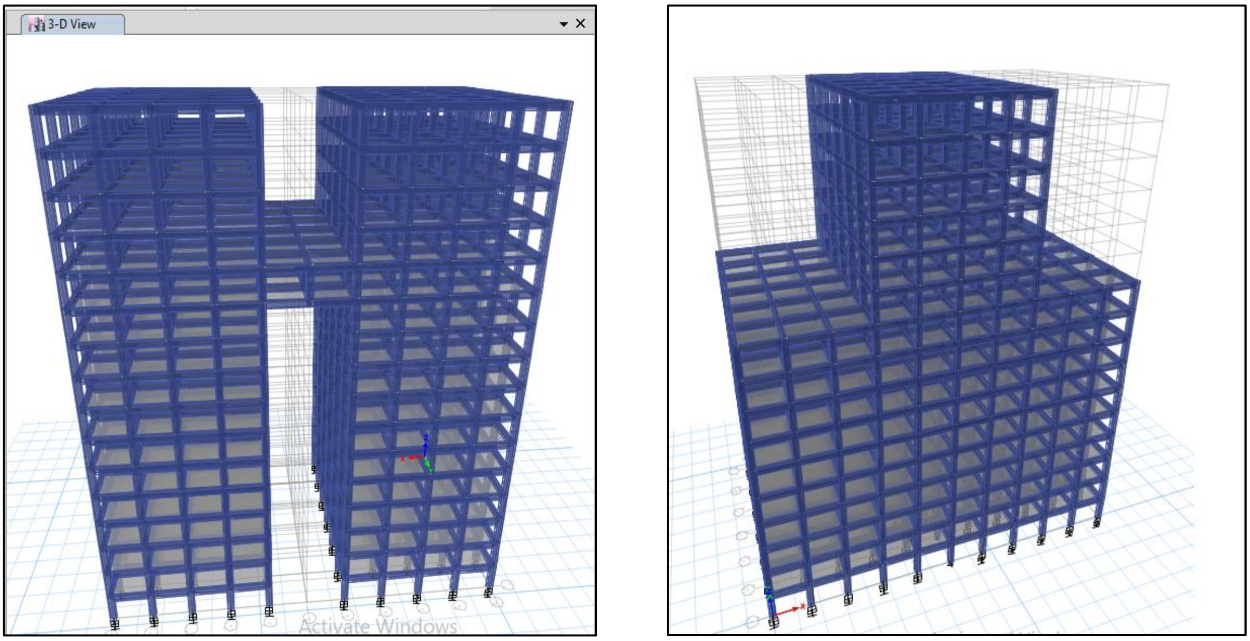
Fig.3.18 a) Structure-1-Fixed Base Regular Building b) Structure-2-Rubber Base Regular Building



(b) (b)

Fig.3.20 a) Structure-3-Configuration C1- Rubber Base System with Decreasing the Floor Heights Along X-Direction. (A/L Ratio 0.3)

b) Structure-4-Configuration C2-Rubber Base System with Decreasing the Floor Heights Along Y- Direction (A/L Ratio 0.35)



(a) (b)

Fig.3.22 a) Structure-5. Configuration C3- Rubber Base System with tower shape. (A/L Ratio 0.2) b) Structure-6-Configuration C4- Rubber Base System with Decreasing the length Along X-Direction. (Inverted T) (A/L Ratio 0.3)

4. RESULTS AND DISUSSION

Analytical investigations have been carried out to study the effect of base isolation using Lead Rubber Bearing (LRB) on regular and irregular 16 story RC structures with 4 different irregular geometries. The dynamic response of the regular 16 storey RC building is compared with 4 different geometric irregular buildings with base isolation. Dynamic analysis is carried out using Response Spectrum Method based on IS 1893-2002 for earthquake loading of zone V. Dynamic response parameters namely maximum story displacement, story shear, time period, overturning moments and Mass participation factor are analysed. Based on this work following comparisons are made.

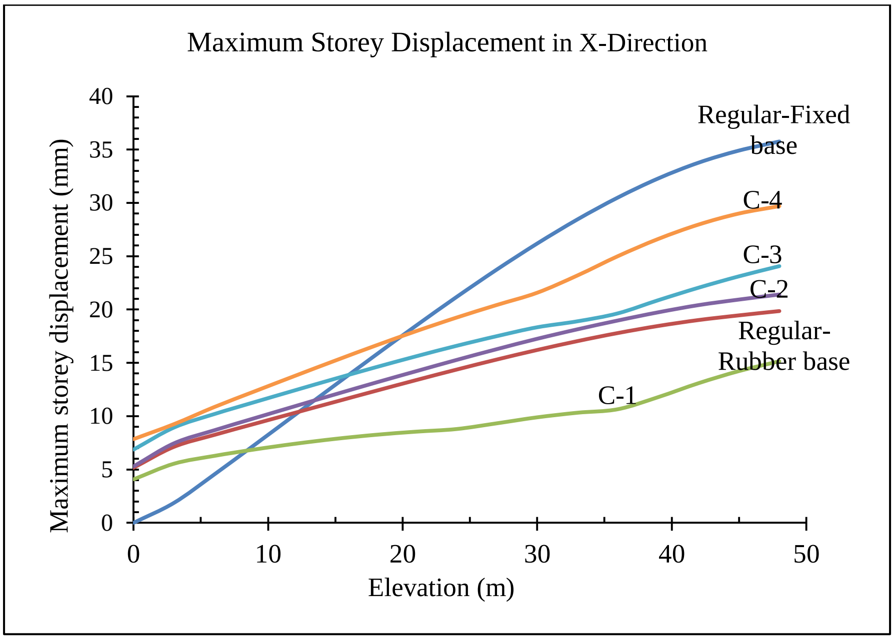


Fig. 4.1: Maximum Story Displacement along X-direction

Fig. 4.1 depicts the variation of maximum storey displacement in the X-direction for 16 storey regular and irregular buildings with 4 different configurations. The maximum storey displacement is lower for regular configuration buildings with LRB, which shows the effect of base isolation on dynamic response. The configuration C1 with vertical irregularity shows better dynamic performance compared to other configurations and regular buildings. The 16 storey building with configuration C1 with LRB has lower maximum storey displacements.

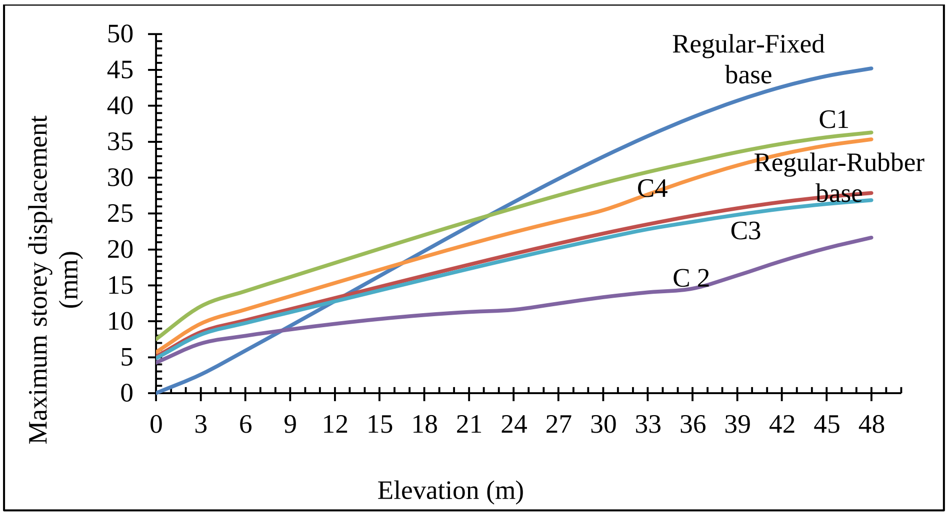


Fig. 4.2: Maximum story displacement along Y-direction

Maximum storey displacement along Y-direction is shown in Fig. 4.2 for 16 storey buildings with regular and irregular configurations provided with base isolation. Similar variations as depicted in Fig. 4.1 is observed but the configuration namely C2 has lower storey displacements among other configurations.The story displacement at the base is zero along X and Y directions with the fixed base, but in the case of the rubber base, there is a displacement of about 5.16 mm along the x-direction (Fig.4.1) and 5.07mm (Fig. 4.2) along the Y-direction. It is also observed that the maximum storey displacement at the top of the building with a fixed base is 35.75 mm along the X-direction (Fig. 4.1) and 42.2 mm along the Y-direction (Fig. 4.2). The maximum story displacement at the top of the building with a rubber base is 19.85 mm and 27.86 mm along the X-direction and Y-direction, respectively. Replacing the fixed base with a rubber base reduces the maximum story displacements by 44.47% and 38.37% along the X-direction and Y-direction, respectively, by introducing the rubber base system or base isolation. Further, for 4 different configurations having vertical irregularities in structures, the displacements along the X direction are 15.14mm, 21.4mm, 24.06 mm, and 29 mm. And the displacements along the Y direction are 36.28mm, 21.65mm, 26.86mm, and 35.33mm. It showed that LRB buildings have undergone lower values of story displacement than fixed-base buildings. The configurations C1 and C2 performed better in terms of top storey displacement among other configurations.

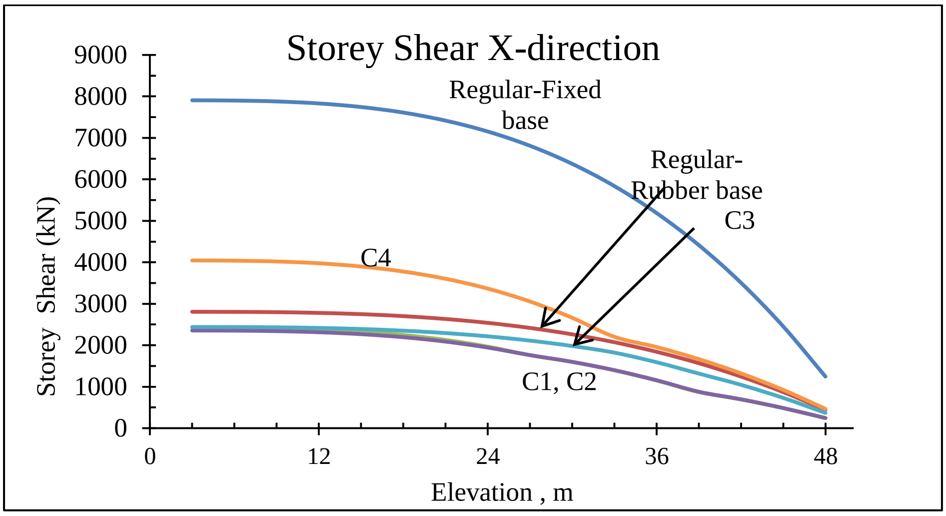


Fig.4.3. Variation of storey shear along X-direction for 16 storey regular and irregular buildings with 4 configurations.

Fig. 4.3 gives the variation of storey shear along the X-direction for 16 regular and irregular buildings. A comparison is made between the responses of regular and irregular buildings with and without LRB base isolation. The storey shear is maximum at the base and reduces with the height of the building in a nonlinear manner. The building with vertical irregularity in configurations C1 and C2 with LRB shows lower storey shear values compared to other types.

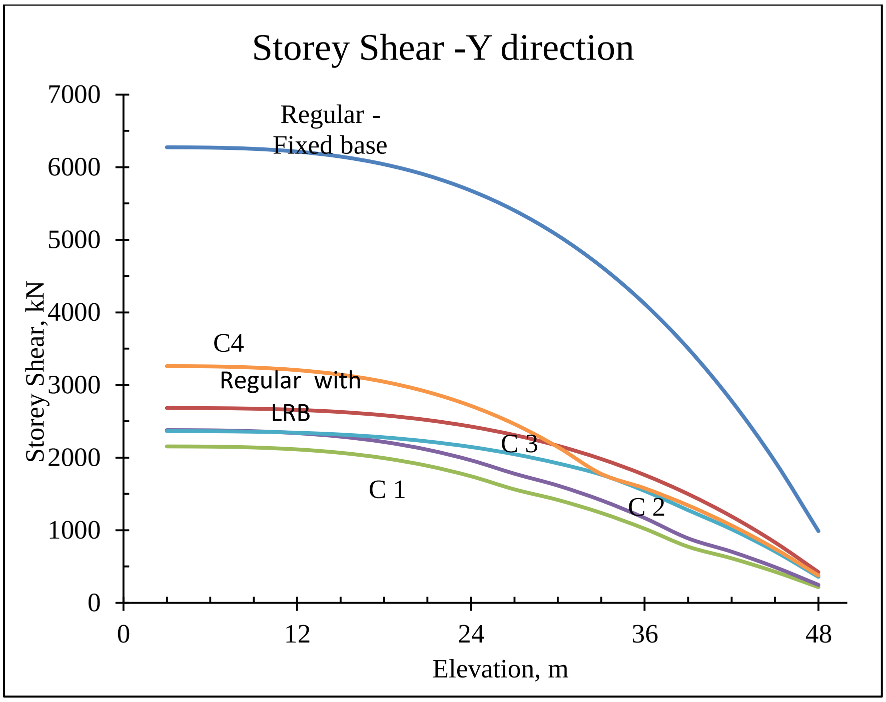


Fig.4.4. Variation of storey Shear along Y-direction for 16 storey regular and irregular buildings with 4 configurations.

The variation of storey shear along the Y-direction is given in Fig. 4.4. The effect of base isolation with LRB is indicated by the lower storey shear values for base isolated buildings, both in regular and irregular configurations. The story shear at the bottom of the building is decreased by 64.5% along the X-direction and 57.24% along the Y-direction with the replacement of the fixed base with LRB. C1 has the least storey shear, with 2153.5 kN along the Y-direction. So, it can be concluded that the base shear is reduced by 65.6% with the lead rubber base system as the base isolator. Table 4.3 shows the modal time period values for 16 storey regular and irregular configurations with and without LRB. The time period for the fixed base buildings in single mode is 1.336 seconds, which is increased to 3.124 seconds for the fixed base replaced with a rubber base. The time period is longer for all the buildings with a rubber base system than for those with a fixed base system. The C-3 building time period is high compared with other configurations, C-1, C-2, and C-4. Base isolation in the form of LRB helps in increasing the time period with respect to fixed base building.

Table. 4.3. Modal Time period for 16 storey regular and irregular buildings with LRB.

Case	**Mode**	Regular - Fixed base	Regular with LRB	Irregular buildings with LRB			
				C-1	C-2	C-3	C-4
		Period sec	**Period sec**	**Period sec**	**Period sec**	**Period sec**	**Period sec**
Modal	1	1.336	3.124	2.849	2.707	3.038	2.007
Modal	2	1.13	2.985	2.525	2.682	2.944	1.89
Modal	3	1.06	2.871	2.178	2.329	2.869	1.618
Modal	4	0.441	0.654	0.585	0.605	0.688	0.578
Modal	5	0.375	0.544	0.488	0.517	0.676	0.467
Modal	6	0.349	0.526	0.431	0.459	0.63	0.437
Modal	7	0.256	0.316	0.309	0.326	0.609	0.331
Modal	8	0.222	0.274	0.271	0.285	0.561	0.302
Modal	9	0.203	0.254	0.264	0.251	0.544	0.278
Modal	10	0.182	0.21	0.22	0.223	0.309	0.2
Modal	11	0.157	0.182	0.186	0.202	0.304	0.171
Modal	12	0.143	0.167	0.181	0.171	0.293	0.163

The first three fundamental mode periods found for 16 storey regular building are 1.336 sec, 1.13 sec and 1.06 sec, whereas for regular building with LRB are 3.124 sec, 2.985 sec and 2.871 sec respectively. The time period increases by 133%, 164%, and 170% for a 16 storey regular building with base isolation by LRB. Similarly, the time period for 4 configurations with base isolation by LRB is 2.84 sec, 2.70 sec, and 3.03 sec for configurations C1, C2, and C3, respectively. It is found that base isolation in the form of LRB increases the time period for all configurations with respect to regular 16 storey buildings without LRB.

4.1 MAXIMUM STORY DIRFT

Table 4.5. Maximum Story Drift for 16 storey regular and irregular buildings with LRB

MAXIMUM STOREY DRIFT					
		X-Direction	Storey Level	Y-Direction	Storey Level
16 storey building	Regular-fixed base	0.000939	Story 5	0.001163	Story 5
	Regular with LRB	0.001162		0.001869	
	C1	0.000978	Between base and 2^{nd} Story	0.00211	Between base and 2^{nd} Story
	C2	0.001119		0.001606	
	C3	0.001157		0.001816	
	C4	0.003057		0.003197	

Table 4.5 shows the values of maximum storey drift for 16 storey regular and irregular buildings with LRB base isolation system. The maximum storey drift is observed between the base and 2nd storey for the 16 storey regular building with LRB, which is about 0.001162 along the X-direction and 0.001869 along the Y-direction. The maximum story drift is observed between the base and 2nd storey for the irregular 16 storey buildings with configurations C1, C2, C3, and C4 with LRB. They are 0.000978, 0.001119, 0.001157, and 0.003057

along the X-direction, respectively, for C1, C2, C3, and C4. Similarly, along the Y-direction, the maximum story drift values are 0.00211, 0.001606, 0.001816, and 0.003197, which occur between the base and 2nd storey.

Table 3.4 Modal Mass Participation Ratio

STRUCTURE	X	Y
Structure-1 (Fixed-regular)	0.746	0.91
Structure-2 (Rubber base – regular)	0.915	0.998
C1	0.916	0.954
C2	0.949	0.915
C3	0.915	0.997
C4	0.829	0.995

The modal mass participation factor of different modes in all buildings for X and Y directions is found. The combined modal mass participation should be more or equal to 90% (0.9) of the actual mass in each orthogonal response direction. In a fixed-base structure, 74.6% of mass participated in translation in the X direction, and 91.0% of mass participated in translation in the Y direction. For the rubber base structure, 91.5% of the mass participated in translation in the X direction, and 99.8% of the mass participated in translation in the Y direction. Buildings with configurations C2 and C3 have higher mass participation ratios.

5 CONCLUSIONS

After the analysis of fixed-base and base isolated (LRB) buildings by response spectrum analysis, the following conclusions can be drawn: From the above analysis, it is observed that vertical irregular base isolated buildings showed better dynamic performance than regular base-isolated buildings.

1. Replacing the fixed base with LRB, the maximum story displacement at the top of the building is decreased by 15.9 mm along the X-direction and 17.348 mm along the Y-direction. Overall, the displacements are reduced by 44.47% along the X-direction and 38.37% along the Y-direction by introducing the LRB base system.
2. The base shear is reduced by 50% when rubber base systems are used.
3. The time period for the rubber base buildings has increased compared with the fixed base buildings.
4. Overall, the C-2 building has low overturning moments along the X-direction, and the C-1 building has low values along the Y-direction.
5. Maximum storey displacements are increased in every story after providing LRB, which is important to make a structure flexible during an earthquake. The maximum storey displacement increases with the increasing height of the building.
6. Story drift values are reduced in higher stories, which makes structures safe against earthquakes.
7. Base shear is also reduced after providing LRB, which makes the structure stable during an earthquake. The reduction of storey shear decreases with an increase in the height of the building.
8. Overall, there is an increase in the time period of high-rise buildings with base isolation to avoid severe accelerations during earthquakes.

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