

Seismic Behavior of Reinforced Soil Structures, Embankments, and Foundations: Integrated Analysis of Soil–Structure Interaction

1. Abstract

Earthquake-induced failures of geotechnical and structural systems highlight the need for an integrated understanding of soil–structure interaction. Reinforced soil structures, embankments, and foundations are key components of modern infrastructure, yet their seismic behavior is influenced by nonlinear interactions between soil and reinforcement materials. This research aims to investigate the coupled dynamic response of such systems through advanced numerical modeling, experimental validation, and parametric analysis. By integrating both soil and structural responses, the study will develop performance-based design criteria and simplified analytical models to enhance seismic resilience. The outcomes will contribute to improved design codes and safer infrastructure development in seismically active regions.

2. Introduction and Background

The performance of soil structure systems during earthquakes is governed by complex interactions between the deformable soil mass and the structural elements supported or reinforced by it. Failures of embankments, retaining walls, and foundations in past earthquakes (e.g., Kobe 1995, Bhuj 2001, Nepal 2015) demonstrate the critical role of soil–structure coupling under dynamic loading.

Reinforced soil structures such as mechanically stabilized earth (MSE) walls and geosynthetic-reinforced embankments have become increasingly popular due to cost-effectiveness and flexibility. However, their seismic performance remains inadequately understood because conventional design methods often neglect nonlinear SSI effects. Similarly, foundation systems (both shallow and deep) experience significant interaction with surrounding soils, altering stiffness, damping, and failure modes during ground shaking.

Hence, an integrated approach that combines soil and structural responses under seismic conditions is essential for accurate prediction and improved design.

3. Problem Statement

Despite extensive research on individual components (soil, reinforcement, or structural members), limited studies have comprehensively captured their coupled dynamic behavior. The lack of holistic SSI-based design leads to uncertainties in evaluating deformation, sliding, and rotational failure mechanisms during earthquakes. Moreover, existing design codes (e.g., AASHTO, Eurocode 8, IS 1893) offer simplified pseudo-static methods that are often conservative or unconservative for complex reinforced soil systems.

Thus, there is a pressing need to:

- Quantify the coupled seismic behavior of reinforced soil and foundation systems.
 - Develop validated numerical models to simulate real dynamic interaction.
 - Propose performance-based design modifications for improved safety and cost-effectiveness.
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4. Objectives

1. **To study** the seismic behavior of reinforced soil structures, embankments, and foundations through integrated soil–structure interaction analysis.
 2. **To develop** advanced finite element/finite difference models to simulate nonlinear dynamic behavior.
 3. **To validate** numerical models using available experimental or field data.
 4. **To conduct** a detailed parametric study on reinforcement stiffness, soil type, and earthquake intensity.
 5. **To propose** simplified analytical models and design recommendations for seismic-resistant reinforced soil and foundation systems.
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5. Scope of the Research

The research focuses on:

- Reinforced soil retaining structures and embankments used in transportation and infrastructure projects.
- Shallow and pile foundations subjected to earthquake loading.
- Dynamic SSI effects using 2D and 3D numerical models.