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# Evaluation of Seismic Isolation of High Rise Structure by Using Bearing and Dampers

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**ABSTRACT:** This paper presents a comprehensive evaluation of seismic isolation techniques in high-rise structures through the utilization of bearings and dampers. With the increasing vulnerability of tall buildings to seismic events, seismic isolation has emerged as a critical strategy to enhance structural resilience. By introducing flexible elements such as bearings and dampers between the building and its foundation, seismic forces are decoupled from the structure, reducing damage and improving occupant safety during earthquakes. The study encompasses a thorough review of various types of bearings and dampers, examining their effectiveness through numerical simulations and experimental investigations. Factors such as displacement reduction, energy dissipation, and system complexity are analyzed to provide insights into the optimization of seismic isolation systems for high-rise structures. The findings contribute to advancing the understanding of seismic resilience in urban infrastructure, facilitating the design of more robust and resilient buildings capable of withstanding seismic hazards.

**KEYWORDS:** seismic Isolation, High-Rise Structures, Bearings, Dampers, Structural Resilience, Earthquake Mitigation, Numerical Simulation, Experimental Investigation, Urban Infrastructure, Seismic Hazard etc.

## I. INTRODUCTION

**1.1 Introduction:** Seismic isolation techniques using bearings and dampers represent a critical aspect of structural engineering, particularly for high-rise buildings located in earthquake-prone regions. With the growing urbanization and construction of tall structures worldwide, the vulnerability of these buildings to seismic events has become a significant concern. Seismic isolation offers a proactive approach to mitigate the potentially devastating effects of earthquakes by decoupling the structure from ground motion. Bearings and dampers act as flexible elements inserted between the building and its foundation, effectively isolating the structure and dissipating seismic energy. This introduction sets the stage for a comprehensive exploration of the evaluation of seismic isolation techniques in high-rise structures, highlighting the importance of this research area in enhancing structural resilience and minimizing the impact of earthquakes on urban infrastructure.

**1.2 Concept:** An earthquake occurs when stored energy in the Earth's crust is suddenly released, generating seismic waves that propagate through the bedrock, causing significant vibrations. These seismic waves carry varying frequencies of vibration, with some frequencies retaining more energy depending on the soil's mechanical properties. Most buildings have a fundamental frequency that often overlaps with seismic frequencies, leading to floor accelerations and inter-storey drifts during seismic events. The challenge lies in balancing the need to minimize inter-storey drift and floor accelerations simultaneously, as excessive drifts can damage non-structural components, while stiffening the structure to reduce drift amplifies ground motion, causing higher floor accelerations and structural damage. Base isolation emerges as a practical solution, providing flexibility to the structure while concentrating displacements at the isolation level. This approach typically involves installing isolation bearings between the foundation and superstructure, often combined with energy damping devices, effectively reducing both inter-storey drift and floor acceleration. Figure 1 illustrates the typical configuration of a base-isolated building, featuring isolation bearings and energy damping devices, with some isolation systems incorporating self-damping mechanisms, eliminating the need for additional passive damping devices.

### 1.3 Objectives:

- This research aims to use ETAB 2016 software to model and analyze both fixed base and base isolated buildings, investigating how earthquakes affect these structures.
- The study will focus on designing and evaluating the effectiveness of lead rubber bearings as a base isolation system.
- By comparing fixed base and base isolated buildings in terms of dynamic properties such as maximum shear force, maximum bending moment, base shear, storey drift, and storey acceleration, the research seeks to assess the advantages of base isolation.
- Additionally, the behavior of different buildings under strong earthquake ground motions will be examined to determine the effectiveness of the base isolation system and provide recommendations for its future applications.

## II. LITERATURE REVIEW

Yang et al. propose a simplified approach to integrating ground acceleration data for seismic soil-structure interaction analysis, aiming to obtain more realistic displacement-time series by baseline correction in the time domain and frequency domain filtering to remove long-period oscillations. Their method is validated through comparisons with other procedures using several examples.

Yoshioka et al. present an experimental study on an adaptable base isolation system employing magneto rheological (MR) dampers, demonstrating its efficacy for protecting structures against a wide range of seismic events. The system's adaptability is tested using a base-isolated two-degree-of-freedom building model subjected to simulated ground motion, showcasing its effectiveness for both far-field and near-field earthquake excitations.

Islam et al. address the need for seismic base isolation design procedures in Bangladesh, proposing simplified design procedures for lead rubber bearings (LRB) and high damping rubber bearings (HDRB) in multi-storey buildings. Their study establishes numerical formulation and design criteria for isolation devices, aiming to incorporate these procedures into the Bangladesh National Building Code (BNBC).

Salic et al. investigate the dynamic response of a seven-story residential building under earthquake ground motions, comparing fixed-base and seismic isolated models. They analyze mode shapes, natural frequencies, damping ratios, and dynamic responses using ARTEMIS and ETABS software, demonstrating the reduction of base shear force and interstorey drifts with the implementation of lead rubber bearing seismic isolation.

Kilaret al. design a four-storey RCC building according to Euro Code 8 for seismic analysis and evaluate its dynamic performance using different sets of base isolation devices. Their study concludes that stiffer isolators with higher damping result in smaller target base displacements, while softer isolators with higher damping minimize relative displacements of the superstructure, highlighting the importance of selecting appropriate isolation parameters for effective seismic protection.

Nakashima and Chusilp review Japanese seismic design and construction practices post-1995 Kobe earthquake, advocating for a shift towards more performance-based engineering. They discuss the evolution of seismic design codes and the importance of considering larger ground shaking scenarios for improved structural resilience.

Ramallo et al. investigate the use of controllable semi-active dampers, such as magnetorheological fluid dampers, in base isolation systems. Through a two-degree-of-freedom model of a base isolated building, they demonstrate the effectiveness of semi-active dampers in reducing inter storey drifts and floor accelerations, offering a cost-effective solution for seismic protection. Their study suggests that semi-active dampers show promise for use in base isolation applications with reduced power requirements compared to active systems.

## III. METHODOLOGY

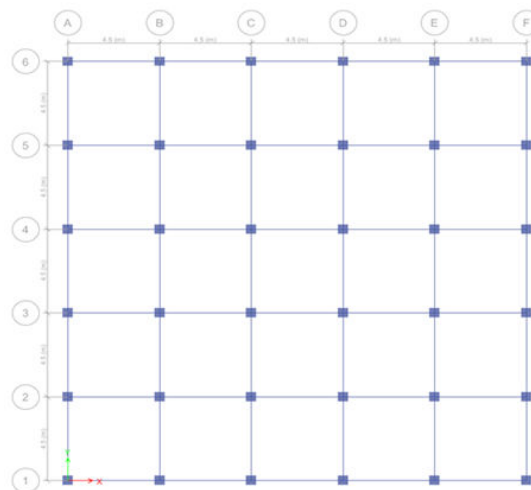
The models which have been adopted for study are symmetric five storey (G+5), ten storey (G+10), fifteen storey (G+15) and twenty storey (G+20) buildings. All buildings are consists of square columns with dimension 500mm x 500mm, all beams with dimension 400mm x 250mm. The floor slabs are taken as 125mm thick. The foundation height is 1.5m and the height of the all stories is 3m. The M30 grade concrete and Fe415 steel is used. The modulus of elasticity and shear modulus of concrete have been taken as  $E = 2.7386 \times 10^7 \text{ kN/m}^2$  and  $G = 1.19 \times 10^7 \text{ kN/m}^2$ .

Eight models have been considered for the purpose of the study.

- Five storey (G+5) building with fixed base.



- Five storey (G+5) building with LRB isolated base.
- Five storey (G+5) building with Mass Tuned Dampers.
- Ten storey (G+10) building with fixed base.
- Ten storey (G+10) building with LRB isolated base.
- Five storey (G+5) building with Mass Tuned Dampers.
- Fifteen storey (G+15) building with fixed base.
- Fifteen storey (G+15) building with LRB isolated base.
- Fifteen storey (G+15) building with Mass Tuned Dampers.
- Twenty storey (G+20) building with fixed base.
- Twenty storey (G+20) building with LRB isolated base.
- Twenty storey (G+20) building with Mass Tuned Dampers.



TYPICAL PLAN OF RCC BUILDING

### 3.1 Defining the material properties, structural components and modelling the structure:

Beam, column and slab specifications are as follows:

Column 500mm x 500mm

Beam 400mm x 250mm

Slab thickness 125mm

The required material properties like mass, weight density, modulus of elasticity, shear modulus and design values of the material used can be modified as per requirements or default values can be accepted.

Beams and column members have been defined as ‘frame elements’ with the appropriate dimensions and reinforcement.

Soil structure interaction has not been considered and the columns have been restrained in all six degrees of freedom at the base.

Slabs are defined as area elements having the properties of shell elements with the required thickness. Slabs have been modeled as rigid diaphragms.

### 3.2 Assigning loads.

After having modeled the structural components, all possible load cases are assigned. These are as follows:

#### 3.2.1 Gravity loads

Gravity loads on the structure include the self-weight of beams, columns, slabs, walls and other permanent members. The self-weight of beams and columns (frame members) and slabs (area sections) is automatically considered by the program itself. The wall loads have been calculated and assigned as uniformly distributed loads on the beams.

Wall load = unit weight of brickwork x thickness of wall x height of wall.

Unit weight of brickwork = 20KN/m<sup>3</sup>

Thickness of wall = 0.23m

Thickness of parapet wall = 0.125m

Wall load on roof level = 20 x 0.125 x 1 = 2.50KN/m (parapet wall height = 1m)

Wall load on all other levels =  $20 \times 0.23 \times 3 = 13.8 \text{ KN/m}$  (wall height = 3m)

Live loads have been assigned as uniform area loads on the slab elements as per IS 1893 (Part 1) 2016

Live load on roof 1.5 KN/m<sup>2</sup>  
Live load on all other floors 3.0 KN/m<sup>2</sup>

As per Table 10, Percentage of Imposed load to be considered in Seismic weight calculation, IS 1893 (Part 1) 2016, since the live load class is up to 3 KN/m<sup>2</sup>, 25% of the imposed load has been considered.

Quake loads have been defined considering the time history method for medium soil as per IS 1893 (Part 1) 2016.

### 3.2.2 Defining load combinations:

According to IS 1893 (Part 1) 2016 for the limit state design of reinforced and prestressed concrete structures, the following load combinations have been defined.

The basic load combinations given by the code as per clause 6.3.4.1 are as follows

1.  $1.2(DL+LL\pm(EQX\pm 0.3EQY\pm 0.3EQZ))$
2.  $1.2(DL+LL\pm(EQY\pm 0.3EQX\pm 0.3EQZ))$
3.  $1.5(DL\pm(EQX\pm 0.3EQY\pm 0.3EQZ))$
4.  $1.5(DL\pm(EQY\pm 0.3EQX\pm 0.3EQZ))$
5.  $0.9DL\pm 1.5(EQX\pm 0.3EQY\pm 0.3EQZ)$
6.  $0.9DL\pm 1.5(EQY\pm 0.3EQX\pm 0.3EQZ)$

### 3.2.3 Earthquake lateral loads

The design lateral loads at different floor levels have been calculated corresponding to fundamental time period and are applied to the model. The method of application of this lateral load varies for rigid floor and flexible floor diaphragms. In rigid floor idealization the lateral load at different floor levels are applied at center of rigidity of that corresponding floor in the direction of earthquake in order to neglect the effect of torsion.

While idealizing the floor diaphragms as flexible, the design lateral load at all floors is applied such that the lateral load at each floor is distributed along the length of the floor in proportion to the mass distribution.

In our case, the slabs have been modeled as rigid diaphragms and response spectrum is applied at ground level and the earthquake lateral loads have been calculated.

### 3.3 Analysis of the structure

Namely three types of analysis procedures have been carried out for determining the various structural parameters of the model. Here we are mainly concerned with the behavior of the structure under the effect of IV earthquakes and the displacement of the structure in the elastic range. The analyses carried out by Response Spectrum method.

Here we are primarily concerned with observing the deformations, forces and moments induced in the structure due to dead, live loads and earthquake loads. The load case 'Dead' takes care of the self-weight of the frame members and the area sections. The wall loads have been defined under a separate load case 'Wall' and the live loads under the case 'Live'. Analysis is carried out for all three cases for obtaining the above-mentioned parameters.

Modal analysis is carried out for obtaining the natural frequencies, modal mass participation ratios and other modal parameters of the structure. Response spectrum analysis of the eight models are done in the zone IV where  $Z = 0.24$  considering zone factor IV

$I = 1.0$  considering residential building.

$R = 3.0$  considering ordinary RC moment resistant frame (OMRF)

$S_a/g = B_y$  software

For the Seismic effect of buildings, analysis is carried out using the spectra for medium soil as per IS 1893 (Part 1) 2016.

The spectral acceleration coefficient ( $S_a/g$ ) values are calculated as follows.

For medium soil sites,

$$S_a/g = 1 + 15 * T \quad T \leq 0.10$$

$$= 2.5 \quad 0.10 \leq T \leq 0.55$$

$$= 1.36/T \quad 0.55 \leq T \leq 4.00$$

$$= 0.34 \quad T > 4.00$$

### 3.4 Lead Rubber Bearing

A variety of isolation devices including elastomeric bearings (with and without lead core), frictional/sliding bearings and roller bearings have been developed and used practically for a seismic design of buildings during the last 25 years.

Among the various base isolation systems, the lead–rubber bearings (LRB) had been used extensively. It consists of alternate layers of rubber and steel plates with one or more lead plugs (Figure 3.4) that are inserted into the holes. The lead core deforms in shear providing the bilinear response (i.e. adds hysteretic damping in the isolated structure) and also provides the initial rigidity against minor earthquakes and strong winds. The steel plates in the elastomeric bearing gives large plastic deformations. So, an elastomeric bearing was then replaced by lead plug and was tested.

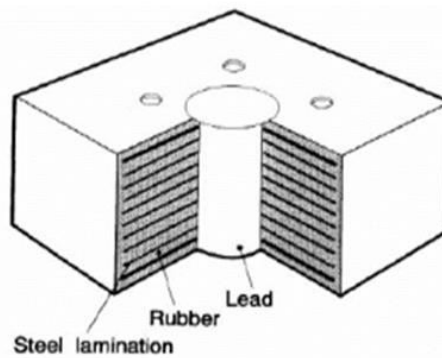


Figure 3.4. Section of Lead Rubber Bearing

The lead-rubber bearings represent an economic solution for the seismic isolation problems because it combines the functions of vertical support, of rigidity at service load levels, and of horizontal flexibility at earthquake load.

Lead yields at low stress, around 10MPa, and behaves like an elastic-plastic solid. Lead is also “hot-worked” when plastically deformed at ambient temperature and the mechanical properties of the lead are being continuously restored by the simultaneous interrelated processes of recovery, recrystallization and grain growth. As a matter of fact, deforming lead at 20°C is like deforming steel at temperatures higher than 400°C. Lead has good fatigue properties during cycling at plastic strains. The hole for the lead-plug can be machined through the bearing after manufacture, or the hole can be made in the steel plates and rubber sheets before they are joined together. The lead, in any case, must fit tightly in the elastomeric bearing and this is achieved by making the lead plug a little larger (1%) than the hole and forcing it into it. In this way, when the bearing is deformed horizontally, the lead insert is forced by the interlocking steel plates to deform in shear throughout its whole volume. The yield force of the lead insert can be easily determined from the yield stress of the lead in the bearing.

#### IV. MODELING IN E-TABS

##### 4.1 THE SUBSEQUENT ANALYSES IN THIS SECTION ARE CATEGORIZED INTO THREE MAIN AREAS:

###### 4.1 Problem statement

The building analyzed are G+5, G+10, G+15, G+20 R.C framed building of symmetrical square plan configuration. Complete analysis is carried out for dead load, live load & seismic load using ETAB 2016 software. Response spectrum Method is used. All combinations will considered as per IS 1893:2016.

###### 4.2 Modeling

The main aim of the modeling is to study the change in building responses (mainly deflection and storey drift) due to lead rubber base isolation technique as per IS 1893:2016. The building is analyzed in stages as follows,

- G+5 R.C framed building with fixed base: It is simple structure with fixed base support and is configured as per the problem statement as stated in 4.1. is as shown in figure 4.1 All the loads and details are same as mentioned conforming to IS 1893:2016. It is a simple structure analyzed for earthquake resistant conforming to the Indian design standard codes.
- G+5 R.C framed building with isolated base: It is the modification over the first model. Lead rubber bearing (LRB) is used in support as base isolation technique as shown in figure 4.2. Table 4.1 shows calculation of stiffness of LRB support need to in software modeled as a link and spring property.

c) G+5 R.C framed building with Mass Tuned Dampers: It is also the modification over the first model. Mass Tuned Damper is used in support as shown in figure 4.3. Table 4.1 shows calculation of stiffness of Mass Tuned Dampers support need to in software modeled as a link and spring property.

Required stiffness $K_{eff}$	1908.241	KN/m
Bearing horizontal stiffness	118.4252	KN/m
Vertical stiffness	19706.24	KN/m
Yield Force	22.12101	KN
Stiffness ratio	0.1	
Damping	0.1	

Table 4.1 Summary of LRB parameters for RCC G+5 building

d) G+10 R.C framed building with fixed base: It is simple structure with fixed base support and is configured as per the problem statement as stated in 4.1. is as shown in figure 4.4 All the loads and details are same as mentioned conforming to IS 1893:2016. It is a simple structure analyzed for earthquake resistant conforming to the Indian design standard codes.

e) G+10 R.C framed building with isolated base: It is the modification over the third model. Lead rubber bearing (LRB) is used in support as base isolation technique as shown in figure 4.5. Table 4.2 shows calculation of stiffness of LRB support need to in software modeled as a link and spring property.

f) G+10 R.C framed building with Mass Tuned Dampers: It is also the modification over the first model. Mass Tuned Damper is used in support as shown in figure 4.6. Table 4.2 shows calculation of stiffness of Mass Tuned Dampers support need to in software modeled as a link and spring property.

Required stiffness $K_{eff}$	4692.163	KN/m
Bearing horizontal stiffness	310.6764	KN/m
Vertical stiffness	119775	KN/m
Yield Force	54.39322	KN
Stiffness ratio	0.1	
Damping	0.05	

Table 4.2 Summary of LRB parameters for RCC G+10 building

g) G+15 R.C framed building with fixed base: It is simple structure with fixed base support and is configured as per the problem statement as stated in 4.1. is as shown in figure 4.7. All the loads and details are same as mentioned conforming to IS 1893:2016. It is a simple structure analyzed for earthquake resistant conforming to the Indian design standard codes.

h) G+15 R.C framed building with isolated base: It is the modification over the fifth model. Lead rubber bearing (LRB) is used in support as base isolation technique as shown in figure 4.8. Table 4.3 shows calculation of stiffness of LRB support need to in software modeled as a link and spring property.

i) G+15 R.C framed building with Mass Tuned Dampers: It is also the modification over the first model. Mass Tuned Damper is used in support as shown in figure 4.9. Table 4.3 shows calculation of stiffness of Mass Tuned Dampers support need to in software modeled as a link and spring property.

Required stiffness $K_{eff}$	7627.365	KN/m
Bearing horizontal stiffness	517.2998	KN/m
Vertical stiffness	294564	KN/m
Yield Force	88.41913	KN
Stiffness ratio	0.1	
Damping	0.05	

j) G+20 R.C framed building with fixed base: It is simple structure with fixed base support and is configured as per the problem statement as stated in 4.1. is as shown in figure 4.10. All the loads and details are same as mentioned

conforming to IS 1893:2016. It is a simple structure analyzed for earthquake resistant conforming to the Indian design standard codes.

k) G+20 R.C framed building with isolated base: It is the modification over the seventh model. Lead rubber bearing (LRB) is used in support as base isolation technique as shown in figure 4.11. Table 4.4 shows calculation of stiffness of LRB support need to in software modeled as a link and spring property.

l) G+20 R.C framed building with Mass Tuned Dampers: It is also the modification over the first model. Mass Tuned Damper is used in support as shown in figure 4.12. Table 4.4 shows calculation of stiffness of Mass Tuned Dampers support need to in software modeled as a link and spring property.

Required stiffness $K_{eff}$	10922.21	KN/m
Bearing horizontal stiffness	751.3657	KN/m
Vertical stiffness	550734.2	KN/m
Yield Force	126.6141	KN
Stiffness ratio	0.1	
Damping	0.05	

Table 4.4 Summary of LRB parameters for RCC G+20 building

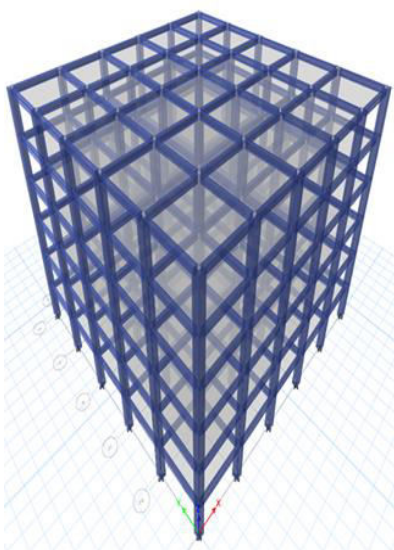


Fig.4.1 G+5 RC building with fixed base

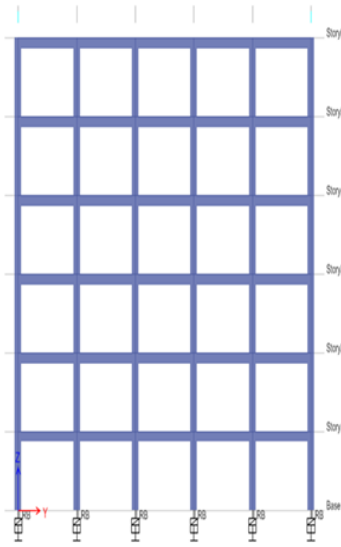


Fig.4.2 RC building with isolated base

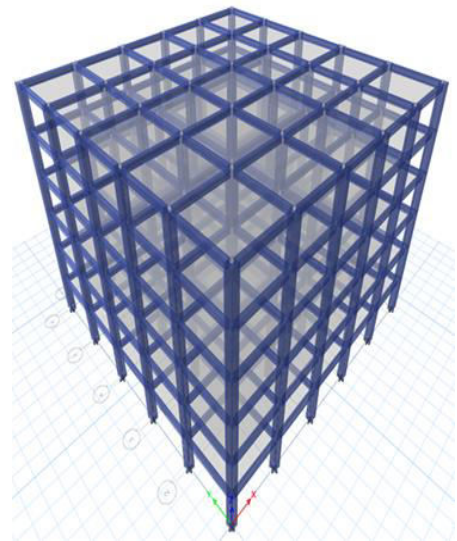


Fig.4.3 RC building with Tuned Mass Damper



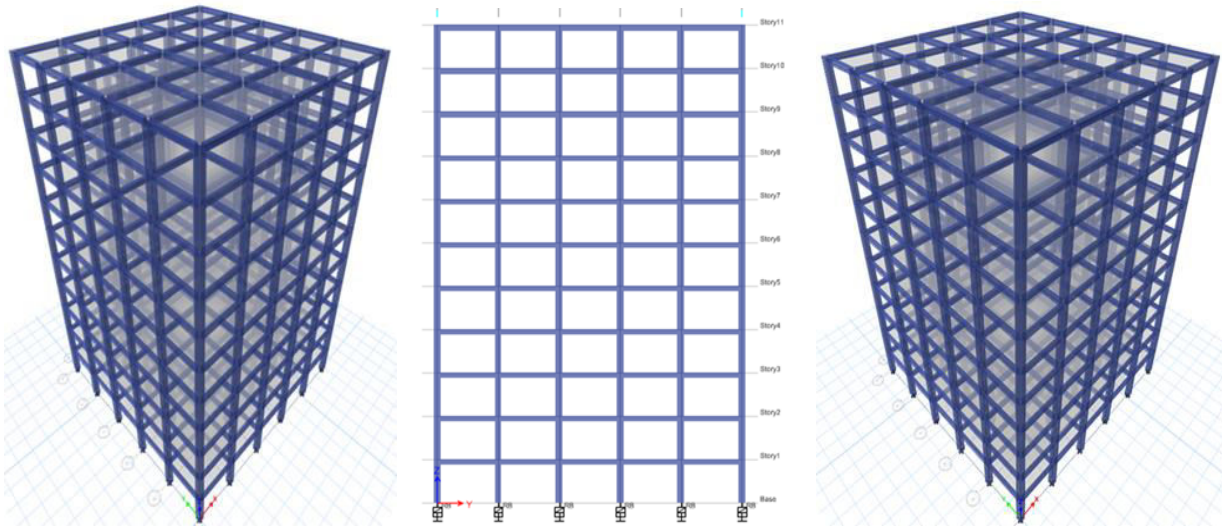


Fig.4.4 G+10 RC building with fixed base Fig.4.5 RC building with isolated base Fig.4.6 RC building with Tuned Mass Damper

### V. CONCLUSION

#### 5.1 BASE SHEAR

The response spectrum method had been adopted for seismic analysis in ETAB 2016. The Table No. 5.1 shows maximum base shear in X and Y direction for fixed base, LRB isolated base and Mass tuned dampers.

Number of Storey	Fixed Base	Isolated Base	Mass Tuned Dampers
G+5	3600.9946	1012.894	2096.4571
G+10	6289.1541	3356.4534	3930.6254
G+15	6418.3179	5059.5389	6047.246
G+20	6465.9956	6723.4584	6284.624

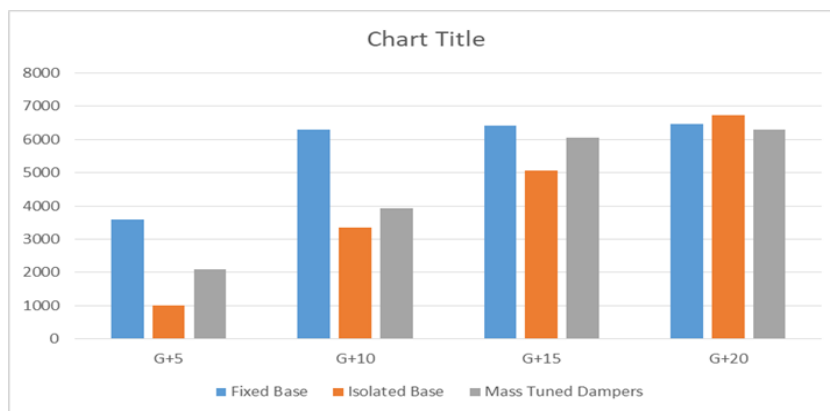


Figure 5. 1: Base shear (kN)

Figure 5.1 shows the comparative analysis of seismic performance across different building heights (G+5 to G+20) reveals distinct advantages of isolated base systems over fixed bases and mass tuned dampers. Isolated bases consistently exhibit superior effectiveness in reducing seismic forces transmitted to the structure, particularly noticeable as building height increases. While mass tuned dampers show moderate effectiveness, especially in shorter buildings, their performance appears less robust compared to isolated bases in taller structures.

### 5.2 Modal periods

The response spectrum method had been adopted for seismic analysis in ETAB 2016. The Table No. 5.2 shows modal periods for fixed base, LRB isolated base and Mass tuned dampers in G+5 building.

Mode	Fixed Base	Isolated Base	Mass Tuned Dampers
1	0.941	6.127	2.103
2	0.941	6.127	2.103
3	0.87	5.629	1.642
4	0.287	0.554	0.464
5	0.287	0.554	0.464
6	0.266	0.449	0.347
7	0.153	0.213	0.189
8	0.153	0.213	0.168
9	0.142	0.199	0.154
10	0.099	0.127	0.112
11	0.099	0.127	0.112
12	0.092	0.117	0.104

Table 5.2: Modal periods (Sec) – G+5

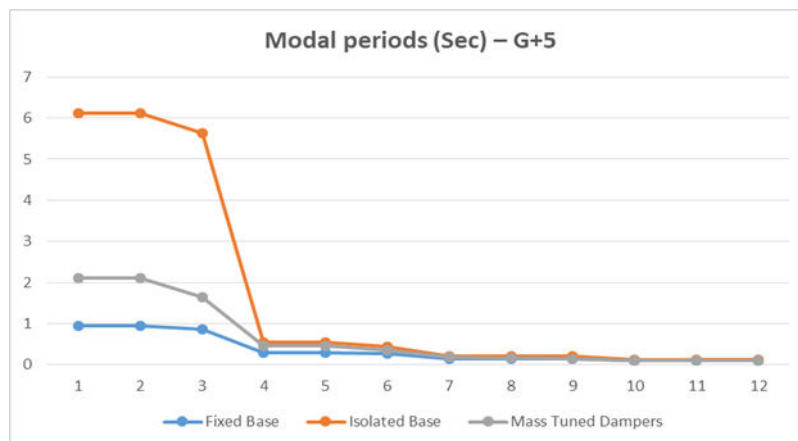


Fig. 5.2: Modal periods (Sec) – G+5

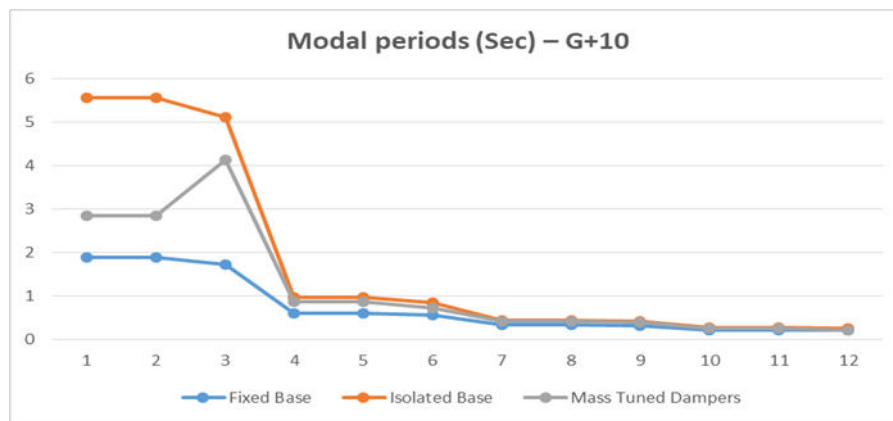
Figure 5.2 shows the mode shapes analysis across modes 1 to 12 shows that the isolated base system consistently exhibits the highest mode shapes, indicating greater lateral flexibility in response to seismic forces. The fixed base system demonstrates moderate flexibility, with mode shapes generally higher than the mass tuned dampers, which exhibit the lowest mode shapes indicating stiffer behavior.

The response spectrum method had been adopted for seismic analysis in ETAB 2016. The Table No. 5.3 shows modal periods for fixed base, LRB isolated base and Mass tuned dampers in G+10 building.

Mode	Fixed Base	Isolated Base	Mass Tuned Dampers
1	1.878	5.56	2.842
2	1.878	5.56	2.842
3	1.727	5.101	4.124
4	0.603	0.969	0.874
5	0.603	0.969	0.874
6	0.555	0.853	0.719

7	0.338	0.445	0.412
8	0.338	0.445	0.412
9	0.313	0.412	0.402
10	0.224	0.28	0.246
11	0.224	0.28	0.246
12	0.207	0.258	0.212

Table 5.3: Modal periods (Sec) – G+10



**Final Conclusion: Isolated Base System Superiority:** The isolated base system consistently demonstrates the lowest seismic response values across all building heights compared to both fixed base and mass tuned dampers. This indicates that isolated base systems are highly effective in reducing the transmission of seismic forces to the structure, resulting in improved structural performance and lower displacements during seismic events.

**Fixed Base Performance:** The fixed base system generally exhibits intermediate response values, which are consistently higher than those of the isolated base system. This suggests that conventional fixed base structures are less effective in mitigating seismic forces compared to isolated base systems.

**Mass Tuned Dampers Effectiveness:** Mass tuned dampers show moderate effectiveness in reducing seismic response, but their performance is generally less efficient compared to isolated base systems, especially evident at higher building heights (G+15 to G+20).

**Overall Recommendation:** Based on the collective findings, isolated base systems emerge as the preferred choice for enhancing seismic resilience in buildings across various heights. Their ability to significantly reduce structural response to seismic forces underscores their effectiveness in improving building safety during earthquakes. While fixed base structures and mass tuned dampers also offer some level of seismic mitigation, they are outperformed by isolated base systems in terms of reducing seismic response and enhancing structural performance during seismic events.

In summary, the use of isolated base systems should be prioritized in seismic design and retrofitting of buildings to achieve optimal seismic resilience and minimize structural damage during earthquakes, particularly in regions prone to seismic activity. Fig. 5.3: Modal periods (Sec) – G+10

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