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Seismic Base Isolation For Earthquake Resistant Structure

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Abstract - ETABS are mostly use to design the building structure. This software is used to design base isolated structure and compare with conventional structure.

The present study is based on the comparative study of fixed base building and isolated base building.

1) INTRODUCTION

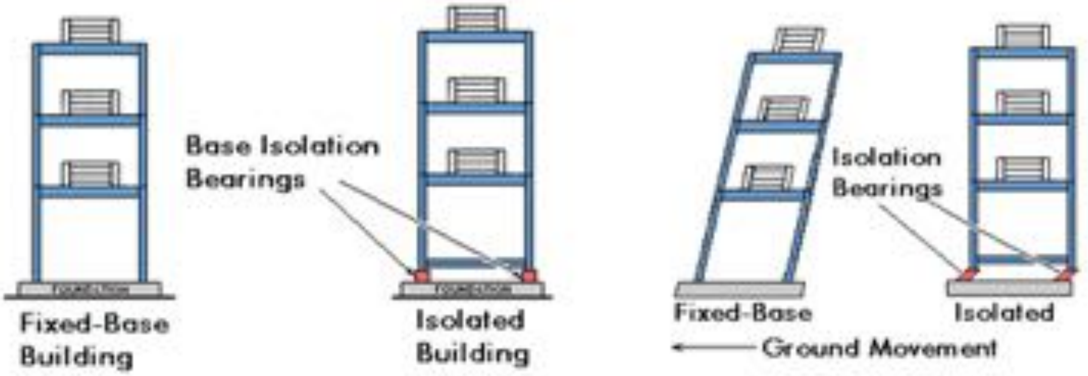
Base isolation, also known as seismic base isolation or base isolation system, is one of the most popular means of protecting a structure against earthquake forces. It is a collection of structural elements which should substantially decouple a superstructure from its substructure resting on a shaking ground thus protecting a building or non-building structure's integrity.

Base isolation is one of the most powerful tools of earthquake engineering pertaining to the passive structural vibration control technologies. It is meant to enable a building or non-building structure to survive a potentially devastating seismic impact through a proper initial design or subsequent modifications. In some cases, application of base isolation can raise both a structure's seismic performance and its seismic sustainability considerably. Contrary to popular belief base isolation does not make a building earthquake proof.

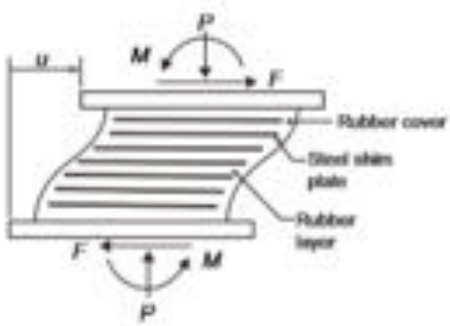
Base isolation system consists of isolation units with or without isolations components, where:

1. Isolation units are the basic elements of a base isolation system which are intended to provide the aforementioned decoupling effect to a building or non-building structure.
2. Isolation components are the connections between isolation units and their parts having no decoupling effect of their own.

Isolation units could consist of shear or sliding units.



Base isolation is not suitable for all buildings. Mostly low or medium rise building rested on hard strata underneath, high rise building or building resting on soft strata are not suitable for base isolation.



2) AIM AND OBJECTIVE

- To prepare earthquake resistant building.
- To analyze the seismic effect on base isolated structure.
- To study the strength and applicability of base isolation system.
- To estimate the cost difference between normal structure and base isolated structure.
- To design base isolators..
- To check the stability of base isolation.

3) DESIGN OF BASE ISOLATOR

- This maximum vertical reaction of fixed base building is 2800 KN for internal column and 2007.71 KN for external column is considered as supporting weight of LRBs.
- Target period (2.5 seconds) and the effective damping β. β is assumed to be 5% for reinforced concrete structure according to IS 1893:2002 clause 7.8.2.1
- Spectral acceleration from the response spectrum graph in relation with the period T= 1 sec is found to be 0.56 and damping factor for 0 .05(β) is 1 from table 3, IS 1893:2002.
- **Bearing stiffness: -**

1. For rubber bearing

$$K_H{}^E = \left(\frac{2\pi}{T_{EFF}}\right)^2 \times \frac{W_i}{g}$$

$$K_H{}^E = \left(\frac{2\pi}{2.5}\right)^2 \times \frac{2007.71}{9.81}$$

$$K_H{}^E = 1292.8\ KN/M$$

$$K_H{}^I = \left(\frac{2\pi}{2.5}\right)^2 \times \frac{2799.66}{9.81}$$

$$K_H{}^I = 1802.66\ KN/M$$

- **First estimation of design displacement**

$$D_{bd} = \frac{g \times C_V \times T_{EFF}}{4 \times \pi^2 \times B}$$

$$D_{bd} = \frac{9.81 \times 0.56 \times 2.5}{4 \times \square^2 \times 1}$$

$$D_{bd} = 0.347\ M$$

Assuming total rubber thickness t_r= 200mm with shear modules 0.4MPa for external column and 1MPa for internal column.

Hence,

$$K_H{}^E = \frac{G_I \times A}{t_r}$$

$$K_H{}^E = 1292.8\ KN/M$$

SO,

$$A = \frac{t_r \times K_H{}^E}{G_I}$$

$$A = \frac{0.2 \times 1292.8 \times 10^3}{0.4 \times 10^6}$$

$$A = 0.646\ M^2$$

And hence diameter,

$$\emptyset = \left(\frac{4 \times A}{\pi}\right)^{\frac{1}{2}}$$

$$\emptyset = 0.907\ M$$

Taking $\emptyset = 0.9m$ and A= 0.636 m^2

- **Actual bearing stiffness**

$$K_H{}^E = \frac{G_I \times A}{t_r}$$

$$K_H{}^E = \frac{0.4 \times 0.636}{0.2}$$

$$K_H{}^E = 1.272\ MN/m$$

And,

$$K_H{}^I = \frac{G_E \times A}{t_r}$$

$$K_H{}^I = \frac{4 \times 0.636}{0.2}$$

$$K_H{}^I = 3.18\ MN/m$$

- **Composite stiffness**

$$K_H = 16 \times K_H{}^E + 9 \times K_H{}^I$$

$$K_H = 48.452\ MN$$

Therefore,

$$\omega^2 = \frac{48.452 \times 10^6}{1292.8 \times 10^3}$$

$$\omega^2 = 37.47$$
$$\omega = 6.12$$

$$T = \frac{2\pi}{\omega}$$
$$T = 1.02$$

So ,

$D_D = \frac{9.81 \times 0.56 \times 1.02}{4 \times 3.14^2 \times 1}$ = 0.141 m

- **Allowance for torsion**

$$D_T = \left[D \left(1 + Y \frac{12e}{b^{2+d^2}} \right) \right]$$

Where b = dimension of shorter side=16
Y =d/2 = 8
d = 16
e = 0.05 times longer direction = 0.05 X 16 = 0.8

$$D_T = \left[D \left(1 + 8 \frac{12 \times 0.8}{16^{2+16^2}} \right) \right]$$

$$D_T = 0.162\ m$$

- **Elastic base shear**

$$V_S = \frac{K_H \times D_D}{R_{WC}}$$

$$V_S = \frac{48.45 \times 0.141}{2}$$
$$V_S = 3.41 \times 10^6 N$$

- **Bearing details**

Assume $f_v = 10\ Hz$
And

$$s = \frac{1}{\sqrt{6}} \times \frac{f_v}{f_h}$$

$$s = \frac{1}{\sqrt{6}} \times \frac{10}{\frac{1}{2.39}}$$

$$s = 10$$

To calculate the vertical frequency and the buckling load for bearing, we use small strain shear modulus for each rubber such as 20%.
So,
$G_{0.2}{}^{A} = 0.7\ MPa$ AND $G_{0.2}{}^{B} = 1.4MPa$
Assuming K= 2000 MPa

$$E_C = \frac{6GS^2K}{6GS^2 + K}$$

$E_C{}^{A} = \frac{6\times0.7\times10^2\times2000}{420+2000}$= 347 MN/$m^2$

$E_C{}^{B} = \frac{8.4\times100\times200}{2840}$= 592 MN/$m^2$

Composite $K_H = (16\times347 + 9\times592)\frac{A}{T_R}$

$K_H = (16\times347 + 9\times592)\frac{0.636}{0.2}$ = 34598.4 MN/m = ω^2

Hence, $\omega = 186$
f = 29 Hz

Therefore, $S = \frac{\emptyset}{4\times T}$

$T = \frac{0.9}{4\times10}$ = 22.5 mm

So, $N_t = 200\ mm$

No. of layers = $\frac{200}{22.5}$ = 8.88

Taking 8 layers of thickness T= 25mm

$S = \frac{200}{4\times25}$ = 2

$f_v = \frac{2\times29}{10}$ = 5.8 Hz

Assuming thickness of end plate = 25mm

Total height = 25 x 2+ 200 + 8 x 2
Where, 2mm is the thickness of each rubber shrimp
Hence, Total height =266 mm

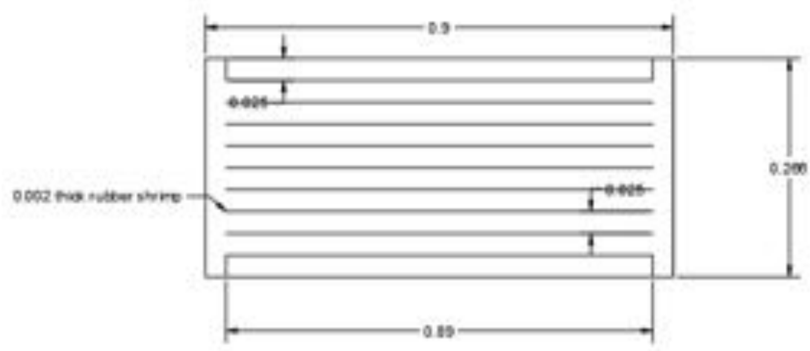
With cover of 5mm

Diameter of steel plate= 900 – 10 = 890 mm

- **Lead rubber bearing parameters**

ITEMS	DESIGN VALUE
Diameter of rubber	900 mm
Thickness of rubber layer	200 mm

Thickness of single rubber layer	25 mm
No. of layers	8 nos.
Height of isolator	266 mm
Thickness of steel plate	25 mm
Thickness of cover plate	5 mm
Diameter of steel plate	890 mm



4) DEVELOPMENT OF MODEL

G+10 storied buildings are modeled using conventional beams, columns and slab. These buildings were given square geometry with plan dimension 16m x 16m. They are loaded with dead, live, wind and seismic forces. These models are then analyzed using response spectrum method for earthquake zone V of India. The details of the modeled building are listed below. Modal damping of 5% is considered, R= 5 and I= 1. The performance of the models were recorded through ETABS to present brief idea about the role of base isolation in protecting the structure against earthquake hazards.

The following assumptions were made before the start of modeling procedure so as to maintain similar conditions for both the models:

1) Only main block of the building is considered. The staircase are not considered in the design procedure.
2) At ground floor, slabs are not provided and the floor is resting directly on found.
3) The beams are resting centrally on the column so as to avoid eccentricity.
4) For all structural elements, M25 & Fe415 are used.
5) The footings are not designed. The footings are assigned in the form of either fixed support or link support.
6) Seismic loads are considered in the horizontal direction only (X & Y) and the loads in vertical direction are assumed to be insignificant.

I. Description of models

- Model 1= fixed base
- Model 2= isolated base

II. Building details

- Structure = RCC
- Structure type = plan regular structure
- Plan dimension = 16m x 16m
- Height of building = 30.2m (G+10)
- Height of each story= 3m except bottom story (3.2m)
- In X-Direction = 4 bay of 4m
- In Y-Direction = 4 bay of 4m

III. Material property

- Grade of concrete = M25
- Grade of steel = Fe415
- Density of concrete = 25KN/m^3
- Density of brick work = 20KN/m^3

IV. Section property

- Beam size = 300mm X 450mm
- Column size = 500mm X 500mm
- Slab thickness = 200mm
- Wall thickness = 230mm

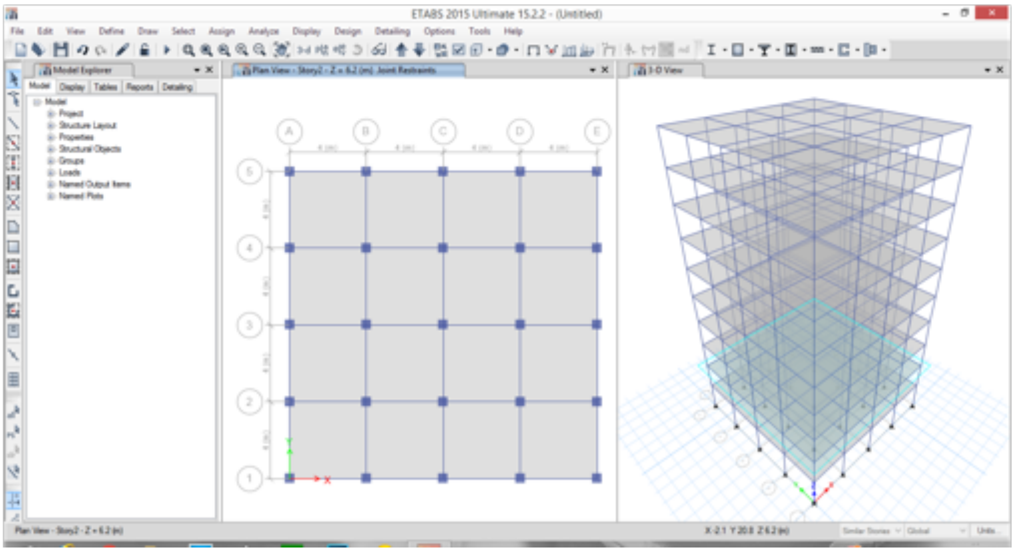
V. Load consideration

1) Gravity load
    - Dead load = column, beam, slab
    - Live load= 3KN/m^2

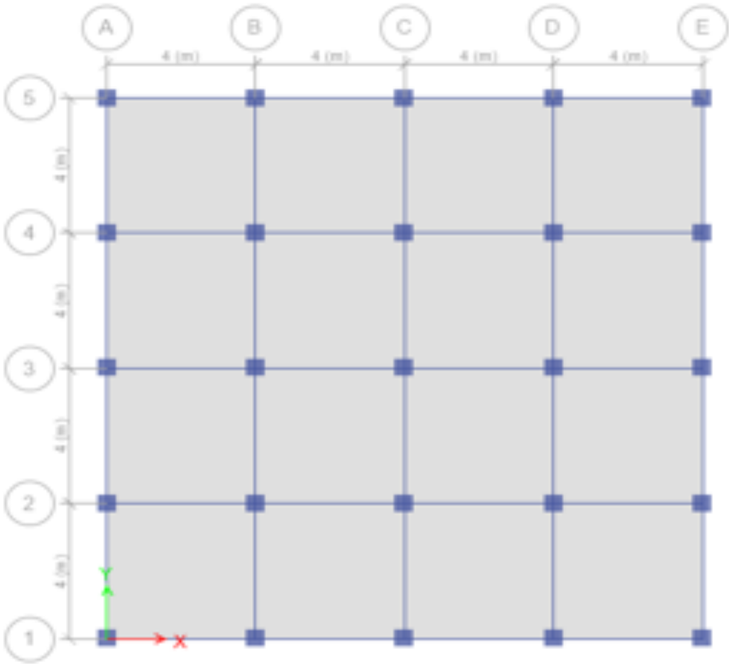
- Floor finish = 1KN/m^2

2) Lateral Load of Response Spectrum Analysis
    - Soil Profile type = Medium
    - Seismic Zone Factor = Zone 5
    - Response Reduction Factor = 5.0
    - Importance Factor = 1.0
    - Damping = 5.0

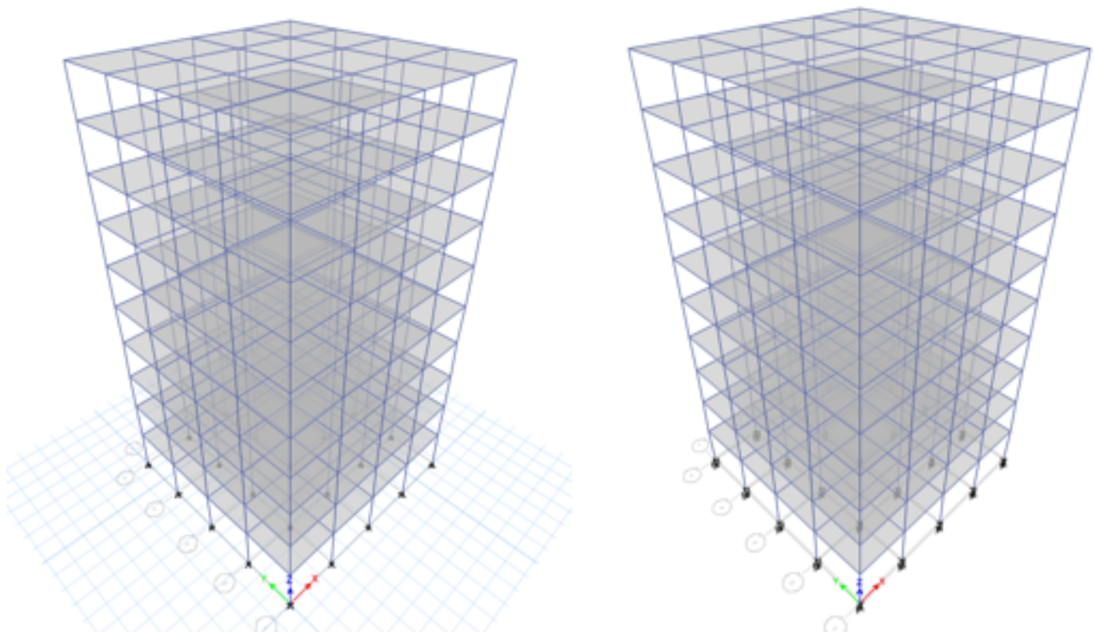
3) Characteristics of Lead Rubber Bearing
    Isolators are provided above every footing at 0.266m above base level. Properties of LRB are mentioned below :
    - Vertical stiffness (linear) = 771200KN/m
    - Horizontal stiffness (linear) = 1103.7KN/m
    - Horizontal stiffness (Nonlinear) = 11037 KN/m



(DESIGN WINDOW OF ETABS)



(PLAN OF ETABS MODEL)



(3D STRUCTURAL VIEW OF FIXED BASE AND ISOLATED BASE BUILDING)

5) ESTIMATION OF STEEL DIFFERENCE

- **Column steel (isolated base)**
  As we see in the designed output that the column steels of both the models are different. So, we will be calculating the required steel.

1) Vertical bars

COLUMN NOTATION	NO. OF COLUMNS	LENGTH OF BAR	NO OF BARS	DIAMETER OF BAR	WEIGHT OF BAR
CC1	12	33.84	12	16	7689.53
CC2	4	27.84	12	16	2108.7
	4	6	12	20	710.2
CC3	4	7.12	12	28	1650.7
	4	7.6	12	20	897.4
	4	20.56	12	16	1558.28
CC4	4	7.12	12	28	1650.7
	4	7.76	12	22	1109.99
	4	20.56	12	16	1558.28
CC5	1	7.28	12	32	551.24
	1	6.88	12	22	246.02
	1	20.56	12	16	39.28
				TOTAL STEEL =	**19770.32**

(VERTICAL REINFORCEMENT IN ISOLATED BASE BUILDING)

2) Stirrups

COLUMN NOTATION	NO OF COLUMN	LENGTH OF BAR	NO OF STIRRUPS	DIAMETER OF BAR	WEIGHT
CC1	12	2.24	340	10	5638.88
CC2	4	2.24	340	10	1879.62
CC3	4	2.24	344	10	1901.74
CC4	4	2.24	338	10	1868.57
CC5	1	2.24	338	10	467.1
				TOTAL STEEL=	11755.91

(STIRUPS IN ISOLATED BASE BUILDING)

Hence the total weight of steel required for column of isolated base is **31526.23** Kg.

- **Column steel (fixed base)**

1) Vertical bar

COLUMN NOTATION	NO. OF COLUMNS	LENGTH OF BAR	NO OF BARS	DIAMETER OF BAR	WEIGHT OF BAR
CC1	4	4	22	25	1358.72
	4	30.84	12	16	2338.9
CC2	4	4.04	22	25	1372.3
	4	7.6	12	20	901.05
	4	24.2	12	16	917.66
CC3	2	4.12	18	28	717.86
	2	7.6	12	20	450.52
	2	24.2	12	16	917.66
CC4	4	4	22	25	1358.72
	4	7.44	12	18	714.24
	4	24.2	12	16	1835.32
CC5	4	4.28	12	32	1298.38
	4	7.76	12	22	1113.71
	4	24.2	12	16	1835.32
CC6	4	4.28	12	32	1298.38
	4	8	12	25	1482.24
	4	24.2	12	16	1835.32
CC7	2	4	22	25	679.36
	2	7.6	12	20	450.52
	2	24.2	12	16	917.66
CC8	1	4.28	12	32	324.59
	1	8.68	12	28	248.06
	1	7.44	12	18	102.72
	1	14.56	12	16	81.14
				TOTAL=	**24550.35**

(VERTICAL REINFORCEMENT IN FIXED BASE BUILDING)

2) Stirrups

COLUMN NOTATION	NO OF COLUMN	LENGTH OF BAR	NO OF STIRRUPS	DIAMETER OF BAR	WEIGHT
CC1	4	2.24	345	10	1904.17
CC2	4	2.24	345	10	1904.17
CC3	2	2.24	345	10	952.08
CC4	4	2.24	345	10	1904.17
CC5	4	2.24	345	10	1904.17
CC6	4	2.24	345	10	1904.17
CC7	2	2.24	345	10	952.08
CC8	1	2.24	331	10	476.04
				TOTAL=	**11901.05**

(STIRPUS IN FIXED BASE BUILDING)

Hence the total weight of steel required for column of fixed base is **36451.4** Kg

- **Beam steel**

There is no difference between beam reinforcement in fixed base model and isolated base model

- **Reinforcement steel difference**

  The steel difference is as follows:

  % difference = $\frac{\textbf{\textit{steel in fixed base}} - \textbf{\textit{steel in isolated base}}}{\textbf{\textit{steel in fixed base}}} \times \mathbf{100}$

  % difference = $\frac{\mathbf{36451.4 - 31526.33}}{\mathbf{36451.4}} \times \mathbf{100}$

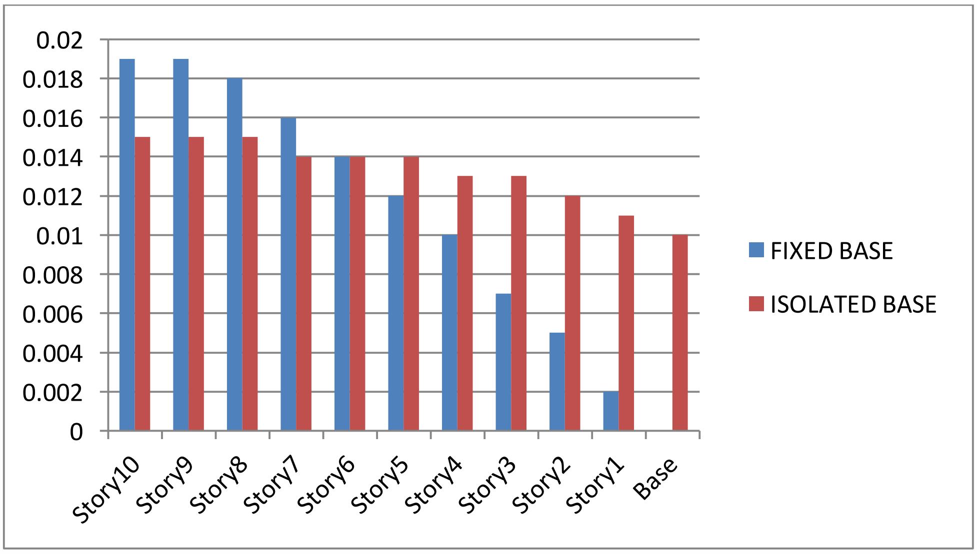
  % difference = 13.51

  Cost of steel is decreased be 13.51% to make it earthquake resistant.

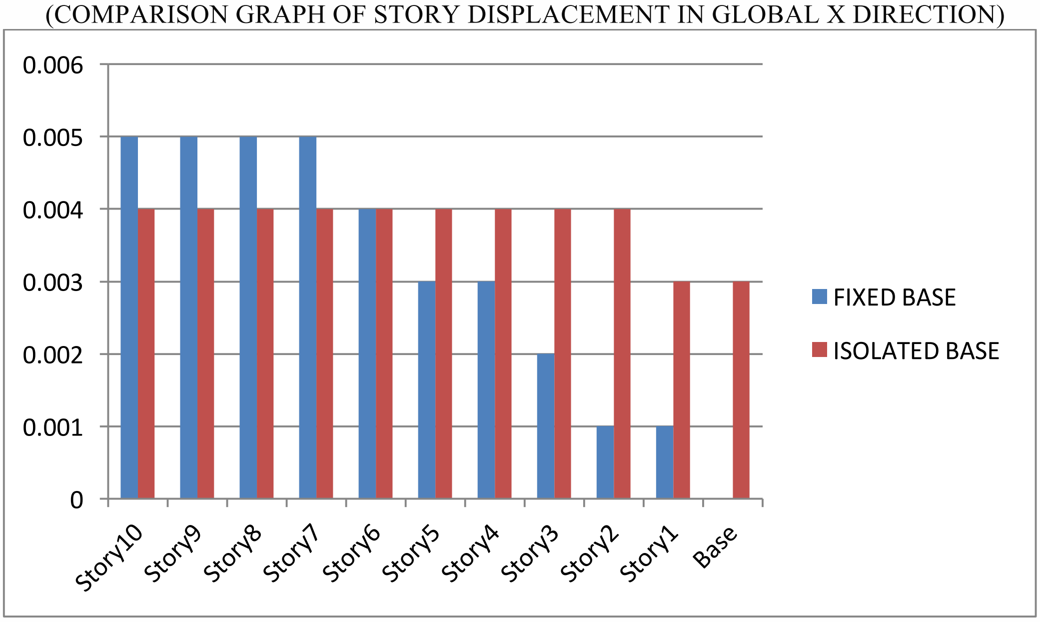
6) CONCLUSION

- Fixed base model base isolated model by providing lead rubber bearing these two models were analyzed by response spectrum analysis from these building models following conclusions can be made

  a. Modal displacements are increased in every story after providing LRB which is important to make a structure flexible during earthquake.

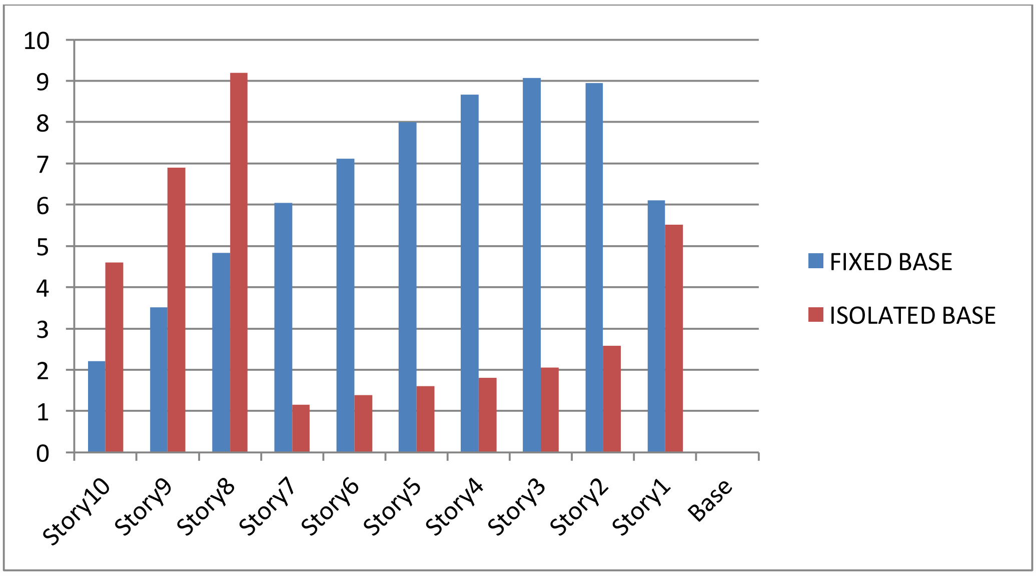


(COMPARISON GRAPH OF STORY DISPLACEMENT IN GLOBAL X DIRECTION)

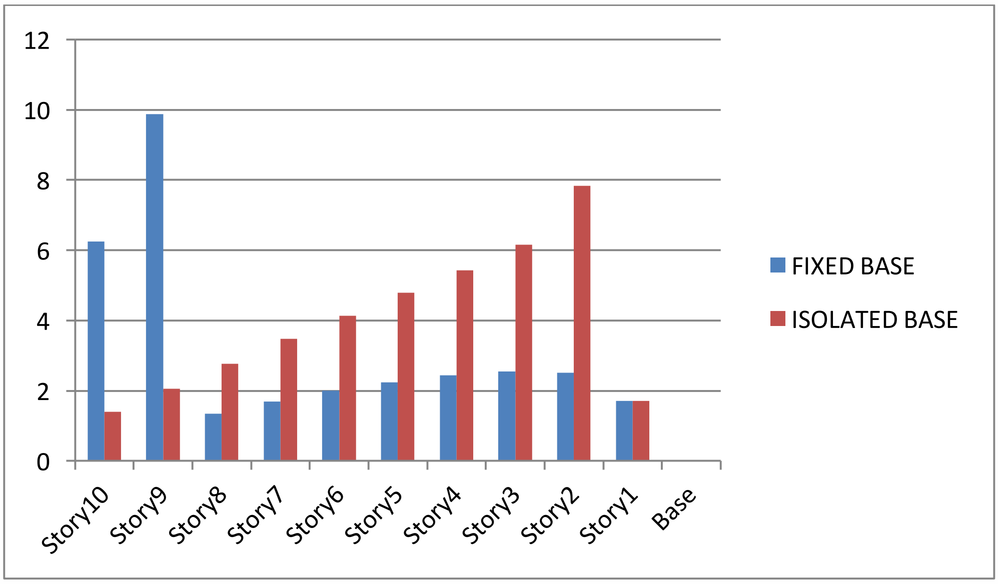


(COMPARISON GRAPH OF STORY DISPLACEMENT IN GLOBAL Y DIRECTION)

  b. Story drift are reduced in higher stories which makes structure safe against earthquake.

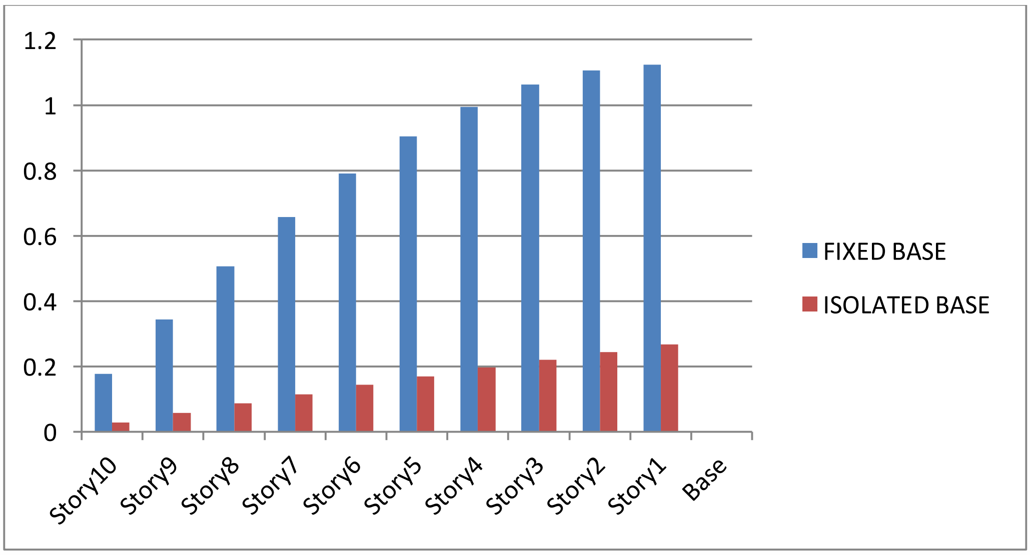


(COMPARISON GRAPH OF STORY DRIFT IN GLOBAL X DIRECTION)

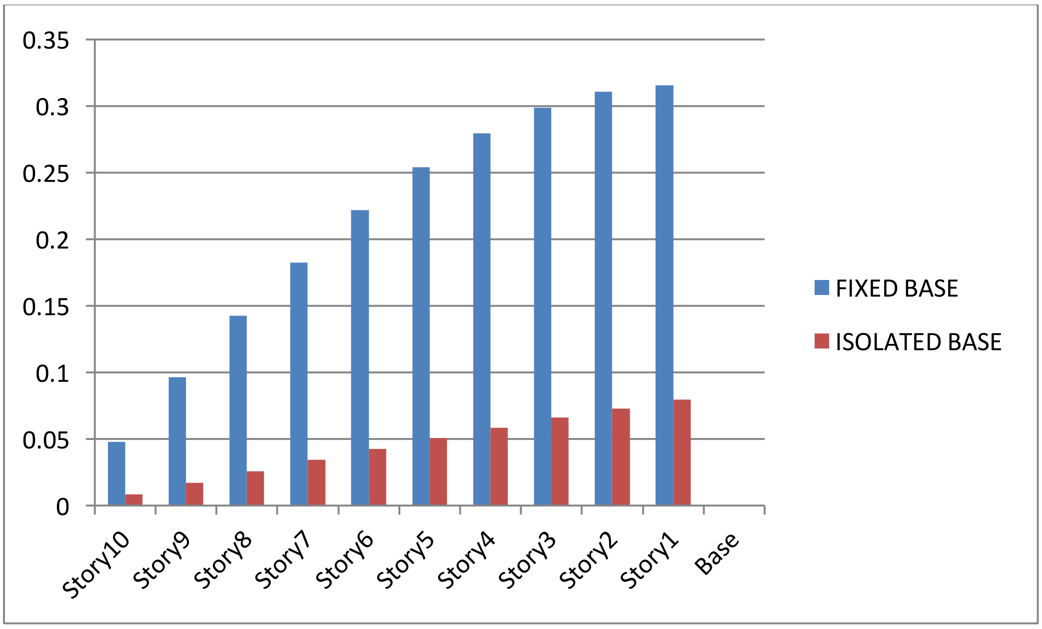


(COMPARISON GRAPH OF STORY DRIFT IN GLOBAL Y DIRECTION)

c. Story shear reduced after the lead rubber bearing (LRB) is provided as base isolation system which reduces the seismic effect on building.



(COMPARISON GRAPH OF STORY SHEAR IN GLOBAL X DIRECTION)



(COMPARISON GRAPH OF STORY SHEAR IN GLOBAL Y DIRECTION)

d. Steel in beam and slab of building remains same.
e. There is change only in the column reinforcement of the structure.
f. The cost of steel is reduced by 13.51% in columns to make it earthquake resistant.
g. 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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