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Base Isolation and Energy Dissipating System in Earthquake Resistant Building Design

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Abstract: The utilization of base isolation is a crucial strategy for enhancing seismic resilience in structures. The method involves installing isolators and energy-absorbing devices beneath a building's superstructure to mitigate the destructive effects of earthquakes. When base isolation is implemented in a building, it not only makes the structure stronger and more stable, but also helps to safeguard lives and properties. This technique is particularly valuable for seismic retrofitting of historical buildings. In the present study, software called simulation of seismic isolation systems in structural analysis is employed, considering isolator characteristics, whether they exhibit nonlinear or equivalent linear behavior. Adhering to the IS 1893:2016 Code, the analysis utilized the SAP 2000 software package. A study was carried out to compare the effectiveness of base isolation systems versus fixed-base buildings in dealing with seismic activity. The study focused on analyzing various seismic indicators such as joint displacement, shear force, bending moment, building torsion, and the period of natural frequency. Results showed that models utilizing base isolation systems had significantly higher base shear values than those with a fixed-base building configuration. However, there was a significant 35% reduction in story shear values for the rubber isolation system and a 40% decrease for the friction pendulum model. Additionally, there was a 25% reduction in story drift for the rubber base model and a 30% decrease for the friction pendulum model. The friction pendulum model demonstrated the most effective control of these parameters across various seismic zone conditions.

Key words: The topic of discussion pertains to Seismic Isolation with Rubber Bearing System and the Friction Pendulum Technique. Additionally, it includes SAP2000 Analysis, Story Drift Measurement, and Shear Force Evaluation in relation to these techniques.

I. INTRODUCTION

Seismic isolation is a method employed to minimize the consequences of shocks during earthquakes on structures and their components, thus ensuring their protection from damage. This technique employs specific mechanisms, which will be detailed later, to reduce the lateral movement (drift) of structures.

Seismic isolation is a fundamental concept in earthquake engineering, involving the separation or decoupling of a structure from its foundation. [1-7] Put simply, it is a method designed to prevent or minimize structural damage during seismic events. This essay aims to elucidate the notion of base isolation by drawing parallels with examples from other engineering and sports disciplines. Such examples include automotive suspension systems and defensive strategies in boxing. Furthermore, the essay will present experimental data and analytical graphs to enhance comprehension of the base isolation concept. [8-10]

This study simulates seismic isolation systems using structural analysis software and considers isolator characteristics such as non-linear or equivalent linear behavior. The analysis adheres to the IS 1893:2016 Code and is conducted using the SAP 2000 software package. The effectiveness of base isolation systems is compared to fixed-base structures by analyzing various seismic indicators, including joint displacement, shear force, bending moment, building torsion, and natural frequency period. [11-12]

In the realm of structural design aimed at withstanding the destructive forces of earthquakes, two pivotal systems come to the forefront: base isolation and energy dissipating systems. These engineering methods serve as integral components in contemporary earthquake-resistant building design, working in concert to bolster safety, reduce structural harm, and safeguard human lives in seismic scenarios. [13-15] In the following exploration, we will delve into the fundamental principles and practical applications of these systems, shedding light on their vital roles in fortifying buildings against earthquake-induced challenges.

The primary objective of this research is to contribute to the understanding of base isolation and energy dissipating systems, providing insights into their practical applications and effectiveness in designing earthquake-resistant buildings. [16-17] through a comprehensive analysis and comparison, this study aims to identify the most effective seismic mitigation strategies for enhancing structural resilience and minimizing earthquake-related damage.

1.1Friction pendulum bearings

Friction pendulum systems are widely employed as kinematic systems, particularly in the field of base isolation. These systems are characterized by the presence of a steel pendulum, which is positioned between two steel concave curved surfaces or within a cylindrical component with

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spherical contact surfaces. Special metals are utilized in crafting these components.

Friction pendulum bearings, commonly known as FPs or friction pendulum isolators, stand as a pivotal advancement in the realm of structural engineering and seismic isolation technology. These mechanical components are strategically engineered to bolster the earthquake resistance of buildings and bridges through the facilitation of controlled movement and the dissipation of energy when seismic forces come into play. In the following exploration, we will delve into the underlying principles, design considerations, and practical applications of friction pendulum bearings, underscoring their vital role in fortifying structures against the destructive impacts of earthquakes.

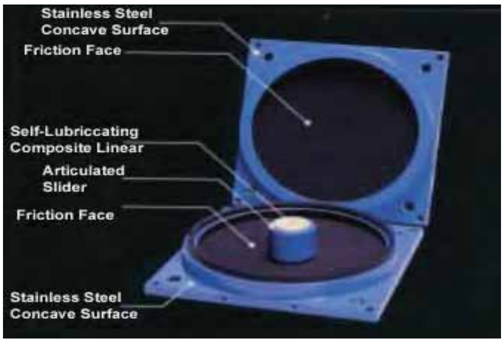

Figure 1. Friction pendulum bearing system

1.2 Rubber Bearings isolation

Rubber bearing isolation, commonly known as base isolators, represents a significant breakthrough in the realm of structural engineering, specifically in the context of earthquake-resistant design. [18] These specialized elements serve a crucial purpose in safeguarding buildings and infrastructure against the destructive effects of seismic forces. In the ensuing discourse, we shall delve into the fundamental principles, design factors, and real-world implementations of rubber bearing isolation, underscoring its substantial role in enhancing structural resilience and minimizing earthquake-related harm.

Apart from the bridge bearings, these systems come in various types, including steel laminated rubber bearings, steel laminated rubber bearings with a lead core, and those made from a combination of rubber and neoprene materials. The rubber elements, originally used in bridge bearings, underwent enhancements, and were later reintroduced as elastomeric bearings. These elastomeric bearings that used as seismic isolators have gained widespread adoption. Rubber laminated isolators are created by vulcanizing thin steel plates to rubber plates. Among these, the most advanced are the laminated rubber bearings with a lead core. The Lead Laminated Rubber Bearing systems are a sophisticated seismic isolation technology that comprises of layers of steel and rubber laminated with a central core of lead.

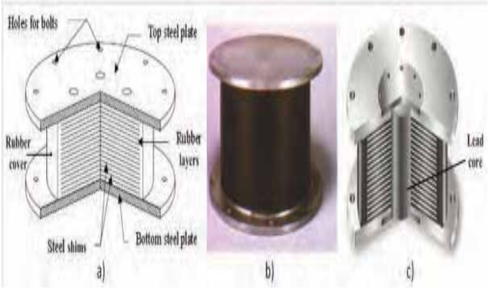

Figure: 2. Lead rubber bearing isolation

The main objectives of this ongoing research project are to examine the seismic behavior of a G+9 building according to the IS 1893:2002 code, using the response spectrum method in the SAP2000 software. The research aims to assess the performance of the G+9 building in Seismic Zone V using different base isolation systems, namely Rubber Bearing Isolation and Friction Pendulum Bearing Isolation systems. A comparative analysis will be conducted to evaluate the seismic performance of structures employing different base isolation systems compared to a fixed-base building in various seismic zone scenarios. The aim is to determine the most effective earthquake-resistant system based on the analysis outcomes, which encompass parameters like joint displacements, shear forces, bending moments, torsion, base shear, and the building's time period.

II. LITERATURE REVIEW

Gyawali et al. (2020): An investigation was conducted on GF+4 storied buildings with regular, plain irregular, and vertical irregular designs using SAP software for both fixed-base and base-isolated models. The analysis utilized the response spectrum method by IS1893:2002 and cross-validated the findings with ETABS software. As per the results, implementing Lead Rubber Bearings (LRB) was found to decrease the base shear by 45 to 50% as compared to buildings with a fixed base. However, it was also observed that the displacement at the top story of the buildings increased by 81 to 99% when LRB systems were used.

Dr. R. S. Tali Koti et al. (2014): In a separate study by a comprehensive examination was conducted on the design, functionality, testing, and compliance with Indian Standards of base isolation. The study focused on a (G+15) RCC building, which was modeled in SAP2000 software. The building was analyzed under various conditions, including fixed base, bracing, and isolator systems. Theoretical analyses were performed using SAP2000 software to compare fixed base structures with base-isolated structures. Various parameters were considered in these comparisons, which included base shear, modal period, story displacement, story drift, and story acceleration.

III. METHODOLOGY

Several factors were considered in these analyses, such as the base shear, modal period, story displacement, story drift, and story acceleration. In this specific study, IS 1893:2016 (Part 1) was used as the governing code. Key data such as seismic zone factors and soil types were obtained from the relevant tables within the IS 1893:2016 (Part 1) code.

In this analysis, a standard damping ratio of 5% was applied. The response spectrum curve, designed for medium soil conditions, is presented in the figure below. This graphical representation illustrates the correlation between time period and spectral acceleration coefficient (Sa/g).

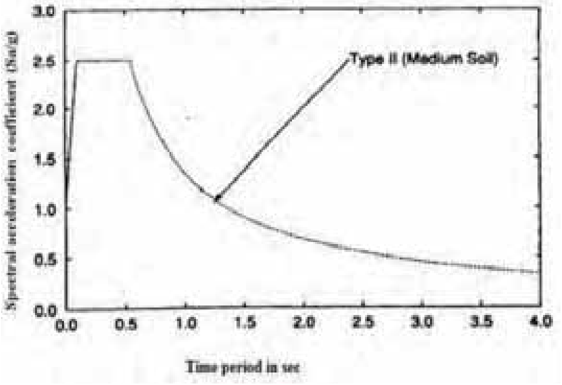

Figure 3. Response spectrums for medium soil type with 5% damping.

Our objective for this study is to determine the strength of the forces, specifically X, Y, and Z, and evaluate their effects on the structure. To achieve this, we're utilizing various combination techniques, which include absolute summation, square root of the sum of squares (SRSS), and complete quadratic combination (CQC) - an adaptation of SRSS that's suitable for modes that are closely spaced.

It is important to keep in mind that the results obtained through Response Spectrum Analysis can differ significantly from those produced by linear dynamic analysis using ground motions. The accuracy of response analysis may be compromised in situations involving irregular or high-rise structures. In such cases, alternative methods such as non-linear static or dynamic analysis are required. The main objective of our study was to assess the behavior of a medium rise building with a conventional structure when subjected to seismic loads.

IV. SPECIFICATIONS AND BUILDING MODELS

Within this research, we examined a multi-story G+9 building and constructed a three-dimensional model of the structure using SAP 2000 software.

Here are the key parameters considered for the analysis:

1. Building Occupancy: Residential
2. Number of Stories: Ground + 9 (10 stories)
3. Building Height: 30 meters
4. Building's Shape: Rectangular
5. Geometric Specifications:
   a. Ground Floor Elevation: 3 meters
   b. Inter-Floor Height: 3 meters
6. Material Specifications:
   -Concrete grade specified for columns and beams: M30.
   - Type of Steel: HYSD 415
   - Soil Bearing Capacity: 200 kN/m^2
7. Type of Construction: Reinforced Concrete (RCC)
8. Column Dimensions: 0.35 meters × 0.35 meters
9. Beam Dimensions: 0.25 meters × 0.35 meters
10. Slab Thickness: 0.125 meters
11. Live Load: 2.5 kN/m^2 (as per IS: 875:1987)
12. Site Type: II
13. Significance Factor: 1.0
14. Seismic Response Reduction Factor specified: 3.
15. Damping Coefficient: 5%
16. Structural Category: C
17. Wind design code referenced: IS 875: 1987 (Part 3)
18. Reinforced Concrete Design Code: IS 456:2000
19. Steel design code referred to: IS 800: 2007
20. Earthquake design code specified: IS 1893: 2016

Building models in SAP 2022.

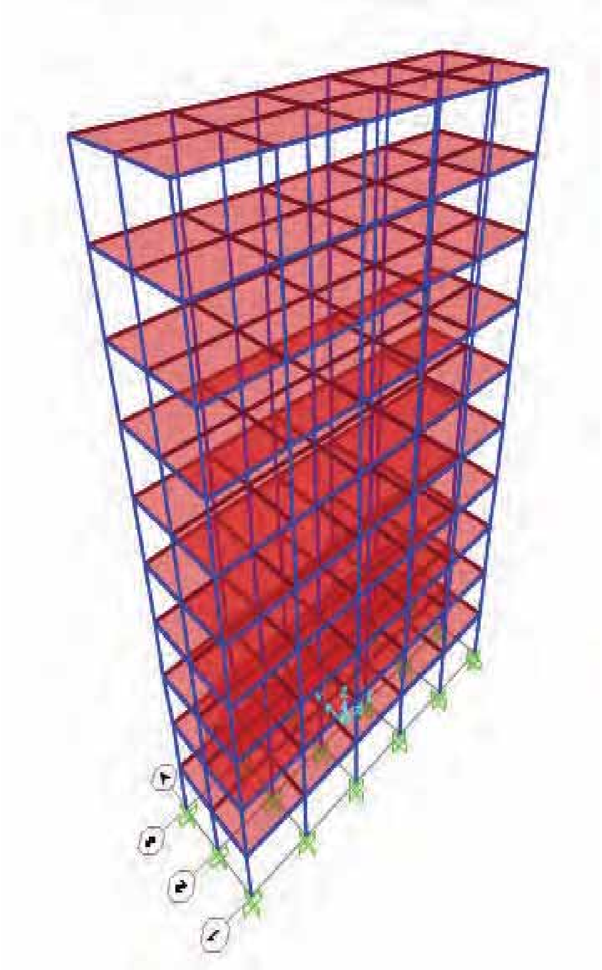

Figure 4. Building fixed Model with supports

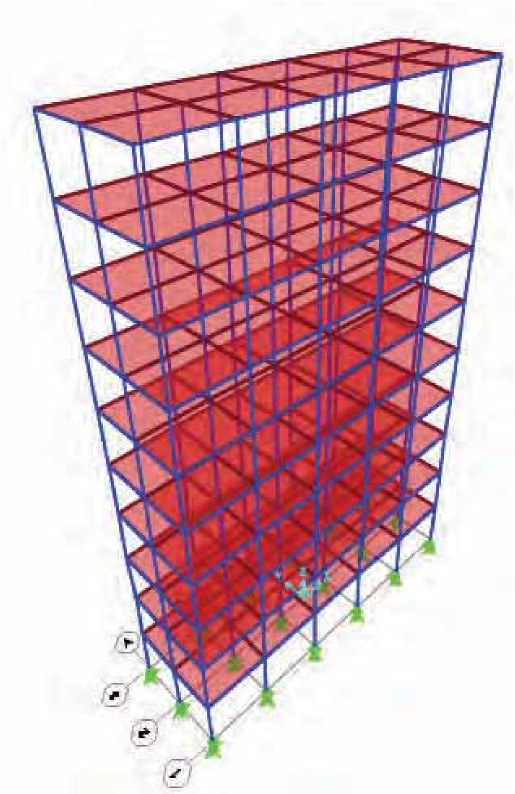

Figure 5. Building Model with rubber isolator at supports

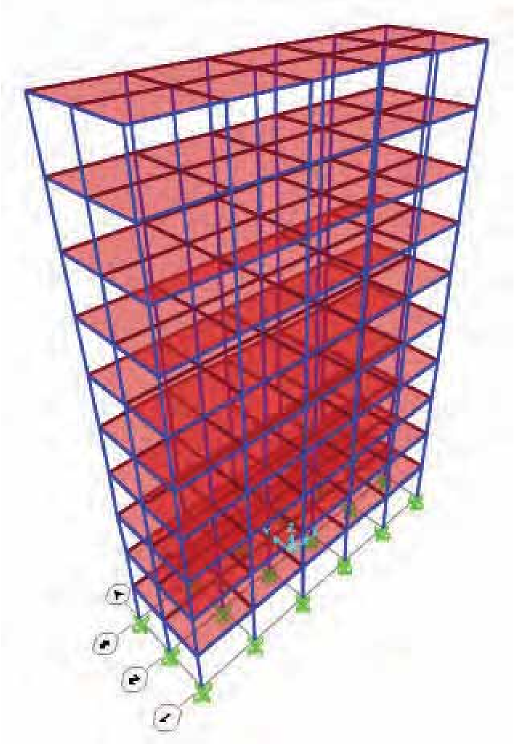

Figure 6. Building Model with friction isolator at supports

V. RESULTS AND DISCRECTION

1.Comparison of joint displacement

TABLE I.
JOINT DISPLACEMENT VALUES FOR DIFFERENT STORIES

S.no	Load Case	Joint displacement in mm for fixed base	Joint displacement in mm for rubber base	Joint displacement in mm for friction base
1	RSA	0	0	0
2	RSA	4.23	7.08	2.909
3	RSA	1.48	2.109	1.039
4	RSA	1.72	1.609	1.2009
5	RSA	1.71	1.309	1.2009
6	RSA	1.75	1.309	1.209
7	RSA	1.6	1.279	1.159
8	RSA	1.69	1.309	1.109
9	RSA	0	0	0
10	RSA	1.97	1.057	1.3811
11	RSA	2.42	6.813	1.611
12	RSA	1.05	1.162	7.352
13	RSA	7.16	2.412	5.012
14	RSA	1.64	2.412	1.111
15	RSA	1.26	1.412	8.812

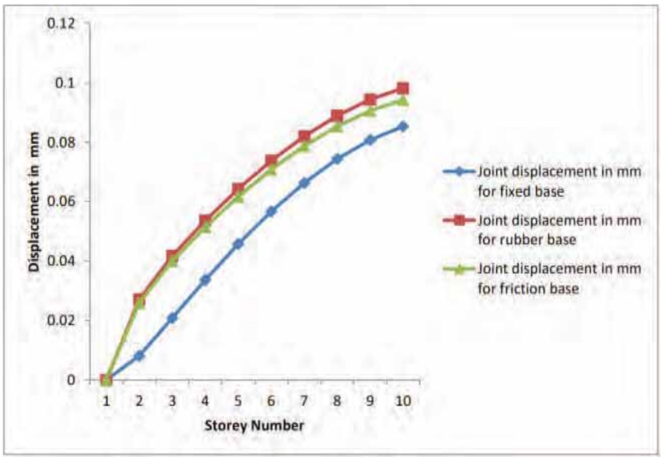

Figure 7. Comparison of joint displacement for different base conditions in Zone V

Based on the test results mentioned above, a comparison was made between the joint displacements under seismic conditions. Based on the observations, it was found that the joint displacement values were higher in the rubber fixed base, rubber base, and friction pendulum systems present in the zone base as compared to the fixed base and friction pendulum models. This can be attributed to the intense seismic loading, which specifically causes increase in displacement values for the rubber base model when compared to other isolation systems.

2. Comparison of Lateral load P

TABLE II.
COMPARISON OF LATERAL LOAD P FOR DIFFERENT STORIES

Storey Number	Lateral P for fixed base in kN	Lateral P for rubber base in kN	Lateral P for friction base in kN
Storey 1	0.026	0.043	0.018
Storey 2	0.0008	0.019	0.00060
Storey 3	0.0016	0.003	0.00116
Storey 4	0.0010	0.00047	0.00073
Storey 5	0.0010	0.00070	0.0007
Storey 6	0.0007	0.00050	0.00051
Storey 7	0.0008	0.00054	0.00060
Storey 8	0.0006	0.0002	0.00047
Storey 9	0.0041	0.003	0.002
Storey 10	0.0085	0.007	0.005

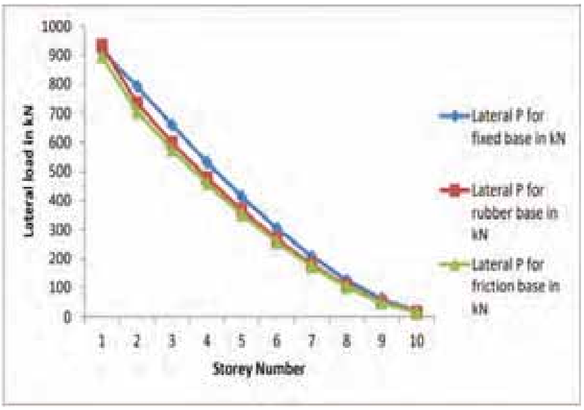

Figure 8. Comparison of Lateral load for different base conditions in Zone V

The G+10 building model encounters more significant effects from lateral load conditions in zone II seismic conditions when employing a rubber base isolation system as opposed to other isolation methods. This discrepancy arises from the comparatively lower resistance rate exhibited by the rubber base model.

3. Comparison of Story Shear

TABLE III.
COMPARISON OF STORY SHEAR FOR DIFFERENT STORIES

Storey Number	Shear Vx for fixed base in kN	Shear Vx for rubber base in kN	Shear Vx for friction base in kN
Storey 1	0.367	0.543	0.257
Storey 2	0.37	0.341	0.259
Storey 3	0.343	0.301	0.24
Storey 4	0.31	0.269	0.217
Storey 5	0.276	0.238	0.193
Storey 6	0.239	0.204	0.167
Storey 7	0.197	0.165	0.138
Storey 8	0.148	0.12	0.103
Storey 9	0.087	0.067	0.061
Storey 10	0.03	0.021	0.021

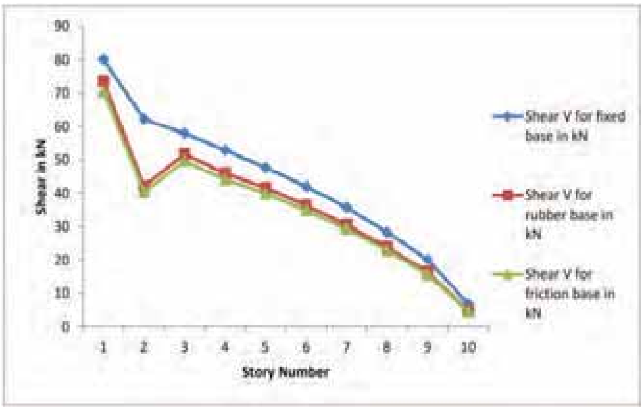

Figure 9. Comparison of stores shear V for different base conditions in Zone V

The Y direction shear values are compared in the graph depicted above. From the results, it can be deduced that the utilization of isolation systems can effectively resist seismic loading, leading to a reduction in shear values.

4. Comparison of Torsion T

TABLE IV.
COMPARISON OF TORSION T FOR DIFFERENT STORIES

Storey Number	Torsion T for fixed base in kN-m	Torsion T for rubber base in kN-m	Torsion T for friction base in kN-m
Storey 1	6.62E-06	6.58E-06	4.64E-06
Storey 2	1.27E-05	1.03E-05	8.91E-06
Storey 3	1.76E-05	1.30E-05	1.23E-05
Storey 4	2.31E-05	1.72E-05	1.62E-05
Storey 5	2.84E-05	2.08E-05	1.99E-05
Storey 6	3.30E-05	2.40E-05	2.31E-05
Storey 7	3.68E-05	2.66E-05	2.57E-05
Storey 8	3.95E-05	2.86E-05	2.76E-05
Storey 9	4.09E-05	2.96E-05	2.86E-05
Storey 10	6.04E-05	4.34E-05	4.23E-05

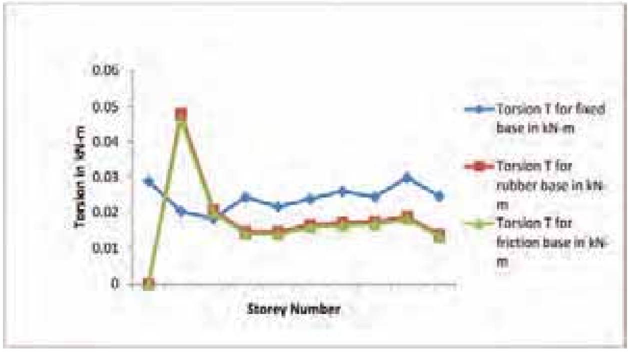

Figure 10. Comparison of Torsion T for different base conditions in Zone V

The comparison of torsion is shown in the above graph due to the unequal forces in both directions. The torsion is created in multi storey building, the effect of seismic isolation will be decreased, which is demonstrated from above graph.

5. Comparison of Storey moment

TABLE V.
COMPARISON OF STORY MOMENT DIFFERENT STORIES

Storey Number	Bending My in fixed base in kN-m	Bending My in rubber base in kN-m	Bending My in friction base in kN-m
Storey 1	1.0842	1.5879	0.759
Storey 2	1.1049	1.0255	0.7734
Storey 3	1.02	0.8926	0.714
Storey 4	0.9206	0.7978	0.6444
Storey 5	0.8156	0.7028	0.5709
Storey 6	0.7045	0.6008	0.4931
Storey 7	0.579	0.4851	0.4053
Storey 8	0.4311	0.35	0.3017
Storey 9	0.2516	0.1925	0.1761
Storey 10	0.0757	0.0498	0.053

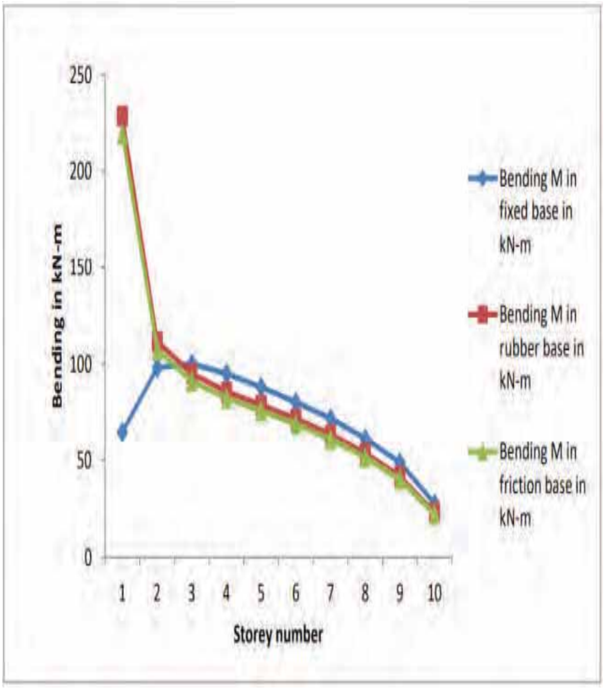

Figure 11. Comparison of moment M for different base conditions in Zone V

The above graph illustrates a reduction in the intensity of seismic loading action in zone II condition, which can be attributed to the presence of base isolation systems. Furthermore, the values of bending consistently rise from storey 1 to storey 10 across all the isolation models.

6. Comparison of Base shear

TABLE VI.
COMPARISON OF BASE SHEAR DIFFERENT STORIES

S. No	Building Type	Base shear in kN
1	Fixed base	11.928
2	Rubber base	10.879
3	Friction pendulum	8.35

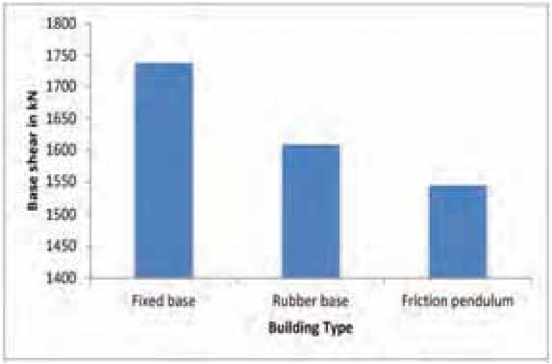

Figure 12. Comparison of base shear for different base conditions in Zone V

Based on the graph provided, it can be observed that both friction pendulum and rubber base isolation models show a decrease in base shear values when compared to the fixed base isolation system. This suggests that seismic loading conditions have less impact on the former two models, resulting in a reduction in the overall impact of seismic activity.

7. Comparison of Time period

TABLE VII.
COMPARISON OF TIME PERIOD FOR VARIOUS TYPES OF BASES

Mode Number	Time period for fixed base	Time period for rubber base	Time period for friction base
1	1.58	1.897	1.588
2	1.348	1.627	1.348
3	1.254	1.492	1.254
4	0.522	0.6180	0.522
5	0.44	0.524	0.446
6	0.41	0.48	0.413
7	0.3012	0.337	0.301
8	0.2619	0.293	0.2619
9	0.2420	0.270	0.245
10	0.214	0.232	0.214
11	0.184	0.202	0.186
12	0.16	0.184	0.1697

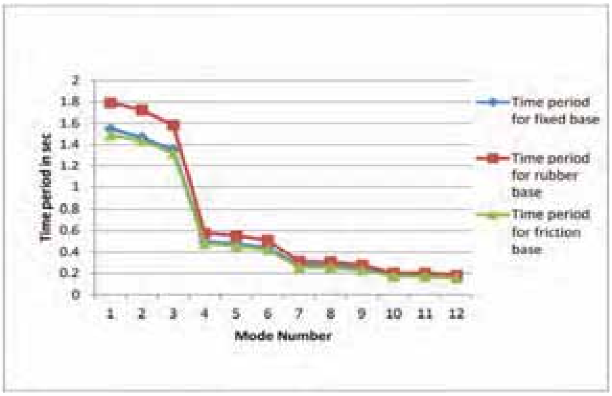

Figure 13. Comparison of time -period for different base conditions in Zone V

It is evident from the table and graph that the time-period values of the rubber base isolation system model in all modes are higher than those of the fixed base isolation system building model, because of seismic loading conditions. The time-period values decrease for both models as the mode number increases from 1 to 12.

8. Comparison of frequency

TABLE: VIII
COMPARISON OF FREQUENCY FOR VARIOUS TYPES OF BASES.

Mode Number	Frequency for fixed base	Frequency for rubber base	Frequency for friction base
1	0.62932	0.52708	0.629327
2	0.74179	0.6142	0.74179
3	0.7970	0.6698	0.79701
4	1.91257	1.6180	1.91257
5	2.23993	1.9058	2.2399
6	2.41607	2.080	2.4160
7	3.31934	2.959	3.3193
8	3.81780	3.4054	3.81780
9	4.13060	3.692	4.130
10	4.6715	4.306	4.67152
11	5.36986	4.9494	5.3698
12	5.8898	5.4120	5.88985

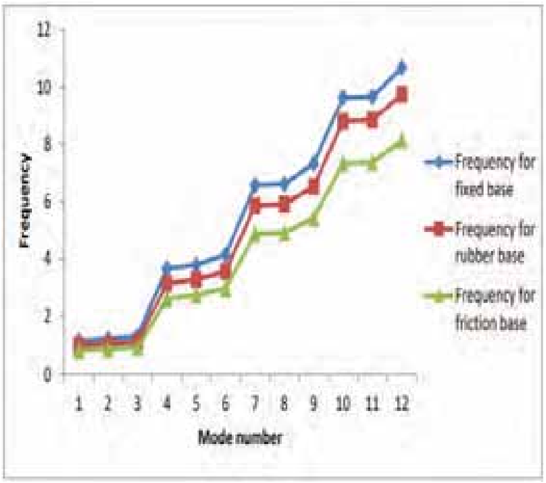

Figure 14. Comparison of frequency for different base conditions in Zone V

The comparison of frequency values is shown in the graph and Table, from these observations it clearly states that the frequency values are increasing from mode 1 to mode 12 for both the cases it has higher values for fixed base isolation building and friction pendulum than the rubber base isolation systems.

VI. CONCLUSIONS

It is evident from the results of simulation that the implementation of base isolation techniques plays a crucial role in reducing the seismic response of a building when compared to a fixed base structure. The changes in various result parameters concerning the building's stories in comparison to the fixed base model are discussed below:

1. Across all seismic zones, the implementation of Lead Rubber Isolation and Friction Pendulum Isolation systems consistently leads to a decrease in the stories shear values. By incorporating rubber base isolation and friction pendulum systems at the base, the story shear values decrease by 28.57% and 34.427%, respectively.
2. The story moment values decrease by 16.88% and 23.20% for the rubber base isolation and friction pendulum isolation, respectively.
3. A reduction in story torsion of 44.12% for the Rubber Base Isolation model and 48.52% for the Friction Pendulum Base Isolation model was observed.
4. The utilization of base isolation systems leads to increased joint displacements in all seismic zones by 15.08% for the rubber base model and 5.63% for the friction pendulum model.
5. Base isolation results in a significant decrease in story lateral loads in all seismic zones, with reductions of 17.95% and 24.69% for the rubber base model and friction pendulum model, respectively.
6. Employing isolation systems has the potential to reduce steel consumption, resulting in substantial savings of 8.7% for rubber base isolation and 30%

for friction pendulum systems. This reduction significantly influences building design.

7. The parameters under consideration are best controlled when the building is equipped with Friction Bearing Isolation systems.
8. Base isolation leads to a substantial decrease in base shear in all seismic zones, with reductions of 7.36% and 14.97% for the rubber base model and friction pendulum model, respectively.

To sum up, the results of this study indicate that both the Rubber Base Isolation system and the Friction Pendulum system serve as valuable supplementary damping systems for managing seismic loads. Nevertheless, when comparing the two, it becomes evident that the Friction Pendulum Bearing Isolation system stands out as the superior and optimal choice for the building type under consideration in this project.

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