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Soil-Structure Interaction in Nonlinear Pushover Analysis of RC Buildings

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Abstract: The seismic performance of reinforced concrete (RC) buildings is significantly influenced by soil–structure interaction (SSI). Traditional pushover analysis, based on FEMA 356 and ATC-40, assumes a fixed base and neglects foundation flexibility, potentially leading to unsafe designs. This study presents a nonlinear pushover analysis incorporating SSI for a four-storey RC frame using SAP2000. Different soil conditions—soft, medium, and hard—were modeled using equivalent spring stiffness. Performance was evaluated in terms of base shear, roof displacement, hinge formation, and performance points. Results indicate that flexible soil drastically reduces base shear (by over 80% in soft soil compared to fixed base) and increases displacements, significantly altering hinge formation patterns. The study concludes that neglecting SSI may result in overestimation of seismic capacity. Recommendations for future work include torsional analysis, higher-mode effects, and experimental validation.
Keywords: Soil–Structure Interaction, Nonlinear Pushover Analysis, RC Buildings, Performance-Based Seismic Design, SAP2000.

I. INTRODUCTION

Earthquake-induced forces impose complex demands on reinforced concrete (RC) buildings, where mass, stiffness, and strength distribution govern structural response. Pushover analysis has become a practical tool for seismic evaluation due to its simplicity. However, most applications assume a rigid foundation, neglecting the deformability of soil and foundation systems.

Soil–structure interaction (SSI) modifies global stiffness, damping, and dynamic response. Flexible soil increases displacements, delays hinge formation, and redistributes seismic demands. This study focuses on quantifying the influence of SSI in nonlinear pushover analysis of a low-rise RC frame subjected to varied soil conditions.

II. LITERATURE REVIEW

Several studies have explored SSI effects:

1) Bybordiani et al. (2019) highlighted the altered seismic demand of steel frames under dynamic SSI.
2) Matale and Khedekar (2018) demonstrated that SSI significantly influences base shear in RC frames.
3) Zubair and Shilpa (2018) observed higher displacements in flexible soil conditions.
4) Hasan et al. (2002) and Gehlot & Sharma (2013) emphasized pushover analysis for performance-based design but assumed fixed bases.

Few studies integrate SSI into nonlinear pushover analysis for RC frames, motivating the present research.

III. METHODOLOGY

A four-storey, single-bay RC frame (6 m × 6 m plan, 3.5 m storey height) was modeled in SAP2000.

1) Columns: 500 mm × 500 mm (M30 concrete, Fe500 steel)
2) Beams: 230 mm × 500 mm
3) Slab thickness: 150 mm
4) Loading: Live load 3.0 kN/m² (floors), 1.5 kN/m² (roof)

A. Soil Models

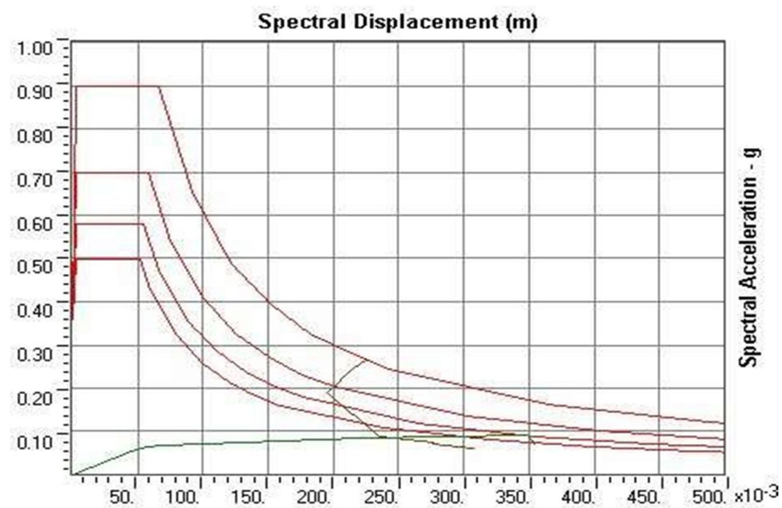
Equivalent linear springs were used to represent soft (E = 12,000 kN/m²), medium (E = 35,000 kN/m²), and hard soils (E = 200,000 kN/m²).

B. Pushover Analysis

1) Load pattern: First mode shape distribution
2) Hinges: M3 (beams), P-M3 (columns) per FEMA 356
3) Performance levels: IO, LS, CP evaluated
4) Capacity Spectrum Method used to determine performance points

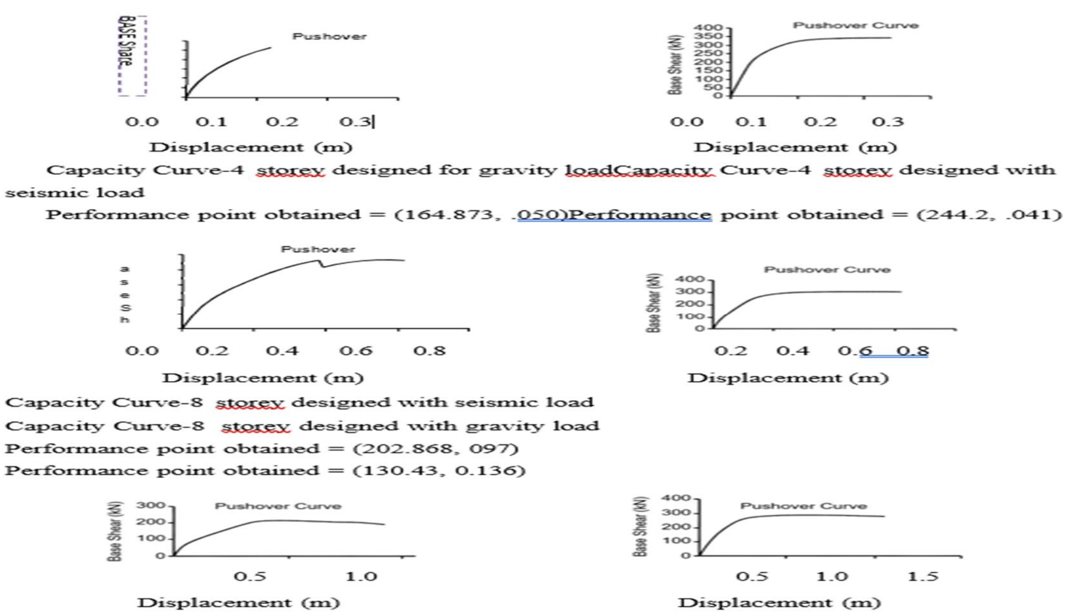
IV. RESULTS AND DISCUSSION

A. Capacity Curves, Demand Curves



[Fig. 1. : ADRS plot for the analysis (Capacity curve in green, demand curves in red, and locus of Performance Point in dark yellow)]

B. Pushover Curves



[Fig. 2. Pushover curves under soft, medium, and hard soils]

Soft soil models showed larger displacements and earlier hinge formation, whereas hard soil models closely matched fixed-base results.

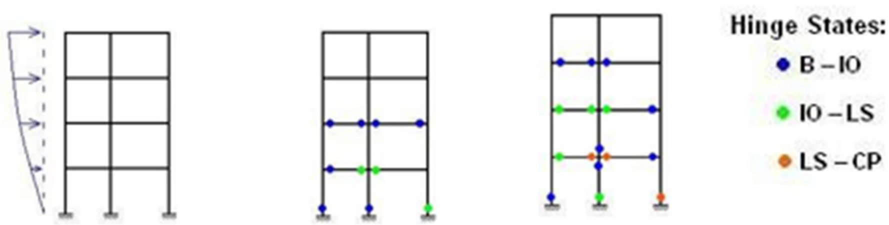
C. *Base Shear and Roof Displacement*

Category	Base Reactions (KN)	Roof Displacement (mm)
Fixed Base	614.801	16.2
Soft Soil	86.089	2.4
Medium Soil	157.998	0.9
Hard Soil	244.057	0.2

[Table I. Soil structure interaction due to the in homogeneity of soil]

Soft soil caused the maximum roof drift, exceeding Life Safety levels but within Collapse Prevention range.

D. *Hinge Formation Patterns*



[Fig. 3. Plastic hinge formation under soft soil condition]

Flexible soils redistributed hinges, increasing LS-level hinges while reducing CP hinges, suggesting partial ductility improvement.

V. CONCLUSION

This study demonstrates that SSI significantly impacts nonlinear pushover analysis of RC buildings.

- Soft soil reduced base shear by >80% compared to fixed base.
- Roof displacements increased with soil flexibility.
- Hinge patterns shifted toward LS level under flexible bases.
- Neglecting SSI may lead to unsafe overestimation of seismic capacity.

Future Work: Consider torsional effects, higher modes, and experimental validation to strengthen design guidelines.

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