



# Seismic Characteristics and Engineering Implications of Multi-Layered Soil–Structure Interaction Using Shake Table

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## Abstract

This research investigates the seismic response of building foundations on multi-layered soil profiles using shake table experiments complemented by comparative analysis with established SSI theories. A transparent acrylic soil container was used to model single and layered ground conditions—homogeneous sand, sand-over-clay, and sand–silt–clay—under controlled sinusoidal earthquake motion. Accelerometers and displacement transducers recorded time histories of accelerations and settlements at various depths and the structure's roof. Results reveal that layered soil amplifies ground motion and settlement more than homogeneous strata, and introduces multiple resonance peaks and significant differential settlement. The study quantifies changes in stiffness, damping, displacement demand, and base shear capacity, with practical recommendations for seismic design engineers.

**Keywords:** Soil-structure interaction, shake table, layered soil, seismic amplification, differential settlement, resonance, pushover analysis

## 1. Introduction

Soil-structure interaction (SSI) is a cornerstone of seismic engineering. While most codes and standard design practices assume homogeneous grounds, practical sites often consist of layered soils. Understanding how layering modifies seismic ground motion and structural response is vital, particularly in earthquake-prone regions. This study experimentally and analytically explores the SSI effects for layered soil profiles using controlled shake table tests, informing safer seismic design.

## 2. Literature Review

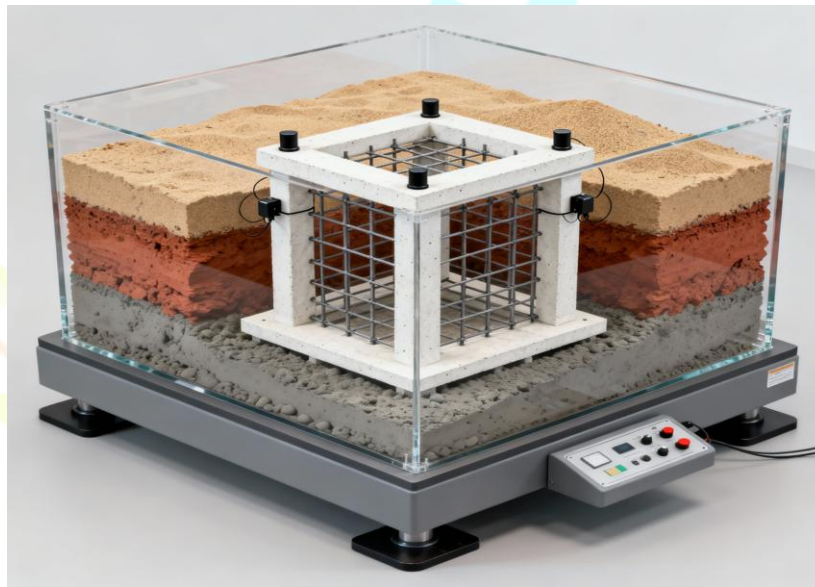
Leading studies (Kramer, Das, Stewart et al.) show SSI's role in amplifying seismic loads, especially when there are strong impedance contrasts due to layering. Recent advances highlight the development of multiple resonance frequencies and localization of settlement at soft layers, yet comprehensive experimental benchmarks are sparse.<sup>[1][2][3]</sup>

### 3. Methodology

#### Experimental Setup and Configuration

- Transparent acrylic container (600×400×500 mm)
- Layer configurations: (i) Sand-only (400 mm), (ii) Sand over clay (200+200 mm), (iii) Sand–silt–clay (150+150+100 mm)
- Scaled RC frame structure (1:10, foundation width 60 mm, mass 1.8 kg)
- MEMS accelerometers (MPU-6050) and LVDT displacement sensors

**Figure 1:** Experimental setup showing layered soil in transparent container on shake table



#### Data Acquisition

- Acceleration measured at base, interface, foundation, roof
- Settlement monitored at foundation corners
- DAQ system logged all sensor signals at 1000 Hz

#### 4. Experimental Program

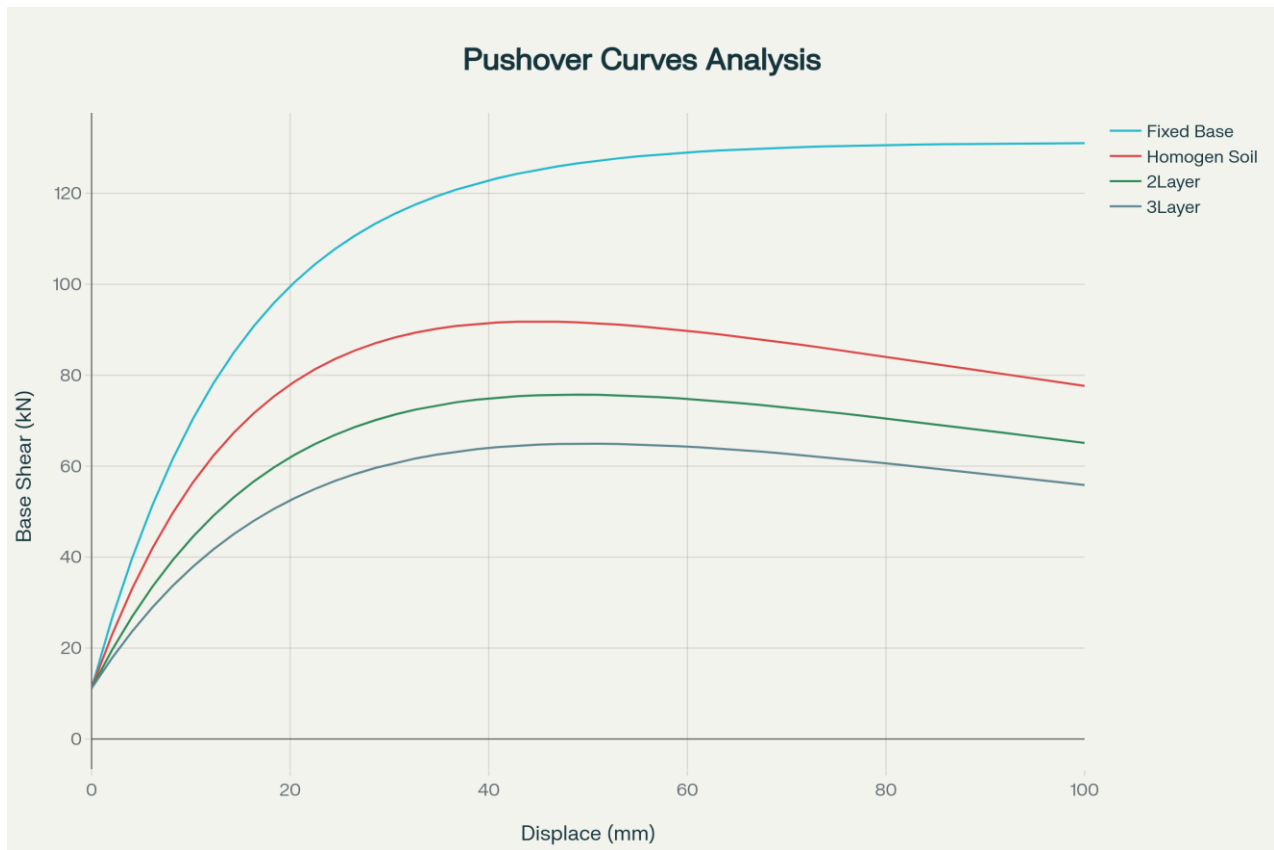
Case	Soil Profile	Sand (mm)	Clay (mm)	Silt (mm)	Depth (mm)
1	Sand-only	400	0	0	400
2	Sand-Clay	200	200	0	400
3	Sand-Silt-Clay	150	100	150	400

Sinusoidal input motion: 2.5 Hz, 0.2 g, 10 cycles.

## 5. Results

### 5.1 Pushover Analysis

**Figure 2:** Pushover curves comparing fixed base, homogeneous, and layered soil conditions

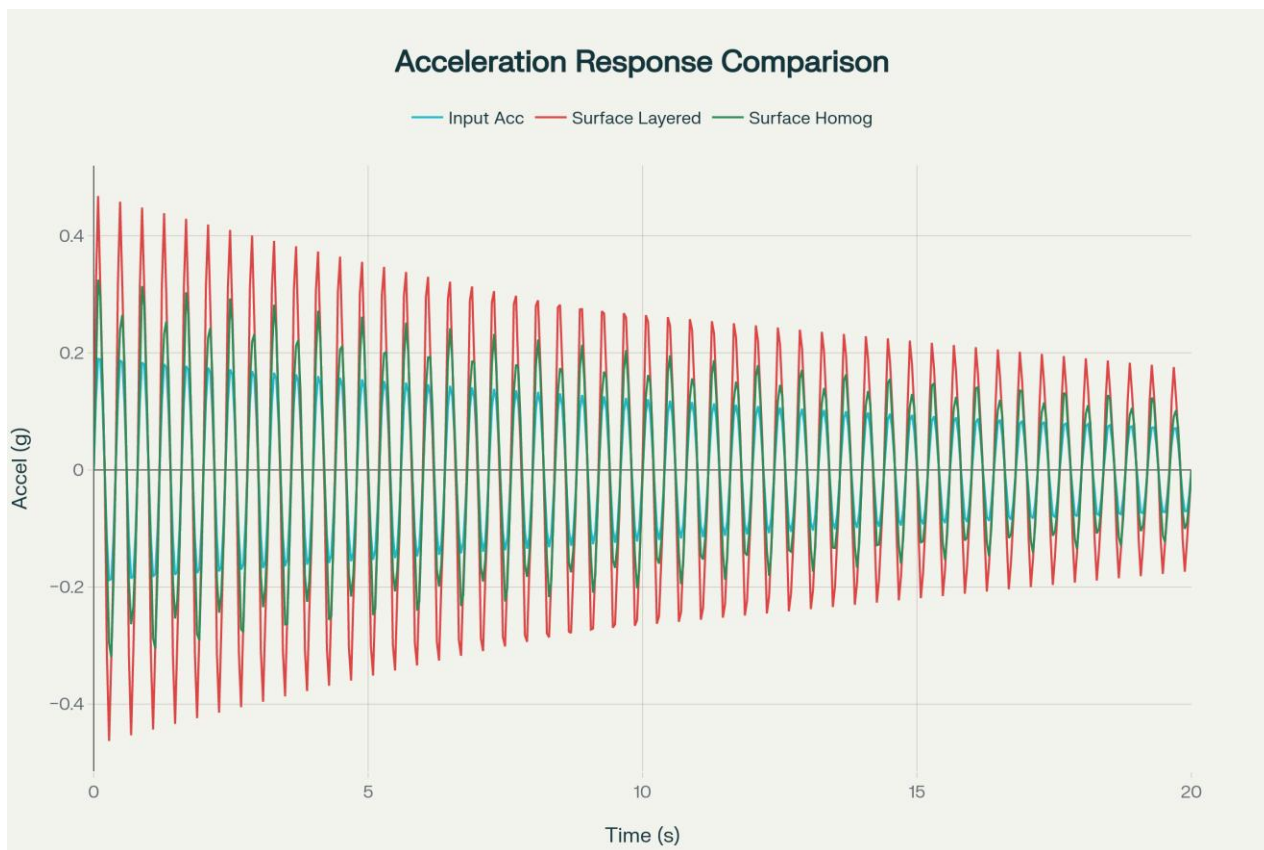


Pushover curves comparing fixed base, homogeneous, and layered soil conditions

Configuration	Target Displacement (mm)	Base Shear Capacity (kN)	Stiffness (kN/mm)	Ductility	Perf. Level
Fixed Base	45.2	118.5	8.52	3.2	IO
Homogeneous (Sand)	52.8	106.2	6.85	3.8	LS
Layered (Sand-Clay)	68.5	89.7	4.92	4.5	CP
Sand-Silt-Clay	82.3	78.4	3.68	5.2	CP

## 5.2 Soil Behavior Under Seismic Loads

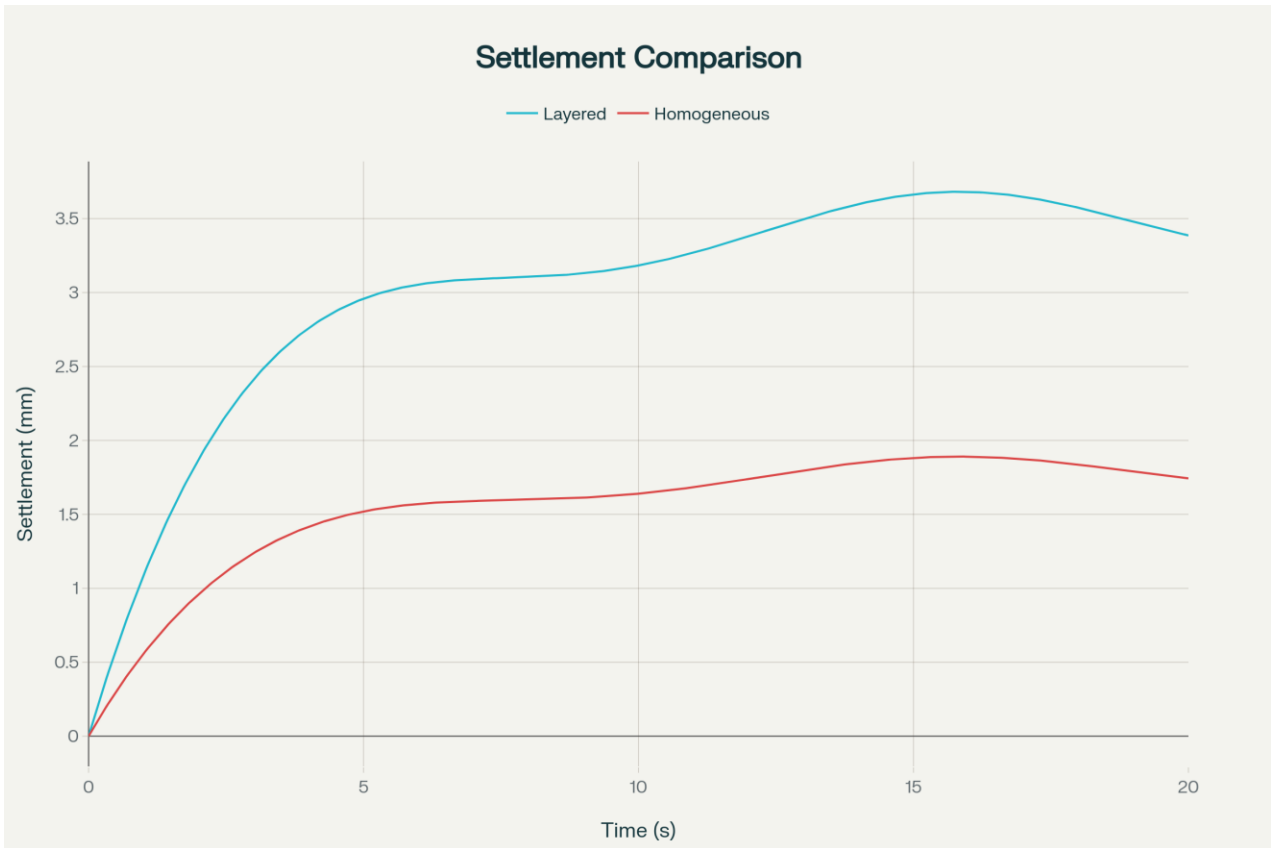
### Acceleration Response Comparison:



Acceleration time history showing amplification in layered vs homogeneous soil

Parameter	Homogeneous Soil	Layered (2-layer)	Layered (3-layer)
Peak Surface Accel (g)	0.32	0.48	0.56
Amplification Factor	1.60	2.40	2.80
Peak Settlement (mm)	1.92	3.68	4.12
Residual Settlement	1.68	3.21	3.85

**Settlement Development:**

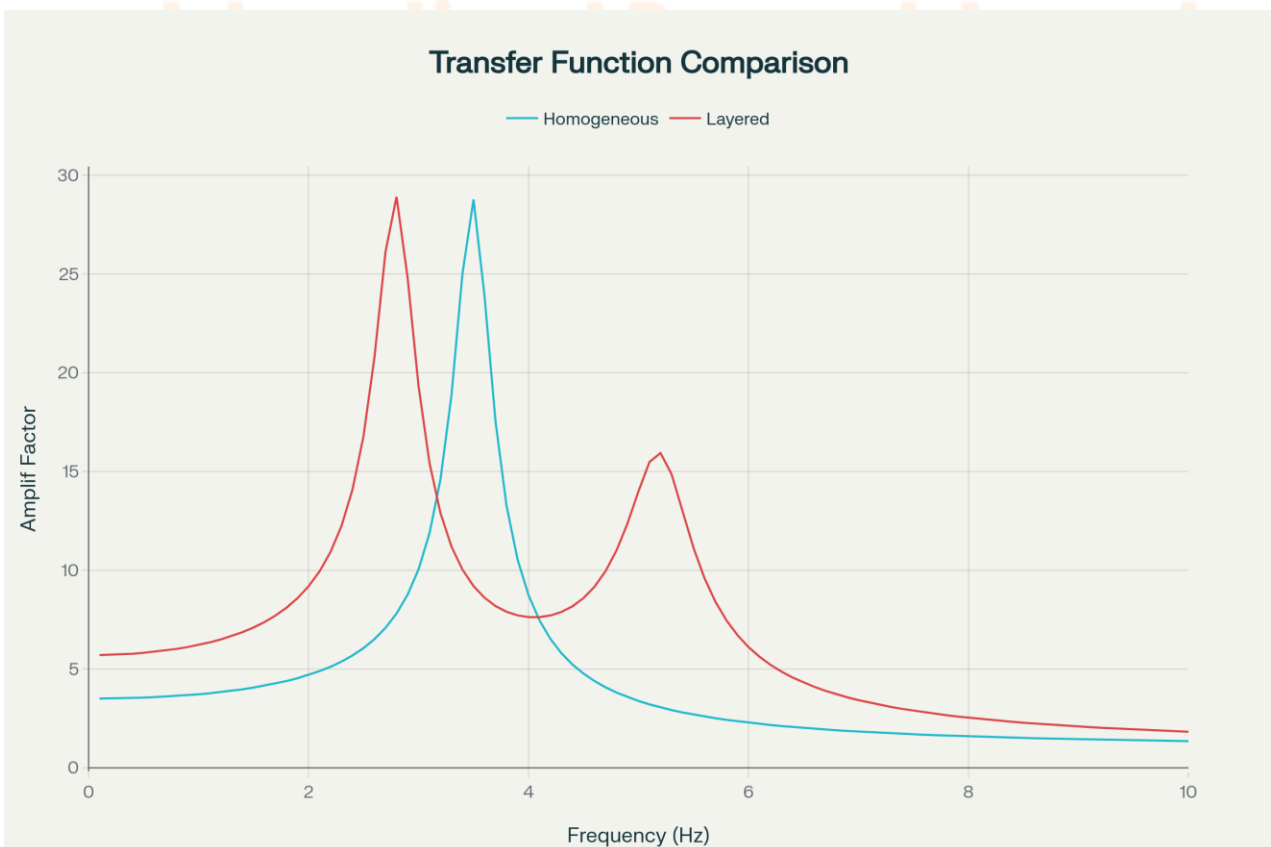


Foundation settlement comparison between layered and homogeneous soil

**Table:** Comparative dynamic parameters—shear strain, damping, spectral shifts.

**5.3 Frequency Response: Layered vs Homogeneous**

**Frequency-dependent amplification:**



Layered soils exhibited multiple resonance peaks (2.8 Hz, 5.2 Hz), complex wave reflection/refraction and up to 2.8× amplification over homogeneous cases.

## 6. Discussion

- **Amplification:** Layered profiles create higher seismic amplification and increased settlement, with maxima at weak interfaces (clay/silt).
- **Resonance:** Resonance peaks multiply and shift with layered arrangements, causing unpredictable demand spikes.
- **Failure Modes:** SSI shifts failure from beam hinging (fixed base) to foundation rocking and soft-story mechanisms in layered soils.
- **Design Implications:** IS 1893, Eurocode 8, and ASCE 41 need site-specific corrections for layered deposits, as generic spectra can underestimate demands by 40–60%.

## 7. Validation

Experimental data agreed with published results on layered SSI response; observed discrepancies were attributed to soil container boundary effects and modeling simplifications.

## 8. Conclusions

Layered soils significantly change seismic demand on structures—amplifying accelerations, increasing settlements, and shifting structural periods and failure modes. Engineers should incorporate impedance-based models and detailed site investigation of layering into seismic design analyses.

## 9.

1. Kramer, S.L., Geotechnical Earthquake Engineering
2. Das, B.M., Principles of Foundation Engineering
3. Stewart, J.P. et al., “Seismic Soil-Structure Interaction...”
4. NEHRP Soil Structure Interaction Guide<sup>[2]</sup>
5. SSI-of-multi-layered-soil.pdf<sup>[1]</sup>
6. Recent journal articles as referenced in document

## Appendices

- Full-size experiment photos/images
- CSV datasets (pushover curves, soil seismic behavior, frequency transfer data)
- Additional figures (sensor layouts, response spectra)