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DESIGN OF LEAD RUBBER BEARING SYSTEM AND HIGH DAMPING RUBBER BEARING SYSTEM FOR ISOLATED STRUCTURE FOR LONG TIME PERIODS FOR A FIVE STOREY R.C. BUILDING

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ABSTRACT

Seismic base isolation is now a days moving towards a very efficient tool in seismic design of structure. Increasing flexibility of structure is well achieved by the insertion of these additional elements between upper structure and foundation as they absorb larger part of seismic energy. Base isolators isolate the building and the structure can freely move to dissipate the energy. This paper deals with the design lead rubber bearing system and high damping rubber bearing system for a G +4 building for long time periods and to compare both base isolation systems.

The study was made with use of IS: 1893(Part 1) : 2002 and ASCE – 07 for obtaining dimensions of the bearing systems. Results obtained from the present study showed that use of high damping rubber bearing system is more efficient than lead plug rubber bearing system.

KEY WORDS: Lead rubber bearing, high damping rubber bearing, base isolation

INTRODUCTION

The main concept of base isolation is a system which decouples the structure/building from the horizontal components of the structure, of the ground motion by interposing structural elements with low horizontal stiffness between the structure and foundation. This system gives less fundamental frequency than the predominant frequency of the ground motion. The deformation due to ground motion involves only in isolation system. Isolation system does not absorb earth quake energy but it defects it through dynamics of the system. The concept of isolation has become practical since it was used in the elementary school in Skopje, Yugoslavia, by rubber isolation system to protect the school from earthquake. At present multilayer isolation bearings are used which are made by vulcanization of sheets of rubber to thin steel reinforced plates. These bearing systems are very stiff in vertical direction and carry the vertical load of the structure, very flexible in horizontal direction to move in lateral direction under strong ground motion.

A high proportion of the world is subjected to earthquake and society expects the structural engineers will design our buildings so that they can survive the effects of these earthquakes. As for all the load cases of application, such as gravity and wind the capacity of base isolation should be greater than demand.

The earthquakes happen and are uncontrollable. So, in that sense, we have to accept the demand and make sure that the capacity exceeds it. The earth quake causes inertia forces as that ground accelerations increases, the strength of the building, the capacity, must be increased to avoid structural damage. In high seismic zones the accelerations causing forces may exceed one or even two times the acceleration due to gravity. It is easy to visualize the strength needed for the level of load, strength to resist, means than the building could resist gravity applied sideways, which means that the building could be tripped on its side and held horizontally without damage.

Designing for the level of strength is not so easy, nor cheap. So most of the codes allow engineers to use ductility to achieve the capacity. Ductility is a concept of allowing the structural elements to deform beyond their elastic limit but in a controlled manner. Beyond this limit the structural elements soften and the displacements increase with only a small increase in force.

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LITERATURE

Tong Guo et al [2012] explained the design methods and corresponding requirements of the school buildings retrofitted with seismic isolation. Also given procedures for practice engineers point of view and explained a case study with existing buildings. Base isolation design was made with vertical compressive stress of all isolators, maximum long term compressive stress with not exceeding 12Mpa for school buildings.

Maximum considered earthquake with no tensile stress in buildings was expected. If tensile stress appears it should not be greater than 1.0Mpa. Analytical models of base isolated structures are presented in a simplified form with finite element models.

The earthquakes selected for the analysis procedure are, Chi-Chi earthquake, Ducze earthquake, Imperial valley earthquake, Northridge earthquake, Yountvill earthquake, Nanjing earthquake, Suqian earthquake. Time history analysis was applied in both x and y directions of the considered building.

A typical construction procedure was explained considering initial rubber bearings. The parameters considered are effective area, diameter of lead core, number of rubber layers, total thickness of rubber, vertical stiffness, equivalent stiffness, deformation, post yielding, yielding force, shear force, damping, number of bearings used in project are lead plug bearings of 37 numbers and rubber bearings of 26 numbers. With the use of these structural properties the investigation was found that the school building will be safe with earthquake effect.

Jared weisman et al [2012] examined the stability of elastomeric and lead rubber seismic isolation bearings for shape factors of 10 and 12. The load range of lateral displacements corresponding to 150 to 280% shear strain in comparison with the elastomeric bearing. A schematic of small bearing testing machine was used for characterization testing of bearing system. The investigation of results were carried out with finite element analysis. The investigation results are compared with the literature review results for critical load capacity of bearing systems and overlapping area method system was examined for bearing systems.

D.P.Soni et at [2011] studied the behaviour of liquid storage slender and broad tanks isolated by the double variable frequency pendulum isolator for the tank with seismic isolation. Four different DVFPI design cases with different geometry and coefficient friction of isolators at top and bottom are considered. Influence of initial time period, coefficient of friction and frequency variation factors at the two sliding surfaces and the tank aspect ratio are investigated. It was found that the performance of the DVFPI be optimized by top sliding surfaces with high initial slender tank whereas both surfaces be designed with equal initial stiffness and coefficient friction for a broad tank.

For analysis mathematical models were prepared for liquid storage tanks. Assumptions considered are self weight of the tanks are neglected as it is very small than the effective weight of the tank. Damping constants are made using sloshing and impulsive masses with damping ratios. Friction coefficient was considered with relative velocity at sliding interface. Slider isolators have uniform contact with sliding surfaces. Effect of the vertical acceleration due to increase was neglected. On view the total analysis was associated with numerical investigation of seismic response of the liquid tank.

AIM & OBJECTIVE

The present study aims is to make a detail of high rubber bearing and lead plug rubber bearing system for a G + 4, multi storied building considering the effect of earthquake with reference to IS : 1893 (Part I) : 2002, in zone V and IV regions, so as to make building isolate from earth to dissipate earthquake effect. The objective of the study is to make use of latest American standard code ASCE – 07, for design of high rubber bearing system and lead plug rubber bearing system, for G + 4 multi storied building and to detail the bearing system details. The bearing systems considered are also observed for change in their design detail for zone V and zone IV as per IS: 1893(Part I): 2002. The use of ASCE code was made in consideration of the statement made in preface of IS: 1893(Part I): 2002, which gives us freedom to use international codes of standards for safeguarding the structures in Indian nation. Lead plug bearing system, high rubber bearing system are two systems extensively used for isolation of buildings and hence are considered for the design of seismic isolation of considered building. This study objective is to make a way for utilization of international standards in Indian conditions of design.

ANALYSIS PROCEDURE

4.1. Building Data:

Thickness of slab = 0.15m

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Load due to roof finish = $2kN/m^2$
Load due to floor finish = $2kN/m^2$
Thickness of outer walls = 0.3m
Thickness of inner walls = 0.15m
Imposed load = $4kN/m^2$
Size of column at ground level = (0.4 x 0.4) m
Type of foundation used is isolated footing.
Soil condition considered is medium soil and soft soil available at depth of 1.5m below ground level.
Seismic zones considered are Zone V and Zone IV
Length in x-direction and length in y - direction are (20 x 20)m
Number of infill panels in x direction are = 3
Number of infill panels in y direction are = 4
Total floor area considered is = 400m2
Floor to floor height of building is = 3.5m
Ground level is = 4m
Total height of the building is = 19.5m
Unit weight of masonry = 20 kN/m^3
Unit weight of reinforced concrete masonry considered is = 25 kN/m^3
Self weight of slab is = 3.75kN/m
No. of floors without silt and roof floor is = 3

4.2. Design data considered for HDRB:

Design time period is T_D = 1.0 sec
Mean horizontal time period is T_M = 2.5 sec
Consideration of response reduction factor for the building is :
R = 5 (seismic load reduction factor)
shear modulus of rubber at large strains is G = 500 KN/m^2 (for large shear strains)
shear modulus of rubber at small strains is G = 700 KN/m^2 (for small shear strains)
Bulk modulus of rubber is K = 2000000 KN/m^2 (Bulk modulus)
Maximum shear strain as per IBC code is γ_{max} = 150% ;
Weight of the structure calculated as per IS : 1893 : 2002 is W_T = 27442.31 KN
Analytical procedure considered:

Step 1: Specifying of the soil condition for isolated structure.

IS :1893(part 1): 2002 forwarded page 4; specifies the use of international standards for design of isolated buildings from earth using base isolation and energy absorbing device .Base isolation system is useful for short period structures ,say less than 0.7sec including soil-structure interaction.

Clause 6.4.5 of IS: 1893(part 1):2002 proposed 5% spectra for rocky sites, medium sites, soft sites.“ Sa/g “value for the considered five storeyed building is same for all types of soils specified as in IS: 1893(part 1):2002.

International standard considered is ASCE/SEI-7-05;(American society of civil engineers).

Clause:-21.1.3 of ASCE/SE2-7.05 also specifies 5% damped response spectra of the soil profile.

From table 11.4-1and 11.4.3 of ASCE/SEI-07-05 ;The soils considered are medium soils and soft soils of T_D =1sec and T_D =1.5secrespectively ,as per ASCE/SEI-17.5.2.

Step 2: Selection of design shear strain and effective damping ratio for the bearing and the target time period for isolated structure is to be assumed.

For assumption of design shear strain as per ASCE/SEI 7-05 Three Limits are Imposed :-

(i)”V_S” should not be less than base shear required for a final base structure.

(ii)” V_S” should not be less than shear corresponding to the wind load.

(iii)” V_S” should not be less than150% of seismic force.

Hence maximum design shear strain is considered as **150%**

Total Height of the rubber is determined by using the formula i.e.,

$$t_r = \frac{D_D}{\gamma_{max}}$$

Where D_D is the displacement of isolated system (or) design displacement as per clause 17.5.3.1 of ASCE/SEI-7-05.

Step 3: Determination of total weight of the building.
For calculation at roof no imposed load to be lumped.
The roof load consists of self weight of slab + 50% load due to weight of wall below the storey weight of wall at each floor level.

Weight of wall at each floor level
=(total length of outer walls x thickness x storey height x unit weight of masonry) + (total length of inner walls x thickness x storey height x unit weight of masonry)

Step 4: Layout of the bearing locations and determination of number of bearings.

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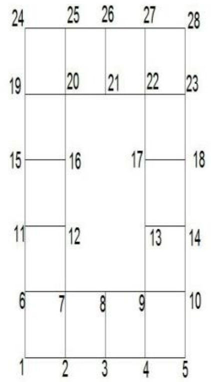

Figure 1: plan of a considered building

Step 5: Determination of maximum vertical load using IS 1893 PART I: 2002.
Maximum vertical load of the structure = P(Dead loads +Live loads)
$P_{vertical}$ = P(Dead loads +Live loads)

Step 6: Determination of fundamental time period of isolated structure using IS: 1893 (PART I): 2002.
As per Clause 7.6.2 of IS :1893(part 1): 2002 gives fundamental period of vibration (T_a) in seconds

$$T_a = \frac{0.09 * h}{\sqrt{d}}$$

Step 7: Determination of base shear and lateral inertia force distribution over the entire height of the multistory structure as per clause 7.7.1 of IS: 1893 (PART I): 2002.
Base shear formula according to clause 7.7.1 of IS 1893 (part 1) :2000

$$Q_i = V_B * \frac{Wihi\string^2}{\sum_{j=1}^{n} Wjhj\string^2}$$

Q_i = Design lateral force at floor
W_i = seismic weight of the floor
h_i = height of the floor measured in meters from base and
n= number of storeys in the building
V_B =Base shear along the lateral axis

Step 8: Determination of effective horizontal stiffness and maximum horizontal displacement of the bearing is made by using static/dynamic analysis.
(i) Determination of Effective Horizontal Stiffness:-
From table 11.4-1 and clause 11.4.3 of ASCE/SEI 07-05
for building in zone V using HRD for medium soils
T_D =1sec considered as explained in step 2:-
As per clause 17.5.3.2 effective time period

$$T_D = 2\pi \sqrt{\frac{w}{K_{Dmin} X g}}$$

(ii)Determination of maximum horizontal displacements of bearings:-
As per clause 17.5.3.3 of ASCE/SEI 07-05

$$D_D = \frac{g}{4\pi^2} \; X \; \frac{S_{D1} T_D}{B_D}$$

g= Accerlation due to gravity
S_{D1} = Minimum design damped spectral accerlation
B_M =numerical coefficient related to the effective damping of the isolation system at maximum displacement

$$D_D = \frac{g}{4\pi^2} \; X \; \frac{S_{D1} T_D}{B_D}$$

From code IBC 2000 clause 1615.1.2
Where, $S_{D1} = \frac{2}{3}$ x S_{M1}
S_{M1} = F_v x S_1
The damping reduction factor B_D is calculated from the equation

$$\frac{1}{B_D} = 0.25(1 - \ln \beta)$$

Where D_D and D_M are the displacements of the isolation system corresponding to the design earthquake and max capable earthquake respectively
Step 9: Material properties, young's modulus E and shear modulus G, are assumed as per the requirement.
Material properties are assumed as per the field requirements and products of HRDB and LPB are available from the market. Hence, the considered shear modulus of rubber at large strains is $G=500kN/m^2$
shear modulus of rubber at large strains is $G=700kN/m^2$
Bulk modulus of rubber is $K=2000000$ kN/m^2
Step 10: height of the rubber in the bearing system is to be calculated according to the design displacement and design shear strain.
Height of the rubber in the bearing system is calculated by Considering the thin steel plates thicknesses and top, bottom end plate thickness considerations.
Step 11: effective area and thickness of individual rubber, lead layers is to be calculated.
Taking γ_{max} =150% shear strain as per ASCE/SEI 07-05

$$\gamma = \frac{D}{tr}$$

Thickness of the disc can be calculated from

$$t_r = \frac{D_D}{\gamma_{max}}$$

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Step 12: Calculation of effective cross section area of the rubber bearing was calculated as per rubber hardness, young's modulus, shear modulus, load free area. Obtaining of minimum cross section area of the bearing system is calculated for shear failure of the bearing, identification of the requirement of the rectangular/circular bearing system.

for building in Zone V using HRDB γ_{max} =150%

Shear modulus of rubber G=500kN/m^2

Area can be calculated from the formula

$K_H = \frac{G*A}{tr}$

$A = \frac{KH*tr}{G}$

Step 13: shape factor and thickness of the rubber, lead bearing system is to be calculated.

We know that shape factor for circular bearing is

$S=\frac{\varphi}{4t}$

φ= diameter of the bearing

According to IBC-2000 S=shape factor =8

The compression modulus, E_c, from Equation

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

Step 14: steel plate's thickness which will be on the top and bottom of the rubber, lead bearing system is to be calculated.

end plate thicknesses are 25mm thick and steel shims are 2mm thick each are considered

Step 15: All the parameters made for design of rubber bearing system are to be checked against shear strain and stability conditions and then the shear force and roll out displacement of the bearing system is to be calculated.

$\sigma_c = \frac{P}{A} < \sigma_{cr} = \frac{GsL}{2.5tr}$

4.3.Design of Lead rubber bearing:

Design time period is T_D = 1.0 sec

Mean horizontal time period is T_M = 2.5 sec

Consideration of response reduction factor for the building is :

R = 5 (seismic load reduction factor)

shear modulus of rubber at large strains is G = 500 KN/m^2 (for large shear strains)

shear modulus of rubber at small strains is G = 700 KN/m^2 (for small shear strains)

Bulk modulus of rubber is K = 2000000 KN/m^2 (Bulk modulus)

Maximum shear strain as per IBC code is γ_{max} = 150% ;

Weight of the structure calculated as per IS : 1893 : 2002 is W_T = 27442.31 KN

Analytical procedure considered:

Step 1: Specifying of the soil condition for isolated structure.

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Step 2: Selection of design shear strain and effective damping ratio for the bearing and the target time period for isolated structure is to be assumed.

For assumption of design shear strain as per ASCE/SEI 7-05 Three Limits are Imposed :-

(i)"V_S" should not be less than base shear required for a final base structure.

(ii)" V_S" should not be less than shear corresponding to the wind load.

(iii)" V_S" should not be less than150% of seismic force.

Hence maximum design shear strain is considered as **150%**

Total Height of the rubber is determined by using the formula i.e.,

$$t_r = \frac{D_D}{\gamma_{max}}$$

Where D_D is the displacement of isolated system (or) design displacement as per clause 17.5.3.1 of ASCE/SEI-7-05.

Step 3: Determination of total weight of the building.

For calculation at roof no imposed load to be lumped. The roof load consists of self weight of slab + 50% load due to weight of wall below the storey weight of wall at each floor level.

Weight of wall at each floor level

=(total length of outer walls x thickness x storey height x unit weight of masonry) + (total length of inner walls x thickness x storey height x unit weight of masonry)

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Step 4: Layout of the bearing locations and determination of number of bearings.

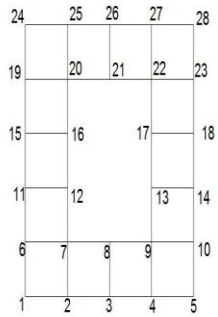

Figure 2: plan of a considered building

Step 5: Determination of maximum vertical load using IS 1893 PART I: 2002.

Maximum vertical load of the structure = P(Dead loads +Live loads)

$P_{vertical}$ = P(Dead loads +Live loads)

Step 6: Determination of fundamental time period of isolated structure using IS: 1893 (PART I): 2002.

As per Clause 7.6.2 of IS :1893(part 1): 2002 gives fundamental period of vibration (T_a) in seconds

$$T_a = \frac{0.09*h}{\sqrt{d}}$$

Step 7: Determination of base shear and lateral inertia force distribution over the entire height of the multistory structure as per clause 7.7.1 of IS: 1893 (PART I): 2002.

Base shear formula according to clause 7.7.1 of IS 1893 (part 1) :2000

$$Q_i = V_B * \frac{Wihi\,\hat{}\,2}{\sum_{j=1}^{n} Wjhj\,\hat{}\,2}$$

Q_i = Design lateral force at floor

W_i = seismic weight of the floor

h_i = height of the floor measured in meters from base and

n= number of storeys in the building

V_B =Base shear along the lateral axis

Step 8: Determination of effective horizontal stiffness and maximum horizontal displacement of the bearing is made by using static/dynamic analysis.

(i) Determination of Effective Horizontal Stiffness:-

From table 11.4-1 and clause 11.4.3 of ASCE/SEI 07-05

for building in zone V using HRD for medium soils T_D =1sec considered as explained in step 2:-

As per clause 17.5.3.2 effective time period

$$T_D = 2\pi\sqrt{\frac{w}{K_{D\,min}\,X g}}$$

(ii)Determination of maximum horizontal displacements of bearings:-

As per clause 17.5.3 of ASCE/SEI 07-05

$$D_D = \frac{g}{4\pi^2} \ X \ \frac{S_{D1}T_D}{B_D}$$

g= Accerlation due to gravity

S_{D1} = Minimum design damped spectral accerlation

B_M =numerical coefficient related to the effective damping of the isolation system at maximum displacement

$$D_D = \frac{g}{4\pi^2} \ X \ \frac{S_{D1}T_D}{B_D}$$

From code IBC 2000 clause 1615.1.2

Where, $S_{D1} = \frac{2}{3}$ x S_{M1}

S_{M1} = F_v x S_1

The damping reduction factor B_D is calculated from the equation

$$\frac{1}{B_D} = 0.25(1 - \ln\beta)$$

Where D_D and D_M are the displacements of the isolation system corresponding to the design earthquake and max capable earthquake respectively

Step 9: Material properties, young's modulus E and shear modulus G, are assumed as per the requirement.

Material properties are assumed as per the field requirements and products of HRDB and LPB are available from the market. Hence, the considered shear modulus of rubber at large strains is $G=500kN/m^2$

shear modulus of rubber at large strains is $G=700kN/m^2$

Bulk modulus of rubber is K=2000000 kN/m^2

Step 10: height of the rubber in the bearing system is to be calculated according to the design displacement and design shear strain.

Height of the rubber in the bearing system is calculated by Considering the thin steel plates thicknesses and top, bottom end plate thickness considerations.

Step 11:- Effective Area and Thickness of Individual rubber:-

Taking γ_{max} =150% shear strain as per ASCE/SEI 07-05

$$\gamma = \frac{D}{tr}$$

Energy dissipated per cycle is $W_D = 2\pi\left(K_{eff}\right)D^2$ x β_{eff}

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Area of the hypothesis loop, however is given by
$W_D = 4Q_d(D – D_y)$
D_y is very small so neglecting it.
$W_D = 4Q_d(D)$
Yield strength of lead plug bearing is $D_y = Q_d/(K_u – K_d)$ but here $K_u \approx 10 K_d$

$$\therefore D_y = \frac{Q_d}{9K_d}$$

Step 12:-for building in Zone V using HRDB γ_{max} =150%
Shear modulus of rubber $G=500kN/m^2$
The total cross sectional area of the lead plug area needed for the entire isolation system is

$$A_{pd}^{total} = \frac{Q_d}{F_y^{pb}}$$

Vertical fundamental period of vibration:

$T_v = T_H/(\sqrt{6} \text{ x } S)$

RESULTS AND DISCUSSIONS

Analysis and design of seismic isolation of a 5 storey building was done with a response reduction factor of "1" and mean horizontal time period as 2.5 seconds as per IBC code. shear modulus of rubber considered is $500kN/m^2$ and bulk modulus was 2000000 kN/m^2. Shear strain considered is γ = 150% weight of the structure calculated and was 27442.31kN. Fv of lead plug bearing was 2000kN.

Step 13 :-Shape factor $S = \frac{\varphi}{4*to}$

$t_o = \frac{\varphi}{4*s}$

Step 14:- end plate thicknesses are 25mm thick and steel shims are 2mm thick each are considered
Step 15:- check for shear strains & stability conditions :

$$\sigma_c = \frac{P}{A} < \sigma_{cr} = \frac{GsL}{2.5tr}$$

Where σ_c is the average compressive stress,
σ_{cr} is the critical compressive stress and the bearing should full fill the following above condition
This check is done for bearing to prevent it from becoming unstable
(ii) rollout bearing system:

$$\delta_{max} = \frac{Pload*L}{Pload+(Kh*h)}$$

Tab 1: The details of the calculated seismic isolation bearing system details are tabulated as:

Details	Case	Thickness of rubber (To)(mm)	Total height of bearing (mm)	End plate thickness (mm)	Area (m^2)	Dia of bearing (cm)
Zone V HRD	CASE I	40mm	468mm	25mm	1.23	125
Zone V LPRD	CASE II	60mm	668mm	25mm	1.301	190
Zone IV HRD	CASE III	30mm	368mm	25mm	0.701	95
Zone IV LPRD	CASE IV	40mm	468mm	25mm	0.950	110

CONCLUSION

1. Compared to case I and case II for zone V and T = 1.0 sec the single rubber layer thickness To has increased a percentage of 33%.
2. Compared to case III and case IV for zone IV and T = 1.5 sec, the single rubber layer thickness To has increased a percentage of 25%.
3. The increase in height of Lead plug rubber bearing system is due to the consideration of compressive strength consideration of lead plug and also due to the consideration of yield strength of the lead plug.
4. The above considerations of lead plug are essential due to the load resistance properties of the lead plug, lead plug is an alloy of carbon and at its highest bearing capacity of the axial load stress applications the plug losses its load bearing capacity resulting in brittle failure, hence an increase in area of the lead plug with respect to height is indirectly effecting the height of the rubber cover surrounded by the lead plug. The change in height comes due to the effect of lead plug material property.
5. Increase in height will not affect the lead plug in buckling condition, due to its property of toughness and protected by the rubber cover throughout its surface.
6. In conclusion the change in increase in area of the lead plug bearing system is due to the increase in area of plug system resulted in

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increase in area of LPRD of nearly 6% than the area of HRD. An increase in area of 6% is minimum when not considering the economical standard.

7. On the other hand, consideration of energy cycle in lead plug rubber bearing design, the bearing system also resists the energy comes from fatigue loads or cyclic load conditions which increase the safety of the bearing system.
8. Total height of the bearing system of case I high rubber damping system is nearly equal to case IV lead plug bearing system.
9. Lowest diameter and area of bearing are obtained for case III i.e., zone IV high rubber damping system of 95cm and 0.701m^2 respectively.
10. Effective horizontal stiffness of the bearing system is 3944.149 KN/m and for LRB is 631.06 KN/m which has a reduction of 16% of horizontal stiffness for each bearing system.
11. Obtained time period of the building is 0.392(Ta), and obtained design time period for the bearing systems is 0.7(T_D) which satisfies the condition of $Ta < T_D$ as per ASCE 07-10 coda provisions.
12. Obtained base shear for zone V is 3704.712kN, and for zone IV is 2469.13kN, the change of base shear considering in calculation of horizontal stiffness considering base shear value as "W" for determining time period is also a parameter which governs the change of bearing dimensions of the bearing systems.
13. Area of HRD bearing in zone V is 1.23m^2 and in zone IV is 0.701m^2 by change of zone intensity value from 0.36 to 0.24 the change of base shear considered in calculation of design time period finally resulted in reduction of 56.9% of area of bearing system which shows the effect of base shear in determining the dimensions of bearing systems.
14. Similarly there is a reduction in thickness of rubber bearings from zone V to zone IV of nearly 20% for HRDB to LRB systems.
15. Similarly for zone V the diameter of HRDB system reduced by 20% to zone IV diameter HRDB system. For LRB system nearly 40% reduction was observed from change of zone intensity from zone V to zone IV.
16. Roll out condition of HRD bearing system for zone V is 0.06151 and for LRB system is 0.06814 which is similar, for Zone IV condition HRD bearing system, roll out condition is 0.1254 and for LRB is 0.110 which also a nearer value show that the roll out condition depends on the intensity of the base shear obtained from static condition in recurrent of horizontal stiffness of the bearing system calculations.
17. Design displacement for zone V condition is 0.1m and maximum allowable displacement is 0.2340m, Design displacement for zone IV is 0.15m and maximum allowable displacement is 0.2340m. In both cases of zones maximum allowable displacement is 0.2340m but the design of base isolation displacement is restricted to 0.1m to 0.15m for the considered zones so as to increase the safety of the building from much displacement due to horizontal forces of ground acceleration.

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