Design of Lead Rubber Bearing Base Isolator system for High Rise Structure

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Abstract—The main objective of project is to protect buildings by earthquake resistant structure. While no structure can be entirely immune to damage from earthquakes, the goal of earthquake resistant construction is to erect structures that fare better during Seismic activity than their conventional counterparts. Damper systems are designed and manufactured to protect integrities and structural damages and to prevent injuries. There are many techniques to make seismic resistant structure. The base isolation technique is used in this project to resist against earthquake. Lead Rubber Bearing is a new type earthquake resistance rubber bearing, formed by inserting lead core into ordinary laminated rubber bearing, vertical supporting, and horizontal displacement and hysteric damping are combined in single unit together.

Index Terms—Base isolator, Lead Rubber Bearing, High rise structure, Horizontal and Vertical Stiffness

1 INTRODUCTION

Traditional seismic design of buildings is founded on structural ductility and redundancy. Forces induced by severe earthquakes are reduced as a function of the energy dissipation capacity at the structural components and their connections.

Base isolation systems partially uncouple a structure from the seismic ground motion by means of specially designed, replaceable, devices inserted between the structure and its foundation. It illustrates a conventional P+10 storey building and a protected base isolated one. The conventional building reduces dynamic forces by plasticity of the structural and non-structural components. In order to understand the performance of the building under seismic effect and the effect of lateral loads on a structure, it is necessary to evaluate the time period of a structure. It is necessary to determine the significance of the time period before evaluating the time period of a structure. Time period plays an important role in estimating the lateral loads and hence contributes to the seismic assessment of a structure. Time period depends on mass and stiffness. Based on the time period which is purely dependent on stiffness and mass, the behavior of building under lateral loads can be evaluated. It is difficult to determine the exact time period. For the design of earthquake resistant structures which seem to be safe and economical, the determination of time period is necessary. In this project an attempt is done to understand the various parameters which affect the time period of a building. Hence a parametric study is done on time period of a structure as per the codal provisions. IS code (IS 1893(part I):2016) is referred for the parametric study. The model is prepared and analyzed using ETABS software considering various parameters in the model. The value obtained for time period as per the code and as per the software is compared.

1.1 Base Isolation system

In base isolation technology during earthquake, separating the superstructure or reducing the lateral movements of building superstructure from the movement of ground or foundation.

The bearings of base isolation are designed in such a way that they are stiff vertically and flexible horizontally to allow for the difference in lateral movement while still supporting the superstructure. 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.

1.2 Lead Rubber Bearing System:-

Lead rubber bearing (LRB) was firstly invented by Williamson in 1975. It was found in Newzeland. Lead rubber bearing is applied to building and bridge constructions, is a practical and cost-effective choice for seismic isolation. It is composed of laminated elastomeric bearing pad, top and bottom sealing & connecting plates and lead plug inserted.

1.3 components of Lead Rubber Bearing System

LRB has 4 main Components which are listed below

A) Upper and Bottom sealing plate :-

They transfer loading and constraint deformation of lead core. These plates are connected to base and column

These plates are connected by anchorage bolting

Plates having circular cutout at center for lead ore.

B) Lead plug:

Lead metal has several useful mechanical properties, including high density, low melting point, ductility, and relative inertness. Lead's high density and resistance to corrosion have been exploited in a number of related applications. It is used as ballast in sailboat keels; its density allows it to take up a small volume and minimize water resistance, thus counterbalancing the heeling effect of wind on the sails. It dissipate energy and decrease displacement.

C) Steel reinforcing plates: It is reinforced elastomeric bearings, is made of multi-layer rubber and reinforced with steel plate (also known as shim plates) through sulfureting and adhesion. It has sufficient vertical rigidity which can reliably transfer the concentrated down-loads and impact loads of the superstructure to both ends. Rubber plates are alternately placed and these plates are separated by
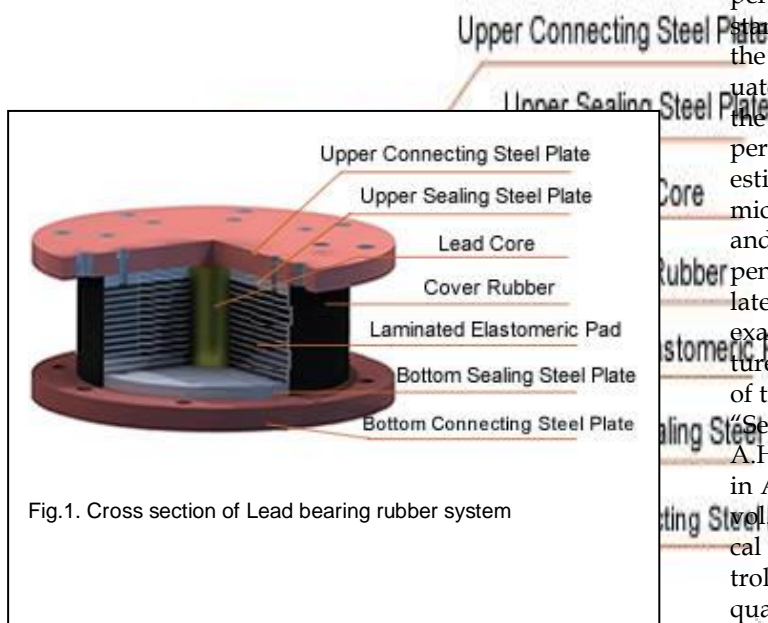

Fig.1. Cross section of Lead bearing rubber system

2. Objective Study

In the present study, the work includes the analysis of a P+10 storey reinforced concrete plan geometric irregular and vertical geometric irregular buildings in accordance with IS1893-2002,UBC provisions; one with fixed base and other with base isolated.

The objectives of the study are as follows;

➢ The main objective of project is to design lead rubber bearing for high rise structure.

➢ Making two dynamic models: one is for regular with base foundation and one is with lead rubber bearing on ETBS 19.1.0 software.

➢ Compare response mode time period between two models on software

3 LITERATURE SURVEY

"On the effect of seismic base isolation on seismic design requirements of RC structures" on this topic was researched by Mahdi Ghasemi et.al. was published on Elsevier structure in 28(2020). According to the basic concept of seismic isolation, the base-isolated structures must remain elastic during an earthquake. On the one hand, the existing technical documentation and codes strongly noted that the superstructure of isolated buildings should be designed the same as a fixed base structure. The only difference is the isolator. So, its period is higher, and consequently the applied acceleration is lower. One of the criteria for designing fixed-base structures is a seismic design and especially compact transverse rebars for beams and columns near the support. In the present study, 12 structures of 8 to 24 stories were designed in both fixed and isolated forms. Having these curves, the structures were pushover analyzed in three sway conditions "ordinary", "intermediate" and "special". The results also showed that, unlike fixed-base structures, the response modification factor (Ru) of the isolated structures was not affected by the seismic design level of beams and columns.

Laril Lawline Cutinha et.al had studied on "STUDY ON TIME PERIOD AS PER IS CODE USING ETABS SOFTWARE." This research study paper is published in science direct journal in 2020. They had studied about seismic analysis and their time period calculation using ETABS software. In order to understand the performance of the building under seismic effect and the effect of lateral loads on a structure, it is necessary to evaluate the time period of a structure. It is necessary to determine the significance of the time period before evaluating the time period of a structure. Time period plays an important role in estimating the lateral loads and hence contributes to the seismic assessment of a structure. Time period depends on mass and stiffness. Based on the time period which is purely dependent on stiffness and mass, the behavior of building under lateral loads can be evaluated. It is difficult to determine the exact time period. For the design of earthquake resistant structures which seem to be safe and economical, the determination of time period is necessary

"Seismic Analysis of Base Isolated Buildings" is studied by A.H,Barbat et.al. Their study and research paper is published in Archives of Computational Methods in engineering journal vol.4,2,153 (2021). This paper presents a survey of the numerical simulation of base isolation systems for the vibration control of buildings and their equipment, primarily against earthquakes. Base isolation has received much attention in the recent twenty years and many buildings have been protected using this technology. The article focusses mainly on the different numerical methods used in the analysis of base isolated buildings. The conventional form of solving the equations of motion governing the seismic response of building structures with nonlinear base isolation consists of using monolithic step by step integration methods

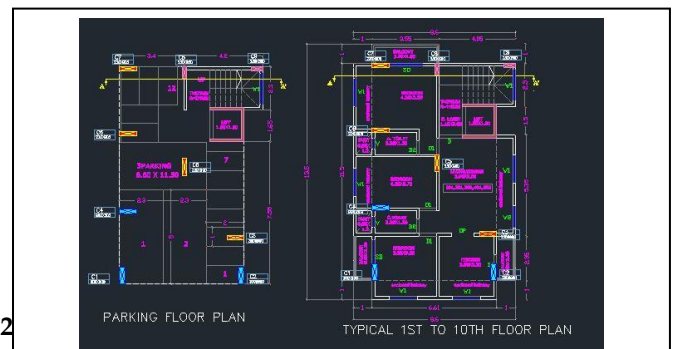## 4 METHODOLOGY

4.1. Modeling

Fig. 2. Working Plan in Autocad.

1. Software used for analysis is ETABS v 9.7.1
2. Measurements are in Kn-m
3. Code Provisions as per
   - IS 456-2000
   - IS 875-1987(PART 1,2,3,)
   - IS 1893- PART 1
   - UBC 1997
4. Types of analysis performed are response spectrum analysis and time history analysis

4.3. Building details:-
- Location of site:- Ahmednagar
- Plan dimensions :- 8.5m X 13.5m
- Total number of Storeys :- 11 (Parking+10)
- Type of building :- Residential
- Structure type :- plan regular type
- Height of each storey:- 3.15m
- Total height of structure:- (3.15X11+2.55)=37.2m
- Material Properties
- Grade of concrete: - M25
- Grade of steel: - FE500
- All wall thickness:- 150 mm
- Interior beam sizes:- 230mm X 530mm
- Exterior beam sizes:- 230mm X 530mm
- Slab thickness:- 150mm

4.4. Gravity loads:-
Dead load (slab) = 25X0.15X13.5X8.5
　　　　　　　　= 430KN (3.75KN/M2)
Live load　　　　= 2 KN/M2
Floor finish load = 1.5 KN/M2
Beam load　　　= 150 KN/M
Wall load　　　　= 20X0.15X2.7=7.9 KN/M
Parapet load　　= 20X0.15X1.2= 3.6 KN/M

Calculation of various design parameters

- Zone factor:-
  For Ahmednagar zone III (As per IS 1893:2002) (Clause -6.4.2)
  $Z = 0.16$
- Importance factor
  Building is residential building type so as per (As per IS 1893:2002) (Clause -6.4.2)
  $I = 1$
- Response reduction factor
  Building s special RC moment resisting frame
  $R=5$ (As per IS 1893:2002) (Table-7)

- Calculation of time period
  $T_{ax} = 0.09h/d^{0.5}$
  　　$= 0.09X37.2/(8.5)^{0.5}$
  　　$= 1.15$ sec
  $T_{ay} = 0.09h/d^{0.5}$
  　　$= 0.09X37.2/(13.5)^{0.5}$
  　　$= 0.92$ sec
- Average acceleration coefficient
  For Hard Soil
  $Sa/g = 1/T$ ………(0.4<T<4)
  　　　$= 1/1.15$
  　　　$= 0.87$

Damping percentage = 5%
Factor =1.00

$Sa/g=0.87$

- Calculation of horizontal seismic coefficient
  $A_h = Z \times I \times Sa / (2 \times R \times g)$
  　　$= 0.16X1X0.87/(2X5)$
  　　$= 0.014$
  Total load on structure = 32565 KN
  Base shear = V_b = 32565 X 0.014
  　　　　　　= 455.9 KN

4.5. Design of LRB
Seismic Zone Factor (Z) – Zone 3
Soil Profile Type – hard
Seismic Coefficient Ca - 0.36
Seismic Coefficient Cv (CVD) - 0.54
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.
Maximum compression load on column = 4250 KN
Calculate lead rubber bearing structure maximum load =4250 KN
Size of column = 300 mm X 900 mm
By applying various loading combinations, static period is Increased on software and for safety precautionary take designed time period is 2 sec
Design time period = 2 sec

Steps are as follows
1. Calculate design displacement :-
   Assume Design Time Period T_D=2 sec
   $$D_D = \frac{g}{4\pi^2} \times \frac{\bar{C}_{VD}T_D}{B_D}$$
   All values are mentioned above and put in formula we get
   D_D = 0.268 m
2. Effective stiffness (K_{eff})
   $$K_{eff} = \frac{W}{g} \times \left(\frac{2\pi}{T_D}\right)^2$$
   $= (4250/9.81) \times (2\pi/2)^2$
   $= 4275.83$ KN/M
3. Energy dissipated per energy cycle
   $W_D = 2\pi \times K_{eff} \times D_D^2 \times \beta^2$
   　　$= 2 \times 3.14 \times 4275.83 \times 0.268 \times 0.05$
   　　$= 359.82$ KN-M
4. Force at design displacement
   $Q = W_D/4D_D$
   　$= 359.82/(4 \times 0.268)$
   　$= 335.66$ KN
5. Stiffness in rubber
   $K_2 = K_{eff} - (Q/D_D)$
   　$= 4275.83 - (335.66/0.268)$
   　$= 3023.36$ KN/M
6. Yield displacement (D_γ)
   $D_\gamma = Q/(K_1-K_2)$
   As we have $K_1 = 10K_2$
   　$= 335.66/(9 \times 3023.36)$
   　$= 0.0123$ m
7. Recalculation of Q to Q_R
   $Q_R = W_D/4(D_D-D_\gamma)$
   　$= 359.82 / 4(0.268-0.0123)$
   　$= 351.80$ KN
8. Calculation of area and diameter of lead plug

Yield strength of lead is around 10 MPa
The area of lead plug needed
$A_{PB} = Q_R/10 \times 10^3$
     $= 351.80/10^4$
$\Pi \times d^2/4 = 0.0351$
$d = 211.4$ mm

9. Revising rubber stiffness K_{eff} to $K_{eff(R)}$ (after revising Q to Q_R)
$K_{eff(R)} = K_{eff} - Q_R/D_D$
     $= 4275.83 - 351.80/0.268$
     $= 2963.15$ KN/M
Total thickness of rubber layer
$t_\gamma = D_D/\gamma$
Where $\gamma = 100\%$ (maximum shear strain of rubber)
     $= 0.268/1$
     $= 0.268$ m

10. Area of bearing
$A_{LRB} = K_{eff(R)} \times t_\gamma / G$
     $= 2963.15 \times 0.268 / (0.7 \times 1000)$
     $= 1.15$ M^2.
Where shear modulus is 0.7 MPa
Diameter of bearing
     $= 1210$ mm

11. Shape Factor
$S = (1/2.4) \times (f_v/f_H)$
Where, f_v is vertical frequency
f_H is horizontal frequency
$f_H = \frac{1}{2} = 0.5 H_Z$
$f_v = 10$ Hz
$S = 1 \times 10 / (2.4 \times 0.5)$
     $= 8.33$
Also we have,
$t = \Phi_{LRB}/4S$
     $= 1210 / (4 \times 8.336)$
     $= 36.31$ mm
Number of rubber layers $= t_\gamma/t$
     $= 0.268/0.0363$
     $= 7.4$
Provide 40 mm thick 8 rubber layers

12. Dimensions of lead rubber bearing
Let thickness of shim plates = 2.8 mm
No. of shim plates = (8-1) = 7
End plate thickness varies between 19.05 mm to 38.1 mm
Adopt thickness of end plate as 25 mm
Total height of LRB = (8 $\times$ 40) + (7 $\times$ 2.8) + (2 $\times$ 25)
     $= 389.6$ mm
     $= 0.389$ m

Diameter of rubber layer
$\Phi = N \times t$
     $= 8 \times 40$
     $= 0.32$ M
Area of rubber layer
$A = \pi \times \Phi^2 / 4$
     $= 0.0803$ M^2

13. Compression Modulus Ec
$E_c = 6GS2(1-(6GS^2/K))$
Where, K = bulk modulus = 2000 MPa
G = shear modulus = 0.7 MPa
$E_c = 248.96 \times 10^3$ KN/M^2

Horizontal stiffness
$K_H = G \times A_{LRB}/t\gamma$
     $= 0.7 \times 10^3 \times 1.15 / 0.268$
     $= 3003.72$ KN/M
Vertical stiffness
$K_v = E_c \times A_{LRB}/t\gamma$
     $= 248.96 \times 10^3 \times 1.15 / 0.268$
     $= 1068.29 \times 10^3$ KN/M
Size of End plate = 450 mm X 1200 mm X 25 mm

Placing of LRB

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

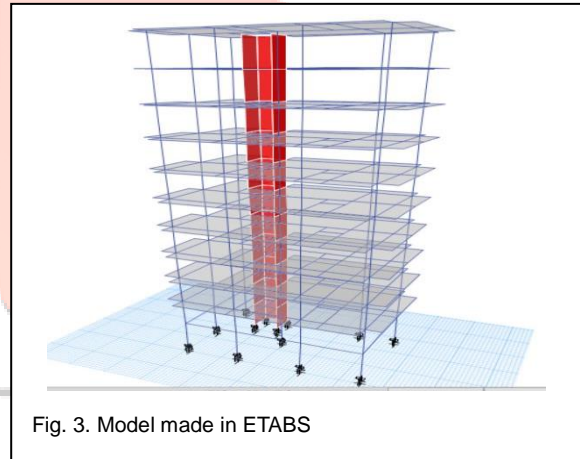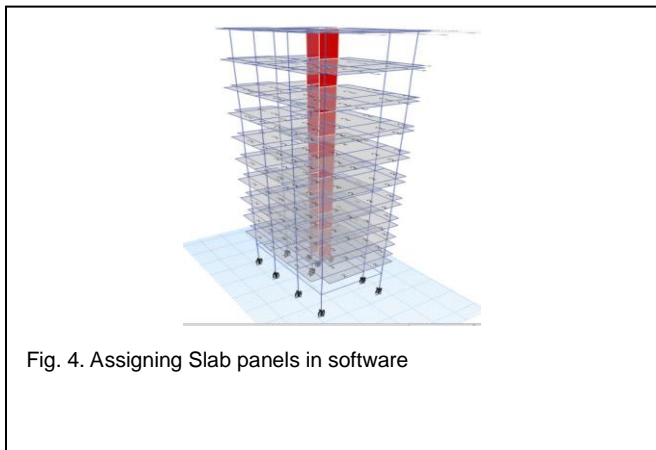| Property type	Response Spectrum Analysis
Effective stiffness $K_{eff(R)}$	2693.15 KN/M
Horizontal Stiffness K_H	3003.72 KN/M
Vertical Stiffness KV	1068.29 MN/M
Yield strength QR	351.80 KN
Post yield stiffness ratio	0.1

Fig. 3. Model made in ETABS

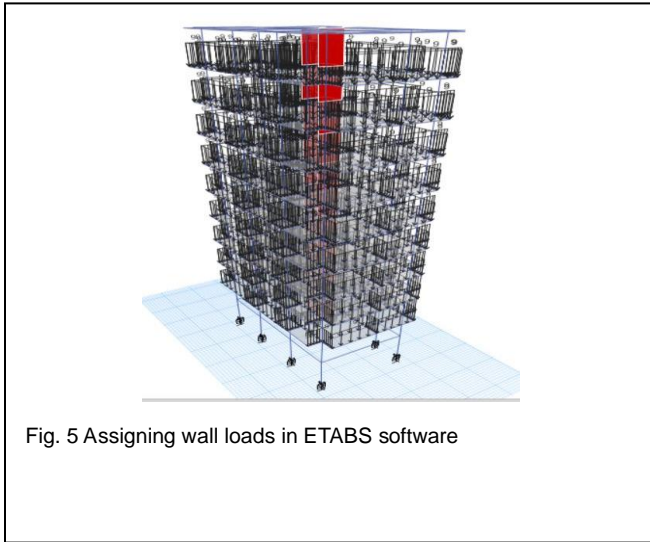Fig. 4. Assigning Slab panels in software

Fig. 5 Assigning wall loads in ETABS software

The above figures indicate loading applied to the stories of the building. The major loads considered are wall load and slab load. The major displacement and moment are caused due to this load. The analysis did by the software have generated some images as shown below.

5 SOFTWARE OUTCOME

As loading is applied there will some shear force generated at the base . This shearer forces are result of loading from all the floors above and there individual floor load. The shear load generated by the software as shown below. There are loads pre calculated by the software according to pre-defined IS parameters.
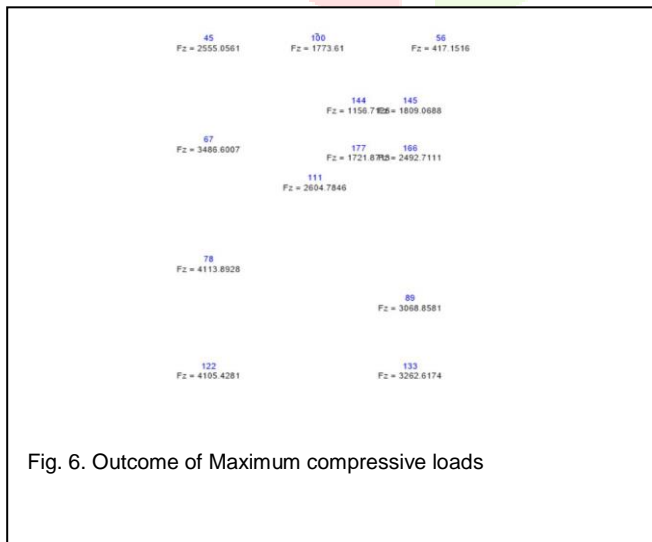

Fig. 6. Outcome of Maximum compressive loads

5 RESULTS

Analysis was done in ETBS 19.1.0 software. On the basis of analysis of data we designed for maximum compressive loaded column. And we get sizes of lead rubber bearing components are as follows

1. Size of upper and Bottom connecting plate:- 450mmX1200mmX25mm
2. Laminated rubber bearing plate:- We needed 40 mm thick 8 rubber plates and 2.8 mm thick 7 shim plate
3. Size of lead plug :- Diameter of lead plug: - 250 mm

And our second objective is to compare mode time period between 2 models using ETBS 19.1.0 software. In regular structure we get time period 2 sec but in LRB structure model we get response time period up to 3 sec. so it is increased by 50%

Table 1:- Mode period result of all models.

Mode Number	Mode direction	Type of model	
		Model 1	Model 2
Mode 1 in sec	Y direction	1.9	2.9
Mode 2 in sec	X direction	2	3
Mode 3 in sec	Torsion	2.1	3.1

From above figure the outcome we can declare is that we have increased the time by 50%

6 CONCLUSION

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

LRB is designed and their sizes of all components are found

By using lead rubber base isolation mode time period is increase by 50%

Structure made more earthquake resistant than conventional practice

LRB is provided as base isolation system it increases the structure stability against earthquake and reduces reinforcement.

correctly sized will be returned to the author for reformatting.

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