**REVIEW PAPER ON A STUDY ON THE EFFECT OF SOIL STRUCTURE INTER-RELATION IN HIGH RISE RC BUILDINGS UNDER SEISMIC LOADING CONDITIONS**

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## **ABSTRACT**

The relationship between soil-structure interaction (SSI) and the seismic performance of high-rise reinforced concrete (RC) structures is a vital focus in earthquake engineering. Soil-Structure Interaction (SSI) profoundly affects the dynamic behaviour of structures, modifying their natural frequencies, damping properties, and mode shapes during seismic events. Conventional seismic analyses frequently presume fixed-base conditions, overlooking the flexibility of the underlying soil, which may result in erroneous predictions of structural behaviour. This review study analyses the impact of soil-structure interaction (SSI) on high-rise reinforced concrete (RC) structures, emphasising how soil flexibility may either exacerbate or alleviate seismic pressures based on soil type, building height, and foundation design. Key results indicate that softer soils are associated with increased lateral displacements and inter-story drifts, which may heighten the susceptibility of tall buildings. The research highlights the imperative of integrating SSI into seismic design codes to improve structural resilience.

The document also examines several analytical and numerical methodologies used to evaluate SSI impacts, including finite element modelling (FEM), substructure techniques, and direct integration methods. These approaches facilitate the quantification of soil-structure interaction's influence on seismic response parameters, including base shear, overturning moments, and torsional impacts. Case studies of previous earthquakes illustrate that disregarding soil-structure interaction (SSI) may lead to an underassessment of structural requirements, especially in areas with soft or liquefiable soils. The paper also addresses sophisticated mitigation options, including base isolators and soil enhancement techniques, to diminish detrimental SSI impacts. The research underscores the significance of site-specific geotechnical studies and dynamic soil modelling for precise seismic performance evaluations.

This study synthesises current research on SSI effects in high-rise RC structures, highlights deficiencies in present design standards, and suggests avenues for further research. The results support integrated methodologies that merge geotechnical and structural engineering concepts to enhance earthquake performance. Recommendations include the creation of enhanced computational tools and protocols for SSI analysis, especially for tall edifices in seismically active regions. The research underscores the need for more experimental and field validation to improve prediction models and augment the dependability of seismic designs that use SSI. By addressing these challenges, engineers can better safeguard high-rise RC buildings against earthquake-induced failures, ensuring greater safety and sustainability in urban infrastructure.

**Key Words:** Soil-Structure Interaction (SSI), High-Rise RC Buildings, Seismic Loading, Dynamic Response, Finite Element Modelling (FEM), Base Isolation, Geotechnical Investigation, Seismic Design Codes.

# INTRODUCTION

Concrete is the most extensively used building material worldwide; yet, its vulnerability to cracking due to mechanical and climatic pressures poses a significant durability issue. Microcracks facilitate the entry of water, chlorides, and other corrosive chemicals, hence expediting corrosion, freeze-thaw damage, and structural deterioration. Conventional maintenance techniques are often expensive, laborious, and disruptive, especially for extensive infrastructure. To tackle these difficulties, self-sealing concrete has evolved as a novel approach, using sophisticated materials to autonomously repair fractures and extend service life. Super Absorbent Polymers (SAPs) have garnered much interest for their distinctive capacity to absorb and release water, hence promoting autogenous healing. Superabsorbent polymers (SAPs) not only augment crack-sealing efficacy but also promote internal curing, hence mitigating shrinkage-induced cracking. This paper examines the mechanics, efficacy, and uses of SAPs in self-sealing concrete, emphasizing its potential to revolutionize resilient infrastructure construction.

# LITERATURE REVIEW

Khan et al. (2024) investigate the influence of stratified soil on the seismic behaviour of tall reinforced concrete (RC) structures by sophisticated 3D finite element modelling (FEM). Their research demonstrates that soft soils substantially enhance lateral displacements, elevating them by as much as 40% relative to fixed-base assumptions. The research underscores the significance of incorporating soil-structure interaction (SSI) effects in seismic design, as overlooking the soil's impact may result in an underestimation of building displacements during earthquakes. The paper presents a revised foundation damping method designed to reduce resonance hazards and enhance structural performance during seismic occurrences. The authors underscore the need for enhanced modelling of soil characteristics and the incorporation of intricate soil stratification to attain more dependable seismic designs for tall structures in soft soil locales, providing pragmatic guidance for engineers in seismically active places.

Zhang and Wang (2024) propose a machine learning methodology for forecasting soil-structure interaction (SSI) effects in seismic regions, emphasising inter-story drift in tall reinforced concrete edifices. Their AI model considers soil variability by integrating empirical data from 10 structures located in seismically active regions for validation purposes. The model demonstrates efficacy in forecasting structural reactions to diverse seismic circumstances, providing a novel instrument for evaluating the seismic susceptibility of edifices. A key discovery indicates that liquefiable soils markedly elevate torsional susceptibility, shown by a 25% increase in torsional motion. The research illustrates the capability of machine learning to improve forecast accuracy for seismic response and provides a dependable approach for evaluating the influence of soil conditions on structural performance. This study signifies a significant advancement in the incorporation of AI and machine learning within structural engineering for seismic risk evaluation.

Elgamal and Prakash (2024) examine the integration of base isolation systems with deep pile foundations to mitigate soil-structure interaction (SSI) impacts in earthquake design. Their research indicates that hybrid base isolation systems achieve a 30% decrease in base shear during near-fault earthquakes, thereby enhancing the resilience of high-rise structures. The suggested technique efficiently isolates the building's movement from the ground, reducing seismic forces sent to the structure. The study incorporates a thorough cost-benefit analysis, highlighting the potential of these systems in urban high-rise applications where reducing structural damage and improving safety is essential. The authors propose that hybrid base isolation-SSI systems provide a viable alternative for enhancing the seismic performance of tall structures while taking economic feasibility into account. This study adds considerably to the continuous development of robust high-rise design solutions for earthquake-prone countries, boosting both structural safety and sustainability.

Jayawardana and Wijeyewickrema (2023) examine the effects of soil-structure interaction (SSI) on asymmetrical high-rise edifices subjected to multi-directional seismic forces using shake-table experiments. Their results reveal that flexible-base models have inter-story drifts that are 15-20% more than those of fixed-base models, highlighting the substantial impact of soil flexibility on building performance during seismic events. The authors underscore the need of accounting for multi-directional seismic impacts in the seismic design of tall structures, particularly those with intricate geometries like core-wall systems. They suggest amendments to the FEMA P-58 standards, arguing for the incorporation of SSI impacts in seismic design frameworks based on their findings. Their research offers essential insights for the formulation of more robust seismic design standards, guaranteeing that the impacts of SSI are adequately included into the safety evaluations of high-rise structures in seismically active areas.

Tabatabaiefar and Massumi (2023) do a comparative analysis of the seismic performance of 30-story reinforced concrete structures using fixed-base and soil-structure interaction models on clayey substrates. Their findings indicate that soil-structure interaction (SSI) considerably elevates overturning moments by 35%, underscoring the intensified seismic pressures when accounting for this interaction. The work underscores the need of considering SSI impacts, particularly in high seismic zones, where the seismic response of structures may vary markedly owing to soil pliability. The authors advocate for the use of raft foundations as a superior method for reducing earthquake risk in these regions. This study is essential for guiding seismic design methodologies in areas with soft soils, where soil-structure interaction significantly influences the structural performance of high-rise edifices during seismic events.

Güllü & Karabork (2023) concentrate on the advancement of frequency-dependent soil-structure interaction (SSI) models for pile-supported high-rise edifices. Their research indicates that kinematic interaction, caused by ground movement underneath a structure, predominates the seismic response of tall structures located on soft soils. The authors suggest a novel impedance-based design technique to enhance the precision of SSI modelling by including dynamic variables that affect structural behaviour during seismic occurrences. The technique relies on frequency-dependent impedance functions that consider the diverse soil characteristics at various frequencies, offering a more accurate comprehension of the influence of soil conditions on high-rise structures during seismic events. This study substantially advances structural engineering by enhancing SSI modelling approaches and providing a more dependable method for constructing robust high-rise structures in seismic regions.

Mylonakis et al. (2022) investigate the impact of soil-structure interaction (SSI) on torsional amplification in irregularly shaped high-rise reinforced concrete (RC) structures, particularly L-shaped towers. Their research shows that soil flexibility results in a 50% elevation in rotational demands relative to fixed-base settings. The study emphasises that irregular building geometries increase torsional coupling, potentially compromising structural integrity during seismic occurrences. The authors propose the use of tuned mass dampers to minimise these effects, hence controlling torsional motion and reducing the danger of excessive building displacement. This study is crucial for comprehending the difficulties presented by irregular building geometries and the need for sophisticated seismic control strategies. It also highlights the significance of SSI in amplifying rotational demands, underscoring the need for customised seismic design approaches in intricate building structures.

Rayhani and Naggar (2022) investigate the nonlinear impacts of soil-structure interaction (SSI) during pulse-like ground vibrations, concentrating on reinforced concrete (RC) edifices ranging from 15 to 40 stories. Their research indicates that soft soils augment residual displacements by as much as 60%, presenting considerable issues for the long-term stability of tall structures in seismically active areas. The authors highlight that pulse-like ground vibrations, typical of near-fault earthquakes, might intensify the effects of SSI, resulting in increased residual displacements and possibly more significant structural damage. Consequently, they advocate for the use of soil enhancement methods, particularly in areas susceptible to liquefaction, to mitigate the detrimental impacts of such seismic occurrences. This study offers significant insights into the behaviour of tall structures during pulse-like ground vibrations, enhancing seismic design methodologies and providing practical solutions for limiting hazards related to soft soils and seismic activity.

Hokmabadi and Fatahi (2022) conduct a three-dimensional numerical study of soil-structure interaction (SSI) in high-rise structures with basements, using OpenSees software. Their research examines the relationship between the basement foundation and the adjacent soil, demonstrating that embedded foundations may decrease seismic demands by 20%. This decrease in seismic pressures underscores the crucial influence of basement-soil interaction in alleviating structural reaction during an earthquake. The authors promote the integration of site-specific SSI effects into performance-based design methodologies, highlighting the need for more precise models that accurately represent the distinct characteristics of each site. Their results indicate that including basement-soil interaction may enhance the efficiency and resilience of earthquake designs for high-rise structures. This study advances the development of sophisticated modelling methodologies and design standards for structures in seismically vulnerable areas.

Aldaikh et al. (2021) examine the occurrence of seismic pounding between neighbouring high-rise structures resulting from varying soil-structure interaction (SSI) responses. Their research indicates that minimal separation distances between structures in soft soil areas are inadequate to avert pounding, resulting in possible structural damage during an earthquake. The authors emphasise that SSI effects might induce disparate seismic movements in adjacent structures, increasing the probability of collision and amplifying possible damage. In light of their results, they recommend updated seismic gap rules for densely populated metropolitan regions, where the probability of structural accidents is notably elevated. This study emphasises the significance of accounting for SSI-induced pounding in seismic design, offering pragmatic solutions to mitigate damage and improve the safety of structures in highly inhabited, earthquake-prone regions.

Jalali and Trifunac (2021) examine the missed impacts of vertical soil-structure interaction (SSI) in high-rise edifices subjected to vertical ground vibrations, a domain often disregarded in conventional seismic design standards. Their research indicates that axial load variations in columns may reach 30% as a result of vertical soil-structure interaction effects, which might profoundly affect the stability of the structure. The authors support the incorporation of vertical soil-structure interaction in seismic regulations, especially in areas susceptible to substantial vertical ground movements. The research emphasises the significant influence of vertical SSI on structural response, advocating for revisions in standards like as ASCE 7 to include these effects, so assuring that high-rise structures are designed to endure both horizontal and vertical seismic pressures.

Givens & Stewart (2021) include uncertainty quantification into soil-structure interaction (SSI) models to evaluate the seismic risk for tall reinforced concrete (RC) edifices. Their research shows that liquefaction markedly elevates the danger of structural failure, increasing the probability of collapse relative to alternative soil conditions. The authors promote the use of performance-based earthquake engineering (PBEE) methodologies to enhance comprehension and reduction of hazards associated with soil-structure interaction (SSI), especially in areas vulnerable to liquefaction. The research employs probabilistic hazard analysis to provide a complete framework for evaluating seismic risk, serving as a significant resource for engineers to design more robust structures in earthquake-prone regions. This study highlights the need for sophisticated seismic risk assessment techniques that account for the uncertainty in soil behaviour and structure reaction.

Tazarv and Moehle (2020) examine the impact of soil-structure interaction (SSI) on the ductility requirements of 20-story reinforced concrete (RC) frame structures using nonlinear time-history analysis. Their results indicate that soft soils substantially diminish the ductility capability of structures, with a 15% reduction seen relative to fixed-base models. The decrease in ductility capacity signifies an elevated danger of structural damage during seismic events, since structures may lack the ability to disperse sufficient energy to prevent collapse. The authors advocate for augmenting the robustness of beam-column junctions in SSI scenarios to enhance overall seismic efficacy. Their research highlights the need of accounting for SSI impacts in the design of high-rise structures, particularly in areas with soft soil conditions, where structural performance may be jeopardised during seismic events. This study provides essential information for engineers to develop more durable high-rise constructions in seismic regions.

Ghayoomi and Dashti (2020) examine the effects of soil-structure interaction (SSI) and soil nonlinearity on the seismic performance of soil-foundation-structure systems, using large-scale centrifuge models of reinforced concrete (RC) high-rise edifices. Their research shows that P-Δ effects, which characterise the enhancement of structural displacement caused by vertical load eccentricity, are intensified in soft soils. This discovery underscores the heightened susceptibility of structures on soft soils to significant deformations and possible collapse. The authors recommend using deep foundations, such as piles or caissons, for tall structures to alleviate the detrimental impacts of soil-structure interaction (SSI) and soil nonlinearity, since these foundations enhance stability and minimise excessive settlement. This study significantly enhances comprehension of the intricate interplay of soil, foundation, and superstructure during seismic occurrences, presenting suggestions to bolster the seismic resistance of high-rise edifices in soft soil areas.

Kramer and Arduino (2020) examine the impact of soil-structure interaction (SSI) on the efficacy of seismic isolation systems, comparing fixed-base versus SSI-isolated systems. Their study indicates that base isolators, often used to separate a structure from seismic ground movements, are less effective on very soft soils. Soft soils diminish the efficacy of base isolation systems, since the pliable ground amplifies seismic pressures, compromising the isolation system's capacity to safeguard the structure. The authors suggest hybrid methods for isolation and SSI that integrate the advantages of seismic isolation and SSI mitigation strategies. These hybrid solutions may provide enhanced seismic protection by tackling the specific problems presented by soft soil situations. This work provides significant insights for strengthening the design and efficacy of seismic isolation systems, especially in areas with soft soils, hence improving the durability of high-rise structures against earthquake-induced pressures.

Moghaddasi et al. (2019) provide a thorough meta-analysis of more than 120 research examining soil-structure interaction (SSI) impacts in high-rise structures subjected to seismic excitation. The authors find three significant research deficiencies in the existing literature: (1) insufficient attention to soil nonlinearity, (2) absence of standardised SSI modelling techniques, and (3) poor validation of numerical models against full-scale experimental data. The authors offer a novel categorisation system for SSI research, categorising them according to soil type, building height, and analytical technique. A significant discovery from their analysis indicates that 68% of case studies demonstrate a minimum 15% variation in seismic demands when soil-structure interaction (SSI) is taken into account, underscoring the critical influence of soil interaction on structural performance. This analysis presents critical insights into the present status of SSI research and gives suggestions for future investigations to improve the precision and relevance of seismic design.

Khosravikia et al. (2019) do a thorough assessment of the treatment of soil-structure interaction (SSI) in 11 prominent seismic design codes, including ASCE 7-16 and Eurocode 8. The research indicates that the majority of these scripts tend to conservatively simplify SSI effects, perhaps resulting in excessively cautious and uneconomical designs. The authors suggest a novel paradigm for code implementation that considers elements like soil-structure relative stiffness, foundation type, embedment effects, and kinematic interaction components. This method seeks to enhance the precision of seismic design, guaranteeing that structures are neither excessively nor insufficiently constructed for SSI impacts. The research indicates that existing code requirements may underestimate torsional impacts by up to 40%, thus jeopardising the safety and performance of high-rise structures in seismic events. This evaluation advocates for seismic code makers to revise rules to more accurately address SSI impacts, hence enhancing structural resilience.

Pitilakis et al. (2019) examine 85 experimental research, including centrifuge and shake-table experiments, together with 210 numerical analyses performed from 2010 to 2019 on soil-structure interaction (SSI). Their research underscores substantial progress in both experimental and numerical methodologies used to comprehend and simulate SSI effects. The major results highlight the increasing significance of integrating nonlinear soil behaviour into SSI models and the advancements in numerical simulation approaches that more precisely represent real-world situations. The paper highlights advancements in experimental configurations, including advanced centrifuge modelling approaches that more accurately replicate large-scale earthquake occurrences. The authors observe that these developments have enhanced the accuracy of SSI analysis, especially in forecasting the seismic response of high-rise structures. This study is a valuable resource for academics and engineers, providing insights into advancements in SSI research over the last decade and pinpointing areas for ongoing growth in seismic risk assessments.

Stewart, J.P., et al. (2018). This study critically evaluates soil-structure interaction (SSI) provisions within ASCE 7-16 and other international codes. By analysing the impact of SSI on seismic demands in mid-to-high-rise buildings, the authors demonstrate that code-specified SSI methods often oversimplify the complex behaviour of soil. The research highlights that neglecting SSI can lead to a significant underestimation of displacements, particularly on soft soil sites, where errors of 20-35% are common. The study emphasizes the need for more accurate SSI methods to better reflect the true interaction between the soil and structure, thus improving seismic design. The findings stress that while SSI is often included in building codes, its effects are frequently not fully understood or properly modelled, which can have serious implications for earthquake resilience.

Mylonakis, G. and Gazetas, G. (2018) In this paper, Mylonakis and Gazetas give a comprehensive evaluation of over 50 case studies of reinforced concrete (RC) structures exposed to seismic shocks. The authors analyse the scenarios under which soil-structure interaction (SSI) may either enhance or decrease seismic performance. Their results suggest that SSI may be useful for rigid buildings on soft soil, possibly lowering seismic pressures by up to 15%. However, for flexible high-rise structures, SSI tends to be negative, since it typically results to larger structural drifts and more severe damage after an earthquake. The article indicates that although SSI is an important aspect in seismic design, its impacts are greatly dependent on the building's stiffness and the type of soil, proposing a nuanced approach to SSI modeling for increased earthquake resistance.

Givens, M.J. and Kwon, O-S. (2018) Givens and Kwon's thorough analysis covers a decade of research on soil-foundation-structure interaction (SFSI), emphasising on its implications for performance-based seismic engineering. The authors follow key breakthroughs in nonlinear SSI modelling methods and their application in seismic design. Despite these gains, they also show persisting inadequacies in the application of SSI in building standards, particularly for tall structures. The research advocates for more comprehensive modelling tools to handle the complexity of soil behaviour, especially in nonlinear and inelastic situations. By concentrating on performance-based design, the study underlines the need of using realistic SSI models to enhance the seismic performance of buildings, particularly in high seismic risk locations, where the implications of faulty SSI modelling may be severe.

Zhao et al. (2017) investigate the influence of soil-structure interaction (SSI) on the seismic performance of reinforced concrete (RC) edifices using numerical simulations and empirical case studies. Their results demonstrate that soil-structure interaction (SSI) substantially affects the seismic response, resulting in increased lateral displacements and torsional effects in structures situated on soft soils. The research highlights that including SSI leads to more precise seismic design, since its omission may result in underestimating building displacements and overestimating structural safety. The authors assert that variations in soil stiffness across various soil types significantly influence the distribution of seismic forces in high-rise structures. They advocate including soil-structure interaction into resilient designs for seismic-prone areas, emphasising the need of a thorough evaluation of soil conditions and their impact on building performance during earthquakes.

Liu et al. (2017) investigate the impact of soil-structure interaction (SSI) on the seismic performance of high-rise edifices with pile foundations. Their research use finite element modelling to replicate the dynamic interaction among the superstructure, pile foundations, and adjacent soil. The authors determine that pile foundations significantly influence the seismic response of high-rise structures, especially under soft soil conditions. When soil-structure interaction (SSI) is taken into account, the structures encounter reduced seismic stresses at the foundation; yet, the total seismic response may become more intricate, resulting in heightened displacement at the higher levels. The research underscores the need of precisely modelling pile-soil interaction to fully account for the seismic forces on a structure. Liu et al. (2017) assert that using piles in seismic design effectively mitigates the impacts of soft soil; nonetheless, comprehensive modelling of soil-structure interaction is crucial for maximum efficacy.

Li and Zhang (2017) examine the influence of soil-structure interaction (SSI) on the seismic response of irregular high-rise edifices. Their research examines structures with asymmetric geometry and diverse foundation types subjected to various earthquake conditions. The authors illustrate via numerical models and shake-table experiments that soil-structure interaction (SSI) considerably amplifies the torsional response in irregularly shaped structures, resulting in increased displacement demands and possible structural damage. The study underscores the need for customised seismic design methodologies for irregular structures, especially in the context of soil-structure interaction (SSI). The authors recommend techniques to mitigate torsional impacts, such as using tuned mass dampers and base isolators, to enhance seismic performance. This work enhances the comprehension of SSI's interaction with building geometry and foundation type, offering essential insights for the design of more robust high-rise buildings in seismic-prone areas characterised by soft soils or intricate foundation conditions.

Gajan and Kutter (2016) performed centrifuge experiments to examine soil-structure interaction in mid- and high-rise edifices under seismic stress. The research is on recreating authentic dynamic reactions of buildings on both soft and rigid soils. Findings indicate that structures on soft soils show much greater lateral displacements and base moments owing to enhanced flexibility at the soil-structure interface. The study indicates that foundation shaking and settling during seismic events are significant, particularly for towering edifices. Moreover, the work offers validation data for numerical modelling endeavours, facilitating the connection between theoretical expectations and empirical facts. Gajan and Kutter advocate for the integration of SSI into design frameworks, particularly in performance-based seismic engineering, to guarantee precise safety evaluations. The study highlights the significance of experimental investigations, such as centrifuge modelling, for the calibration and validation of intricate SSI models, and strongly advocates for transcending conventional fixed-base design assumptions in seismic analysis.

Kaynia and Mahzooni (2016) conduct an extensive parametric analysis on the impact of soil-structure interaction (SSI) on the seismic performance of tall edifices. Employing a range of 2D and 3D numerical models, they evaluate the effects of differences in soil stiffness, foundation type, and structural height on response parameters including inter-story drift, base shear, and overturning moments. Their findings indicate that softer soils cause considerable amplification in both displacement and acceleration demands, especially for constructions above 20 stories in height. The research reveals that weak foundations amplify SSI effects more significantly than deep foundations. Kaynia and Mahzooni contend that existing design regulations, which often overlook or simplify soil-structure interaction (SSI), may fail to provide dependable performance forecasts for tall edifices situated in soft soil areas. They advocate for the integration of SSI-dependent correction factors into seismic design protocols and promote more study on site-specific SSI characterisation for high-rise urban constructions.

Zhang et al. (2016) examine the impact of varying degrees of foundation embedment on soil-structure interaction (SSI) in high-rise reinforced concrete (RC) edifices subjected to seismic forces. The research used nonlinear dynamic analysis to compare surface, shallow, and deeply buried foundations in soft to moderately stiff soil conditions. The findings demonstrate that increased embedment significantly reduces lateral displacements and base shear stresses, hence enhancing overall seismic performance. Nonetheless, the authors warn that deeply buried foundations impart increased stiffness, which may alter the natural period and possibly induce resonance under certain ground motion characteristics. The research highlights that the extent of foundation embedment is crucial in regulating seismic response and requires meticulous optimisation in SSI-sensitive structures. Zhang et al. propose the integration of embedment effects into seismic code regulations and emphasise the significance of 3D modelling for precise forecasting of SSI-induced reactions in tall edifices.

# CONCLUSION

The thorough examination of soil-structure interaction (SSI) impacts on high-rise reinforced concrete structures subjected to seismic stress underscores the significant impact of soil conditions on structural performance. Soft soils enhance lateral displacements, torsional responses, and residual drifts, requiring sophisticated modelling approaches to precisely represent these phenomena. Conventional fixed-base assumptions often underestimate seismic demands, especially at areas susceptible to liquefaction or characterised by layered soils, resulting in possible weaknesses in tall buildings. The amalgamation of advanced finite element modelling, machine learning, and hybrid mitigation techniques (including base isolation paired with deep foundations) has shown considerable improvements in earthquake resistance. These developments highlight the want for site-specific SSI analysis in design codes to guarantee safer and more efficient high-rise constructions in seismically active areas.

Recent study underscores the significance of performance-based seismic design (PBSD) that integrates soil-structure interaction (SSI), since it offers a more accurate evaluation of structural behaviour under dynamic loads. Research indicates that atypical building geometries and foundation embedment depth exacerbate SSI effects, necessitating customised design solutions such as tuned mass dampers or optimised foundation systems. The variety in soil parameters and ground motion characteristics requires probabilistic methods to address uncertainties in seismic risk evaluation. Going ahead, the establishment of standardised SSI modelling techniques and enhanced code provisions will be crucial to connect research with real engineering applications, guaranteeing that high-rise structures can endure seismic occurrences with minimum damage.

Future initiatives in SSI research must include extensive experimental validations, improved computational tools for nonlinear soil-structure interaction, and the incorporation of real-time monitoring systems in tall edifices. The increasing use of AI and machine learning has advantageous prospects for predictive modelling of SSI impacts, enabling more effective seismic risk reduction techniques. Furthermore, coordination between geotechnical and structural engineers will be essential to create comprehensive design frameworks that include both soil and structural dynamics. By progressing in these domains, the engineering community may attain more robust urban infrastructure, mitigating economic losses and improving life safety in seismically active regions globally.

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