SEISMIC ANALYSIS OF R.C BUILDINGS PROVIDED WITH HDRB ISOLATORS OF VARIOUS RUBBER THICKNESS

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ABSTRACT

This article presents an outline of the base isolation techniques with special emphasis for reducing earthquake forces on the structures. The effects of base isolation on structures are briefly discussed. Base isolation is an anti-seismic design strategy that can reduce the effect of earthquake ground motion by isolating the superstructure from the foundation. The important feature of the base isolation technique is that it introduces flexibility to the structure. In this paper linear static and linear dynamic analysis of R.C building models of G+11, situated in seismic zone V, by providing base isolators are analyzed. The base isolator considered here is High Damping Rubber bearing (HDRB) system of rubber thickness 25cm and 16cm. The analyses are done using finite element package software ETABS9.7.4 and for each analysis method, the comparisons are performed and conclusions are discussed for the total base shear forces, storey displacements and storey drifts. And also these conclusions and modal analysis results are compared for both fixed and isolated base structures.

Keywords: Base Isolation, Dynamic Analysis, HDRB System, Isolated Base, Modal Analysis

I. INTRODUCTION

Recently, even the structures constructed with good techniques and machines also had destroyed due to earthquakes leading to immense loss of life and property and immeasurable sufferings to the survivors of the earthquake hit area. This compelled the engineers and scientists to think of new techniques and methods to save the structures from the destructive forces of earthquake. The earthquakes in the recent past have given new ideas to them by giving enough evidence of performance of different type of structures under different earthquake conditions and foundation conditions. This has given birth to different type of innovative techniques to save the structures from the earthquakes. The technique of base isolation has been developed in an attempt to reduce the response on buildings and their contents during earthquake attacks and has proven to be one of the most effective methods for a wide range of seismic design problems on buildings in the last two decades. Seismic isolation essentially consists of the installation of mechanisms which decouple the structures from possibly damaging earthquake-induced ground motions. This decoupling is done by increasing the flexibility of the structure, together with adding a suitable damping. The most important purpose in seismic isolation is to reduce considerably the transmission of the earthquake forces and energy into the structure. This is done by placing the structure on an isolation system with substantial horizontal flexibility so that only moderate motions are induced within the structure during the earthquake. As we told, the main feature of seismic isolation is that it increases flexibility in the structure. This increases the natural period of the structure. If the period is increased beyond that of the earthquake, the seismic acceleration response gets reduced.. Many types of isolation systems have been developed to achieve this function, such as laminated elastomeric rubber bearings, high damping rubber bearings, lead-rubber bearings, yielding steel devices, friction devices and lead extrusion devices, etc Base isolated structures significantly reduce the ductility demands in the superstructure compared to fixed structures so that it results in reasonable simplification of the structural detailing and other seismic design considerations required by the more conventional problems.

In the recent past, base isolation has become a popular technique for providing earthquake protection to building structures and it has often been considered as a technique for problem structures or for equipment which requires a special seismic design approach. This may occur accordance of their function (sensitive or high risk industrial or commercial facilities); their special importance after an earthquake (hospitals, disaster control centers such as police stations); poor ground conditions (proximity to a major fault); or other special problems. Therefore, in these special situations seismic isolation technique have particular advantages over other approaches, because it is able to provide much better protection under extreme earthquake motions. Therefore the seismic isolation may be used to provide effective solutions for a wide range of seismic design problems.

1.1 Base Isolation in Real Buildings

Since 1980s, seismic isolation has been in increased use and now has been used in many buildings in countries like Italy, Japan, New Zealand, and USA.**.** By now, more than 1000 buildings across the world have been provided with seismic base isolation. In India, base isolation technique was first provided in Killari town, Maharashtra, after the 1993 Killari Earthquake [EERI, 1999]. There two single storey buildings (one school building and one shopping complex building) were built with rubber base isolators. The other one was Bhuj Hospital building in Gujarat, after the 2001 Bhuj earthquake. It is a four-storey building and built with base isolation technique (figure 1).

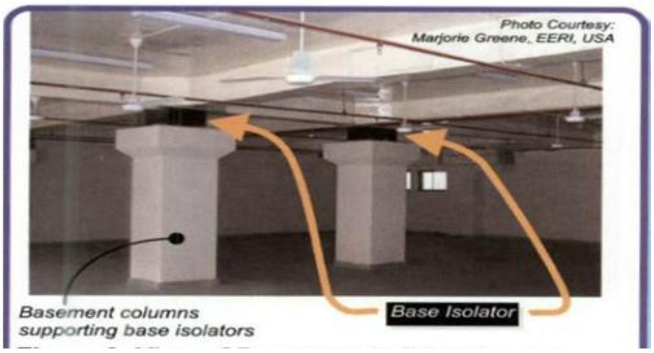


Fig-1: Basement view of Bhuj hospital - built with base isolators after the failure of original district hospital at Bhuj during the 2011 Bhuj earthquake (photo courtesy: Earthquake Tips)

1.2 Literature Review

1. C.V.R Murthy in his publication entitled, "*Earthquake Tips*" in number 24 had discussed that, how and why the effects of earthquake are to be reduced and also the concept of base isolation is explained through an example building resting on frictionless rollers.

2. S.J.Patil, G.R.Reddy, in their journal entitled, "*State Of Art Review -Base Isolation Systems For Structures*", International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 7, July 2012), had discussed on overview of the present state of base isolation

techniques with special emphasis and a brief on other techniques developed world over for mitigating earthquake forces on the structures. The dynamic analysis procedure for isolated structures is briefly explained. The provisions of FEMA 450 for base isolated structures are highlighted. The effects of base isolation on structures located on soft soils and near active faults are given in brief. Simple case study on natural base isolation using naturally available soils is presented. Also, the future areas of research are indicated.

3. Syed Ahmed Kabeer K I and Sanjeev Kumar K.S in their research paper entitled, "*Comparison of Two Similar Buildings with and without Base Isolation*", Kabeer et al., International Journal of Advance research, Ideas and Innovations in technology. 1, Issue 1; Oct,2014), had discussed on a reinforced concrete building with a lead rubber bearing is used. The study analysis performed to check for the adequacy of the base isolation against earthquake damage when compared to the conventional earthquake resistant design. A building was analyzed using the equivalent lateral force method and response spectrum analysis as fixed base (FB) and as isolated base (IB) with lead rubber bearing. The analysis represents a case study for reinforced concrete to show the ultimate capacity of the selected bearing system, and to make a comparison for the difference between the isolated base and the fixed base buildings. Results show that the presence of the lead rubber bearing reduces significantly the displacement, moment and shear generated for the same mode and hence the reinforcement required is also lesser when compared to the traditional fixed based structure.

4. T. Subramani, J. Jothi, M. Kavitha in their journal entitled, "*Earthquake Analysis of Structure by Base Isolation Technique in SAP*" had discussed, the present state of base isolation techniques with special emphasis and a brief on other techniques developed world over for mitigating earthquake forces on the structures. The dynamic analysis procedure for isolated structures is briefly explained. The provisions of FEMA 450 for base isolated structures are highlighted. The effects of base isolation on structures located on soft soils and near active faults are given in brief. Simple case study on natural base isolation using naturally available soils is presented. Also, the future areas of research are indicated.

II. METHODS OF ANALYSIS

There are many methods for the seismic analysis; however in this paper we are analyzing the building model using linear static and linear dynamic analysis only. They are briefly described here.

1. Linear Static Analysis
2. Linear Dynamic Analysis

2.1 Linear Static Analysis

These methods provide us a good sign of elastic capacity of the structure. And it also indicates the occurrence of the first yielding. However this method of analysis is limited to small and regular buildings.

2.2 Linear Response Spectrum Analysis

This is a most commonly used type analysis. In this paper we are doing analysis on HDRB isolators. For isolation system such as LRB and HDR bearings, this method is the most sufficient one. The Response Spectrum is a method of evaluating maximum responses (acceleration, velocity and displacement) of a family of SDOF systems subjected to a specified ground motion. In IS: 1893:2002, in Clause 4.2.1, depending upon the zone and building height, it is asked to decide the method to be used. And also it is clearly mentioned that building with irregular shape or irregular distribution of mass and stiffness in horizontal or vertical plane, shall be analyzed as per Response Spectrum Method. Response Spectrum method is a time consuming and boring process, so most of time, it resort to computer applications.

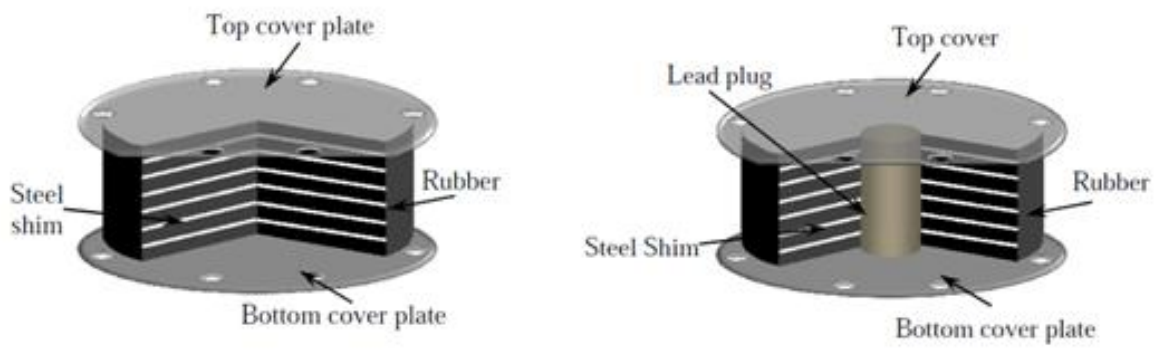
III. TYPES OF ISOLATION SYSTEMS

The most popular techniques for base isolated systems are

- Elastomeric bearing system
- Friction pendulum system (FPS)
- High damping rubber bearing system (HDRB)

3.1 Elastomeric Bearing System

Elastomeric bearing system is the most widely suggested base isolation system in the recent years. This system consists of elastomers made of either natural or neoprene. In this system, a layer with low horizontal stiffness is interposed between the structure and foundation to isolate the structure from foundation. There are two types of elastomeric bearing; one is laminated rubber bearing and the other one is lead rubber bearing. A typical laminated rubber bearing is shown in figure 2a.. The second type is similar to the first but a solid lead plug is provided in the middle to absorb energy and add damping is called a lead rubber bearing is as shown in figure 2b.



(a) **(b)**

Fig -2: a) Laminated Rubber Bearing b) Lead Rubber Bearing

3.2 Friction Pendulum System (FPS)

The friction pendulum system (FPS) is a widely used bearing system. It works based on the principle of sliding system with a pendulum type isolator to provide a damping function using friction. The FPS isolator consists of an articulating slider moving on a spherical friction surface as shown in figure-3. FPS isolators reduce transmission of the earthquake forces to the structure by deflection (the pendulum motion) and by friction (damping) on the sliders. The radius of the curvature of the concave surface will dominate the effective stiffness and the system period.

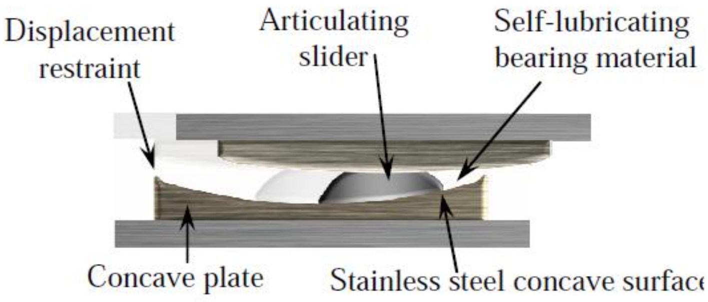


Fig-3: Friction Pendulum System

3.3 High Damping Rubber (HDR) Bearing System

HDR bearings work on the principle of base isolation and during an earthquake it limits the energy transferred from the ground to the structure. The rubber and steel laminated bearing is designed to support the weight of the structure and to provide flexibility to the structure. An elastomeric bearing gives only 5% damping, while HDR bearing provides damping up to 16%. The reinforcement steel plates are protected against corrosion as they are placed in rubber covers. HDRB devices are made from natural rubber and it provides a high resistance against mechanical wear.

Benefits of HDRB:

• Dissipation of energy during earthquakes leads to an optimized structure size and reduced structure cost
• Combined transfer of service and seismic loads leads to minimal space requirement for the devices
• Effective solution for the retrofitting or upgrading of existing structures
• Serviceability of the structure to be maintained even after a seismic event
• Well researched technology with several decades of track record for many applications worldwide

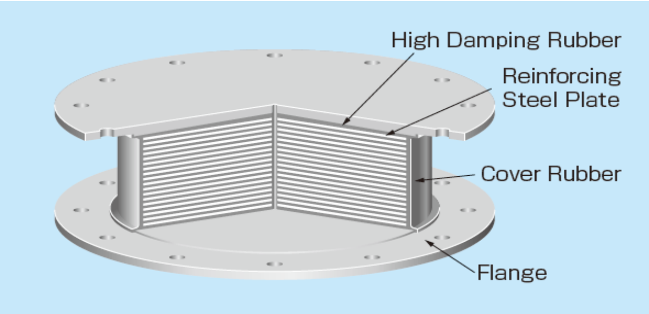


Fig-4: Schematic View of a HDRB Device

IV. MODELLING AND ANALYSIS

The details of model are G+11 stories, 4 bays along X-direction and 3 bays along Y-direction. The buildings considered have a plan dimension of 24m in length and 21m width of the building. The plan and elevations of buildings are shown in figure 5 and 6. The height of each story of the building is 3.5m and a column height of 0.6m has been extended below the plinth beams. The size of the columns and beams in all the floors and roof are 500x650mm and 350x550mm respectively. A solid slab of thickness 150mm has been considered for all storeys. As per IS: 875(Part-2)-1987, Live load intensity and floor finishes of 3 kN/mm² and 1.2 kN/mm² has been assumed on each storey and the roof has been assumed a uniform live load intensity in 1.75 kN/mm². The modeling has been performed by ETABS nonlinear 9.7.4 software. The seismic zone is V. Grade of concrete is M30 and for steel Fe415. The values of various factors have been assumed as per IS: 1893(Part-1) -2002. The design of members has been carried out as per IS: 456-2000 the beam and column has been design by IS: 456-2000. Other details are as tabulated below in the table 1. The isolators used here are HDRB with rubber thickness 160mm and 250mm. The other properties of the isolators are as tabulated in table 2.

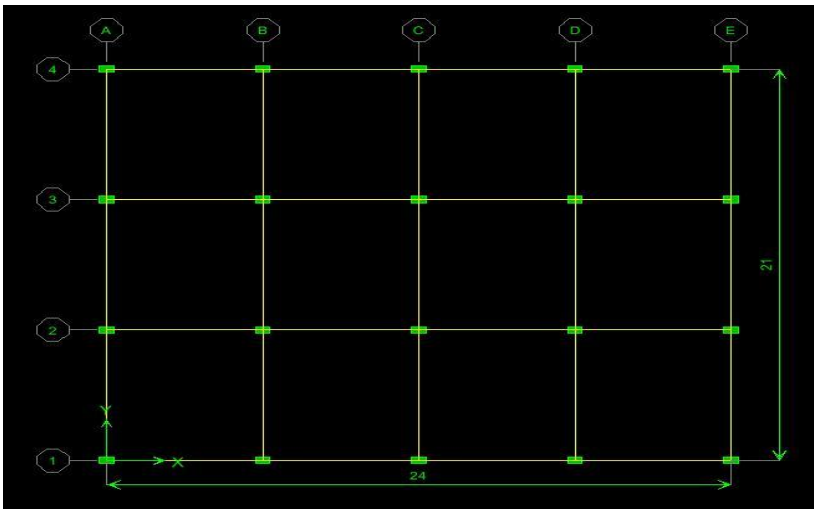
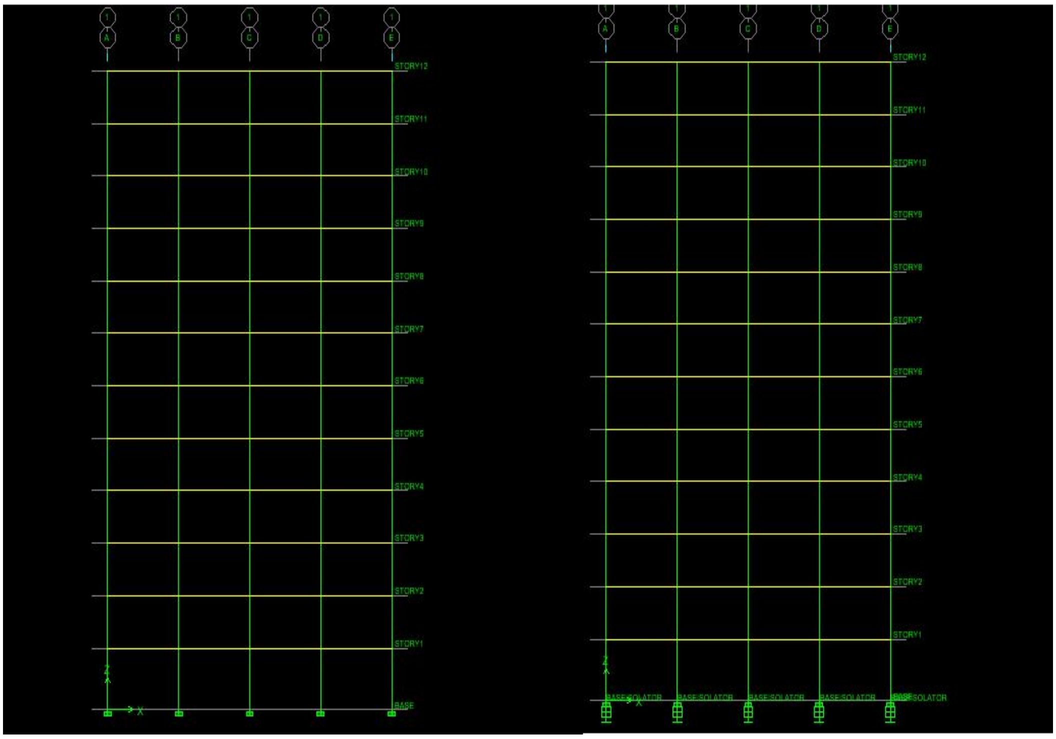


Fig-5: Plan of the Proposed Building Model



(a) **(b)**

Fig-6: a) Elevation of the Fixed Base Building Model (b) Elevation of the Isolated Base Building Model

Table -1: Assumed data for G+11 RCC Framed Building

S.No	Content	Description
1	Type Of Structure	Multi storey high raised frame (moment resisting frame)
2	Specific weight of RCC	24kN/mm³
3	Type of soil	medium
4	Response spectra	As per IS 1893(Part-1):2002 for 5%damping
5	Importance factor	1
6	Response reduction factor	5

Table-2: Dimensions and Properties of HDRB

CHARACTERISTICS	HDRB(Rubber thickness 160mm)	HDRB(Rubber thickness 250mm)
Height	342mm	496.4mm
Weight	5.7kN	16.2kN
Compressive Stiffness	2440X10³ kN/m	3530X10³kN/m
Initial Stiffness	6400kN/m	9260kN/m
Post Yield Stiffness	640kN/m	926kN/m
Characteristic Strength	71.5kN	161kN
Equivalent Shear Stiffness	1080 kN/m	1560kN/m
Damping Ratio	0.240	0.240

Here this building frame is analytically investigated in different models. It is firstly investigated as a fixed-base case without base isolators by considering only bare frames. In the second model, HDRB isolators of rubber thickness 250mm are used at the base level of the building by considering only bare frames. In the third model, HDRB isolators of rubber thickness 160mm are used at the base level of the building by considering only bare frames.

V. RESULTS

5.1 Base Shear

Table 3 shows base shear forces for various analyses and for various buildings. And chart-1 shows the comparison graph of base shear in FB (fixed base) and IB (isolated base) buildings for both the analysis.

Table -3: Base Shear Values for Fixed and Isolated Base Building for Different Analysis.

TYPE OF ANALYSIS	STATIC (FB)	STATIC(IB-160mm thickness)	STATIC(IB-250mm thickness)	DYNAMIC (FB)	DYNAMIC(IB-160mm thickness)	DYNAMIC(IB-250mm thickness)
BASE SHEAR VALUES (KN)	3165.91	2215.64	1899.55	3130.14	2189.96	1815.48

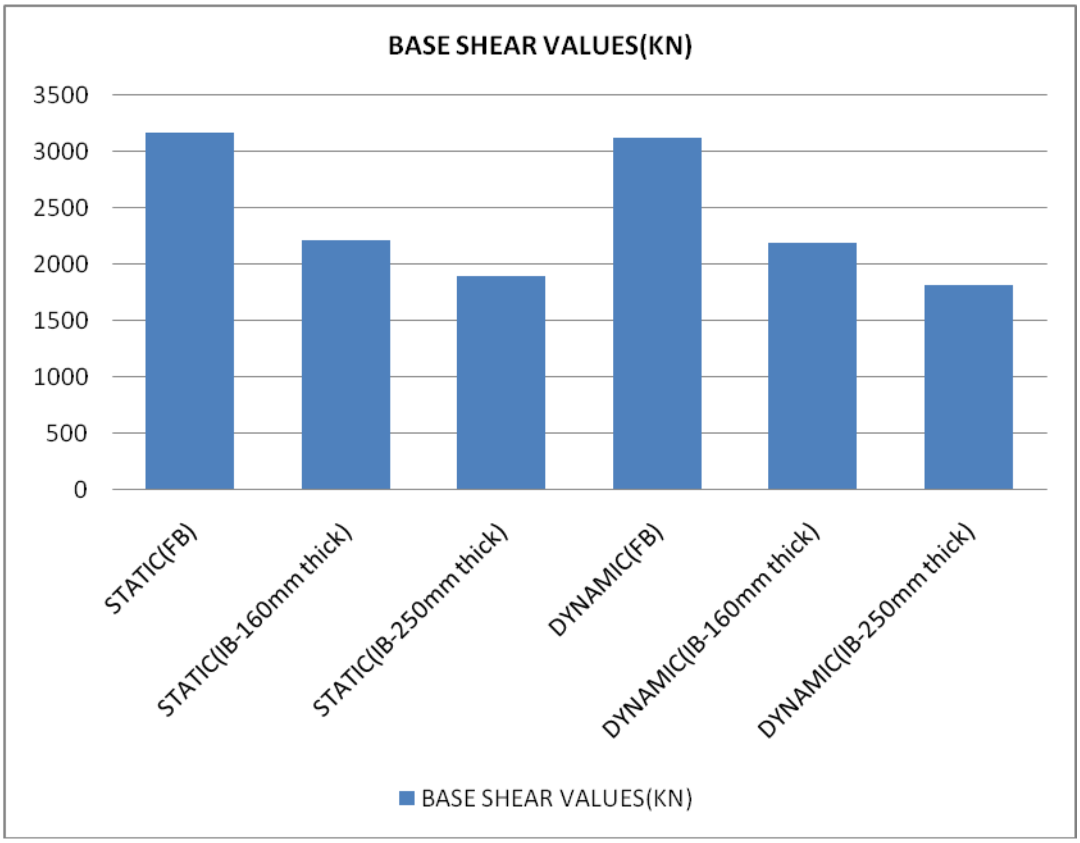


Chart-1: Comparison of Base Shear Values in FB and IB Buildings for Different Analysis

5.2 Lateral Storey Drift

Table 4 shows storey drifts in FB buildings and in both the IB buildings for load cases EQX and SPECX. And chart-2 and chart-3 shows the comparison graph of storey drifts in FB and IB buildings for the load cases EQX and SPECX respectively

Table -4: Lateral Storey Drifts for FB and IB Building for the Load Cases EQX and SPECX

STOREY NO	LOAD CASE:EQX			LOAD CASE:SPECX		
	FB	IB-250mm thick	IB-160mm thick	FB	IB-250mm thick	IB-160mm thick
12	0.000896	0.000420	0.000538	0.00078	0.000358	0.000455
11	0.001403	0.000666	0.000855	0.001218	0.000566	0.000721
10	0.001896	0.001013	0.001306	0.001607	0.000843	0.001078
9	0.002313	0.001277	0.001650	0.001913	0.001037	0.001329
8	0.002646	0.001593	0.002065	0.00215	0.001272	0.001623
7	0.0029	0.001772	0.002304	0.002342	0.001408	0.001802
6	0.003084	0.001912	0.002489	0.002513	0.001533	0.001965
5	0.003205	0.002003	0.002610	0.002678	0.001647	0.002113
4	0.003266	0.002145	0.002801	0.002838	0.001836	0.002361
3	0.003245	0.002181	0.002855	0.002957	0.001959	0.002564
2	0.003034	0.004717	0.006132	0.002892	0.004524	0.005791
1	0.001905	0.019061	0.025137	0.001874	0.018769	0.024212
Isolator		0.070161	0.092613		0.060869	0.079130

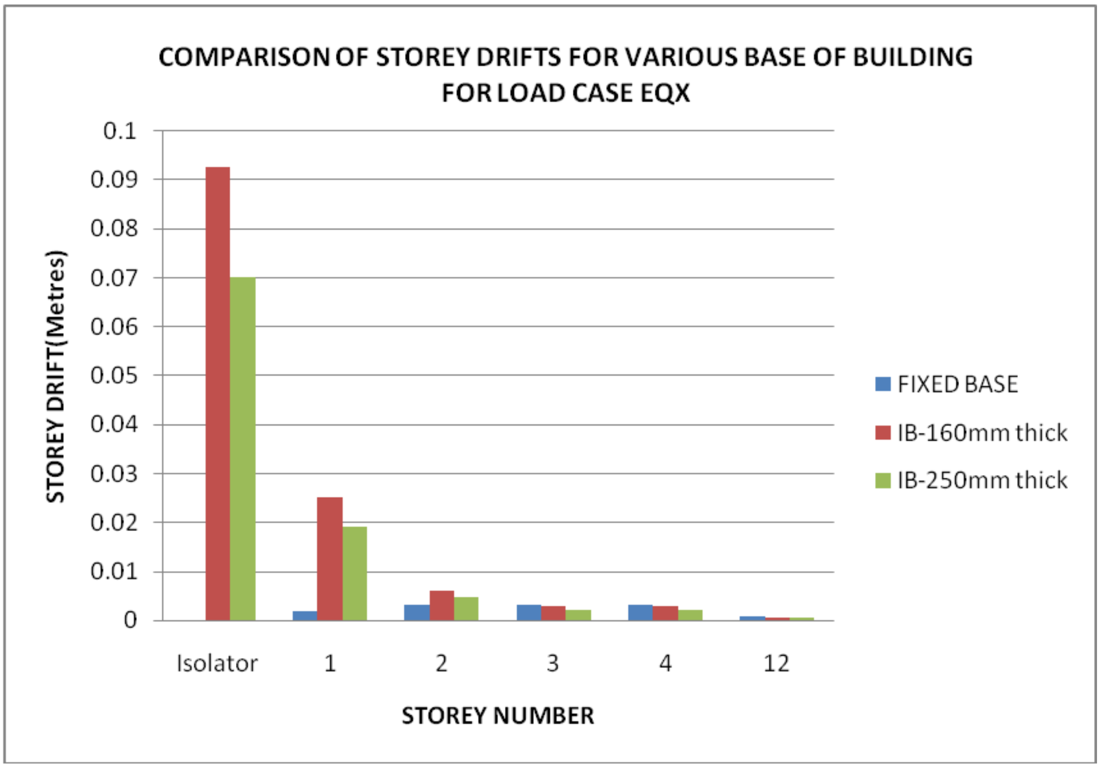


Chart-2: Comparison of Storey drfts in FB and IB Buildings for the Load Case EQX.

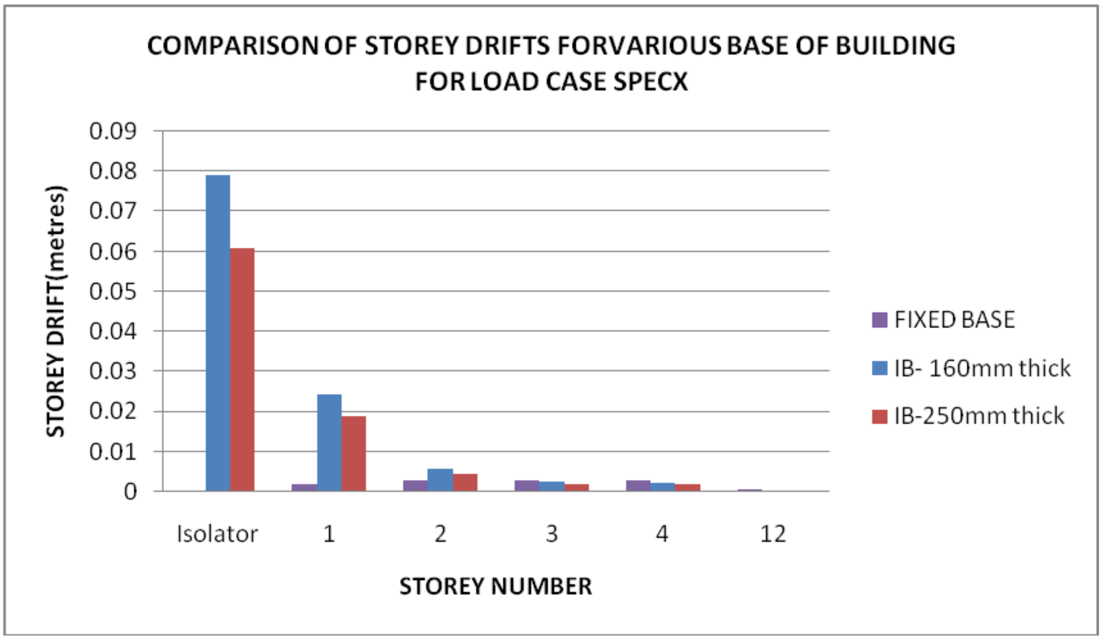


Chart-3: Comparison of Storey drfts in FB and IB Buildings for the Load Case SPECX

5.3 Lateral storey displacement

Table 5 shows storey displacements in FB buildings and in both the IB buildings for load cases EQX and SPECX. And chart-4 and chart-5 shows the comparison graph of storey displacement in FB and IB buildings for the load cases EQX and SPECX respectively.

Table -5: Lateral Storey Displacement for FB and IB Buildings for the Load Cases EQX and SPECX

STOREY NO	LOAD CASE:EQX			LOAD CASE:SPECX		
	FB	IB-160mm thick	IB-250mm thick	FB	IB-160mm thick	IB-250mm thick
12	0.1054	0.189	0.2492	0.084	0.1470	0.1975
11	0.1023	0.1927	0.2523	0.0819	0.1523	0.2016
10	0.0974	0.1962	0.2546	0.0787	0.1574	0.2056
9	0.0907	0.1976	0.2551	0.0742	0.1607	0.2083
8	0.0826	0.198	0.2543	0.0687	0.1632	0.2101
7	0.0734	0.1964	0.2523	0.0623	0.1654	0.2109
6	0.0632	0.2038	0.2579	0.0549	0.1752	0.2193
5	0.0524	0.1957	0.2492	0.0468	0.1695	0.2133
4	0.0412	0.1857	0.2384	0.0378	0.1618	0.2047
3	0.0298	0.1826	0.2339	0.0281	0.1602	0.2019
2	0.0184	0.1762	0.227	0.0178	0.1558	0.1961
1	0.0078	0.169	0.2183	0.0077	0.1474	0.1872
Isolator		0.1656	0.2137		0.1351	0.1734

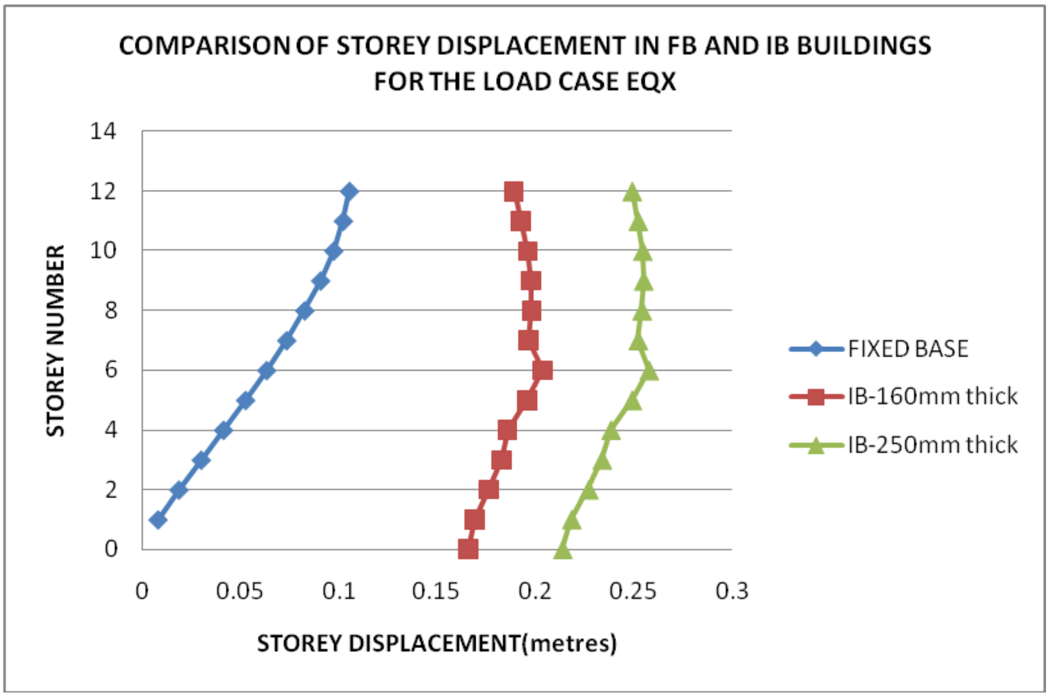


Chart-4: Comparison of Storey Displacements in FB and IB Buildings for the Load Case EQX

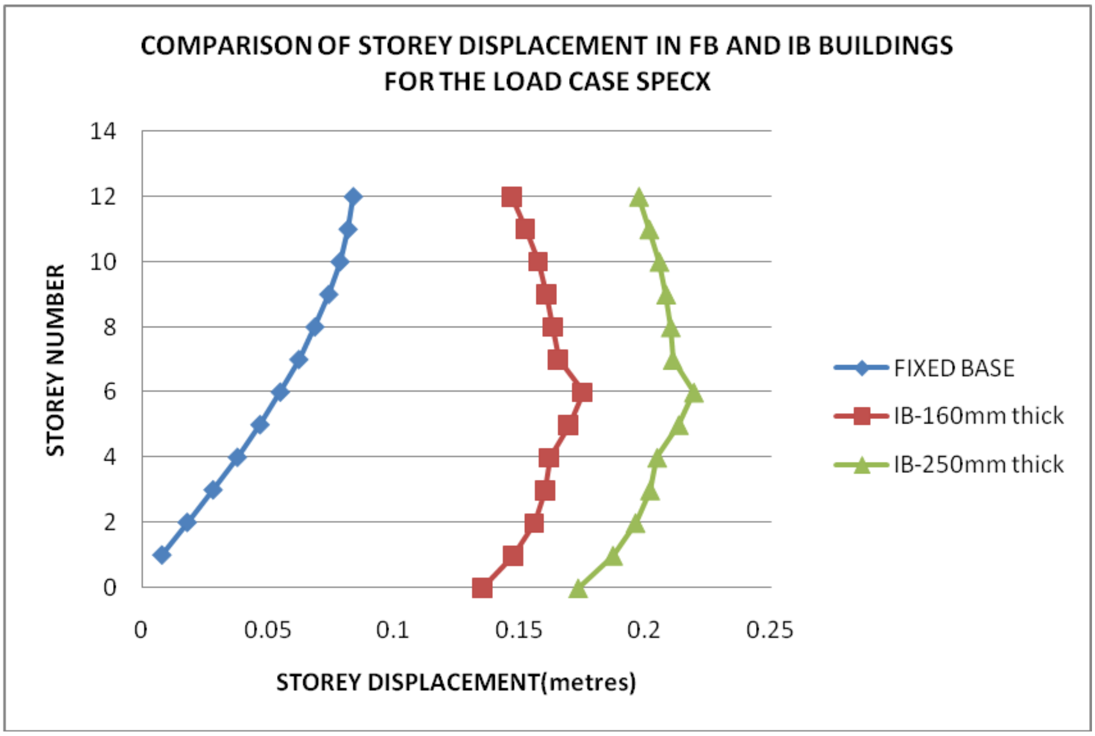


Chart-5: Comparison of Storey Displacements in FB and IB Buildings for the Load Case SPECX

5.4 Modal Analysis Results

Table-6 shows that overall response is mainly affected when using isolators in the structure. The period of the structure is lengthened with the provision of isolators at the base.

Table -6: Comparison of Modal Analysis Results for FB and IB Buildings

MODE NO	PERIODS(SECONDS)		
	FB	IB(160mm thick)	IB(250mm thick)
1	2.290599	4.005342	4.705730
2	1.985153	3.160178	3.633155
3	0.746883	1.134267	1.292494
4	0.642851	1.065747	1.242704
5	0.428468	0.580619	0.646450
6	0.364471	0.377734	0.383693
7	0.291248	0.322493	0.336335
8	0.24473	0.248540	0.250189
9	0.205754	0.227853	0.237056
10	0.171016	0.179858	0.183593
11	0.124235	0.128274	0.129964
12	0.101617	0.104147	0.105231

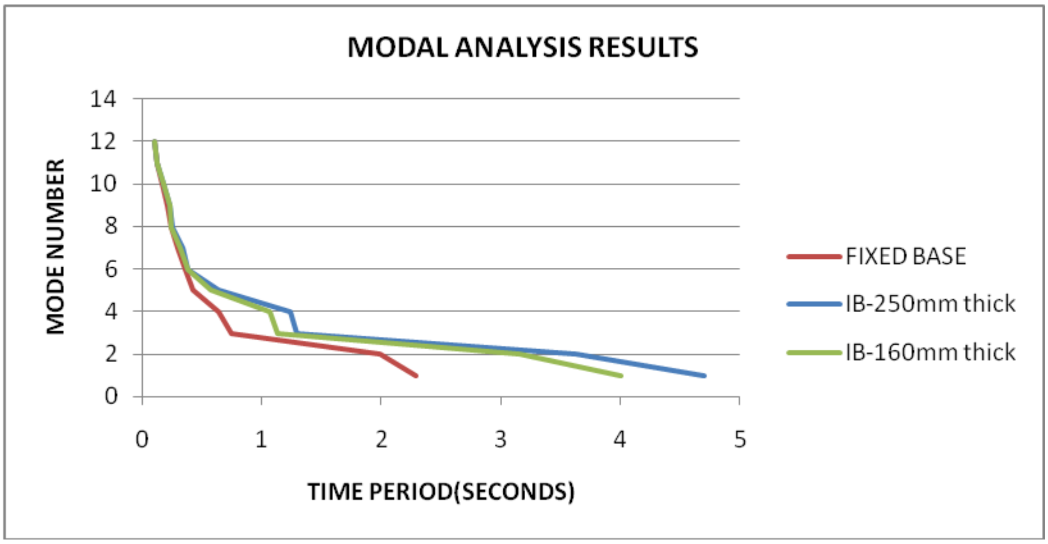


Chart-6: Comparison of Time Period in FB and IB Buildings for the Modal Analysis

VI. CONCLUSIONS

From the analysis and results we can conclude that

- It is seen from the table that base shear values for static and dynamic analysis are approximately equal. For load case EQX there shows a reduction of 30% for isolator of 160mm rubber thickness and 40% reduction for isolator of rubber thickness 250mm in base shear values. And for the load case SPECX, there shows a reduction of 30% for isolator of rubber thickness 160mm and 42% reduction for isolator of rubber thickness 250mm in the base shear values. Therefore there shows 35-50% reduction in the base shear forces, when isolators are provided in the structures.

- It is seen from chart-2 and chart-3, for FB building, the storey drifts increases from storey 1 to storey 2 and then gradually decreases from storey 2 to storey 12. And for IB building, at isolator level drift is so high and it gradually decreases from isolator level to storey 12. When isolators are provided in the structures, the storey drifts are very much reduced. And isolator having higher rubber thickness gives less drift. According to IS 1893-2002 finally permissible value of storey drift is 0.004h. Analysis shows storey drift of all structure are within permissible limit.
- From the tables and graphs it is clear that the storey displacements are much higher for IB buildings. The isolator with rubber thickness 250mm has more displacement compared to isolator with rubber thickness 160mm.There is an increment of 140mm displacement for the IB structure compared to FB structure. However the building does not undergo deformation. We can reduce it by adding suitable dampers.
- Analysis shows that the fundamental period of the structure is approximately doubled for the isolated structure. Fundamental period is the period of first mode of vibration. Increment in fundamental period reduces the maximum acceleration and hence the earthquake induced forces in the structure.
- When linear static and linear dynamic results are compared, close results are obtained. Even though dynamic results give comparatively a small reduction in base shear forces, storey drifts and displacements.
- The isolator with higher rubber thickness gives much better results.

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