Seismic Analysis of Tall Structures using Shear Walls and Friction Dampers

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Abstract: ***This study investigates the seismic performance enhancement of Reinforced Cement Concrete (RCC) buildings using passive energy dissipation systems, specifically friction dampers and shear walls. In earthquake-prone regions, RCC structures are vulnerable to seismic damage, necessitating the incorporation of advanced structural design features. The research involves modelling two types of G+14 high-rise RCC buildings a regular-shaped and a Plus-shaped configuration using ETABS software, and analysing them under Seismic Zone V conditions per IS 1893:2016 Part 1. Various support systems, including bare frames, friction dampers, and shear walls, were assessed based on key parameters such as storey displacement, storey drift, storey shear, overturning moment, and base shear. The results reveal that the Plus-shaped building with shear walls (Structure VI) exhibits the most effective seismic resistance, showing the lowest storey displacement (14.47 mm) and minimum story drift. Additionally, the highest base shear (2606.01kN) was observed in this structure, indicating enhanced energy dissipation. Comparatively, the Plus-shaped structure with friction dampers (Structure V) demonstrated the highest storey shear, highlighting the dampers' role in lateral force management. While overturning moments increased marginally, they remained within safe limits. This comprehensive analysis emphasizes the critical role of friction dampers and shear walls in improving seismic resilience. The findings support the strategic integration of these systems, particularly in irregular structures, to enhance overall stability and safety during seismic events.***

Keywords: Friction Dampers, Seismic Performance, RCC Structures, Shear Walls, ETABS Analysis

1. Introduction

Earthquakes pose a significant threat to structures, particularly in seismically active regions. While reinforced concrete (RCC) buildings are widely used for their strength and versatility, they remain susceptible to damage during seismic events. To enhance their seismic resistance, modern design practices have adopted passive energy dissipation devices, such as friction dampers, which play a vital role in minimizing structural damage by reducing vibrations during earthquakes.

Friction dampers function by converting seismic energy into heat through controlled sliding between two surfaces under pressure. This energy dissipation mechanism reduces the amplitude of seismic-induced vibrations, thereby protecting the building from excessive stress and potential collapse. This study investigates the performance of friction dampers in improving the seismic behaviour of RCC structures, alongside shear walls, which are another common seismic resistance element.

The research involves the modelling and seismic analysis of two RCC structures -one with a regular G+14 layout and the -other with a Plus-shaped layout using ETABS software. Both structures are assessed with different support systems: friction dampers and shear walls, under Zone V seismic conditions as per IS 1893:2016 Part 1. The analysis focuses on critical structural parameters such as story displacement, story drift, story shear, overturning moment, and base shear.

Seismic design requires a deep understanding of dynamic loads, material behaviour, and structural configuration. Common mitigation techniques include base isolation, energy dissipation devices (viscous dampers, yielding steel braces, and friction dampers), and seismic retrofitting. Among these, dampers are especially effective in reducing structural vibrations during seismic motion. IS 1893:2016 provides the guidelines for calculating seismic loads and ductility design to ensure structural safety.

ETABS, a widely used software for seismic analysis, enables accurate modelling of RCC structures by incorporating material properties, dimensions, and reinforcement data. It ensures code compliance and helps simulate realistic behaviour under various loading conditions.

2. Objectives of the Study

- To evaluate the effectiveness of friction dampers in improving the seismic performance of RCC buildings in Seismic Zone V.
- To assess the role of shear walls in enhancing seismic resistance.
- To compare the seismic response of a regular-shaped structure and a Plus-shaped structure.
- To analyse key parameters including story displacement, story drift, story shear, overturning moment, and base shear.
- To investigate the optimal placement and sizing of friction dampers for maximizing structural stability during earthquakes.

3. Methodology

3.1 General

The design process for all the structural instances is presented in this section. This thesis conducts a thorough analysis and comparison of the seismic performance of reinforced cement concrete (RCC) structures with and without friction dampers and shear walls. The study focuses on buildings located in Seismic Zone V, which has a zone factor of 0.36, and on soil type III (soft soil), which is particularly susceptible to seismic pressures. Friction dampers, a kind of passive energy dissipation device, enhance structural performance by reducing lateral vibrations by distributing seismic energy through regulated frictional resistance.

3.1 Steps involved in methodology and design process

Step 1: Initialization of the structure which is focused towards analyzing multi-story high-rise structures considering seismic loads with same seismic zones and soil condition.

Step 2: In order to initiate the modelling of the case study, firstly there is a need to initialize the structural model on the basis of defining display units on metric SI in region India as ETABS supports the building codes of different nations. The steel code was considered as per IS 800:2007 and concrete design code as per IS 456:2000.

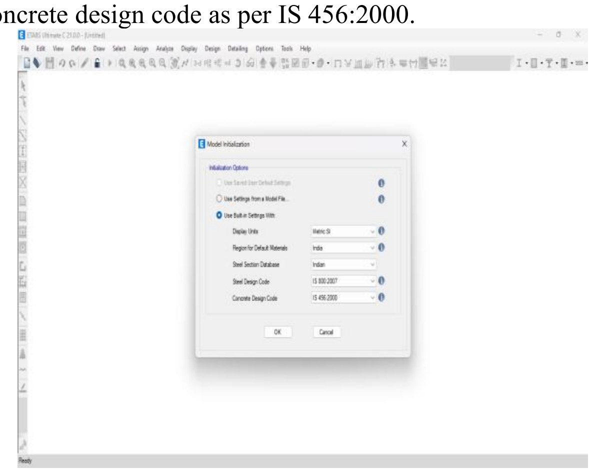

Figure 3.1 Model Initialization

Step 3: ETABS provides the option of modelling the structure with an easy option of Quick Template where the grids can be defined in X, Y and Z direction. Here in this case, we are considering 45m long Regular and Plus Shaped Building. G+14 story structure is considered with typical story height of 3 m and Bottom story height of 3 m.

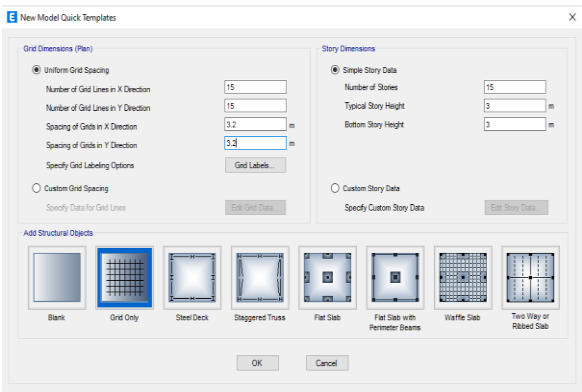

Figure 3.2 New Model Quick Template

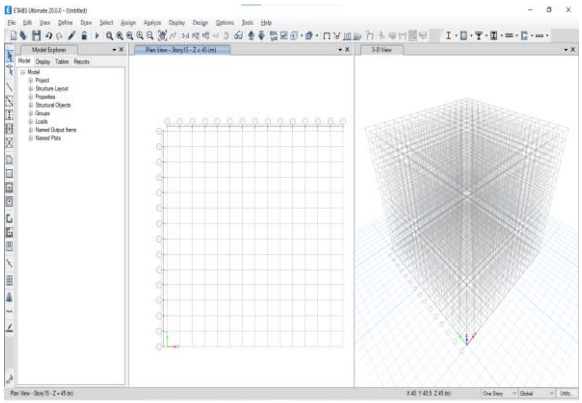

Figure 3.3: Grid Plan of the Structure

Step 4: Next step is to define the material properties of concrete and steel. Here in this case study, M30 concrete is considered and its predefined properties are available in the ETABS application.

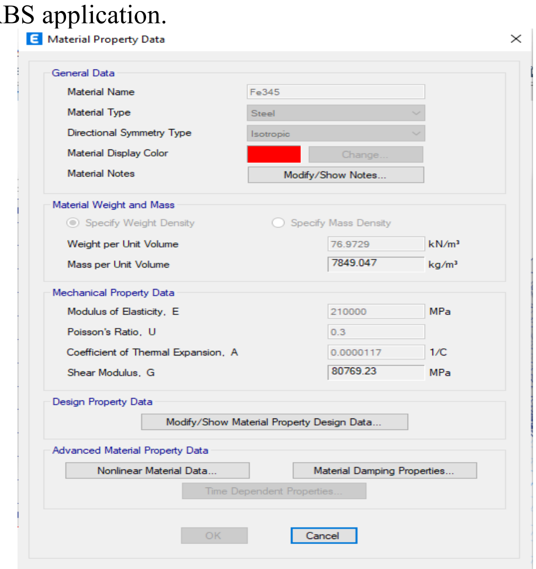

Figure 3.5: Defining Properties of Steel as Fe345

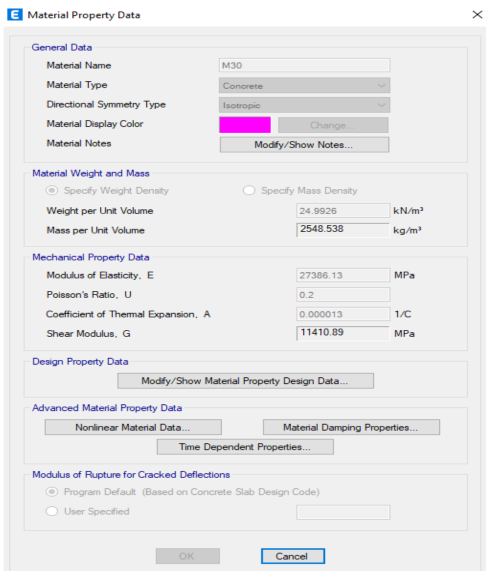

Figure 3.6: Defining Properties of Concrete M30

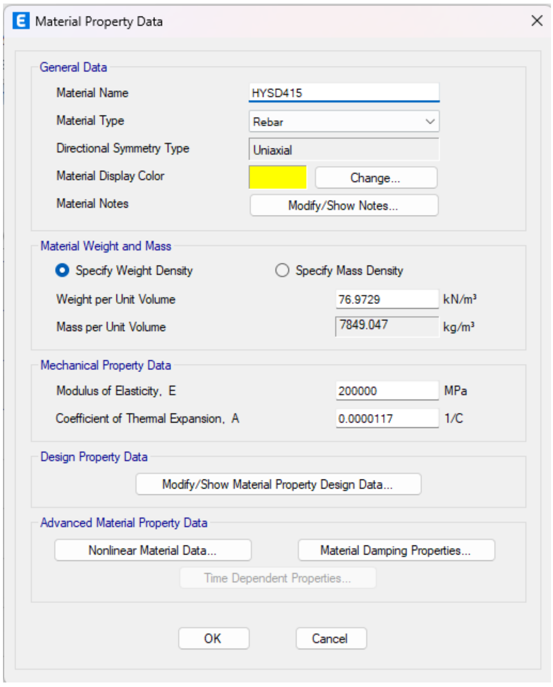

Figure 3.7: Defining Properties of Rebar as HYSD415

Step 5: Defining section properties for Beam, Column. Beam size of 400x200mm, Column size of 500x400mm and Slab size of 150 mm are considered in the study.

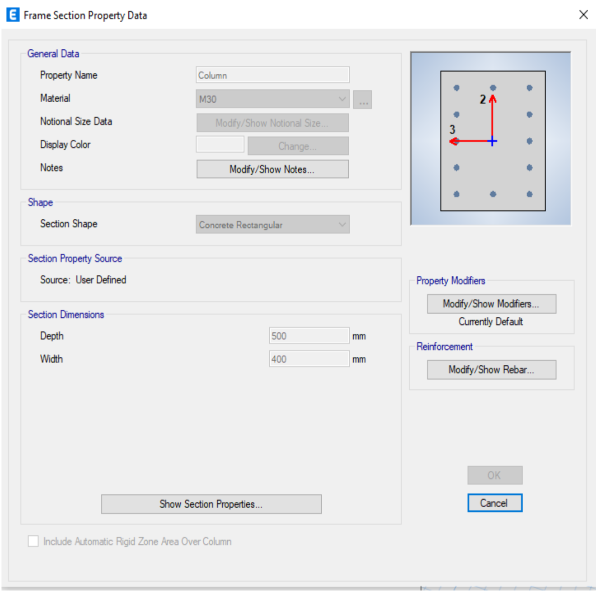

Figure 3.8: Defining Properties of Column

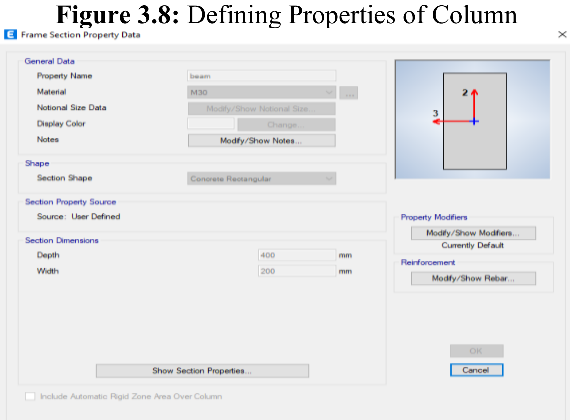

Figure 3.9: Defining Properties of Beam

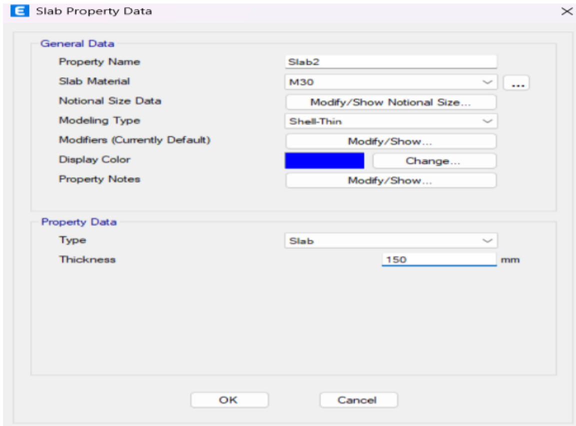

Figure 3.10: Defining Properties of Slab

Step 6: Assigning Fixed Support at bottom of the structure in X, Y and Z direction for all the considered cases.

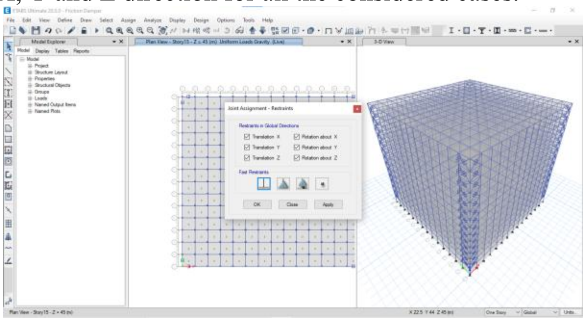

Figure 3.11: Assigning Fixed Support

Step 7: Defining Load cases for dead load, live load and seismic analysis for X and Y Direction.

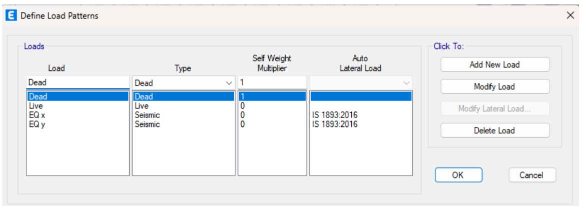

Figure 3.12: Defining load cases

Step 8 Defining Seismic Loading as per IS 1893: 2016 Part I.

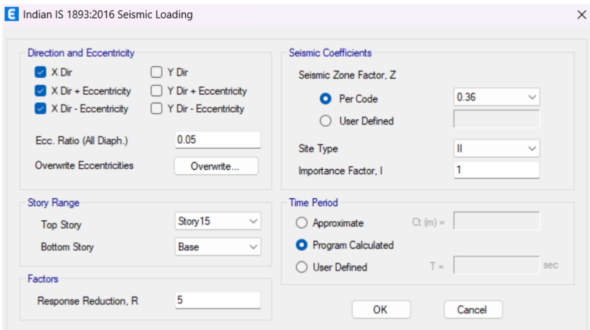

Figure 3.13: Seismic Loading

Step 9: Application of damper and shear walls.

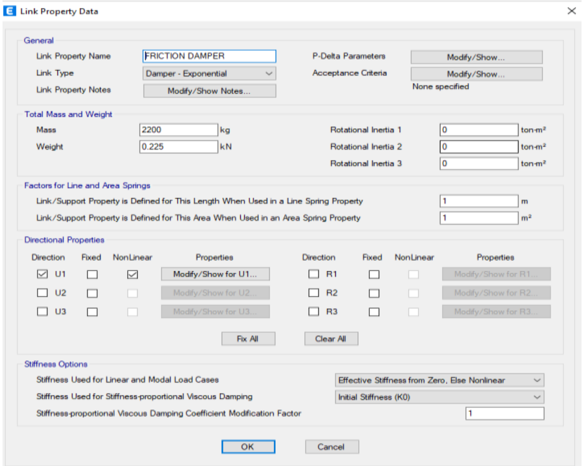

Figure 3.14: Application of Damper

Step 10: Conducting the model check for both the cases in ETABS.

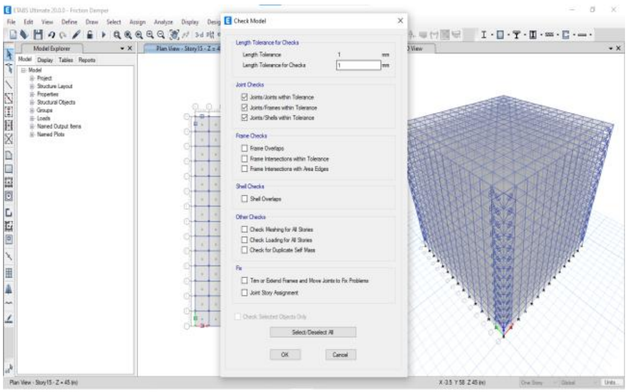

Figure 3.15: Model Check (with damper)

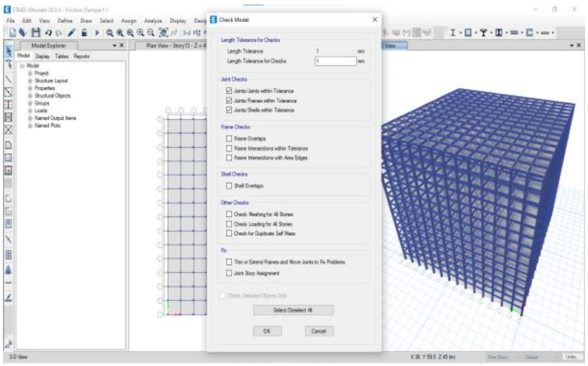

Figure 3.16: Model Check (without damper)

Step 11: Analyzing the structure for dead load, stress analysis and displacement.

4. Results & Discussion

4.1 General

The observed results are shown in this section. This thesis conducts a thorough analysis and comparison of the seismic performance of reinforced cement concrete (RCC) structures with and without friction dampers and shear walls. The study focuses on buildings located in Seismic Zone V, which has a zone factor of 0.36, and on soil type III (soft soil), which is particularly susceptible to seismic pressures. Friction dampers, a kind of passive energy dissipation device, enhance structural performance by reducing lateral vibrations by distributing seismic energy through regulated frictional resistance.

4.2 Maximum story displacement X-direction

Table 4.1 Maximum story displacement in mm

Maximum story displacement in X-Direction						
Story	Structure I	Structure II	Structure III	Structure IV	Structure V	Structure VI
Story 15	35.98	18.14	17.22	24.46	21.34	14.47
Story 14	34.16	17.88	16.45	24.33	21.17	13.81
Story 13	31.02	16.74	15.51	24.23	20.98	13.22
Story 12	28.6	15.98	14.72	24.09	20.68	12.61
Story 11	26.13	14.64	13.65	23.21	20.02	11.82
Story 10	24.76	13.47	12.76	22.17	18.98	10.81
Story 9	22.41	12.67	11.83	20.78	17.59	9.69
Story 8	20.4	11.5	10.78	19.09	15.93	8.49
Story 7	18.36	10.83	9.99	17.17	14.05	7.25
Story 6	16.33	9.56	8.89	15.69	12.02	5.98
Story 5	13.6	7.51	6.99	12.83	9.87	4.73
Story 4	10.56	5.47	4.82	10.51	7.66	3.53
Story 3	7.37	3.62	2.64	8.13	5.42	2.43
Story 2	4.49	2.04	1.97	5.7	3.22	1.47
Story 1	2.01	1.07	0.01	3.13	1.28	0.67

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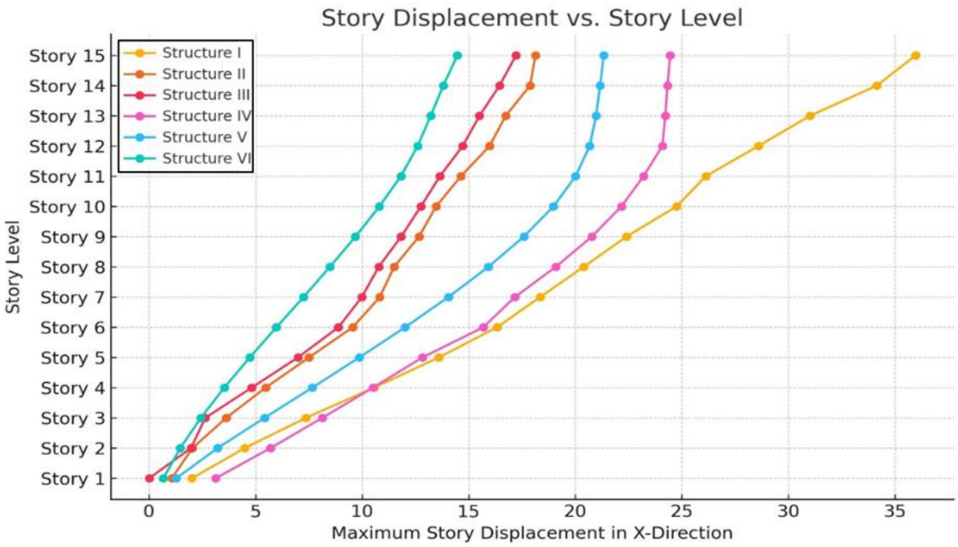

Figure 4.1: Maximum story displacement in mm

Inference- The different structure shapes were compared with bare frame supported with friction dampers and shear wall and similar results were compared for the plus shape structure with friction dampers and shear walls at the corners. The story displacement was found to be stable in all the compared cases but the least maximum displacement was visible for Structure VI as 14.47 mm which was 49.21 % less than Structure IV and 61.19% less when compared to bare frame Structure I.

4.3 Story drift X-direction

Table 5.2: Story drift

Maximum story Drift in X-Direction						
Story	Structure I	Structure II	Structure III	Structure IV	Structure V	Structure VI
Story15	4.60E-05	4.30E-05	0.000233	3.50E-05	0.00007	0.000066
Story14	7.00E-06	7.00E-06	0.000227	4.50E-05	5.8E-05	0.000053
Story13	1.00E-06	1.00E-06	0.000232	8.90E-05	0.00011	0.000064
Story12	1.00E-06	1.90E-07	0.000248	0.00021	0.00022	0.000107
Story11	1.00E-06	1.94E-07	0.000286	0.00035	0.00035	0.000225
Story10	1.00E-06	1.94E-07	0.000331	0.00046	0.00046	0.000355
Story 9	1.00E-06	2.03E-07	0.000372	0.00056	0.00055	0.000469
Story 8	1.00E-06	2.11E-07	0.000399	0.00064	0.00063	0.000563
Story 7	1.00E-06	2.21E-07	0.000423	0.00070	0.00068	0.000637
Story 6	1.00E-06	2.33E-07	0.000417	0.00074	0.00072	0.000693
Story 5	1.00E-06	2.44E-07	0.000400	0.00077	0.00074	0.000732
Story 4	1.00E-06	2.69E-07	0.000369	0.00079	0.00075	0.000756
Story 3	2.00E-06	2.94E-07	0.000324	0.00081	0.00074	0.000766
Story 2	4.00E-06	1.00E-06	0.000272	0.00086	0.00068	0.000695
Story 1	1.00E-05	4.00E-06	0.000226	0.00104	0.0004	0.000405

Paper ID: SE25519112125 DOI: https://dx.doi.org/10.70729/SE25519112125

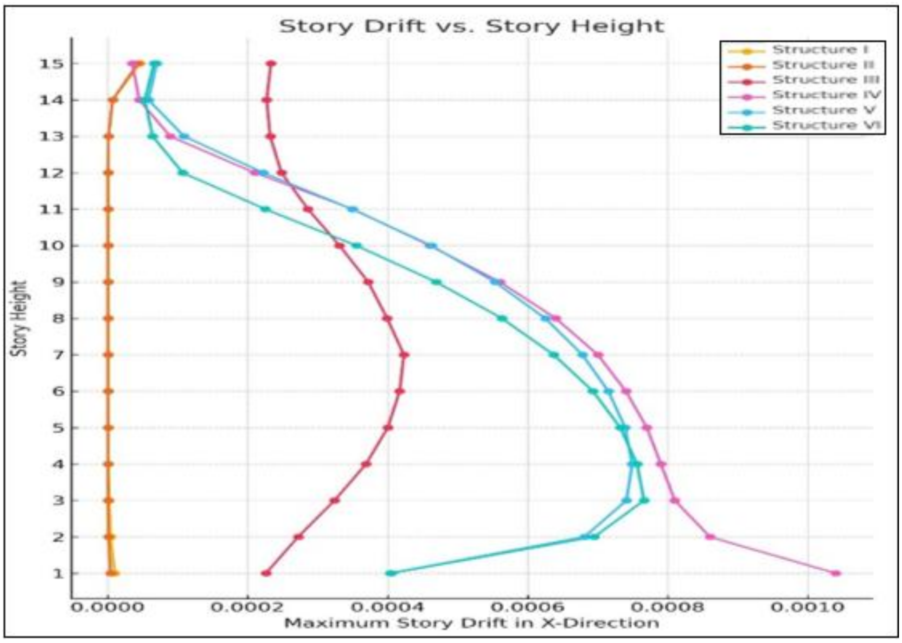

Figure 4.2: Story Drift

Inference- According to the investigation, it was found that the story drift of Plus shaped Structure IV was minimum and the frame is much stiffer than the others. Story drift depends upon the relative displacement to its height. Structure IV shows the highest story drift in most cases, meaning it experiences the most significant relative displacement. This suggests that its design is less effective in controlling lateral movements compared to the other structures. There are a number of possible explanations for this discrepancy, including differences in the other Structures loading circumstances, material composition, or structural design.

4.4 Story shear in X-direction

Table 4.3: Story shear in kN

Story Shear in kN						
Story	Structure I	Structure II	Structure III	Structure IV	Structure V	Structure VI
Story 15	3.48E+02	4.03E+02	397.03	4.98E+02	5.53E+02	547.08
Story 14	6.82E+02	8.30E+02	814.12	8.32E+02	9.80E+02	964.17
Story 13	9.67E+02	1.19E+03	1169.05	1.12E+03	1.34E+03	1319.1
Story 12	1.21E+03	1.50E+03	1468.12	1.36E+03	1.65E+03	1618.17
Story 11	1.40E+03	1.75E+03	1714.91	1.55E+03	1.90E+03	1864.96
Story 10	1.56E+03	1.96E+03	1914.82	1.71E+03	2.11E+03	2064.87
Story 9	1.69E+03	2.12E+03	2072.76	1.84E+03	2.27E+03	2222.81
Story 8	1.79E+03	2.24E+03	2193.69	1.94E+03	2.39E+03	2343.74
Story 7	1.86E+03	2.33E+03	2282.54	2.01E+03	2.48E+03	2432.59
Story 6	1.91E+03	2.40E+03	2344.24	2.06E+03	2.55E+03	2494.29
Story 5	1.94E+03	2.44E+03	2383.72	2.09E+03	2.59E+03	2533.77
Story 4	1.96E+03	2.46E+03	2405.94	2.11E+03	2.61E+03	2555.99
Story 3	1.97E+03	2.47E+03	2415.81	2.12E+03	2.62E+03	2565.86
Story 2	1967.51	2.47E+03	2418.28	2117.56	2.62E+03	2568.33
Story 1	1.97E+03	2.47E+03	2421.07	2.12E+03	2.62E+03	2571.12

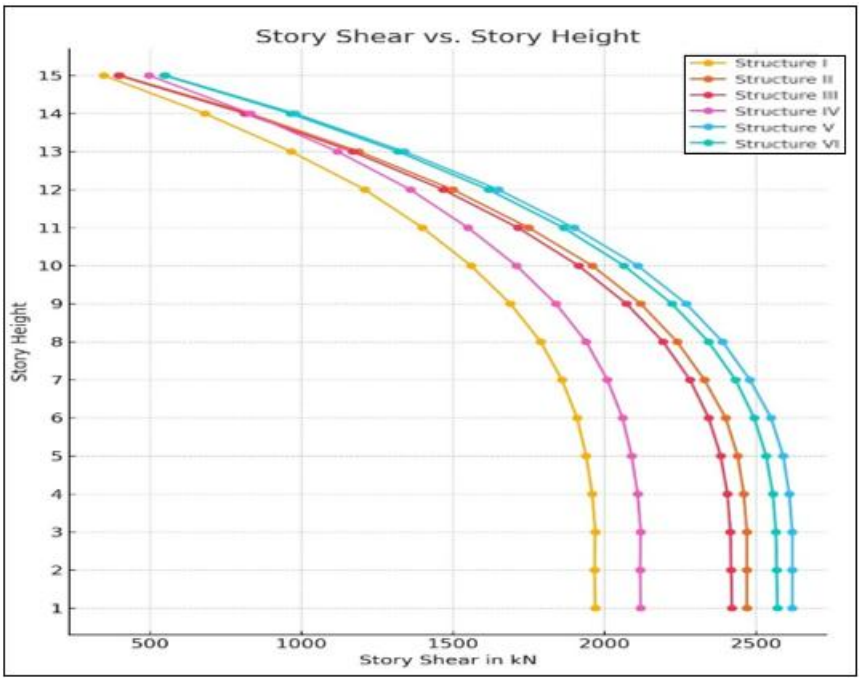

Figure 4.3: Story Shear in kN

Inference:- Story shear is the lateral force that acts on a buildings story due to wind or seismic forces. It's the shear load that the structure below the story must resist. The maximum shear force was visible for the Structure V for the structure in plus shaped with dampers which was 127.71% on higher side when compared to the bare frame structure I.

4.5 Overturning moment X-direction

Table 4.4: Overturning moment

Overturning moment						
Story	Structure I	Structure II	Structure III	Structure IV	Structure V	Structure VI
Story 15	111.2829996	101.8434163	70.0672497	1.90E+02	1.52E+02	110.3287401
Story 14	2212.265324	1973.995575	1462.47583	2.99E+03	2.5000	2001.32749
Story 13	18600.04743	16565.4336	12742.5221	20558.06743	18523.4536	25485.0442
Story 12	26207.33048	23287.26816	18017.412	28348.33048	25428.26816	36034.824
Story 11	34574.88945	30670.19463	23723.1926	37059.88945	33155.19463	47446.3852
Story 10	43580.46474	38648.7276	29715.4145	46334.46474	41402.7276	59430.829
Story 9	53111.82654	47164.22839	35891.6389	56213.82654	50266.22839	71783.2778
Story 8	63115.05641	56183.35594	42214.4867	66713.05641	59781.35594	84428.9734
Story 7	73597.04646	65695.33982	48715.3748	78362.04646	70460.33982	97430.7496
Story 6	84579.74916	75688.35378	55459.0749	90533.74916	81642.35378	110918.1498
Story 5	96073.14537	86143.62632	62514.4069	103218.1454	93288.62632	125028.8138
Story 4	108076.3237	97044.64386	69936.2225	116726.3237	105694.6439	139872.445
Story 3	120582.1808	108378.7321	77754.2875	131034.1808	118830.7321	155508.575
Story 2	133554.7644	120111.5782	85956.3265	145541.7644	132098.5782	171912.653
Story 1	149613.3517	134606.1379	96215.8919	162637.3517	147630.1379	192431.7838

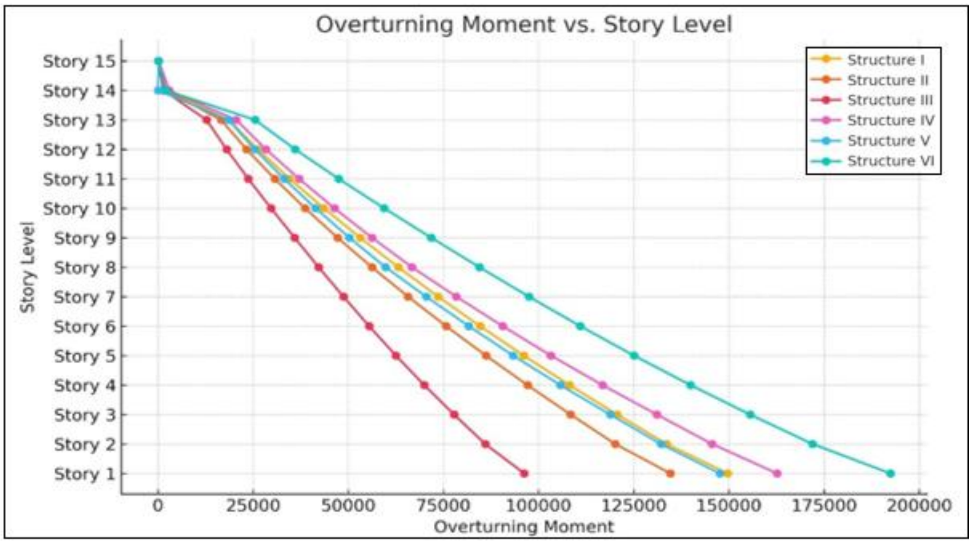

Figure 4.4: Overturning Moment in kN-m

Inference: The Overturning moment is the sum of all forces that can cause a structure to tip over around a pivot point, typically at or near its foundation. It's a measure of the potential for a structure to become unstable and turn over. The maximum story overturning moment of Structure VI was 9.8% more than that of Structure I. This suggests that the Structure VI experiences slightly higher rotational force due to slightly higher lateral forces than the other compared Structure. However, the overall overturning moment of the two Structure does not differ significantly.

4.6 Base shear in X-direction

Table 4.5: Base shear

Base Shear in KN					
Structure I	Structure II	Structure III	Structure IV	Structure V	Structure VI
2167.513	2298.308	2418.281	2012.908	2598.655	2606.011

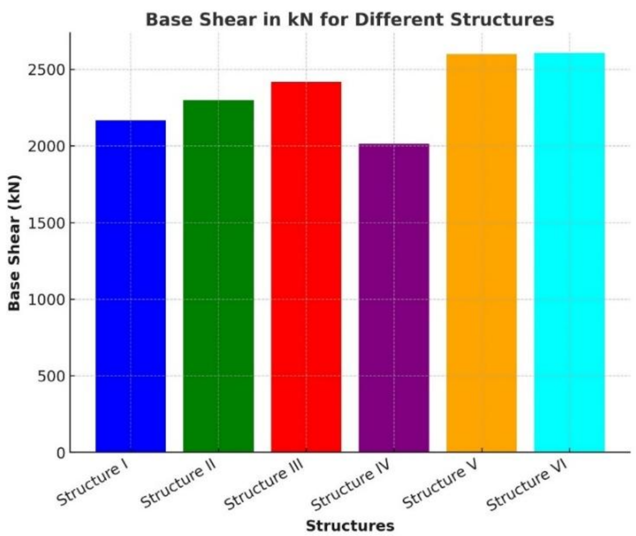

Figure 4.5: Base shear in kN

Inference: Base shear is used in the design of buildings to ensure they can withstand seismic activity. It is the maximum lateral force that acts on the base of a structure during an earthquake. It's a key property of a structure that's calculated during structural analysis. The base shear of Structure VI was 37.1% greater than that of Structure I. This might be explained by differences in the two structure loading circumstances, material composition, or structural design.

5. Conclusion

This study compared the seismic performance of RCC buildings with two structural configurations Regular and Plus-shaped under various support systems, including shear walls and friction dampers. Key seismic parameters such as story displacement, story drift, story shear, overturning moment, and base shear were analysed. The results indicate that Structure VI (Plus-shaped with shear walls) demonstrated the best overall performance, showing the lowest storey displacement (14.47 mm), which was significantly lower than both the bare frame and other configurations. It also exhibited the minimum storey drift, reflecting better control over lateral movements. In terms of storey shear, Structure V (Plus-shaped with dampers) experienced the highest lateral force, suggesting increased energy dissipation. For the overturning moment, Structure VI showed only a moderate increase (9.8%) compared to the bare frame, indicating slightly higher rotational forces but within safe limits. Finally, base shear was highest in Structure VI about 37.1% more than the bare frame - implying greater resistance to seismic forces due to improved structural configuration and support. Overall, the integration of shear walls and friction dampers, particularly in a Plus-shaped structure, significantly enhances the seismic performance of RCC buildings.

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