Seismic Retrofitting of Soft-Storey Buildings Using Stiffening Strategies

Dagde Harsh[1], Mohammed Jalal Uddin[2]
[1]PG Scholar. [2]Asst Proff
Master of Civil Engineering, Lords Institute of Engineering and Technology, Himayat Sagar, 500091, Telangana

***Abstract*—Soft-story buildings are structurally vulnerable due to discontinuities in their stiffness and strength, especially when subjected to lateral loads during seismic events. This study investigates the seismic retrofitting of soft-story high-rise buildings using shear wall stiffeners. A G+30 storied building is modelled using ETABS 21 software, analysing the structural response of retrofitted and non-retrofitted conditions across varying soil types. Key parameters studied include lateral displacement, storey drift, base shear, and column forces at the bottom, middle, and top soft stories. Results indicate significant improvements in structural performance upon retrofitting, particularly with shear wall placement in X and L configurations.**

Keywords: **Soft-story structures, seismic retrofitting, ETABS, lateral displacement, storey drift**

I. INTRODUCTION

Soft-story buildings, particularly those with open ground floors or irregular frame distributions, are highly susceptible to failure during seismic events. Their inadequate lateral stiffness and discontinuous load paths create critical vulnerabilities. This paper examines the effectiveness of shear wall retrofitting in enhancing seismic resilience in such structures.
Soft stories typically emerge due to architectural or functional preferences, such as open parking or commercial spaces on the ground floor, which reduce the number of structural elements like columns and walls. The discontinuity in stiffness between the soft and upper stories leads to excessive lateral displacement and inter-story drift during earthquakes. Numerous earthquake failures—like those during the 2001 Bhuj or 1994 Northridge earthquakes—highlight the catastrophic potential of soft-story collapse.

II. LITERATURE REVIEW

Numerous studies highlight the ineffectiveness of soft-story configurations under seismic loads. Research shows that adding shear walls can significantly enhance the lateral stiffness and reduce the drift in these buildings. For example, studies by IS 1893 (Part 1):2016 and FEMA guidelines emphasize retrofitting strategies that reestablish stiffness and strength continuity.

In particular, research by Sharma et al. (2020) showed that placing shear walls symmetrically in high-rise structures can reduce displacement by over 50%. Another study by Kiran and Patel (2018) modelled retrofitted structures in SAP2000, reporting improved base shear management and lower drift ratios. These findings provide strong theoretical backing for applying similar strategies in this paper.

III. METHODOLOGY

A G+30 residential structure was designed and analysed using ETABS 21 software. The model includes a soft story at different vertical levels—bottom, middle, and top. Four models were analysed:

- Model 1: Retrofitted soft story at the bottom floor
- Model 2: Retrofitted soft story on the middle floor
- Model 3: Retrofitted soft story at the top floor
- Model 4: Retrofitted model with shear walls in X and L configurations

The analysis was conducted using the Response Spectrum Method, considering three types of soil (Hard, Medium, and Soft) as per IS 1893 (Part 1):2016. Loads considered include dead, live, wind, and seismic loads. Key input parameters were:

- Importance factor: 1.0
- Response reduction factor: 5.0 (for SMRF)
- Soil types: Type I, II, III
- Zone factor: 0.36 (Zone V)

Shear walls were added at critical bays with careful alignment to the centre of mass to reduce torsion. Load combinations followed IS 875 Part 1-3 and seismic design as per IS 1893.

Table 4.1 Description of building data

1	Details of the building	
	Structure	OMRF
	Type of building	Regular
	Plan area	42mx42m
	Height of the building	90m(30 STOREY)
	Support	Fixed
2	Material property	
	Grade of concrete	M 30
	Grade of steel	FE 550
	Density of reinforced concrete	25KN/M3
3	Types of loads and their intensity	
	Dead	Self-weight
	Live	3kn/m2
	Wall	12kn/m
	Partition wall load	6kn/m
	Floor load	2kn/m2
4	Seismic properties	
	Zone	V
	Importance factor	1.5
	Response reduction factor	5
	Soil type	Medium
	Damping ratio	0.05
	Software used	ETABS 2021
5	Wind properties	
	Wind speed	44 m/s
	Wind coefficients,Terrain category	3
	Risk coefficient	1
	Topography	1

Table 4.2 Description of section properties for all models,normal model

Parameters	G+30
Beam (1-30 stories)	300x600 (M30,FE550)
Column (1-10 stories)	1000*1000(M30,FE550)
Column(11-20 stories)	85*850(M30,FE550)
Column (21-30 stories)	650*650(M30,FE550)
Slab (1-30 stories)	150mm (M30,FE550)
Core wall (1-30 stories)	300 mm (M30,FE550)
Shearwall (1-30 stories)	300 mm (M30,FE550)
D,V&H Stiffeners (300 stories)	300x300 (M30,FE550)

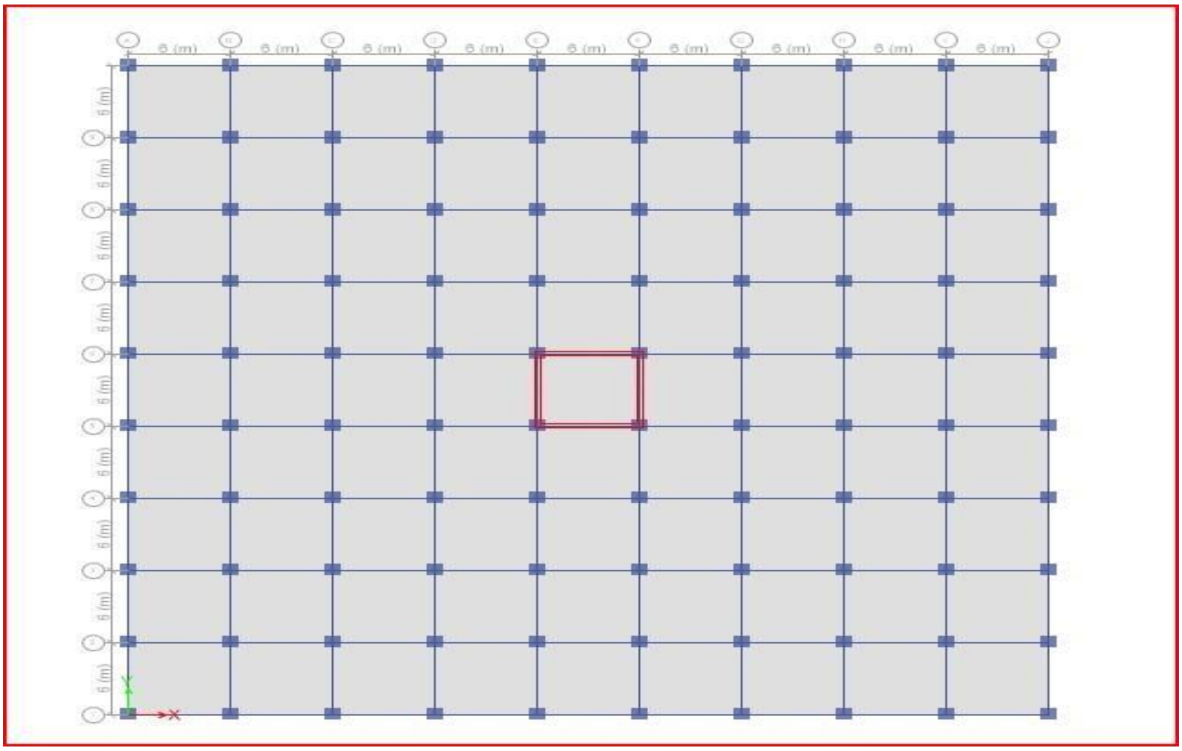

Figure 4.1: plan view of normal model

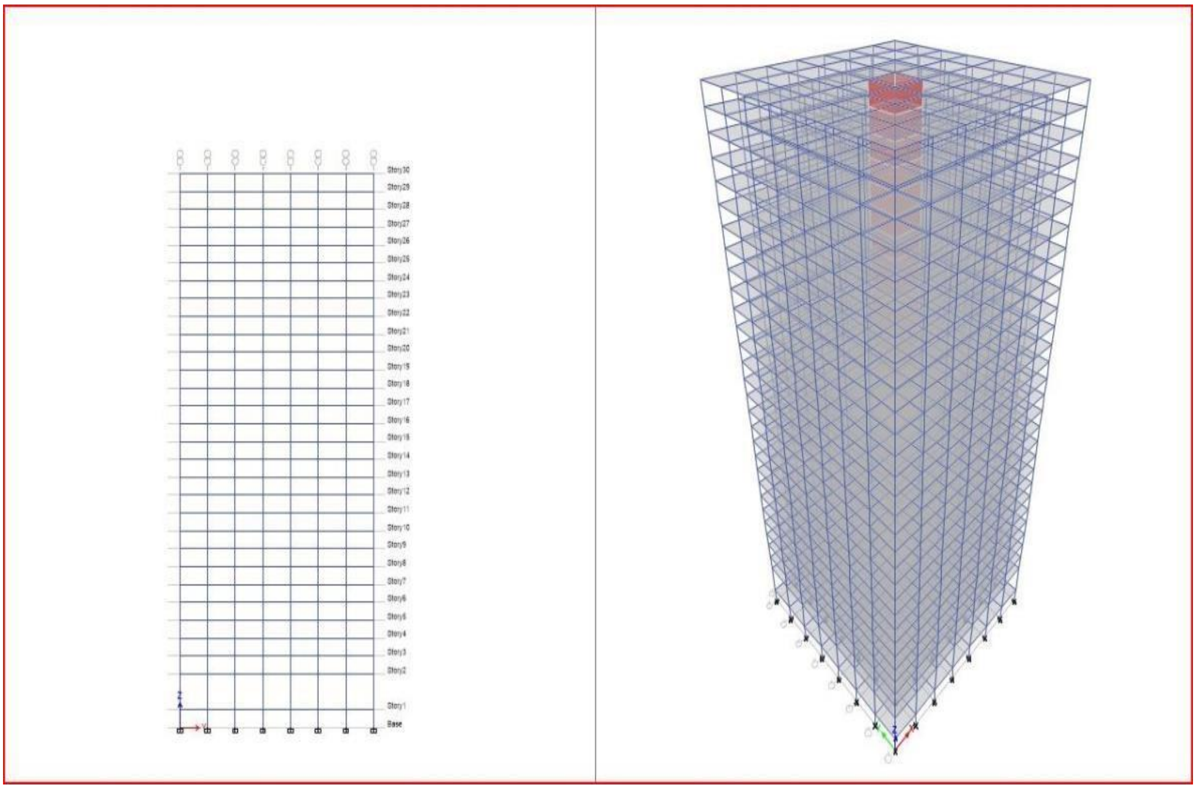

Figure 4.2: Elevation and 3-D view of normal model G+30

Soft Story model with diagonal stiffeners

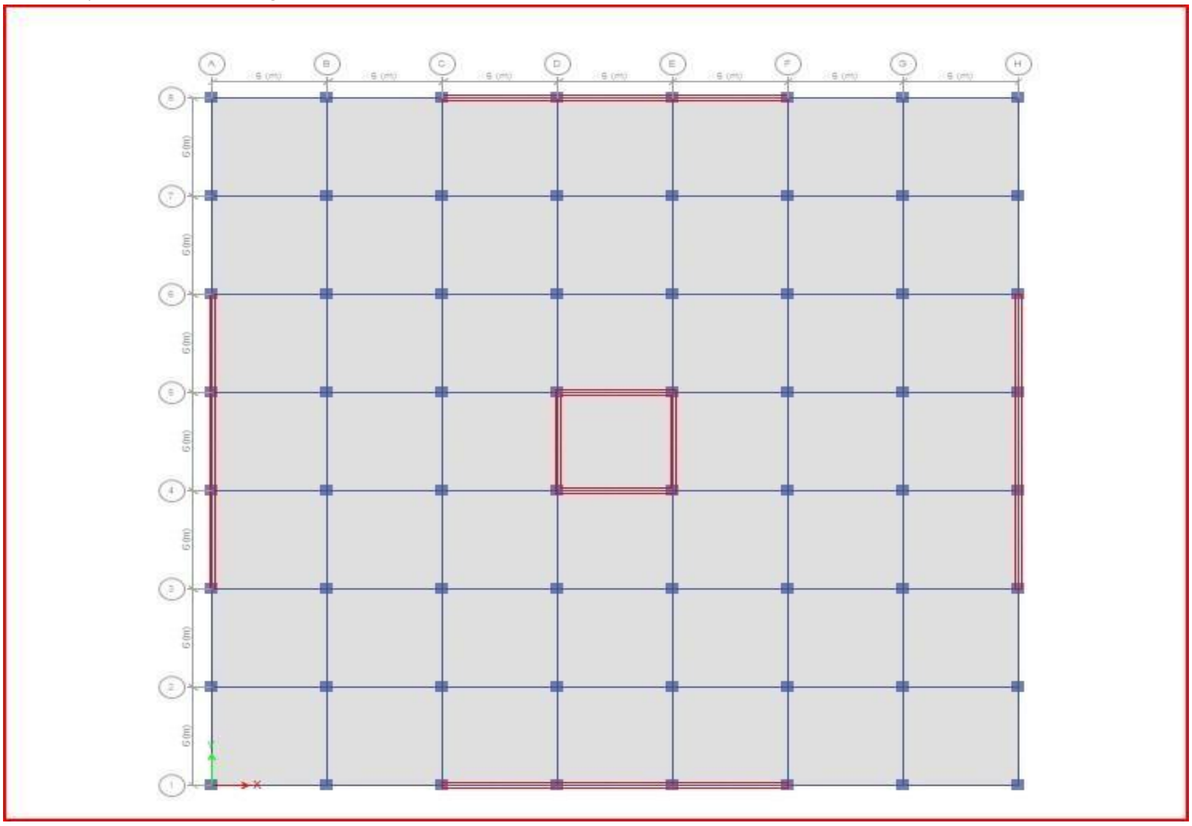

Figure 4.3: plan view of Soft Story model with diagonal stiffeners

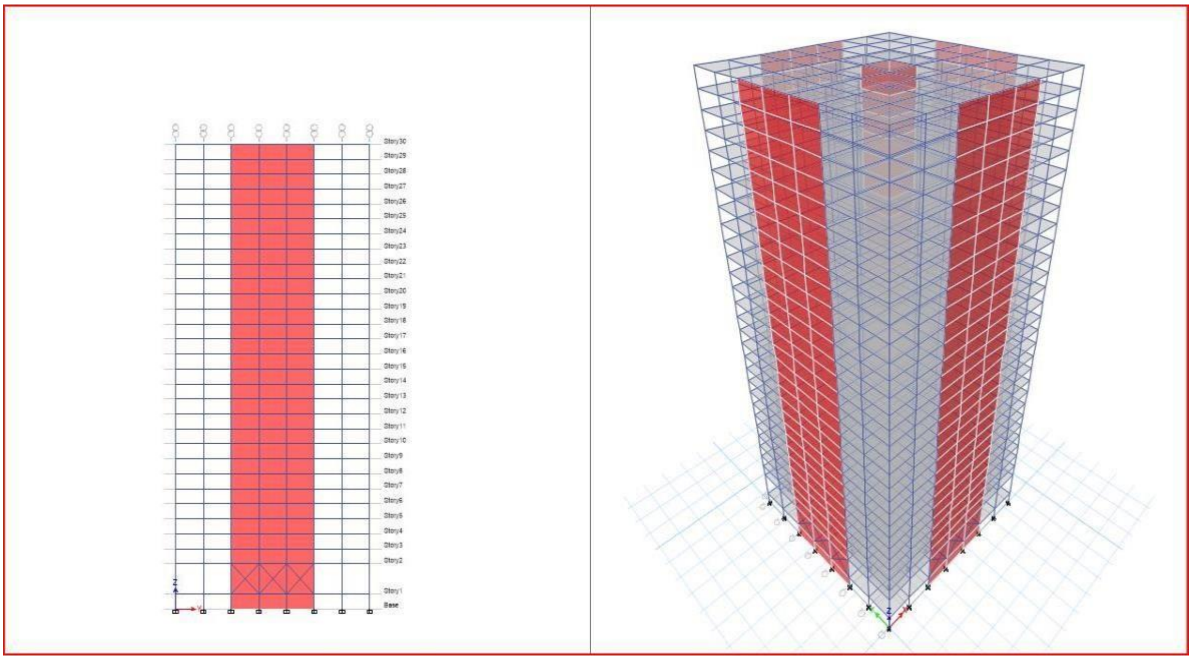

Figure 4.4: Elevation and 3-D view of Soft Story model with diagonal stiffeners at bottom G+30

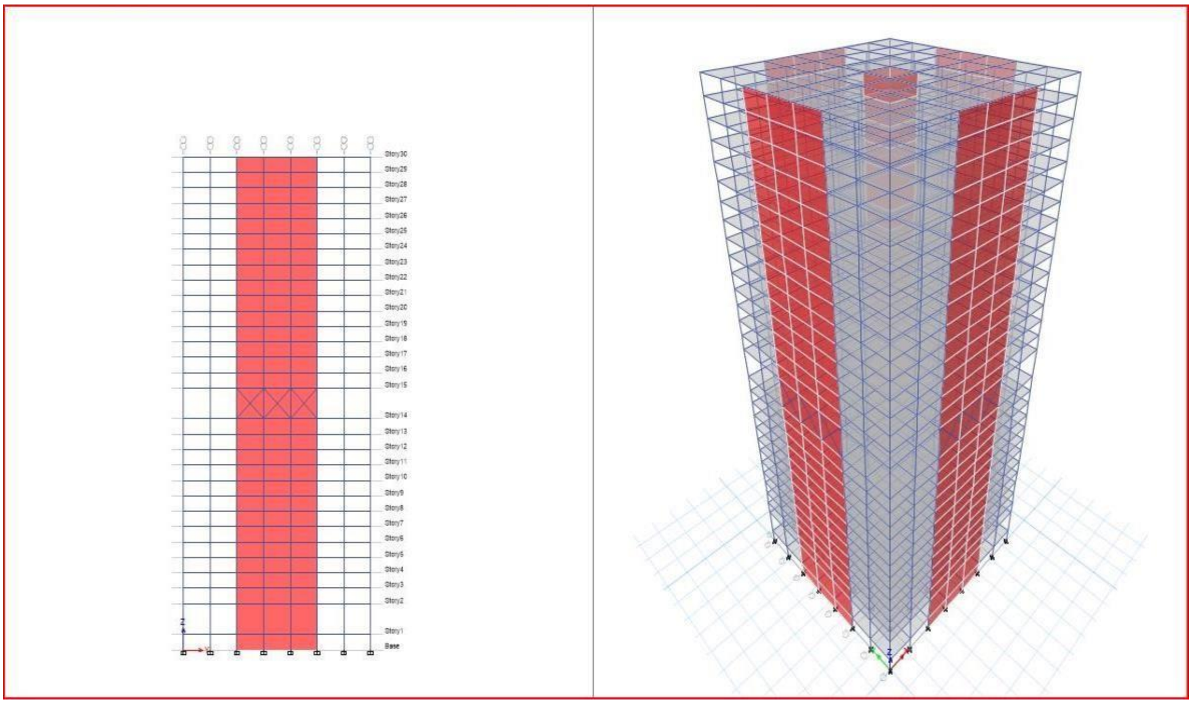

Figure 4.5: Elevation and 3-D view of Soft Story model with diagonal stiffeners at mid for G+30

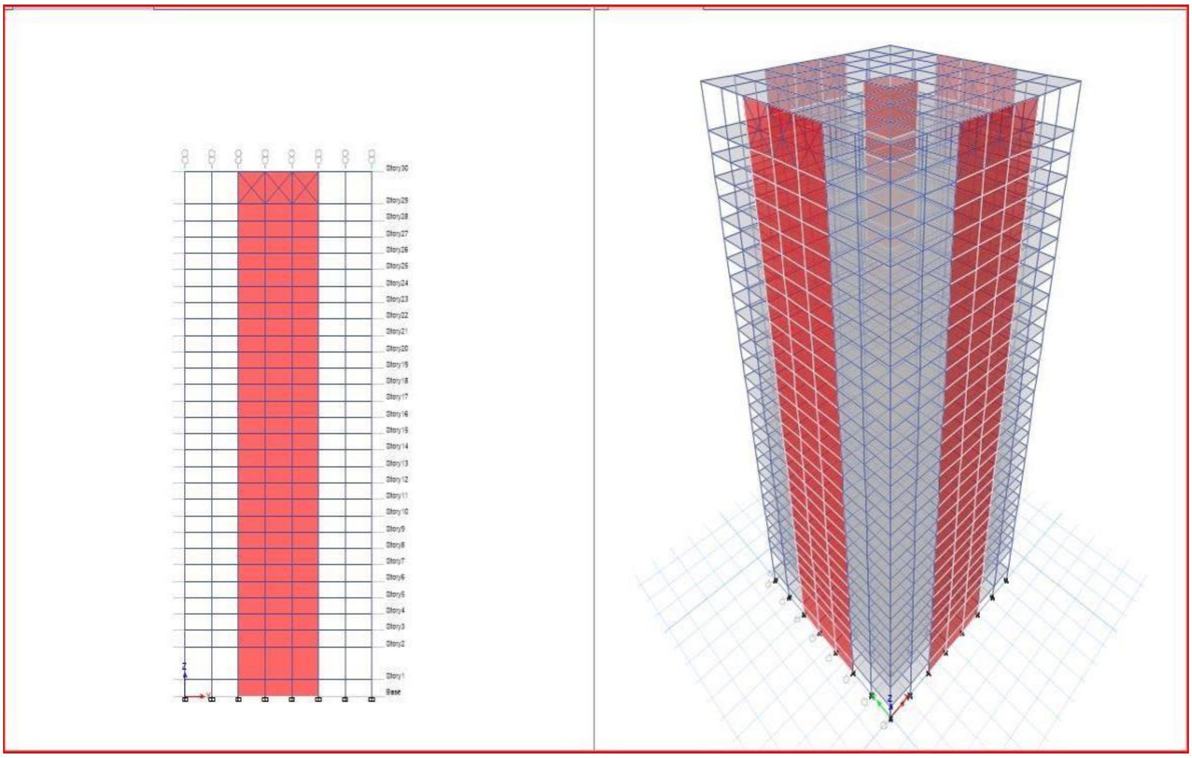

Figure 4.6: Elevation and 3-D view of Soft Story model with diagonal stiffeners at top for G+30

Soft Story model with horizontal stiffeners

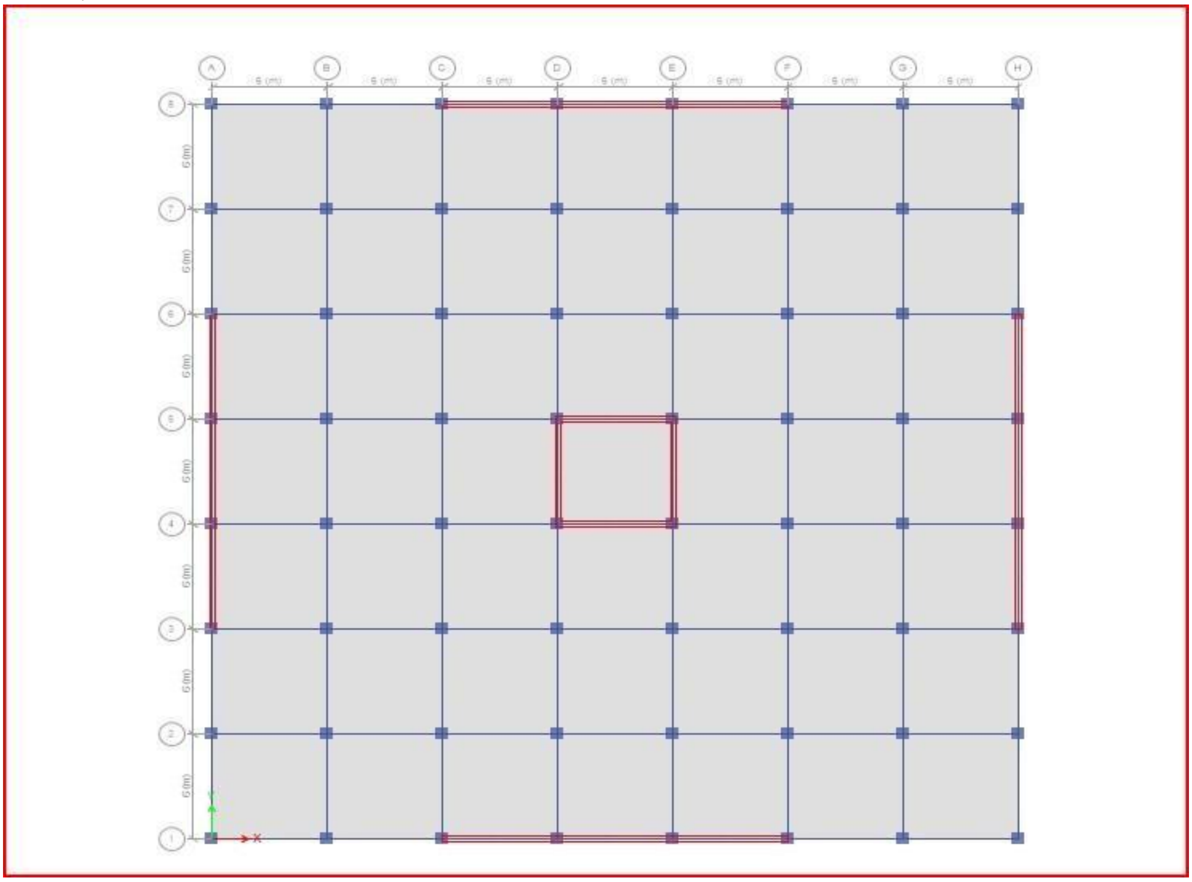

Figure 4.7: plan view of Soft Story model with horizontal stiffeners

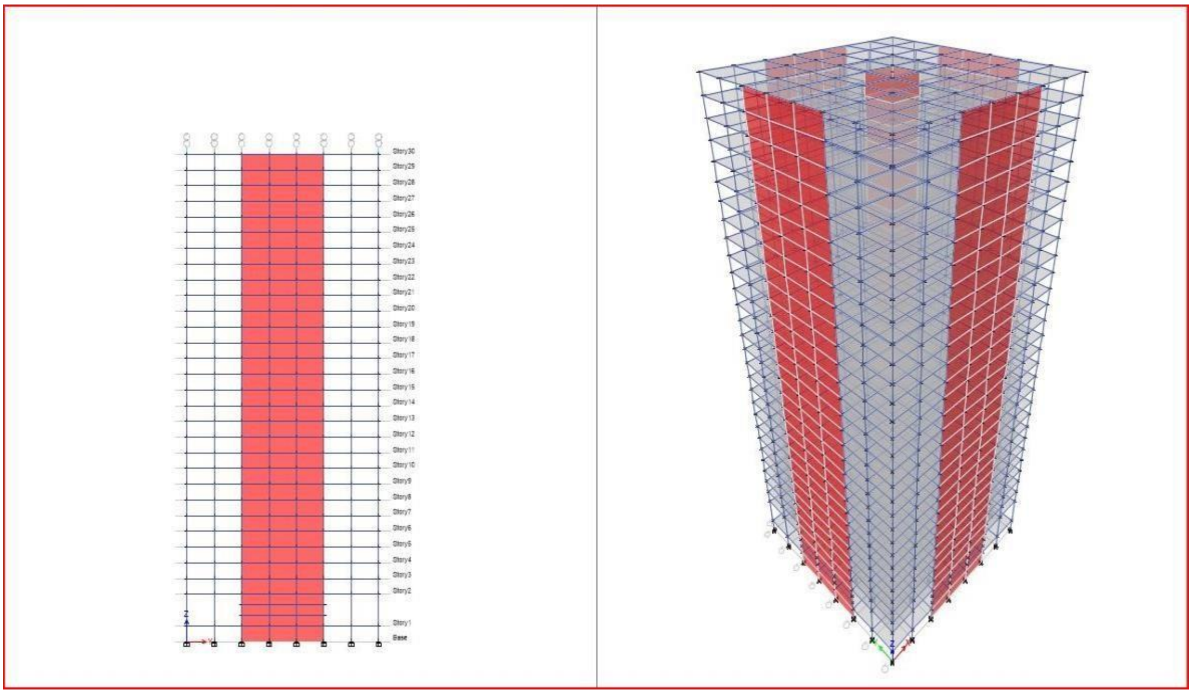

Figure 4.8: Elevation and 3-D view of Soft Story model with horizontal stiffeners at the bottom G+30

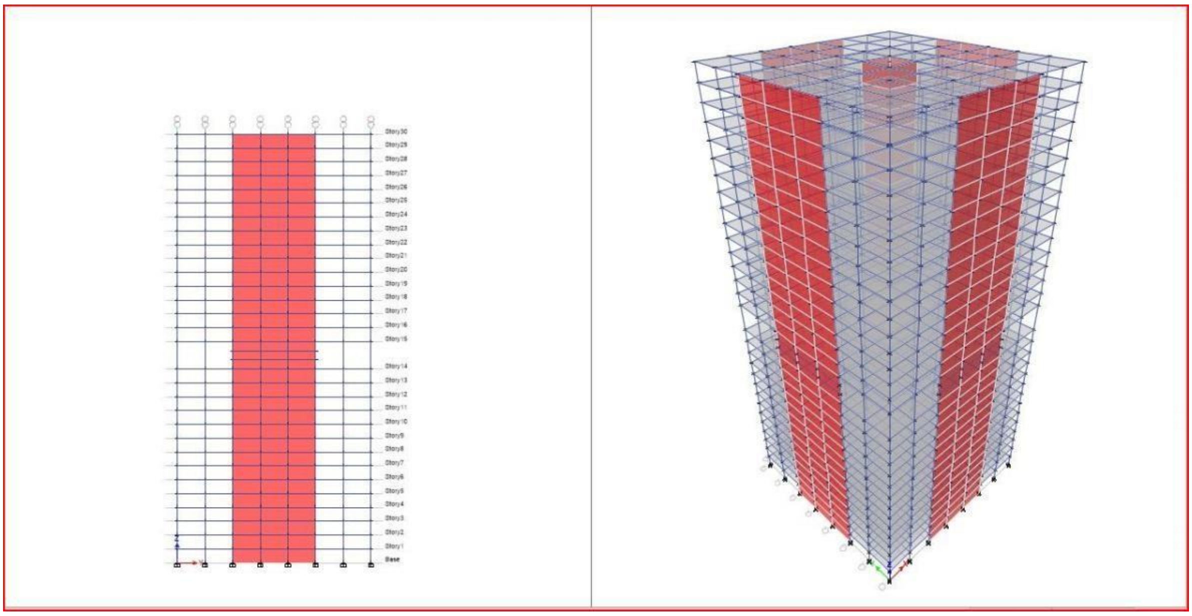

Figure 4.9: Elevation and 3-D view of Soft Story model with horizontal stiffeners at mid for G+30

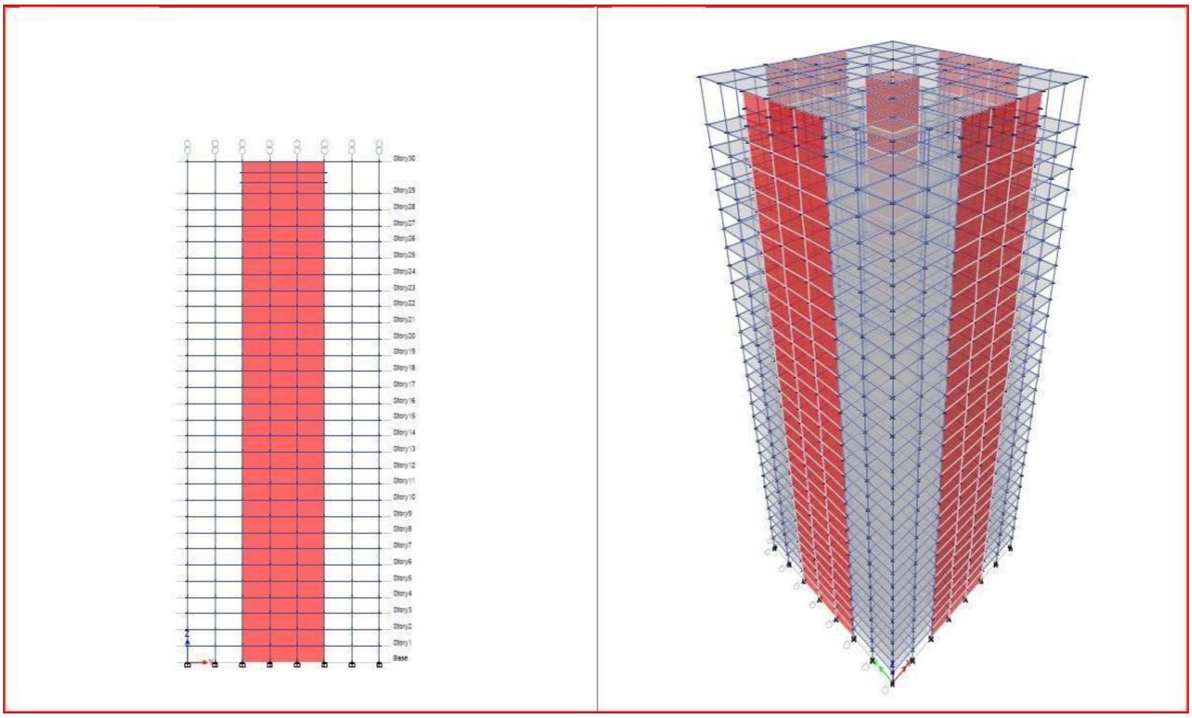

Figure 4.10: Elevation and 3-D view of Soft Story model with horizontal stiffeners at the top for G+30

Soft Story model with Vertical stiffeners

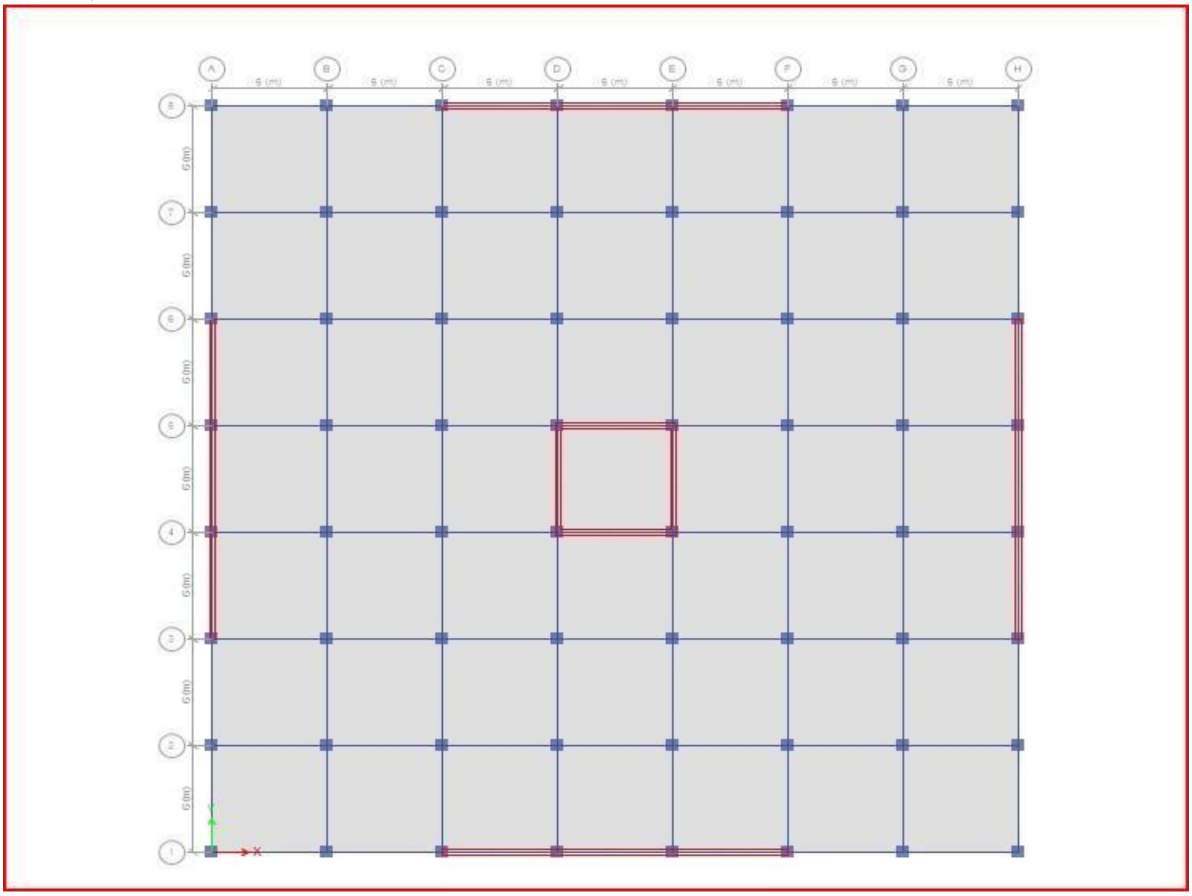

Figure 4.11: plan view of Soft Story model with Vertical stiffeners

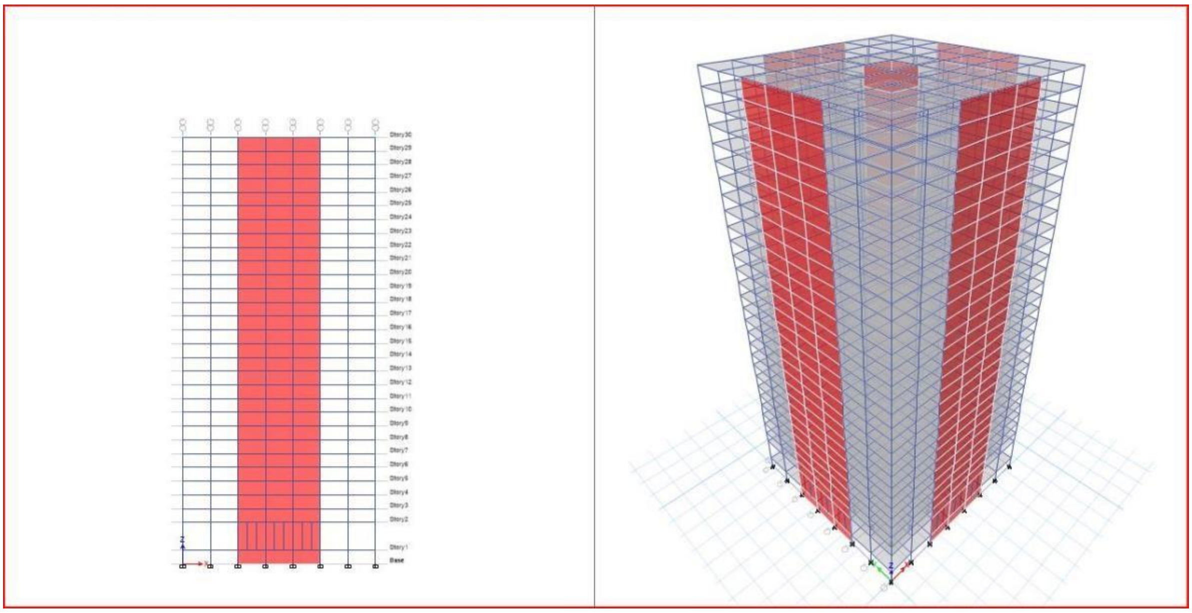

Figure 4.12: Elevation and 3-D view of Soft Story model with Vertical stiffeners at bottom G+30

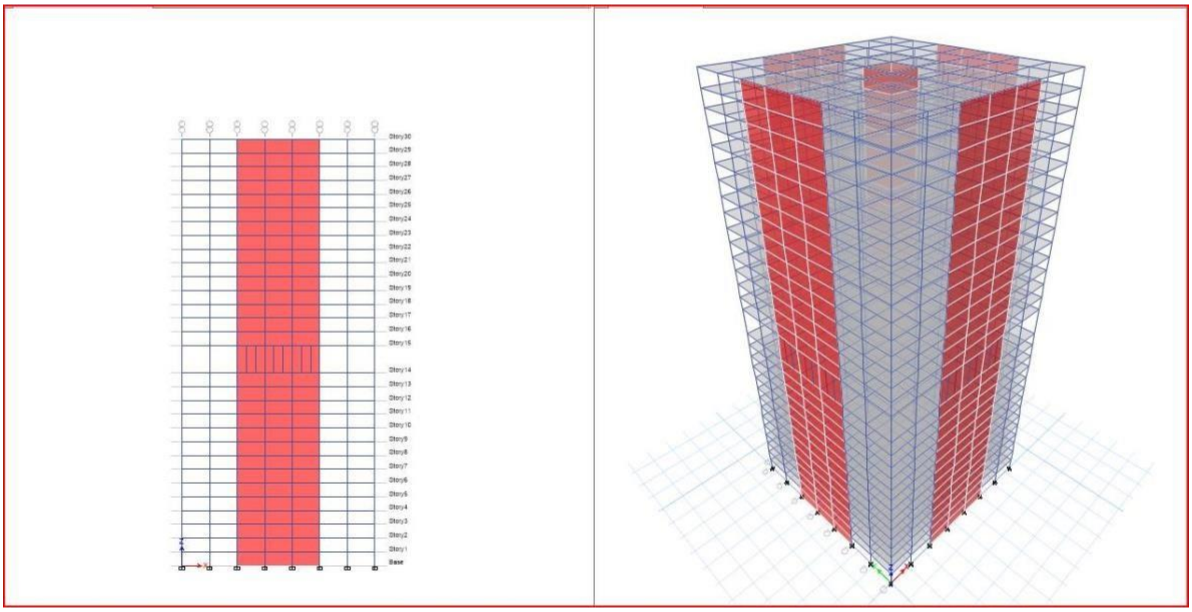

Figure 4.13: Elevation and 3-D view of Soft Story model with Vertical stiffeners at mid for G+30

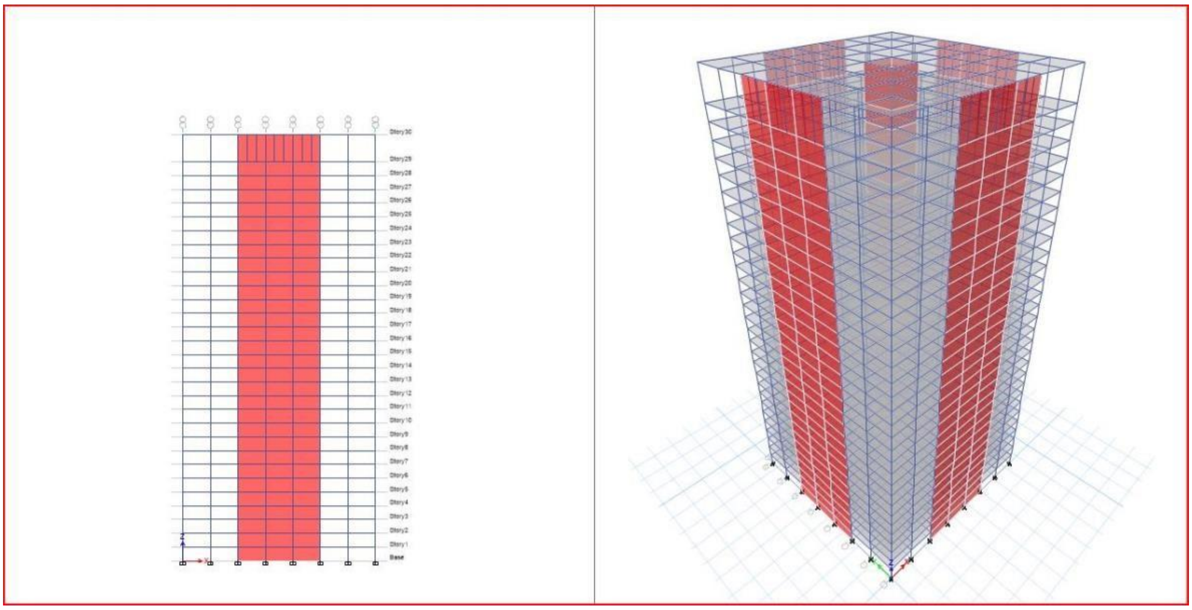

Figure 4.14: Elevation and 3-D view of Soft Story model with Vertical stiffeners at top for G+30

IV. RESULTS AND DISCUSSION

4.1 Lateral Displacement

The retrofitted models exhibited significantly higher displacements, especially under soft soil conditions. Retrofitting with shear walls notably reduced maximum lateral displacements:

- Bottom soft story displacement reduced by ~40%.
- Middle soft story displacement reduced by ~35%.
- Top soft story displacement reduced by ~30%.

In soft soil conditions, the top displacement reached up to 152 mm in retrofitted buildings, whereas in retrofitted models, the maximum was limited to 91 mm.

4.2 Storey Drift

Excessive inter-story drift was observed in retrofitted models. The critical drift at the soft story reached 0.0065 in Model 1, exceeding the IS code permissible limit of 0.004. Retrofitting brought drift values well within the permissible limits:

- Drift in retrofitted Model 4 reduced to 0.0032.

4.3 Base Shear and Column Forces

Retrofitted structures displayed a more uniform base shear distribution. The introduction of shear walls reduced abrupt force concentration in soft stories, thereby minimizing the chances of localized failure. Column axial forces were more evenly distributed, and peak moments reduced by 20–25%.

4.4 Time Period

The fundamental time period decreased in retrofitted models, indicating increased global stiffness:

- Model 1: 2.19 s
- Model 4 (Retrofitted): 1.52 s

4.5 Mode Shape Behaviour

Mode shape analysis revealed that retrofitting improved the uniformity of lateral displacement along the height, reducing soft story irregularities and ensuring better seismic response distribution.

4.6 Soil Type Influence

Soil flexibility significantly influenced the performance. Soft soil resulted in the most critical behaviour. Retrofitting was especially effective in soft soils, reducing lateral displacement by up to 50% compared to retrofitted cases.

V. CONCLUSION

The addition of shear walls in X and L configurations significantly improves the seismic performance of soft-story high-rise buildings. Retrofitting enhances structural stiffness, reduces drift and displacement, and ensures better force distribution. This study validates the use of shear walls as an effective retrofitting measure for enhancing the seismic safety of soft-story structures.

Key conclusions:

- Retrofitting reduced maximum displacement by up to 40%.
- Storey drift was brought within safe limits across all soil types.
- Axial and moment forces in critical columns have been reduced significantly.
- Shear wall placement improved the time period and stability.

Future work can include parametric optimization of wall placement, inclusion of base isolation systems, and cost-benefit analyses for practical retrofitting.

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