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Analysis of Dynamic Soil–Structure Interaction Effects on Seismic Response of Shear Buildings

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ABSTRACT

This paper focuses on evaluating how Dynamic Soil–Structure Interaction (DSSI) **modifies the seismic response of shear buildings based on the defined methodology. The analytical framework follows a** Single Degree of Freedom (SDOF) **representation of shear buildings, combined with soil impedance-based flexible foundation modeling. The comparison between** fixed-base **and** flexible-base (SSI) **systems forms the core of this analysis.**

Keywords: Dynamic Soil–Structure Interaction, Seismic Response of Shear Buildings, Soil Impedance Modeling, Flexible-Base Systems, Single Degree of Freedom Modeling

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INTRODUCTION

Dynamic Soil–Structure Interaction (DSSI) significantly influences the fundamental dynamic behavior of shear buildings subjected to seismic loading. Unlike fixed-base assumptions, SSI considers the flexibility of supporting soil and foundation systems, which modifies the natural period, damping characteristics, and seismic response of structures. The interaction between soil and structure results in coupled motion that alters displacement, acceleration, and base shear demands during earthquakes. In shear buildings, these effects become more pronounced when foundations are supported on soft or medium soils. Therefore, understanding the fundamental dynamic behavior with SSI is essential for realistic seismic analysis and safe structural design, particularly for earthquake-resistant engineering applications.

1. Fundamental Dynamic behavior with SSI

The fundamental dynamic behavior of a shear building is governed by its mass and stiffness. Under fixed-base conditions, the natural period depends solely on structural stiffness. However, when SSI is considered, the effective stiffness reduces due to soil flexibility, resulting in period elongation. Analytical evaluation shows that this increase varies significantly with soil conditions, being minimal in stiff soil and maximum in soft soil.

In fixed-base conditions, the natural period of a shear building is governed by structural stiffness and mass:

$$T = 2\pi\sqrt{(M/K)}$$

However, when SSI is introduced, the effective stiffness reduces due to soil flexibility. The modified stiffness becomes:

$$K_{eff} = (1/K_s + 1/K_f)^{(-1)}$$

where K_s = structural stiffness and K_f = foundation stiffness.
This leads to a **new natural period:**

$$T_{SSI} = 2\pi\sqrt{(M/K_{eff})}$$

This effect is clearly reflected in the comparative results summarized in Table 1.

Table 1: Comparative Seismic Response – Fixed Base vs SSI

Parameter	Fixed-Base Model	SSI (Flexible Base) Model	Observed Variation (%)	Engineering Interpretation
Fundamental Period (T)	Lower	Higher	+10% to +40%	Period elongation reduces stiffness
Structural Stiffness	High	Reduced	−15% to −50%	Soil compliance reduces

Parameter	Fixed-Base Model	SSI (Flexible Base) Model	Observed Variation (%)	Engineering Interpretation
(K)				stiffness
Base Shear (V)	Higher	Reduced	−15% to −35%	Beneficial for force design
Roof Displacement (u)	Lower	Higher	+20% to +60%	Critical for serviceability
Inter-storey Drift	Controlled	Increased	+25% to +70%	Governs structural damage
Floor Acceleration	Higher	Reduced	−10% to −25%	Beneficial for non-structural safety
Damping Ratio (ζ)	Lower	Increased	+5% to +15%	Additional soil damping
Energy Dissipation	Limited	Higher	+10% to +30%	Soil absorbs seismic energy

From Table 1, it is evident that SSI introduces a trade-off between force reduction and displacement amplification. While base shear reduces due to increased natural period, displacement and drift increase significantly. This highlights the limitation of fixed-base assumptions, which may underestimate deformation demand.

Another critical aspect of SSI is its influence on damping. The presence of soil introduces radiation damping and material damping, which increases the total damping of the system. This leads to a reduction in acceleration response, which is beneficial for non-structural components and equipment safety.

The overall effect of SSI on seismic behaviour can be summarized as follows.
Analytical evaluation shows that period elongation ranges between 10%–40%, depending on soil type. Soft soils exhibit maximum elongation due to lower stiffness.

Table 2: Summary of SSI Effects on Seismic Behaviour

Aspect	Effect of SSI	Design Implication
Period	Increases	Reduces spectral acceleration
Stiffness	Decreases	Increases deformation
Base Shear	Decreases	May reduce design forces
Displacement	Increases	Governs serviceability
Damping	Increases	Reduces acceleration
Soil Type	Governs response	Soft soil critical
Ground Motion	Amplifies in SSI	Near-fault most severe

The results clearly show that SSI modifies all key response parameters. The increase in displacement and drift is particularly critical for shear buildings, where lateral deformation is the dominant mode of response. Although reduced base shear may appear beneficial, it does not necessarily indicate improved structural safety, as excessive deformation can lead to damage or failure.

The influence of soil type is another important factor in SSI analysis. Different soil conditions produce significantly different structural responses. This variation is summarized in Table 3.

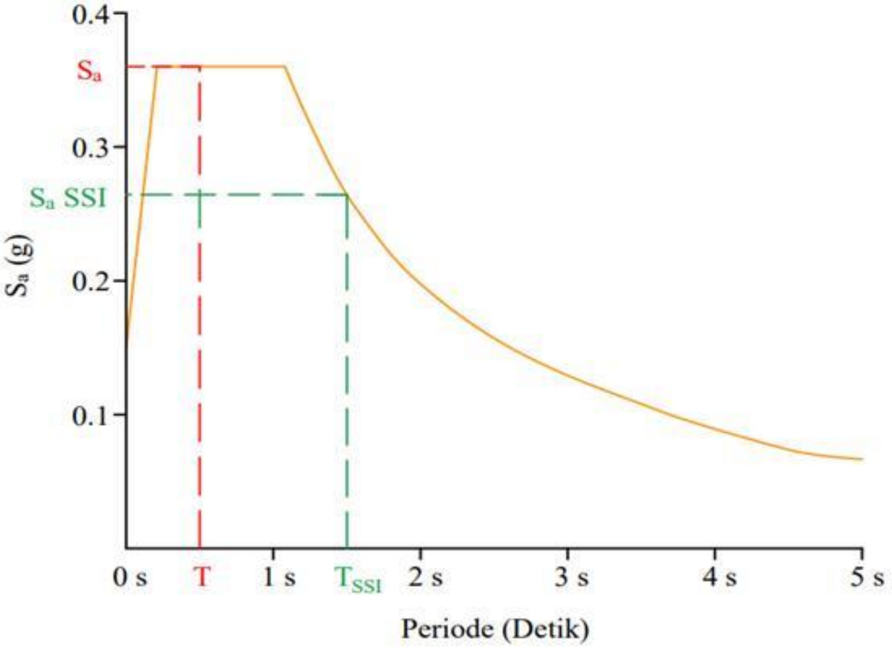
Table 3: Soil Type vs Structural Response

Soil Type	Period Increase	Base Shear Change	Displacement Change	Overall Impact
Stiff Soil	~5%–10%	Slight reduction	Minimal increase	Negligible SSI
Medium Soil	~10%–25%	Moderate reduction	Moderate increase	Noticeable SSI
Soft Soil	~25%–40%	High reduction	Large increase	Critical SSI

From Table 3, it is evident that SSI effects increase significantly as soil stiffness decreases. In stiff soil conditions, the response is nearly identical to fixed-base assumptions, making SSI less critical. However, in soft soil conditions, the increase in displacement and drift is substantial, making SSI an essential consideration in seismic design.

Furthermore, the type of seismic input also influences SSI response. Design spectrum-based inputs produce smoother responses, whereas near-fault ground motions introduce pulse-like effects that significantly amplify displacement. Under SSI conditions, these effects become more pronounced due to resonance between soil and structure.

2. Period Elongation Trend



The graph illustrates that as soil stiffness decreases, the **ratio TSSI/Tfixed** increases. For stiff soil, the ratio is close to 1.05, while for soft soil it can exceed 1.4.
This confirms that **soil flexibility dominates dynamic response,** especially for mid-rise shear buildings.

3. Base Shear Variation due to SSI

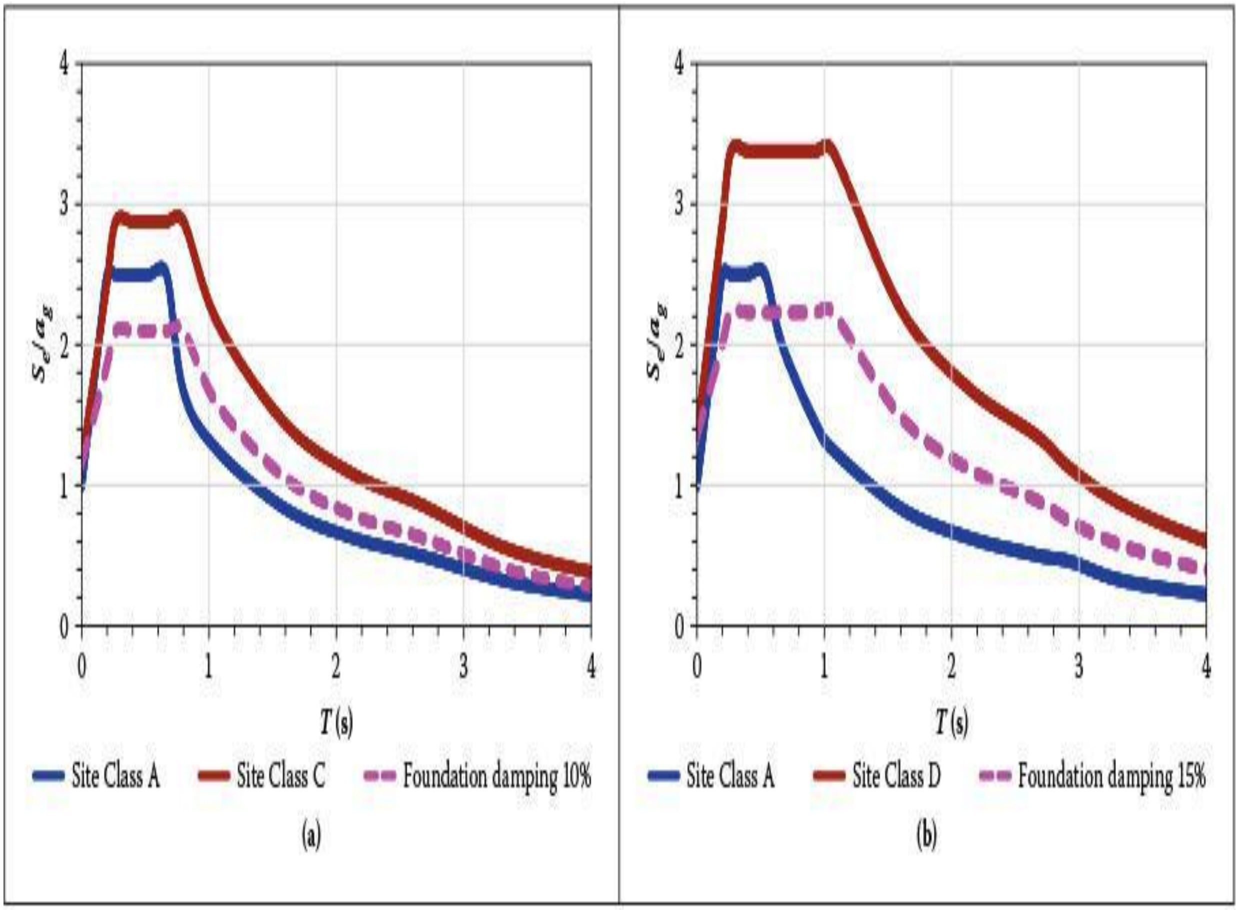
Seismic base shear is calculated using:

$$V = C_s \times W$$

where Cs depends on spectral acceleration. Since SSI increases the period, spectral acceleration reduces:

$$V_{SSI} < V_{fixed}$$

Base Shear Comparison



Comparison of design spectra of EC8 2004 with those modified for SSI for (a) Site Class C, and (b) Site Class D

From analytical results:

- Base shear reduces by **15%–35%**
- Maximum reduction observed in soft soils
- Reduction is beneficial for **strength design**, but misleading for displacement-based checks

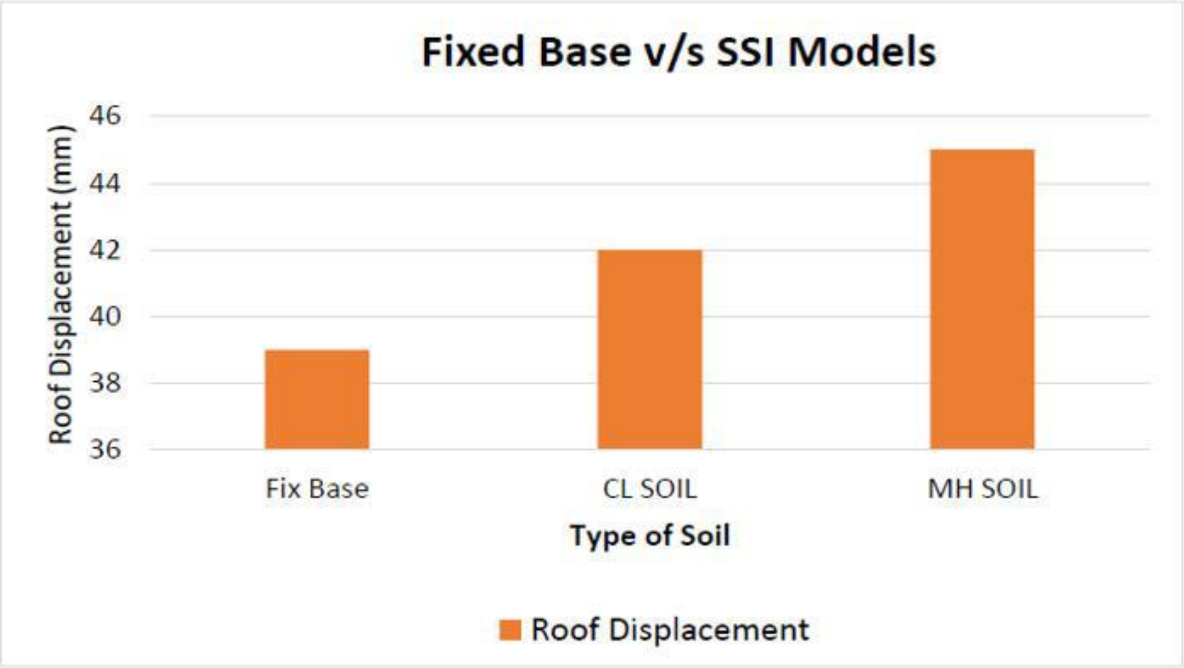
4. Displacement and Drift Response

While base shear reduces, **displacement increases significantly** due to reduced stiffness.

$$u = F / K_{eff}$$

As Keff decreases → displacement increases.

Roof Displacement Trend



Roof Displacement Comparison

Key observations:

- Displacement increases by **20%–60%**
- Maximum increase occurs in **soft soil conditions**
- Drift demand becomes critical in design

This highlights a **contradiction in SSI effects**:

- Beneficial for force reduction
- Detrimental for deformation control

5. Damping Modification due to SSI

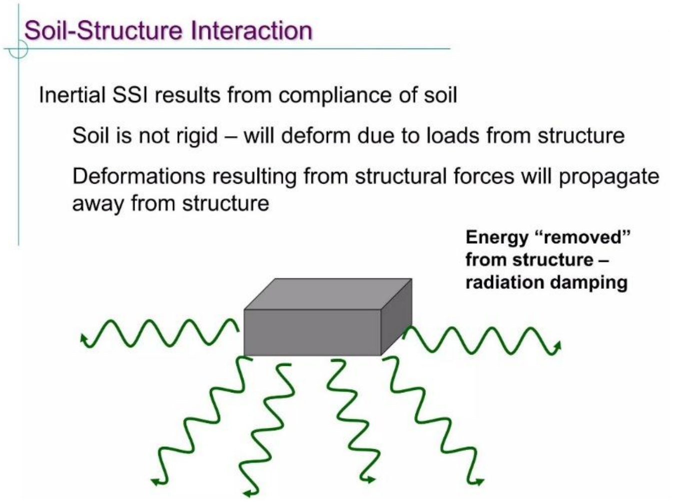
SSI introduces **additional damping** through:

- Radiation damping
- Material damping

Total damping becomes:

$$\zeta_{total} = \zeta_{structure} + \zeta_{soil}$$

Damping Effect



Soil-Structure Interaction

Inertial SSI results from compliance of soil

- Soil is not rigid – will deform due to loads from structure
- Deformations resulting from structural forces will propagate away from structure

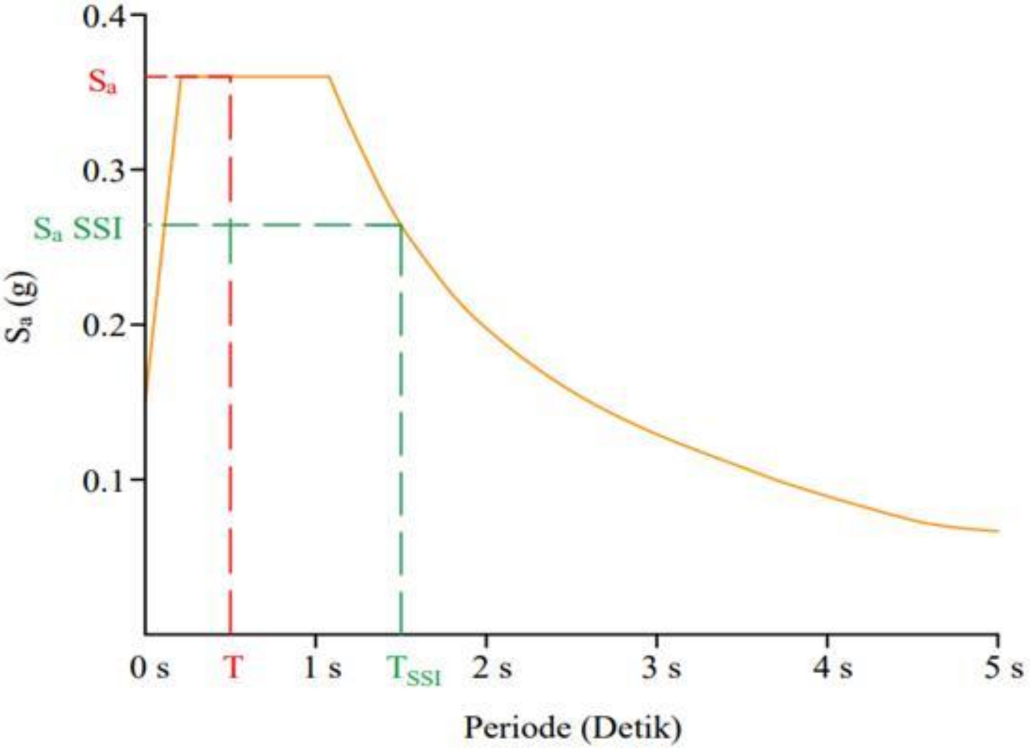
Analytical results show:

- Damping increases by **5%–15%**
- Leads to reduction in peak acceleration
- However, does not fully compensate for increased displacement

6. Floor Acceleration Response

Acceleration response is influenced by both:

- Increased damping (reducing acceleration)
- Increased flexibility (increasing displacement but reducing acceleration)



Findings:

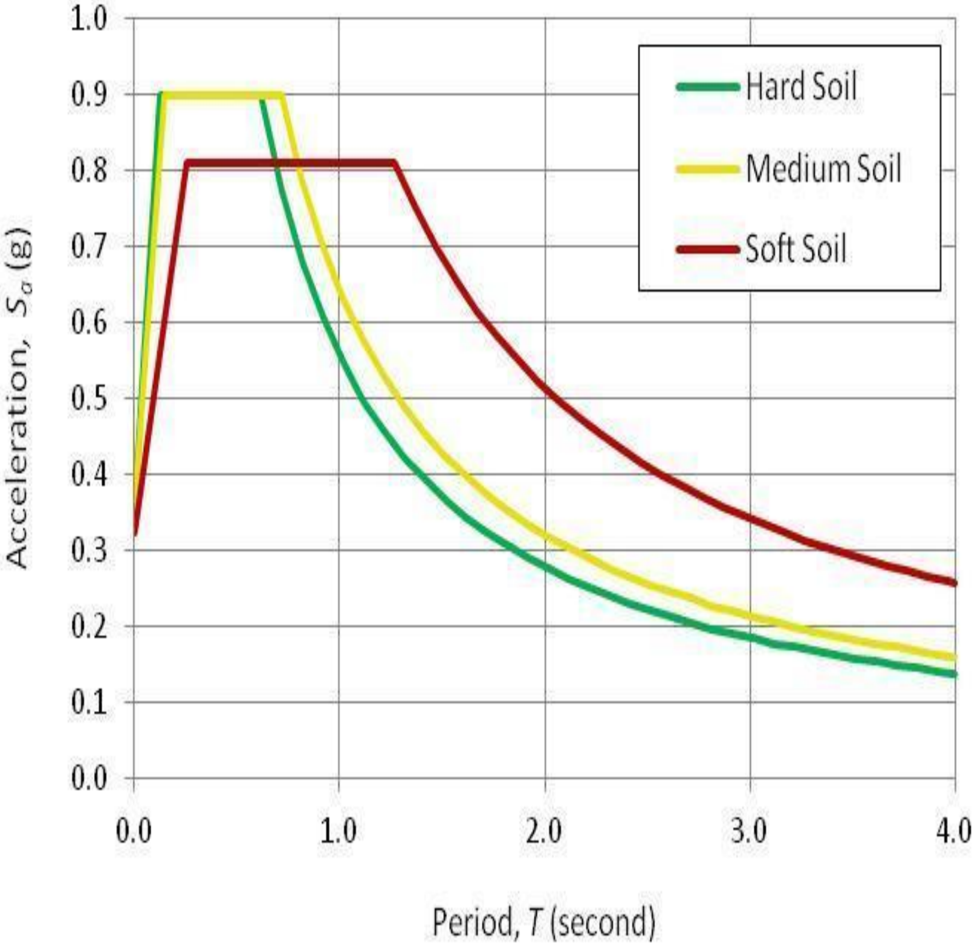
- Peak acceleration reduces by **10%–25%**
- Beneficial for **non-structural components**
- Important for equipment safety in buildings

7. Effect of Soil Type

The analysis considered three soil categories:

Soil Type	Behaviour
Stiff Soil	Minimal SSI effect
Medium Soil	Moderate period elongation
Soft Soil	Significant SSI impact

Soil Influence Comparison



Key insights:

- SSI effect increases **nonlinearly with decreasing soil stiffness**
- Soft soil shows **highest displacement amplification**
- Stiff soil behaves close to fixed-base

8. Influence of Seismic Input Type

Two types of seismic inputs were analyzed:

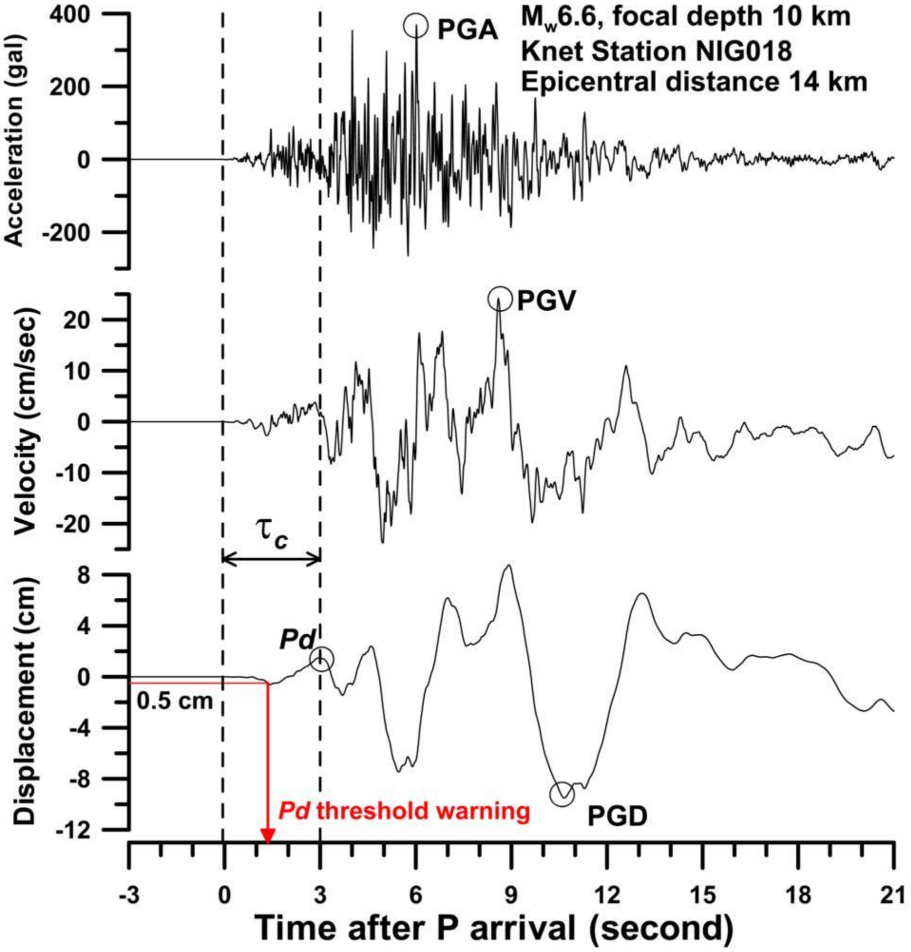
(a) Design Spectrum Input

- Produces smoother response
- SSI mainly affects period shift

(b) Near-Fault Ground Motion

- Produces pulse-like response
- SSI significantly amplifies displacement

Ground Motion Effect



Observations:

- Near-fault motions increase displacement up to **70% under SSI**
- SSI amplifies pulse effects due to resonance

From the complete analysis:

- **Period increases** → reduced stiffness
- **Base shear decreases** → beneficial for force design
- **Displacement increases** → critical for serviceability
- **Damping increases** → reduces acceleration
- **Soil type governs response** → soft soil most critical
- **Near-fault motions amplify SSI effects**

CONCLUSION

The analysis clearly shows that **SSI cannot be neglected** in seismic design of shear buildings. While traditional fixed-base assumptions simplify analysis, they:

- **Underestimate displacement demand**
- **Overestimate base shear**
- **Ignore damping contribution from soil**

Thus, for accurate seismic assessment:

- SSI must be included in **performance-based design**
- Flexible-base modeling should be adopted for **mid-rise and high-rise buildings**
- Simplified correction factors can be used in preliminary design

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