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Seismic Response Control of Vertically Irregular R.C.C. Structure using Base Isolation

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Abstract: In recent years considerable attention has been paid to research and development of structural vibration control devices with particular emphasis on mitigation of wind and seismic response of buildings. Many vibration-control measures like passive, active, semi-active and hybrid vibration control methods have been developed. Base isolation is a passive vibration control system. The isolator partially reflects and partially absorbs input seismic energy before it gets transmitted to the superstructure. Lead rubber bearing isolators are placed between the superstructure and foundation, which reduces the horizontal stiffness of the system. It thereby increases the time period of the structure and decreases the spectral acceleration of the structure. The superstructure acts like a rigid body, thus inter storey drift is reduced. This study is concerned with the effects of various vertical irregularities on the seismic response of a structure and controls this response using base isolation. The objective of the study is to carry out response spectrum analysis and time history analysis of fixed base and base isolated vertically irregular RCC structure according to IS 1893:2002 (Part-1). Three types of vertical irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered. From the modal analysis of G+14 regular RCC structure, first mode time period of fixed base building is found to be 1.762 sec. whereas the first mode time period of isolated building is found to be 4.343 sec. Base isolation reduces the lateral displacement, shear forces, bending moments, base shear, storey acceleration, interstorey drift as compared to the conventional fixed base structure. Which shows the effectiveness of base isolation and concluded that base isolation is very effective seismic response control device.

Keywords: Vertical irregularities, Fixed base, Base isolation, Response spectrum analysis, Time history analysis, ETABS software.

1. Introduction

1.1. Seismic Response Control

Conventional seismic design attempts to make buildings that do not collapse under strong earthquake shaking, but may sustain damage to non-structural elements and to some structural members in the building. Non-structural components may consist of furniture, equipment, partitions, curtain wall systems, piping, electrical equipment and many other items. There are mainly three main categories: architectural components, mechanical and electrical equipments, and building contents. This may render the building non-functional after the earthquake, which may be problematic in some structures, like hospitals, which need to remain functional during the earthquake. Non-structural components are sensitive to large floor accelerations, velocities, and displacements. When a building is subjected to an earthquake ground motion, the building induces motion, resulting in floor accelerations higher than the ground acceleration. Hence, it is present need and also a duty of civil engineers to innovate earthquake resisting design approach to reduce such type of structural damages. Special techniques are required to design buildings such that they remain practically undamaged even in a severe earthquake. There are two basic technologies used to protect buildings from damaging earthquake effects. These are base isolation devices and seismic dampers. Many vibration-control measures like passive, active, semi-active and hybrid vibration control methods have been developed. Base isolation is a passive vibration control system. The isolator partially reflects and partially absorbs input seismic energy before it gets transmitted to the superstructure. The idea behind base isolation is to detach (isolate) the building from the ground in such a way that earthquake motions are not transmitted up through the building, or at least greatly reduced. Seismic dampers are special devices introduced in the building to absorb the energy provided by the ground motion to the building.

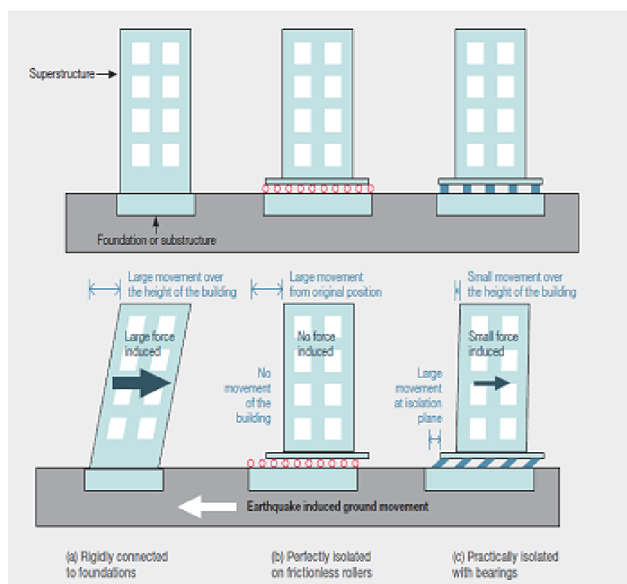

Figure 1 The concept of base isolation

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1.2 Irregular Structure

During an earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structures having this discontinuity are termed as irregular structures. Irregular structures contribute a large portion of urban infrastructure. Vertical irregularities are one of the major reasons of failures of structures during earthquakes. For example structures with soft storey were the most notable structures which collapsed. So, the effect of vertically irregularities in the seismic performance of structures becomes really important. Height-wise changes in stiffness and mass render the dynamic characteristics of these buildings different from the 'regular' building.

IS 1893 definition of vertically irregular structures:

The irregularity in the building structures may be due to irregular distributions in their mass, strength and stiffness along the height of building. When such buildings are constructed in high seismic zones, the analysis and design becomes more complicated.

There are two types of irregularities:-
Plan Irregularities
Vertical Irregularities

Vertical Irregularities are mainly of five types:-

a) Stiffness Irregularity:- Soft Storey-A soft storey is one in which the lateral stiffness is less than 70 percent of the storey above or less than 80 percent of the average lateral stiffness of the three storey's above.

b) Stiffness Irregularity:- Extreme Soft Storey-An extreme soft storey is one in which the lateral stiffness is less than 60 percent of that in the storey above or less than 70 percent of the average stiffness of the three storey's above.

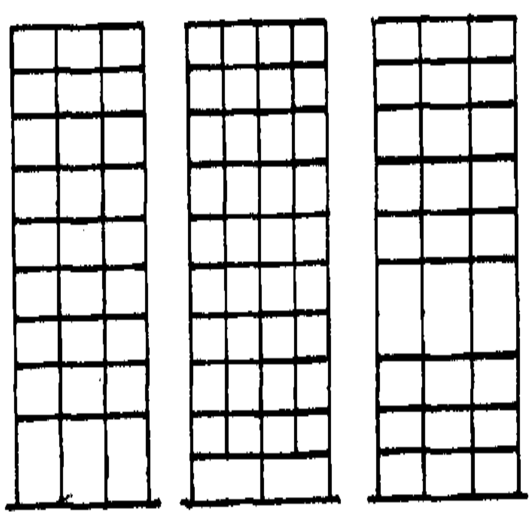

Figure 2 Stiffness irregularity when Ki > 0.7 Ki+1

Mass Irregularity:- Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent storey's. In case of roofs irregularity need not be considered.

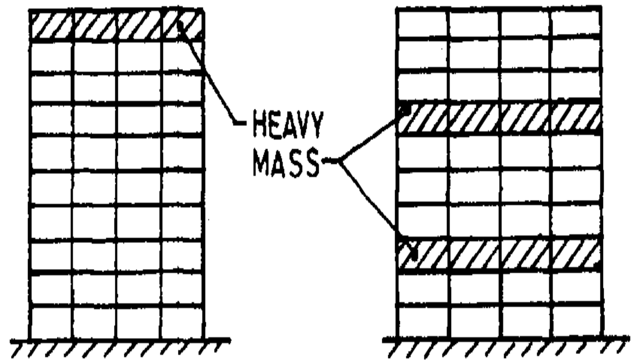

Figure 3 Mass irregularity when Wi > 2.0 Wi+1

Vertical Geometric Irregularity:- A structure is considered to be vertical geometric irregular when the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storey

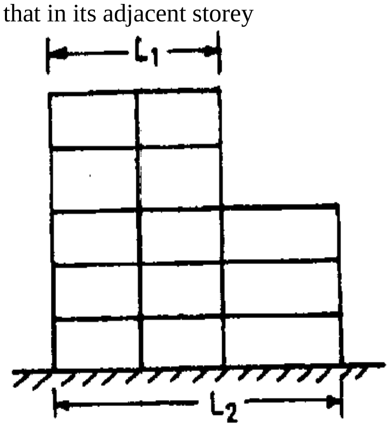

Figure 4 Vertical geometric irregularity when L2 >1.5L1

In-Plane Discontinuity in Vertical Elements Resisting Lateral Force:- An in-plane offset of the lateral force resisting elements greater than the length of those elements.

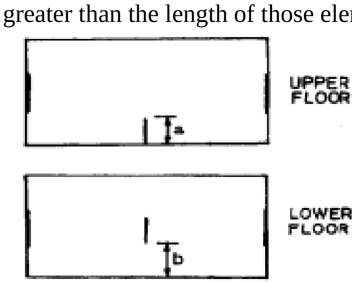

Figure 5 In-plane discontinuity in vertical elements resisting lateral force when b>a

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Discontinuity in Capacity :- Weak Storey-A weak storey is one in which the storey lateral strength is less than 80 percent of that in the storey above.

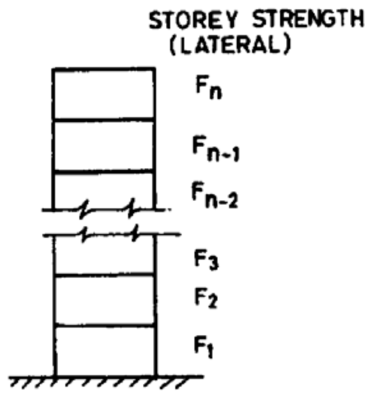
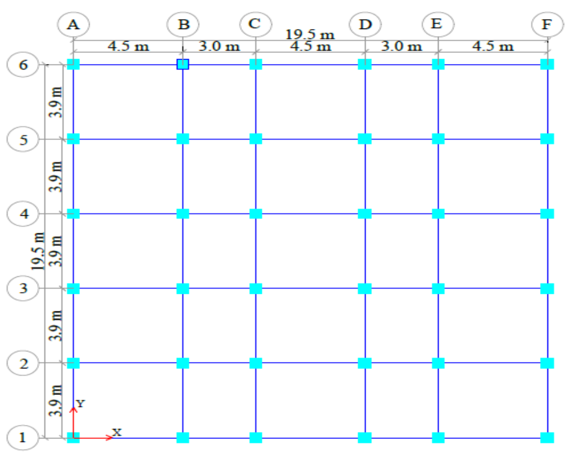


Figure 6 Discontinuity in capacity weak storey when Fi < 0.8 F_{i+1}

2. Modeling and analysis structure

2.1 Preliminary Data Required for Analysis of RCC Structure



The main aim of this project work is to study the dynamic behavior of fixed base and base isolated RCC structures, during strong earthquake ground motions. For this fixed base regular building is modeled and analyzed under 1940 El Centro earthquake California ground motion records using ETAB 2015. The Figure 7 and Figure 8 show Grid-Plan of regular RCC building and elevation of building respectively.

The types of structure considering for analysis and modeling are as follows:

Regular Structure
Stiffness Irregular Structure
Mass Irregular Structure
Vertical Geometric Irregular Structure

Figure 7 Grid-plan of regular building model

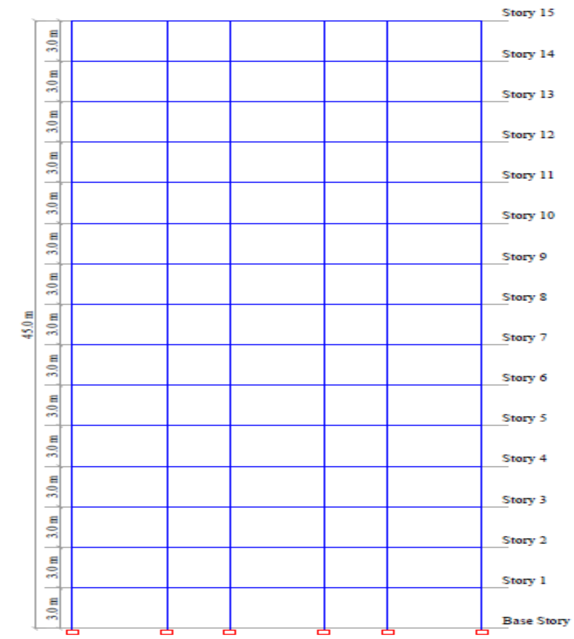


Figure 8 Elevation of regular building model

Table 1 **Preliminary data required for analysis of RCC structure**

Sr. No.	Parameter	Values
1.	Type of structure	Special RC moment resisting frame
2.	Number of storey	G+14
3.	Floor height	3.0 m and 4.5m at 5th story for stiffness irregular structure.
4.	Infill wall	150 mm thick
5.	Materials	Concrete M25 and Reinforcement Fe 415
6.	Frame size	19.5m X 19.5m building size and 12.0m X 19.5m above 10th floor for vertical geometric irregular structure
7.	Grid spacing	4.5m and 3.0m alternative grids in X-direction and 3.9m grids in Y-direction.
8.	Size of column	500 mm x 500 mm ; 36no's.
9.	Size of beam	300mm x 600 mm
10.	Depth of slab	165mm

Table 2 Loading according to IS 875 for RCC structure

Sr. No.	Parameter	Values
1.	Impose load	3 KN/m^2 and 1 KN/m^2 for Terrace
2.	Floor finish load	1 KN/m^2
3.	Super dead load	1 KN/m^2 and 20KN/m^2 at 10^{th} story for mass irregular structure
4.	Specific weight of RCC	25 KN/m^3
5.	Specific weight of infill	20 KN/m^3

Table 3 Seismic data required for analysis

Sr. No.	Parameter	Values as per IS 1893:2002 (Part1)	Reference
1.	Type of structure	Special RC moment resisting frame	Table 7, Clause 6.4.2
2.	Seismic zone	V	Table 2, Clause 6.4.2
3.	Zone factor (Z)	0.36	Table 2, Clause 6.4.2
4.	Type of soil	Rock or Hard Soil	Clause 6.4.5
5.	Damping	5 %	Figure 2, Clause 6.4.5
6.	Response spectra	As per IS 1893 (part 1):2002	Figure 2, Clause 6.4.5
7.	Time history	El Centro earthquake records	
8.	Load combinations	1) 1.5(DL + IL) 2) 1.2(DL + IL + EL)	Clause 6.3.1
9.	Response reduction factor (R)	5	Table 6, Clause 6.4.2
10.	Importance factor (I)	1.5 (Hospital, Schools, Hotel Buildings)	Table 7, Clause 6.4.2

2.2 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 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.

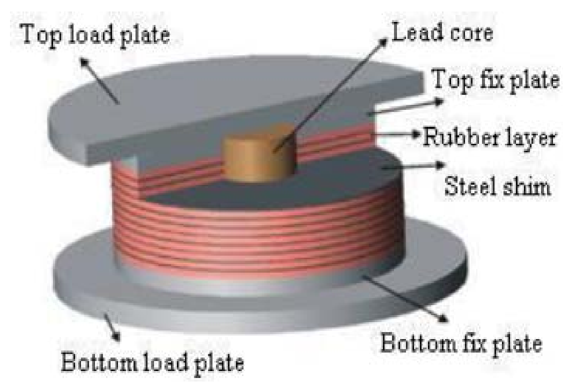


Figure 9 Section of lead rubber bearing

Table 4 Calculation Summary of Lead Rubber Bearing Design

Sr. No.	LRB Parameter	Horizontal stiffness (K_h) KN/m	Vertical Stiffness (K_v) KN/m
1.	Regular Building	735.29	406292.18
2.	Stiffness Irregular Building	735.63	406612.92
3.	Mass irregular Building	812.31	482043.64
4.	Vertical Geometrical Irregular Building	703.93	376760.99

3. Observation and result

3.1 Maximum Shear Force

Maximum shear force in column of fixed base and base isolated building are shown in Figure 10. From Figure 10, it is observed that maximum shear force in base isolated buildings is decreased by 20-30% in comparison to fixed base building model.

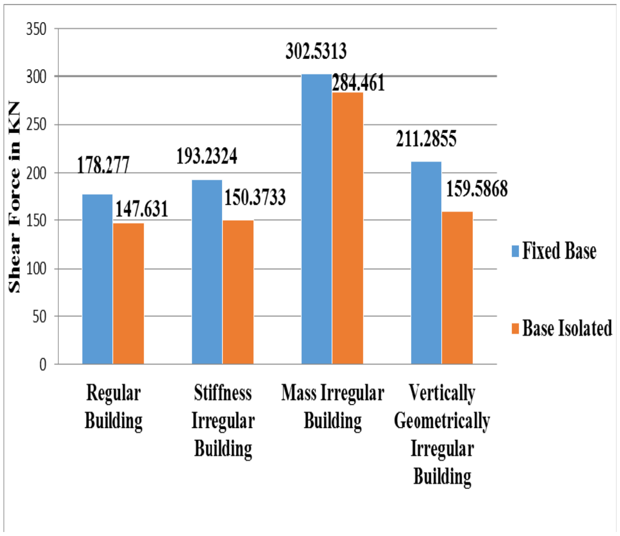


Figure 10 Maximum shear force in RCC building

3.2 Maximum Bending Moment

Maximum bending moment in column of fixed base and base isolated building are shown in Figure 11. From Figure 11, it is observed that maximum bending moment in base isolated buildings is decreased by 25-35% in comparison to fixed base building model.

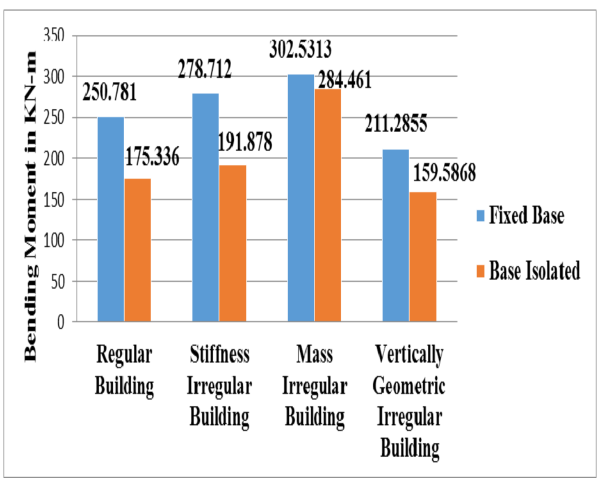


Figure 11 Maximum bending moment in RCC building

3.3 Base Shear

Maximum base shear in fixed base and base isolated building are shown in Figure 12. From Figure 12, it is observed that maximum base shear in base isolated building is decreased by 40-50% in comparison to fixed base building model.

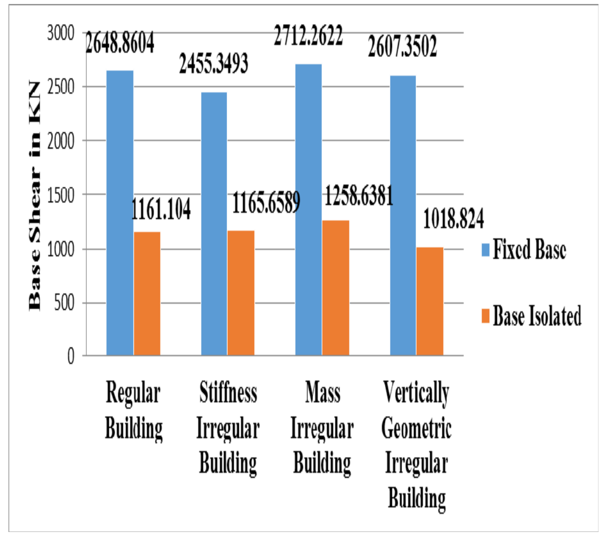


Figure 12 Base shear in RCC building

3.4 Storey Acceleration

Maximum storey acceleration in fixed base and base isolated building are shown in Figure 13. From Figure 13, it is observed that maximum storey acceleration in base isolated building is decreased by 45-55% in comparison to fixed base building model.

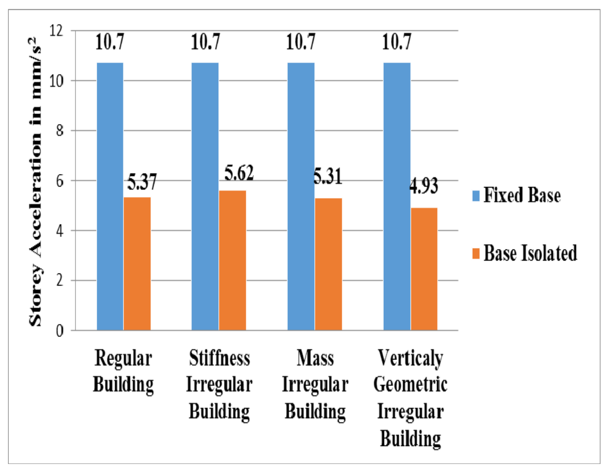


Figure 13 Storey acceleration in RCC building

3.5 Storey Drifts

Maximum storey drift in fixed base and base isolated building are shown in Figure 14. From Figure 14, it is observed that maximum storey drift in base isolated building is decreased by 50-55% in comparison to fixed base building model.

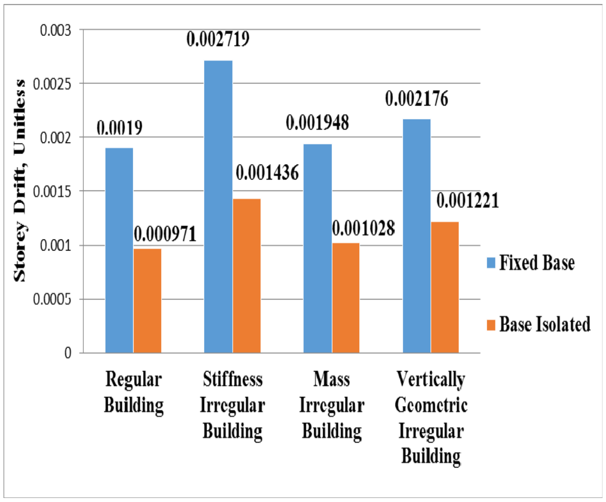


Figure 14 Maximum storey drift in RCC building

3.6 Lateral Displacement

Maximum lateral displacement in fixed base and base isolated building are shown in Figure 15. From Figure 15, it is observed that maximum lateral displacement in base isolated building is increased by 60-65% at base in comparison to fixed base building model.

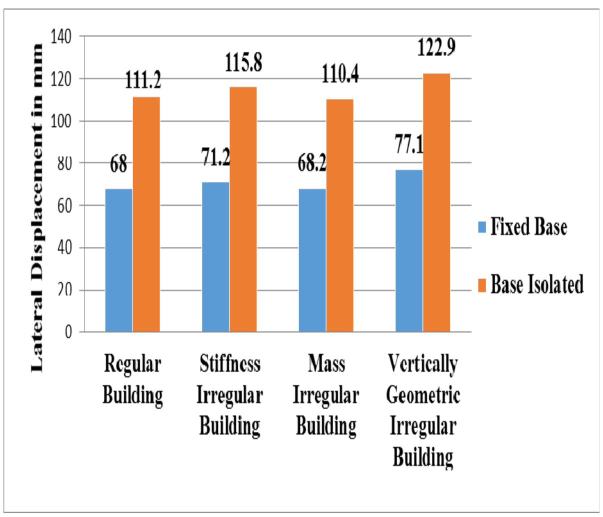


Figure 15 Maximum Lateral Displacements in RCC Building

3.7 First Time period

First time period of fixed base building and for base isolated building are shown in Figure 16. From Figure 16, it is observed that first time period of base isolated building is increased by 2.2-2.6 times the fixed base building model.

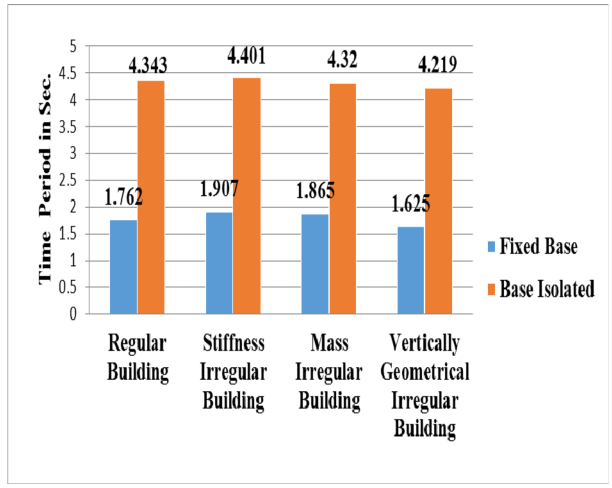


Figure 16 First time period in RCC building

4. Conclusion

The results show that the base isolation reduces the responses lateral displacement, shear forces, bending moments, base shear, storey acceleration, interstorey drift as compared to the conventional fixed base structure drastically. Also, base isolation reduces the stiffness and thereby increases the fundamental period of the building to bring it out of the maximum spectral response region. Therefore it can be concluded from the results presented here that base isolation is very effective seismic control measures.

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