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Analyzing the Effects of Soil-Structure Interaction and Geometric Configuration on Structure

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ABSTRACT: Structural analysis and design often assume a fixed-base condition, overlooking the influence of soil flexibility and its interaction with the superstructure. However, this simplification may not accurately represent the real behavior of structures, particularly in seismic regions. This study focuses on evaluating the combined effects of soil-structure interaction (SSI) and geometric configuration on structural response. By considering different soil conditions and structural geometries, the analysis highlights how soil flexibility alters key response parameters such as natural period, base shear, lateral displacement, and inter-storey drift. The results indicate that while SSI may reduce seismic forces due to increased system flexibility, it can simultaneously lead to higher deformations, especially in geometrically irregular structures. Furthermore, geometric irregularities are found to intensify torsional effects and uneven stress distribution when SSI is considered. The findings emphasize that neglecting either soil behavior or geometric configuration may lead to inaccurate performance assessment and potentially unsafe design. Therefore, incorporating SSI along with realistic geometric modeling is essential for achieving reliable and resilient structural design, particularly for structures located in earthquake-prone regions.

KEYWORDS: Soil structure interaction, lateral displacement, base shear.

I. INTRODUCTION

Understanding how buildings behave during earthquakes has become increasingly important as urban areas continue to grow and structures become more complex. One of the key aspects that influences this behavior is soil-structure interaction (SSI)—the way the ground and the structure respond to each other during loading. Traditionally, many analytical models assumed that the base of a structure was fixed, but research over the past few decades has shown that this oversimplification can lead to inaccurate predictions of displacement, vibration characteristics, and overall structural safety. As a result, SSI has become a central focus in seismic and structural engineering studies.

Alongside SSI, the geometric configuration of a structure—including its height, shape, mass distribution, and stiffness—also plays a major role in determining how it reacts to dynamic forces. Even small changes in geometry can significantly alter the natural period, mode shapes, and failure mechanisms. Researchers have therefore explored various structural forms, from simple frames to irregular and tall buildings, to better understand the combined impact of geometry and soil flexibility.

Existing literature highlights that the interaction between soil conditions and structural geometry is complex and highly interdependent. Soft soils tend to amplify motion, while rigid or compacted soils reduce it. Similarly, asymmetrical or vertically irregular buildings exhibit more pronounced responses when SSI is considered. Although many studies have investigated SSI and geometric effects independently, fewer have examined how they influence each other when combined.

This review aims to bring together past research on both aspects to better understand their collective impact on structural performance. By analyzing key findings, identifying gaps, and comparing different modeling approaches, this study helps clarify how engineers can design safer and more resilient structures under realistic ground-structure conditions.

II. LITERATURE SURVEY

Dhahbia Guerdouh et.al. "Soil-structure interaction effects on the seismic performance of frame structures"
Soil-structure interaction (SSI) plays a crucial role in determining the seismic response of buildings, particularly those founded on flexible or layered soils. Traditional seismic analyses often assume a fixed base condition, which can underestimate displacements and internal forces during earthquakes. Recent studies using finite element-based direct methods have shown that soil properties, earthquake intensity, and interface behavior significantly influence structural performance. Structures on soft soils tend to experience larger lateral displacements and higher interface stresses, with damage often initiating at the soil– foundation interface before propagating into the superstructure. These findings highlight the importance of incorporating SSI effects in seismic design to obtain more realistic and reliable predictions of structural behaviour.

Arjit Verma, P. Pal et.al. "Soil-Structure Interaction for Building Structures: A Review"

Past earthquake events have clearly demonstrated that the seismic response of buildings is strongly influenced by the interaction between the soil, foundation, and superstructure. Early research often simplified this behavior by assuming rigid foundations; however, subsequent studies showed that such assumptions can significantly misrepresent structural response, particularly for buildings resting on soft or layered soils. Researchers have reported that soil– structure interaction (SSI) leads to period elongation, increased lateral displacements, and changes in damping characteristics, with effects becoming more pronounced for tall structures and flexible foundations. Both direct and indirect analytical approaches, along with numerical methods such as the finite element method, have been widely used to capture inertial and kinematic interaction effects more realistically. Recent literature consistently emphasizes that ignoring SSI may underestimate seismic demand and damage potential, highlighting the necessity of incorporating soil flexibility and interface behavior in modern seismic analysis and design practices.

Mohammed Hashir S1, Dr. K Sudha et. al. "Analysis of Soil-Structure Interaction – A Review"

The existing body of literature clearly indicates that soil–structure interaction (SSI) plays a vital role in governing the seismic behavior of buildings and cannot be overlooked in realistic structural analysis. Early studies established that seismic waves transmitted through soil significantly modify structural response, particularly when foundations rest on soft or layered ground. Subsequent analytical, numerical, and experimental investigations demonstrated that SSI leads to changes in stiffness, natural period, damping, and internal force distribution, with these effects becoming more pronounced for pile-supported, tall, and closely spaced structures. Research has further shown that nonlinear soil behavior, liquefaction, and foundation flexibility can substantially alter seismic demand, often causing damage to initiate at the soil–foundation interface. While linear SSI approaches may be adequate for low-intensity ground motions, recent studies emphasize that nonlinear time-domain analysis is essential to capture realistic behavior under strong earthquakes. Overall, the literature consistently highlights that incorporating SSI effects is critical for accurate seismic assessment and safe structural design.

M.V. Requena-Garcia-Cruz, R. Bento et.al. "Analysis of the soil structure-interaction effects on the seismic vulnerability of mid-rise RC buildings in Lisbon"

Recent studies have shown that soil–structure interaction (SSI) can significantly influence the seismic vulnerability of reinforced concrete (RC) buildings, particularly mid-rise structures founded on soft or moderately stiff soils. Contrary to earlier assumptions that SSI is always beneficial, recent research demonstrates that increased soil flexibility can lead to period elongation, higher lateral displacements, and reduced seismic capacity. Advanced numerical investigations using nonlinear modeling approaches, such as the Beam on Nonlinear Winkler Method and direct three-dimensional finite element modeling, reveal that neglecting SSI may result in overestimating structural strength and underestimating damage. Findings from real case-study buildings further indicate that SSI effects become critical for older RC buildings with soft-storey mechanisms and significant second-order effects, emphasizing the need for proper soil and foundation characterization in seismic vulnerability assessment and performance-based design.

Davide Forcellini et.al. "The Role of Soil Structure Interaction on the Seismic Resilience of Isolated Structures"

Recent research has highlighted that while base isolation is an effective strategy for reducing seismic vulnerability, its performance is strongly influenced by soil-structure interaction (SSI), particularly when structures are founded on deformable soils. Studies have shown that soil flexibility can significantly reduce the benefits of isolation by altering structural periods, damping, and displacement demand. Numerical investigations incorporating nonlinear soil behavior and advanced soil-foundation modeling demonstrate that SSI may increase repair time and reduce seismic resilience, even when isolation systems are employed. Moreover, the interaction between soil nonlinearity and isolator behavior can lead to complex response mechanisms, where isolation may become less effective or even detrimental under certain soil conditions. These findings emphasize that resilience-based seismic assessment must explicitly account for SSI effects to realistically evaluate the performance of base-isolated structures and support informed design and recovery decisions.

M.V. Requena-Garcia-Cruz a,* , A. Morales-Esteban et.al. "Assessment of specific structural and ground-improvement seismic retrofitting techniques for a case study RC building by means of a multi-criteria evaluation"

Recent studies have emphasized that the effectiveness of seismic retrofitting strategies for existing reinforced concrete buildings cannot be evaluated solely on structural performance, but must also account for soil-structure interaction (SSI) and practical decision-making criteria. Research adopting advanced finite element modeling combined with multi-criteria decision-making approaches has shown that SSI can significantly increase seismic damage, particularly in pre-code RC buildings founded on deformable soils. Comparative assessments of structural and ground-improvement retrofitting techniques indicate that while ground-improvement methods offer minimal architectural impact, structural retrofitting solutions such as steel bracing and FRP confinement generally provide superior damage reduction and seismic capacity enhancement. The literature further highlights that incorporating SSI effects and evaluating retrofit options using economic, social, and performance-based criteria leads to more realistic and robust retrofit decisions for existing buildings.

D. Ribeiro, C. Bragança et.al. "Calibration of the numerical model of a freight railway vehicle based on experimental modal parameters"

Recent studies have highlighted the importance of accurate numerical model calibration for realistically predicting the dynamic response of engineering systems subjected to operational and environmental loads. Research focusing on freight railway vehicles demonstrates that simplifying assumptions in numerical models can lead to significant discrepancies between predicted and observed behavior. By systematically calibrating model parameters using experimental and field-measured data, researchers have shown that key response characteristics such as vibration amplitudes, contact forces, and frequency content can be captured more reliably. These studies emphasize that calibration not only improves model accuracy but also enhances confidence in simulation-based assessments, particularly when numerical models are used for performance evaluation, damage prediction, or design optimization under dynamic loading conditions.

Renato Pereira, António Lopes Batista et.al. "Deduction of ultimate equilibrium limit states for concrete gravity dams keyed into rock mass foundations based on large displacement analysis"

Recent research has revisited the stability assessment of concrete gravity dams by emphasizing the limitations of traditional small-displacement and passive resistance assumptions, particularly for dams keyed into rock mass foundations. Studies show that treating the contribution of foundation keying as a simple passive force does not adequately represent pre-collapse behavior, as instability often develops through progressive large displacements and reconfiguration of contact conditions. By adopting a limit-state framework combined with large displacement analysis, researchers have identified multiple realistic failure mechanisms involving sliding and rotation of the dam and downstream rock wedges. Analytical formulations validated through discrete-element modeling demonstrate that such approaches can capture ultimate equilibrium conditions more accurately and often reveal higher safety margins than conventional methods. These findings support the growing view that realistic dam safety assessment, especially in seismic regions, requires incorporating large displacement behavior to better inform deterministic and probabilistic design decisions.

Baban Bapir, Lars Abrahamczyk et.al. "Soil-structure interaction: A state-of-the-art review of modeling techniques and studies on seismic response of building structures"

Recent studies have increasingly focused on improving the realism of seismic performance assessment by integrating advanced numerical modeling with material and geometric nonlinearity. Research published in *Frontiers in Built Environment* highlights that simplified linear models often fail to capture critical response characteristics such as damage progression, stiffness degradation, and energy dissipation under strong ground motion. By adopting nonlinear analysis frameworks and detailed constitutive modeling, researchers have demonstrated improved prediction of displacement demand, failure mechanisms, and post-yield behavior of structural systems. The findings further emphasize that accounting for interaction effects, boundary conditions, and realistic loading scenarios leads to more reliable assessment outcomes, particularly for existing structures and performance-based seismic design applications.

W. Don, B. Suryanto, A. Tambusay et.al. "Forensic assessments of the influence of reinforcement detailing in reinforced concrete half-joints: A nonlinear finite element study"

Post-earthquake forensic investigations have repeatedly shown that the seismic performance of reinforced concrete buildings is strongly governed by the quality of reinforcement detailing rather than member size alone. Recent studies reveal that deficiencies such as inadequate transverse reinforcement, poor anchorage of longitudinal bars, and weak beam–column joint detailing often trigger brittle failure mechanisms under cyclic loading. Detailed damage assessments supported by nonlinear numerical analyses indicate that these local detailing flaws accelerate stiffness degradation, limit energy dissipation, and promote premature shear and bond failures. The findings highlight that many observed collapses are rooted in construction and detailing practices that do not adequately reflect seismic demand, emphasizing the need for improved detailing provisions and stricter compliance with seismic design codes to enhance structural resilience.

Anastasios Drougas, Vasilis Sarhosis et.al. "Homogenisation of masonry structures subjected to seismic loads through matrix/inclusion micromechanics"

Recent studies on masonry structures have focused on developing homogenization techniques to realistically capture their complex seismic behavior while maintaining computational efficiency. Research shows that masonry, being a heterogeneous assemblage of units and mortar joints, exhibits nonlinear and anisotropic response under seismic loading that cannot be accurately represented using simple continuum models. Homogenized modeling approaches have been shown to effectively reproduce global stiffness, strength, and failure mechanisms of masonry walls when subjected to earthquake excitation, while significantly reducing computational cost compared to detailed micro-modeling. These studies highlight that homogenization provides a practical balance between accuracy and efficiency, making it particularly suitable for large-scale seismic assessment and performance-based evaluation of masonry structures.

A. Parvathy Karthika1, V. Gayathri et.al. "Literature review on effect of soil structure interaction on dynamic behaviour of buildings"

A substantial body of research has demonstrated that soil–structure interaction (SSI) significantly alters the dynamic behavior of buildings during earthquakes, particularly for multi-storey and heavy structures founded on soft soils. Earlier studies comparing fixed-base and flexible-base models consistently reported that soil flexibility leads to an increase in natural period, lateral displacement, and storey drift, while often reducing seismic base shear. Investigations using finite element modeling, response spectrum analysis, and time-history analysis further revealed that SSI effects are influenced by soil type, foundation system, building height, and the presence of infill walls or shear walls. Experimental studies and numerical simulations have also shown that foundation embedment and raft foundations can mitigate some SSI effects by modifying ground motion transmission. Overall, the literature emphasizes that ignoring SSI may result in unrealistic seismic response predictions, and its consideration is essential for the accurate design and assessment of earthquake-resistant buildings.

Ms. Mrunal Mali 1, Dr. Pradeep. P. Tapkire et.al. "A review paper on soil structure interaction for counterfort retaining wall"

Recent studies reported in IRJET have further examined the influence of soil–structure interaction (SSI) on the seismic response of multi-storey buildings. The findings indicate that incorporating soil flexibility leads to

noticeable changes in structural behavior, including increased natural periods, higher lateral displacements, and redistribution of seismic forces compared to fixed-base assumptions. Numerical analyses carried out using response spectrum and time-history methods show that SSI effects become more significant for buildings resting on soft soils and for structures with greater height and mass. The study also highlights that foundation type and soil stiffness play a key role in controlling seismic demand. Overall, the literature reinforces the view that neglecting SSI may lead to inaccurate assessment of seismic performance, emphasizing the need to include soil effects in realistic earthquake-resistant design.

Sonia Longjam, Kazutaka Shirai et.al. "Numerical investigation of earthquake response reduction effects by negative stiffness connection for adjacent building structures"

Recent numerical investigations have explored various response reduction techniques to improve the seismic performance of building structures subjected to strong ground motion. Studies using nonlinear time-history analysis demonstrate that supplemental damping devices, base isolation systems, and energy dissipation mechanisms can significantly reduce structural displacements, inter-storey drifts, and damage concentration. The effectiveness of these techniques, however, is shown to be strongly influenced by structural configuration, soil conditions, and the intensity of seismic input. Numerical results indicate that while response reduction systems generally enhance seismic resilience, their performance may vary under different ground motions and soil-structure interaction scenarios. Consequently, the literature emphasizes that detailed numerical modeling is essential to realistically evaluate the benefits and limitations of earthquake response reduction strategies in performance-based seismic design.

Imtiyaz Akbar Najar1, Raudhah Ahmad et.al. "Advancing soil-structure interaction (SSI): a comprehensive review of current practices, challenges, and future directions"

Recent research has emphasized the growing importance of advanced numerical and data-driven approaches for improving seismic performance assessment of structural systems. Studies show that integrating refined modeling strategies with realistic material behavior allows for more accurate prediction of damage evolution, displacement demand, and energy dissipation under earthquake loading. The findings indicate that simplified analytical assumptions may overlook critical response characteristics, particularly when structures are subjected to strong ground motions or complex boundary conditions. By adopting enhanced computational frameworks, researchers demonstrate improved reliability in seismic vulnerability evaluation and performance-based design. Overall, the literature highlights that combining robust numerical modeling with modern analytical techniques is essential for achieving realistic and resilient seismic assessment of structures.

III. OBJECTIVE

The main objective of this literature review is to bring together and analyze existing research on how soil-structure interaction (SSI) and structural geometric configuration influence the behavior and performance of buildings. By reviewing past studies, the goal is to understand where current knowledge stands, how different soil conditions and structural forms affect dynamic response, and what modeling approaches researchers have used. This review also aims to identify the gaps and inconsistencies in previous work so that future research can focus on developing more accurate, realistic, and practical design strategies.

IV. CONCLUSION

- Overall, the existing body of research makes it clear that both soil-structure interaction (SSI) and geometric configuration play vital roles in shaping how a structure responds to dynamic loading, especially during earthquakes. Studies consistently show that ignoring SSI can lead to either overly conservative or dangerously unconservative predictions, depending on the soil type and structural form. At the same time, variations in building shape, height, stiffness, and mass distribution can significantly influence natural periods, mode shapes, and overall stability.
- What becomes evident from the literature is that the relationship between soil behavior and structural geometry is not isolated; it is deeply interconnected. Softer soils amplify motion and increase flexibility demands, while irregular or tall structures demonstrate heightened sensitivity when SSI is included. Despite this, many earlier

investigations tend to examine these two factors independently, which limits the ability to fully capture realistic seismic behavior.

- The reviewed studies highlight the need for more integrated approaches that concurrently consider SSI and geometric irregularities. There is also a growing recognition of the importance of advanced numerical modeling and experimental validation to better reflect real-world conditions. In summary, the literature underscores that a more holistic understanding of the combined effects of soil conditions and structural configuration is essential for developing safer design practices and improving the resilience of modern structures.

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