COMPARATIVE STUDY ON DYNAMIC ANALYSIS OF MEDIUM AND HIGH RISE RC STRUCTURE WITH AND WITHOUT BASE ISOLATION

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Abstract- *The seismic isolation system is mounted beneath the superstructure and is referred as 'Base Isolation'. The main aim of using Base isolation is to separating ("isolating") the structure from the ground to reduce the inertia forces introduced in the structure due to earthquake and lateral forces of an earthquake. Here lead rubber bearing base isolation which is designed to take the weight of the building and let the foundations move sideways during an earthquake. In the paper a parametric study on Reinforced Concrete (RC) building medium rise(G+4 storied frame structure) and high rise(G+14 storied frame structure) building with fixed and isolated base with lead rubber bearing (LRB) are carried out using time history analysis. To evaluate the seismic response of the buildings is performed using the computer program ETABS2015*

Keywords: **Base Isolation, Lead Rubber Bearing**

1. INTRODUCTION

1.1 BACKGROUND

For seismic design of building structures, the traditional method, *i.e.*, strengthening the stiffness, strength, and ductility of the structures, has been in common use for a long time. Therefore, the dimensions of structural members and the consumption of material are expected to be increased, which leads to higher cost of the buildings as well as larger seismic responses due to larger stiffness of the structures. Thus, the efficiency of the traditional method is constrained. To overcome these disadvantages associated with the traditional method, many vibration-control measures, called structural control, have been studied and remarkable advances in this respect have been made over recent years.

Structural Control is a diverse field of study. Structural Control is the one of the areas of current research aims to reduce structural vibrations during loading such as earthquakes and strong winds. In terms of different vibration absorption methods, structural control can be classified into active control, passive control, hybrid control, semi-active control and so on. The passive control is more studied and applied to the existing buildings than the others. Base isolation is a passive vibration control system that does not require any external power source for its operation and utilizes the motion of the structure to develop the control forces. Performance of base isolated buildings in different parts of the world during earthquakes in the recent past established that the base isolation technology is a viable alternative to conventional earthquake-resistant design of medium-rise buildings.

The application of this technology may keep the building to remain essentially elastic and thus ensure safety during large earthquakes. Since a base-isolated structure has fundamental frequency lower than both its fixed base frequency and the dominant frequencies of ground motion, the first mode of vibration of isolated structure involves deformation only in the isolation system whereas superstructure remains almost rigid. In this way, the isolation becomes an attractive approach where protection of expensive sensitive equipment's and internal non-structural components is needed. It was of interest to check the difference between the responses of a fixed-base building frame and the isolated-base building frame under seismic loading. This was the primary motivation of the present study.

1.2 IMPORTANCE OF PRESENT STUDY:

Civil Engineers are still unable to rigorously predict even in a probabilistic way the loads which structures may have to withstand during their useful life. All structures are subjected to vibration. Recent destructive earthquakes in California and Japan have shown how vulnerable our structures and societies remain to natural phenomena. The enormous losses inflicted by such catastrophes have motivated ever more stringent requirements on the performance of structural systems, in an effort to reduce the cost of repair and disruption. The cost and performance requirements for both buildings and equipment have motivated advances in the field of Structural Control, which deals with methodologies for the protection of high performance structural systems. The vibration isolator is a device that is designed to effectively isolate such structures from harmful vibrations.

1.3 VIBRATION CONTROL:

Vibration control is the mechanism to mitigate vibrations by reducing the mechanical interaction between the vibration source and the structure, equipment etc. to be protected. Structural control relies on stiffness (i.e. energy storage) and damping (i.e. energy absorption/dissipation) devices in a structure to control its response to undesirable excitations caused by winds and moderate earthquakes. This control has, in most cases, been achieved passively by means of bracing systems and shear walls, which do not require any additional external energy input. More recently, we have seen the emergence of more modem passive structural control systems. The tuned mass damper and base isolation systems are examples of such relatively modern passive systems.

1.4 BASE ISOLATION OF STRUCTURES

1.4.1 Concept of base isolation

Base isolation technology works by separating or reducing the lateral movement of a building's superstructure from the movement of the ground/foundation during an earthquake event. To allow for this difference in lateral movement while still supporting the weight of the superstructure, base isolation bearings are designed to be very flexible laterally while being stiff vertically. This base condition is in contrast to a typical fixed-base structure, in which the connections between the superstructure and its base/foundation are rigid and translation of the superstructure is resisted in all directions. The difference between these two base conditions is illustrated in (Fig 1) below. The ultimate purpose of a base isolation system is to reduce the seismic forces exerted on a building's superstructure. This reduction in seismic forces is achieved in part by reducing the superstructure's spectral accelerations. These accelerations are reduced both by increasing the effective fundamental period of the isolated structure and through damping caused by energy dissipated within the isolation bearings.

Seismic base isolation of structures such as multi-storey buildings, nuclear reactors, bridges, and liquid storage tanks are designed to preserve structural integrity and to prevent injury to the occupants and damage to the contents by reducing the earthquake induced forces and deformations in the super-structure. This is a type of passive vibration Control. The performance of these systems depends on two main characteristics:

1. The capacity of shifting the system fundamental frequency to a lower value, which is well remote from the frequency band of most common earthquake ground motions.
2. The energy dissipation of the isolator.

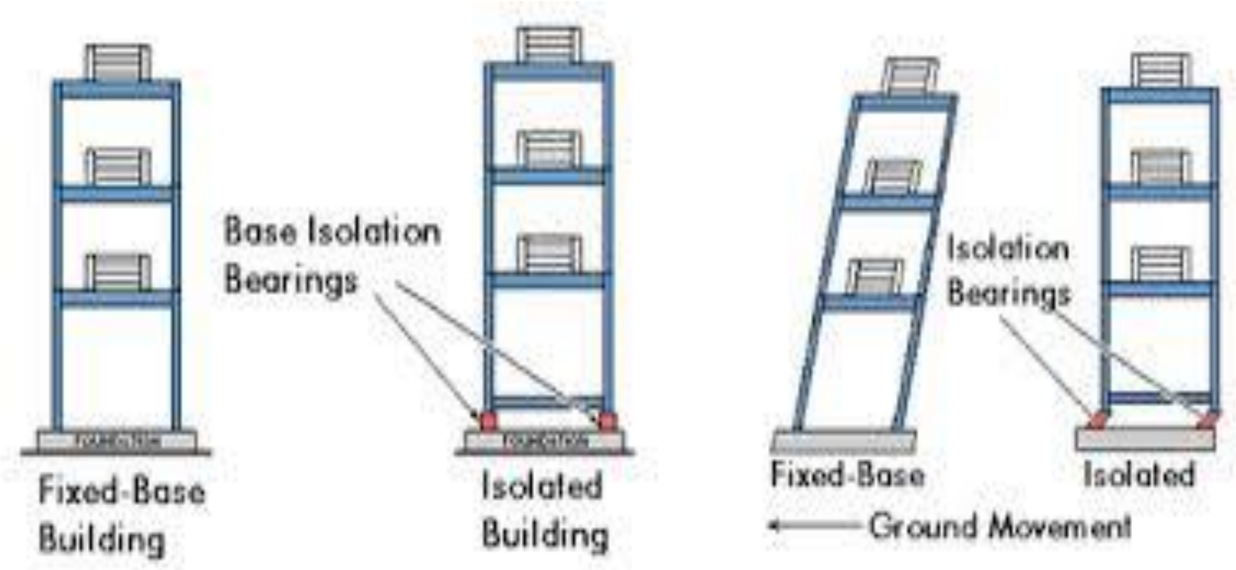


Fig 1.1 Difference between two base conditions

1.4.2 Types of Bearings:

Following types of bearings are available as per literature as per their materials:

1) Rubber bearing
2) Steel reinforced elastomeric
3) Roller bearing

4) Rocker bearing
5) Pot bearing
6) Disc bearing
7) Spherical and cylindrical bearing

Rubbers are further divided into four categories,

a) Rubber Bearing

b) Steel laminated rubber bearing (RB).

c) Lead rubber Bearing (LRB).

d) High damping rubber bearing (HDRB).

1.4.3 Lead rubber bearing (LRB):

Lead Rubber Bearing or LRB is one type of elastomeric bearing. This type of bearing consists of a lead core at center of the bearing and thin layers of steel plates and high damping rubber built in alternate layers. Horizontal stiffness of the bearing is controlled by the low shear modulus of elastomeric while steel plates and lead core provides high vertical stiffness as well as prevent bulging of rubber. The vertical stiffness of the bearing is several hundred times of the horizontal stiffness due to the presence of internal steel plates and lead core.

Multilayer construction rather than single layer rubber pads provides better vertical rigidity for supporting a building. With the help of LRB earthquake vibration is converted to low speed motion. As horizontal stiffness of the multi- layer rubber bearing is low, strong earthquake vibration is lightened and the oscillation period of the building is increased. Horizontal elasticity of LRB returns the building to its original position. In a LRB, elasticity mainly comes from restoring force of the rubber layers.

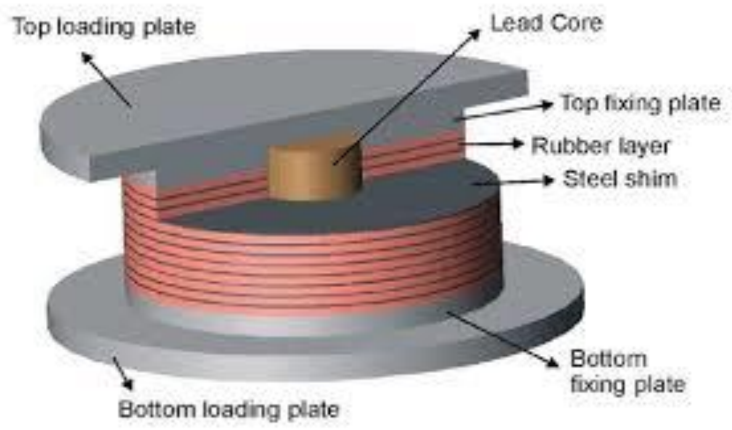


Fig 1.2 lead rubber bearing (LRB)

1.5 RESPONSE OF THE BUILDING UNDER EARTHQUAKE.

1.5.1 Building frequency and period:

The magnitude of Building response mainly accelerations depends primarily upon the frequencies of input ground motions and Buildings natural frequency. When these are equal or nearly equal to one another, the buildings response reaches a peak level. In some cases, this dynamic amplification level can increase the building acceleration to a value two times or more that of ground acceleration at the base of the building. Generally buildings with higher natural frequency and a short natural period tend to suffer higher accelerations and smaller displacement. Buildings with lower natural frequency and a long natural period tend to suffer lower accelerations and larger displacement. When the frequency content of the ground motion is around the building's natural frequency, it is said that the building and the ground motion are in resonance with one another. Resonance tend to increase or amplify the building response by which buildings suffer the greatest damage from ground motion at a frequency close to its own natural frequency.

1.5.2 Building stiffness:

Taller the building, longer the natural period and the building is more flexible than shorter building.

1.5.3 Ductility:

Ductility is the ability to undergo distortion or deformation without complete breakage or failure. In order to be earthquake resistant the building will possess enough ductility to withstand the size and type of earthquake it is likely to experience during its lifetime.

1.5.4 Damping:

All buildings possess some intrinsic damping. Damping is due to internal friction and adsorption of energy by buildings structural and non- structural components. Earthquake resistant design and construction employ added damping devices like shock absorbers to supplement artificially the intrinsic damping of a building.

1.6 INTRODUCTION ABOUT ETABS:

ETABS is the **Extended three – dimensional analysis of building systems**.

ETABS is a sophisticated, yet easy to use, special purpose analysis and design program Developed specifically for building systems. ETABS features an intuitive and powerful Graphical interface coupled with unmatched modeling, analytical, and design procedures, All integrated using a common database. Although quick and easy for simple structures, ETABS can also handle the largest and most complex building models, including a wide Range of geometrical nonlinear behaviors, making it the tool of choice for structural engineers in the building industry. The accuracy of analytical modeling of complex Wall Systems have always been of concern to the Structural Engineer. The computer models of

These systems are usually idealized as line elements instead of continuum elements. Single walls are modeled as cantilevers and walls with openings are modeled as pier and Spandrel systems. For simple systems, where lines of stiffness can be defined, these models can give a reasonable result.

However, it has always been recognized that continuum model based upon the finite element method is more appropriate and desirable. Nevertheless this option has been impractical for the Structural Engineer to use In practice primarily because such models have traditionally been costly to create, but more importantly, they do not produce information that is directly useable by the Structural Engineer.

However, new developments in ETABS using object based modeling of simple and complex wall systems, in an integrated single interface environment, has made it very practical for Structural Engineers to use finite element models routinely in their practice. Wall is a vertical load bearing member whose length Exceeds four times its thickness. Un-braced wall is designed to carry lateral loads (horizontal loads) in addition to vertical loads. Braced wall does not carry any lateral loads (horizontal loads).

All horizontal loads are carried by principal structural bracings or lateral supports. Reinforced wall contains at least the minimum quantities for reinforcement. Plain walls contain either no reinforcement or less than the minimum quantity of reinforcement. The wall which is investigated in this research is consisting of several separated blocks which are placed in such a way that they form an infill wall for IBS construction.

Recently the application of precast components in construction of many structures is accelerating due to its simplicity for fabrication and saving in time and labor force of many construction projects.IBS is a construction technique where components are manufactured in a controlled environment (on or off site), transported, positioned and assembled into a structure with minimal additional site works. For nearly30 years, ETABS has been recognized as the industry standard for Building Analysis and Design Software. Today, continuing in the same tradition, ETABS has evolved into a completely integrated building analysis and design environment. The system built around a physical object based graphical user interface, powered by targeted new special purpose algorithms for analysis and design, with interfaces for drafting and manufacturing, is redefining standards of integration, productivity and technical innovation.

The integrated model can include moment resisting frames, braced frames, staggered truss systems, frames with reduced beam sections or side plates, rigid and flexible floors, sloped roofs, ramps and parking structures, mezzanine floors, and multiple tower buildings and stepped diaphragm systems with complex concrete, composite or steel joist floor framing systems. Solutions to complex problems such a spaniel zone deformations, diaphragm shear stresses, and construction sequence loading are now at your fingertips. ETABS is the solution, whether you are designing a simple2D frame or performing a dynamic analysis of a complex high-rise that utilizes nonlinear dampers for understory Drift control.

1.7 SEISMIC ANALYSIS:

Seismic analysis is a subset of structural analysis and is the calculation of the response of a building (or non-building) structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment and retrofit (see structural engineering) in regions where earthquakes are prevalent.

As seen in the figure, a building has the potential to _wave 'back and forth during an earthquake (or even a severe wind storm). This is called the _fundamental mode', and is the lowest frequency of building response. Most buildings, however, have higher modes of response, which are uniquely activated during earthquakes. The figure just shows the second mode, but there are higher _shimmy'(abnormal vibration) modes. Nevertheless, the first and second modes tend to cause the most damage in most cases.

The earliest provisions for seismic resistance were the requirement to design for a lateral force equal to a proportion of the building weight (applied at each floor level).This approach was adopted in the appendix of the 1927 Uniform Building Code (UBC), which was used on the west coast of the USA. It later became clear that the dynamic properties of the structure affected the loads generated during an earthquake. In the Los Angeles County Building Code of 1943 a provision to vary the load based on the number of floor levels was adopted (based on research carried out at Caltech in collaboration with Stanford University and the U.S. Coast and Geodetic Survey, which started in 1937). The Concept of "response spectra" was developed in the 1930s, but it wasn't until 1952 that a Joint committee of the San Francisco Section of the ASCE and the Structural Engineers Association of Northern California (SEAONC) proposed using the building period (the Inverse of the frequency) to determine lateral forces.[1]

Earthquake engineering has developed a lot since the early days, and some of the more complex designs now use special earthquake protective elements either just in the foundation (base isolation) or distributed throughout the structure. Analyzing these types of structures requires specialized explicit finite element computer code, which divides time into very small slices and models the actual physics, much like common videogames often have "physics engines". Very large and complex buildings can be modeled in this way (such as the Osaka International Convention Center).

2. MODELLING:

2.1. MODELLING:

The modeling procedure of fixed base and base isolated building in ETABS2015 and design steps of isolators and linear static analysis using UBC 97 for isolated building has been carried out and seismic design procedure has been done using IS 1893:2002 (Part 1), for that the following data is used.

Models are symmetrical plan with medium rise structure (G+ 4 storied frame structures) and high rise structure (G+14 storied frame structure). For symmetrical structures 4 bays in x-direction 5 bays in y-direction. Plans applied base isolation.

- Group-1 Symmetrical plan with medium (G+4) and high (G+14) rise structure.
- Group-2 Lead rubber bearing isolators are applied to symmetrical plan of both medium and high rise structure.

3.1.1 RC structure details for (G+4) & (G+14):

General details of RC structure (G+4) with and without base isolation.

1. Grade of Concrete – M25, Steel Grade – Fe500
2. Floor to Floor height is 3m, Plinth height above GL is 0.5m
3. External wall thickness = 230mm, Internal wall thickness = 115mm,
4. Size of Columns = 300X450 mm, Size of Beams = 230*450mm
5. Live load on floor = 3 KN/m^2, Live load on Roof = 1.5 KN/m^2
6. Site located in Seismic zone 2, i.e. Z= 0.1
7. Building is resting on medium soil, Take importance factor as 1.
8. Building frame type – OMRF, Density of Concrete = 25 KN/m^3

General details of RC structure (G+14) with and without base isolation.

1. Grade of Concrete – M25, Steel Grade – Fe500
2. Floor to Floor height is 3m, Plinth height above GL is 0.5m
3. External wall thickness = 230mm, Internal wall thickness = 115mm,
4. Size of Columns = 450X650 mm, Size of Beams = 300*450mm
5. Live load on floor = 3 KN/m^2, Live load on Roof = 1.5 KN/m^2
6. Site located in Seismic zone 2, i.e. Z= 0.1
7. Building is resting on medium soil, Take importance factor as 1.
8. Building frame type – OMRF, Density of Concrete = 25 KN/m^3

2.1.2 Load Calculations for Both (G+4) & (G+14):

1. Dead Loads:

230mm thick wall load = 0.23x2.55x20 = 11.73Kn/m^2 = 12 Kn/m

115mm thick wall load = 0.115x2.55x20 = 5.865Kn/m^2 = 6 Kn/m

230mm thick parapet wall load = 0.23x1.0x20 = 4.6Kn/m

Floor Finish Load = 1Kn/m^2

Dead loads on staircase landing Beams (1^{st} & 3^{rd} Flights) = (4.75x3.71)/2 = 8.81 Kn/m

Dead loads on staircase landing Beams (2^{nd} Flight) = (4.75x5.00)/2 = 11.875 Kn/m

2. Live Loads (As Per IS 875 PART-2):

LL for floors (except Top Floor) = 3Kn/m^2

LL for Top Floor = 2Kn/m^2

LL for Staircase = 3Kn/m^2

Live loads on staircase landing Beams (1^{st} & 3^{rd} Flights) = (3.00x3.71)/2 = 5.565 Kn/m

Live loads on staircase landing Beams (2^{nd} Flight) = (3.00x5.00)/2 = 7.5 Kn/m

3. Seismic Loads (As Per IS 1893-2002(PART-1)):

Seismic Zone ZONE=II (HYDERABAD)

Zone Factor Z=0.10

Response Reduction Factor RF=3.0 (AS PER TABLE 7 OF CODE PG.23)

Importance Factor I=1.0 (AS PER TABLE 6 OF CODE PG.18)

Rock/Soil Sites Factor SS=2 (1 FOR ROCK,

2 FOR MEDIUM &

3 FOR LOOSE SOILS)

(AS PER TABLE 1 OF CODE PG.15)

Type of Structure. ST=1 (1 FOR R.C.C, 2 FOR STEEL)

Damping Ratio DM= 2% FOR STEEL, 5% FOR RCC..... 7.8.2.1

3. Wind Loads (As Per IS 875 PART-3):

FOR MEDIUM RISE PLAN (G+4):

Basic Wind Speed = 44 mt/sec (APPENDIX-A OF IS: 875(PART-III)-1987

Factor K1=1.0 TABLE.1 OF IS: 875(PART-III)-1987

Factor K2=0.94 TABLE.2 OF IS: 875(PART-III)-1987 TERRAIN CAT 3 CLASS B (HT=15M)

Factor K3=1.0 CL.5.3.3.1 OF IS: 875(PART-III)-1987

Therefore Design Wind Speed = 44 X 1.0 X 0.94 X 1.0

= 41.36

Design Wind Pressure = 0.6 X 41.36 X 41.36

= 1026.38

= 1.026 KN/Sq.mt

FOR HI RISE PLAN (G+14):

Basic Wind Speed = 44 mt/sec (APPENDIX-A OF IS: 875(PART-III)-1987

Factor K1=1.0 TABLE.1 OF IS: 875(PART-III)-1987

Factor K2=1.075 TABLE.2 OF IS: 875(PART-III)-1987 TERRAIN CAT 3 CLASS B (HT=45M)

Factor K3=1.0 CL.5.3.3.1 OF IS: 875(PART-III)-1987

Therefore Design Wind Speed = 44 X 1.0 X 1.075 X 1.0

= 47.3

Design Wind Pressure = 0.6 X 47. X 7.3

= 1342.37

= 1.342 KN/Sq.mt

2.1.3 Load Combinations (As Per IS 875 PART-5):

1. (1.5DL+1.5LL)

2. (1.5DL+1.5EL(X))

3. (1.5DL+1.5EL (-X))

4. (1.5DL+1.5EL(Y))

5. (1.5DL+1.5EL (-Y))

6. (1.2DL+1.2LL+1.2WL(X)

7. (1.2DL+1.2LL+1.2WL (-X)

8. (1.2DL+1.2LL+1.2WL(Y)

9. (1.2DL+1.2LL+1.2WL (-Y)

10. (1.5DL+1.5WL(X))

11. (1.5DL+1.5WL (-X))

12. (1.5DL+1.5WL(Y))

13. (1.5DL+1.5WL (-Y))

14. (1.2DL+1.2LL+1.2EL(X)

15. (1.2DL+1.2LL+1.2EL (-X)

16. (1.2DL+1.2LL+1.2EL(Y)

17. (1.2DL+1.2LL+1.2EL (-Y)

18. (0.9DL+1.5EL(X))

19. (0.9DL+1.5EL (-X))

20. (0.9DL+1.5EL(Y))

21. (0.9DL+1.5EL (-Y))

22. (0.9DL+1.5WL(X))

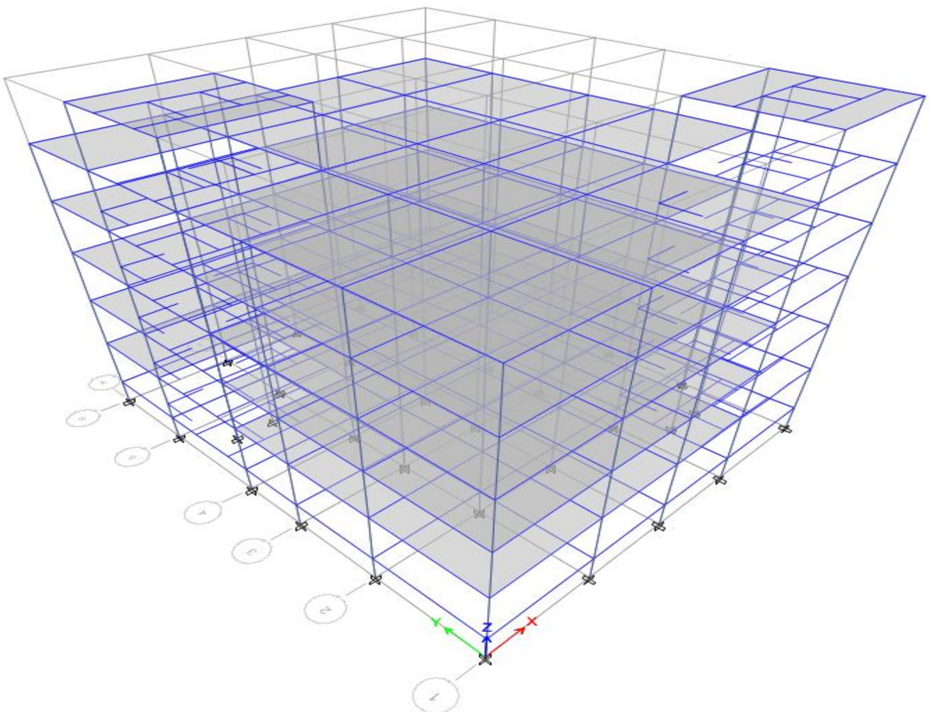
23. (0.9DL+1.5WL (-X))

24. (0.9DL+1.5WL(Y))

25. (0.9DL+1.5WL (-Y))

2.1.4 INPUT REPORT OF STRUCTURE FROM ETABS

ETABS® 2015
Integrated Building Design Software



Summary Report

Model File: G+4, Revision 0 11/3/2015

1 Structure Data

This chapter provides model geometry information, including items such as story levels, point coordinates, and element connectivity.

1.1 Story Data

Table 1.1 - Story Data

Name	Height mm	Elevation mm	Master Story	Similar To	Splice Story
HEADROOM	3000	19500	Yes	None	No
4TH FLOOR	3000	16500	Yes	None	No
3RD FLOOR	3000	13500	No	GROUND	No
2ND FLOOR	3000	10500	No	GROUND	No
1ST FLOOR	3000	7500	No	GROUND	No
GROUND	3000	4500	Yes	None	No
PLINTH	1500	1500	Yes	None	No
Base	0	0	No	None	No

2 Loads

This chapter provides loading information as applied to the model.

2.1 Load Patterns

Table 2.1 - Load Patterns

Name	Type	Self Weight Multiplier	Auto Load
Dead	Dead	1	
Live	Live	1	
WALL	Superimposed Dead	0	
PARAPET	Superimposed Dead	0	
FF	Superimposed Dead	0	
EQ +X	Seismic	0	IS1893 2002
EQ +Y	Seismic	0	IS1893 2002
SELF WEIGHT	Dead	1	
WL +X	Wind	0	Indian IS875:1987
WL -X	Wind	0	Indian IS875:1987
WL +Y	Wind	0	Indian IS875:1987
WL -Y	Wind	0	Indian IS875:1987

2.2 Load Cases

Table 2.2 - Load Cases - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
WALL	Linear Static
PARAPET	Linear Static
FF	Linear Static
EQ +X	Linear Static
EQ +Y	Linear Static
SELF WEIGHT	Linear Static
WL +X	Linear Static
WL -X	Linear Static
WL +Y	Linear Static
WL -Y	Linear Static

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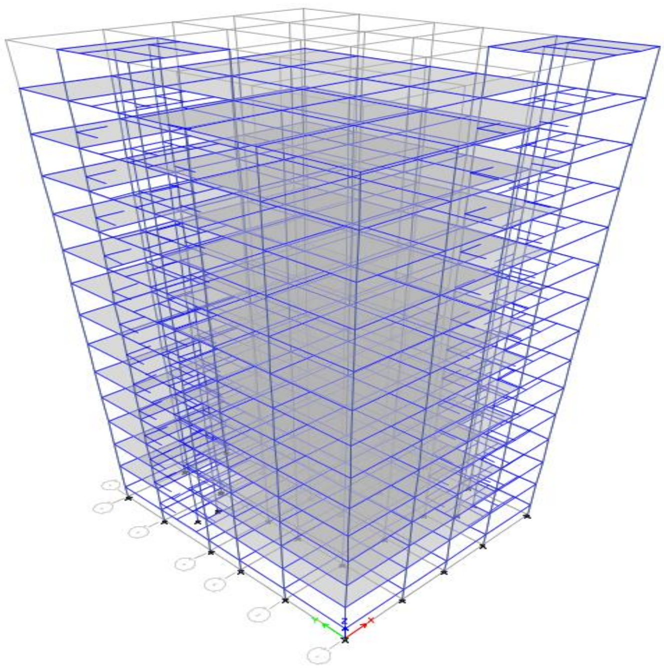


Name	Type

Summary Report

Model File: G+14, Revision 0
11/3/2015

1 Structure Data

This chapter provides model geometry information, including items such as story levels, point coordinates, and element connectivity.

1.1 Story Data

Table 1.1 - Story Data

Name	Height mm	Elevation mm	Master Story	Similar To	Splice Story
14	3000	43500	No	None	No
13	3000	40500	No	None	No
12	3000	37500	No	1	No
11	3000	34500	No	1	No
10	3000	31500	No	1	No
9	3000	28500	No	1	No
8	3000	25500	No	1	No
7	3000	22500	No	1	No
6	3000	19500	No	1	No
5	3000	16500	No	1	No
4	3000	13500	No	1	No
3	3000	10500	No	1	No
2	3000	7500	No	1	No
1	3000	4500	Yes	None	No
PLINTH	1500	1500	Yes	None	No
Base	0	0	No	None	No
14	3000	43500	No	None	No
13	3000	40500	No	None	No
12	3000	37500	No	1	No
11	3000	34500	No	1	No
10	3000	31500	No	1	No
9	3000	28500	No	1	No
8	3000	25500	No	1	No
7	3000	22500	No	1	No
6	3000	19500	No	1	No
5	3000	16500	No	1	No
4	3000	13500	No	1	No
3	3000	10500	No	1	No
2	3000	7500	No	1	No
1	3000	4500	Yes	None	No
PLINTH	1500	1500	Yes	None	No
Base	0	0	No	None	No

2 Loads

This chapter provides loading information as applied to the model.

2.1 Load Patterns

Table 2.1 - Load Patterns

Name	Type	Self Weight Multiplier	Auto Load
Dead	Dead	1	
Live	Live	0	
SELF WEIGHT	Dead	1	
WALL	Superimposed Dead	0	
PARAPET	Superimposed Dead	0	
FF	Superimposed Dead	0	
EQ+X	Seismic	0	IS1893 2002
EQ-X	Seismic	0	IS1893 2002
EQ+Y	Seismic	0	IS1893 2002
EQ-Y	Seismic	0	IS1893 2002
WL +X	Wind	0	Indian IS875:1987
WL -X	Wind	0	Indian IS875:1987
WL +Y	Wind	0	Indian IS875:1987
WL -Y	Wind	0	Indian IS875:1987

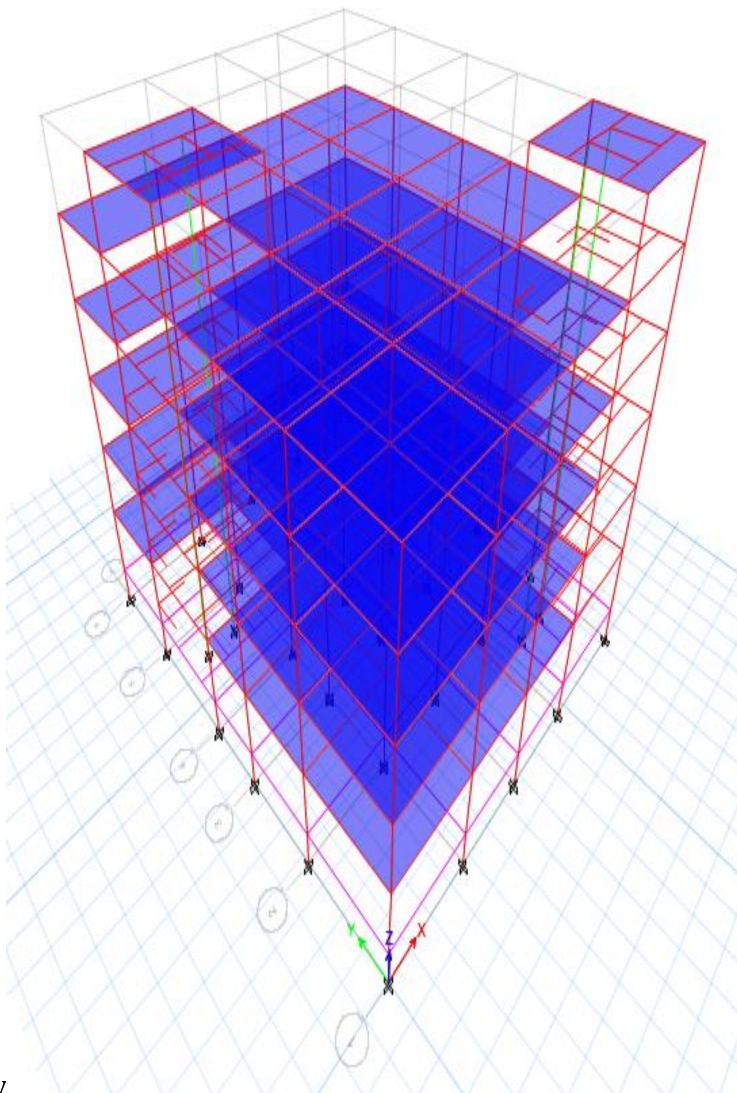
2.2 Load Cases

Table 2.2 - Load Cases - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
SELF WEIGHT	Linear Static
WALL	Linear Static
PARAPET	Linear Static
FF	Linear Static
EQ+X	Linear Static
EQ-X	Linear Static
EQ+Y	Linear Static
EQ-Y	Linear Static
WL +X	Linear Static
WL -X	Linear Static
WL +Y	Linear Static
WL -Y	Linear Static

2.2 3D VIEWS OF MODELS:

2.2.1 Group-1:



Symmetrical structural of 3-D view

Fig.3.1 Medium rise structure (G+4)

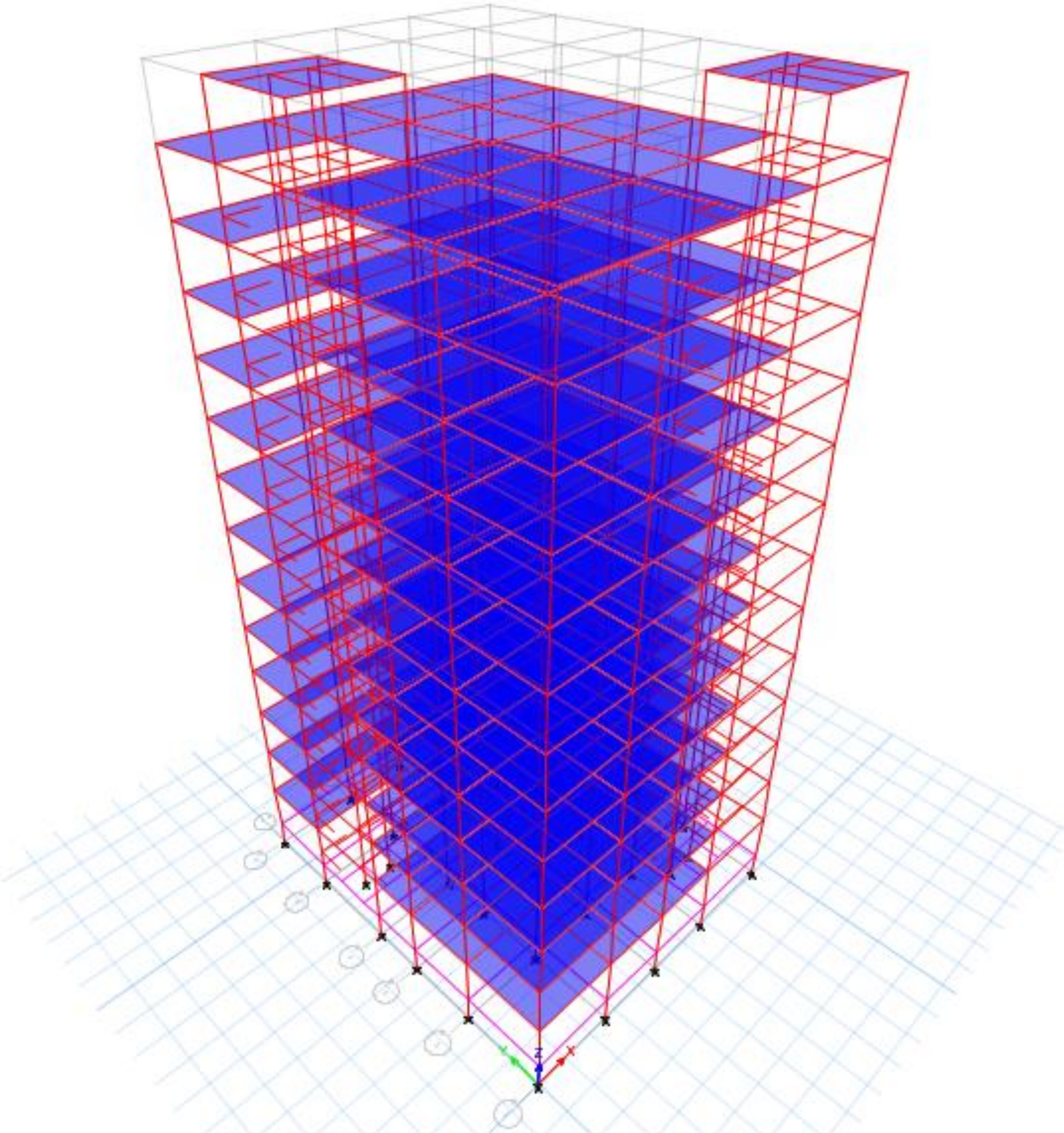


Fig.3.2 High rise structure (G+14)

2.2.2 Group-2

Group -2 structures are applying lead rubber bearing isolators at bottom of structure where it separates the sub-structure and super-structure to same structural plan of group-1 respectively.

For group-2 structure Plinth height above GL is 0.5m to provide the base isolators. Where base isolator having nearly 350mm height for high rise structure and 250mm height for medium rise structure.

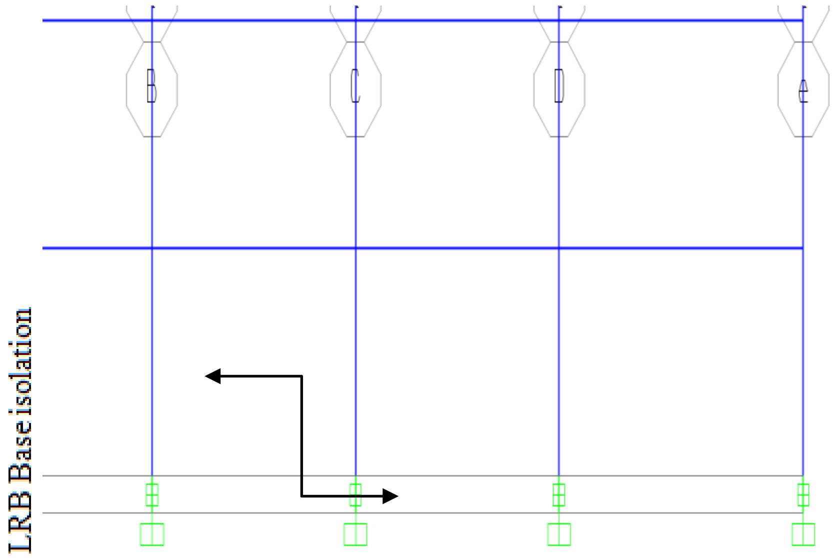


Fig. 3.3 LRB base isolator apply to structures

Using the above plan in (G+4) RC structure and (G+14) RC structures , the RC G+14 frame building is generated using commercial software ETABS 2015. Beams and Columns are modeled by 3D frame elements. The concrete floor slabs were assumed to act as diaphragms, which ensure integral action of all the vertical lateral load-resisting elements. The weight of the slab was distributed as triangular and trapezoidal load to the surrounding beams. Both have been analyzed for a fixed base & isolated base with Lead Rubber Bearing for time history analysis forces by ETABS2015 software.

3. MATHEMATICAL FORMULATION

3.1 LEAD RUBBER BEARING:

In the present paper, the isolators were initially designed to follow some available recommendations of the Uniform Building Code (UBC-97). The mechanical properties of the LRB isolation system were set to comply with a recommendation of the UBC-97 building code. The design parameters considered here are the ratio Q/W of the characteristic strength Q over the total weight on the isolation system W, the yield force Fy , the isolator diameter D, the lead core diameter d, the number of rubber layers n, and the layer thickness t. For design and analysis, the shape of the nonlinear force–deflection relationship, termed the hysteresis loop (represented as a bilinear curve as shown in Fig. 4), has an elastic (or unloading) stiffness ke and a yielded (or post-elastic) stiffness kp.

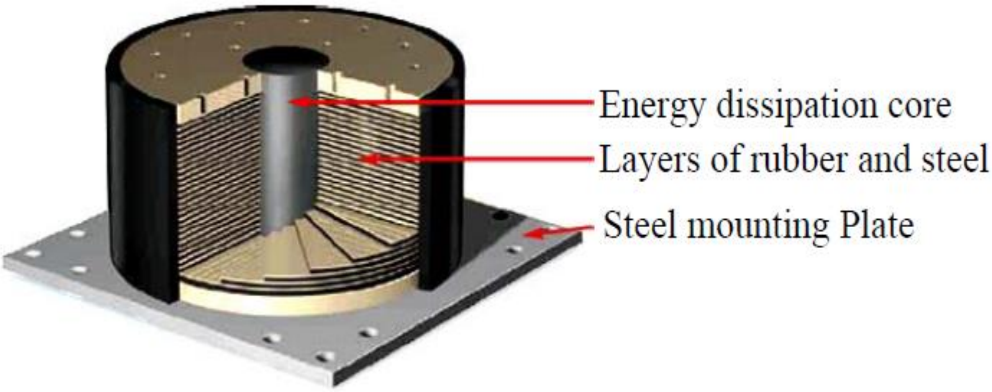


Fig. 4.1 the Lead Rubber Bearing. (The top mounting plate is not shown)

Table 1. Parameters of basic hysteresis loop of isolator

Symbols	Terms
k_e	= Elastic stiffness
K_2 or k_p	= Yielded stiffness
k_{eff}	= Effective stiffness
Δ	= Designed displacement
D_y	= The yield displacement of isolator
Zeff	= Effective damping ratio
F_y	= Yield force
T^{iso}	= Fundamental isolation period

3.1.1 Elastic stiffness (*ke*):

Elastic stiffness *ke* is defined as the ratio of the yield strength to the yield displacement. This is the initial stiffness of the isolator, its value is dominated by lead core size and is important in controlling the response to service load such as wind.

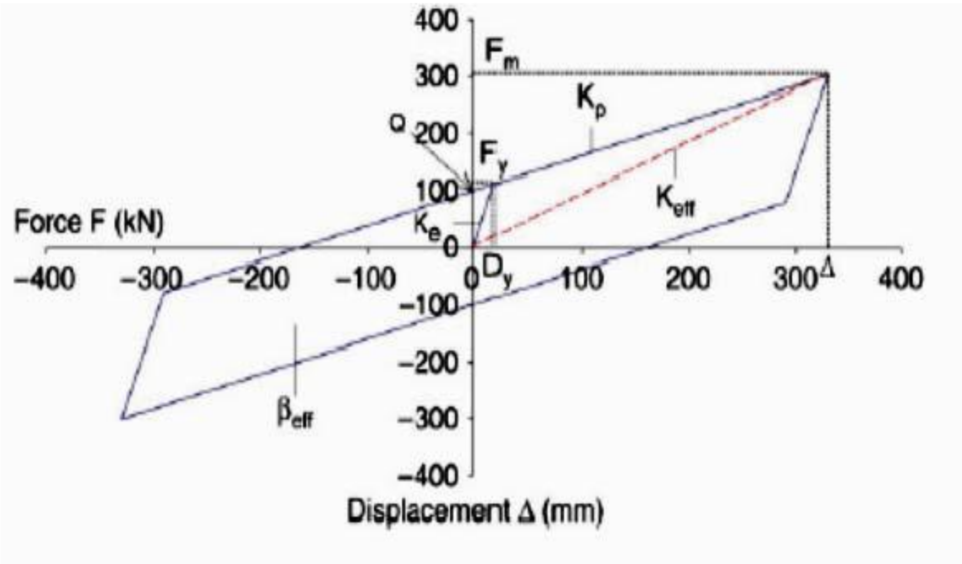


Fig. 4.2 Hysteresis loop of the LRB.

3.1.2 Yielded Stiffness (*K*2 or *Kp*):

This is the secondary stiffness of the isolator and is a function of the shear modulus, total height and area of the rubber.

Its post-yield stiffness is given by the formula,

$$k_p = \frac{G.A_r}{t_r} f_l$$

Where,

G = Shear modulus of the rubber.

A_r = Cross-sectional area of the rubber layers

t_r = Total thickness of the rubber consisting of n-layers.

f_l= factor given by 1.15.

3.1.3 Effective Stiffness (k_{eff}):

This is the isolator force divided by the displacement. This is a displacement-dependent quantity. The average or effective stiffness k_{eff} is defined as the ratio between the force F_m (Force at designed displacement) (from fig. 9), occurring at a specified LRB isolator displacement Δ (Designed displacement), and the Δ (Designed displacement)

$$k_{eff} = \frac{F_m}{\Delta}$$

The effective stiffness k_{eff} can also be expressed as a function of the characteristic

Strength Q as in the following equation:

$$k_{eff} = k_p + \frac{Q}{\Delta} (\text{Where } \Delta > D_y)$$

Where,

D_y= Yield displacement.

On the other hand, when the designed displacement is $\Delta < D_y$, the effective stiffness (k_{eff} is equal to elastic stiffness (k_e). The force F_m can be defined as

$$F_m = Q + k_p \Delta$$

While the yield force F_y can be obtained from

$$F_y = Q + k_p D_y$$

For lead-rubber bearings in which the elastic stiffness is approximately equal to 6.5, the yield displacement can be estimated as:

$$D_y = \frac{Q}{5.5k_p}$$

The area ED of the hysteresis loop can be obtained from the equation,

$$ED = 4Q(\Delta - \Delta_y)$$

This area represents the energy dissipation at each cyclic motion of LRB isolator. Then, the effective damping ratio ζeff, which produces the same amount of damping energy dissipation as the hysteretic energy dissipated at each cyclic motion of the LRB isolator, is expressed as;

$$\zeta\text{eff} = \frac{\mathrm{ED}}{2\pi \mathrm{k_{eff}}\ \Delta^2}$$

Finally, the fundamental isolation period T^{iso} is given by the equation

$$T^{iso} = 2\pi\sqrt{\frac{M}{\sum k_{eff}}}$$

Where, M is the total mass on the isolation system, including the mass of the superstructure and the mass of the isolation system. The term $\Sigma\, k_{eff} = k_{eff}$ is the total effective stiffness of the isolation system.

$$C_{eff} = 2\zeta_{eff}\sqrt{M\, k_{eff}}$$

Where,

C_{eff} = effective damping coefficient

High-damping rubber bearings are made of specially compounded rubber that exhibits effective damping between 0.10 and 0.20 of critical. The increase in effective damping of high-damping rubber is achieved by the addition of chemical compounds that may also affect other mechanical properties of rubber.

3.1.4 Vertical Stiffness (*Kv*):

This is the vertical stiffness of the isolator.

3.1.5 Yield Force (*Fy*):

The yield force is the point in the model at which the initial stiffness changes to secondary stiffness. In reality there is a smooth transition from one stiffness to the other, rather than a well-defined point. This value is mainly used in analytical modeling.

The characteristics strength is given by equation;

$$Q = A_{pb}\,\sigma_{ypb}$$

Where

A_{pb} = area of the lead core.

σ_{ypb} = The yield strength of lead core (ranginh between 7.0 and 8.5 MPa)

3.1.6 Hysteretic Strength (Qd):

This is the force-axis intercept of the isolator hysteresis loop. This parameter relates to damping and isolator response to service loads.

3.2 ISOLATION SYSTEM

The isolation systems, which can be elastomeric systems, exhibit highly nonlinear behavior. Nonlinear behavior is restricted to the base and the superstructure is considered to be elastic at all times. All of the isolation bearings in this study are modeled by a bilinear model, based on three parameters: elastic stiffness ($K1$), yielded stiffness ($K2$), and characteristics Strength (Q). Refer Fig. 10 for details. The elastic stiffness ($K1$) is either estimated from elastomeric bearing tests or as a multiple of $K2$ for lead plug bearing. The characteristics strength (Q) is estimated from the hysteresis loops for the elastomeric bearings. For lead plug bearings Q is given by the yield stress in the lead and the area of the lead. The post-yield stiffness can be accurately estimated or predicted for the bearing. The effective stiffness, defined as the secant slope of the peak-to-peak values, in a hysteresis loop, is given by:

$$K_{eff} = K_2 + Q/D$$

Where, D > Dy

Here, $D_y = \frac{Q}{k_1 - k_2}$ is the yield displacement.

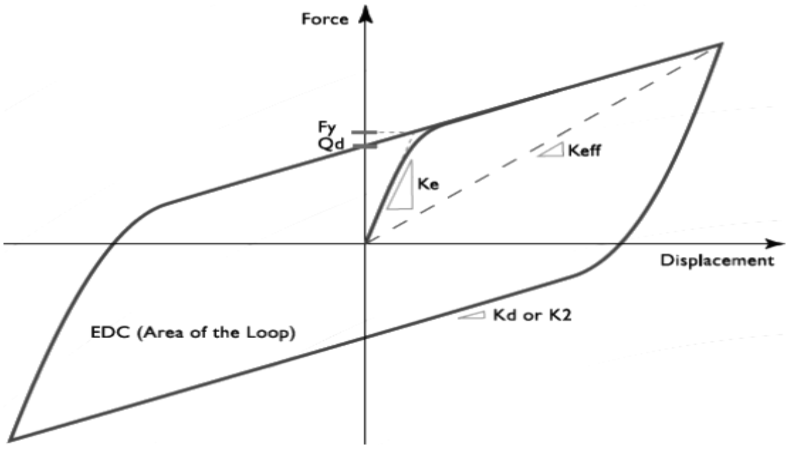


Fig. 4.2 Parameters of basic hysteresis loop of isolator for bilinear modeling

The natural frequency w is given by:

$$\omega=\sqrt{k_{eff}g/W}$$

$$\omega = \sqrt{\omega_0^2 + \mu\frac{g}{D}}$$

Where,

$$\mu = {}^{Q}/_{W}, \qquad \omega_0^2 = \sqrt{\frac{k_2 g}{W}}$$

The effective time period T is given by

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

$$\omega = \frac{2\pi}{\sqrt{\omega_0^2 + \mu\frac{g}{D}}}$$

And the area of the hysteresis loop is (the energy dissipated per cycle), W_D, is given as;

$W_D = 4Q\,(D - D_y)$

The effective damping β_{eff} is given by

$\beta_{Eff} = \frac{areaofthehysterisisloop}{2\pi K_{eff} D^2}$

This can be expressed in non-dimensional quantities by defining a non-dimensional displacement.

$Y = {}^{D}/_{D_y}$

And a non-dimensional characteristics strength

$a = {}^{Q}/_{k_2 D_y}$

Then effective damping becomes

$$\beta_{eff} = \frac{2a}{\pi} \frac{y-1}{(y+a)*y}$$

$y \geq 1$

3.3 MATERIALS OF LRB

Tableted 2. Materials of lead rubber bearing

1	Rubber
2	Steel
3	Lead core
4	Mounting plate.(steel mounting plate and top mounting plate)

3.4 PROPERTIES OF BASE ISOLATION:

The isolation elements (Fig. 4.1) used is modeled by biaxial behavior of elastomeric bearings (Fig. 4.3). The lead-rubber bearings are modeled using the biaxial model for elastomeric bearings. In the present study, bilinear isolators such as the commonly used lead rubber bearing (LRB) isolation systems were investigated.

The introduction of LRB isolators in the nonlinear time-history analysis was achieved by activating the nonlinear link element of ETABS. The performance of a base isolated framed structure with a fixed base otherwise similar framed structure was compared one by one as described below using computer program ETABS 2015 to conclude the effectiveness of base isolation using bilinear behavior of elastomeric bearing.

	STOREY PLAN	
	G+4	G+14
U1 Linear effective stiffness(kN/m)	445060	811800
U2 and U3 Linear effective stiffness (kN/m)	1750	2102.5
U2 and U3 Nonlinear stiffness (kN/m)	6820	9530
U2 and U3 Yield strength (kN)	132	169
U2 and U3 Post yield stiffness ratio	0.065	0.07

Table 3 Properties of lead rubber bearing isolator

3.5 DESIGN OF BASE ISOLATORS:

ISOLATOR DESIGN FOR G+4

1. Seismic zone factor, z = 0.30 (Table 16 – I)
2. Soil profile type S_B (Table 16 – J)
3. Seismic co-efficient, C_A = 0.33 (Table 16 – Q)
4. Seismic co-efficient, C_V = 0.45 (Table 16 – R)
5. Near source factor, N_A = 1.5 (Table 16 – S)
6. Near source factor, N_V = 2 (Table 16 – T)

7. MCE Shaking intensity M_MZ $N_A = 0.40$, $M_M = 1.21$
8. MCE Shaking intensity M_MZ $N_V = 0.48$
9. Seismic Source type ~~A~~ → (Table 16 – U)
10. Distance of known source (km) = 2 (from site seismology)
11. MCE Response co-efficient, $M_M = 1.21$ (Table A-16-D)
12. Lateral force co-efficient, $R_1 = 2$ (Table A-16-E)
13. Fixed base Lateral force co-efficient, R = 5.5 (Table 16 – N)
14. Importance factor, I = 1 (Table 16 – K)
15. Seismic co-efficient, $C_{AM} = 1$ (Table A-16-F)
16. Seismic co-efficient, $C_{VM} = 1$ (Table A-16-G)
17. Eccentricity, e =1.45 (5% of d)
18. Shortest building dimension, b = 22 (Building site)
19. Longest building dimension, d = 22
20. Dimension of extreme isolator, y = 6 (from geometry)
21. $D_{TD} / D_D = D_{TM} / D_M = [1 + (y \times 12 \times e) / (b^2 + d^2)]$
    $= 1.1$

Parameters:

22. Shear modulus (G) = 0.0004 (shear modulus of rubber, Table 5.4)
23. Ultimate elongation , $€_U = 6.5$ (shear modulus of rubber, Table 5.4)
24. Material constant, K = 0.87 (shear modulus of rubber, Table 5.4)
25. Elastic modulus, E = 0.00135 (shear modulus of rubber, Table 5.4)
26. Bulk modulus, $E_\infty = 1.5$ (Typical value for neutral rubber)
27. Damping, β = 0.05 (5% used for plain rubber bearings)
28. Lead yield strength, $\sigma_y = 0.008$ (Usually 7 to 8.5 Mpa)
29. Teflon co-efficient of friction, μ = 0.1 (Use high velocity for design)
30. Gravity, g = 9810

Isolator type & load data:

Number of bearing = 30

Avg DL + LL, $P_d = 803$

Max DL + LL = 1180

Wing load/isolator = 50 → 50 x 30 = 1500

Seismic weight = 30 x 803 + 1500 = 25590

Isolator Dimension:

Plan dimension, B = 520mm

Layer thickness, t_1 = 10

No of Layers, N = 16

Lead core size, d_{pl}= 150

Side cover, t_{sc} = 10

Internal slim thickness, t_{sl} = 3

Load plate thickness, T_{pl} = 40 [required to get total height]

Total rubber thickness, T_r = 160 [Nt_1]

Total height, H = 285 [$Nt_1 + (N-1)\, t_{sl} + 2T_{pl}$]

Gross area , A_g = 212371.66 [$\pi B^2 / 4$]

Bonding dimension, B_b = 500 [$B-2\, t_{sc}$]

Bonding depth = Nil

Bond area, A_b = 196349.54 [$\pi B_b^2 / 4$]

Plug area, A_{pl} = 17671.45 [$\pi d_{pl}^2 / 4$]

Net bonding area, A_{bn} = 178678.08 [$A_b - A_{pl}$]

Total rubber thickness, T_r = 160 [Nt_1]

Bonded perimeter, P = 1570.79 [πB_b]

Shape factor, S =11.39 [$A_{bn} / t_1 p$]

Characteristic strength, Q_d = 141.37 [$\sigma_y A_{pl}$]

Shear modulus [50%] = 0.0004 [G]

Yielded stiffness, K_r = 0.48 [$G (A_g - A_{pl}) / T_r$]

For LRB,

C_1, Co-efficient on K_r = 6.5 [Typical value]

C_2, Co-efficient on A_{pl}/A_b = 12 [Typical value]

Elastic stiffness, K_v = 6.82 [6.5 K_r (1 + (12 A_{pl} / A_{bn}))]

Yield force, F_y = 131.42 [Q_d (1- (K_r / K_v))]

Yield displacement, Δ_V = 19.26 [F_y / K_v]

Moment of inertia, I = 0.3067x 10^{10} [πB_b^4 / 64] (circular)

Buckling factors

Height free to buckle, H_r = 205 [$T_r + t_{sl}$ (N-1)]

Buckling modulus, E_b = 0.197 [E (1+0.742S_1^2)]

Constant, T = 0.776 x 10^{10} [E_b I H_r / T_r]

Constant, R = 76.8 [K_r T_r]

Constant, Q = 0.0153 [π / H_r]

Factor on $€_U$ = 0.33 [factor of safety 3 for gravity]

Applied vertical load, P_{DL+LL} = 803

Applied displacement = 0

Applied rotation = 0

Shape factor, S_1 = 14.00 [from properties]

Constant, K = 0.87 [from properties]

E= 0.0014 [from properties]

Compressive modulus, E_c = 0.478 [E (1+2KS_1^2)]

Reduced area, A_r = 196349.54 [πB_b^2 / 4]

Vertical stiffness, K_{vi} = 9385.50 [E_c A_r / t_1] per layer

Compressive strain, $€_c$ = 0.0167 [P / K_{vi} t_1]

Compressive shear strain, $€_{sc}$ = 1.40 [6 $S_1€_c$]

Displacement strain, $€_{sl}$ = 0

Rotational strain, $€_{sv}$ = 0

Total strain, € = 1.40 [$€_{sc}$ + $€_{sl}$ + $€_{sv}$]

Allowable strain = 2.16 [$€_U$ / f]

Status → Ok Satisfactory

If € $\leq$ $€_V$ / f

Adjusted shear modulus = 0.00045 [G]

Adjusted stiffness, K_r^* = 0.48 [K_r]

Vertical stiffness calculation

K_{vi} = 9385.5

K_v = 586.59

Bulk modulus, E_∞ = 1.5 [from material properties]

Vertical stiffness, K_V = 445.06 [K_v / (1+ (E_c / E_∞))]

DBE: (Performance)

No of Isolators = 30

Elastic stiffness, K_U = 6.82

Adjusted stiffness, K_r^* = 0.48

Yield displacement, Δ_V = 19.26

Characteristic strength, Q_d = 141.37

Iteration 1

Seismic displacement, D_D = 160 [Assume a displacement adjust until S_D / D_D = 1]

Bearing force, F = 218.17 [Q_d + D_D K_r^*]

Effective stiffness, K_e = 1.36 [F/D_D] $\longrightarrow$ K_e x 30 = 40.9

Seismic Weight = 25590 $\longrightarrow$ dead load

Seismic Weight = 2.592 $\longrightarrow$ W / g

Effective period, T_E = 1.58 [2π (M/ K_e)$^{0.5}$]

Loop area, A_h = 79585.655 [4 Q_d (D_D - Δ_V)

Damping = 36.38% [(1/2π) x (A_h / K_e D_D^2)]

Damping factor, B = 1.81 [UBC Table A-16-C]

Spectral acceleration, S_A = 0.1 [C_V / BT_E]

Spectral displacement, S_D = 98.20 [(g x C_V x T_E) / (4 π^{2}B)]

Iteration 2

Seismic displacement, D_D = 98.20

Bearing force, F = 167.41

Effective stiffness, K_e = 1.70 [F/D_D] $\longrightarrow$ K_e x 30 = 51.14

Seismic Weight = 25590 $\longrightarrow$ dead load

Seismic Weight = 2.59 $\longrightarrow$ W / g

Effective period, T_E = 1.41

Loop area, A_h = 44684.22

Damping = 43.38%

Damping factor, B = 1.9

Spectral acceleration, S_A = 0.1

Spectral displacement, S_D = 83.49

Iteration 3

Seismic displacement, D_D = 83.49

Bearing force, F = 181.44

Effective stiffness, K_e = 2.17 [F/D_D] $\longrightarrow$ K_e x 30 = 65.199

Seismic Weight = 25590 $\longrightarrow$ dead load

Seismic Weight = 2.59 $\longrightarrow$ W / g

Effective period, T_E = 1.25

Loop area, A_h = 36213.33

Damping = 38.1%

Damping factor, B = 1.86

Spectral acceleration, S_A = 0.1

Spectral displacement, S_D = 83

Check convergence = 1 [S_D / D_D]

MCE performance

No of isolator = 30

Elastic stiffness, K_U = 6.82

Adjusted stiffness, K_r^* = 0.45

Yield displacement, Δ_V = 19.26

Characteristic strength, Q_d = 141.37

Iteration 1

D_M =85

F = 182.17

K_e = 2.14

T_E = 1.26

Loop area, A_h = 37174.655

Damping = 38.2%

Damping factor, B = 1.86

Spectral acceleration, S_A = 0.1

Spectral displacement, S_D = 76.21

Iteration 2

D_M = 76.21

F = 177.95

K_e = 2.33

T_E = 1.20

Loop area, A_h = 32204.08

Damping = 37.8%

Damping factor, B = 1.8

Spectral acceleration, S_A = 0.1

Spectral displacement, S_D = 75

Check convergence = 1 [S_D / D_D]

Earthquake design

E_u = 0.75

Applied vertical load, P_{DL} + S_{LL} + E = 8206 [Max DL + SLL + E]

DBE displacement = 156 [DBE displacement D_D]

Factor on displacement = 1.25 [D_{TD} / D_D]

Applied displacement = 195 [D_D]

Applied rotation = 0

Shape factor, S_1 = 14

Constant, K =0.87 [from properties]

E = 0.0014

E_C = 0.6

A_r = 318500

K_{vi} = 19110

$€_c$ = 0.042

$€_{sc}$ = 3.6

$€_{sh}$ = 0.928

$€_{sr}$ = 0

€ = 4.5, allowable strain = 4.88

Buckling load, P_{cr} = 19703

Status → Ok [$€ \leq €_u$ / f & $P_{cr} > P_{DL+LL}$]

MCE

Factor of $m_u€_u$ = 1

Applied vertical load = 8206

MCE displacement = 156.2

Factor on displacement = 195.2

Factor on rotation = 0

Shape factor = 14

K = 0.87

E = 0.0014

E_c = 0.6

A_r = 318500

K_{vi} = 19110

$€_c$ = 0.042

$€_{sc}$ = 3.6

$€_{sh}$ = 0.928

€ = 4.5, allowable strain = 6.5

Buckling load, P_{cr} = 19703

Status → Ok

Gravity strain FS	4.03	€u / € = 6.5 / 1.61
Buckling FS	7.57	P_{cr} / P = 25542 / 3372.5
DBE strain FS	1.44	€u / € = 6.5 / 4.5
Buckling FS	2.4	P_{cr} / P = 19703 / 8206
MCE strain FS	1.44	€u / € = 6.5 / 4.5
Buckling FS	2.4	P_{cr} / P = 19703 / 8206
Reduced area / Gross area	98.6	at MCE = A_r / A_b
Max shear strain		at MCE = $€_{sh}$

	DBE	MCE	Comments
Effective period T_D T_M	2.38	2.4	From seismic performance
Displacement D_D D_M	165	15	
Total Displacement D_{TD} D_{TM}	206	206	
Force co- efficient V_b / w	0.1	0.1	S_A

Force co- efficient V_s / w	0.05		S_A / R_1
1.5 x yield force / w			F_y / w
Wind force / w	0.018		F_w / w
Fixed base v @ T_D			From UBC
Base shear force			Max (V_s , V_y , V_w , V_f) x w @ DBE
Damping, D_{eff}	36%	36%	From seismic performance
Damping co-efficient B_D B_M	1.82	1.84	

No.			Comments
	First data line:		
1	ID	1	Identification No
2	Type	LRB	Biaxial Hysteretic
3	KE2	2.15	Spring effective stiffness = $K_r^* + Q_d / D_d$
4	KE3	2.15	
5	DE2	0.310	Spring effective damping ratio = β – 0.05
6	DE3	0.310	
	Second data line:		
7	K1	445.06	Spring stiffness along Axis 1 (axial)
8	K2	6.82	Initial spring constant = K_u
9	K3	6.82	

10	FY2 / K11 / CFF2	132	Yield force = (F_y for LRB)
11	FY3 / K22 / CFF3	132	
12	RK2 / K33 / CFF2	0.065	Post – yield stiffness ratio = K_r^* / K_u
13	RK3 / CFS3	0.065	

Hysteresis properties

	Displacement	Force	Comments
Yield displacement	19.32		Bearing properties
Design displacement	83		DBE properties
Yield force, F_y	132		Bearing properties
Origin	0	0	Start of plot
Point A	19.32	132	$\Delta = \Delta Y$ $F = F_y$
Point B	83	178.72	$\Delta = D_D$ $F = Q_D + D_D K_r^*$
Point C	44.26	-85.26	$\Delta = D_D - 2\Delta Y$ $F = Q_D + D_D K_r^* - 2F_y$
Point D	-83	--178.72	$\Delta = -D_D$ $F = - Q_D - D_D K_r^*$
Point E	-44.26	+85.26	$\Delta = - D_D + 2\Delta Y$ $F = - Q_D - D_D K_r^* + 2F_y$

Point A	19.32	132	$\Delta = \Delta Y$ $F = F_y$

ISOLATOR DESIGN FOR G+14

1. Seismic zone factor, z = 0.3 (Table 16 – I)
2. Soil profile type S_B (Table 16 – J)
3. Seismic co-efficient, C_A = 0.33 (Table 16 – Q)
4. Seismic co-efficient, C_V = 0.45 (Table 16 – R)
5. Near source factor, N_A = 1.5 (Table 16 – S)
6. Near source factor, N_V = 2(Table 16 – T)
7. MCE Shaking intensity $M_M Z N_A$ = 0.40 , M_M = 1.21
8. MCE Shaking intensity $M_M Z N_V$ = 0.48
9. Seismic Source type A (Table 16 – U)
10. Distance of known source (km) = 2 (from site seismology)
11. MCE Response co-efficient, M_M = 1.21 (Table A-16-D)
12. Lateral force co-efficient, R_1 = 2 (Table A-16-E)
13. Fixed base Lateral force co-efficient, R = 5.5 (Table 16 – N)
14. Importance factor, I = 1 (Table 16 – K)
15. Seismic co-efficient, C_{AM} = 1(Table A-16-F)
16. Seismic co-efficient, C_{VM}= 1 (Table A-16-G)
17. Eccentricity, e =1.45 (5% of d)
18. Shortest building dimension, b = 22 (Building site)
19. Longest building dimension, d = 22
20. Dimension of extreme isolator, y = 6 (from geometry)
21. $D_{TD} / D_D = D_{TM} / D_M$ = [1 + (y x 12 x e) / ($b^2 + d^2$)]
    = 1.10

Parameters:

22. Shear modulus (G) = 0.0004 (shear modulus of rubber, Table 5.4)
23. Ultimate elongation , $€_U$ = 6.5 (shear modulus of rubber, Table 5.4)
24. Material constant, K = 0.87 (shear modulus of rubber, Table 5.4)
25. Elastic modulus, E = 0.00135 (shear modulus of rubber, Table 5.4)
26. Bulk modulus, E_∞ = 1.5 (Typical value for neutral rubber)
27. Damping, β = 0.05 (5% used for plain rubber bearings)
28. Lead yield strength, σ_y = 0.008 (Usually 7 to 8.5 Mpa)
29. Teflon co-efficient of friction, μ = 0.1 (Use high velocity for design)

30. Gravity, g = 9810

Isolator type & load data:

Number of bearing = 30

Avg DL + LL, P_d = 3113.2

Max DL + LL = 4078

Wing load/isolator = 50 $\longrightarrow$ 50 x 30 = 1500

Seismic weight = 32 x 2593.5 + 1500 = 94896

Isolator Dimension:

Plan dimension, B = 800mm

Layer thickness, t_1 = 10

No of Layers, N = 21

Lead core size, d_{pl}= 175

Side cover, t_{sc} = 10

Internal slim thickness, t_{sl} = 3

Load plate thickness, T_{pl} = 40 [required to get total height]

Total rubber thickness, T_r = 210 [Nt_1]

Total height, H = 350 [$Nt_1 + (N-1)\, t_{sl} + 2T_{pl}$]

Total yield level of system = 7.2% [(Q_d x No of bearing) / W]

Gross area, A_g = 502654.8 [$\pi B^2 / 4$]

Bonding dimension, B_b = 780 [B-2 t_{sc}]

Bonding depth = Nil

Bond area, A_b = 477836.24 [$\pi B_b^2 / 4$]

Plug area, A_{pl} = 24052.81 [$\pi d_{pl}^2 / 4$]

Net bonding area, A_{bn} = 453783.42 [A_b - A_{pl}]

Total rubber thickness, T_r = 210 [Nt_1]

Bonded perimeter, P = 2450 [πB_b]

Shape factor, S =14.00 [A_{bn} / $t_1 p$]

Characteristic strength, Q_d = 192.4 [σ_y A_{pl}]

Shear modulus [50%] = 0.0004 [G]

Yielded stiffness, K_r = 0.911 [G (A_g - A_{pl}) / T_r]

For LRB,

C_1, Co-efficient on K_r = 6.5 [Typical value]

C_2, Co-efficient on A_{pl}/A_b = 12 [Typical value]

Elastic stiffness, K_v = 7.53 [6.5 K_r (1 + (12 A_{pl} / A_{bn}))]

Yield force, F_y = 169.12 [Q_d (1- (K_r / K_v))]

Yield displacement, Δ_V = 22.45 [F_y / K_v]

Moment of inertia, I = 1.81 x 10^{10} [πB_b^4 / 64] (circular)

Buckling factors

Height free to buckle, H_r = 270 [T_r + t_{sl} (N-1)]

Buckling modulus, E_b = 0.197 [E (1+0.742S_1^2)]

Constant, T = 0.458 x 10^{10} [E_b I H_r / T_r]

Constant, R = 191.31 [K_r T_r]

Constant, Q = 0.0116 [π / H_r]

Factor on $€_U$ = 0.33 [factor of safety 3 for gravity]

Applied vertical load, P_{DL+LL} = 3113.2

Applied displacement = 0

Applied rotation = 0

Shape factor, S_1 = 14.00 [from properties]

Constant, K = 0.87 [from properties]

E= 0.0014 [from properties]

Compressive modulus, E_c = 0.478 [E $(1+2KS_1^2)$]

Reduced area, A_r = 477836 [πB_b^2 / 4]

Vertical stiffness, K_{vi} = 22840.56 [E_c A_r / t_1] per layer

Compressive strain, $€_c$ = 0.0107 [P / K_{vi} t_1]

Compressive shear strain, $€_{sc}$ = 0.9 [6 $S_1 €_c$]

Displacement strain, $€_{sl}$ = 0

Rotational strain, $€_{sv}$ = 0

Total strain, € = 0.9 [$€_{sc}$ + $€_{sl}$ + $€_{sv}$]

Allowable strain = 2.16 [$€_U$ / f]

Status → Ok Satisfactory

If $€ \leq €_V / f$

Adjusted shear modulus = 0.00045 [G]

Adjusted stiffness, K_r^* = 0.8[K_r]

Vertical stiffness calculation

K_{vi} = 22480.5

K_v = 1070.5

Bulk modulus, E_∞ = 1.5 [from material properties]

Vertical stiffness, K_V = 811.80 [K_v / (1+ (E_c / E_∞))]

DBE: (Performance)

No of Isolators = 30

Elastic stiffness, $K_U = 7.53$

Adjusted stiffness, $K_r^* = 0.8$

Yield displacement, $\Delta_V = 22.45$

Characteristic strength, $Q_d = 192.4$

Iteration 1

Seismic displacement, D_D =160 [Assume a displacement adjust until S_D / D_D = 1]

Bearing force, F = 320.4 [$Q_d + D_D K_r^*$]

Effective stiffness, $K_e = 2.0$ [F/D_D] $\longrightarrow K_e \times 30 = 60$

Seismic Weight = 94896 $\longrightarrow$ dead load

Seismic Weight = 9.61 $\longrightarrow$ W / g

Effective period, $T_E = 2.51$ [$2\pi (M/ K_e)^{0.5}$]

Loop area, $A_h = 105858.48$ [$4 Q_d (D_D - \Delta_V)$]

Damping = 33. % [$(1/2\pi) \times (A_h / K_e D_D^2)$]

Damping factor, B = 1.76 [UBC Table A-16-C]

Spectral acceleration, $S_A = 0.1$ [C_V / BT_E]

Spectral displacement, $S_D = 160.44$ [$(g \times C_V \times T_E) / (4 \pi^2 B)$]

Check convergence = 1 [S_D / D_D]

MCE performance

No of isolator = 30

Elastic stiffness, $K_U = 7.53$

Adjusted stiffness, $K_r^* = 0.8$

Yield displacement, $\Delta_V = 22.45$

Characteristic strength, Q_d = 192.4\

Iteration 1

D_M = 160

F = 320.4

K_e = 2.00

T_E = 2.51

Loop area, A_h = 105858.48

Damping = 33%

Damping factor, B = 1.76

Spectral acceleration, S_A = 0.1

Spectral displacement, S_D = 160.44

Check convergence = 1 [S_D / D_D]

Earthquake design

E_u = 0.75

Applied vertical load, P_{DL} + S_{LL} + E = 8206 [Max DL + SLL + E]

DBE displacement = 156 [DBE displacement D_D]

Factor on displacement = 1.25 [D_{TD} / D_D]

Applied displacement = 195 [D_D]

Applied rotation = 0

Shape factor, S_1 = 14

Constant, K =0.87 [from properties]

E = 0.0014

E_C = 0.6

A_r = 318500

K_{vi} = 19110

$€_c$ = 0.042

$€_{sc}$ = 3.6

$€_{sh}$ = 0.928

$€_{sr}$ = 0

€ = 4.5, allowable strain = 4.88

Buckling load, P_{cr} = 19703

Status → Ok [$€ \leq €_u$ / f & $P_{cr} > P_{DL+LL}$]

MCE

Factor of $m_u€_u$ = 1

Applied vertical load = 8206

MCE displacement = 156.2

Factor on displacement = 195.2

Factor on rotation = 0

Shape factor = 14

K = 0.87

E = 0.0014

E_c = 0.6

A_r = 318500

K_{vi} = 19110

$€_c$ = 0.042

$€_{sc}$ = 3.6

$€_{sh}$ = 0.928

€ = 4.5, allowable strain = 6.5

Buckling load, P_{cr} = 19703

Status →Ok

Gravity strain FS	4.03	€u / € = 6.5 / 1.61
Buckling FS	7.57	P_{cr} / P = 25542 / 3372.5
DBE strain FS	1.44	€u / € = 6.5 / 4.5
Buckling FS	2.4	P_{cr} / P = 19703 / 8206
MCE strain FS	1.44	€u / € = 6.5 / 4.5
Buckling FS	2.4	P_{cr} / P = 19703 / 8206
Reduced area / Gross area	98.6	at MCE = A_r / A_b
Max shear strain		at MCE = $€_{sh}$

	DBE	MCE	Comments
Effective period T_D T_M	2.38	2.4	From seismic performance
Displacement D_D D_M	165	15	
Total Displacement D_{TD} D_{TM}	206	206	
Force co- efficient V_b / w	0.1	0.1	S_A
Force co- efficient V_s / w	0.05		S_A / R_1
1.5 x yield force / w			F_y / w
Wind force / w	0.018		F_w / w
Fixed base v @ T_D			From UBC

Base shear force			Max (V_s , V_y , V_w , V_f) x w @ DBE
Damping, D_{eff}	36%	36%	From seismic performance
Damping co-efficient B_D B_M	1.82	1.84	

Sl No.			Comments
	First data line:		
1	ID	1	Identification No
2	Type	LRB	Biaxial Hysteretic
3	KE2	2.0025	Spring effective stiffness = $K_r^* + Q_d / D_d$
4	KE3	2.0025	
5	DE2	0.310	Spring effective damping ratio = β – 0.05
6	DE3	0.310	
	Second data line:		
7	K1	811.80	Spring stiffness along Axis 1 (axial)
8	K2	7.53	Initial spring constant = K_u
9	K3	7.53	
10	FY2 / K11 / CFF2	169.12	Yield force = (F_y for LRB)
11	FY3 / K22 / CFF3	169.12	
12	RK2 / K33 / CFF2	0.07	Post – yield stiffness ratio = K_r^* / K_u
13	RK3 / CFS3	0.07	

Hysteresis properties

	Displacement	Force	Comments
Yield displacement	22.45		Bearing properties
Design displacement	160		DBE properties
Yield force, F_y	169.12		Bearing properties
Origin	0	0	Start of plot
Point A	22.45	169.12	$\Delta = \Delta Y$ $F = F_y$
Point B	160	320.4	$\Delta = D_D$ $F = Q_D + D_D K_r^*$
Point C	115.1	-17.84	$\Delta = D_D - 2\Delta Y$ $F = Q_D + D_D K_r^* - 2F_y$
Point D	-160	-320.4	$\Delta = -D_D$ $F = - Q_D - D_D K_r^*$
Point E	-115.1	-17.84	$\Delta = - D_D + 2\Delta Y$ $F = - Q_D - D_D K_r^* + 2F_y$
Point A	22.45	169.12	$\Delta = \Delta Y$ $F = F_y$

4. RESULT AND DISCUSSION

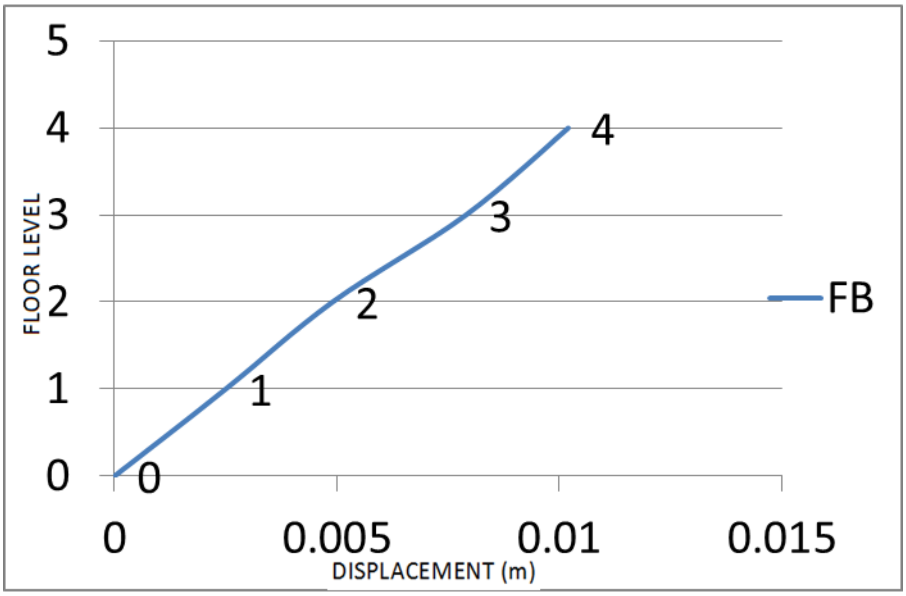
4.1 RESULTS:

It is compared for behavior of base isolated structure with fixed base structure under seismic load. From this it have been observed that structural effects like story displacement, story drift, base shear of structure are reduced due to use of the isolators. The above results-parameters of structural effects like story displacement, story drift.

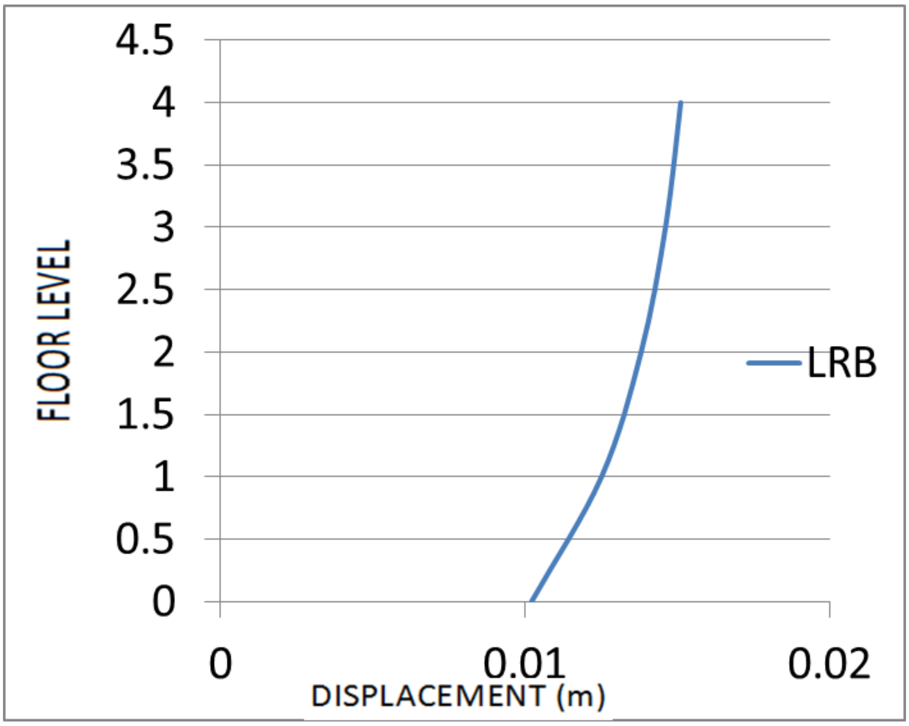
4.1.1 Response of symmetric model of fixed base and LRB base isolated structure (G+4)

Table 4 max story displacement of (G + 4) structure

Story NO	Story displacement (m)	
	Symmetrical Plan (G+4)	
	Fixed base	Base Isolation
Headroom	0.0125	0.0159
4	0.0102	0.0151
3	0.0084	0.0146
2	0.0045	0.0138
1	0.0025	0.0125
Base	0.0000	0.0102



Graph 5.1 Floor level vs displacement of fixed base structure (G+4)

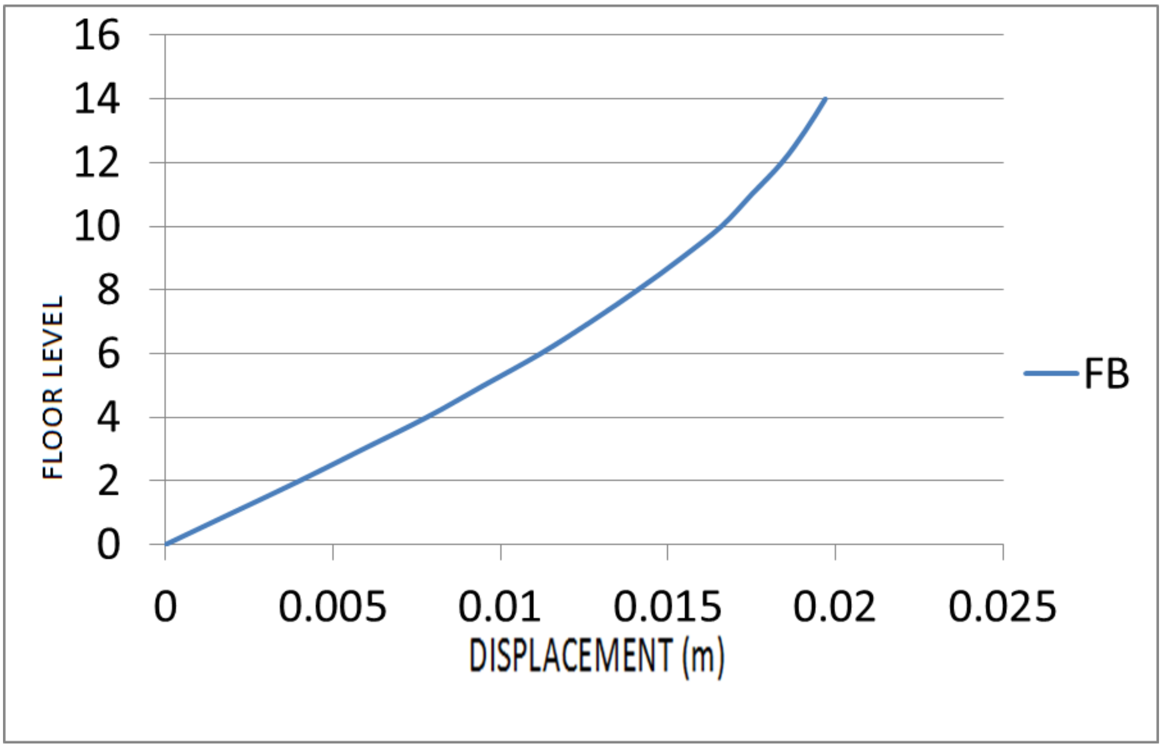


Graph 5.2 Floor level vs displacement of LRB base isolation structure (G+4)

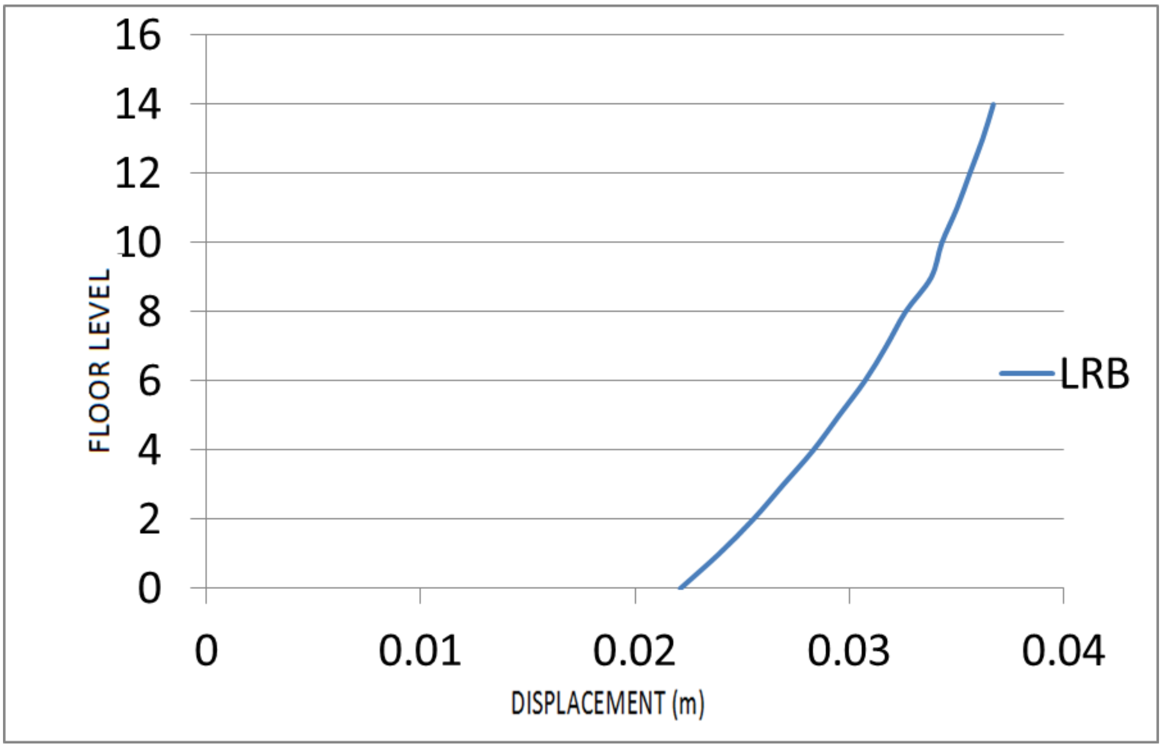
4.1.2 Response of symmetric of fixed base and LRB base isolated structure (G + 14)

Table 5 Max story displacement of (G + 14) structure

Story NO	Story displacement (m)	
	Symmetrical Plan (G+14)	
	Fixed base	Base Isolation
Headroom	0.0201	0.0371
14	0.0197	0.0367
13	0.0191	0.0362
12	0.0184	0.0356
11	0.0175	0.0350
10	0.0166	0.0343
9	0.0154	0.0338
8	0.0141	0.0326
7	0.0127	0.0317
6	0.0112	0.0307
5	0.0095	0.0295
4	0.0078	0.0283
3	0.0059	0.0269
2	0.0040	0.0255
1	0.0020	0.0239
Base	0.0000	0.0221



Graph 5.3 Floor level vs displacement of fixed structure (G+14)



Graph 5.4 Floor level vs displacement of LRB base isolation structure (G+14)

4.1.3 Deformed shape of structure with fixed base and base isolation structure

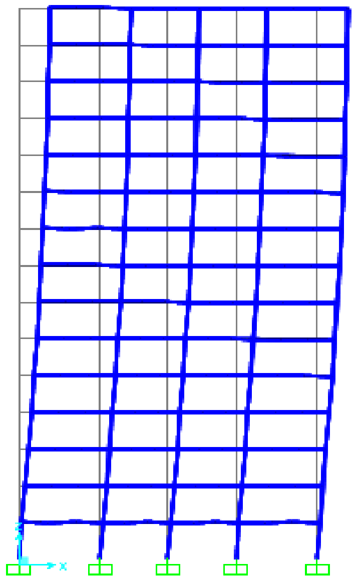


Fig 5.1 Deformed shape of fixed base structure from ETABS window

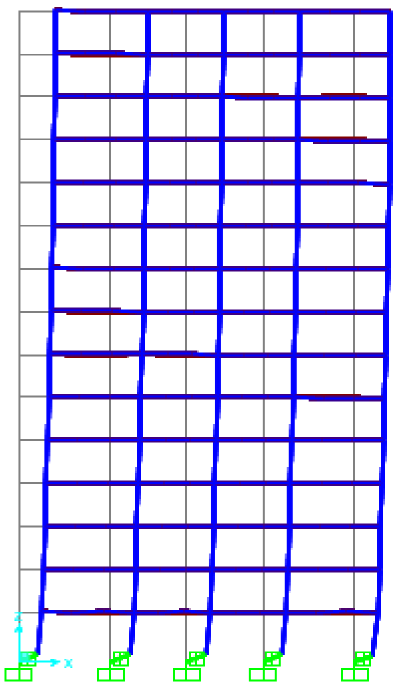


Fig 5.2 Deformed shape of base isolation structure from ETABS window

5. CONCLUSION & FUTURE SCOPE

- Base isolation is very promising technology to protect different structures like buildings, bridges, airport terminals and nuclear power plants etc. from seismic excitation.
- Storey drift decreases whereas generally lateral displacement increases in base isolated building.
- Fixed base buildings have zero storey acceleration at base of building whereas, in case of base isolated building appreciable amount of storey acceleration will been found out at base.
- The variation in maximum displacement of stories in base isolated model is very low while compared with fixed base model.
- The significant characteristic of base isolation a system affect the superstructure to have a rigid movement and as a result shows the relative story displacement & story drift of structural element will decrease and consequently the internal forces of beams and columns will be reduced.
- From the above points, it is concluded that the performance of isolated structure is efficient in the Earthquake prone areas.
- The analysis of structure is carried out by considering ZONE II, but further it is to be analyzed by considering all zones in India.
- In Future, the analysis is to be carried out by using other national codes such as Euro Codes& British Codes.

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