

Push over Analysis of Flat Slab Structure with Lateral Resistant System

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Abstract - Reinforced concrete flat slab systems are widely used in modern construction due to their architectural flexibility, reduced storey height, and ease of construction. However, the absence of beams decreases lateral stiffness, making such structures vulnerable to seismic effects and punching shear failures at slab-column connections. This study investigates the nonlinear seismic behaviour of flat slab buildings with and without lateral load-resisting systems using pushover analysis in ETABS. Parameters such as base shear, roof displacement, storey drift, and plastic hinge formation are evaluated. The results indicate that the inclusion of shear walls and perimeter beams significantly enhances seismic performance by improving stiffness, ductility, and overall structural stability.

Key Words: Flat slab, Pushover analysis, Seismic performance, Shear wall, RC structures.

1. INTRODUCTION

Flat slab systems are widely adopted in modern construction due to their architectural flexibility, reduced storey height, and ease of construction. However, the absence of beams decreases lateral stiffness and ductility, making these structures more vulnerable to seismic effects such as excessive drift and punching shear failure at slab-column connections. To improve seismic performance, lateral load resisting systems such as shear walls and perimeter beams are incorporated into flat slab buildings.

This study evaluates the nonlinear seismic behavior of reinforced concrete flat slab structures with and without lateral resisting systems using pushover analysis in ETABS. Parameters such as base shear, roof displacement, storey drift, and plastic hinge formation are analyzed to assess structural performance under earthquake loading. The results demonstrate that the inclusion of lateral resisting systems significantly enhances stiffness, ductility, and overall seismic stability of flat slab structures.

2. LITERATURE REVIEW

Previous studies indicate that flat slab structures are vulnerable to seismic forces due to low lateral stiffness, limited ductility, and susceptibility to punching shear failure at slab-column connections. Dhananjay and Pranesh [9], Gagankrishna and Nethravathi [10], and Hassaballa et al. [11] reported that flat slab buildings experience excessive storey drift and lateral displacement during earthquake loading. Mishra and Dubey [14] also discussed the seismic response of flat slab systems as per IS 1893 provisions.

Researchers observed that the inclusion of lateral load resisting systems such as shear walls, steel bracing, and drop panels significantly improves structural stiffness and seismic performance. Karthik [12] and Kumar [13] highlighted the effectiveness of shear walls and steel bracing systems, while Tejaswini [16], Hasibuan et al. [5], and Najafgholipour et al. [20] confirmed improved seismic behavior through nonlinear analysis. Nugraha et al. [25] also reported better structural performance in buildings provided with shear walls.

Several studies focused on punching shear behavior and nonlinear pushover analysis of flat slab systems. Elnahla and Abdalla [3], Truong et al. [23], and Mendes et al. [24] investigated punching shear strength of RC flat slabs. ATC-40 [17] provided guidelines for performance-based seismic evaluation, while Baitule [8] and Nisarg et al. [15] emphasized the effectiveness of nonlinear pushover analysis in assessing inelastic structural behavior.

The present authors previously carried out a review study on performance-based seismic analysis of flat slab buildings with lateral resistance systems [1] and also presented a conference paper on the seismic behavior of flat slab buildings with lateral resistance systems [2]. However, limited research is available on the comparative nonlinear seismic performance of flat slab structures with different lateral resisting systems. Therefore, the present study focuses on evaluating their seismic behavior using nonlinear pushover analysis.

3. RESEARCH METHODOLOGY

The methodology adopted in this study aims to investigate the nonlinear seismic response of reinforced concrete flat slab structures through pushover analysis. A three-dimensional flat slab building model is prepared in ETABS software by defining appropriate geometry, material properties, loading conditions, and boundary conditions in accordance with relevant Indian Standard codes.

To evaluate the influence of lateral load resisting systems, different structural configurations consisting of flat slabs with and without shear walls and perimeter beams are considered. Gravity loads and seismic loads are applied to simulate realistic structural behavior under earthquake excitation. Nonlinear hinge properties are assigned at critical locations to represent yielding and inelastic deformation of structural members.

Pushover analysis is performed by gradually increasing lateral loads until the target displacement or collapse condition is reached. The seismic behavior of the models is assessed using parameters such as base shear, roof displacement, storey drift, capacity curves, and plastic hinge formation. The obtained results are compared to determine the effectiveness of lateral resisting systems in enhancing the seismic strength, stiffness, and overall performance of flat slab structures.

4. PROBLEM STATEMENT

4.1. INTRODUCTION

The study titled “Pushover Analysis of Flat Slab Structure with Lateral Resistant System” focuses on the seismic vulnerabilities of flat slab structures, which are widely used due to their architectural and economic advantages. The absence of beams reduces lateral stiffness and ductility, making these structures susceptible to excessive displacement, storey drift, and punching shear failure during earthquakes. Although lateral load resisting systems such as shear walls and perimeter beams improve structural performance, their effectiveness requires detailed evaluation. Therefore, pushover analysis is carried out to assess the seismic capacity, ductility, and failure behavior of flat slab structures under earthquake loading.

4.2. PROBLEM STATEMENT

Table -1: Building Plan Geometry and Grid System

Item	Plan / Grid Details
Structural prototype	Basement + Ground + 4 Typical Floors + Attic (Total 7 levels)
Overall plan size	23.40 m (X direction) × 16.60 m (Y direction)
Grid system type in ETABS	Custom grid spacing (non-uniform bay widths)
No. of grid lines (X direction)	6 grid lines → 5 bays
X-direction bay spacing (m)	4.80, 4.80, 3.60, 4.75, 4.95 (Total = 23.40 m)
No. of grid lines (Y direction)	5 grid lines → 4 bays

Item	Plan / Grid Details
Y-direction bay spacing (m)	4.00, 3.95, 4.10, 3.95 (Total ≈ 16.00–16.60 m as per plan)
Typical storey height	3.00 m (typical floors)
Ground storey height	3.40 m
Attic storey height	2.70 m
Basement storey height	3.00 m

Table -2: Beam, Column and Slab Section Details

Structural Member	Size / Thickness
Columns	600 × 600 mm
Beams	400 × 400 mm
Slab (frame slab)	140 mm
Flat slab	200 mm

Table -3 : Material Properties Used for Structural Modelling

Property	Concrete (M30)	Reinforcement Steel (Fe500)
Material Type	Reinforced Concrete	High Yield Strength Deformed (HYSD) Bars
Grade	M30	Fe500
Characteristic Strength	$f_{ck} = 30$ MPa	$f_y = 500$ MPa
Ultimate Strength	—	$f_u \approx 545$ MPa
Modulus of Elasticity (E)	27.4 GPa ($\approx 5000\sqrt{f_{ck}}$)	200 GPa
Poisson's Ratio (ν)	0.2	0.3
Unit Weight	25 kN/m ³	78.5 kN/m ³
Shear Modulus (G)	11.4 GPa	76.9 GPa
Thermal Expansion Coefficient	1.0×10^{-5} /°C	1.2×10^{-5} /°C
Design Code Reference	IS 456:2000	IS 1786:2008

Table -4: Load Patterns

Load Name	Type	Self Weight Multiplier
Dead	Dead	1
Live	Live	0
Ex	Seismic	0
Ey	Seismic	0

4.3. MODELLING IMAGES

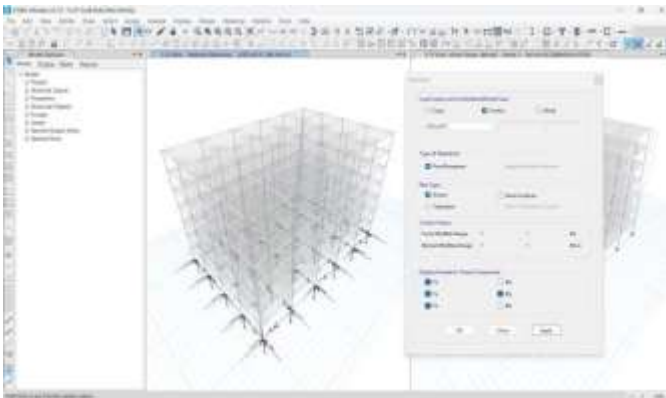


Fig -1: ETABS 3D View of Flat Slab Building Model with Reaction Forces Display

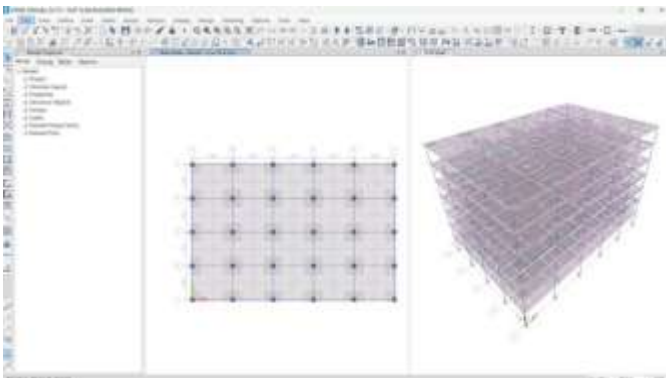


Fig -2: ETABS Plan View and 3D View of Flat Slab Building Model

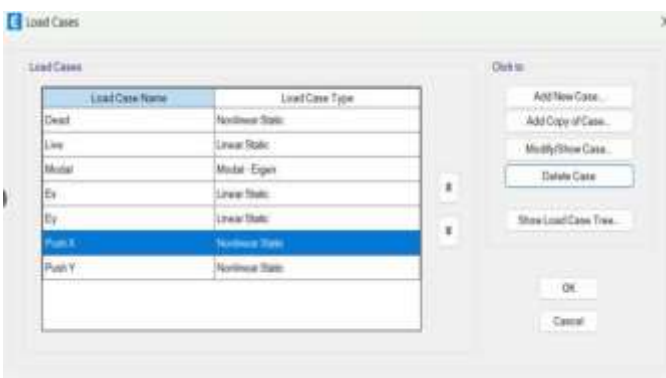


Fig -3: ETABS Load Cases Window with Nonlinear Static Load Cases



Fig -4: ETABS Frame Hinge Assignment Window with User-Defined Settings

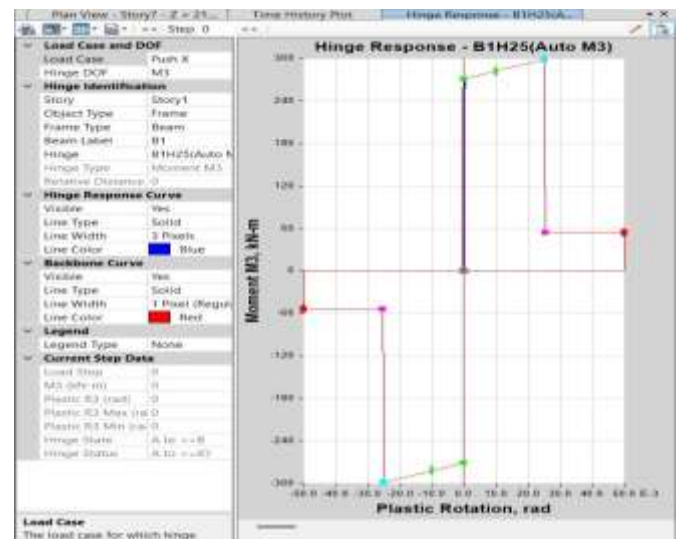


Fig -5: ETABS Hinge Response Curve for Beam B1H25 (Auto M3) under Push X Load Case

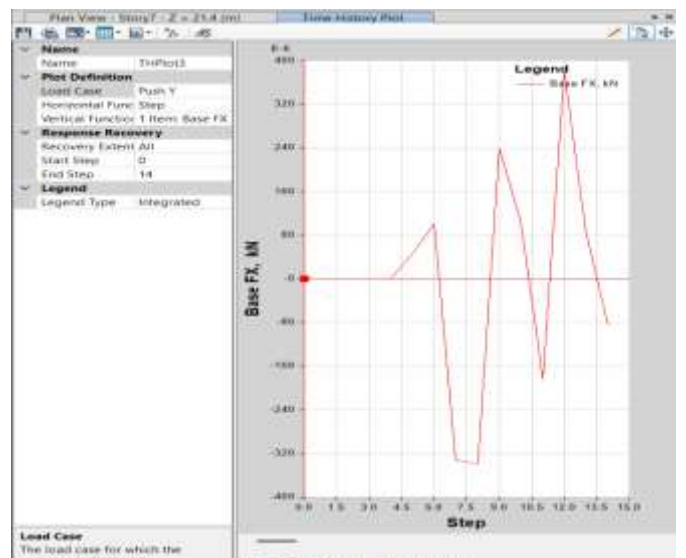


Fig -6: ETABS Time History Plot of Base FX for Push Y Load Case

5. RESULTS

5.1. STORY DISPLACEMENT

- Story displacement in both X and Y directions was lower for the structure with lateral resistance.
- In the X direction, the maximum displacement at Story 7 reduced from 0.026 mm to 0.021 mm.
- In the Y direction, the maximum displacement reduced from 0.00007869 mm to 0.00003869 mm.
- The reduction in displacement indicates improved stiffness and better seismic stability due to lateral load-resisting systems.

5.2. STORY DRIFT

- Story drift values were lower in the structure with lateral resistance in both directions.
- In the X direction, the maximum drift reduced from 8.34E-06 to 3.44E-07.
- In the Y direction, the maximum drift reduced from 8.34E-06 to 5.34E-06.
- Lower drift values indicate better control of lateral movement and improved seismic performance.

5.3. BASE SHEAR

- Base shear values were higher for the structure with lateral resistance in both X and Y directions.
- In the X direction, the base shear increased from 5.9622 kN to 6.9622 kN.
- In the Y direction, the base shear increased from 5.7622 kN to 6.8622 kN.
- Higher base shear indicates improved strength and better resistance against seismic forces.

6. CONCLUSIONS

The pushover analysis of flat slab structures with and without lateral load-resisting systems demonstrated that the inclusion of lateral resistance significantly improves seismic performance. The structure with lateral resistance exhibited lower story displacement and story drift in both X and Y directions, indicating enhanced stiffness, reduced lateral deformation, and improved structural stability under seismic loading. Additionally, higher base shear values were observed in structures with lateral resistance, reflecting greater strength and improved capacity to resist earthquake forces. Overall, the study concludes that the incorporation of lateral load-resisting systems such as shear walls and perimeter beams effectively enhances the seismic behavior, safety, and resilience of flat slab structures.

7. REFERENCES

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