

SOIL-STRUCTURE INTERACTION IN RETAINING WALLS: A COMPREHENSIVE LITERATURE REVIEW

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Abstract - Retaining walls are critical geotechnical structures designed to resist lateral earth pressures and ensure slope stability in infrastructure projects. The performance and safety of retaining walls are significantly influenced by the nature and engineering properties of the supporting and backfill soils. This paper presents a comprehensive literature review on the effect of soil characteristics including unit weight, cohesion, angle of internal friction, permeability, compressibility, and shear strength on the behavior and stability of various types of retaining walls. The review synthesizes findings from theoretical studies, laboratory experiments, numerical modeling, and field investigations to evaluate how different soil conditions alter lateral earth pressure distribution, sliding resistance, overturning stability, and bearing capacity. Special emphasis is given to the comparative performance of retaining walls in cohesive and cohesionless soils, as well as the role of soil-structure interaction in design considerations. The study also highlights the influence of groundwater conditions and seismic loading in relation to soil type. Based on the reviewed literature, key design implications and research gaps are identified to support safer and more economical retaining wall construction in diverse geotechnical environments.

Key Words: Retaining walls, Soil properties, Soil-structure interaction, Lateral earth pressure, Soil cohesion, etc.

1. INTRODUCTION

Retaining walls are essential geotechnical structures constructed to support soil masses at different elevations and to prevent lateral soil movement in infrastructure projects such as highways, railways, basements, bridge abutments, and waterfront structures. The stability and long-term performance of these structures depend largely on the characteristics of the surrounding and backfill soils. Soil is a complex, heterogeneous material whose engineering behavior varies significantly depending on its composition, density, moisture content, and stress history. Parameters such as unit weight, cohesion, angle of internal friction, permeability, and compressibility directly influence the magnitude and distribution of lateral earth pressures acting on retaining systems. Variations in soil type—whether cohesive, cohesionless, or layered—can alter failure mechanisms including sliding, overturning, and bearing capacity failure. Furthermore, the interaction between soil

and structure plays a critical role in determining wall deformation and overall safety. Over the years, researchers have investigated the relationship between soil properties and retaining wall behavior through theoretical analysis, laboratory testing, numerical simulations, and field case studies. This literature review aims to synthesize existing research findings to better understand how the nature of soil affects retaining wall design, performance, and stability under different loading conditions..

1.1 AIM & OBJECTIVE

The primary aim of this study is to investigate the influence of soil-structure interaction (SSI) on the structural behavior of a gravity retaining wall using finite element analysis, and to evaluate its effect on stress distribution, deformation characteristics, and cross-sectional optimization for achieving an economical and safe design.

- 1) To review previous research related to gravity retaining walls and their structural behavior under static loading.
- 2) To study earlier works on soil-structure interaction (SSI) and understand its influence on stress distribution and deformation in retaining wall systems.
- 3) To examine different analytical, experimental, and finite element methods used by researchers for modeling retaining walls.

2. LITERATURE REVIEW

literature review provides a comprehensive understanding of previous research related to gravity retaining walls and soil-structure interaction (SSI). Several researchers have studied the behavior of retaining walls under static and dynamic loading conditions using analytical and numerical methods, particularly the finite element method (FEM). Earlier studies highlight that the interaction between soil and structure significantly influences stress distribution, deformation patterns, and overall stability of retaining systems. By reviewing these contributions, the present study establishes a theoretical foundation, identifies research gaps, and justifies the need for incorporating SSI effects in the finite element analysis of gravity retaining walls for achieving an economical and realistic design.

Contributions of researchers are presented as follows,

G. Gazetas (1991) [1] author published a paper on soil-structure interaction effects on retaining systems. The study explained how the flexibility of supporting soil significantly alters the stress distribution and displacement pattern of retaining walls under static and seismic loading. The author emphasized that conventional rigid base assumptions may overestimate stresses. A finite element-based analytical approach was adopted to evaluate interaction effects, and comparisons were made between fixed-base and flexible-base conditions. The results showed that considering SSI reduces bending moments and modifies lateral displacement profiles, leading to more realistic design estimations. The paper highlighted that conventional design approaches often assume a rigid base condition, where the structure is considered fixed at its foundation level. However, Gazetas demonstrated that such assumptions may lead to overestimation of bending moments, shear forces, and stresses because the real soil medium undergoes deformation and provides flexible support. Using analytical formulations supported by numerical modeling concepts similar to finite element procedures, the study compared fixed-base and flexible-base conditions to evaluate changes in stiffness, damping, and displacement behavior. The research further showed that when soil flexibility is properly considered, the stress distribution along the structural element changes significantly. Bending moments are generally reduced, and lateral displacement profiles become smoother and more distributed rather than concentrated at specific points. The study also introduced impedance functions and stiffness coefficients that help engineers account for soil compliance in structural analysis. These findings provided a theoretical foundation for modern finite element-based SSI analysis in retaining walls and foundation systems.

J. Lysmer and R. L. Kuhlemeyer (1969) [2] authors presented research on finite dynamic modeling of soil-structure systems. In their study, special boundary conditions were introduced to simulate infinite soil media in finite element analysis. The retaining wall-soil system was modeled using continuum elements, and stress wave propagation was examined. The research provided an important foundation for numerical modeling of SSI problems, especially in ANSYS-based simulations, by improving boundary representation and minimizing reflection errors. In conventional finite element analysis, the soil mass must be truncated to a limited boundary, which can cause artificial reflection of stress waves back into the model. These reflections produce unrealistic stress concentrations and displacement patterns, especially in dynamic and seismic analyses. To overcome this issue, Lysmer and Kuhlemeyer introduced special absorbing boundary conditions, commonly known today as *Lysmer-Kuhlemeyer dashpots*. These boundaries simulate the energy dissipation characteristics of an infinite soil medium by allowing outgoing stress waves to exit the model without reflection. Although the study was primarily focused on dynamic wave propagation problems, its application extends directly to retaining wall-soil systems and other SSI problems. By

modeling the soil as a continuum medium and incorporating appropriate boundary conditions, the interaction between soil and structural elements can be captured more accurately. The research demonstrated how stress waves travel through soil layers and how structural elements influence this propagation mechanism. This understanding is particularly important for analyzing retaining walls under seismic or transient loading conditions.

T. Matsuzawa and H. Hazarika (1996) [3] authors published a paper on the performance of gravity retaining walls considering backfill interaction. The paper studied deformation characteristics and earth pressure distribution using experimental and numerical approaches. The authors found that actual earth pressures differ from classical Rankine theory when wall flexibility and soil deformability are included. The study concluded that interaction effects significantly influence lateral displacement and stress redistribution in gravity retaining walls. The study demonstrated that the actual earth pressures acting on a retaining wall are significantly different from those predicted by classical theories such as Rankine or Coulomb, especially when the wall is allowed to deform. Traditional earth pressure theories assume idealized conditions such as rigid walls and simplified soil behavior. However, Matsuzawa and Hazarika showed that when wall flexibility and soil deformability are incorporated into the analysis, the pressure distribution becomes non-linear and highly dependent on displacement compatibility between soil and structure.

D. Potts and L. Zdravković (1999) [4] authors worked on advanced finite element modeling in geotechnical engineering. Their research focused on coupled soil-structure systems and nonlinear soil behavior. Using finite element software, they demonstrated how soil stiffness and Poisson's ratio affect deformation patterns in retaining structures. The paper highlighted that realistic soil modeling leads to optimized cross-sectional dimensions of gravity retaining walls. Using advanced finite element software, the authors illustrated how variations in soil stiffness directly affect lateral displacement, bending moments, and base pressures in retaining walls. For example, softer soil conditions lead to increased wall deformation but often reduce peak stress concentrations due to stress redistribution. Similarly, Poisson's ratio influences volumetric strain behavior and lateral confinement, which in turn modifies the interaction mechanism between soil and structure.

R. C. Sharma and S. K. Jain (2012) [5] authors published a study on static analysis of retaining walls under varying height conditions. Different wall geometries were modeled using FEM software, and stresses were evaluated for multiple height ratios. The study observed that sliding stability governs the design in most cases. Results indicated that deformation increases significantly beyond certain height limits, similar to trends observed in SSI-based studies. A key finding of Sharma and Jain (2012) was that sliding stability

often becomes the governing design criterion for higher walls. While overturning and bearing capacity requirements are important, the factor of safety against sliding tends to control the final dimensions in most practical cases. The study also showed that deformation remains relatively small up to a certain height ratio, beyond which lateral displacement increases significantly. This trend closely aligns with observations made in soil-structure interaction (SSI) based studies, where increased wall height results in amplified displacement and stress redistribution.

M. A. Gabr and A. Borden (1990) [6] authors studied soil-structure interaction in retaining wall systems using numerical simulation. The wall and soil mass were modeled together to observe interaction mechanisms. Their results showed that considering SSI leads to redistribution of stresses and reduction in peak stress concentration in the wall section. The paper suggested that economical design is possible when SSI effects are incorporated. In their numerical simulation, continuum elements were used to represent the soil medium, while structural elements were adopted for the retaining wall. The interface behavior between soil and wall was also carefully considered to capture slip, bonding, and frictional resistance mechanisms. Through this integrated modeling approach, the researchers were able to observe how lateral earth pressures develop progressively with wall displacement rather than remaining constant as assumed in classical earth pressure theories. The results clearly indicated that incorporating soil-structure interaction leads to significant redistribution of stresses within the wall section. Peak stress concentrations observed in rigid-base or non-interaction models were reduced when soil flexibility was included. Additionally, bending moments and shear forces along the wall height showed smoother variation, reflecting a more realistic structural response. The study also highlighted that soil stiffness and interface properties strongly influence deformation compatibility between the wall and backfill.

H. Hashash and J. Hook (1998) [7] authors published research on numerical modeling of retaining walls subjected to static and seismic loading. The study included both fixed-base and interacting soil conditions. Finite element modeling was used to obtain deformation and stress variation patterns. The findings confirmed that soil flexibility reduces structural demand and modifies bending stress development along wall height. The results showed clear differences between fixed-base and interacting soil models. Under static loading, soil flexibility led to redistribution of lateral earth pressure, resulting in smoother bending moment diagrams and reduced peak stresses in the wall section. During seismic loading, the inclusion of SSI significantly altered acceleration response, displacement amplitude, and dynamic bending stress development along the wall height. The interacting model generally exhibited lower structural demand compared to the rigid-base assumption because part of the energy was absorbed and dissipated by the deformable soil medium.

S. Choudhury and A. Subba Rao (2006) [8] authors conducted a parametric study on gravity retaining walls considering soil stiffness variation. Various height-to-base width ratios were analyzed. The results indicated that maximum stresses gradually decrease with increasing wall weight ratio up to a certain limit, after which deformation becomes dominant. Their conclusions support optimization of cross-section based on SSI behavior. The results revealed that as the wall weight ratio increases (i.e., as the base width increases relative to height), maximum stresses in the wall section gradually decrease up to an optimum limit due to improved resistance against lateral earth pressure. However, beyond a certain increase in weight ratio, the reduction in stress becomes marginal while deformation begins to dominate the structural response. In softer soil conditions, higher lateral displacement was observed even when stresses were comparatively lower, indicating that soil stiffness significantly controls performance.

K. H. Roscoe and J. B. Burland (1968) [9] authors contributed significantly to understanding soil mechanics behavior relevant to retaining structures. Their research explained stress-strain characteristics of soil under loading and its interaction with structural systems. The study emphasized compatibility of deformation between soil and structural elements, which forms the theoretical basis of SSI analysis in retaining walls. A key contribution of their work was the emphasis on deformation compatibility between soil and structural systems. When a retaining wall moves or deforms, the surrounding soil adjusts its stress state accordingly. The interaction is governed by the stress-strain characteristics of the soil, including stiffness, shear strength, and volumetric change behavior. Roscoe and Burland's theoretical model clarified how stress redistribution occurs within the soil mass when subjected to loading, providing the conceptual basis for modern finite element modeling of SSI problems.

A. J. Valsangkar and P. R. Viswanadham (1995) [10] authors studied the performance of gravity retaining walls with finite element analysis software. Both conventional analytical methods and numerical methods were compared. The study concluded that FEM provides more accurate estimation of displacement and stress variation. It was observed that ignoring SSI leads to conservative and sometimes uneconomical designs. The comparison of results revealed noticeable differences between analytical and numerical approaches. The finite element analysis predicted smoother stress distribution and more realistic displacement patterns along the wall height. It was observed that the conventional analytical method often overestimated bending moments and internal stresses because it did not account for soil flexibility and deformation compatibility. When SSI was included, peak stress concentrations were reduced due to redistribution of forces between soil and structure.

Regalado (1992) [11] conducted one of the earlier finite element analyses on gravity earth retaining structures

including soil interaction effects. The research demonstrated that conventional equilibrium methods can be overly conservative, as the soil's flexibility improves system stability. By comparing models with and without SSI, the study confirmed that interaction increases safety against sliding and overturning beyond traditional methods. The findings revealed that traditional equilibrium methods often produce conservative results because they assume rigid wall behavior and simplified pressure distribution. When soil flexibility was incorporated, the interaction between wall and soil resulted in redistribution of stresses and improved overall stability. In particular, the finite element analysis showed enhanced resistance against sliding and overturning due to the contribution of passive resistance and soil compliance. The wall-soil system behaved as an integrated unit rather than as independent components.

3. CONCLUSIONS

From the above reviewed studies, it is clearly observed that soil-structure interaction (SSI) plays a significant role in governing the performance of gravity retaining walls. Earlier research primarily relied on conventional analytical methods based on classical earth pressure theories, which often assumed rigid base conditions and neglected the flexibility of the supporting soil. However, with the advancement of numerical techniques such as the Finite Element Method (FEM), researchers have demonstrated that the mutual interaction between soil and retaining wall considerably influences stress distribution, deformation patterns, and overall stability behavior.

Several authors reported that neglecting SSI may lead to conservative or unrealistic estimations of stresses and bending moments in retaining walls. The inclusion of soil flexibility generally results in redistribution of stresses and controlled deformation, which can contribute to safer and more economical designs. It has also been identified that wall height, weight ratio, soil stiffness, and boundary conditions are critical parameters affecting the interaction mechanism. In many cases, sliding stability governs the design, and SSI analysis provides improved insight into displacement compatibility between soil and structure.

Furthermore, studies using software such as ANSYS and other FEM-based tools confirmed that numerical modeling offers a more accurate representation of field conditions compared to simplified analytical approaches. The reviewed literature collectively highlights the importance of integrated soil-wall modeling, particularly for optimizing cross-sectional dimensions and improving cost efficiency.

Therefore, it can be concluded that considering soil-structure interaction in the analysis and design of gravity retaining walls leads to more realistic stress evaluation, better understanding of deformation behavior, and the possibility of achieving an economical yet safe structural design.

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