ENHANCING SEISMIC RESILIENCE OFHIGH-RISE BUILDING USING BASE ISOLATION TECHNIQUE WITH VARIOUS RUBBER THICKNESS

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ABSTRACT

This project presents a smart way to protect tall buildings from earthquakes using base isolation techniques. The main aim is to reduce the impact of earthquake forces on structures by separating the building from its foundation. This clever anti-earthquake strategy adds flexibility to the structure. This project studies G+10 building made of reinforced concrete, located in a high seismic zone (Zone V). To make them safer, High Damping Rubber bearing (HDRB) systems with rubber thicknesses of 15cm, 20, 25 and 30cm as base isolators is used. For analysis, ETABS software is used. By comparing the results of different analysis methods, effectiveness of base isolation technique is in lessening the building's movement during an earthquake is checked. Things like total base shear forces, how much each floor moves (storey displacements), and how much each floor tilts (storey drifts) are analyzed. In this project, the findings for buildings with fixed bases and those with base isolation is compared. This study gives valuable insights into how base isolation can make high-rise buildings safer in earthquake-prone areas. This can help engineers and designers make better choices to protectbuildings and the people inside them during earthquakes.

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Keyword: - *Seismic resilience, Base Isolation, HDRB Dampers, high-rise building, seismic zone etc….*

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1. INTRODUCTION

An earthquake is a ground vibration due to the rapid release of energy. The vibration produced causing the ground to be in motion where such ground motion generates complicated transient vibrations in structures. The response of a structure under earthquake loading is directly associated with the response of soil to ground shaking. Thus, the extent and degree of damage during an earthquake is mainly influenced by the response of soil to ground vibrations. Therefore, it is vital to evaluate the response of soil due to ground vibration.

Though the structures are supported on soil, most of the designers do not consider the soil structure interaction and its subsequent effect on structure during an earthquake. Different soil properties can affect seismic waves as they pass through a soil layer. When a structure is subjected to an earthquake excitation, it interact the foundation and soil, and thus changes the motion of the ground. It means that the movement of the whole ground structure system is influenced by type of soil as well as by the type of structure. Tall buildings are supposed to be of engineered construction in sense that they might have been analyzed and designed to meet the provision of relevant codes of practice and building byelaws. IS 1893: 2002 “Criteria for Earthquake Resistant Design of Structures” gives response spectrum for different types of soil such as hard, medium and soft soil.

1.1 Seismic Zones

A seismic zone is a region in which the rate of seismic activity remains consistent. This may mean that seismic activity is incredibly rare, or that it is extremely common. Some people often use the term “seismic zone” to talk about an area with an increased risk of seismic activity, while others prefer to talk about “seismic hazard zones” when discussing areas where seismic activity is more frequent.

Many nations have government agencies concerned with seismic activity. These agencies use the data they collect about seismic activity to divide the nation into various seismic zones. A number of different zoning systems are used, from numerical zones to colored zones, with each number or color representing a different level of seismic activity.

1.1.1. Classification of seismic zones

The 1993 Latur earthquake of magnitude 6.3-caused intensity IX damages but prior to the earthquake, Latur was placed in seismic zone 1, where no such magnitude of earthquake was expected. The Latur earthquake further led to the revision of the seismic zonation map of India. The map was revised again in 2002 with only four zones such as II, III, IV and V (IS: 1893 (Part 1): 2002). The Peninsular India was modified and Zones I and II were combined. The new zone placed the 1993 Latur earthquake in zone III. The areas falling under zone V is most seismically active. The areas under this zone are the entire northeastern part of India, parts of northwestern Bihar, the Kangra Valley in Himachal Pradesh, Andaman and Nicobar Islands, eastern part of Uttaranchal, the Rann of Kutchh in Gujarat and the Srinagar area in Jammu and Kashmir. Two major metropolitan cities, with a high population density, i.e. Delhi, lie in zone IV, and Kolkata, at the boundary of zone III and IV of the zonation map. The recent four seismic zones of India are assigned PGA values ranging from 0.1 g to 0.4 g with 10% probability of exceedance in 50 years. The changes in zonation map of India with the occurrence of significant earthquakes are an indication that the zoning at a national level does not providethe solution for tackling the seismic hazards.

Table -1: Zone value for different zones

Zone	II	III	IV	V
Intensity	Low	Medium	Severe	Very Severe
Zone value	0.1	0.16	0.24	0.36

1.3. Soil Classification

Determining Soil Profile Type for Identifying the Response Spectrum

The soil profile mainly constituting the local soil below the foundation required for use of response spectra is divided into three types. It is quite natural to have variation in properties of soil, and most soil depositshave both vertical as well as lateral variation of properties depending on the geomorphic forces and source of soil formation. There may be soil layers of varying properties of the similar soil type namely coarse-grained soils (Gravels, Sands or Sandy Gravels, or Gravelly Sands); fine-grained soils (Clays or Silty Clays or Clayey Silts) or there may be interlaying of coarse grained soils and fine grained soils. The importance of local site conditions and its role on the response of structures has been well recognized. The soil and rock at a site have specific characteristics that can significantly amplify the incoming earthquake motions traveling from the earthquake source.

IS: 1893-2002 - Part 1 has acknowledged the importance of local site effects and has defined three soil profile types, which essentially are rock or hard soils (Type I), medium soils (Type II), and soft soils (Type III). The code has suggested a design spectrum for each of these soil profile types. However, the code does not explain how to decide the type of soil profile to be used to select the appropriate design acceleration spectrum, given the variation of soil profile in a particular locality. Thus, a procedure is required to arrive at the type of soil profile.

Soil profile types are to be characterized based on the average soil properties for the upper 30 m of the soil profile. Standard penetration test is a field test conducted at regular intervals in every borehole, which has a good correlation with engineering properties of soil. N values, which are corrected for overburden and dilatancy effects, are correlated with relative density and hence the angle of internal friction for coarse-grained type of soils and the undrained shear strength of fine-grained soils. Relative density reflects the state of compactness of coarse-grained soils, and the undrained strength reflects the stiffness of fine-grained soils. These, in turn, reflect the field behavior of a profile of soil. For layered soils having varying properties over the exploration depth of30 m, the average N values are to be obtained.

2. SEISMIC ANALYSIS

In general, the methods of seismic analysis can be classified as (1) Static and (2) Dynamic. Dynamic analysis can further be classified as (i) Dynamic Characteristics based (static) Analysis and (ii) Time Domain Analysis. All of the above categories have their (a) Linear and (b) Non-linear counterparts

2.1 Static Analysis

The static procedure of building is modelled with their linearly elastic stiffness of the building. The equivalent viscous damps the approximate values for the lateral loads to near the yield point. Design earthquake demands for the LSP (LINEAR STATIC PROCEDURE) are represented by static lateral forces whose sum is equal to the pseudo lateral load. When it is applied to the linearly elastic model of the building it will result in design displacement amplitudes approximating maximum displacements that are expected during the design earthquake. To design the earth quake loads to calculate the internal forces will be reasonable approximate of expected during to design earth quake.

a. Linear Analysis

Seismic Coefficient Method (SCM): Here the seismic base shear for the building is determined by using an emphatically determined time period, and distributed over the stories as lateral load proportional to an assumed mode shape, which is parabolic (but interestingly with 100% mass participation assumed). Here lateral load determination is all formula based, no modal analysis is required, and the method is therefore STATIC.

b. Non-linear Analysis

Non-linear Static Analysis (NSP) or Pushover Analysis: Unlike as SCM (where the lateral load of a calculated intensity is applied in whole - in one shot), in NSP, analysis model is gently 'pushed over' by a monotonically increasing lateral load applied in steps up to a predetermined value or state. Here also seismic base shear for the building is distributed over the stories as lateral load proportional to an assumed mode shape, which is either uniform or a power distribution with the value of “k” determined to be a value between 1 (inverted triangular distribution) and 2 (parabolic distribution) by an empirical method.
(k is the power of h shown with k=2 in the formula under IS: 1893, Clause 7.7.1)

2.2 Dynamic Analysis

The representation of the maximum response of idealized single degree freedom system having certain period and damping, during earthquake ground motions. The maximum response plotted against of un-damped natural period and for various damping values and can be expressed in terms of maximum absolute acceleration, maximum relative velocity or maximum relative displacement. For this purpose response spectrum case of analysis have been performed according to IS 1893.

a. Linear Analysis

Dynamic Characteristics based (static) Analysis

i. Response Spectrum Analysis (RSA) (IS: 1893, 7.8.4) – Here a DYNAMIC (modal) analysis is done to get the dynamic characteristics of the building (natural frequencies and mode shapes) from which the lateral loads corresponding to each mode shape is calculated, with which a STATIC analysis is performed for each mode, theresults (BM, SF, etc.) of which are then combined (SRSS) to get the design forces.

ii. Time Domain Analysis

Linear Time History Analysis (IS: 1893, Cl.7.8.3): In THA, the support points of the model is oscillated back and forth in accordance to a recoded ground motion of an actually occurred earthquake (as recorded by a seismograph, and available in tabular form of time vs. acceleration). The results (BM, SF, etc.) are usually takenas the maximum enveloped over time (i.e., the max. BM on the mid span of a particular beam in the maximum among all the BMs, each corresponding to each time point over the duration of earthquake.

b. Non-linear Analysis

Dynamic Characteristics based (static) Analysis

i. Non-linear Static Analysis (NSP) or the same Pushover Analysis mentioned above, but with the 1st mode proportionate lateral loads or more rightly, a combination (SRSS) proportionate lateral loads. Note that unlike the RSA, it’s not the results corresponding to each mode shape that is SRSS’ed, but the loads themselves. No one considers putting this version of pushover analysis under Non-linear Dynamic Analysis (and as the non- linear counterpart of RSA.)

ii. Time Domain Analysis: Non-linear Time History Analysis (NL-THA) Here since the structure has non- linear hinges inserted, the members can undergo and stiffness degradation, strength deterioration – in general, damage, as a real building would, during the progress of an earthquake.

Table -2: Elastic property of foundation

Type of Soil	Shear Modulus G(kN/m^2)	Elastic Modulus E(KN/m^2)	Poisson's Ratio ν
Hard	2700	6750	0.25
Medium	451.1	1200	0.33
Soft	84.5	250	0.48

3. Numerical Investigation

Structural design of earthquake resistant buildings has almost become mandatory now all over India. As such, many companies implemented relevant clauses of IS 1893(Part 1):2002 and IS: 13920-1993 applicable for RC buildings in structural analysis software. The intention is to provide a fast and reliable tool to structural engineers using which they can off-load the arduous task of cumbersome calculations to software and at the same time can apply their own good judgment for interpretation of results to provide appropriate practical design & detailing for all components of buildings like slabs, beams, columns and foundation. The best part of software is that, it calculates the Earthquake loads automatically from the basic parameters provided by user.

The design of a building can be done by conventional method or with the help of Software. In this study structure are designed by using Software for very severe seismic condition (zone 5) and various soil type because designing by conventional method consumes lot of time, effort and can contain errors whereas by using software time will be saved and can obtain more accurate results. As mentioned above, software named "ETABS" abbreviated as "Structural Analysis Design and Detailing Software" is used.

The purpose for us using the software is that it is user friendly and has unique features like it designs the structural components individually along with their Analysis and Results. Another useful feature of this software is that we can view the analysis result of each member at any story level. In this report regular building modal has been analyzed by static analysis with very severe seismic condition (zone 5) and different soil conditions. The static has done on computer with the help of software using the parameters for the designing as per the IS 1893(Part 1): 2002 for the all zone and soil conditions and the post processing result obtained hassummarized in succeeding tables.

3.1 Model Description

The building is consisting of Ground + 10 storey of RC MULTI COMPLEX Building. The floor plan of the building is given in Fig.3.1. The beam and column layouts are first fixed and the modelling will be done using software ETABS. During analysis, the dead loads and live loads will be calculated from IS: 875 (Part 1 & 2) and seismic load calculated by referring IS 1893 (Part 1) 2002 and their combinations were applied on the space frame. An equilibrium check on the support reaction was made to ensure the correctness of the analysis. From the analysis various load combinations were taken to obtain the maximum design loads, moments and shear on each member. The design is carried as per IS code for the critical load combinations. The concrete mix used is M25 & steel used is Fe500 grade. The floor plans, column location and typical beam and slabarrangement of the structure are as shown in the figures 3.1&3.2.

The properties of various frame sections such as cross-sectional dimensions of beams, columns, slabs and the material property were calculated and assigned on a particular member is given in table 3.1. The support condition was given as hinge support. As per IS 456:2000 clause 24.1, L/D= 32 for all and slab and the initial dimensions were calculated. In the case of beams and columns as per IS 456:2000 clause 25.1.1 L/D = L/B= 12, was used to determine the initial dimensions and using these values modelling was done.

Table -3: Properties of the member sections

Member		Dimensions (mm)
Slab	S1	150(Thickness)
Column	C1	600 x 600
	C2	400 x 400
Beam	B1	230 x 600
	B2	230 x 500
	B3	230 x 400
	B4	230 x 300

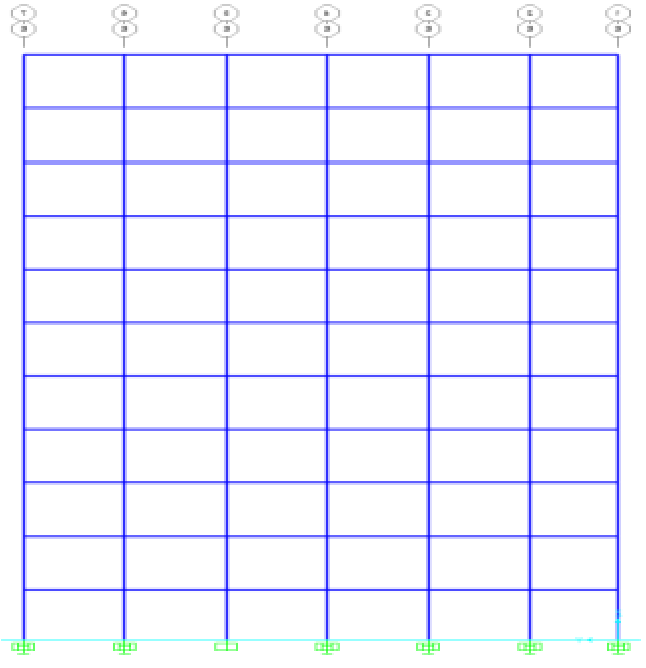


Fig -1: Elevation of the model – Fixed Base Model

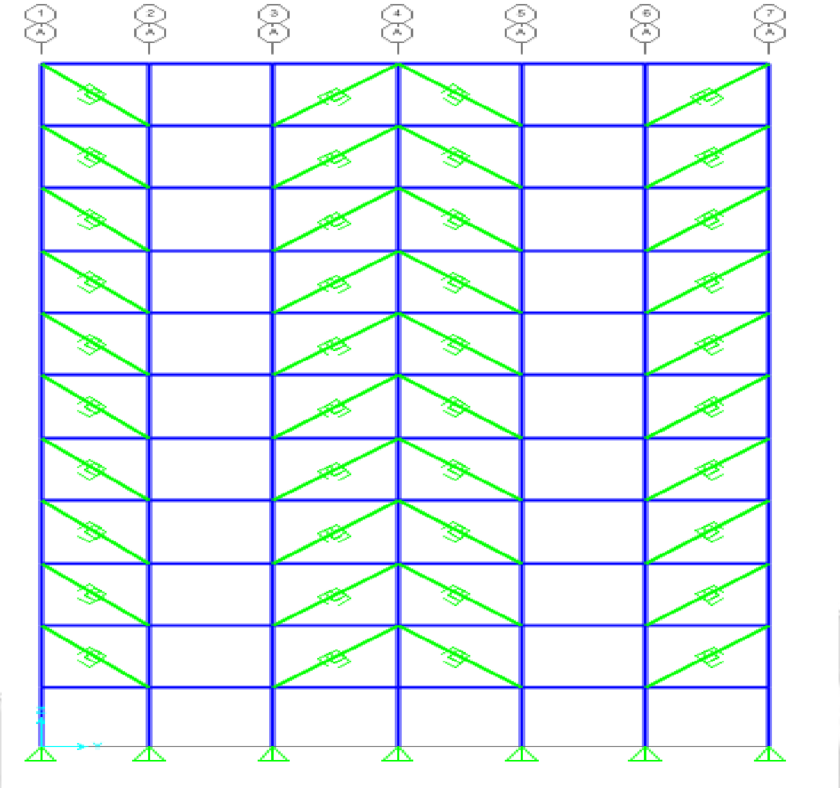


Fig -2: Elevation of the model – HDRB Model

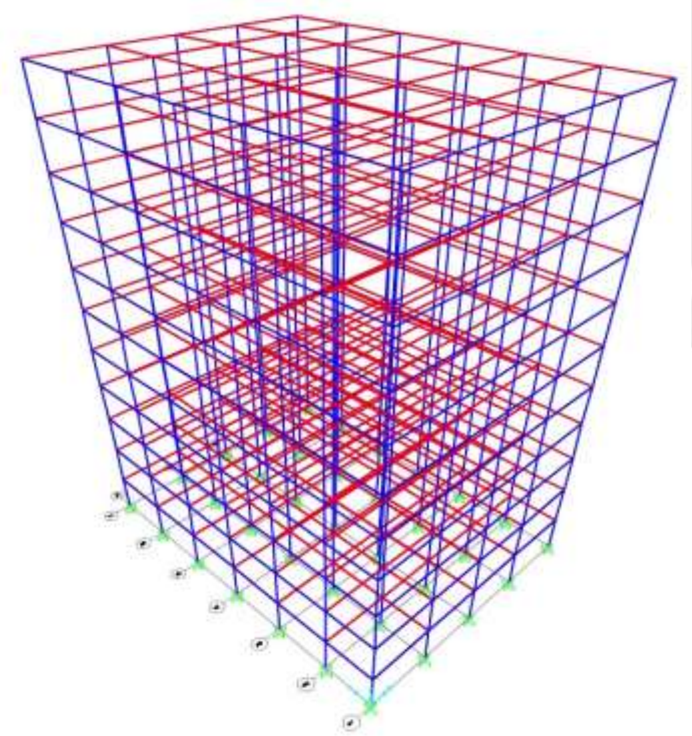


Fig -3: 3D view of the model –Fixed Base Model

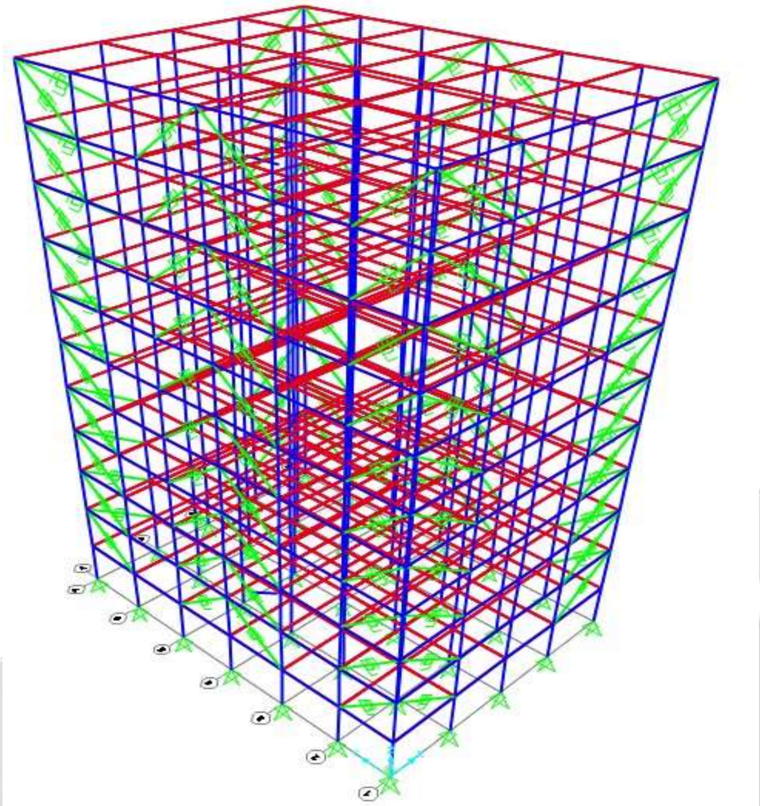


Fig -4: 3D view of the model HDRB Model

3.2 Loads and Load Calculations

The different load cases which are considered are dead load, live load land seismic load.

3.2.1 Dead Load Calculations

Dead load is primarily due to self-weight of structural members, permanent partition walls, fixed permanent equipment and weights of different materials. Loads shall be calculated on the basis of unit weight ofmaterials used and is specified in IS 875 (Part I) 1987.

Self-weight of wall due; to brick = Unit weight of brick x Thickness of wall x (Height of wall – Depth of beam)

Dead load of full brick wall

For beam 600 mm depth
Self-weight = 19 X .24 X (3-0.6) = 10.94 kN/m
For beam 500 mm depth
Self-weight = 19 X .24 X (3-0.5) = 11.4 kN/m
For beam 300 mm depth
Self-weight = 19 X .24 X (3-0.3) = 11.856 kN/mFloor
Finish = 1 kN/m^2

3.2.2 Live Load Calculations

Live loads were taken from IS 875: 1987(Part 2). The live load is considered as 5 KN/m^2 uniformlydistributed loads.

3.2.3 Earthquake Forces

Earthquakes generate beams which move from the origin of its location with velocities depending onthe intensity and magnitude on earthquake. The impact of earthquake on structures depends on the stiffness of the structure, stiffness of the soil media, height and location of the structure. Etc. The earthquake forces are prescribed in IS 1893:2002 Part 1. Since the building is located in Tamilnadu, it is included in zone 5, and the seismic base shear calculation and its distribution was done as per IS 1893:2002 Part 1 Clause 7.5.3.

The base shear or total design lateral force along any principal direction shall be determined by the following expressions:

$$V_b = Ah \times W$$

Where,
V_b = Design seismic base shear
Ah = Design horizontal acceleration spectrum value using the fundamental natural period in the considered direction of vibration.
W = Seismic weight of the building.

The design horizontal seismic coefficient as per Clause 6.4.2 of IS 1893:2002 Part 1

$$Ah = ZIS_a/2Rg$$

Where,
Z = Zone factor
Zone factor for different seismic zones is given below in table.3.2.

Table -4: Zone factor

Seismic Zone	II	III	IV	V
Seismic Intensity	Low	Moderate	Severe	Very Severe
Zone factor	0.10	0.16	0.24	0.36

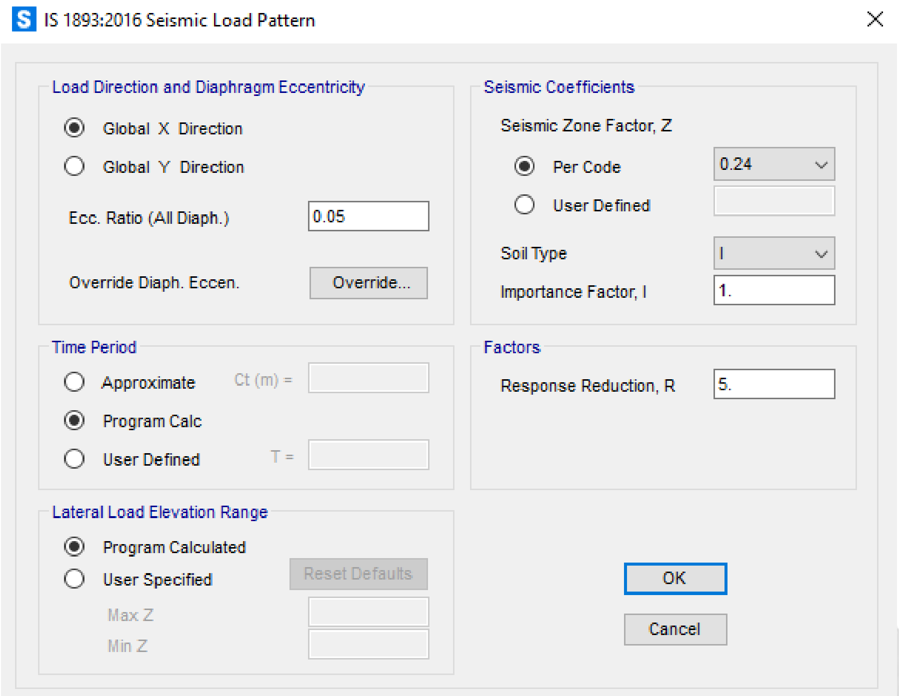
I = Importance factor (Table 6 of IS 1893 (Part -1) :2002)
R = Response reduction factor (Table 7 of IS 1893 (Part - 1): 2002)Sa/g= Average response acceleration coefficient

Apart from the Gravity loads, lateral loads are assumed, Seismic definition is given as per the IS 1893:2002 (part 1) Seismic value is very severe condition which is zone V, response reduction factor is assumed to be 5, assumption is taken that it is the ductile detailing design and Importance factor is taken as 1, while the building soil change and accordingly (Sa/g) value changes.

The seismic analysis of the proposed building was done by using the software ETABS 2015 as per IS1893 (Part 1): 2002 by giving the following data:

Table -5: Seismic Property

Seismic Zone	IV
Seismic Zone factor (Z)	0.24
Importance factor (I)	1
Response Reduction factor (R)	5



IS 1893:2016 Seismic Load Pattern

Load Direction and Diaphragm Eccentricity

● Global X Direction
○ Global Y Direction
Ecc. Ratio (All Diaph.): 0.05
Override Diaph. Eccen.: Override...

Seismic Coefficients

Seismic Zone Factor, Z
● Per Code: 0.24
○ User Defined
Soil Type: I
Importance Factor, I: 1.

Time Period

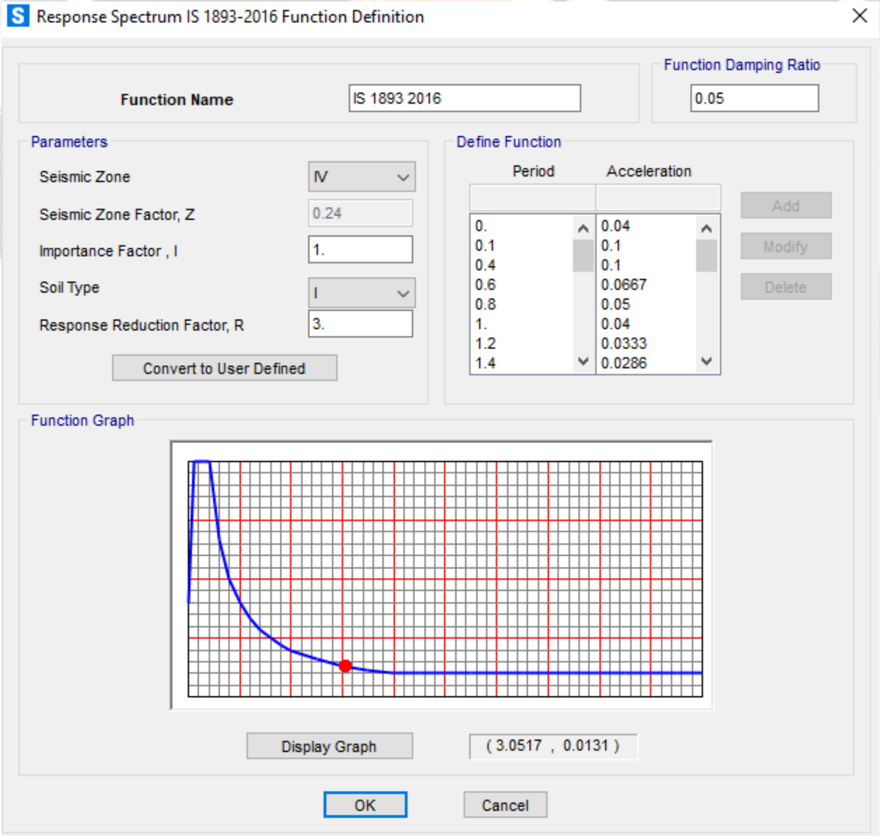
○ Approximate Ct (m) =
● Program Calc
○ User Defined T =

Factors

Response Reduction, R: 5.

Lateral Load Elevation Range

● Program Calculated
○ User Specified
Max Z
Min Z



Response Spectrum IS 1893-2016 Function Definition

Function Name: IS 1893 2016
Function Damping Ratio: 0.05

Parameters

Seismic Zone: IV
Seismic Zone Factor, Z: 0.24
Importance Factor , I: 1.
Soil Type: I
Response Reduction Factor, R: 3.

Define Function

Period	Acceleration
0.	0.04
0.1	0.1
0.4	0.1
0.6	0.0667
0.8	0.05
1.	0.04
1.2	0.0333
1.4	0.0286

Function Graph

(3.0517 , 0.0131)

Fig -5: Seismic Property

3.3 Load Combinations

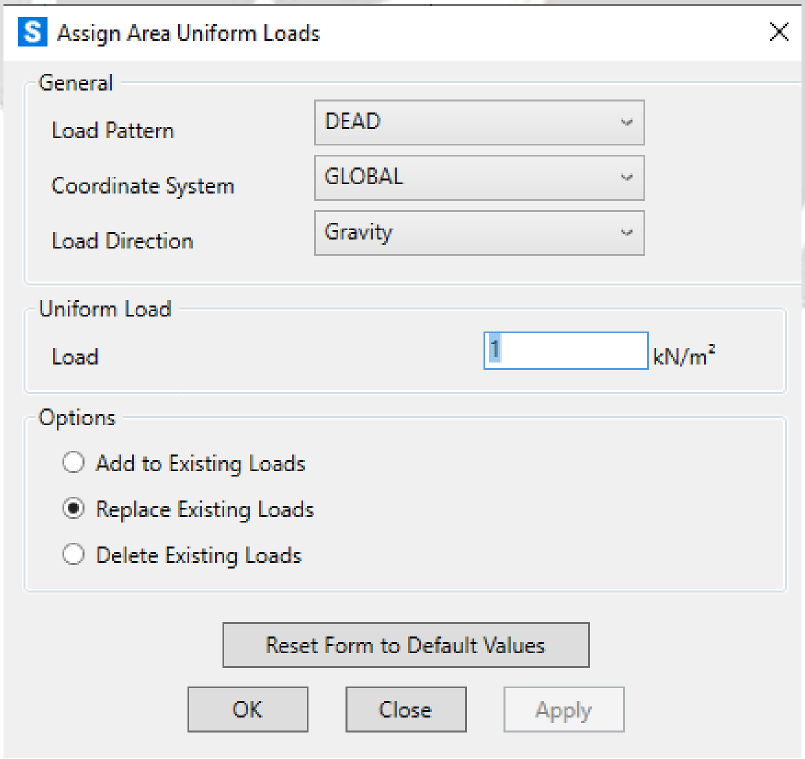
Design of structures would have become highly expensive in order to maintain serviceability and safety, if all types of forces would have acted on all structures at all times. Accordingly, the concept of characteristic loads has been accepted to ensure at least 95 percent of the case, the characteristic loads considered will be higher than the actual loads on the structure. However, the characteristic loads are to be calculated on the basis of average or mean load of some logical combinations of all loads mentioned below. IS 456:2000 and IS 1893 (Part I): 2002 stipulates the combination of the loads to be considered in the design of thestructures.

The different load combinations used were:1. 1.5 DL
2. 1.5 (DL+LL)
3. 1.2 (DL+LL+EQX) 4. 1.2
(DL+LL+EQ-X)
5. 1.2 (DL+LL+EQZ) 6. 1.2
(DL+LL+EQ-Z)7. 1.5 (DL+EQX)
8. 1.5(DL+EQ-X)
9. 1.5 (DL+EQZ)
10. 1.5 (DL+EQ-Z)
11. 0.9DL+1.5EQX
12. 0.9DL+1.5EQ-X
13. 0.9DL+1.5EQZ
14. 0.9DL+1.5EQ-Z

All these combinations are built in the ETABS.

Analysis results from the critical load combinations are used for the design of the structural members.

Note:
DL - Dead load
LL - Live load
ELX - Earthquake load in X direction ELZ -
Earthquake load in Z direction EQ-X - Earthquake
load in (–X) directionEQ-Z - Earthquake
load in (–Z) direction



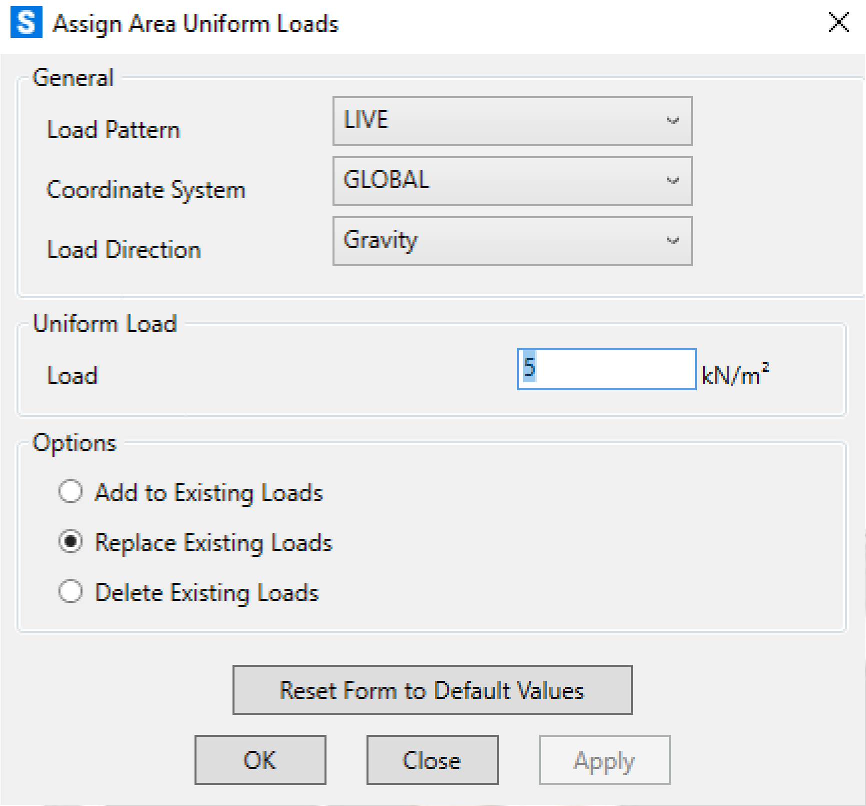
Assign Area Uniform Loads

General
Load Pattern DEAD
Coordinate System GLOBAL
Load Direction Gravity

Uniform Load
Load 1 kN/m²

Options
○ Add to Existing Loads
● Replace Existing Loads
○ Delete Existing Loads

Fig -6: Dead Load Diagram of Typical floor



Load Pattern: LIVE
Coordinate System: GLOBAL
Load Direction: Gravity
Load: 5 kN/m²
○ Add to Existing Loads
● Replace Existing Loads
○ Delete Existing Loads

Fig -7: Live Load Diagram of Typical floor

3.4 HDRB Dampers

HDRB dampers (High Damping Rubber Bearings) are a type of energy dissipation system used in civil engineering to improve the seismic resilience of structures, particularly bridges and buildings. These dampers consist of a combination of rubber bearings and steel plates, designed to absorb and dissipate seismic energy during earthquakes.

The key features of HDRB dampers include:

High Damping Capacity: The name "High Damping Rubber Bearings" reflects their ability to provide significant damping or energy absorption during seismic events. The rubber material in the bearings allows for high energy dissipation, reducing the seismic forces transmitted to the superstructure.

Vertical and Lateral Movement: HDRB dampers offer both vertical and lateral movement, allowing the structure to move independently of the ground motion during an earthquake. This movement helps in isolating the building or bridge from the damaging effects of seismic waves.

Replaceable and Reusable: In the event of a severe earthquake that activates the dampers, they may experience damage. One advantage of HDRB dampers is that they can be designed to be replaceable and reusable, ensuring the system can be restored after a major seismic event.

Design Flexibility: HDRB dampers can be designed to cater to various structural configurations and loads, making them suitable for retrofitting existing buildings and bridges, as well as incorporating them into new construction projects.

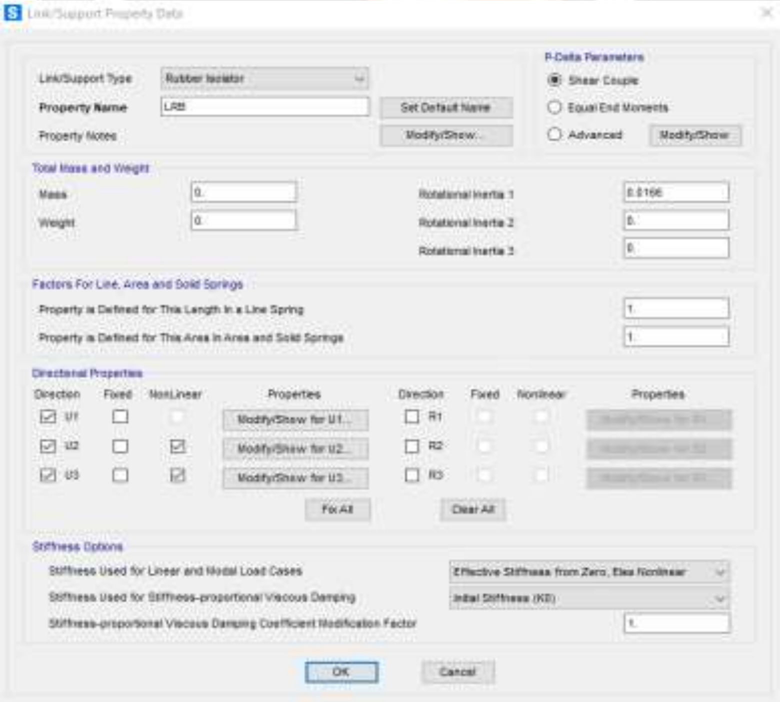
Reduced Structural Damage: By effectively absorbing and dissipating seismic energy, HDRB dampers can reduce structural damage during earthquakes. This characteristic is particularly crucial for critical infrastructure, such as hospitals, emergency response centers, and lifeline structures.

Cost-Effectiveness: Compared to other advanced seismic-resistant systems, HDRB dampers are often considered cost-effective, especially when retrofitting existing structures. They provide a viable alternative to enhance seismic performance without substantial alterations to the original design.

Characteristics	HDRB (Rubber thickness 150mm	HDRB (Rubber thickness 200mm)	HDRB (Rubber thickness 250mm)	HDRB (Rubber thickness 300mm)
Height	300 mm	500 mm	700 mm	900 mm
Weight	6 kN	18 kN	22.5 kN	55 kN
Compressive Stiffness	2500x10^3 kN/m	3995x10^3 kN/m	8540x10^3 kN/m	10040x10^3 kN/m
Post Yield Stiffness	690 kN/m	980 kN/m	1120 kN/m	1400 kN/m
Characteristic Strength	60.5kN	182 kN	2250 kN	5501 kN
Equivalent Shear Stiffness	1100 kN/m	2470 kN/m	4504 kN/m	7840 kN/m
Damping Ratio	0.240	0.240	0.240	0.240

Table -6: HDRB Dampers Properties

Reference: UBC-97 & Design of Seismic Isolated Structure from Theory of Practice by JamesM.Kelly and Farzad Naeim


Link/Support Property Data

Link/Support Type: Rubber Isolator
Property Name: LRB
P-Delta Parameters: ● Shear Couple ○ Equal End Moments ○ Advanced

Total Mass and Weight
Mass: 0.
Weight: 0.
Rotational Inertia 1: 0.0166
Rotational Inertia 2: 0.
Rotational Inertia 3: 0.

Factors For Line, Area and Solid Springs
Property is Defined for This Length In a Line Spring: 1.
Property is Defined for This Area In Area and Solid Springs: 1.

Directional Properties

Direction	Fixed	NonLinear	Direction	Fixed	Nonlinear
☑ U1	☐	☐	☐ R1	☐	☐
☑ U2	☐	☑	☐ R2	☐	☐
☑ U3	☐	☑	☐ R3	☐	☐

Stiffness Options
Stiffness Used for Linear and Modal Load Cases: Effective Stiffness from Zero, Else Nonlinear
Stiffness Used for Stiffness-proportional Viscous Damping: Initial Stiffness (K0)
Stiffness-proportional Viscous Damping Coefficient Modification Factor: 1.

Fig -8: HDRB Dampers Properties

Table -7: Analysis Models Description

Models	Description
Model -1	Fixed Base
Model -2	HDRB –Rubber Thickness 150mm
Model -3	HDRB –Rubber Thickness 200mm
Model -4	HDRB –Rubber Thickness 250mm
Model -5	HDRB –Rubber Thickness 300mm

4. RESULT AND DISCUSSION

The chapter describes an analytical investigation of a building frame using different models to assess its seismic performance. The focus is on studying the effects of High Damping Rubber Bearings (HDRB) as base isolators in the building's seismic response. The investigation involves four models:

Model 1: Fixed-Base Case

In the first model, the building frame is considered as a fixed-base case without any base isolators. This means that the building is directly anchored to the foundation, forming a rigid connection. During an earthquake, the ground motion is transmitted directly to the building, causing it to experience significant lateral forces and vibrations. This model serves as a baseline to understand the building's seismic behavior without any seismic isolation system.

Model 2: HDRB Isolators with Rubber Thickness - 150mm

In this model, High Damping Rubber Bearings (HDRB) are introduced as base isolators at the base level of the building. These isolators consist of rubber material with a thickness of 150mm. The HDRB isolators allow the building to move independently of the ground, and the rubber material absorbs and dissipates a significant portion of the seismic energy. As a result, the building experiences reduced lateral forces and vibrations compared to the fixed-base case in Model 1.

Model 3: HDRB Isolators with Rubber Thickness - 200mm

In this model, the HDRB isolators are used again, but this time with a rubber thickness of 200mm. The thicker rubber isolators may offer more damping capacity and energy dissipation compared to the 150mm thick isolators used in Model 2. This variation allows engineers to analyse the effect of increasing the rubber thickness on the building's seismic response.

Model 4: HDRB Isolators with Rubber Thickness - 250mm

In this model, HDRB isolators with a rubber thickness of 250mm are used as base isolators. The purpose is to assess the seismic performance of the building with this specific thickness of rubber isolators. The thicker rubber isolators are expected to provide even higher damping capacity and energy dissipation compared to Models 2 and 3.

Model 5: HDRB Isolators with Rubber Thickness 300mm

In the fifth model, the HDRB isolators are used once again, but this time with a rubber thickness of 300mm. The thicker rubber isolators in this model are expected to offer the highest damping capacity and energy dissipation among all the models considered. Engineers can evaluate the benefits and trade-offs of using such thick rubber isolators in seismic performance.

The analytical investigation of these five models will provide valuable insights into the effectiveness of HDRB isolators with different rubber thicknesses in reducing seismic forces and enhancing the seismic resilience of the building. By comparing the responses of each model, engineers can make informed decisions about the most suitable seismic isolation system for the specific project and the level of seismic risk in the region.

4.2 Analysis of RC Building with various rubber thickness of HDRB dampers

4.2.1 Fixed Base Model

Analysis results can be obtained in the graphical as well as in the tabular form, from which the maximum bending moment values are obtained for each member. Concrete dimension and reinforcement quantities are designed from these quantities appropriately.

Table -8: Fixed Base Model – Storey Displacement

(DL+LL+EQ)			
STOREY DISPLACEMENT (mm)			
Story	**Elevation**	**X-Dir**	**Y-Dir**
	m	mm	mm
Story10	35	14.82	13.229
Story9	31.8	14.33	13.701

Story8	28.6	13.62	12.965
Story7	25.4	12.69	12.019
Story6	22.2	11.55	10.896
Story5	19	10.26	9.635
Story4	15.8	8.84	8.271
Story3	12.6	7.33	6.835
Story2	9.4	5.74	5.342
Story1	6.2	4.05	3.778
GF	3	2.18	2.049
Base	0	0	0

Allowable displacement, Drift = 0.004 H
= 0.004x35 = 0.14 m.
Max displacement < allowable displacement.

Table -9: Fixed Base Model – Storey Drift

(DL+LL+EQ)		
STOREY DRIFT		
Story	**Elevation (m)**	**Drift**
Story10	35	0.00175
Story9	31.8	0.00245
Story8	28.6	0.00315
Story7	25.4	0.00375
Story6	22.2	0.00422
Story5	19	0.00457
Story4	15.8	0.00482
Story3	12.6	0.00501
Story2	9.4	0.00525
Story1	6.2	0.00581
GF	3	0.00734
Base	0	0

Table -10: Fixed Base Model – Storey Shear

STOREY SHEAR (kN)		
Story	**Elevation**	**Storey Shear**
	m	**kN**
Story10	35	214.11
Story9	31.8	439.19
Story8	28.6	629.38
Story7	25.4	788.79
Story6	22.2	923.17
Story5	19	1039.82
Story4	15.8	1145.19
Story3	12.6	1243.42
Story2	9.4	1336.63
Story1	6.2	1422.36
GF	3	1485.42

In Fixed Base Model the maximum deflection is got from ETABS results is 13.815 mm,it is within the allowable limit. The each storey drift and Shear value showed in the Table 5.2 & 5.3.

4.2.2 Various thickness of HDRB Model

Table -11: HDRB Model – Storey Displacement

(DL+LL+EQ)									
STOREY DISPLACEMENT (mm)									
Story	**Elevation**	**150 Thk.**		**200 Thk.**		**250 Thk.**		**300 Thk.**	
		X-Dir	**Y-Dir**	**X-Dir**	**Y-Dir**	**X-Dir**	**Y-Dir**	**X-Dir**	**Y-Dir**
	m	mm	mm	mm	mm	mm	mm	mm	mm
Story10	35	13.82	14.07	8.80	14.84	9.85	11.24	10.15	10.32
Story9	31.8	13.33	13.56	8.20	14.41	9.32	10.80	9.62	9.83
Story8	28.6	12.99	12.85	7.50	13.89	8.66	10.22	8.96	9.22
Story7	25.4	12.69	11.92	6.72	13.28	7.90	9.53	8.19	8.50
Story6	22.2	11.55	10.82	5.90	12.62	7.06	8.75	7.34	7.68
Story5	19	10.26	9.58	5.07	11.92	6.19	7.91	6.44	6.80

Story4	15.8	8.84	8.23	4.54	10.83	5.76	5.75	5.21	5.09
Story3	12.6	7.33	6.81	3.46	10.44	4.42	6.07	4.62	4.90
Story2	9.4	5.74	5.32	2.75	9.71	3.59	5.18	3.74	3.94
Story1	6.2	4.05	3.77	2.10	9.03	2.78	4.32	2.86	2.99
GF	3	2.18	2.04	1.33	8.33	1.75	3.27	1.75	1.84
Base	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table -12: HDRB Model – Storey Drift

(DL+LL+EQ)					
STOREY DRIFT					
Story	**Elevation (m)**	**150 Thk.**	**200 Thk.**	**250 Thk.**	**300 Thk.**
Story10	35	0.0018	0.0020	0.0018	0.0012
Story9	31.8	0.0022	0.0024	0.0022	0.0015
Story8	28.6	0.0026	0.0027	0.0026	0.0018
Story7	25.4	0.0029	0.0028	0.0028	0.0020
Story6	22.2	0.0030	0.0029	0.0030	0.0023
Story5	19	0.0031	0.0028	0.0030	0.0025
Story4	15.8	0.0030	0.0026	0.0029	0.0028
Story3	12.6	0.0029	0.0024	0.0028	0.0029
Story2	9.4	0.0029	0.0022	0.0028	0.0032
Story1	6.2	0.0038	0.0027	0.0035	0.0045
GF	3	0.0064	0.0052	0.0066	0.0084
Base	0	0.0000	0.0000	0.0000	0.0012

Table -13: HDRB Model – Storey Shear

STOREY SHEAR (kN)					
Story	**Elevation (m)**	**150 Thk.**	**200 Thk.**	**250 Thk.**	**300 Thk.**
Story10	35	180.66	175.87	188.04	185.18
Story9	31.8	355.04	327.78	370.42	363.91
Story8	28.6	491.67	448.60	518.96	503.96
Story7	25.4	598.47	544.68	638.67	613.44

Story6	22.2	682.17	622.65	735.94	699.22
Story5	19	752.47	689.20	818.73	771.28
Story4	15.8	817.38	751.17	894.45	837.81
Story3	12.6	883.51	812.47	968.64	905.60
Story2	9.4	951.74	873.41	1042.67	975.53
Story1	6.2	1017.06	931.22	1113.41	1042.49
GF	3	1064.37	973.17	1166.05	1090.98

4.3 Comparison of RC Building behavior with Fixed Base model & various thickness of HDRB Model

4.3.1 Storey Displacement

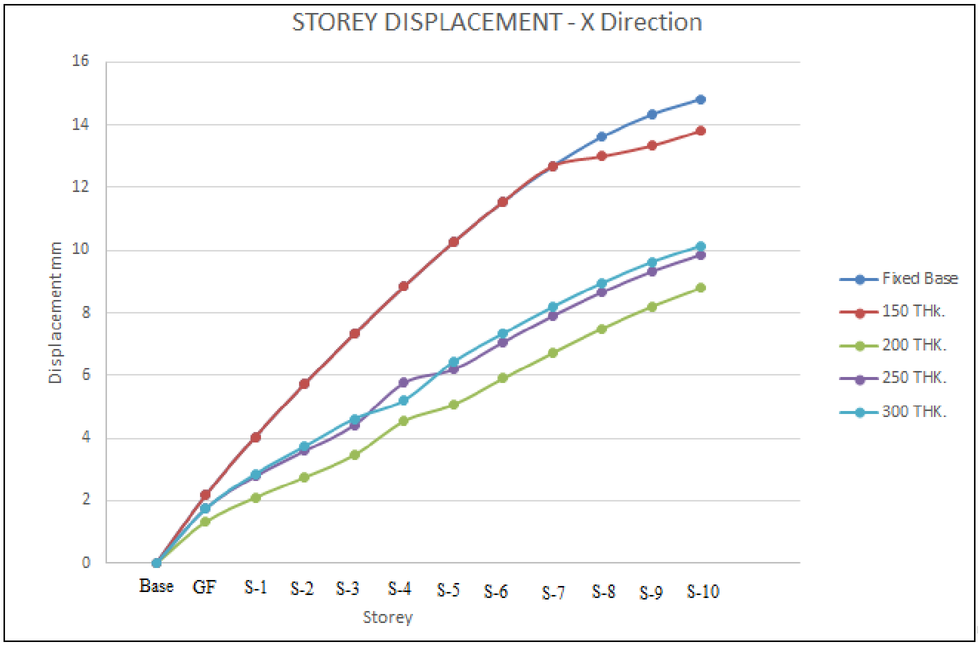


Chart -1: Comparison of Storey Displacement – X direction

In the provided table, the values represent the story elevation and the displacement in millimeters for different thicknesses of the base of a structure in the X-Direction. The displacement values are given for different stories (from Story10 to Ground Floor (GF) and Base).

To determine which one is best in terms of storey displacement, the objective or criteria for "best" should be clarified first. Usually, in structural engineering, the goal is to minimize the displacement to ensure the safetyand stability of the building during seismic events or other external forces. The displacement directly affects the building's response to these forces.

The following values are observed in the table by assuming that the objective is to minimize the displacement to determine the most effective thickness of the base in reducing displacements. Generally, thicker bases are expected to provide better stability and reduce displacements.

For example, comparing the displacements in the X-Direction for different thicknesses at a particular story (e.g., Story10), we see the following values:
For 150 mm thick base: 8.8 mm
For 200 mm thick base: 9.85 mm
For 250 mm thick base: 10.15 mm

For 300 mm thick base: 13.82 mm

From these values, it can be seen that the 150 mm thick base has the lowest displacement (8.8 mm) at Story10. Therefore, if the goal is to minimize displacements, the 150 mm thick base seems to be the best choice for this specific story.

However, it's essential to note that this comparison is only made for Story10, and different stories may have different optimal base thicknesses depending on the loading conditions, structural design, and other factors.

To determine the overall best option for the entire structure, a comprehensive analysis is needed, taking into account all the stories and considering other factors such as building codes, material properties, and design requirements. Professional structural engineers use sophisticated software and conduct detailed simulations to arrive at the most appropriate design for a building's base thickness to ensure its safety and stability.

Chart -2: Comparison of Storey Displacement – Y Direction

After analyzing the data, it is find that for most storey, the 300 mm thick fixed base has the smallest displacements in the Y-Direction compared to other thicknesses. This means that the 300 mm thick fixed base provides the best performance in minimizing the building's movement or displacement in the Y-Direction during various loading conditions or external forces.

So, if the goal is to reduce the overall displacement of the structure, the 300 mm thick fixed base is the best option among the choices provided.

4.3.2 Storey Drift

The data shows that a 300 mm thick fixed base is the best option for reducing lateral movement between floors in tall buildings. It consistently gives the smallest drift values for most stories compared to other options (150 mm, 200 mm, and 250 mm). Using this thickness improves the building's stability during earthquakes and other lateral forces, making it safer for occupants. However, other factors like local building codes and materials should be considered, and professional engineers should be involved in the design process to ensure overall safety and efficiency. In conclusion, the 300 mm thick fixed base is a recommended choice to minimize storey drift in tall structures.

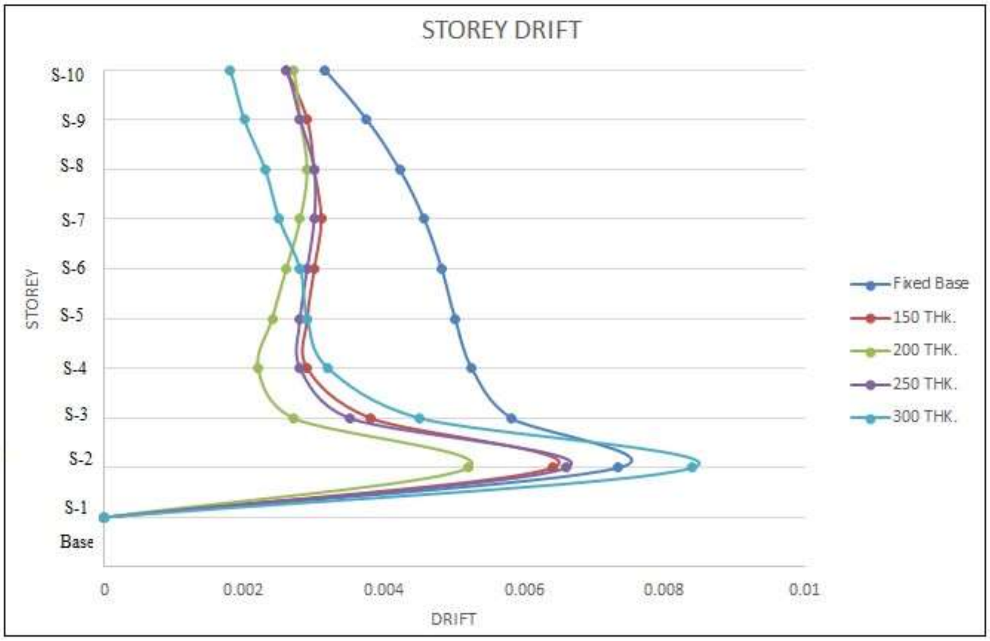


Chart -3: Comparison of Storey Drift

4.3.3 Storey Shear

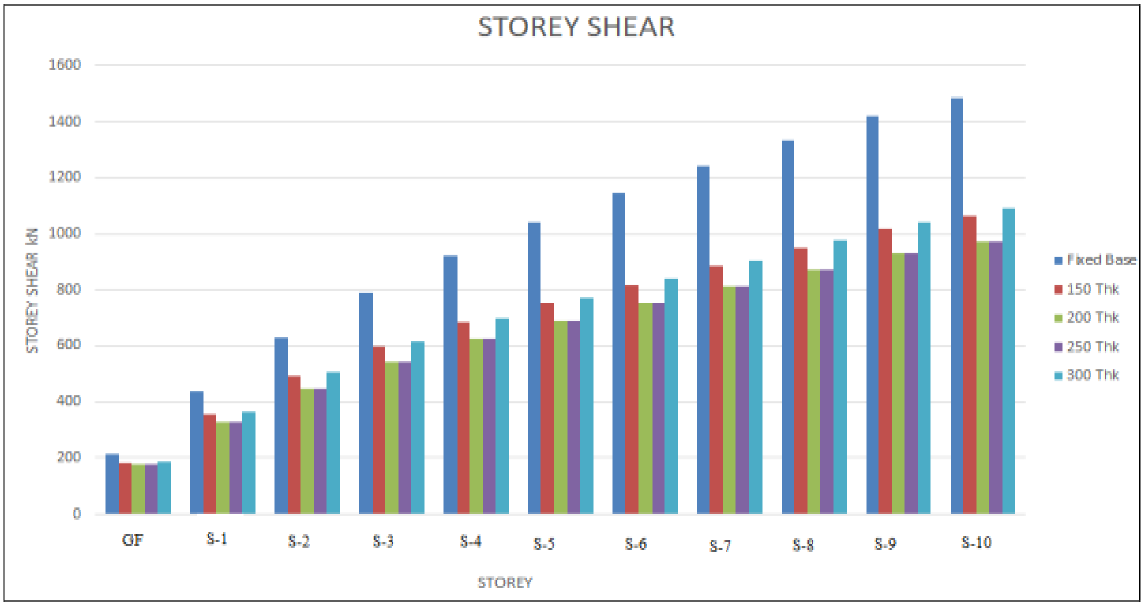


Chart -4: Comparison of Storey Shear

Storey shear represents the lateral force acting on each storey of a building due to various loads and external forces. From the provided table, the storey shear values for each story and each fixed base thickness are in Kilo Newton (kN).

The minimum shear value for each story should be considered to identify the best option for storey shear. The fixed base thickness that provides the smallest storey shear value is the best option for minimizing lateral forces on each storey.

For example:
For Story10: The smallest storey shear value is 175.87 kN, which corresponds to the 200 mm thick fixed base.For Story9: The smallest storey shear value is 327.78 kN, which corresponds to the 200 mm thick fixed base. For Story8: The smallest storey shear value is 448.60 kN, which corresponds to the 200 mm thick fixed base.
Based on this data, it appears that the 200 mm thick fixed base consistently provides the smallest storey shear values for most of the stories. Therefore, if the goal is to minimize the lateral forces acting on each storey (storey shear), the 200 mm thick fixed base seems to be the best option among the choices provided.

5. CONCLUSION

The analytical investigation of the G+10 RC Buildings with very severe seismic conditions (zone 5) and various rubber thicknesses of HDRB dampers has been conducted to assess their seismic performance. The study compares the results obtained with various thickness of HDRB. The focus is on the time period, horizontal seismic co-efficient, top story lateral displacement, and base shear results.

The investigation involves five models: Fixed-Base Case (Model 1) without any base isolators, and four models (Models 2 to 5) using HDRB isolators with rubber thicknesses of 150 mm, 200 mm, 250 mm, and 300 mm, respectively. The goal is to understand the impact of these isolators on the building's seismic response.

The analysis shows that the HDRB isolators significantly reduce storey displacement, drift, and shear compared to the fixed-base case. Among the models with different rubber thicknesses, the 200 mm thick isolators consistently provide the best performance in terms of reducing storey displacement, drift, and shear for most of the stories.

The results suggest that using 200 mm thick HDRB isolators can effectively enhance the seismic resilience of the building, as it experiences reduced lateral forces and vibrations. However, it's essential to consider other factors like building codes and materials to arrive at an optimal design solution.

Overall, the analytical investigation provides valuable insights into the effectiveness of HDRB isolators with various rubber thicknesses in mitigating seismic forces. Engineers can use this information to make informed decisions about the most suitable seismic isolation system for similar projects in very severe seismic zones.

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