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DYNAMIC ANANYSIS OF 11 STOREY RC STRUCTURE BY PROVIDING LEAD RUBBER BEARING AS BASE ISOLATION SYSTEM

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Abstract - *The main objective of this project is to protect the buildings by designing it as earthquake resistant structure. Earthquake is one of major natural disaster in which many structures damage and collapse due to improper design against seismic motion. Earthquake also affects the economy of the nation, so essential proper measures of prevention must be developed. There are many concepts of designing a building as earthquake resistant structure; the concept used in this project is base isolation. There are many types of base isolation systems but lead rubber bearing (LRB) is used as base isolation system in this project, LRB is most widely used as isolation system for buildings.*

Key Words: Lead Rubber Bearing (LRB), Base Isolation, Response Spectrum Analysis

1. INTRODUCTION

Earthquake is natural disaster which is caused when the stress is produced on lithosphere due to collision between the plates when this stress is high the lithosphere breaks or shifts. The collision between plates may be of two types one is inter-plate and other is intra-plate. Most of the earthquakes occurred near Himalayan region are inter-plate earthquakes and earthquakes occurred near Peninsular region are intra-plate earthquakes. The most of earthquakes occurred since last century is in populated and urbanized areas which caused huge damage. There are some earthquakes which are un-noticed since they occurred deep underneath earth's crust. India lies in the northwestern end of the Indo-Australian Plate, which includes India, Australia, a major portion of the Indian Ocean and other smaller countries. This plate is colliding against the huge Eurasian Plate and going under the Eurasian Plate, this process of one tectonic plate getting underneath other is called subduction (shown in the Fig 1.1).

During an earthquake energy is released from fault, in the form of heat and seismic waves. These seismic waves radiate from focus (source) and shake the ground, these seismic waves travel 100's of km away from the source. The point exactly above the focus on the earth's surface is called the epicenter. The figure below shows faults, plates, focus, epicenter, seismic waves. (Shown in Fig 1.2)

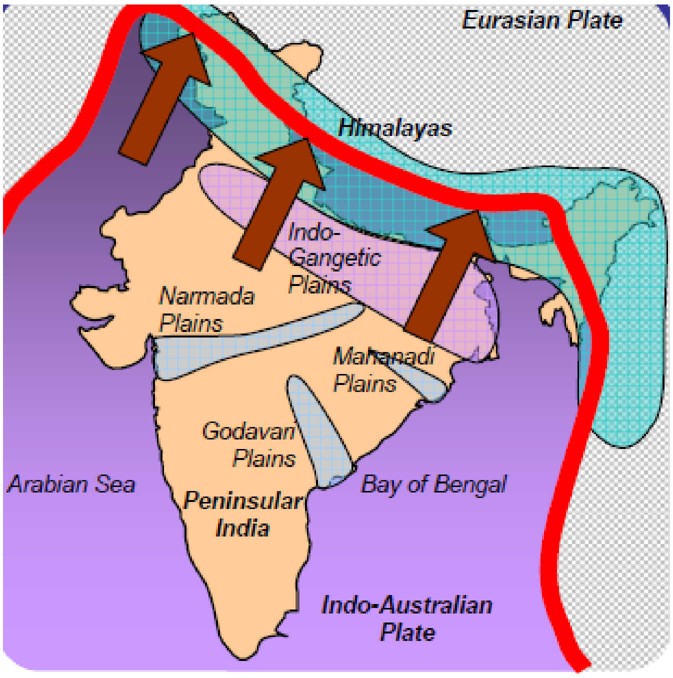

FIG 1.1: Map showing collision between different Plates

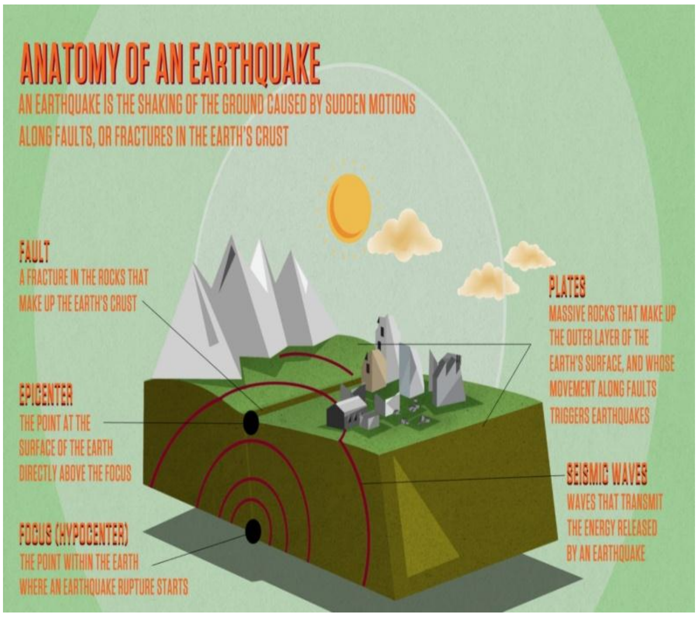

FIG 1.2: Anatomy of earthquake

1.1 Introduction to Base Isolation Systems

Seismic isolation also known as base isolation is an earthquake resistant design concept in which a building is decoupled from the earthquake ground motion or seismic waves. When a building is decoupled from ground motion it significantly reduces response in the structure which would have affected building if it is fixed base. Base isolation decouples the building from ground motion by decreasing the fundamental frequency when compared to fix based building. This concept of base isolation also makes to remain building elastic during an earthquake. Base isolation concept is also used in bridges, nuclear power plants and liquid storage tanks etc.

The earthquake resistant structures are divided as rigid and flexible structures. In rigid structures the inter-story displacements are reduced by providing diagonal bracings, shear walls, and using composite materials. In flexible structures the excitation input is reduced with the help of using dampers and Isolators. But in rigid structures they result in large inter-storey drifts, due to which the building components and nonstructural components may get damaged even if the building is stiff during earthquake.

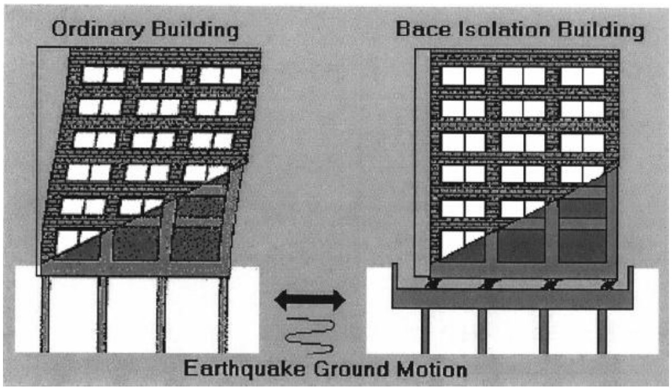

Fig 1.3: Difference between performance of fixed base and base isolated structure

1.2 Types of Base Isolation Systems

Base isolation is classified in passive control category of structural control systems. The various types of isolators are classified as shown in fig 1.4.

Among these types of Isolation System Lead plug rubber bearing is used in this work.

Lead-Plug Rubber Bearing (LRB)

LRB was first invented in 1975 in New-Zealand. The components of the LRB are lead plug, endplates, steel shims and rubber layers. The steel shims provide vertical stiffness to the LRB and layers of rubber provide lateral flexibility or horizontal stiffness. Lead core of the LRB gives extra stiffness to the isolators and it also provides damping to the system.

Inferable from current very much created innovations; it is conceivable to fabricate LRB with enormous shear deformation and high stiffness. Advancements in materials and configuration related innovations, for example, investigation programme's (software's) and development techniques have empowered the idea of isolation turn into a reality. Companies like Dynamic Isolation Systems (DIS) and Bridgestone design and manufacture isolators according to the requirements of a client. LRB has the properties of both damper and isolator, lead plug's plastic deformation makes LRB to absorb energy from vibration hence has property of damper and it has a flexibility property to deflect seismic waves hence act also as isolator. Fig 1.5shows the cross section of LRB.

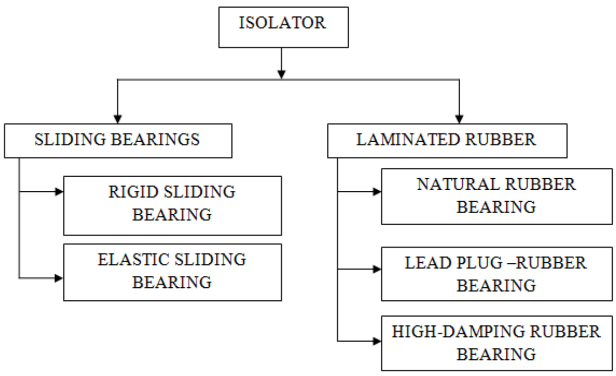

Fig 1.4: Flowchart showing types of isolators

The LRB has four functions listed below:-

- Due to its property of vertical stiffness is functions as load supporter
- Provide elasticity in horizontal direction due to the property of horizontal stiffness
- It has energy restoring capability
- As it has lead core it provides damping to the structure by deforming plastically
- It reduce ground acceleration of a structure by increasing the time period of vibration
- It can be easily installed since no separate damper is required

It has low maintenance when compared to other types of isolators.

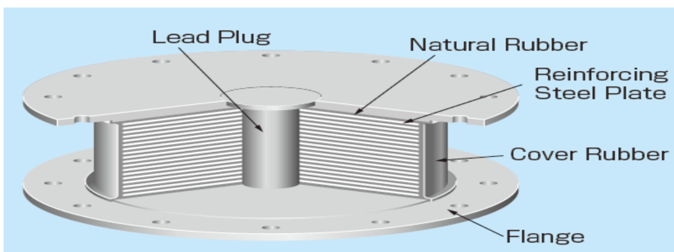

Fig 1.3.1.2.1: Cross section of LRB

Some structures in India with base isolation system are listed below,

- GTB Hospital, Delhi installed in 2008
- Dwarka hospital installed in 2006
- World bank, Delhi installed in 1998
- Bhuji hospital, Gujarat

2. OBJECTIVE OF THE PROJECT

The main objective of project was to compare fixed base and base isolated structure by dynamic analysis. Response spectrum analysis method is used for analysis. The results were compared for Story drifts, Base shear, Story shear, Point displacements and Mode shapes.

The objective of the project is as explained below:-

- The 11 storey RC bare frame is isolated using Lead core rubber bearing to reduce the story drifts when compared with conventional building
- To make the structure earthquake resistant
- To increase the mode period of the base isolated structure when compared to conventional building
- To increase the displacement of base isolated structure in all stories when compared to conventional structure when analyzed by response spectrum analysis
- To increase the displacement of bottom stories of base isolated structure when compared with conventional structure when analyzed using Nonlinear time history analysis
- To decrease the story drift of a base isolated structure when compared with fixed base structure
- To decrease the base shear of a base isolated structure when compared with fixed base structure
- To study the effectiveness of providing Lead core rubber bearing
- To know the method of response spectrum analysis using E-TABS
- To gain a knowledge in the base isolation systems
- To know the design of earthquake resistant structure
- To design the Lead plug rubber bearing by using the data from E-TABS
- To design LRB

3. METHODOLOGY

- The software used for analysis of a structure is E-TABS v 9.7.1
- The dynamic analysis is carried for structural analysis
- The codes used are IS 1893 (PART I) 2002, UBC 1997, IBC 2006 and NEHRP Recommended Provisions Published by FEMA-451 (Federal Emergency Management Agency) in 2003
- There are many types of dynamic analysis in this project Response spectrum analysis
- The building is modeled first then the loads are applied as per code provisions of IS 875 (PART II) Reaffirmed in 2008 for live and dead load
- For Response Spectrum Analysis UBC 1997 Spectrum is used
- After the analysis of a fixed base structure is performed the maximum axial load is noted from support reaction results
- Then once axial load is noted the Lead core rubber bearing is designed
- Then Properties of Lead core rubber bearing are calculated
- Then these properties are used as link properties for base isolation structure
- Then the Base Isolation Structure is analyzed
- Then results are tabulated and discussed

4. LITERATURE SURVEY

S. Etedali, M.R. Sohrab (2011), in this paper torsional behavior of asymmetric building with and without isolation system is studied for three and eight story steel structure to analyze the structure time history analysis is performed by using Tabas, El Centro and Bam earthquake data. The results were observed and torsion was reduced after using isolation system. Increasing flexible edge stiffness of isolation and superstructure reduces torsional effect on the superstructure. When eccentricity is increased the effect of isolation system on torsion was very less.

Md. Arman Chowdhury, Wahid Hassan (2013), in this paper 20 story irregular building is modeled and analyzed using SAP2000 v15. Dynamic analysis of an irregular structure with and without isolator is performed. Both response spectrum analysis and time history analysis are performed. The structure was designed for Bangladesh earthquake zone. For time history analysis CHI-CHI, El Centro and Northridge seismic data were used. The results of displacement for different stories in X and Y direction for all methods of analysis were compared and it is observed displacement was significant in first five stories of base isolated structure and difference was decreasing between displacement with increasing story height and relative inter-story displacement of base isolated structure was less then fixed base structure. This indicates that axial load on column was reduced after using isolator which also reduces reinforcement of the column. Finally base isolation is required to reduce design loads and safety of structure against earthquake

H.P. Santhosh, K.S. Manjunath, K. Sathish Kumar (2013), in this paper a lead plug rubber bearing is designed for a building. The mechanical properties of LRB were tabulated. Then these properties of LRB are used to study the response of a structure under seismic motion. Response spectrum analysis is performed. The results show that these properties of LRB were effective. For analysis 6 story building was modeled and results were compared between conventional structure and isolated structure.

5. MODELING AND ANALYSIS

5.1 Response Spectrum Analysis

A response spectrum is a curve which is plotted between maximum response of single degree of freedom system which is subjected to a specified seismic motion and its frequency (or time period). This spectra helps in obtaining peak structural responses (only when linear), it is also possible to find lateral forces developed in a building due to an earthquake, hence used for design of earthquake resistant structure. Response spectrum method is applicable for only linear systems and for nonlinear systems whose nonlinearity is same in whole system. For soil class E and F of UBC 1997 code use of response spectrum method is restricted.

Procedure for using response spectrum method of analysis in Etabs

- Define response spectrum functions
- Choose function type
- For UBC spectra assign seismic coefficients C_a and C_v
- Assign damping ratio
- This completes defining response spectra function
- Now define response spectrum cases
- In response spectrum cases assign damping ratio
- Select type of model combination
- Next select type of directional combination
- To input response spectra is next step in which we have to calculate scale factor from following formula

  $$\text{Scale factor} = \frac{I \times g}{2R}$$

  Where, I= Importance factor of a building
  g= Acceleration due to gravity
  R= Response reduction factor
- Next run the analysis and get result

5.2 Description and Modeling of Building

- Software used for analysis is ETABS v 9.7.1
- Units used are 'KN-m'
- Code provisions as per UBC 1997 and IS 1893 (Part 1)
- Types of analysis performed are Response spectrum analysis and Time history analysis

5.3 Building Details:

Structure: RCC (SMRF)

Structure Type: Plan Irregular structure

Plan Dimension: 36m×54m

Height of Building: G+11 (34.65m)

Height of Each Storey: 3.15

Building Type: Commercial

In X Direction: 8 bays of 4.5m length

In Y Direction: 9 bays of 6m length

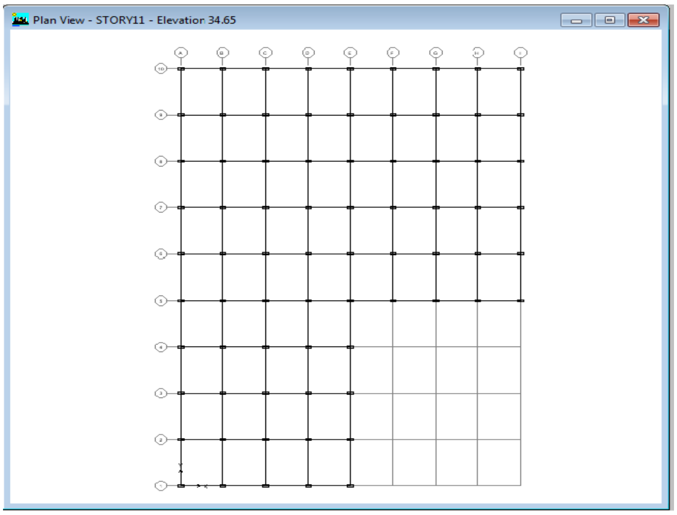

Fig 5.1: Plan of Building

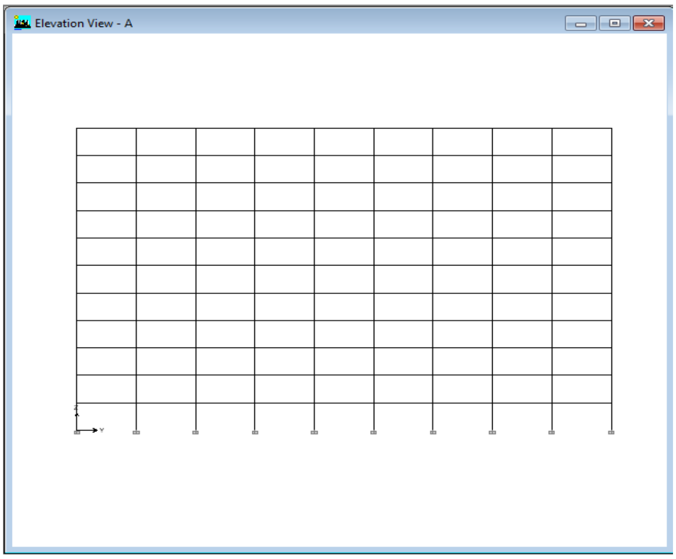

Fig 5.2: Elevation along Grid Line A

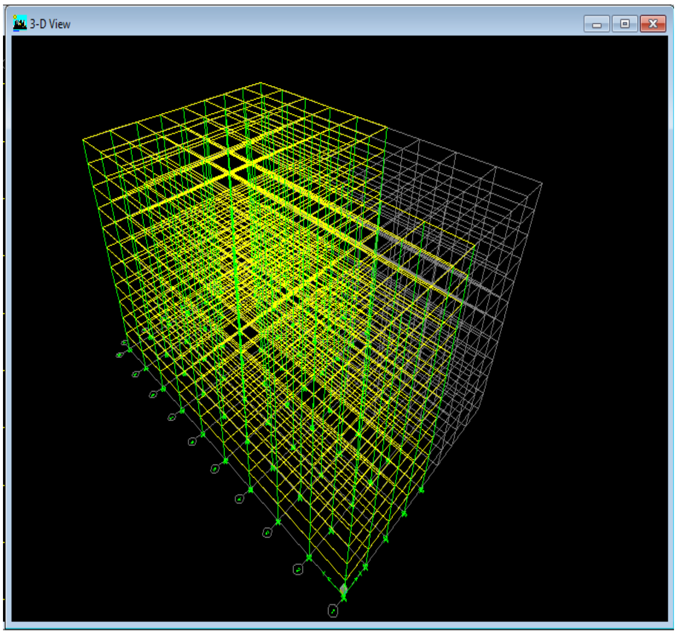

Fig 5.3: Isometric View of model

5.4 Material Properties

Grade of Concrete: M25 (For Beams and Slab)

M20 (For column)

Grade of Steel: Fe415

5.5 Section Properties

Interior Beam Size: 230mm×400mm

Exterior Beam Size: 230mm×500mm

Slab Thickness: 150mm

Wall thickness: 230mm

5.6 Load Consideration

5.6.1 Gravity Load

Dead Load: Column, Beam, Slab (Default Values)

Live Load for Floors: 3.0 kN/m^2

Live Load for Roof: 1.5 kN/m^2

Floor Finish: 1.0 kN/m^2

Wall Load: thickness × density × height

= 0.23×18×2.75

= 11.385 kN/m

Parapet Load: = 0.23×18×1 = 4.14 kN/m

5.6.2 Lateral Load for Response Spectrum Analysis (according to UBC 1997)

Seismic Zone Factor (Z) – Zone 3

Soil Profile Type - S_D

Seismic Coefficient C_a - 0.36

Seismic Coefficient C_v (C_{VD}) - 0.54

Importance Factor (I) – 1.25

Response Reduction Factor (R) – 8.5(For SMRF)

Seismic Source Type – B

Near Source Factor N_a – 1

Near Source Factor N_v – 1

Damping coefficient (B_D or B_M) – 1

Damping (β_{eff}) – 5%

5.7 DESCRIPTION OF MODELS

Model 1: Response Spectrum Analysis with Fixed Base

Model 2: Response Spectrum Analysis with Lead Rubber Bearing

5.8 DESIGN OF BASE ISOLATOR FOR MODEL 2

The type of base isolator used for analysis is lead rubber bearing isolator, to get the properties of isolator its design is carried out as shown below.

i. Note down the maximum support reaction
   - After the analysis of Model 1 the maximum support reaction is noted
   - Display>show-tables>analysis result>reactions>support reactions
   - Tabulate the support reaction result in excel sheet and get the maximum support reaction
   - Max support reaction (W)= 3566.06 Kn

ii. Calculate Design Displacement (D_D)
Assume Design Time Period T_D=2.5 sec

$$D_D = \frac{g}{4\pi^2} \times \frac{C_{VD} T_D}{B_D}$$

all the values are in 3.5.3.2

$$D_D = \frac{9.81}{4\pi^2} \times \frac{0.54 \times 2.5}{1} = 0.3355\text{m}$$

iii. Effective stiffness (K_{eff})

$$K_{eff} = \frac{W}{g} \times \left(\frac{2\pi}{T_D}\right)^2$$

$$K_{eff} = \frac{3566.06}{9.81} \times \left(\frac{2\pi}{2.5}\right)^2$$
$$= 2296.15\ kN/m$$

iv. Energy dissipated per cycle (W_D)

$$W_D = 2\pi K_{eff} D_D^2 \beta_{eff}$$
$$W_D = 2\pi \times 2296.15 \times 0.3355^2 \times 0.05$$
$$= 81.20\ kN\text{-}m$$

v. Force at design displacement or characteristic strength (Q)

$$Q = \frac{W_D}{4D_D} = \frac{81.20}{4 \times 0.3355} = 60.51\ kN$$

vi. Stiffness in rubber (K_2)

$$K_2 = K_{eff} - \frac{Q}{D_D}$$
$$= 2296.15 - \frac{60.51}{0.3355}$$
$$= 2115.79\ kN/m$$

Where, $\frac{Q}{D_D}$ = Stiffness of lead core

vii. Yield Displacement (D_Y)

$$D_Y = \frac{Q}{K_1 - K_2} \quad \text{we have } K_1 = 10K_2$$
$$= \frac{Q}{10K_2 - K_2}$$
$$= \frac{Q}{9K_2} = \frac{60.51}{9 \times 2115.79} = 0.0032\ m$$

viii. Recalculation of Q to Q_R

$$Q_R = \frac{W_D}{4 \times (D_D - D_Y)}$$
$$= \frac{81.20}{4 \times (0.3355 - 0.0032)} = 61.09\ kN$$

ix. Calculation of area and diameter of lead plug

Yield strength of lead is around 10 Mpa

the area of lead plug needed is

$$A_{PB} = \frac{Q_R}{10 \times 10^3}$$
$$= \frac{61.09}{10 \times 10^3} = 0.0061\ m^2$$

dia of lead plug

$$d = \sqrt{0.0061 \times \frac{4}{\pi}}$$

= 0.08813 m

= 88.13 mm

x. Revising Rubber stiffness K_{eff} to $K_{eff(R)}$ (after revising Q to Q_R)

$$K_{eff(R)} = K_{eff} - \frac{Q_R}{D_D}$$
$$= 2296.15 - \frac{61.09}{0.3355}$$
$$= 2114.06\ kN/m$$

xi. Total thickness of rubber layer (t_r)

$$t_r = \frac{D_D}{\gamma}$$

Where, γ = 100% (maximum shear strain of rubber)

$$t_r = \frac{0.3355}{1} = 0.3355\ m$$

xii. Area of bearing

$$A_{LRB} = \frac{K_{eff(R)} \times t_r}{G} = \frac{2114.06 \times 0.3355}{0.7 \times 1000} = 1.01 m^2$$

where, G $\rightarrow$ Shear modulus which is 0.7 Mpa

xiii. Diameter of bearing

$$\emptyset_{LRB} = \sqrt{A \times \frac{4}{\pi}} = \sqrt{1.01 \times \frac{4}{\pi}} = 1.13 = 1130\ mm$$

xiv. Shape factor

$$S = \frac{1}{2.4} \times \frac{f_v}{f_h}$$

where, f_v is vertical frequency

f_h is horizontal frequency

Take horizontal period to be 2 sec

$$f_h = \frac{1}{2} = 0.5\ Hz$$

Consider, f_v=10 Hz

$$S = \frac{1}{2.4} \times \frac{10}{0.5} = 8.33$$

Also we have,

$$S = \frac{\emptyset_{LRB}}{4t}$$

where, t is thickness of single rubber layer

$$\therefore t = \frac{\emptyset_{LRB}}{4S} = \frac{1.13}{4 \times 8.33} = 0.0339\ m = 33.9\ mm$$

$$\text{Number of rubber layers} = \frac{t_r}{t} = \frac{0.3355}{0.0339} = 9.89$$
$$\approx 10\ \text{no's}$$

$\therefore$ provide 35mm thick 10 rubber layers

xv. Dimensions of Lead rubber bearing (LRB)

- Let thickness of shim plates be 2.8mm
  Number of shim plates = (10-1) = 9
- End plate thickness is between 19.05 to 38.1
  Adopt thickness of end plate as 25mm
- Total height of LRB (h)
  $= 10 \times 35 + 9 \times 2.8 + 2 \times 25$
  $= 425.2$ mm
  ≈ 0.4252 m
- Diameter of rubber layer
  $\emptyset = N \times t$
  =10×35 = 350 mm
  =0.35 m
- Area of rubber layer
  $A = \frac{\pi}{4} \times \emptyset^2$

$$= \frac{\pi}{4} \times 0.35^2 = 0.09621 \text{ m}^2$$

xvi. Compression modulus E_C

$$E_C = 6GS^2\left(1 - \frac{6GS^2}{K}\right)$$

Where, K- Bulk modulus = 2000 Mpa
G- Shear modulus = 0.7 Mpa

$$E_C = 6 \times 0.7 \times 1000 \times 8.33^2 \times \left(1 - \frac{6 \times 0.7 \times 1000 \times 8.33^2}{2000 \times 1000}\right)$$

= 248.96×10^3 kN/m²

xvii. Horizontal stiffness K_H

$$K_H = \frac{GA_{LRB}}{t_r}$$

$$= \frac{0.7 \times 10^3 \times 1.01}{0.3355} = 2107.20 \text{ kN/m}$$

xviii. Vertical Stiffness K_V

$$K_V = \frac{E_C A_{LRB}}{t_r}$$

$$= \frac{248.96 \times 10^3 \times 1.01}{0.3355}$$

= 749470 kN/m
= 749.47 mN/m

The procedure of design of lead rubber bearing is referred from Textbook of DESIGN OF SEISMIC ISOLATED STRUCTURE from theory of practice by JAMES M.KELLY and FARZAD NAEIM

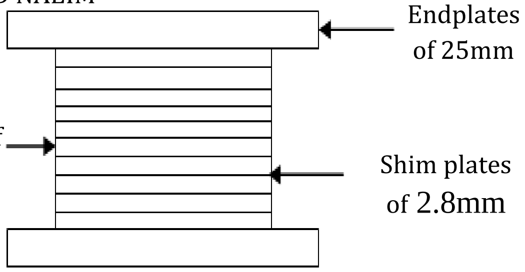

Fig 5.8.1 Cross sectional properties of LRB for response spectrum analysis

6. PLACING LEAD RUBBER BEARING

- Base isolators are placed at 0.5m above base level
- Isolators are provided above every footing
- Properties of LRB Calculated are mentioned in the below table,

Property type	Response Spectrum Analysis
Effective stiffness $K_{eff(R)}$	2114.06 kN/m
Horizontal Stiffness K_H	2107.20 kN/m
Vertical Stiffness K_V	749.47×10^3 kN/m
Yield strength Q_R	61.09 kN
Post yield stiffness ratio	0.1
Damping	5%

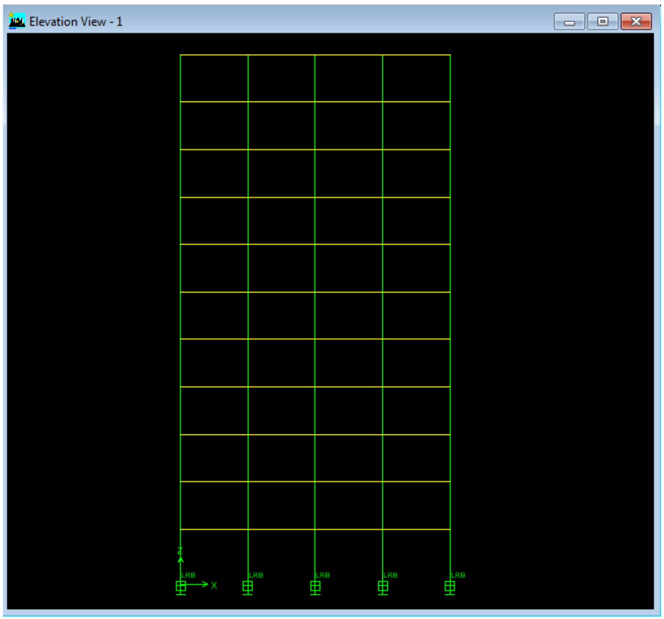

Fig 6.1: Figure showing LRB above base in elevation view along XZ plane

7. RESULTS AND DISCUSSION

7.1 Story Shear

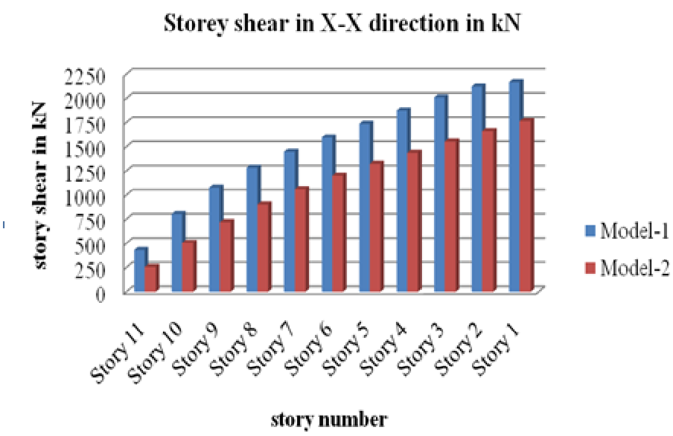

Fig 7.1.1: Graph showing Story shear results in X-X direction of Model 1 and Model 2

Discussion: From fig 7.1.1 which are response spectrum analysis results it can be seen in model-2 (base isolated building) story shear in x-x direction were reduced significantly at each story when compared to model-1 (fixed base building). This means after the use of Lead rubber bearing as base isolator the story shear in x-x direction are reduced. The model-2 story shears in x-x direction at top story reduced by 40% when compared with model 1.

7.2 Base Shear

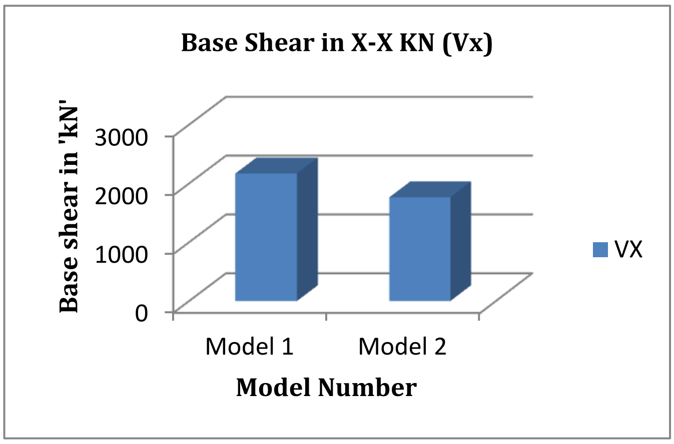

Fig 7.2.1 Base Shear in x-x direction

Discussion: In Fig 7.2.1 above the base shear in x-x direction is plotted to both models, from this graph we see that the base shear is reduced in model-2 which is base isolated when compared to model-1 which is fixed base . In response spectrum analysis the base shear reduced in model-2 by 18.63% when compared to model-1.

4.3 Story Drift

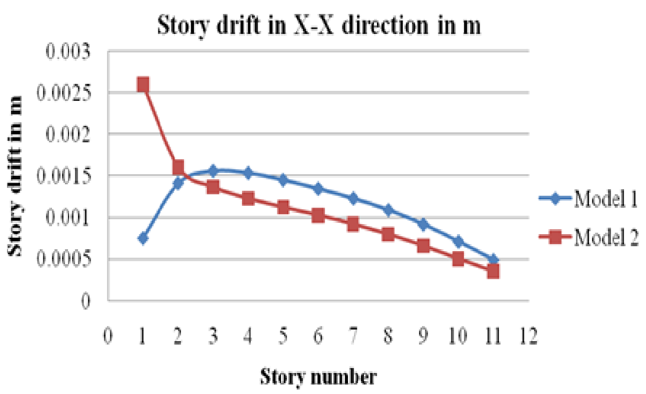

Fig 7.3.1: Graph showing Story drift in X-X direction comparison between model-1 and model-2

Discussion: In figure 7.3.1 it is observed that story drifts in x-x direction are increased in story 1 and 2 of model-2 when compared to model-1 and in story 3 to story 11 the story drifts in x-x direction are reduced in model-2 compared to model-1 which is the effect of lead rubber bearing at base. It is important to reduce story drifts of top stories which damage structure during earthquake. In model-2 (base isolated) story drift in x-x direction at story 6 reduced by 23.98% when compared to model-1 (fixed base) and in model-2 story drift in x-x direction of story 11 reduced by 28.95% when compared to model-1.

7.4 Mode Period

The mode period of all four models are tabulated in table 7.4.1 below we can observe that model 2 which is base isolated by providing lead rubber bearing at base have increase in mode period in all three modes when compared to model 1 which is fixed base. Mode 1 increased by 24%, Mode 2 increased by 29% and Mode 3 increased by 30% in model 2 (base isolated) when compared to model 1 (fixed base).

Mode Number	Mode direction	Type of model	
		Model 1	**Model 2**
Mode 1 in sec	Y direction	2.2002	2.886
Mode 2 in sec	X direction	1.6911	2.3703
Mode 3 in sec	Torsion	1.5942	2.2508

Table 7.4.1: Mode period results of all models

8. CONCLUSIONS

Model 1 which is fixed base and Model 2 which is base isolated by providing lead rubber bearing these two models were analyzed by response spectrum analysis from these building models following conclusions can be made.

- Story shear reduced after the lead rubber bearing (LRB) is provided as base isolation system which reduces the seismic effect on building
- Base shear is also reduced after providing LRB which makes structure stable during earthquake
- Story drift are reduced in higher stories which makes structure safe against earthquake
- Point displacements are increased in every stories after providing LRB which is important to make a structure flexible during earthquake
- Mode periods are increased which increases reaction time of a structure during earthquake
- Finally it is concluded that after LRB is provided as base isolation system it increases the structures stability against earthquake and reduces reinforcement hence make structure economical.

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