

A CRITICAL STUDY INVESTIGATING SOIL- STRUCTURE INTERACTION FOR ENHANCED EARTHQUAKE PREPAREDNESS IN HYDERABAD, TELANGANA

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LIST OF ABBREVIATIONS

Abbreviations	Indication
SSI	Soil-Structure Interaction
FEA	Finite Element Analysis
IBC	International Building Code
ASCE	American Society Of Civil Engineers
GIS	Geographic Information Systems
PGA	Peak Ground Acceleration
UNDRR	United Nations Office For Disaster Risk Reduction
SSSI	Structure-Soil-Structure Interaction
S-STAF	Seismic-Slope Topographic Amplification Factor
FEM	Finite Element Method
RC	Reinforced Concrete
OGS	Open Ground Story
FE	Finite Element
SR	Seismic Resilience
TH	Time History
ESL	Equivalent Static Load
FB	Fixed-Based
NR	Newton-Raphson

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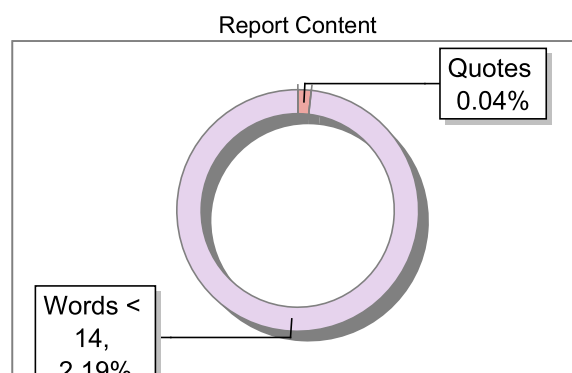
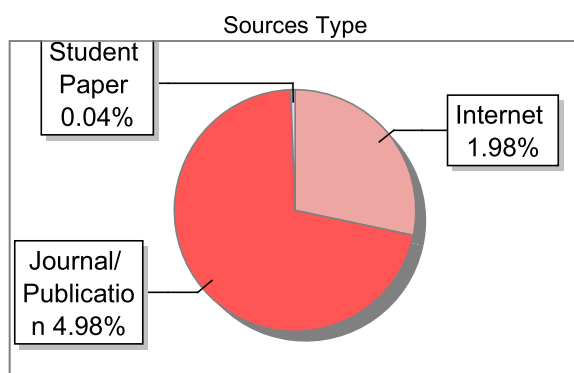
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ABSTRACT

Soil layers are the usual foundation for superstructures, unless the bedrock is quite near to the surface. Layers of soil are crucial in determining how the earth's surface moves. By ensuring that the ground is sufficiently firm, we may study the structure under the fixed base condition during earthquakes without worrying too much about how the soil qualities would affect its dynamic response. The interaction between the soil and the structure during a structure's rest on a flexible medium causes the structure's dynamic reaction to vary from that of a fixed base condition. The purpose of this study is to improve earthquake readiness by learning more about soil-structure interaction (SSI), a key component that affects how buildings react to earthquakes. Soil conditions and structure performance during seismic occurrences are intricately related, and understanding this link is the primary priority. We want to build stronger buildings that can endure the pressures of earthquakes by better comprehending these relationships.

An approach to seismic evaluation and design known as performance-based engineering (PBE) uses performance level prediction to evaluate risks and safety. Unbraced buildings on moderately soft soils may experience lateral displacements and inter-storey drifts that are greatly amplified by soil structure interaction. A change in the building frames' performance level may result from this amplified lateral deformation. Because of this, SSI impacts should be included in a thorough dynamic study that assesses a structure's true performance level. A simpler approach to simulating the interaction between a soil structure and its foundation was the primary impetus for this investigation. The implementation of a flexible interface between the soil-to-raft and soil-to-pile models is essential in interaction problems for achieving analytical continuity and obtaining the most realistic model. Both the near field and the far field representations of the soil half space are valid. By using a non-reflecting viscous border to prevent multiple wave reflection in the dynamic analysis, the far field is described as linear and the close field as nonlinear. Interfaces, nonlinear soil behavior, and structure all contribute to the large scale of the soil structure interaction issue, making it computationally costly. This expense has been growing at an exponential rate in relation to the soil volume, interface area, and structural geometry. In the case of piling foundations, it is necessary to simplify the model using certain procedures since the soil domain has to be considered deeper and larger. Using the

comparable pier approach to replace the piling group has been the primary focus of this work in order to decrease the soil domain. There has been extensive research on this method for analyzing soil-structure interactions. This may help get the answer quickly while also reducing the interface loudness to some degree. Dynamic analysis's finite element software was built in C++, a flexible low-level object-oriented language. Given a set of dynamic loading conditions for both the original pile design and the equivalent pier, the displacement and stress histories in the time domain have been computed. In order to determine the optimal deviational response of the superstructure, we tested the equivalent pier technique for various pier locations in the plan area and found the combination of piers that works well. Estimates are based on the following criteria: the importance of SSI analysis for a given loading and local soil condition; the use of the Equivalent Pier Method to simplify and streamline modeling; and the impact of soil-structure interactions on the superstructure's responses. This research delves at the usual intricate floor plans of asymmetrical structures in an effort to deduce how form impacts the superstructure's reaction. Soil dynamic structural analysis takes these three building shapes into account: C, L, and T.

This paper proposes an EPM method for asymmetrical pile groups that demonstrates numerical efficiency but may overestimate the superstructure's reactions, leading to a more cautious SSI strategy. The use of EPM approach on the asymmetrical pile architecture was shown to improve the analysis time. A computationally efficient analysis is therefore provided by the approach proposed in this paper. The behavior of the asymmetrical superstructure was investigated by a thorough SSI study, which included adjusting a critical parameter in the seismic analysis. For varying earthquake magnitudes, pile L/D ratios, and supporting domain soil types, the superstructure's reaction is evaluated. Depending on the intricacy of the design, the research found that each asymmetrical building behaves differently. Soil type and dynamic loading both affect the displacements. Any given aspect ratio of a pile foundation system will result in a unique kinematic interaction conveyed via the piles.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

The vibrant city of Hyderabad, which is the capital of the Indian state of Telangana, is steeped in history, culture, and commerce. However, this bustling city is never really safe from earthquakes, a natural disaster that may cause widespread devastation. Given the critical nature of earthquake preparedness, this research delves into the complex dynamics of soil-structure interaction in the urban setting of Hyderabad. The goal of this study is to better understand the connection between soil qualities and structural integrity in order to increase earthquake resilience and decrease the likelihood of damage. Hyderabad is geologically susceptible to earthquakes due to its location on the Deccan Plateau and the potential presence of regional fault lines. Soil type diversity and seismic reactivity are accentuated by the city's diversified environment, which encompasses rocky regions, alluvial plains, and sedimentary basins. Soil strata and their interaction to the built environment must be considered when calculating the city's seismic vulnerability. We hope that by shedding light on the nuances of this relationship, we can take preventative measures to lessen the likelihood of seismic activity. Because of its profound effect on earthquake resistance, the soil-structure interaction is of paramount importance. The damping properties, density, and rigidity of soil all contribute to the amplification of ground motion when seismic waves pass through it. In addition, the varied and heterogeneous nature of the soil deposits around Hyderabad makes it more challenging to conduct consistent hazard assessments and structure designs. This research seeks to analyse the interplay between soil and structure in order to get a better comprehension of seismic activity and its impact on urban resilience. [1]

Among other things, this research intends to detail the geotechnical features of soils often seen in Hyderabad and how they connect to the assessment of seismic risk. Data from field studies, geophysical surveys, and laboratory testing will be combined to build a comprehensive database of soil attributes. This database will include shear strength, liquefaction susceptibility, and dynamic modulus, among others. With this empirical groundwork in place, By simulating soil behavior under seismic loading

circumstances, more accurate seismic hazard maps and risk assessments may be achieved via the development of strong geotechnical models. The project also intends to look at how the dynamic response of infrastructure and buildings in Hyderabad is impacted by soil-structure interactions. By combining state-of-the-art numerical models with experimental studies, we will analyse the coupled behaviour of soil and structures exposed to seismic excitation, taking into account crucial factors such foundation flexibility, site amplification effects, and soil-structure resonance. By elucidating the complex interplay between soil factors, structure dynamics, and ground motion features, this study aims to pinpoint vulnerable structural typologies and provide retrofitting solutions to enhance their seismic resistance. Socioeconomic factors are also included in this critical analysis of Hyderabad's seismic readiness and resilience-building efforts. Recognizing that various demographic and socioeconomic groups are susceptible and exposed in different ways, we will advocate for a more inclusive strategy to risk assessment and mitigation. [2] Community engagement activities, capacity-building programs, and policy interventions will all be a part of this study to make sure that everyone in society benefits from increased resilience. The goal is to make sure that everyone is aware of earthquakes and knows how to be prepared. The results of this crucial research will provide important information and recommendations for engineers, politicians, and urban planners who are working to make Hyderabad, Telangana more earthquake-proof. This project seeks to combine geotechnical, structural, and socioeconomic aspects via multidisciplinary cooperation, with the goal of catalysing transformative change towards a more resilient and sustainable urban future. In order to save lives, livelihoods, and the architectural heritage of this dynamic city, Hyderabad may fortify its defences against the approaching seismic threats by implementing preventative measures guided by a thorough understanding of the dynamics of soil-structure interaction.

1.2 SOIL-STRUCTURE INTERACTION (SSI)

Soil-structure interaction (SSI) is a critical area of study in civil and geotechnical engineering, focusing on the complex relationship between the soil that supports a structure and the structure itself during various loading conditions, particularly dynamic loads such as earthquakes. At its core, SSI examines how the mechanical properties of soil influence the behaviour of structures built upon or within it, which is vital for ensuring the safety and stability of these structures. When a building experiences

stresses from outside sources—such as seismic waves, wind, or even static loads—the response is not solely determined by the structure's inherent characteristics. Instead, the interaction with the underlying soil significantly influences how these loads are distributed, absorbed, and transmitted through the foundation to the soil. This interaction is essential to understand as it impacts the overall performance of the structure, particularly in seismic regions where ground motion can cause significant vibrations. Soil reacts in a nonlinear way to changing loads, meaning that the relationship between stress and strain does not follow a straightforward linear path; it is affected by factors such as soil type, moisture content, loading rates, and the history of the applied loads. For instance, granular soils may exhibit different behaviours under cyclic loading compared to cohesive soils, necessitating a tailored approach to modelling these interactions. The mechanisms of soil-structure interaction can be categorized into several key processes: inertial interaction, kinematic interaction, and compliance interaction. Inertial interaction occurs when the mass of the structure moves as a response to ground motion, leading to the soil exerting forces on the structure. Kinematic interaction arises when the movement of the structure induces displacements in the soil, affecting the overall motion. Compliance interaction refers to the deformation of the soil itself under loading, which affects the response of the structure. Together, these interactions contribute to the dynamic response of the system and must be carefully modelled to predict how structures will behave during earthquakes. The significance of SSI is particularly pronounced in the context of seismic design. Traditional design approaches often assume fixed base conditions, where the foundation is treated as rigid and unyielding. However, in reality, foundations interact with the surrounding soil, which can alter the natural frequency of structures and lead to resonant conditions. This phenomenon is critical when considering high-rise buildings and bridges, where the potential for resonance with seismic waves can lead to catastrophic failures. Therefore, a comprehensive understanding of SSI is essential for developing accurate predictive models that inform the design process. [3]

The analysis of soil-structure interaction is inherently complex and requires advanced methodologies to capture the intricate behaviour of both the soil and the structure. Finite Element Analysis (FEA) has become a widely used computational technique for modelling SSI, allowing engineers to simulate the behaviour of structures under dynamic loading by breaking down the system into smaller, manageable elements. FEA

accounts for the nonlinear properties of soil, varying soil types, and structural geometry, providing valuable insights into how structures will respond during seismic events. Another important methodology is the use of hybrid modelling techniques that combine physical modelling with numerical analysis. Physical models allow researchers to observe real-time interactions in controlled environments, providing data that can validate numerical simulations. Additionally, field tests and monitoring of existing structures can provide empirical data on how soil-structure interaction occurs in practice, helping to refine theoretical models and improve predictive accuracy. The implications of soil-structure interaction extend beyond just understanding how buildings respond to seismic events; they also play a critical role in informing construction practices and standards. Current building codes and standards, such as the International Building Code (IBC) and ASCE 7, incorporate provisions for SSI in seismic design, emphasizing the importance of considering these interactions in structural assessments. For instance, in regions with soft soil conditions, engineers are often required to apply specific design considerations to mitigate the effects of potential ground motion amplification. Furthermore, the integration of SSI into performance-based design approaches allows engineers to evaluate a structure's expected performance during seismic events, guiding decision-making processes for design and retrofitting strategies. As urbanization continues to increase, the need for robust buildings that can withstand seismic events becomes paramount, particularly in densely populated areas where the potential for loss of life and economic disruption is significant. Challenges associated with soil-structure interaction analysis include the variability of soil properties and the complexity of the interactions involved. Soil is inherently heterogeneous, meaning that its properties can change significantly over short distances. Factors such as soil layering, moisture content, and compaction history contribute to this variability and complicate the modelling process. Engineers must also account for the presence of nearby structures and infrastructure, as these can influence the behaviour of the soil and the interacting structures. Moreover, the effects of time-dependent behaviour, such as consolidation and creep in soils, can further complicate the understanding of SSI. To address these challenges, on-going research is focused on developing improved methodologies and tools for analysing soil-structure interaction. This includes advancements in computational techniques, such as enhanced finite element models that can simulate the time-dependent behaviour of soils and structures, as well as the development of machine learning algorithms that can analyse large

datasets to identify patterns and predict behaviours in complex soil-structure systems. [4]

In addition to advancements in modelling and analysis, The significance is becoming more recognized of ground improvement techniques to enhance soil performance during seismic events. Methods such as soil stabilization, grouting, while geosynthetics have the potential to greatly enhance soil's mechanical characteristics, thereby enhancing the overall performance of structures. For instance, ground improvement techniques can increase the shear strength of soils, reduce settlement, and mitigate liquefaction risks, all of which are critical considerations in seismic regions. Moreover, the implementation of base isolation systems—where the structure is decoupled from ground motion through flexible bearings—has gained popularity as an effective method to reduce seismic forces transmitted to buildings. These systems are designed to allow for independent movement between the structure and the ground, significantly enhancing resilience against earthquakes. The relationship between soil-structure interaction and disaster preparedness cannot be overstated. A comprehensive understanding of SSI allows engineers to design structures that are not only resilient to seismic forces but also adaptable to changing environmental conditions. As climate change continues to influence the frequency and intensity of natural disasters, the importance of integrating SSI considerations into urban planning and infrastructure development becomes increasingly clear. By adopting a proactive approach that incorporates SSI principles, communities can enhance their overall resilience to seismic events and minimize the impact of disasters on public safety and economic stability. In conclusion, soil-structure interaction is a vital area of study that has far-reaching implications for the safety and resilience of structures, particularly in seismically active regions. As urbanization accelerates and populations grow, the need for comprehensive assessments of how soil and structures interact becomes paramount. By utilizing advanced methodologies, improving ground conditions through innovative techniques, and integrating SSI considerations into design practices, engineers can significantly enhance the earthquake preparedness of urban environments. This multifaceted approach not only protects physical infrastructure but also safeguards lives and promotes sustainable development in the face of natural disasters. As research continues to evolve, the insights gained from studying soil-structure interaction will

undoubtedly play a critical role in shaping the future of earthquake engineering and disaster resilience. [5]

1.3 IMPORTANCE OF SOIL-STRUCTURE INTERACTION

Soil-structure interaction (SSI) plays a crucial role in the field of civil engineering, particularly in the design and analysis of structures subjected to dynamic loads such as earthquakes, wind, and other environmental forces. Understanding SSI is essential for ensuring the safety and performance of structures, as it governs how buildings and other constructions respond to the forces imposed upon them. At its core, SSI involves the mutual influence between the soil and the structure, where both components affect each other's behaviour under load. This relationship is particularly significant in regions that are seismically active or prone to other dynamic loading conditions, making the study of SSI a fundamental aspect of modern engineering practice. The significance of SSI can be attributed to several factors, beginning with its direct impact on the structural performance and stability. When a structure is built on soil, the characteristics of that soil—such as its stiffness, damping properties, and density—significantly influence how the structure behaves during loading. For instance, soft or loose soils can amplify seismic waves, leading to increased lateral forces on the structure and potentially resulting in failure. Conversely, stiff soils can reduce the effects of ground motion, providing a more stable foundation for buildings. Therefore, understanding the nature of the soil and its interaction with structures is critical for engineers to predict the behaviour of buildings during seismic events accurately. This understanding informs design practices that ensure structures are resilient and capable of withstanding the forces they may encounter throughout their lifespan.

In addition to safety and performance, SSI also plays a pivotal role in the economic aspects of construction and infrastructure development. When structures are designed without considering the effects of soil-structure interaction, the risk of structural failure or significant damage during an earthquake increases. This can lead to costly repairs, extended downtime, and potential loss of life. By incorporating SSI principles into the design process, engineers can create structures that are not only safer but also more cost-effective over their lifecycle. For instance, proper assessment of SSI can lead to the adoption of appropriate materials and construction techniques that enhance performance while minimizing costs. Furthermore, understanding the interaction

between soil and structures can help in optimizing the design for construction practices, ensuring that resources are used efficiently and effectively. The importance of SSI is further underscored by the challenges posed by modern urbanization. As cities expand and populations grow the demand for new infrastructure increases. Many urban areas are built on or near hazardous sites, including those prone to liquefaction, landslides, and other geotechnical failures. In such environments, the implications of soil-structure interaction become even more critical. Engineers must account for the variability in soil properties, which can significantly change over small distances. This variability complicates the design process, as it introduces uncertainties that must be carefully managed to avoid structural failures. The ability to accurately model and predict soil-structure interactions enables engineers to design structures that can accommodate these uncertainties, ultimately enhancing public safety and minimizing risks associated with natural disasters. [6]

Moreover, the concept of performance-based design has emerged as an essential framework for incorporating SSI into engineering practice. Traditional design methods often rely on prescriptive approaches that may not adequately address the specific needs of a given site or structure. In contrast, performance-based design emphasizes the need for structures to meet defined performance criteria during seismic events. This approach necessitates a thorough understanding of SSI, as it allows engineers to evaluate how structures will respond to various loading scenarios. By utilizing advanced modelling techniques, including finite element analysis (FEA) and hybrid modelling approaches, engineers can simulate the behaviour of both the soil and the structure under dynamic loading conditions. This leads to more informed design decisions that enhance the overall resilience of buildings and infrastructure. Another critical aspect of the importance of SSI is its role in advancing building codes and standards. As research in soil-structure interaction continues to evolve, the knowledge gained from these studies informs the development of building codes that promote safer construction practices. Codes such as the International Building Code (IBC) and standards from organizations like the American Society of Civil Engineers (ASCE) incorporate SSI considerations into their guidelines, recognizing its significance in achieving structural safety and resilience. By adhering to these codes, engineers can ensure that their designs account for the effects of soil-structure interaction, thereby decreasing the possibility of failures and enhancing the overall safety of buildings. Furthermore, SSI's significance goes

much beyond only new construction; it is also crucial for assessment purposes and retrofitting of existing structures. Many buildings were constructed before the full implications of SSI were understood, leaving them vulnerable to seismic forces. By conducting thorough assessments of soil-structure interaction, engineers can identify weaknesses in these older structures and develop retrofitting strategies to enhance their resilience. This is particularly relevant in areas with aging infrastructure, where the cost of replacing buildings may be prohibitive. Retrofitting can involve various approaches, such as strengthening foundations, adding base isolation systems, or improving the stiffness of structural elements. By understanding how the existing soil interacts with the structure, engineers can implement targeted interventions that improve performance and safety.

Moreover, advancements in technology have revolutionized the field of soil-structure interaction analysis.

The development of more sophisticated computational tools and modelling techniques has enhanced engineers' ability to analyse complex systems accurately.

These advancements allow for the incorporation of nonlinear soil behaviour, dynamic loading conditions, and the interaction between multiple structures. As a result, engineers can better predict the performance of buildings during seismic events and optimize design strategies accordingly.

The integration of technologies such as Geographic Information Systems (GIS) and remote sensing further supports the analysis of SSI, providing valuable data on site conditions and soil properties. The significance of SSI is also reflected in its contribution to disaster preparedness and risk reduction.

As natural disasters become increasingly frequent and severe due to climate change, the need for resilient infrastructure is more pressing than ever.

By incorporating SSI principles into the planning and design of urban environments, communities can enhance their overall preparedness for seismic events.

This includes not only the construction of resilient buildings but also the development of effective emergency response plans that consider the interactions between structures

and soil. Public awareness campaigns can also be informed by research in SSI, imparting knowledge to local populations on the significance of resilient building methods and design. In addition, city planners may benefit from SSI knowledge by keeping it in mind while making decisions and land use decisions.

As cities continue to expand, the selection of building sites must consider the geotechnical characteristics of the soil and its interactions with proposed structures.

This requires a collaborative approach between civil engineers, urban planners, and geotechnical specialists to ensure that new developments are located in areas that minimize seismic risks. By integrating SSI considerations into land use planning, communities can reduce vulnerability to earthquakes and enhance overall resilience.

The importance of soil-structure interaction is multi-faceted and deeply intertwined with the safety, performance, and economic viability of structures in a variety of contexts.

As urbanization continues to accelerate and seismic risks remain a concern in many regions, understanding and addressing SSI becomes increasingly critical. By integrating SSI principles into design practices, engineers can create safer, more resilient structures capable of withstanding the challenges posed by dynamic loading conditions. [7]

1.4 FACTORS INFLUENCING SOIL-STRUCTURE INTERACTION

Soil-structure interaction (SSI) plays a critical role in the response of structures subjected to various loading conditions, particularly during seismic events.

Understanding the factor's influencing SSI is essential for accurate assessments of structural performance and the development of effective design strategies.

This analysis explores key factors affecting SSI, including soil properties, structural characteristics, environmental conditions, and dynamic loading effects.

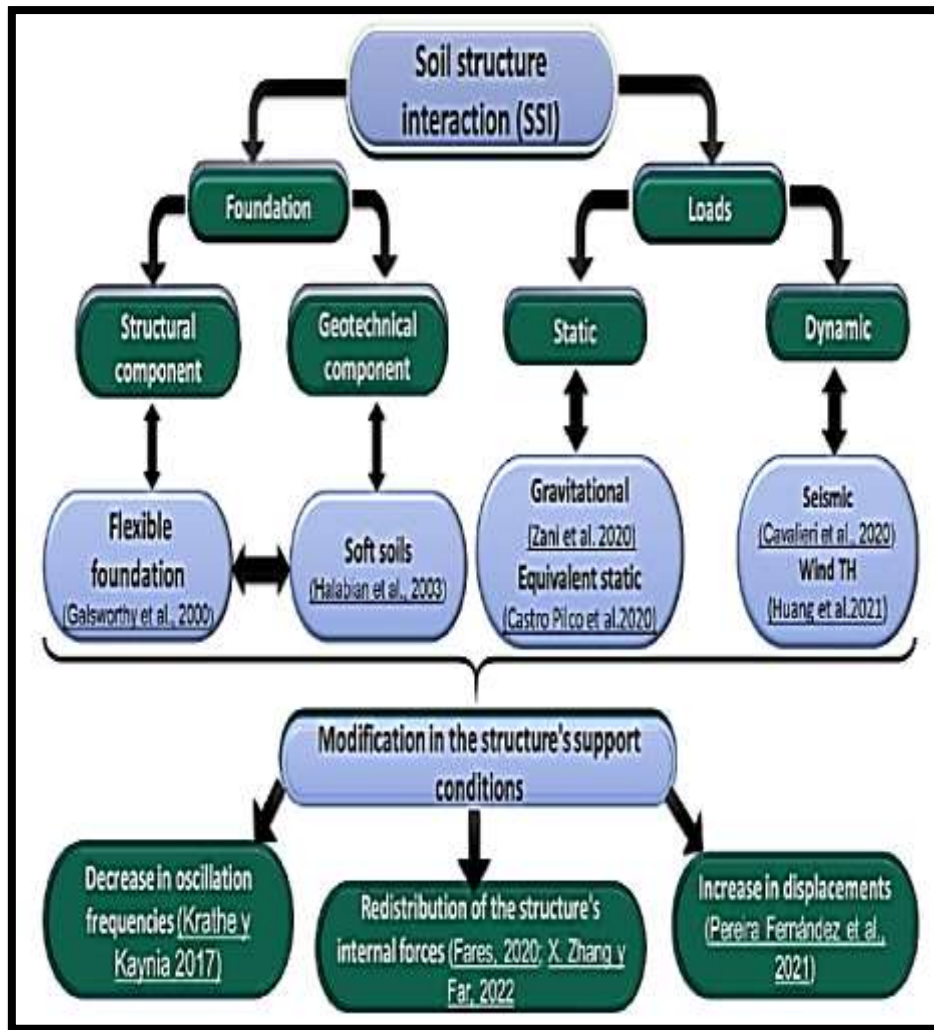


FIGURE 1. 1 Factors and consequences of soil structure interaction

(Source: secondary data taken from https://researchgate.net/publication/373833651_SOIL_STRUCTURE_INTERACTION_GENERALITIES)

1. Soil Properties

The relationship between soil and buildings is greatly affected by the soil's features. For evaluating how structures will respond to dynamic loads.

Soil Type

The type of soil plays a fundamental role in determining its mechanical behaviour under loading conditions.

The three main types of soils are as follows: clay, silt, and sand. Each type exhibits distinct physical and mechanical properties.

- **Clay:** Clay soils are fine-grained and possess cohesive properties. Their behaviour is highly sensitive to moisture content, and they exhibit plasticity, which can lead to significant deformations under loading. The consolidation of clay under applied loads can affect the settlement of structures, making it imperative to consider these effects in design.
- **Silt:** Silt has properties between clay and sand, with moderate plasticity and less cohesion. Silty soils may experience rapid changes in strength when subjected to moisture, making them susceptible to liquefaction during seismic events. The transition from saturated to unsaturated conditions can also influence the overall stability of structures.
- **Sand:** Sand is coarse-grained, non-cohesive, and tends to have high permeability. Its behaviour is characterized by the angle of internal friction, which is critical in determining its load-bearing capacity. During seismic loading, loose sandy soils may experience liquefaction, causing significant settlement and lateral spreading of structures. Conversely, dense sands can provide substantial support but may also generate higher lateral forces during an earthquake.

Soil Stiffness and Strength

The stiffness and strength of the soil significantly influence the soil-structure interaction behaviour. Soil stiffness, often represented by the modulus of elasticity, affects how much a structure will settle under loading.

- **Modulus of Elasticity:** A higher modulus indicates stiffer soil, which leads to less deformation under load. Conversely, low-stiffness soils may exhibit large displacements, affecting the overall performance of the structure.
- **Shear Strength:** The shear strength of soil is critical in resisting lateral forces. It is primarily influenced by effective stress, cohesion, and internal friction angle. Shear strength governs the failure mechanisms of soils, and its variability under different conditions can significantly impact the stability of structures during seismic events.

Soil Density and Compaction

Soil density, which is a function of moisture content and degree of compaction, influences SSI.

Compacted soils typically exhibit increased load-bearing capacity and reduced compressibility.

- **Loose vs. Dense Soils:** Loose soils can lead to increased settlement under loading, while dense soils provide enhanced resistance to shear and lateral loads. The method of compaction, such as mechanical compaction or natural processes, can further modify soil properties and impact SSI.

2. Structural Properties

The design and material properties of structures also play a crucial role in SSI.

Understanding these factors is essential for developing effective engineering solutions to enhance seismic resilience.

Structural Flexibility

The flexibility of a structure directly influences its dynamic response during seismic events. Flexible structures may be able to dissipate energy more effectively, but they can also experience greater displacements and accelerations.

- **Natural Frequency:** The natural frequency of a structure, influenced by its stiffness and mass, determines how it responds to seismic waves. Structures with low natural frequencies may resonate with ground motions, leading to amplified responses.
- **Damping:** Damping mechanisms, whether inherent in the materials or introduced through design (e.g., dampers, base isolation), can help control the response of structures. Damping reduces vibrations and enhances energy dissipation, ultimately affecting the SSI.

Foundation Type

The type of foundation selected for a structure has a significant impact on SSI.

Foundations can be broadly classified into shallow and deep foundations, each with distinct characteristics and suitability for different soil conditions.

- **Shallow Foundations:** Shallow foundations, such as spread footings and mat foundations, are placed near the ground surface. They rely on the bearing capacity of near-surface soils and are generally suitable for stable soils. On the other hand, foundations that are too shallow might cause instability and substantial differential settlement in regions with poor soil.
- **Deep Foundations:** Piles and caissons, which have deep foundations, carry loads to bedrock or deeper, more solid soil layers. Structures in seismically active regions may benefit from their reduced settling and increased resistance to lateral stresses. The interaction between piles and surrounding soil during seismic events is critical for assessing overall performance.

Material Properties

The selection of building materials has a major impacts the performance of structures under dynamic loads.

- **Concrete and Steel:** The strength, ductility, and stiffness of materials influence how a structure will behave during an earthquake. High-strength concrete and ductile steel can provide greater energy absorption and resilience against seismic forces.
- **Material Deterioration:** Over time, materials may experience deterioration due to environmental factors, such as moisture and temperature fluctuations. Understanding the potential impact of material aging on SSI is critical for long-term structural performance.

3. Environmental Conditions

The environmental context in which a structure is built also influences SSI. Factors such as groundwater conditions, temperature, and climate can have significant effects on soil behaviour and, consequently, on the interaction between soil and structures.

Groundwater Conditions

Soil behaviour is greatly affected by groundwater. Soil cohesiveness is influenced by the presence of water, friction, and effective stress, all of which influence SSI.

- **Saturation and Pore Pressure:** Soils that are saturated have lower shear strengths because their effective stress is lower. In soils that are vulnerable to liquefaction, an increase in pore water pressure during a seismic event might cause the soil to collapse, resulting in catastrophic structural failures.
- **Groundwater Fluctuations:** Changes in groundwater levels due to seasonal variations or human activities can alter soil properties over time, impacting stability and load-bearing capacity.

Temperature Effects

Temperature fluctuations can influence soil behaviour, particularly in expansive soils, which swell when wet and shrink when dry.

- **Expansive Soils:** These soils can exert significant pressure on foundations, leading to cracking and other structural issues. The management of moisture content in expansive soils is critical to minimizing SSI problems.
- **Thermal Effects on Materials:** Temperature changes can affect the properties of construction materials, altering their stiffness and strength. For instance, concrete expands when heated, potentially leading to differential movement between soil and structure.

4. Dynamic Loading Effects

Dynamic loading, particularly from seismic events, significantly influences SSI. The nature and characteristics of seismic ground motion can lead to complex interactions between soil and structures.

Characteristics of Seismic Waves

Seismic waves may be broadly classified into three types: Surface waves, P-waves, and S-waves, each of which interacts with soil and structures differently.

- **P-Waves (Primary Waves):** The earth is the quickest medium for these compressional waves. On most buildings, their impacts are milder than those of S-waves but can still induce ground shaking and affect SSI.
- **S-Waves (Secondary Waves):** S-waves travel slower than P-waves and cause shear movements in the ground. They can induce significant stresses in structures, particularly in soft soils, leading to amplified responses and potential failure.
- **Surface Waves:** Most damage is caused by surface waves, which move along the surface of the earth. They induce complex motion patterns that can lead to significant displacements and forces acting on structures.

Ground Motion Parameters

Key parameters of ground motion, such as peak ground acceleration (PGA), frequency content, and duration of shaking, are critical in assessing SSI.

- **Peak Ground Acceleration (PGA):** PGA is a measure of the maximum acceleration experienced by the ground during an earthquake. Higher PGA values can lead to greater demands on structures, necessitating careful consideration of SSI in design.
- **Frequency Content:** The frequency content of seismic waves affects how structures respond. Structures with natural frequencies similar to the predominant frequencies of ground motion may experience resonance, amplifying structural response and leading to potential failure.
- **Duration of Shaking:** The duration of ground shaking influences the energy imparted to structures. Prolonged shaking can lead to cumulative damage and increased displacements, emphasizing the importance of considering SSI in earthquake-resistant design.

Understanding the factors influencing soil-structure interaction is critical for enhancing the resilience of structures, particularly in seismic-prone regions. Soil properties, structural characteristics, environmental conditions, and dynamic loading effects all play vital roles in determining how structures will respond to various loading scenarios. By integrating knowledge of these factors into design and assessment processes,

engineers can develop more effective strategies for mitigating the risks associated with soil-structure interaction, ultimately contributing to safer and more resilient built environments.

1.5 EARTHQUAKE PREPAREDNESS

Earthquakes represent one of the most formidable natural hazards, capable of causing significant loss of life, injury, and destruction of property. The unpredictability of seismic events necessitates a proactive approach to preparedness that encompasses a multifaceted strategy involving risk assessment, public education, infrastructure resilience, emergency response planning, and community engagement. This preparedness is vital for minimizing the impacts of earthquakes on communities, particularly in regions that are seismically active. With rising urbanization, many densely populated areas, including major cities, are at increased risk, making effective preparedness strategies essential for safeguarding lives and infrastructure. [8]

Risk Assessment and Hazard Mapping

Effective earthquake preparedness begins with a comprehensive understanding of the risks involved. Risk assessment is a systematic process that involves identifying and analysing the potential hazards, vulnerabilities, and consequences associated with earthquakes in a given region. This process typically includes the development of hazard maps that illustrate the seismic risks posed by local geological conditions, fault lines, and historical seismic activity.

These maps are crucial for informing urban planning, building codes, and community safety measures. By analysing historical earthquake data, scientists can identify patterns and predict potential future events, allowing communities to understand their risk levels and prepare accordingly. For instance, regions with a history of significant seismic activity, such as California in the United States or Japan, often implement stringent building regulations based on risk assessments to enhance earthquake resilience.

Public Education and Awareness

Public education plays a critical role in earthquake preparedness, as it empowers individuals and communities to take proactive measures to protect themselves. Education initiatives should focus on disseminating information about the nature of

earthquakes, potential risks, and appropriate safety actions before, during, and after an earthquake.

Programs can include school-based education, community workshops, and public service campaigns to raise awareness about earthquake preparedness. Such initiatives teach individuals how to create emergency kits, develop family communication plans, and identify safe locations in their homes and communities.

Furthermore, drills and simulations can reinforce knowledge and preparedness behaviours, helping to ensure that individuals know how to react quickly and effectively during an earthquake.

Infrastructure Resilience and Building Codes

Buildings, bridges, roadways, and other infrastructure must be engineered to resist seismic pressures in order to minimize damage and save inhabitants; this is an essential aspect of earthquake readiness. This requires stringent building codes that incorporate seismic design principles, ensuring that structures can absorb and dissipate the energy released during an earthquake.

Countries with high seismic risks, such as Japan and Chile, are more resilient to earthquakes because they used cutting-edge engineering techniques and materials. Base isolators, which enable structures to shift apart from the ground, are one such example significantly reduces seismic forces on structures. Additionally, retrofitting older buildings to meet modern seismic standards is vital for improving resilience in urban areas where many structures may not have been built with earthquake preparedness in mind.

Emergency Response Planning

Emergency response planning is a critical aspect of earthquake preparedness that focuses on how communities can effectively respond to seismic events when they occur. This planning involves coordinating efforts among various stakeholders, including government agencies, emergency services, and non-governmental organizations.

A well-structured emergency response plan outlines the roles and responsibilities of different entities, establishes communication protocols, and identifies resources needed for effective response and recovery. The plan should also account for the specific needs of vulnerable populations, such as the elderly, disabled, and those living in poverty.

Training and exercises are essential for ensuring that responders are familiar with the plan and can act swiftly and effectively.

Regular drills that simulate earthquake scenarios can help improve coordination among responders and identify areas for improvement in emergency response protocols.

Community Engagement and Resilience Building

Community engagement is vital for fostering a culture of preparedness and resilience. Engaging communities in earthquake preparedness initiatives ensures that residents are aware of risks and actively participate in developing strategies to enhance safety.

Community-based programs can focus on building local capacity to respond to earthquakes, encouraging neighbours to work together to develop emergency plans and support systems. This can include forming neighbourhood groups that share information, resources, and skills related to earthquake preparedness. Such initiatives not only enhance community resilience but also strengthen social ties, which can be critical in the aftermath of a disaster.

Furthermore, integrating local knowledge and cultural practices into preparedness efforts can enhance their effectiveness. For instance, communities may have traditional methods of building or specific materials that are more resilient to seismic activity. Understanding and incorporating these local practices can lead to more culturally relevant and accepted preparedness strategies.

International Collaboration and Best Practices

Earthquake preparedness is a global challenge, and international collaboration is essential for sharing knowledge, resources, and best practices. Countries prone to seismic activity can learn from one another's experiences and adopt successful strategies for risk reduction and resilience building.

For instance, after the devastating 2010 earthquake in Haiti, which highlighted significant gaps in preparedness and response, many countries and organizations worked together to improve Haiti's disaster management capacity. This collaboration included developing earthquake-resistant building standards, enhancing early warning systems, and establishing community preparedness programs.

In order to promote earthquake preparation on a worldwide scale, international organizations like the IFRC and the United Nations Office for Disaster Risk Reduction (UNDRR) are crucial. These organizations facilitate knowledge exchange, provide technical assistance, and support capacity-building initiatives in vulnerable regions. [9]

Technology and Innovation in Preparedness

Advancements in technology are increasingly contributing to earthquake preparedness. Modern technologies can enhance risk assessment, improve communication during emergencies, and facilitate rapid response efforts.

- **Seismic Monitoring and Early Warning Systems:** Advanced seismic monitoring networks provide real-time data on earthquakes, allowing for early warning systems to be established. These systems can alert individuals and community's seconds to minutes before shaking begins, providing critical time for people to take cover and automated systems to trigger emergency protocols.
- **Mobile Applications:** The rise of mobile technology has led to the development of applications that provide users with real-time earthquake information, safety tips, and emergency contacts. These apps can facilitate communication and coordination among community members during and after an earthquake.
- **Remote Sensing and Data Analytics:** Remote sensing technologies can be used to assess damage in the aftermath of an earthquake, providing valuable data for recovery efforts. Similarly, data analytics can help identify patterns and trends in seismic activity, aiding in more accurate risk assessments and preparedness planning.

Challenges to Earthquake Preparedness

Despite the progress made in earthquake preparedness, several challenges persist. One significant challenge is the underestimation of seismic risk, particularly in regions that have not experienced significant earthquakes in recent history. This complacency can lead to inadequate preparedness measures and a false sense of security among residents.

Moreover, funding for earthquake preparedness initiatives can be limited, particularly in low-income communities or developing countries. Governments may prioritize other pressing needs, leading to gaps in infrastructure resilience, emergency response planning, and public education efforts.

Additionally, the rapid pace of urbanization in many regions exacerbates vulnerabilities to earthquakes. There is a higher probability of devastating earthquake damage in densely populated metropolitan areas due to infrastructure that is either old or does not comply with current seismic regulations.

Earthquake preparedness is a multifaceted endeavour that requires a coordinated effort among various stakeholders, including government agencies, communities, and international organizations. By prioritizing risk assessment, public education, infrastructure resilience, emergency response planning, community engagement, and technological innovation, societies can enhance their ability to withstand and recover from seismic events.

While challenges remain, the continued investment in preparedness strategies is essential for reducing the impacts of earthquakes on lives and property. As the global population grows and urban areas expand, the importance of effective earthquake preparedness will only continue to rise, that this unpredictable and destructive natural disaster need preventative actions to safeguard populations.[10]

1.6 STATEMENT OF AIM

The study investigates soil-structure interaction (SSI) with the goal of enhancing earthquake preparedness in Hyderabad, Telangana, a region categorized as moderately seismic.

While Hyderabad has not experienced large-scale seismic activity historically, increasing urbanization and infrastructure development necessitate comprehensive research into its seismic vulnerability. SSI, the interaction between soil properties and

structural response during seismic events, plays a crucial role in determining the overall resilience of buildings. Traditional structural design often overlooks the influence of local soil conditions, which can amplify or dampen seismic forces. This study critically examines the varying soil profiles across Hyderabad, ranging from rocky outcrops to softer alluvial soils, and their potential impacts on building performance during an earthquake.

Therefore, the title of our study is, “A *CRITICAL STUDY INVESTIGATING SOIL-STRUCTURE INTERACTION FOR ENHANCED EARTHQUAKE PREPAREDNESS IN HYDERABAD, TELANGANA*”.

1.7 NEED AND SCOPE OF THE STUDY

Need of the study

Justification for this investigation on soil-structure interaction (SSI) for enhanced earthquake preparedness in Hyderabad, Telangana, stems from the region's growing urbanization and moderate seismic risk. While Hyderabad is situated in a seismically stable zone, the city's rapid infrastructure expansion and population growth increase the potential consequences of even minor to moderate earthquakes. Current building designs in Hyderabad often adhere to generalized national codes that do not fully consider local soil conditions and their interaction with structural foundations during seismic events.

Understanding SSI is crucial because the soil properties beneath structures significantly influence how buildings respond to ground shaking. Certain soils may amplify seismic waves, while others might dampen them, directly affecting the safety and stability of structures.

This gap in region-specific earthquake preparedness exposes Hyderabad's infrastructure to unforeseen vulnerabilities. By conducting a detailed investigation into the local soil conditions and their interaction with building foundations, the present study seeks to provide data-driven insights that enhance structural design practices, making them more resilient to seismic forces.

The findings are essential for updating local building codes, guiding urban planning decisions, and ultimately ensuring the safety of Hyderabad's evolving urban landscape in the face of potential seismic threats.

Scope of the study

The scope of this study on soil-structure interaction (SSI) for enhanced earthquake preparedness in Hyderabad, Telangana, involves a comprehensive investigation into the region's soil characteristics and their impact on structural behaviour during seismic events.

The research analyses different types of soils found across Hyderabad, including hard rock, alluvial soils, and intermediate layers, to assess their dynamic properties and seismic wave amplification potential.

Advanced numerical modelling and field investigations, such as geotechnical surveys, are used to simulate various seismic scenarios and how buildings of different types and heights react under these conditions.

The study also evaluates the performance of existing structures, focusing on both residential and commercial buildings, to identify any vulnerability related to soil conditions. By integrating soil behaviour with structural dynamics, the research proposes recommendations for region-specific seismic design guidelines and improved construction practices.

The scope includes creating a framework for policymakers and engineers to revise building codes and urban planning strategies in Hyderabad.

The study provides essential data that can be used in on-going risk assessments, disaster preparedness plans, and mitigation measures to enhance the resilience of Hyderabad's infrastructure against potential earthquakes, thereby safeguarding lives and property in the region.

1.8 OBJECTIVES OF THE STUDY

1. To investigate soil-structure interaction for enhanced earthquake preparedness

2. To develop an enhanced numerical soil-structure model as per the proposed approach using Finite Element program developed for SSI analysis.
3. To conduct numerical parametric studies to understand the influence of each parameter on SSI effect.
4. To develop a simplified analysis procedure for dynamic soil structure interaction analysis
5. To perform Validation of the soil-structure model with existing experimental investigations

1.9 DEFINITIONS OF THE KY WORDS

Soil-Structure Interaction (SSI):

Soil-structure interaction refers to the effects that soil and structural elements exert on each other during loading conditions, such as earthquakes.

It emphasizes how the dirt around the foundation affects it.

Earthquake Preparedness:

Earthquake preparedness involves the strategies, plans, and measures taken to minimize the risks and impacts of earthquakes on communities, including designing structures to withstand seismic forces and educating the public about safety practices.

Preparedness:

Preparedness refers to the state of being ready to deal with an emergency or disaster.

It involves planning, training, and equipping individuals and communities to respond effectively to potential hazards.

1.10 LIMITATIONS OF THE STUDY

Geographical Scope:

- The study is confined to the Hyderabad region, which may limit the generalizability of the findings to other geographical areas with different soil types, seismic activity, and structural characteristics.

Soil Sampling and Characterization:

- Soil samples may not represent the entire range of soil conditions in the study area. Variability in soil properties, such as compaction, moisture content, and layering, may not be fully captured, leading to incomplete assessments of soil behaviour during seismic events.

Seismic Data Availability:

- The study relies on available seismic data from historical events, which may be limited in terms of frequency, magnitude, or type of earthquakes. This can hinder the robustness of predictions regarding soil-structure interaction during future seismic events.

Modelling Assumptions:

- The study utilizes specific modelling assumptions regarding soil behaviour (e.g., linear vs. nonlinear response), which may not accurately reflect real-world conditions during an earthquake. Simplifications in models may lead to an underestimation or overestimation of risks.

Structural Variability:

- The types of structures analysed in the study may not encompass all potential building designs in Hyderabad. Different materials, construction methods, and architectural styles may influence how structures respond to seismic forces, limiting the applicability of the findings.

Limitations of Laboratory Testing:

- Laboratory tests conducted on soil samples may not replicate in-situ conditions accurately, potentially leading to discrepancies in observed behaviour during actual seismic events.

Time Constraints:

- The study is conducted within a limited timeframe, which may restrict the depth of analysis and the number of samples collected. This can impact the comprehensiveness of the study's conclusions.

Financial Resources:

- Budgetary constraints may limit the scope of field tests, laboratory analyses, and the use of advanced technology or equipment for more thorough investigation of soil-structure interactions.

Human and Technical Resources:

- The expertise of the research team and the availability of skilled personnel can affect the quality of data collection and analysis. Limitations in experience or training may lead to potential errors or biases in the study.

External Factors:

- Factors such as urban development, changes in land use, and climate change can impact soil conditions and earthquake risks over time, making it challenging to provide long-term predictions based on the current study.

Regulatory and Policy Constraints:

- The study may be influenced by local regulations and policies regarding construction practices, which may not align with the findings. This can impact the implementation of recommendations for enhanced earthquake preparedness.

Stakeholder Engagement:

- Limited engagement with local stakeholders, including government agencies, urban planners, and communities, may restrict the study's ability to incorporate local knowledge and priorities, which are crucial for practical application of the research findings.

1.11 PLAN OF WORK

Chapter 1: Introduction

This chapter introduces the study by providing an overview of the research topic, its significance, and the rationale behind choosing it. It presents the problem statement and sets the stage for understanding the key objectives of the research. The introduction typically outlines the scope of the study, its expected contributions, and the key research questions or hypotheses that guide the investigation. Additionally, it provides context by briefly describing the current knowledge in the field and the gaps that this study aims to address.

Chapter 2: Review of Literature

The review of literature examines previous research and scholarly work relevant to the research topic. This chapter systematically explores existing studies, theories, models, and findings that relate to the key aspects of the study. By reviewing related literature, the chapter helps in identifying gaps in the current research, building a theoretical framework, and positioning the study within the existing body of knowledge. This comprehensive review not only highlights previous work but also underscores the contribution that the present study intends to make.

Chapter 3: Materials and Methods

This chapter details the methodology employed in the study, including the materials, tools, and techniques used for data collection and analysis. It provides a clear description of the research design, population or sample, data collection methods (such as surveys, experiments, or interviews), and the statistical or analytical tools applied. The chapter ensures that the study's process is transparent and replicable; giving readers a clear understanding of how the research was conducted. Any limitations of the chosen methodology are also addressed in this section.

Chapter 4: Results and Discussion

The results and discussion chapter presents the key findings of the study, followed by an analysis and interpretation of the data. Results are typically displayed through tables, charts, or graphs, accompanied by descriptive explanations. The discussion part links these findings back to the research questions or hypotheses, comparing them with

previous studies to highlight similarities, differences, or novel insights. This chapter also explores the implications of the results, the significance of the findings, and any patterns or trends observed.

Chapter 5: Conclusion, Recommendations, and Future Scope

The final chapter summarizes the main findings of the study, drawing overall conclusions based on the results. This chapter also offers recommendations for practical applications, policy changes, or further research that may build on the current study. The future scope section highlights areas where additional investigation is necessary, indicating how future research can extend or refine the current study's findings. The chapter concludes by reflecting on the contribution of the research and its potential long-term impact.

CHAPTER 2

REVIEW OF LITERATURE

Bdaiwi, Bassam et al., (2024) [1] The purpose of this research is to examine the reaction of a reinforced concrete structure with sloping supporting leads in the foundations using finite element analysis. The seismic performance of several reinforced concrete buildings was examined in relation to three variables: the degree of foundation inclination (0° , 10° , 20° , and 40°), the number of stories (8, 10, 12, 16, and 20 stories), and the span length (4, 5, and 6 meters). The time history analysis method, influenced by the EL-Centro N-S 1940 earthquake acceleration data, was applied to all buildings using the SAP2000 program. Based on the results, when the building's foundation inclination increased from 0° to 20° , the base shear, time period, and roof displacement values decreased by 23%, 33%, and 55%, respectively. On the other hand, when the number of stories increased by 50%, these values increased by 68%, 53.28%, and 137.6%, respectively. Buildings experience more lateral displacements and base shear as their height increases. The RC building's decreased stiffness and increased displacements at the building's tips cause the duration to rise.

Liu, Peng & Ge, Qi. (2024) [2] this paper utilized MATLAB and ANSYS software to build a numerical model of the structure system in a soil-structure interaction. The numerical simulation results were used to assess the efficacy and accuracy of the model, which is a simplified nonlinear calculation model for soil-structure interaction. At the same time, a set of critical parameters was determined based on their impact on the simplified model. These parameters include input seismic waves, superstructure size and number of stories, site soil parameters, equivalent soil area, and free field area. Using the validated simplified model as a starting point, a number of parametric experiments were conducted by adjusting the chosen critical parameters. The results showed that the streamline calculation model was very efficient and accurate, and it could capture the nonlinear reaction of the structural system. The area of dynamic response analysis of superstructures, taking soil-structure interaction into account, can benefit from it.

Lagaguine, Maroua & Sbartaï, Badreddine. (2024) [3] an in-depth analysis of soil-structure interaction phenomena is presented in this research, which also delves into the

dynamic reaction of structures during earthquakes. Among the many parameters examined are the characteristics of the structure and the velocity of the ground shear wave. The impact of the soil impedance function shape on the system's structural response as a result of independent and dependent frequency scenarios including dashpots and springs. The ground and the superstructure were both represented by linear models. The research in this paper makes use of the substructure method in two distinct ways. An analytical formulation based on the soil-structure system's dynamic equilibrium, as approximated by an analog model with three degrees of freedom, forms the first. The second one is an ABAQUS-based numerical study that uses 2D finite element modeling. All of the SSI models that were evaluated used an SDOF method to depict the superstructure. The main factors impacting the interaction between soil and structure are identified and their impacts are detailed in this investigation. We compare the two sets of findings for the two types of impedance functions that were considered here (frequency-independent and frequency-dependent). The findings demonstrate that buildings are sensitive to soil-structure interaction and draw attention to the many variables and their impacts, including soil and structure parameters, in particular the shear wave velocity, building height, and building mass. All of the fundamental characteristics and the coupled system's response are simultaneously affected by the foundation anchoring height and the excitation frequency. However, evidence suggests that the impedance function forms are crucial for reliable assessment of structure behavior under seismic loading. This means that the dynamic qualities of the building and the soil need to be considered when assessing the impact of SSI on the reaction of the structure.

Vargas-Alzate, Yeudy et al., (2024) [4] the dynamic response of nuclear structures to ground vibrations caused by earthquakes must take soil-structure interaction into account. Nevertheless, because to the high computational expense caused by the huge number of components required, time-domain seismic response modeling utilizing FEM-based models to depict soil volume is not feasible. Because of how quickly and explicitly the system's dynamic response can be solved using 1-D models, they are widely used. However, 3D FEM-based models are occasionally required because of the significance of nuclear structures. Furthermore, with respect to probabilistic assessments of a site's seismic hazard, it is typically required that the model's seismic reaction adhere to the spectrum ordinates of the input action at the surface level. To

achieve this, it is necessary to create accelerograms that act directly on the bedrock. There will always be a little discrepancy between the target free field motion and the response computed at the surface level when these signals are produced by DE convolution using the 1D model and then applied to the 3D one. This variation can be explained by a number of factors, one of which is the 3D model's Poisson effect. So, to get the FEM model's dynamic response to match the target spectrum, the input signal must be adjusted. An improved transfer function derived from the 1D and 3D models is presented in this paper as a novel way to accomplish this aim. A particular soil profile and two earthquake scenarios have served as the basis for this benchmark. This method adequately addresses the issue under investigation, according to the results.

Abdul Khaliq, Mohammed et al., (2024) [5] several devastating earthquakes have rocked various parts of the world in recent months, including Turkey, Syria, and Morocco. As a result, scientists, engineers, and even the general public began to focus on the area of seismic activity. When thinking about this area, the two most important things to keep in mind are soil-structure interaction (SSI) and structure-soil-structure interaction (SSSI). The relationship between a building's foundation, soil, and structure is known as SSI, and the connection between neighboring buildings and soil is known as SSSI. In the past, these factors were disregarded in the numerical and analytical methodologies used to assess the structures' seismic reaction (i.e., the influence of soil was not considered), which resulted in catastrophic expenses, such as property and life loss. With the goal of providing a comprehensive and By outlining the SSSI behavior of adjacent buildings, this article hopes to make a contribution to the field of seismic analysis and design by providing a helpful knowledge of several crucial aspects that have so far been overlooked in previous studies in order to reduce the potential risks of earthquakes, especially strong ones. Considering the influence of soil media, a series of seismic exams will be conducted using a shaking table technique to achieve this purpose. In these experiments, two nearby steel buildings set on sand will have their dynamic responses examined in relation to the influence of orientation and distance. The orientations chosen here fall into one of two categories: either perpendicular to the earthquake wave's direction or parallel to it. The three distance tests that make up each orientation are close, medium, and far. This study makes use of two new three-story small-scale multi-degrees of freedom steel models. The results of the tests showed that the SSSI behavior of nearby buildings is significantly affected by the diversity of

building orientations with respect to distance. It is clear that the dynamic reactions were most affected at long distances by an orientation perpendicular to the earthquake wave's path, whereas the influence was greatest at medium distances by a parallel orientation.

Thakur, Bhairav & Desai, Atul. (2024) [6] Seismic performance of nuclear containment structures on layered fine sand to hard rock is investigated in this study. To better understand the profound effects of earthquakes on soil-structure interactions, this study delves into the complex dynamics of nonlinear soil behavior. This investigation uses models like the heterogeneous mech mohr model and the intrinsic nonlinearity of the soil and confinement structure under different situations. The FLAC 3D program is used to create these models, which have different characteristics. Particularly noteworthy are the following soil models: 83.17% for heterogeneous soils, 85.42% for silty clayey soils, and 25.93% for dense sand soils. It is worth noting that the Hard Rock Model has a vertical stress σ_{zz} of 0.24 and the Silty Clayey Model of 0.42; hence, the Silty Clayey Model has a lower vertical stress σ_{zz} . Depending on the loading conditions, the research indicated that different soil models performed better. This has led to a better understanding of how to apply these models to accurate SSI modeling, which is great for future research and has significant real-world consequences for geotechnical earthquake engineering, especially when it comes to ensuring the security of nuclear facilities in seismically active regions.

Ebadi-Jamkhaneh, Mehdi. (2024) [7] Focusing on the impact of soil-structure interaction, this study examines the seismic response of two 20-story neighboring structures constructed with reinforced concrete and use various techniques for lateral load bearing. Nine earthquake motions, four soil types, and two structural designs were all merged in 72 numerical models. The shear wall structure proved to be more seismically resilient than the bare frame structure, according to the analytical fragility curves. For each level of damage, shear walls boosted the capacity to withstand earthquakes by as much as 56%. The impact of soil characteristics was studied through soil behavior analysis. The reaction of the system was influenced by the ductility of the soil, as seen in the bigger deformations and settlements observed in soft soil as opposed to stiffer soil. Further evaluation of possible hammering between buildings was also part of the investigation. Pounding risk was greatly impacted by the relationship between structural stiffness and soil deformability. Damage to RC components

occurred because the supplied spacing (350 mm) was not enough to prevent pounding under different earthquake scenarios and soil types. The importance of taking soil characteristics and structural systems into account in seismic assessments is highlighted by these results.

Dawoud, Waleed et al., (2024) [8] When designing a high-rise for seismic activity, it is important to account for the following factors: base shear, inter-story drift, and internal pressures acting on structural parts. There are a lot of drawbacks and inconsistencies when dealing with building foundations as a fixed support. Given that it assesses the combined reaction of the building, its base, and the subsurface lithology to a given ground motion, soil-structure interaction (SSI) provides a more precise and realistic model of seismic response of structures. A three-dimensional reinforced concrete high-rise building atop a piled-raft foundation is the subject of the present investigation, which takes a direct approach to soil-structure interaction analysis. The seismic reactions of the structure were evaluated using Plaxis 3D software and fully nonlinear numerical analysis with the finite element method. Seismic performance of tall buildings is studied in relation to base flexibility index (SSI) and increasing pile embedment depths.

Krishnan, Ragi & Sivakumar, Vidhya. (2024) [9] A building's impact on the ground or soil is at the heart of the SSI problem. The tensions between the structure and the soil are affected by the nature of the structure and the soil, which in turn impacts the movement of the structure and the soil beneath it. This is a major problem, especially in areas prone to earthquakes. An intriguing component that can increase or decrease structural damage or movement is the interplay between soil and structure. Deformable soil is more likely to cause static settlement and less likely to cause seismic damage to structures than firm soil. Soil liquefaction is an issue for soft ground in seismic zones, which the engineer must consider. Engineering practice rarely takes into account the lack of adequate research on the dynamic reactivity of a reinforced concrete wall-frame dual structure to SSI. Uncertainty surrounds the seismic performance of structures when SSI effects are considered, and misunderstandings concerning the SSI concept, particularly in relation to RC wall-frame dual systems, persist. The frequency response and dynamic properties of the framework are greatly affected by the soil beneath the

foundations that is studied in the simulation. Thus, this research will examine the entire significance of SSI in terms of structural features and sustainability.

Das, Sukanta & Maheshwari, B.K.. (2024) [10] this article delves into the impact of hilly terrain, non-linear soil, and soil-structure interaction (SSI) in regions that have seen significant damage to hill buildings from previous earthquakes. For three different earthquake time histories, two-dimensional finite element analysis is used to model the seismic response of hillside buildings located at the slopes' centers. The effect of topographic amplification and SSI on ground motion frequency and site condition is studied. Near the crest, the current analysis reveals a notable amplified ground motion. As the slope angle and peak ground acceleration increase, the Seismic-Slope Topographic Amplification Factor (S-STAF), which indicates the effect of slope on the seismic response, increases as well. Nevertheless, considering that the soil is not linear resulted in an increase of up to 30% in S-STAF. We also look at two kinds of buildings—(i) step back and (ii) step back and setback—to see how structural irregularity affects them. For two distinct slopes, the relative displacement of each story, normalized with its height, is indicated as a drift ratio. Compared to both step back and setback buildings, step back buildings have a somewhat lower inter-story drift ratio. The building greatly amplifies the seismic displacement of the slope. The effect of SSI becomes more noticeable as the slope angle increases, and it is heavily influenced by the features of the earthquake. Also examined are the features of period lengthening, seismic displacement, rocking, and stress distribution on the footings of step back buildings situated on slopes.

Claudia, Gheorghe. (2023) [11] the procedure for creating a finite element model of a building is detailed in this article. It is possible to model the seismic behavior of structures using one of two methods. Seismic behavior analysis often presupposes a fixed basis for the structures. The second approach to seismic behavior analysis and modeling is to simulate the soil beneath the building in order to account for the soil-structure interaction. In addition, the research compares the outcomes of two finite element simulations, one of which assumes a rigid basis for the construction and the other a more flexible one. When comparing the results from the flexible basis model to those from the fixed base model, it is clear that the latter produces more uniform stress distribution and higher frequencies.

Uz, Mehmet et al., (2023) [12] Seismic pounding can cause structural damage or even collapse buildings. Two neighboring asymmetric structures with distinct dynamical characteristics lying on the surface of an elastic half-space are the subject of this research. The impact response to torsional pounding between neighboring buildings under different SSI effects has been investigated in connection to the effects of the seismic analysis. The authors of this study present a method for examining the reaction of nearby structures hit by the impact, considering systems with many degrees of freedom and modal equations of motion including four different kinds of soil. The results of all computations are based on the fourth-order Runge-Kutta algorithm. What makes this study unique is that it looks at the impacts of SSI and hammering all at once, using both rigorous and approximation methodologies. Consequently, we have contrasted the outcomes of our exhaustive investigations into these two strategies' effects. When the pounding force increases, the results demonstrate that the rigorous direct integration method yields slightly different results than the approximate method for minor SSI effects. Additionally, numerical examples are used to validate the efficiency of the strategy.

Yanik, Arcan & Ulus, Yalcincan. (2023) [13] The goal of this research is to create a straightforward method for incorporating the combined effects of base isolation with soil-structure interaction (SSI) into a structure's mass, damping, and stiffness matrices using analytical means, using a sample structure as an example. Taking into account both the base-isolated structures and SSI, a spectrum analysis is also conducted. The research is conducted using dynamic simulations. Three shear frame constructions, each with its own unique set of characteristics, are taken into account in these models. Eleven distinct events with both far-fault and near-fault components comprise the strong ground motions chosen for these investigations. Furthermore, four distinct combinations of foundation and soil structure are considered. A typical structure with a stable base and SSI, as well as a seismically isolated structure with or without the SSI, make up these four examples. According to the numerical results, the base isolation system's performance may be diminished when SSI is taken into account; this effect is particularly noticeable in soils with a lower cohesiveness.

Forcellini, Davide. (2022) [14] In order to evaluate the seismic risk associated with a structure's functionality, resilience has emerged as a promising metric. Applying

isolation at the base of the structures may greatly reduce losses due to earthquakes. The impacts of soil deformability and all the interrelated consequences of soil structure interaction (SSI) must be taken into account during creation of isolation. For resilience calculations, it is important to account for factors like soil deformability, which can drastically lessen the advantage of base isolation. The purpose of this study is to examine the matter by computing the seismic resilience for various isolated configurations on various soil conditions. This value was selected as a benchmark for evaluating the isolation models on various soil conditions after numerical simulations were run to determine the durability of the different configurations.

Wani, Faisal et al., (2022) [15] both the superstructure's and the substructure's behavior in relation to the soil's characteristics and characteristics impact the structure's dynamic reaction during intense seismic occurrences. Assuming the foundation's base is entirely constrained, or in a fixed condition, is a common assumption in traditional structural design. This assumption, however, is flawed because it fails to take into account the influence of soil-structure interaction flexibility. The positive or negative impacts of soil-structure interaction (SSI) on seismic response of constructions remain unclear. Examining how SSI affects a G+10 building with multiple stories that is supported by a mat foundation is the primary goal of this article. Finite Element Method (FEM) software is used to model the building, and Winkler's (un-coupled) and pseudo-coupled techniques are used to incorporate SSI. The non-linear dynamic response of buildings with varying soil bearing capacity is studied through a case study. Using fundamental period, base shear, and tale drift, the results are shown.

Wang, Jishuai & Jun, Yang. (2022) [16] Seismic design, retrofitting, and damage assessment all rely heavily on understanding how dynamic soil-structure interaction affects the seismic demand of reinforced concrete frames. One efficient numerical model that accounts for the nonlinearities of a reinforced concrete frame and soil was created and tested against a shaking table test in order to determine how much of an impact the soil-structure interaction has on the seismic response of the structure. After that, we looked at the effects of the pile's length and diameter, the structure's span number and frequency, soil property, and the inherent uncertainty in the seismic record using extensive parametric analyses of the dynamic soil-structure interaction impact. In most cases, the base shear of a pile-supported reinforced concrete frame grows as the

pile diameter and length rise, according to the study's findings. When it comes to the soil-structure interaction effect, the span number and pile diameter can have an impact of up to 40% in certain instances, while the pile length typically has an impact of within 10%. Taking the soil-structure interaction into account can also lead to a significant rise in structural base shear, often exceeding 30%. In most instances, the frequency of the structure, its spectral characteristics, the peak acceleration of the seismic record, the soil shear wave velocity, and the number of spans and pile diameter are the most important factors determining the effect of the dynamic soil-structure interaction.

Awchat, Ganesh et al., (2022) [17] at present, structural engineers disregard soil-structure interaction (SSI) while designing structures as fixed bases. Because there is currently no process in place to incorporate the effects of SSI into seismic design guidelines, and soil modeling is notoriously difficult. The significance of taking SSI into account during earthquakes has been demonstrated by multiple researchers. This document provides an overview of SSI's seismic response, interaction effects, and the standard technique for engineers to consider SSI's influence. The examined International Seismic Codes provide a variety of solutions to SSI issues and details on how to implement them. It is critical, however, that the Indian Seismic code include specific recommendations for dealing with SSI impacts. Consequently, when faced with an SSI job, engineers from India should consult relevant literature, such as international codes.

Cayci, Bayram et al., (2021) [18] This study aims to assess the effects of soil-structure interaction (SSI) on the seismic behavior of residential structures that are of a medium or low height, taking into account both the linear and nonlinear behavioral patterns of structural elements. In order to accomplish this goal, buildings with four and seven stories, which constitute the majority of the existing building stock, were constructed. Depending on ground motion records, modeling methodologies (linear/nonlinear structural modeling and fixed-base or SSI), and soil types, the findings reveal that there are huge variances in displacement demand predictions. These variations are due to the fact that there are large changes. According to the results of this study, linear fixed-base models are very vulnerable to dynamic amplification. This is obvious from the data. As a consequence, the utilization of these may lead to inaccurate estimations of the demand for displacement. The differences in the average displacement demand estimates of the

fixed-base model and the SSI model are insignificant when the soil amplification and nonlinear modeling are taken into consideration. Moreover, the estimation of the displacement demand for soils with a higher degree of stiffness is not dependent on modeling. For the purpose of obtaining demand estimates that are satisfactory for the seismic evaluation of reinforced concrete residential buildings, this study emphasizes that linear structural modeling must use SSI or the fixed-base model. Additionally, nonlinear structural modeling must be utilized in conjunction with linear structural modeling.

Brandis, Adriana et al., (2021) [19] It is always a challenging endeavor to do numerical modeling of the soil in the context of seismic design of structures. The purpose of this study is to outline a straightforward numerical modeling approach that can be utilized for the construction of shallow-founded buildings on compliant soils. For the purpose of calibration, an existing large-scale experimental research project known as TRISEE was utilized. The dynamic sine loading was applied to the physical model, which consisted of a rigid square foundation that was put on a sand bed and connected to a rigid column. Regardless of the results from the TRISEE experiment are well-known and frequently utilized by researchers working in this area, none of the numerical calculations were carried out with the loose sand scenario in mind. In order to give an accurate representation of the soil, nonlinear link components and linear springs were utilized. The stiffness, the specified hysteresis model, and the p-y curve were found to have a significant impact on the behavior of the soil, as these three factors were determined. When the restrictions of the software are taken into consideration, numerical models provide an accurate representation of the experimental behavior. A case study on a steel frame building that contained SSI effects was carried out on the basis of the results that were acquired from the experiment. Taking into consideration the findings of this study, the authors suggest incorporating SSI effects into the design phase of the structure. This is due to the fact that these effects have undesirable consequences on the seismic behavior of the building and can result in structural elements that are not constructed properly. On the other hand, it is essential to note that certain restrictions are present as a result of the simplified modeling methodologies that were utilized for this research.

R M, Thejaswini et al., (2021) [20] The results of the previous studies showed that many non-standard structures were severely damaged by the earthquake which resulted in their failure. Furthermore, the effect of the sub soil conditions in the areas where these buildings have been founded also plays a significant role in the seismic reaction of these buildings. On the other hand, experimental research on the seismic reaction of various setback building designs that was not implemented before. Due to this, the seismic behavior of setback buildings, taking into consideration the Soil Structure Interaction (SSI), has been investigated in the current work by the utilization of both experimental and numerical investigations. There were a number of different setback designs that were taken into consideration, and the buildings were planned to be supported by pile foundations. In accordance with the provisions of the present codal framework, the irregularity index of various building configurations has been calculated. The piles that supported the structures that represented the prototype structure have been reduced in size in accordance with the laws of geometric, kinematic, and dynamic scaling. In order to test the scaled building models, the shaking table equipment is used to subject them to vibrations that are beyond the resonance frequencies. In this study, a comparison of the outcomes obtained from experimental and numerical investigations has been carried out. According to the findings of the study, it has been noticed that the storey displacements of buildings with regular layouts are greater than those of buildings with setbacks. It has also been discovered that symmetrical and asymmetrical setback buildings, both of which have different irregularity indices according to IS:1893-2016, indicate approximately the same displacements at resonant frequencies.

Viladkar, M. & Singh, Manendra. (2021) [21] Underground structures have traditionally been thought to be less susceptible to earthquakes than their above-ground counterparts. However, a number of the earthquakes that have occurred in recent times have shown that underground structures are also capable of suffering catastrophic damage, particularly when these buildings are situated in close proximity to faults that are the source of the earthquake. Due to the interaction between the tunnels and the pre-existing structures that are located above them, the design and construction of a shallow underground tunnel that is excavated in an urban environment can be quite challenging. When it comes to seismic analysis and the construction of underground structures, one of the most important factors is the selection of a ground motion that is really

representative of an earthquake. When there is a lack of earthquake data that is representative of the area in question, it becomes absolutely necessary to develop an artificial or synthetic time history that is compatible with the greatest earthquake that is anticipated to occur in that region. It is possible that, depending on the circumstances, it will be required to take into consideration components of the problem that are three-dimensional rather than relying just on something that is two-dimensional. The loss of strength that can occur in saturated soils with little cohesion can also be caused by strong ground shaking, which can ultimately lead to liquefaction. There is a possibility that liquefaction will force the ground around the tunnels to shift, which could have extremely undesirable repercussions. On the basis of response spectra compatible time histories of the 1999 Chamoli earthquake in Uttarakhand, actual three-dimensional analyses, and some liquefaction studies, an attempt has been made in this paper to discuss various analysis and design considerations of underground lifeline structures. Following that, an investigation into the aspects of stability of metro underground tunnels in Delhi city has been carried out.

Bandyopadhyay, Srijit et al., (2021) [22] The purpose of this research is to investigate the impact of the interaction between the soil and the construction of two neighboring reinforced concrete (RC) three-story buildings that are situated in the most seismically active region of India. The other building is a typical conventional RC-framed structure, whereas the other building is installed on a base isolator, which is also known as a lead rubber bearing. During 2006 and 2007, the buildings were equipped with sensors that captured their real seismic reaction. We expected a 2.6-fold reduction in frequency for the base isolated structure compared to the traditional design, and a 4-5 fold reduction in response. In contrast, the measured response of the adjacent structure showed its frequency, while the response of the base-isolated building showed that there was a contact between the structure and the earth. In this study, we use actual earthquake data to assess the results of a numerical simulation that accounts for two nearby buildings and involves substantial soil modeling. Additionally, the reaction of both buildings is investigated in conjunction with a larger earthquake that occurs in the same region and has a PGA of 0.26 g. The response acceleration of the base separated building is lowered by approximately 4.1 times the response of the conventional building. Furthermore, the floor spectrum of the roof of the base isolated structure has many peaks as a result of the nonlinear deformation of the isolator. This nonlinear

deformation results in varied effective stiffness for different displacements in the hysteretic deformation of the isolator that occurs during cyclic motion. Additionally, it has been noticed that the frequency of the base isolated building decreases as the peak ground acceleration increases.

Rama Rao, G.V. et al., (2021) [23] The Bhuj earthquake that occurred in India in 2001 was responsible for the dramatic failure of a class of reinforced concrete multi-story structures known as Open Ground Storey (OGS) buildings. These buildings were required to have a parking area available within their building plan in order to fulfill their functional requirements. As a result of the absence of brick-infilled walls at the ground level, a sudden decrease in the storey's stiffness might result in a significant increase in the seismic displacement requirement in the ground storey itself. In addition, the column-side sway mechanism is generated as a result of the presence of a soft storey somewhere between the rigid upper storey and the rigid base. This is done under the assumption that the soil support is sufficiently rigid. The purpose of this study is to investigate the impact that soil flexibility has on the level of seismic response that open ground storey buildings exhibit. Using the SAP2000 program, analytical studies on common open ground storey building models that take into consideration the soil flexibility have been carried out. Additionally, static nonlinear analysis, also known as pushover analysis, has been utilized in order to further investigate the lateral response. As described in IS 1893 (Part 1) 2016, the incorporation of variation in boundary conditions is accomplished through the simulation of three distinct soil conditions: hard, medium, and soft. Based on the findings of the current research, it has been discovered that the soil's flexibility leads to an increase in the lateral displacement and secondary forces that are connected with the P-Delta effect. In addition to this, a parametric analysis is conducted in order to investigate the impact that soil flexibility has on OGS buildings that have a variety of slenderness ratios. When trying to establish a realistic performance point for the building, it has been emphasized how important it is to take into account the impact of the dynamic relationship between the soil and the structure. In addition, a simpler approach for calculating the lateral behavior of a flexible base open ground storey building has been created. This methodology was designed for the purpose of conducting preliminary and rapid seismic assessments of a large stock of existing OGS buildings in urban parts of India. The extremely vulnerable OGS buildings that are subjected to a comprehensive assessment prior to retrofitting

can be separated using this methodology, which is particularly valuable. Validation of the suggested methodology is achieved through the use of in-depth analytical investigations conducted on open ground-level architectural structures.

Galagali, NM et al., (2021) [24] the purpose of this research is to investigate new developments in soil reinforcing techniques for earthquake-resistant foundations. The paper focuses on unique technologies that greatly improve soil stability and structural integrity during seismic events. Geosynthetic reinforcement, enhanced soil mixing technologies, micropiles, and innovative materials such as fiber-reinforced soils and nanomaterial's are all subjects of investigation in this topic. Enhanced resistance to liquefaction, increased load-bearing capacity, and decreased settlement in seismic conditions are all attributes that can be attributed to these techniques. These strategies have been shown to be effective in the actual world through the use of case studies from high-risk regions such as Japan and Greece. Quantitative evidence of their advantage over conventional approaches can be obtained through performance evaluations, which make use of shake table testing and numerical simulations. The conclusion of the research is that these technological breakthroughs have the potential to change foundation design in locations that are prone to earthquakes, particularly for high-rise buildings and important infrastructure. The incorporation of intelligent materials, the creation of environmentally friendly reinforcement techniques, and the investigation of self-healing foundation systems are some of the recommendations for investigations that will be conducted in the future. This in-depth analysis highlights the vital role that ongoing innovation in geotechnical engineering plays in strengthening the seismic resilience of the worldwide community.

Phadnis, Punashri & Karjinni, V. (2021) [25] Considering that every structure is in direct touch with the soil, the interaction between the structure, the foundation, and the soil medium underlying the foundation can significantly alter the actual behavior of the structure, which is significantly different from what is gained by focusing just on the structure. For this reason, the impacts of soil flexibility need to be taken into consideration during the seismic analysis in order to guarantee the structure's safety from seismic activity. The soil medium that is depicted as a winkler's model in accordance with AsCE/sEI 41-06. Through the incorporation of Soil-Structure Interaction (SSI) with a fixed base frame-composite shear wall system, a modal

pushover analysis is carried out, and the characteristics of the capacity curve are compared. A comparison is also made between the damage probabilities that are derived from the fragility curves of the models. When carrying out a structural design, it is often expected that the foundation will be attached to the ground. This is the case in the field of structural engineering. In order to simplify analysis and to carry out solutions for static load instances and design combinations in a timely manner, this is taken into consideration. When a building is exposed to earthquakes, the fixed-ground approach fails to capture its dynamic behavior. When the foundation soil is dense, stiff, or soft, a phenomena known as soil structure interaction (SSI) occurs. This phenomenon occurs when the reaction of the soil promotes the motion of the structure, and the motion of the structure induces the response of the soil. It is possible for the supporting soil medium to undergo deformation, which results in an overestimation of the overall stiffness of the system when utilizing the fixed base technique. In addition, the characteristics such as natural time periods, bending moments, and lateral displacements in shear walls are higher than the actual estimated values. This is because sliding and rocking are also contributing factors. 2. The effects of these characteristics might vary greatly depending on the soil profile, with loose soil being the site where they have the most significant impact. 3. The real lateral displacements that were created in the shear wall have caused higher P-delta effects on connected nearby columns, which may lead to failures in frame-shear wall systems when they are subjected to the stresses of an earthquake. The Winkler spring model was utilized by the majority of the researchers in order to theoretically represent the soil system because of its ease of use, precision, and reduced amount of time required for analysis. As a result of the crucial role that the shear wall plays in the construction of tall buildings, it is necessary to generate more precise modeling in order to mimic the interaction between the shear wall, the foundation, and the soil. For the purpose of seismic analysis of frame shear-walls systems, the pushover approach can be utilized, with the effect of SSI being taken into consideration. In spite of the fact that the results of pushover analysis differ from those of time-history analysis, the trend of the maximum story displacement, story drift, and plastic hinges distribution are all the same. 7. Steel-concrete composite shear walls are replacing conventional recycled concrete shear walls due to the significant improvement in strength, stiffness, and ductility that these composite shear walls offer. 88–100. A determination of the consequences is the purpose of the current investigation.

Guojue, Wang et al., (2021) [26] After being damaged by the Mw 7.1 Darfield earthquake that occurred on September 4, 2010, the Manchester Courts building, which was a heritage structure located in the central area of Christchurch, New Zealand, was subsequently demolished as a risk reduction effort. The plan to demolish the building was met with great opposition from heritage advocates who were of the opinion that the building had adequate residual strength to survive any aftershock earthquakes that might occur. This was due to the fact that the building was listed as a heritage building. On February 22, 2011, Christchurch was struck by a significant aftershock, which led to the debate of whether or not the removal of buildings had shown to be the appropriate technique for risk reduction. For the purpose of conducting a performance-based evaluation, finite element analysis was utilized. This allowed for the validation of the model's accuracy by utilizing the damage that was detected in the building before to its ultimate collapse. The relatively low shear wave velocity of the soil was another factor that led to the incorporation of soil-structure interaction into the research. Despite the fact that the decision to demolish a major heritage building was a catastrophe from which Christchurch will never recover, it was made with safety, sociological, economic, and psychological considerations in mind in order to safeguard the city and its residents. The results of the analysis indicate that the Manchester Courts building would have collapsed during the earthquake that occurred in Christchurch in 2011, and that the collapse of the building would have resulted in a high number of fatalities.

Kumar, Hitesh & Saha, Sandip. (2021) [27] A comprehensive computational framework for seismic analysis of liquid storage tanks that takes into account soil-structure interaction (SSI) is described here. A technique based on finite elements is utilized for the earth domain, whereas a lumped mass model is utilized for the tank. Under both near-field and far-field ground motions, the effects of SSI on the seismic performance of ground-supported and elevated liquid storage tanks are investigated. Each of these tanks has a permanent base and many bases that are physically separate from each other. It turns out that SSI has the same impact on fixed base tanks regardless of the kind of ground motion. But the kind of soil determines how effective isolation systems with different stiffness characteristics are, the ratio of tank slenderness to tank slenderness, and the forms of ground motion.

Li, Shuai et al., (2020) [28] With regard to the operational modal analysis of structures, the covariance-driven stochastic subspace identification, also known as SSI-COV, is utilized rather frequently. The SSI-COV method continues to provide a number of challenges, particularly with regard to the modal tracking, and one of these challenges is the right selection of user-defined parameters. For the purpose of modal identification of high arch dams, the purpose of this study is to investigate the impact of four user-defined parameters in SSI-COV by analyzing their effects. The SSI-COV is conducting research on two different finite element (FE) simulations of the Dagangshan dam to find its modal characteristics. This study examines the impact of four user-defined factors on dynamic property identification using the finite element model with a massless base. Additionally, suggestions for the selection of each parameter are offered. Further analysis is performed on the finite element model that acknowledges the semi-unbounded size of foundation rock in order to examine the radiation damping effect. This investigation is based on the proposals of user-defined parameters that have been proposed. It has been determined through the findings that the semi-unbounded foundation rock has a radiation damping effect that ranges from roughly 0.6% to 2.0% for the first four modes. According to the results of the ambient vibration test, the modal parameters of the Xiluodu dam, which is 285 meters in length, have been found. This demonstrates that the ideas that have been provided for selecting user-defined parameters are both effective and appropriate. In the future, the modal tracking and structural health monitoring of arch dams will be substantially aided by this work, which is very advantageous.

Tahghighi, Hossein & Mohamadi, Ali. (2020) [29] the purpose of this study was to determine whether or not soil-structure interaction (SSI) has an effect on the seismic performance and vulnerability of reinforced concrete (RC) structures. The Open Sees finite-element framework was utilized in order to develop and model a collection of RC frames that were situated on three different types of soil. In order to model the interaction between the soil and the foundation, a nonlinear Winkler-based technique was utilized. In order to evaluate the seismic behavior and fragility of reinforced concrete buildings with regard to the rigid and flexible-base assumptions, nonlinear static analysis and incremental dynamic analysis were carried out. The extraordinary significance that SSI plays in changing the fragility and performance of inflexible base structures was revealed by the numerical results. In conclusion, a straightforward

method is presented that allows for the direct acquisition of the vulnerability value for flexible-base structures through the modification of the fundamental mode spectral acceleration factor.

Liu, Shutong et al., (2020) [30] In the course of this research, the phenomenon known as soil-structure interaction (SSI) is explored while seismic loadings are being applied. The dynamic soil-structure interaction subjected to seismic loadings is first studied through shaking table experiments. Then, a comparison between the soil-structure system and the rigid foundation condition is used to study the effects of SSI. Finally, a numerical model that corresponds to the SSI tests is presented. Simulating the nonlinear behavior of soil in the finite element model requires the employment of two distinct methods: a bounding surface plasticity model and an analogous linear method. After further investigation, it has been discovered that the bounding surface plasticity models estimated results are significantly more in line with the experimental findings. In conclusion, a numerical parametric research is used to analyze the impacts of various soil types and structural features on the interaction between the soil and the structure. These results show that SSI has a major impact on lowering the structure's dynamic response. In addition, the impact of soil-structure interaction becomes increasingly apparent when the superstructure frequency approaches that of the soil. The effect of soil-structure interaction is mitigated when the soil's shear wave velocity is increased. It is essential for the goal of investigating the impact that SSI has on structural reactions and for the design of engineering projects that are realistic.

Oz, Ibrahim et al., (2020) [31] The seismic performance of existing buildings, particularly those that were built on unstable soils, has been revealed to be significantly low, according to reconnaissance surveys that were carried out following catastrophic earthquakes. Given the circumstances, it is clear that the interaction between the earth and the structure has a detrimental impact on the seismic performance of structures. These impacts were investigated by selecting forty existent structures from Turkey and constructing nonlinear models by taking into consideration fixed-base and stiff, moderate, and soft soil conditions. The buildings were selected in order to explore these effects. Existing buildings that were designed prior to the Turkish Earthquake code of 1998 were classified as old buildings, while new ones were classified as new buildings. Through the utilization of the substructure approach, various soil conditions that were

classified according to shear wave velocities were successfully reflected. The determination of inelastic deformation needs was accomplished through the utilization of nonlinear time history analysis, and twenty real acceleration records were chosen from among the most significant earthquakes. The findings have demonstrated that the interaction between the soil and the structure, particularly in situations involving soft soil, has a substantial impact on the seismic response of older buildings. The first stories had the most substantial rise in drift needs, and the results that correspond to fixed-base, stiff, and moderate cases are more similar to one another in comparison to the situations that involve soft soil. The dissemination of the findings led to the conclusion that dirt-structure interaction on the seismic performance of new structures is relatively limited in comparison to the performance of older buildings.

Mourlas, Christos et al., (2020) [32] The investigation of the nonlinear dynamic response of reinforced concrete (RC) structures is of great importance in order to gain an understanding of the behavior that is anticipated from these structures when they are subjected to dynamic loading. The significance of this becomes even more apparent when it comes to the design of new reinforced concrete structures or the evaluation of existing structures that are situated in seismically active regions. Despite the significant challenges associated with numerical instabilities and excessive computational demand, the numerical simulation of this problem through the utilization of detailed 3D modeling is still a subject that has not been thoroughly investigated. This is especially true when the soil–structure interaction (SSI) phenomenon is taken into consideration. For the purpose of providing additional insight into the SSI effect on RC structures under nonlinear dynamic loading conditions, the purpose of this work is to propose a nonlinear simulation tool that will analyze this numerically laborious subject. The purpose of this article is to describe the performance and discussion of a complete three-dimensional numerical model of full-scale RC structures that takes into consideration the SSI impact by modeling the nonlinear frame and soil domain. Dynamic loading conditions are applied to the models that have been developed, and an in-depth analysis is offered, taking into consideration the various types of structures, as well as the material qualities of soil domains and depths. The reinforced concrete structures and the soil domains are represented using eight-nodded hexahedral isoperimetric elements. The reinforcing of the concrete using steel bars is modeled using embedded beam and truss finite elements. Modeling the soil domain was accomplished through the use of

the Ramberg–Osgood constitutive law. It was demonstrated that the SSI effect has the potential to considerably increase the system's flexibility. This is accomplished by modifying the nonlinear dynamic response of the RC frames, which results in local damages that are not noticed when the fixed-base model is studied. Furthermore, it was discovered that the structures that were built on soft soil acquired higher base-shear in comparison to the fixed-base model. This is due to resonance phenomena that are coupled to the SSI effect and the imposed accelerograms.

Nguyen, Dong et al., (2020) [33] A three-dimensional nonlinear soil-structure interaction study is simulated in the time domain in order to evaluate the behavior of a nuclear reactor building under various earthquake motions. This is done in order to determine how the building would behave. Through the utilization of three distinct ground motions and four distinct soil types, the effects of earthquake frequency content and soil-structure interaction are taken into consideration. For the purpose of absorbing waves that are propagating and taking into consideration the free-field motion in the soil medium, respectively, viscous boundary and free-field column calculations are utilized. There are three different types of analyses that are performed: (i) linear analysis, (ii) nonlinear analysis with the bonded contact between the superstructure and the soil medium, and (iii) nonlinear analysis with the sliding contact between the superstructure and the soil medium. Validation of the data obtained from the time domain is accomplished through the utilization of a code in the frequency domain, and a satisfactory level of agreement is discovered between the two approaches. It is possible to make some comparisons of the responses of the nuclear reactors by modifying the qualities of the soil and the moves of the earth. After careful consideration, it has been determined that the behavior of nuclear reactor buildings under seismic loading is highly sensitive to both the interaction between the soil and the structure and the earthquake frequency content. This research also results in some novel discoveries that can be valuable for practical applications, particularly when taking into consideration the interaction between the soil and the structure, as well as the earthquake frequency content in nuclear structures.

Arboleda-Monsalve, Luis et al., (2020) [34] The purpose of this study was to analyze the seismic performance of hypothetical tall structures by employing a soil–structure interaction (SSI) numerical framework to estimate intensity measurements, engineering

demand factors, and earthquake-induced losses. Open Sees was used to develop numerical models for forty-story buildings in order to investigate their seismic performance under the following modeling and building configuration conditions: (1) a fixed-base structural model, (2) a model that included SSI effects, (3) a fixed-base model with shear walls, and (4) a model that included shear walls and took into consideration SSI effects. Initially, it was presumed that the structures were supported on subterranean conditions that were typical of the downtown area of Los Angeles. A parametric study was conducted to investigate the natural period of the soil profile. The natural period of the soil was found to be proportional to the magnitude of the building's seismic demands. In comparison to structures that did not have a shear wall system, the natural period of the building was shortened as a result of the incorporation of shear walls, and settlements were computed in reference to those buildings. A change was made to the computed seismic demands of the tall buildings when the impacts of SSI were taken into consideration in the modeling technique. This change was made in terms of maximum interstory drifts, peak story horizontal accelerations, and seismic-induced settlements. Computed median direct economic losses for the 2,475-year mean return period increased by as much as 33 percent when SSI effects were taken into consideration in the numerical studies in compared to building losses that ignored those effects.

Guerdouh, Dhahbia & Salah, Khalfallah. (2019) [35] The purpose of this work is to investigate the effects of soil qualities, seismic impact, and the interaction between frame structure and soil foundation through the framework of a numerical attempt that has been developed. Through the application of the finite element idea, the continuum of the frame, soil, and interface has been brought into model. In this technique, numerical software that is based on the direct method has been built in order to study the interaction between the soil and the structure when it is subjected to seismic loading. There is also the incorporation of the thin-layer interface element that was designed, which guarantees that the degrees of freedom between the frame elements and the soil components are incompatible. The results that were obtained led to the explanation of the following: (1) the influence of the soil-structure interaction on the seismic response of the frame structure and interface media; (2) how the superstructure and interface medium deflect over time when subjected to seismic loading; (3) how the interaction factor between soil and structure affects the seismic behavior of the interface medium

and frame structure; and (4) how the intensity of the earthquake affects the destructive seismic activity. The shear strains at the foundation-structure contact, lateral displacements at the frame's top and interface levels, are plotted and commented on.

Bybordiani, Milad & Arici, Yalin. (2019) [36] The issue of the through-soil coupling of structures has been a source of consternation for scholars working in this field for a considerable amount of time, particularly with regard to the varying performance of identical buildings that are near to one another during earthquakes. The phenomena of structure-soil-structure interaction (SSSI), which has been frequently ignored, has just come to be recognized. The potential consequences in metropolitan areas have not yet been assessed in a comprehensive manner. When considering this aspect, the objective of this work was to conduct a thorough investigation into the impacts of nearby structures interacting with one another in a two-dimensional environment. For the purpose of generating building clusters on the viscoelastic half-space, detailed finite element models of five-story, fifteen-story, and thirty-story structures were utilized. These models were constructed in a realistic manner. In order to accurately define the borders of the half-space, layers that were perfectly matched were utilized. As a result of the presence of spatially changing ground motion on the boundary of the excavated zone, the interaction between the structure and the soil medium was taken into consideration. Drift ratios and base shear quantities were used as the engineering requirement factors of interest in order to explore the impacts of the foundation material and the distance between adjacent structures on the structural behavior of the buildings that are adjacent to one another. In the beginning, the effects of SSSI were explored in the frequency domain. After that, they were quantified in the time domain by employing suites of relevant ground motions that were in accordance with the soil conditions. Finally, the results were compared with the SSI solution of a single building that was the counterpart to the experiment. According to the findings, the effects of SSSI were shown to be insignificant for low-rise structures that were identical to one another. When comparing the results obtained with the rigid base assumption, Research has shown that when SSSI is not taken into account for relatively closely spaced high-rise buildings or building clusters with a considerable stiffness difference, the real seismic demands are significantly underestimated. This held true even when contrasted with the alternative of addressing the issue based on the strict underlying assumption.

Gan et al., (2019) [37] Under earthquake excitation, a computational study is conducted to investigate the dynamic structure-soil-structure interaction (SSSI) that occurs between three nearby structures that have pile-raft foundations and are placed along the east-west direction in a viscoelastic half-space. Within the context of the structural arrangement, the direction of earthquake excitation is perpendicular to the direction of the arrangement. For the purpose of the simulation, the Davidenkov model of the soil skeleton curve is considered to be the behavior of the soil, and the viscous-spring artificial boundary is utilized. The impacts of SSSI are investigated using a battery of numerical simulations. These models account for the obvious space between buildings, building kinds, building heights, and initial natural periods of buildings. Determining the impact of SSSI requires the peak floor displacement and the peak inter-story shear force of structures are investigated. In light of these circumstances, the results demonstrate that the effects of SSSI are dramatically altered. Furthermore, the structural seismic response could be enhanced or decreased as a result of SSSI, with the primary factor being the characteristics of the structures themselves, rather than the location of the buildings. These findings are important for the research of the consequences of SSSI and the sustainable development of cities, particularly with regard to the seismic design of buildings that are densely populated around urban areas.

Bolisetti, Chandrakanth et al., (2018) [38] SSI analysis, which stands for soil-structure interaction, is a stage that is typically necessary in the process of calculating seismic demands in nuclear structures. At the moment, linear methods in the frequency domain are utilized to carry out this study. The use of such methods ought to result in accurate forecasts of reaction for low-intensity shaking; but, the appropriateness of these methods for extreme shaking those results in highly nonlinear soil, structural, or foundation response has not been demonstrated. SSI analysis that is nonlinear and takes place in the time domain can be utilized for these kinds of situations; however, because to a lack of knowledge on the part of analysts, engineers, and regulators, it is not frequently carried out. The paper provides a description of a nonlinear, time-domain SSI analysis process that makes use of a commercial finite-element simulation program. For the purpose of linear SSI analysis and low intensity earthquake shaking, it is compared to the frequency-domain code known as SASSI. We discuss a nonlinear analysis that was performed with the time-domain finite-element code known as LS-DYNA. This analysis's findings are compared to those obtained from an equivalent-

linear analysis performed in SASSI for high intensity shaking. Responses that are equivalent to linear and those that are nonlinear are very different from one another. When there is significant shaking, the nonlinear effects, which include gapping, sliding, and uplift, are at their peak in the immediate area of the boundary between the soil and the structure. These effects cannot be recorded by utilizing procedures that are equal to linear in nature.

Ande, Janaki Rama Phanendra Kumar (2018) [39] The purpose of this project is to gain a better understanding of how to incorporate nonlinear soil-structure interaction (SSI) effects into performance-based seismic design methodologies for high-rise buildings. First and foremost, the objectives are to ascertain the significance of including nonlinear SSI effects, to develop integration strategies for these effects, and to investigate the impact that these effects have on seismic resistance. With regard to the approach, the research makes use of case studies and an analysis of the most recent literature in order to demonstrate its application to the actual world. The significance of nonlinear structural interaction analysis is brought to light by recent discoveries, which highlight its importance in accurately anticipating structural reactions, identifying flaws, and developing targeted mitigation techniques. Specifically, the policy implications highlight the importance of current building rules, expenditures on research and development, and developments in site characterization technologies in order to support the implementation of performance-based design methodology. The findings of this study illustrate the necessity of taking into consideration nonlinear SSI effects during seismic design methods. This is important because it will help increase the resilience and safety of high-rise buildings in places that are prone to earthquakes.

Abell, José et al., (2018) [40] It is a conventional assumption in soil-structure interaction modeling of systems that are susceptible to seismic motions that the incoming wave field, which is produced by an earthquake, is unidimensional and propagates vertically. Through the use of earthquake soil-structure interaction modeling, which includes precise modeling of sources, seismic wave propagation, site, and structure, this work investigates whether or not this assumption is accurate. In order to combine seismic (near-field) simulations with the local soil-structure interaction response, the domain reduction method is utilized. The response of a generic nuclear power plant model that was computed using full earthquake soil-structure interaction

simulations is compared with the current state-of-the-art method of DE convolving in depth the (simulated) free-field motions that were recorded at the site of interest. This comparison is made under the assumption that the earthquake wave field is spatially unidimensional. The findings indicate that the assumption of a one-dimensional wave field does not hold true in general. It has been demonstrated that the fault-to-site geometry and motion frequency content are critical factors in determining the manner in which full three-dimensional analysis results differ from those that assume a one-dimensional wave field. It has been stated that this is of utmost significance for particular categories of soil-structure systems, such as nuclear power facilities that are exposed to earthquakes that occur in close proximity to them.

Alitalesh, Mahtab et al., (2018) [41] Site and soil-structure interaction (SSI) have a major influence on the ground seismic motion characteristics. It is crucial to assess the soil, topography, and structural reaction to seismic activity since some structures are constructed on slopes or hills. Important topographical features pertaining to the interplay of terrain, soil, and structure were examined in the present investigation. Significant parameters of single-faced slope topography were investigated in this work through the application of the numerical method of finite difference. The findings demonstrated that the geometry of the topographic irregularity has the potential to exert a considerable influence on the SSI mechanism. It was also explored how the consequences of free field soil thickness might play out. The SSI mechanism was discovered to be affected by changing the free field soil thickness; however, as the soil was pure topographic, this modification did not significantly affect the acceleration. When topographic influences were taken into consideration, the impact of the soil critical damping ratio on the ground reaction was very obvious. The impedance ratio between the structure and the soil was investigated, and the results revealed that the impedance ratio had a significant impact on seismic ground motion when the SSI and the topography were both present at the same time. The seismic response of the topography was affected by slope height, which is one of the geometrical aspects of the system. This was the case both with and without the presence of structure. An illustration of the regional distribution of acceleration was used to present the findings of this investigation. Another thing that was done was the calculation of transfer functions of the SSI on the slope.

Bougherra, Souhaib & Belgasmia, Mourad. (2018) [42] The behavior of the soil that surrounds the foundation of the building is a significant factor that plays a role in the evaluation of the reaction of reinforced concrete buildings that have been subjected to seismic attacks, wind excitation, or other types of dynamic loading. Over the course of the last century, a great number of academics have been investigating the impact of soil structure interaction (SSI). However, there is still a certain amount of debate over the function that SSI plays and how it affects the behavior of structures. This technique is surely not acceptable, for the reason that the stiffness and damping of the soil are vital for a better designing of a structure. It is common for designers to assume that the base of the structure is fixed. However, this assumption is not appropriate. The authors of this paper will address some potential ways for taking into account the interaction between the soil and the structure, which is something that needs to be taken into consideration from the very beginning of the design process. In addition, an analysis will be carried out regarding the dynamic response of a reinforced concrete structure that is constructed by assuming the foundation linked with discrete spring and dashpot elements. This structure will be subjected to seismic stresses.

Forcellini, Davide (2017) [43] When it comes to defining the seismic resilience (SR) of systems, one of the most important aspects to consider is the assessment of failure probabilities. The evaluation of the most appropriate countermeasure, which may include retrofitting, recovery, or reconstruction, in order to return to the functionality that was there in the beginning is an important issue that concerns the constraints that are imposed by the economy. In this regard, bridges are essential for the serviceability of the network and the functionality of communities during earthquakes. In the event of an emergency, it is imperative that their accessibility be assured. Taking this context into consideration, the purpose of this study is to evaluate the SR of a benchmark bridge and improve its performance by the utilization of isolation technique. The Pacific Earthquake Engineering Research center is responsible for the implementation of a performance-based earthquake engineering technique, which is at the foundation of this approach. The contribution of the isolation approach is evaluated in terms of how much it costs and how much time it takes, together with the peak ground velocity levels. These results have been utilized in order to estimate the SR of the bridge, and as a result, an attempt has been made to successfully apply them to a real-world case study. Within the conventional concept of resilience, recovery costs and time have been incorporated,

and the computation of resilience has been utilized to evaluate a variety of different scenarios. It is possible to use this document as a reference in order to evaluate recovery strategies by analyzing economic performances. An approach of this kind is essential for those who make decisions, those who have a stake in the matter, including professional engineers and consultants.

Behnamfar, Farhad et al., (2017) [44] In the process of studying a structure for earthquake forces, it is a typical assumption that the building is positively bonded to a firm ground. This is done to ensure that the building is able to withstand any tensile pressures that may be applied to it without becoming separated or lifted from its bearing points. In light of the fact that almost no tension can be transferred between a surface foundation and soil, and that soft soils interact with the structure that is being supported during earthquakes, the purpose of this research is to evaluate the effects of uplift and soil–structure interaction on the nonlinear seismic response of structures. Several structures made of reinforced concrete and steel are taken into consideration, each of which is subjected to a different set of consistent ground motions. For the purpose of modeling the base of the buildings, vertical no-tension springs that are nonlinear in compression have been used. The complete soil–structure interaction system is modeled within Open Sees, and a nonlinear dynamic analysis is used to evaluate the seismic behavior of the system. A fixed foundation, a flexible base without uplift, and a flexible base with uplift are the three scenarios that are used to determine and compare the nonlinear responses of buildings. Uplift in conjunction with soil–structure interaction should be addressed in some circumstances, depending on the circumstances that have been recognized.

Far, Harry & Clifton, Timothy. (2016) [45] The aim of this research is to review and evaluate all prior work on the subject of seismic behavior of braced and unbraced building structures affected by soil-structure interaction (SSI). Based on the results of the present study, it is now crystal obvious that SSI implications should not be addressed when constructing braced building structures for seismic activity, and that a fixed-base structure assumption is a safe bet. Conversely, SSI affects have the potential to exacerbate the lateral deflections and inter-storey drifts of unbraced building structures that are founded on soft grounds. This forces the structure to behave in the inelastic range, which ultimately leads to significant damage to the building structures.

As a consequence of this, the seismic design technique for unbraced building structures that are founded on soft soils and do not take into account the harmful effects of SSI is not capable of effectively guaranteeing structural sufficiency and safety for the benefit of the community.

Wankhade, Rajan & Ghugal, Yuwaraj. (2016) [46] the idea of soil–structure interaction was presented, and a discussion was held on the study techniques. An organized review of the history and current status of the study on soil–structure interaction that takes into consideration nearby structures was presented as a reference for researchers. This summary was based on numerous materials already in existence. Because of the intricacy of the model for soil and structures, as well as the excessive simplification of the model, this study is in the process of developing, and it ought to be continued because of the significance it holds. The entire vocabulary of this field of research was attempted to be summed up in a single sentence. In addition, a tabulation of the parametric study on the interaction behavior of soil structure conducted by a number of researchers is shown. We also looked into the issues that are currently being faced and the direction that research is heading in this area.

P.E, Kavitha et al., (2016) [47] Under the influence of a straightforward harmonic dynamic load, a single concrete pile that is immersed in a variety of soil types is subjected to numerical analysis and investigation. Many things, including the kind of soil, the diameter of the pile, the projection of the pile head above ground level, and the mass at the pile head, are observed and analyzed. The analysis focuses on determining how the relationship between the soil structure and the pile's structural behavior can be influenced. For the purpose of this investigation, the finite element program known as PLAXIS-3D, which specializes in the analysis of soil structure interactions, is utilized. The frequency ratio versus the stiffness ratio curves for various mass ratios and the frequency ratio versus the stiffness ratio curves for various slenderness ratios are the two types of dimensionless design curves that are plotted and investigated in this study.

Abdel Raheem, Shehata et al., (2014) [48] The effects of soil structure interaction (SSI) have been shown in a number of recent research may have a negative impact on the seismic response of a structure. Furthermore, ignoring SSI in the analysis process may result in design that is not particularly conservative. The conventional design procedure, on the other hand, typically involves making the assumption of fixity at the base of the

foundation. This assumption disregards the flexibility of the foundation, the compressibility of the soil mass, and consequently the effect of foundation settlement on the further redistribution of bending moment and shear force demands. An examination of the impacts of SSI is carried out on a typical multi-story building that is supported by a raft foundation. The evaluation of seismic demands on the target moment-resistant frame buildings is accomplished through the utilization of three distinct ways of analysis. These approaches include the equivalent static load (ESL) method, response spectrum (RS) methods, and nonlinear time history (TH) analysis with a suit of nine time history records. For the purpose of analyzing the impacts of various soil conditions and the number of stores on the vibration characteristics and seismic response demands of building structures, a three-dimensional finite element (FE) model is created. There is a comparison made between the numerical findings acquired through the use of soil structure interaction model circumstances and the results that match to fixed-base support specifications. An analysis is performed on the peak responses of the tale shear, the story moment, the story displacement, the story drift, the moments at the beam ends, and the force associated with the inner columns.

Kim, Dongwoo. (2014) [49] Under earthquake loading conditions, the purpose of this work is to investigate the interaction that occurs between neighboring structures that have foundation levels that are different from one another. There are three distinct models that are used to portray the earth and buildings here. In the first and second situations, the building itself is described using a typical frame and equivalent bar element. On the other hand, the behavior of the earth is driven by a customized grid model. The third scenario involves the building and the soil being represented by parts that are either plane stress or plane strain structures. Different values are assigned to the ground's modulus of elasticity. As is the case with the adjustment of the modulus of elasticity, the different relations of inertia have a significant impact on the section forces that are present within the buildings. The study is carried out with the assistance of numerical software that was designed based on the axisymmetric fine element method in conjunction with the rough element for the soil region and the wave input technique transit boundary condition. Examples based on numerical data illustrate how the proposed method interacts with other phenomena.

Farghaly, Ahmed. (2014) [50] 3D the investigation focused on two nearby buildings that were in different heights and were built in different types of soil. Both of these structures were connected with viscous dampers and had a special arrangement in plane. For the purpose of providing a realistic representation of the behavior of nearby buildings that are coupled with viscous dampers, the soil for three distinct types of soil—stiff, medium, and soft—was modeled as a three-dimensional Winkler model. In the course of the examination, the structural reactions of two neighboring buildings that are connected with viscous dampers are being studied. These responses are being studied under a variety of earthquake excitations, with consideration given to the impact of the various types of soil that are beneath the buildings. Using SAP2000n to model the system is necessary in order to incorporate the soil-structure interaction, which necessitates the creation of a mathematical model for the foundation and the soil that surrounds it. The selection of a variety of soil qualities and soil damping characteristics provides a comprehensive picture of the behavior of connected structure systems under the effect of soil-structure interaction. The findings of this study indicate that the response of connected structures systems that are established on soft soil is more critical than the response of systems that are founded on stiff soil. The performance of connected structures is distinct from that of structures with fixed bases that are larger by nearly twenty percent, and the effectiveness of viscous dampers that connect two nearby buildings is lowered by approximately twenty-five percent less than that of structures that are founded on stiff soil.

Far, Harry et al., (2014) [51] A more advanced numerical soil-structure model has been constructed as part of this research project. This model takes into account the behavior of both the soil and the structure with equal rigor. Through the use of experimental shaking table testing, the numerical soil-structure model that was suggested has been tested and validated. In order to accomplish this objective, a series of experimental shaking table tests were carried out on the physical fixed based (structure that was directly fixed on top of the shaking table) and flexible base (considering soil and structure) models. These tests were carried out under the influence of four scaled earthquake acceleration records, and the results were measured. When the findings of the experiment are compared to the predictions made by the numerical analysis, it is observed that the numerical predictions and the measurements taken in the laboratory are in a good agreement with one another. As a result, the numerical soil-structure

model that was proposed is a viable and qualified way of simulation that possesses appropriate precision and may be utilized for additional numerical soil-structure interaction inquiry studies. It has been noticed that the lateral deflections of the flexible base model have significantly increased in comparison to the fixed base model. The values of lateral deflections that were predicted and observed for both the fixed base and flexible base models. As a consequence of the lateral deflection amplifications, it has been noted that the performance level of the scaled structural model has undergone a substantial shift, which may pose a threat to the safety of the structure.

Far, Harry et al., (2013) [52] The seismic excitation that structures feel is a result of the earthquake source, the impacts of the travel path, the effects of the local site, and the effects of soil-structure interaction (SSI). The term "free-field ground motion" refers to the outcome that occurs as a consequence of the first three of these causes. The structural soundness index (SSI) has an effect on the structural response to free-field motion. Specifically, the flexibility of the foundation support and variances between the foundation and free-field motions are two factors that have an impact on accelerations that occur within structures. Therefore, a rational consideration of SSI effects may be necessary in order to conduct an accurate assessment of the inertial forces and displacements that are present in buildings. In the current study, in order to illustrate these effects on the seismic response of moment-resisting building frames, a 10-story moment-resisting building frame that was resting on a shallow foundation was chosen in conjunction with three soil types that had shear-wave velocities of less than 600 meters per second. These soil types represented Soil Classes Ce, De, and Ee according to an existing Australian Standard. Following the application of dynamic nonlinear time-history analysis, the structural sections were designed. These sections were based on both the elastic method and the inelastic procedure, and they utilized the elastic-perfectly plastic behavior of the structural parts. For the purpose of modeling and analyzing the frame sections, the finite-difference approach and the FLAC 2D software were utilized. The boundary conditions that were considered were as follows: (1) fixed-base (no SSI), and (2) taking into consideration the SSI. This research used a variety of earthquake data to inform a completely nonlinear dynamic analysis. The results of the two distinct scenarios for elastic and inelastic behavior of the structural model were extracted, compared, and analyzed. According to the findings, the performance level of the model that is resting on Soil Class Ce does not change

significantly and stays in the life safe level. But in contrast, the performance level of the model that is resting on Soil Classes De and Ee significantly increases from the life safe level to the point where it is almost collapsed for both elastic and inelastic cases. Because of this, it is very necessary to take into account the impacts of SSI while designing the elastic and inelastic seismic design of concrete moment-resisting building frames that are supported by soil classes De and Ee. In general, the base shear ratios drop when the dynamic qualities of the subsoil, such as the shear-wave velocity and shear modulus, are decreased. At the same time, the interstory drifts of the moment-resisting building frames increase substantially. In a nutshell, the conventional elastic and inelastic design approach that does not include the SSI is not sufficient to assure structural safety for moment-resisting building frames that are sitting on Soil Classes De and Ee.

Jarernprasert, Sittipong et al., (2013) [53] Using a set of accelerograms recorded in California and a set of recordings from Mexico City, we investigate the impacts of soil-structure interaction (SSI) on the reaction of yielding single-story structures embedded in an elastic half space. Specifically, we focus on the response of these structures to the elastic half space. SSI may result in increased ductility demands and larger overall displacements for nonlinear hysteretic structures, as we have discovered. This is in contrast to the situation in which the soil would be rigid. This behavior is different from what is envisioned under the seismic rules that are already in place. These provisions permit designers to completely disregard SSI or to minimize the base shear force in comparison to the base shear force of the fixed-base structure. For the purpose of addressing this shortcoming, we investigate a method that involves the incorporation of seismic design index (SSI) in the process of determining the seismic design coefficient,, for systems that exhibit non-structural degrading elastoplastic behavior and target ductility μ_t . In this particular approach, the unreduced seismic coefficient, denoted as C , is obtained by utilizing an equivalent fixed-base structure with natural period, which is the natural period of the elastic SSI system. Additionally, the inelastic reduction factor is equal to the λ -root of the fixed-base reduction factor, where λ is equal to and T is the elastic natural period of the structure that disregards SSI. In order to determine the peak relative displacement of the structure, one can calculate it by multiplying the yield displacement by the target ductility, with the symbol μ_t . ($\mu_t + \lambda^2 -$

1) is a near approximation of the peak total displacement, which takes into account the SSI calculation.

Farghaly, Ahmed & Ahmed, Hamdy. (2013) [54] Because of the induced changes in the dynamic characteristics of soil that occur as a result of seismic excitation, buildings are subject to the impacts of soil structure interaction. As a result of this harmful effect, the purpose of this research is to clarify the influence of soil structure interaction on the seismic response of buildings when they are subjected to significant ground motions. The goal of this study is to provide damage control and raise the safety level of such buildings. In order to carry out a three-dimensional time history analysis of nonlinear soil-foundation-building models under the influence of a significant earthquake ground motion, The SAP2000 application was used to conduct an iterative dynamic analysis. The findings suggest that the building's performance might be negatively affected by the inclusion of soil structure interaction, which overestimates the reaction of top displacements. Conversely, there is a noticeable effect of building foundation' flexibility on the structural behavior of buildings. This is because they offer a significant reduction in the internal forces of superstructure reaction when compared to buildings with fixed bases.

Naserkhaki, Sadegh et al., (2012) [55] A great number of structures that are positioned in close proximity to one another have been subjected to pounding during previous earthquakes because they vibrated out of phase. In addition, buildings are typically constructed on soil; consequently, the structures engage in dialogue with one another and the soil that lies beneath them that should also be taken into consideration before construction begins. Both the interaction between nearby buildings as a result of pounding and the interaction between the buildings through the soil as they affect the seismic responses of the buildings are investigated in this research. The model that was constructed is made up of shear buildings that are adjacent to one another and are supported by a discrete soil model. Additionally, there is a linear viscoelastic contact force model that connects the buildings as they are being pounded. It is possible to derive the seismic reactions of neighboring structures as a result of ground accelerations under two different conditions: fixed-based (FB) and structure-soil-structure interaction (SSSI). As a result of the fact that the seismic reactions of the buildings are enhanced after pounding, the findings suggest that pounding makes the condition of the buildings

worse. Furthermore, the underlying soil has a negative impact on the seismic reactions of the buildings when they are subjected to pounding. This is due to the fact that the ratio of the seismic response of the buildings under SSSI conditions with pounding to those without pounding is higher than the ratio experienced under the FB condition.

Naserkhaki, Sadegh & Pourmohammad, Hassan. (2012) [56] This work describes the results of a numerical study that investigated the impacts of soil-structure interaction (SSI) and structure-soil-structure interaction (SSSI) on the response of twin buildings to earthquake excitations. Shear buildings are used to model the buildings, and a discrete model that represents a visco-elastic half-space that is susceptible to earthquake acceleration is used to simulate the soil. An analytical technique is used to generate the equation of motion of twin buildings with varied circumstances, fixed based (FB), SSI, and SSSI. The equation is then solved numerically. When evaluating the responses of buildings to the aforementioned three parameters, various soil types are taken into consideration, and the results are compared together. One must acknowledge that soil is responsible for a change in the distribution of responses throughout the buildings, and that disregarding the interaction between soil and buildings might result in unwanted consequences for the buildings. When two structures with the same SSSI condition interact, however, the soil's detrimental impacts are considerably reduced compared to when only one building has the same problem. What's more, it has been found that soil influences vary greatly for both soft and stiff soils; however it is minimal for soils that are hard.

Lou, Menglin et al., (2011) [57] An introduction was made to the idea of structure–soil–structure dynamic interaction, and a discussion was held on the study techniques. As a resource, researchers have a detailed account of the past and present of the study that considers the dynamic interplay between structures, soil, and neighboring structures. This synopsis relies on a number of articles. Despite being in its early stages owing to the model's oversimplification and the complexity of soil and structure, this research must be maintained because of its importance. An attempt was made to provide a synopsis of the most prevalent significant computer programs that are utilized in this field of research. In addition, the benefits, drawbacks, and the extent to which such programs can be successfully implemented were reviewed. We also looked into the

issues that are currently being faced and the direction that research is heading in this area.

Khalil, Louay et al., (2007) [58] within the scope of this article is an investigation of the impact that the soil–structure interaction (SSI) has on the fundamental period of buildings. In this scenario, it is believed that the earth and the building will behave in an elastic manner. In order to represent the soil–foundation system, translational and rotational discrete springs are utilized. Initially, A study is conducted for structures with a height of one storey. Specifically, it demonstrates that the influence of the SSI on the basic frequency of building is contingent upon the relative rigidity of the soil and the structure, denoted by K_{ss} . The analysis is then extended to include structures with multiple stories. This enables the soil–structure relative rigidity K_s to be generalized to such complex systems, which is a significant benefit. In order to factor in the SSI's effect on the procedure for calculating the fundamental frequency of a wide variety of buildings, charts are being offered.

Tongaonkar, N.P. & Jangid, R.. (2003) [59] In order to accommodate the current transportation amenities, it is necessary to create bridges that span gorges that are situated in seismically active regions. Additionally, the site conditions necessitate that the engineers rest the foundation of the pier on the ground. With the use of elastomeric bearings, the objective of this study is to determine the impact that soil–structure interaction (SSI) has on the peak responses of a three-span continuous deck bridge that is seismically isolated. For the purpose of determining the circumstances in which it is required to incorporate the SSI effects into the design of seismically isolated bridges, the primary focus has been on determining the relevance of the physical characteristics that have an effect on the reaction of the system. Frequency independent coefficients are used to simulate the soil that surrounds the foundation of the pier, and the complex modal analysis method is utilized to carry out the comprehensive dynamic analysis in the time domain. It is necessary to compare the peak responses of an isolated and non-isolated bridge (that is, a bridge that does not have an isolation device) with the peak responses of the similar bridge that does not take into account these effects in order to quantify the impacts of SSI. In addition, a parametric research is carried out in order to explore the impacts of soil flexibility and bearing characteristics (including stiffness and damping) on the response of an isolated bridge system. In certain situations, the

bearing displacements at abutment locations may be underestimated if the SSI effects are not taken into consideration in the response analysis of the system. It has been discovered that the soil that surrounds the pier has a substantial impact on the reaction of the isolated bridges at the same time.

2.1 RESEARCH GAP

In order to improve earthquake readiness, it is necessary to conduct a thorough investigation of soil-structure interaction (SSI) in Hyderabad, Telangana. This is because the city is becoming increasingly urbanized, and it is also susceptible to earthquakes. Despite the fact that previous research has investigated a variety of factors of seismic risk in India, there is still a major lack of study that particularly addresses the complex dynamics that exist between the properties of the soil and the responses of structures during earthquakes in the Hyderabad region. The magnitude of this disparity is especially obvious when considering the local geological conditions, which vary greatly from one region of the city to another and have an effect on the way structures react to seismic forces. The use of international principles and procedures for assessing SSI is restricted in the Indian setting, particularly in locations such as Hyderabad. This is despite the fact that these guidelines and methodologies have been thoroughly documented. The majority of the studies that have been conducted up to now have a tendency to concentrate on either soil mechanics or structural engineering in isolation, ignoring the synergistic effects that take place when these two components interact simultaneously during seismic occurrences. The development of robust engineering procedures that could effectively limit earthquake risks is hampered as a result of this oversight. To create solutions that are specifically matched to the characteristics of the area, it is necessary to conduct a thorough analysis that takes into account the behavior of the soil as well as the response of the structure.

However, there is a paucity of real-time data on the interaction between the soil and the structure during seismic occurrences in Hyderabad, which is another issue that need study. Despite the existence of a large number of theoretical models, there is a dearth of empirical data derived from actual earthquakes that have occurred in the region. There is a shortage of observational data, which makes it difficult to test models and comprehend the specific obstacles that are posed by the conditions of the local soil. These issues include varied stiffness, plasticity, and liquefaction potential

characteristics. This important hole can therefore be filled by a concentrated study that integrates field measurements and post-event assessments, which will ultimately result in improved forecasting skills for future earthquake scenarios. Furthermore, it is possible that the existing construction norms and regulations in India may not appropriately represent the intricacies of SSI while it is being designed for seismic activity. The incorporation of SSI considerations into the regulatory frameworks that are already in place has been inadequate, which has resulted in structures that could be vulnerable in the case of an earthquake. In order to fill this void, it is necessary for geotechnical engineers, structural engineers, and policymakers to work together across disciplinary lines. This will ensure that building rules are updated to include the findings from SSI research, which will ultimately lead to safer construction methods in regions that are prone to earthquakes. In the context of earthquake preparedness in Hyderabad, the research landscape surrounding soil-structure interaction is characterized by a lack of localized studies, empirical data, and incorporation into building codes. This is a problem because these factors are essential for earthquake readiness. By addressing these deficiencies, future research has the potential to make a significant contribution to the enhancement of the resilience of urban infrastructure in Hyderabad, which would ultimately result in increased safety and a reduction in hazards during occasions of seismic activity.

CHAPTER 3

MATERIAL AND METHODS

Kinematic interaction and inertial interaction are the two components that make up the total interaction response in dynamic analysis. This response is the combination of the two. Through the presentation of the extensive numerical methodologies, Wolf (1985) has provided the SSI analysis with a form that is easily comprehensible. Direct technique and substructure methods are two approaches that can be utilized in order to investigate the soil structure interaction problem.

Software developed in C++ using object-oriented approach has integrated the finite element method (FEM) into the present investigation. An investigation of the effects of interaction on pile-supported structures exposed to transient loading conditions is the driving force behind this research. In this context, the numerical implementation of the DSSI problem has been carried out using a finite element process in conjunction with the continuum approach. In the parts that follow, we'll go over the specifics of how to model DSSI by breaking it down into its component parts. These components include element formulation, viscosity and earthquake boundaries, material models, nonlinear solvers (explicit and implicit), and contact element formulations.

3.1 FINITE ELEMENT FORMULATION OF SOIL STRUCTURE INTERACTION (SSI)

For the purpose of determining the response of the SSI system, the generalized equation of motion is utilized. When the system is subjected to the earthquake, the spectral acceleration, in conjunction with the mass of the system, has been taken into consideration as external forces. In the event that the SSI system is subjected to ground motion, the various components of the system are displayed in equation 3.1.

$$[M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = -[M]\{\ddot{U}_g\} \quad (3.1)$$

Within the context of the integrated system, which encompasses both the structure and the foundation system, the mass, damping, and stiffness matrices are denoted by the symbols $[m]$, $[d]$, and $[u]$.

The system's acceleration, velocity, and displacement are denoted by the symbols $\ddot{U}$, $\dot{U}$, and U , respectively, whereas the acceleration of the ground motion is denoted by $\ddot{U}_g$. A damping matrix, denoted by $[C]$, can be obtained through the use of Rayleigh damping, that is, $[C] = \alpha [M] + \beta [K]$, where the coefficients α and β represent the Rayleigh damping coefficients. When conducting transient dynamic analysis, Rayleigh damping is the method that is most suitable.

3.2 MATERIAL MODEL

Through careful observation of the stress strain curve, one can gain a comprehensive understanding of the behavior of the material when it is subjected to the application of it. The way in which soil stuff behaves is extremely complicated. In order to carry out practical applications, it is frequently required to construct straightforward mathematical constitutive laws. The literature contains a number of models that deal with the constitutive behavior of granular and frictional materials. Some examples of these models include Drucker-Prager, Mohr-coulomb, Duncan and Chan, Cam Clay, and others. With regard to the soil, the Drucker-Prager nonlinear material model is utilized in the current investigation. It is expected that all of the structural elements, such as beams, columns, rafts, and piles, conduct themselves in a linear elastic manner when subjected to the loads that are being applied.

3.2.1 LINEAR ELASTIC MATERIAL MODEL

For a linear elastic material, the stress-strain curve comes from the generalized Hooke's law. The stress strain relationship in 3D can be expressed as

$$\sigma = D \varepsilon \quad (3.2)$$

Where,

$$\sigma, \text{ is stress vector} = \{\sigma_{xx} \sigma_{yy} \sigma_{zz} \sigma_{xz} \sigma_{xy}\}^T$$

$$\varepsilon, \text{ is strain vector} = \{\varepsilon_{xx} \varepsilon_{yy} \varepsilon_{zz} \varepsilon_{zy} \varepsilon_{zx} \varepsilon_{xy}\}^T$$

D , is symmetric (6x6) material matrix given by

$$D = \frac{E}{(1+\mu)(1-2\mu)} \begin{bmatrix} 1-\mu & \mu & \mu & 0 & 0 & 0 \\ \mu & 1-\mu & \mu & 0 & 0 & 0 \\ \mu & \mu & 1-\mu & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.5-\mu & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.5-\mu & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.5-\mu \end{bmatrix} \quad (3.3)$$

Where, μ is the poisson's ratio of the material.

3.2.2 DRUCKER-PRAGER NONLINEAR MATERIAL MODEL

In order to describe the stress-strain behavior of pressure-dependent materials including soil, rock, and concrete, proposed the Draucker-Prager material model. This model was developed to describe its behavior. In the principal stress space, the model makes use of a conical failure surface. This surface's projection in the octahedral plane is a circle, and it is centered at the origin (Fig. 3.1). As opposed to the six yield surfaces that have corners, the failure surface is a generalization of the Mohr-Coulomb failure surface, which is depicted by a smooth cone. A cone is represented by this surface in the space of principal stresses, and the axis of the cone corresponds to the space diagonal of the coordinate system of principal stresses σ_1 , σ_2 and σ_3 .

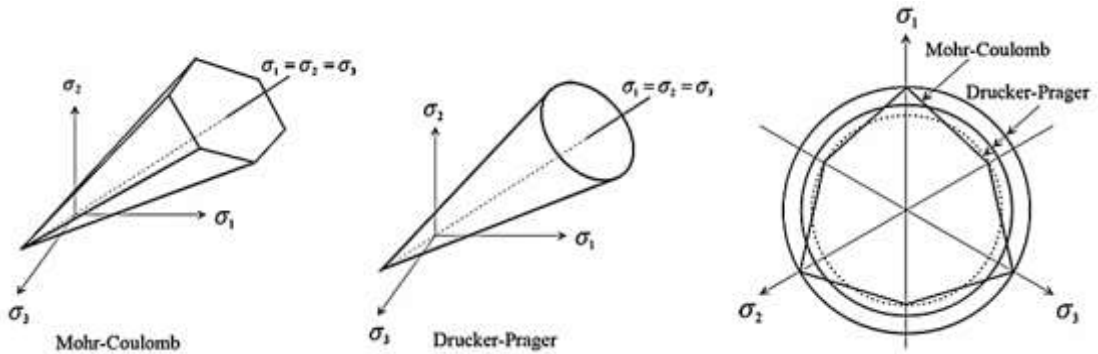


FIGURE 3. 1 Drucker-Prager failure surface

The Drucker-Prager yield surface is defined as:

$$F = \alpha I_1 + \sqrt{J_{2D}} - k; F \leq 0 \quad (3.4)$$

Associative flow rule has been assumed and hence the plastic potential is defined by the same function:

$$G = \alpha I_1 + \sqrt{J_{2D}} - k \quad (3.5)$$

I_1 is the initial stress that remains constant; J_{2D} is the deviatoric stress's second invariant, where α and k are constants that are material.

$$I_1 = 3\sigma_m = \sigma_1 + \sigma_2 + \sigma_3 = \sigma_{xx} + \sigma_{yy} + \sigma_{zz} \quad (3.6)$$

$$J_{2D} = \frac{1}{6} \left[(\sigma_{xx} - \sigma_{yy})^2 + (\sigma_{yy} - \sigma_{zz})^2 + (\sigma_{zz} - \sigma_{xx})^2 \right] + (\sigma_{zy})^2 + (\sigma_{zx})^2 + (\sigma_{xy})^2 \quad (3.7)$$

$$\alpha = \frac{2 \sin \theta}{\sqrt{3} (3 - \sin \theta)} \quad k = \frac{6c \cos \theta}{\sqrt{3} (3 - \sin \theta)} \quad (3.8)$$

To solve the challenge of finding the incremental strains that match the incremental stresses, we use the yield function (Equation 3.4) and their stress-related derivatives.

$$\left\{ \frac{\partial F}{\partial \sigma} \right\}^T = \frac{\partial F}{\partial I_1} \left\{ \frac{\partial I_1}{\partial \sigma} \right\}^T + \frac{\partial F}{\partial J_{2D}} \left\{ \frac{\partial J_{2D}}{\partial \sigma} \right\}^T \quad (3.9)$$

$$\left\{ \frac{\partial F}{\partial \sigma} \right\}^T = \begin{pmatrix} \alpha + \frac{2\sigma_{xx} - \sigma_{yy} - \sigma_{zz}}{\sqrt{6J_{2D}}} \\ \alpha + \frac{-\sigma_{xx} + 2\sigma_{yy} - \sigma_{zz}}{\sqrt{6J_{2D}}} \\ \alpha + \frac{-\sigma_{xx} - \sigma_{yy} + 2\sigma_{zz}}{\sqrt{6J_{2D}}} \\ \frac{\sigma_{xy}}{\sqrt{J_{2D}}} \\ \frac{\sigma_{yz}}{\sqrt{J_{2D}}} \\ \frac{\sigma_{zx}}{\sqrt{J_{2D}}} \end{pmatrix} \quad (3.10)$$

Numerical implementation of elastic plastic material

At its core, every small-strain elastoplastic connection is based on the basic separation of incremental strain into elastic and plastic components. This separation provides the basis for the relationship.

$$\{d\epsilon\} = \{d\epsilon^E\} + \{d\epsilon^P\} \quad (3.11)$$

An expression for the incremental stress is

$$\{d\sigma\} = \{D^E\} + \{d\epsilon^E\} \quad (3.12)$$

Where $[D^E]$ a constitutive matrix with elastic properties according to equation (3.12)

Get what you need by plugging (3.11 into 3.12).

$$\{d\sigma\} = [D^E](\{d\varepsilon\} - \{d\varepsilon^P\}) \quad (3.13)$$

The fundamental premise is that the plastic's progressive stresses may be roughly represented by

$$\{d\varepsilon^P\} = d\lambda \left\{ \frac{\partial G}{\partial \sigma} \right\} \quad (3.14)$$

Where, $d\lambda$ indicates the size and reliability of the $\left\{ \frac{\partial G}{\partial \sigma} \right\}$ becomes the direction of flow when the potential function (here the yield function) is differentiated.

When stresses are at their lowest on the yield surface, the plastic multiplier is zero; when plastic flow is taking place, it becomes positive. Hence, nothing ever goes wrong with the plastic multiplier.

$$d\lambda \geq 0 \quad (3.15)$$

Every time plastic yields, No value has been found for the yield function ($d\lambda > 0$), thus

$$dF = 0 \quad (3.16)$$

Given that F is a function σ

$$dF = \left\{ \frac{\partial F}{\partial \sigma} \right\}^T d\sigma = 0 \quad (3.17)$$

Equation (3.15) is modified by plugging in equations (3.11) and (3.12).

$$dF = \left\{ \frac{\partial F}{\partial \sigma} \right\}^T \left([D^E]\{d\varepsilon\} - d\lambda [D^E] \left\{ \frac{\partial G}{\partial \sigma} \right\} \right) = 0 \quad (3.18)$$

Then, the parameter $d\lambda$ is

$$d\lambda = \frac{\left\{ \frac{\partial F}{\partial \sigma} \right\}^T [D^E] \{d\varepsilon\}}{\left\{ \frac{\partial F}{\partial \sigma} \right\}^T [D^E] \left\{ \frac{\partial G}{\partial \sigma} \right\}} \quad (3.19)$$

To determine plastic strain, plug equation 3.19 into equation 3.14.

$$\{\mathbf{d}\varepsilon^P\} = \frac{\left\{\frac{\partial F}{\partial \sigma}\right\}^T [D^F] \{\mathbf{d}\varepsilon\}}{\left\{\frac{\partial F}{\partial \sigma}\right\}^T [D^E] \left\{\frac{\partial G}{\partial \sigma}\right\}} \left\{\frac{\partial G}{\partial \sigma}\right\} \quad (3.20)$$

It follows that that governs associative flow in $\left\{\frac{\partial G}{\partial \sigma}\right\}$ must be substituted with $\left\{\frac{\partial F}{\partial \sigma}\right\}$.

As $\left\{\frac{\partial G}{\partial \sigma}\right\}$ the constant for the plastic multiplier $d\lambda$, this is then affected by the stress level, as seen in equation (3.14). Given the interdependence of the multiplier constant $d\lambda$ and the incremental plastic strain $d\varepsilon^P$, the issue may now be described as nonlinear. The nonlinear problem has several potential solutions. Nearest Point Path Method (CPPM), Cutting Plane Algorithm, and Newton-Raphson Method are a few examples of such algorithms. The research here makes use of the Cutting Plane Algorithm in conjunction with the Drucker-Prager material model.

The Cutting Plane Algorithm (CPA)

First, the elastic equations are integrated with total strain increments using the return mapping technique, much like the CPA procedure. As a result, an elastic predictor may be found. After that, the elastically anticipated stresses are released onto a yield surface that has been appropriately updated by correcting the plastic strain increments in an iterative manner. This is the geometric explanation of the CPA, which is shown in figure 3.2.

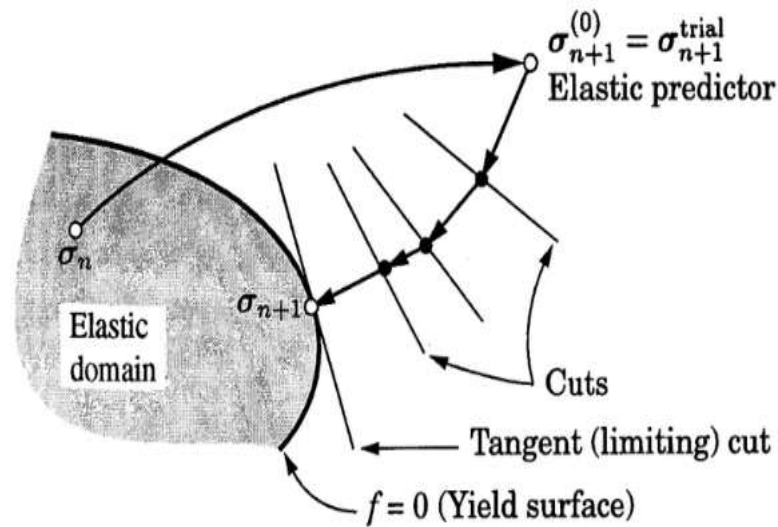


FIGURE 3. 2 Analysis of the cutting plane method from a geometric perspective

Method for nonlinear Drucker Proager materials based on CPA

Step 1: Preliminary phase: Before assessing the elastic trial stress, the plastic strain beginning values should be set to the convergent values from the last load phase. Furthermore, zero should be set for the incremental plasticity parameter.

$$K = 0: \{\epsilon^{P(0)}\} = \{\epsilon_n^p\}, d\lambda^{(0)} = 0 \quad (3.21)$$

$$\{\sigma^{(0)}\} = [D^E](\{\epsilon_{n+1}\} - \{\epsilon^{P(0)}\}) \quad (3.22)$$

Step 2: Use the yield condition and k^{th} iteration to confirm convergence, as shown in equation (3.4)

$$\{F^{(k)}\} = F(\{\sigma^{(k)}\}) \quad (3.23)$$

If $F(K) \leq TOL$ converged else go to 3.

Step 3: Measure the increase in the plasticity parameter

$$d\lambda^k = \frac{F^k}{\left\{\frac{\partial F^k}{\partial \sigma}\right\}^T [C^E] \left\{\frac{\partial G^k}{\partial \sigma}\right\}} \quad (3.24)$$

Step 4: Find the tension and the increase in plastic strain

$$\{d\sigma^k\} = -d\lambda^k \left\{\frac{\partial G^k}{\partial \sigma}\right\} \{d\epsilon\} \quad (3.25)$$

$$\{d\epsilon^{P(k+1)}\} = -d\lambda^k \left\{\frac{\partial G^k}{\partial \sigma}\right\} \quad (3.26)$$

Step 6: Reinstate plastic tension and strain

$$\{\epsilon^{P(k+1)}\} = \{\epsilon^{P(k)}\} + \{d\epsilon^{P(k+1)}\} \quad (3.27)$$

$$\{\sigma^{(k+1)}\} = \{\sigma^k\} + \{d\sigma^k\} \quad (3.28)$$

$k = k + 1$. Go to **Step 2**

3.3 NONLINEAR ANALYSIS

Linear approximations provide the foundation for the solution of a great deal of engineering problems. These approximations are mirrored in the actual behavior of the system analysis by taking into account conservative load circumstances and modest displacements. Because the system's behavior is often nonlinear, it does not always respond in a linear fashion as planned. There are indications that the structural response is linear, but the divergence from linear to nonlinear response is so tiny that it may be ignored. In contrast, the analytical conclusion is significantly affected by nonlinearity when soil is involved, such as in an SSI problem. The inclusion of these processes causes finite element analysis (FEA) to become nonlinear rather than linear. This occurs due to a shift in the set of equilibrium equations. This investigation has resolved the SSI system for both static and dynamic load situations, taking into account the nonlinearity of the material.

3.3.1 STATISTICAL NONLINEARITY

For nonlinear finite element analysis, the usual approach is to apply forward Euler load increase in the predictor step and Newton iterations in the corrector step to ensure equilibrium. A variety of methods exist for dealing with the nonlinear issue. Some of these approaches include the Initial Stiffness Method, the Modified Newton-Raphson Method, and the Newton-Raphson Method (NR). It is necessary for the stiffness of NR to be updated at each cycle. The process of updating the stiffness is both time-consuming and numerically expensive. The Initial Stiffness Method does not modify the global stiffness matrix from one computing step to the next; At the outset of the research, it is constructed. Consequently, there is a single need to estimate the global stiffness matrix for the whole investigation, so there's no need to do it again for the nonlinear material's tangent modulus. A higher number of repetitions is required by this approach, however, when the force exerted causes a change in stiffness from its starting state. Due of its practicality, the Initial Stiffness Method will be used in this empirical investigation. Before going on to the next load (time) step, the Initial Stiffness Method uses iterations to ensure that the global equilibrium is satisfied. The appropriate displacement was found using an iterative method, as shown in Figure 3.3. $U^{t+\Delta t}$ as a result of outside influences $F^{t+\Delta t}$.

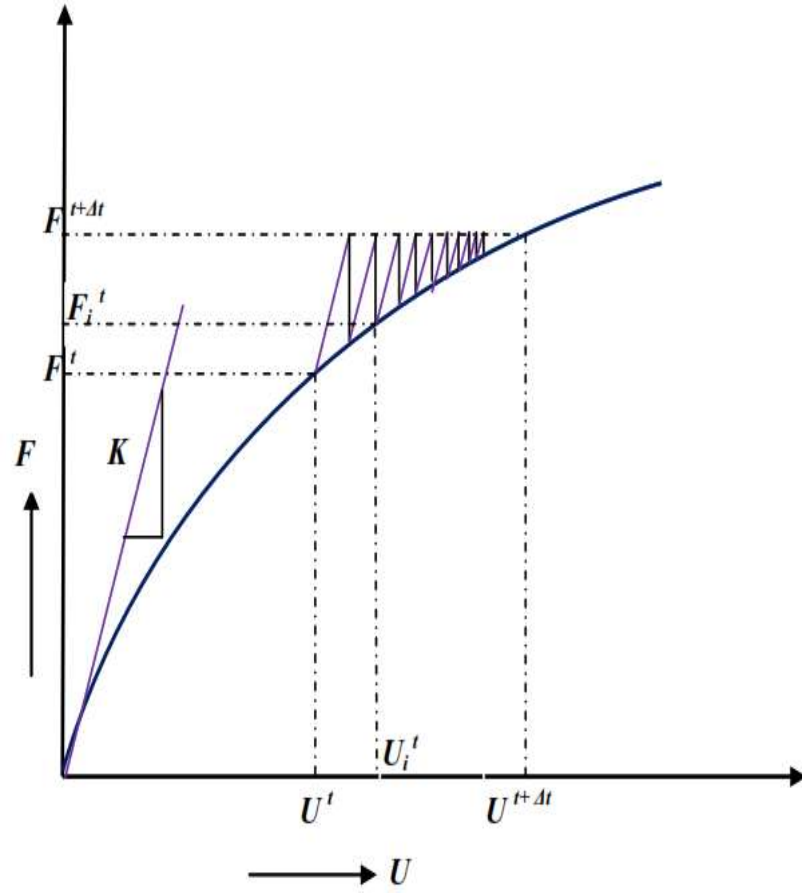


FIGURE 3.3 First-Attempt Stiffness Analysis

The overall displacement and incremental displacement are refined by plugging the results into this formula for each iteration i inside each load step.

$$U_i^{t+\Delta t} = U_{i-1}^{t+\Delta t} + \Delta U \quad (3.29)$$

$$\Delta U = K^{-1} R_i \quad (3.30)$$

The following is an estimate of the residual force, denoted as R_i .

$$R_i = F^{t+\Delta t} - F_{i-1}^{\text{int}} \quad (3.31)$$

$$F_{i-1}^{\text{int}} = \sum \int B^T \sigma_{i-1} dv \quad (3.32)$$

The displacement is proportional to the stresses mentioned before $U_{i-1}^{t+\Delta t}$. It is understood in this version.

Equation (3.30) may be solved using the Eigen open-source program.

The first Stiffness method's algorithm:

Step 1: For each load stage, set the initial values of the residual forces to be the force difference between the previous and current steps. Put $k = 0$ to set the iteration counter.

$$k = 0: R_i = F^{t+\Delta t} - F^t \quad (3.33)$$

Step 2: Using the starting stiffness and residual force, figure out the overall and gradual move.

$$\Delta U = K^{-1} R_i \quad (3.34)$$

$$U_i^{t+\Delta t} = U_{i-1}^{t+\Delta t} + \Delta U \quad (3.35)$$

Step 3: Deduce the internal forces from the element stresses that match the displacements found in step 2.

$$F_{i-1}^{int} = \sum \int B^T \sigma_{i-1} dv \quad (3.36)$$

Step 4: Determine the forces that remain after

$$R_i = F^{t+\Delta t} - F_{i-1}^{int} \quad (3.37)$$

Step 5: It is important to verify convergence at each system degree of freedom.

If $(R_i - F^{t+\Delta t})/F^{t+\Delta t} \geq \text{TOL}$ Proceed to Step 2 if the solution did not converge.

3.3.2 DYNAMIC NONLINEAR MODELING WITH AN EXPLICIT TIME INTEGRATION FORMULATION

While solving for doing a thorough examination of the system, acceleration $\ddot{u}$ is used instead of displacements u . Consequently, inverting the mass matrix (M) is required, but it is feasible to forego inverting the complicated stiffness matrix. Since the mass matrix may be either a lumped or diagonal matrix, or inverting turning the diagonal components into their reciprocal is a straightforward process, and explicit analysis is often used the way to go when dealing with lower-order elements. The upshot is that finite element processes are getting easier to build. Nevertheless, the one and only negative aspect of this plan is that the algorithm does not use the Euler time integration methodology, thereby making the system conditionally stable. Consequently,

advantage of very small temporal increments is required. An explicit analysis provides a valuable alternative for the dynamic analysis when modeling impact loadings, earthquake loadings, or crash testing. This is because it makes the analysis easier to perform and allows it to be performed more quickly computationally.

This research includes an evaluation of the system's behavior under dynamic loading using the Central difference approach and explicit temporal integration. To do dynamic analysis, you must knowledge of the dynamics as well as the analysis and stiffness. A few of these supplementary areas include dampening and mass. It is possible to produce an external load balance by combining mass, damping, and rigidity. The reaction of the soil structure interaction system, as a consequence of the earthquake ground acceleration $\ddot{U}_g$ indicated in the stiff bedrock layer, is calculated using the equation of motion presented below.

$$[M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = -[M]\{\ddot{U}_g\} \quad (3.38)$$

At the n th time step, the following explicit solver approach may to modify the motion equation given earlier:

$$[M]\{\ddot{U}_n\} + [C]\{\dot{U}_n\} + [K]\{U_n\} = F_n^{ext} \quad (3.39)$$

Replacing $[K]\{U_n\}$ with F_n^{int} the above equation becomes

$$[M]\{\ddot{U}_n\} + F_n^{int} + [C]\{\dot{U}_n\} = F_n^{ext} \quad (3.40)$$

Changing the order of the previous equation to get a rough estimate of the accelerations at this instant in time

$$\{\ddot{U}_n\} = [M]^{-1} \{F_n^{ext} - F_n^{int} - [C]\{\dot{U}_n\}\} \quad (3.41)$$

It is possible to determine speeds and accelerations from the central difference approach by

$$\{\ddot{U}_n\} = \frac{\{\dot{U}_{n+\frac{1}{2}}\} - \{\dot{U}_{n-\frac{1}{2}}\}}{\Delta t} \quad \text{OR} \quad \{\dot{U}_{n+\frac{1}{2}}\} = \{\dot{U}_{n-\frac{1}{2}}\} + \{\ddot{U}_n\}\Delta t \quad (3.42)$$

$$\{\dot{U}_{n+\frac{1}{2}}\} = \frac{\{U_{n+1}\} - \{U_n\}}{\Delta t}; \quad \text{OR} \quad \{U_{n+1}\} = \{U_n\} + \{\dot{U}_{n+\frac{1}{2}}\}\Delta t \quad (3.43)$$

Our goal is to determine the displacement at the following time step (n+1), denoted by the notation. It is possible to estimate the speed at the half-time step (n + 1/2), also written as n, by computing the acceleration at the present time step (n) using equation (3.42). The equation (3.43), which may be used to get the displacement at the following time step (n+1), is available here. This is demonstrated by the diagram that is presented below.

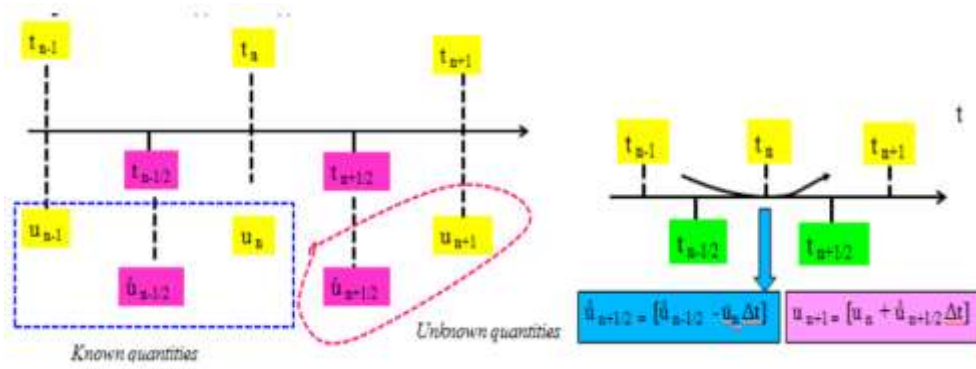


FIGURE 3. 4 Dynamic analysis explicit solver operation

Method for Explicit Scheme-Based Dynamic Nonlinear Analysis

Step 1: Start the displacement at the beginning of the time step $\{U_n\}$ and velocities $\{\dot{U}_{n-\frac{1}{2}}\}$ starting with known amounts as beginning circumstances.

$$n = 0;$$

$$\{U_n\} = \{U_0\}; \quad (3.44)$$

$$\{\dot{U}_{n-\frac{1}{2}}\} = \{\dot{U}_{-\frac{1}{2}}\} = \{\dot{U}_0\}$$

Step 2: Instead of stress levels in the components, use the known displacement at time step n and use the estimated internal forces.

$$F_n^{int} = \sum_{Elements} \int B^T \sigma_n dv \quad (3.45)$$

Step 3: At this same moment, at time step n , calculate the accelerations.

$$\{\ddot{U}_n\} = [M]^{-1} \left\{ F_n^{ext} - F_n^{int} - [C] \left\{ \dot{U}_{n-\frac{1}{2}} \right\} \right\} \quad (3.46)$$

Step 4: Assuming the time step n finishes

Exit

Step 5: Determine the next time step's estimated velocities and displacements. $n + 1$

$$\begin{aligned} \left\{ \dot{U}_{n+\frac{1}{2}} \right\} &= \left\{ \dot{U}_{n-\frac{1}{2}} \right\} + \{\ddot{U}_n\} \Delta t \\ \{U_{n+1}\} &= \{U_n\} + \left\{ \dot{U}_{n+\frac{1}{2}} \right\} \Delta t \end{aligned} \quad (3.37)$$

Time n is equal to n plus one; go to Step 2

3.4 IMPLEMENTING INTERFACES NUMERICALLY

Because it is controlled by several factors, DSSI refers to phenomena where soil and structures interact dynamically that are very challenging to use in actual structural design practice. These characteristics include a wide range of topics; examples include soil wave attenuation, nonlinear soil behavior under dynamic loads, nonlinear interfaces, soil behavior, stratum impedance, and superstructure inertia. Integrating the interaction effect into the analysis is crucial for obtaining an appropriate response from the structure when it is loaded by the earthquake.

Several different methods for modeling the interfaces were provided by the researchers. A few examples of these elements include the Friction-contact interface element, the Zero thickness element, and the Thin Interface Element. The present investigation made use of friction-contact components to forecast interaction patterns between physical

surfaces. There have been several proposals in the literature to solve the contact interface problem. Those strategies are the most popular.

- Penalty Methods,
- Method of Lagrange Multipliers,
- Constraint Methods

Theoretical foundations and numerical applications of contact interfaces for static and dynamic nonlinear analysis are presented here.

3.4.1 INTERACTION BETWEEN NODES SUBJECTED TO STATIC CONDITIONS

In this paper, we provide an element that can simulate the deformation, separation, and rebounding of two entities that start by connecting at a shared interface, and then, according the user's schedule, proceed through static loading. A simple friction contact interface element, this is it. The operation of this component is predicated on several fundamental assumptions, such as the idea that deformations are tiny and cause little changes to the contact angle. Included in the method are the constraint equations and the associated normal and tangent interface forces, which are part of an incremental virtual work equation. The stiffness matrix of an interface element may be obtained from matrices of constraint equations that are connected to the load vector. Incorporating the interface element into the system's global stiffness matrix may therefore be accomplished using techniques often used with finite elements. The state of equilibrium is achieved when the total virtual work is zero as a result of any arbitrarily displaced body. This is because the idea of limitless virtual labor is being put into practice.

$$\delta u^T \{Ku - F\} = 0 \quad (3.48)$$

Where: Digital displacement

K : world's stiffness grid

F : Varied incremental loads

The bodies may deform independently along the interface, leading to overlapping or separation, if the equation given above is a description of the assembly of two entities that are originally in touch with each other at node pairs. Conversely, if the only way for the node pairs at the interface to move is in tandem across the interface, then a fully bonded response is achieved. By preventing the displacement at each pair of nodes from exceeding the interface normal, we may learn the sliding response under each of these conditions. One possible form of the kinematic constraint equation is this:

$$Cu - a = 0 \quad (3.49)$$

Where C : bounding matrix of coefficients

a : Restrictive condition (in this instance, the displacement gap)

Using complementary virtual labor, an alternate form of the kinematic constraint equation may be expressed as

$$\delta \lambda^T \{Cu - a\} = 0 \quad (3.50)$$

We may express the scalar work as equation 3.48, and when we give constraints a virtual movement, we get the same spring stiffness as in equation 3.49, which is a type of constraint virtual work.

$$\delta \{Cu - a\}^T \lambda \quad (3.51)$$

The virtual labor may be represented as in the above equation because a and a are constants.

$$\delta u^T C^T \lambda \quad (3.52)$$

Also included are the system's limitations, or the sum of all virtual work (i.e., the sum of virtual labor from 3.48 and 3.52).

$$\delta u^T \{Ku + C^T \lambda - F\} = 0 \quad (3.53)$$

The matrices for equations 3.50 and 3.53 are as follows:

$$\delta \begin{Bmatrix} u \\ \lambda \end{Bmatrix}^T \left\{ \begin{bmatrix} K & C^T \\ C & 0 \end{bmatrix} \begin{Bmatrix} u \\ \lambda \end{Bmatrix} - \begin{Bmatrix} F \\ a \end{Bmatrix} \right\} = 0 \quad (3.54)$$

The global systems linked matrix equations for u and λ need to be solved. For each interface node, it is possible to represent the load vector f as and the elemental constraint matrix as C^* .

$$C^* = \begin{bmatrix} 0 & C^T \\ C & 0 \end{bmatrix} \quad \text{And } f = \begin{Bmatrix} 0 \\ a \end{Bmatrix} \quad (3.55)$$

Only up to the degree of freedom that the restrictions impact are the values of the matrices and vectors associated with ' u ' important. Since C^* is symmetrical, it may be constructed in the same manner as the load vector f and all other stiffness elements. Producing λ global storage sites becomes a breeze after building 'dummy' nodes in the finite element mesh. A succession of node pairings, representing the modeled interface, is seen in Figure 3.5. The x' and y' coordinates of the interface element are specified relative to the global x and y coordinate system, but they are rotated by a certain amount of degrees. At the conclusion of each specific load step k , the interface forces λ_n^k and Δb^k , as well as the relative motions Δn^k and Δy^k , determine the interface responses. The subscripts f and y represent the normal and tangent directions, respectively, while the superscript indicates the load step.

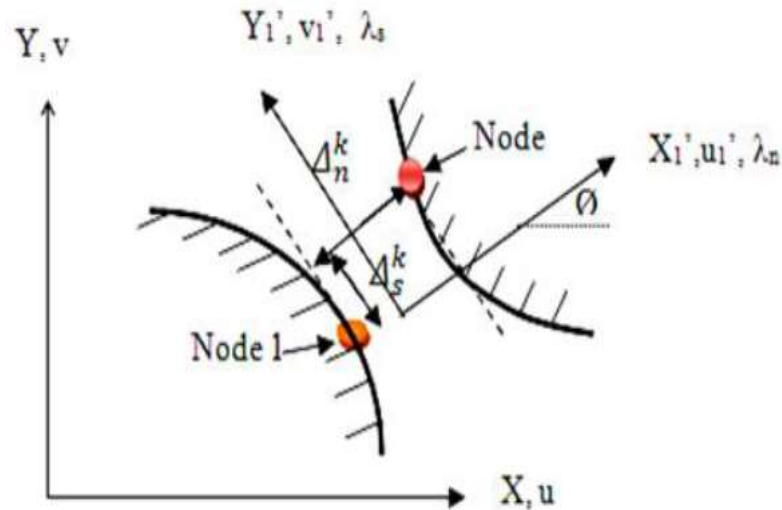


FIGURE 3. 5 Isolated UI Component - Initial Position (x_1' , y_1')

The x' and y' coordinate system allows one to describe nodal separation as a displacement.

$$\Delta_n^k = (u_2' - u_1')^k \quad (3.56)$$

$$\Delta_s^k = (v_2' - v_1')^k \quad (3.57)$$

The interface may transition between three states: fastened, slip, and free.

Fixed state: You may represent the relative normal and tangential movement between the nodes in case 2D using two constraint equations, which are as follows:

$$\begin{bmatrix} -\cos \theta & -\sin \theta & \cos \theta & \sin \theta \\ \sin \theta & -\cos \theta & -\sin \theta & \cos \theta \end{bmatrix} \begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \end{Bmatrix} = \begin{Bmatrix} a \\ b \end{Bmatrix} \quad (3.58)$$

Where, a = Typical distance between objects (reduction)

b= designated relative slip (increment) angle

Equation (3.58), as proposed by Equation (3.59), may be used to generate an element constraint matrix C* and a load vector f in global displacement coordinates. The reason for this is because in the preceding statement, the local u' and v' displacements were substituted by global u and v displacement increments. C* and f are constructed similarly to stiffness elements and are detailed in full in the upper half of Table 3.1.

TABLE 3. 1 Vector f and element constraint matrix C* for three boundary states

State	u_1	v_1	u_2	v_2	λ_n	λ_s	Load= f
Fix	0	0	0	0	-c	s	0
	0	0	0	0	-s	-c	0
	0	0	0	0	c	-s	0
	0	0	0	0	s	c	0
	-c	-s	c	s	0	0	a
	s	-c	-s	c	0	0	b
Slip	0	0	0	0	-c	0	-sT
	0	0	0	0	-s	0	cT
	0	0	0	0	c	0	sT
	0	0	0	0	s	0	-cT
	-c	-s	c	s	0	0	a

	0	0	0	0	0	1	T
Free	0	0	0	0	0	0	cN- sT
	0	0	0	0	0	0	sN + cT
	0	0	0	0	0	0	-cN + sT
	0	0	0	0	0	0	-sN -cT
	0	0	0	0	1	0	N
	0	0	0	0	0	1	T

where, $s = \sin\theta$ and $c = \cos\theta$

The normal gap and relative slip remain constant during the load step when both a and b are set to zero. The two nodes will so experience the same displacement increments.

Establishing the initial position as $a = -\Delta_n^{k-1}$, and $b = -\Delta_s^{k-1}$

Slip State: Technical Details Sliding condition is defined by the tangential interface force increment and the restriction of normal displacement increments.

$$[-\cos\theta \quad -\sin\theta \quad \cos\theta \quad \sin\theta] \begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \end{Bmatrix} = a \quad (3.59)$$

$$\lambda_s = T \quad (3.60)$$

Given that the value of λ_s has been specified, It is definitely possible to arrange the element constraint matrix and load vector as depicted in the center part of Table 3.1. The 6×6 matrix size is kept for computing ease. A common approach to modeling the friction contact interface involves iteratively computing the supplied values (i.e., T and an in the equations above). Think about the previous state of the interface—whether it was fixed, free, or sliding—and the frictional model you choose. Under the assumption of constant Coulomb friction, the maximum allowable contact tangent force at the end of load step k is

$$F^k = \mu |\lambda_n^k| \operatorname{sgn}(\lambda_s^k) \quad (3.61)$$

Where F^k : highest tangential frictional force

μ : Frictional coefficient

$$\text{sgn}(\lambda_s^k) = \begin{cases} +1, & \text{for } \lambda_s^k > 0 \\ -1, & \text{for } \lambda_s^k < 0 \end{cases}$$

Therefore, the provided incremental tangent forces consist of $T = F^k \lambda_s^{k-1}$

Free State: To enter the Free State, before you can give the force increments for the normal and tangent interfaces, you need to suppress the constraint equations,

$$\lambda_n = N \text{ and } \lambda_s = T \quad (3.62)$$

Table 3.2's lower half displays the load vector and suitable interface element matrix. For the sake of computational ease in global assembly, the element matrix size is kept at 6 x 6. What follows is a more in-depth description of an iterative strategy that may be used to identify the proper interface state.

Iterative procedure

At the $k-1$ load stage, the interface solution shown by the symbols Δn^{k-1} , Δy^{k-1} , λ_n^{k-1} , and λ_m^{k-1} , should be considered. To get the right answer at the conclusion of load step k , which can be written as $\alpha^k = \alpha + \alpha^{k-1}$, you have to get the solution increments Θ_s , Θ_n , λ_s , and λ_n . To forecast the phenomenon's physical compatibility, this must be satisfied in order to meet the contract-friction criterion.

Typically, the answer is found by iteratively solving the problem, with each iteration assuming and solving for a different condition (fix, slide, or free) until a temporary fix is found.

This trial solution is used to estimate the new load vector parameters a , b , T , or N , T , depending on whether the new step is predicted to be fixed, slip, or free.

In Table 3.3, given the abundance of tangible evidence, it is possible to test the veracity of an assumption.

As a three-by-three choice matrix, Table 3.2 may be seen as one potential interpretation. You can see the previously assumed states in the rows and the new candidate states in the columns.

TABLE 3. 2 To choose a new state for each iteration of the load step, a decision matrix

Iteration (i)	Fix	Slip	Free
Fix (i-1)	$\lambda_n^k < 0$ and $\lambda_s^k < F^k$	$\lambda_n^k < 0$ and $\lambda_s^k > F^k$	$\lambda_n^k > 0$
Slip	$\lambda_n^k < 0$ and $\Delta_s F^k < 0$	$\lambda_n^k < 0$ and $\Delta_s F^k > F^k$	$\lambda_n^k > 0$
Free	$\Delta_n^k < 0$		$\Delta_n^k > 0$

It is tested in the first row of the decision matrix whether the net normal interface force λ_n^k is compressive and if the net tangent interface force λ_s^k is less than the maximum friction value F^k , for example, if the assumed-to-be-fixed state is truly fixed. Depending on the weather, the next possible state may be sliding or free if this doesn't hold; otherwise, the fixed assumption would be wrong (for this cycle at least). This allows for an approximation of the trial state.

Table 3.3 displays the relevant load vector parameters that may be used to determine the state solution.

TABLE 3. 3 The restricted load vector's specified values

Load step (k)	Fix	Slip	Free
Fix (k-1)	$a=0,$ $b=0$	$a=0,$ $T = F^k - \lambda_s^{k-1}$	$N = -\lambda_n^{k-1}$ $T = -\lambda_s^{k-1}$
Slip	$a=0,$ $b=0$	$a=0,$ $T = F^k - \lambda_s^{k-1}$	$N = -\lambda_n^{k-1}$ $T = -\lambda_s^{k-1}$
Free	$a = -\Delta_n^{k-1},$ $b = < \Delta_s \Delta_n^k $	$a = -\Delta_n^{k-1},$ $T = F^k$	$N = 0$ $T = 0$

With the premise that this iterative technique, the interface state remains constant during each load phase. In the first stage of loading, it was thought that the node pairs were fixed and located in the same geometric spot. Assumptions two and three are correct. You can find the reasoning for verifying a solution in Table 3.2, the load vector parameters in Table 3.3, and the form that has to be constructed to build the matching constraint matrix and load vector in Table 3.1. These tables will also come in handy for subsequent rounds. In order to see convergence, the F_k values must have converged and the criterion on the major diagonal of Table 3.1 must be fulfilled.

Algorithm for contact interface under static loading:

Step 1: It is crucial to identify the initial stiffness of every part before commencing the static analysis and to record this data in the global stiffness matrix, which is represented by the symbol K . Keep in mind that there is no change to any of the interfaces.

$$[K] = K^i$$

$$f = \begin{Bmatrix} a \\ b \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix} \quad (3.63)$$

Load step, $k=0$

Iteration step, $i=0$

Step 2: Various situations are considered while estimating the elemental constraint matrix u^* and the contact load vector f , particularly fixed, slip, and Free states, is critical. As a matter of convenience, two-dimensional equations were used in this instance. Constructing the element matrix using a rotation matrix is an option for three-dimensional study.

Fixed state:

$$C^* = \begin{bmatrix} -\cos \theta & -\sin \theta & \cos \theta & \sin \theta \\ \sin \theta & -\cos \theta & -\sin \theta & \cos \theta \end{bmatrix} \quad (3.64)$$

$$f = \begin{Bmatrix} a \\ b \end{Bmatrix}$$

Slip State:

$$C^* = \begin{bmatrix} -\cos \theta & -\sin \theta & \cos \theta & \sin \theta \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (3.65)$$

$$f = \begin{Bmatrix} a \\ T \end{Bmatrix}$$

Free State

$$C^* = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (3.66)$$

$$f = \begin{Bmatrix} N \\ T \end{Bmatrix}$$

Step 3: Include the matrix of element constraints C^* at the positions of their respective degrees of freedom, place the vector of contact load f into the vectors of global stiffness and load.

Step 4: As mentioned in section 3.3.1, use the initial tangent approach to solve for the displacement and the Lagrange multipliers, which are also known as contact forces.

Step 5: Make sure each contact element is verified using the decision matrix in Table 3.2. whether the interface meets the anticipated requirements.

In the event that any contact element's decision criteria changed:

The revised load vector, Z , may be calculated by consulting Table 3.3.

$i = i+1$

Go to Step 2

Else:

Go to Step 6

Step 6: By the time the load step gets to

Exit

Else:

$$k = k + 1$$

$$n = n + 1$$

3.4.2 INTERACTIONS BETWEEN NODES SUBJECTED TO DYNAMIC LOADING

The Lagrange Multiplier approach is used to address the issue of explicit temporal integration. This is because the same strategy, which was combined with constraint equations, was utilized in the process of solving the static contact interface problem. By using the Lagrange multiplier and contact conditions, this generic dynamic equation may be expressed.

$$[M]\{\ddot{U}_n\} + [C]\{\dot{U}_n\} + [K]\{U_n\} + [G]^T\{\lambda\} = \{F^{ext}\} \quad (3.67)$$

$$[G]\{u + X\} = 0 \quad (3.68)$$

Where,

λ and the nodal contact forces make up its constituent parts, which are the Lagrange multipliers.

The coordinates are transformed from the matrix G representing the kinematic contact constraint from the global to the local axis of contact, which are typically normal vectors of the contact surfaces. It is the three-dimensional contact analysis $[3 \times 6]$ matrix.

u it represents the node's present-day displacements

X Exactly where the contact nodes are located

Conversely, The present version of the explicit time integration technique does not allow the use of the Lagrange multiplier approach. Carpenter used the forward increment Lagrange multiplier approach over explicit approaches. In this method's first stage, we predict the system's acceleration and displacement when interactions are not present. Methods like these are known as predictor-corrector techniques. Afterwards,

the virtual penetration is used to calculate the contact forces. After then, the system's reaction is revised, and the acceleration is adjusted by deducting the force from the contact.

Two parts make up total displacement.

$$u_{n+1} = u_{n+1}^* + u_{n+1}^c \quad (3.69)$$

Where,

u_{n+1}^* is movement independent of contact forces

u_{n+1}^c Displacement caused by forces acting against surfaces

The following is an estimate of the velocities, accelerations, and displacement steps in the predictor step, where there are no contact forces.

$$\{\dot{U}_n^*\} = [M]^{-1} \{F_n^{ext} - F_n^{int} - [C]\{\dot{U}_n^*\}\} \quad (3.70)$$

$$\left\{\dot{U}_{n+\frac{1}{2}}^*\right\} = \left\{\dot{U}_{n-\frac{1}{2}}^*\right\} + \{\ddot{U}_n^*\}\Delta t \quad (3.71)$$

$$\{U_{n+1}^*\} = \{U_n^*\} + \left\{\dot{U}_{n+\frac{1}{2}}^*\right\}\Delta t \quad (3.72)$$

The presence or absence of penetration is ascertained by use of a test. If penetration is detected, In order to account for the displacement caused by contact forces, a corrector step is carried out. To determine the contact force, a method is used.

$$\{\lambda_n\} = [\Delta t^2 [G_{n+1}] [M]^{-1} [G_{n+1}]^T]^{-1} \{[G_{n+1}]\{u_{n+1}^* + X\}\} \quad (3.73)$$

$$\{\ddot{U}_{n+1}^c\} = -\{M\}^{-1}[G_{n+1}]^T \{\lambda_n\} \quad (3.74)$$

$$\left\{\dot{U}_{n+\frac{1}{2}}^c\right\} = -\Delta t\{M\}^{-1}[G_{n+1}]^T \{\lambda_n\} \quad (3.75)$$

$$\{U_{n+1}^c\} = -\Delta t^2 \{M\}^{-1} [G_{n+1}]^T \{\lambda_n\} \quad (3.76)$$

Method for a contact-based, dynamic nonlinear solution:

Step 1: The displacement should be initialized at time step 0, $\{U_n\}$ and velocities $\left\{\dot{U}_{n-\frac{1}{2}}\right\}$ using known amounts as the starting point.

$n = 0;$

$$\{U_n\} = \{U_0\}; \quad (3.77)$$

$$\left\{\dot{U}_{n-\frac{1}{2}}\right\} = \left\{\dot{U}_{-\frac{1}{2}}\right\} = \{\dot{U}_0\}$$

Step 2: The internal forces may be inferred by comparing the known displacement at time step with the stresses in the elements n .

$$F_n^{int} = \sum \int B^T \sigma_n dv \quad (3.78)$$

Step 3: Calculate the accelerations in the part on the predictor at the present time step n .

$$\{\ddot{U}_n^*\} = [M]^{-1} \{F_n^{ext} - F_n^{int} - [C]\{\dot{U}_n^*\}\} \quad (3.79)$$

$$\left\{\dot{U}_{n+\frac{1}{2}}^*\right\} = \left\{\dot{U}_{n-\frac{1}{2}}^*\right\} + \{\ddot{U}_n^*\} \Delta t \quad (3.80)$$

$$\{U_{n+1}^*\} = \{U_n^*\} + \left\{\dot{U}_{n+\frac{1}{2}}^*\right\} \Delta t \quad (3.81)$$

Step 4: Recycle all interfaces that allow communication between nodes

- Verify each contact to see whether there is penetration.

If the following contact interface does not have a penetration test,

- Correcting for contact forces: an estimate

$$\{\lambda_n\} = [\Delta t^2 [G_{n+1}] [M]^{-1} [G_{n+1}]^T]^{-1} \{[G_{n+1}]\{u_{n+1}^* + X\}\} \quad (3.82)$$

$$\{\ddot{U}_n^c\} = -\{M\}^{-1}[G_{n+1}]^T \{\lambda_n\} \quad (3.83)$$

$$\left\{\dot{U}_{n+\frac{1}{2}}^c\right\} = -\Delta t\{M\}^{-1}[G_{n+1}]^T \{\lambda_n\} \quad (3.84)$$

$$\{U_{n+1}^c\} = -\Delta t^2\{M\}^{-1}[G_{n+1}]^T \{\lambda_n\} \quad (3.85)$$

- Use to determine the right answers

$$\{\ddot{U}_n\} = \{\ddot{U}_n^*\} + \{\ddot{U}_n^c\} \quad (3.86)$$

$$\left\{\dot{U}_{n+\frac{1}{2}}\right\} = \left\{\dot{U}_{n+\frac{1}{2}}^*\right\} + \left\{\dot{U}_{n+\frac{1}{2}}^c\right\} \quad (3.87)$$

$$\{U_{n+1}\} = \{U_{n+1}^*\} + \{U_{n+1}^c\} \quad (3.88)$$

Step 4: Assuming the time step n finishes

Exit

Else:

$$n = n + 1 \quad (3.89)$$

go to Step 2

3.5 SOLID STATE INTERMEDIATE FOR SSI

Because of its simplicity and widespread use, the conventional viscous limit is used for as a good example of a local boundary. Two sets of dashpots aligned in a plane perpendicular to the FE mesh as well as a normal plane border allow for its characterization (Fig. 3.6).

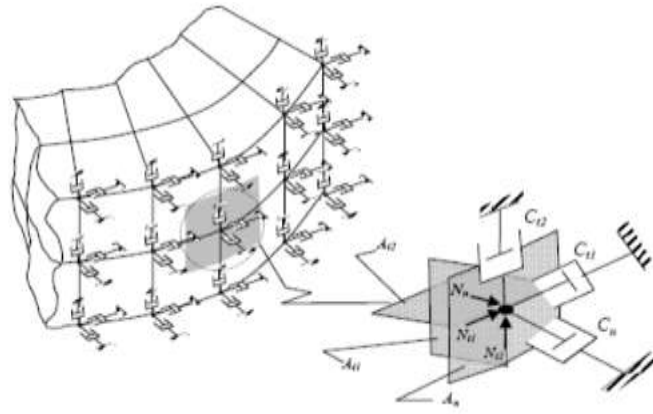


FIGURE 3. 6 Simulation of the boundary's viscosity

The absorption properties of this approach do not rely on the wave frequency, which is a major plus. Thus, the viscous boundary may allow both harmonic and non-harmonic waves to flow through. While this approach works well for one-dimensional body wave propagation, it fails miserably when used to two-and three-dimensional cases where the incidence angle is more than thirty degrees (Fig. 3.7). Large computational domains reduce the likelihood of waves with an excessive angle of incidence due to the distance between them. This means that the boundary's performance improves dramatically as its distance from the model's interest region or the excitation source increases. A number of research papers that were considered At the soil-rock interface, the bottom mesh boundary is where many numerical studies apply the seismic excitation as an acceleration time history. Conversely, to depict the distant field, the previously mentioned limits are imposed along the mesh's edges. The research now makes use of the code with the viscous barrier.

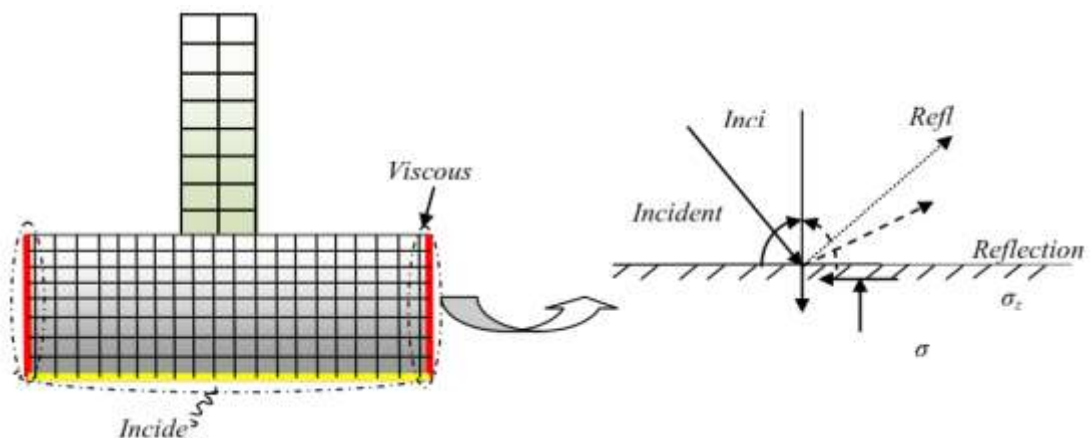


FIGURE 3. 7 Visual depiction of a barrier with viscosity

Through the application of tractions to the boundary in a manner that is counter to the stresses generated by the incident wave and equivalent to them, as shown in Figure 3.7, the energy that reaches the barrier will be absorbed.

$$\sigma_{xz} = -b \rho v_s \dot{U}_x \quad (3.90)$$

$$\sigma_{zz} = -a \rho v_p \dot{U}_z \quad (3.91)$$

Applying viscous boundary conditions allows for maximal absorption, but neither the complete spectrum of input angles nor every one of the medium's material characteristics can be perfectly absorbed.

Hence, for every material and incidence angle, the viscous boundary conditions are defined by the parameters a and b in equations (3.90) and (3.91) may be chosen in a manner that maximizes their efficiency.

One relevant measure for assessing the viscous border's ability to absorb elastic waves impinging on This is the energy ratio, which measures how much power an incident wave has relative to how much power a reflected wave has.

We may determine this ratio when wave amplitude ratios are considered by considering the energy moving into and out of a unit area at the border.

Media characteristics and incident light angle determine the values of the parameters a and b in equations (3.64) and (3.65), respectively. If both a and b are set to 1, we may use the standard boundary, which is also called the totally viscous boundary.

To put these constraints into practice, you may choose values that are equal to the stresses shown in equations 3.67 and 3.68. In order to put the strategy into action, this is certainly doable.

This data requires the following adjustments to the damping matrix.

$$C = \begin{bmatrix} An.\rho.Vp & 0 & 0 \\ 0 & At1.\rho.Vs & 0 \\ 0 & 0 & At2.\rho.Vs \end{bmatrix} \quad (3.92)$$

The area that is perpendicular to the action force is represented by the letter A for every node. The velocities of the compressive and shear waves may be approximated. (V_s) using the material's characteristics.

$$V_p = \sqrt{\frac{E}{\rho(1-2\mu)(1+\mu)}} \quad \text{and,} \quad V_s = \sqrt{\frac{E}{2\rho(1+\mu)}} \quad (3.93)$$

E is the material's elastic modulus.

ρ : determines the material's density.

μ : Poisson's ratio.

3.6 ELEMENT FORMULATION

The modeling process in this work makes use of a three-dimensional beam element and an eight-noded brick element.

The structure has been modelled using the three-dimensional beam element, while the soil and pile have been simulated using the three-dimensional brick element.

Elements with 8 Nodes in a Solid Brick Formula

Brick elements with the linear displacements that occur at each of the eight nodes are reflected by the twenty-four degrees of freedom (DOFs) that each node has. Here you can see the form functions that were obtained: where ξ , η , and μ represent the Natural Coordinates that are commonly used in three dimensions.

$$N_i^e = \frac{1}{8} (1 + \xi \xi_i) (1 + \eta \eta_i) (1 + \mu \mu_i) \quad (3.94)$$

A method for estimating displacement using N, the shape function, is described:

$$u = N u^e \quad (3.95)$$

Node displacements are related to elemental strain in matrix B, which is e

$$e = B u^e \quad (3.96)$$

is constructed and saved with the Constitutive Matrix E, resulting in the element's stiffness K matrix:

$$k_u^e = \int B^T E B dv \quad (3.97)$$

In order when solving for this elemental stiffness, the global stiffness matrix is enhanced by include the relevant degrees of freedom.

Two-Noded Three-Dimensional Beam Elements Formulation

For the purpose of modeling the structure elements, such as the beam and the columns, the two-nodded beam three-dimensional element, which has six degrees of freedom (DOFs) and includes three rotations and three translations, has been utilized.

3.7 PROCEDURE FOR FLOWING DSSI ISSUE

Figures 3.8 and 3.9, which are flow diagrams, show the process that follows in order to resolve the DSSI problem using solvers.

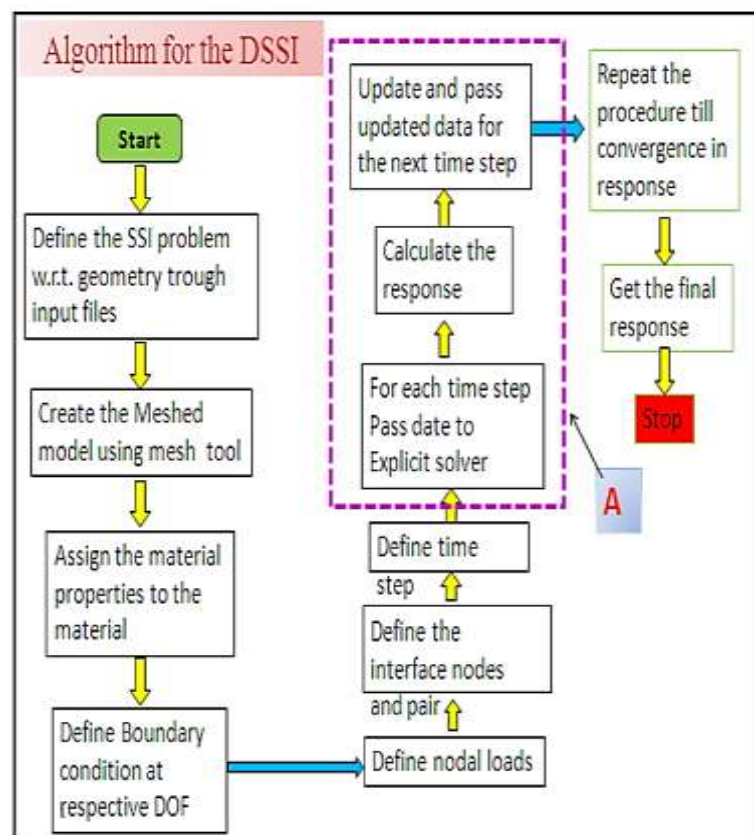


FIGURE 3. 8 Methodology for DSSI issue flow

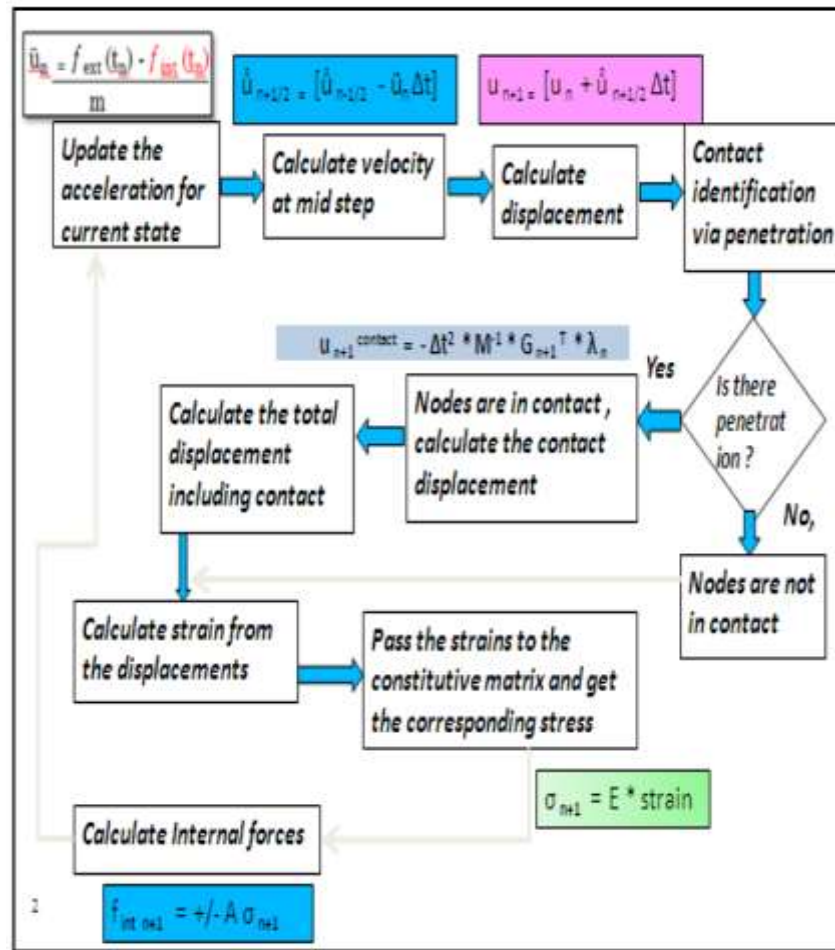


FIGURE 3. 9 Specifics of Section A

3.8 VERIFICATION OF THE APPLICATION

Accurate finite element software for interaction analysis requires precise model geometry for verification between pile-supported structures and nonlinear soil dynamics. There is a model of a square building that is 45.0 meters tall and is supported by a pile foundation system.

The findings of this model are validated with the results that have already been obtained. The purpose of this is to verify the accuracy of the software developed for this research.

In the research that was conducted by Hokmabadi, the prototype structure model was placed on the shaking table. Considering the essential features of the model structure, the SAP2000 software was used to construct the model structure. The model that was taken into account for the validation is detailed in Table 3.4.

TABLE 3. 4 Specifics of the models' underlying data

Details of foundation system						
Engg. Properties	Unit Wt. (kN/m ³)	Cohesion (kN/m ²)	Poisson's Ratio	E (kN/m ²)	V _s (m/s)	Damping
Soil	14.75	35	0.3	445,872	200	Mass Proportionate
Details of pile layout						
Pile length	Cross section	Slenderness ratio	RCC Grade	Spacing	# piles in layout	Layout shape
20.0 m	1.2 dia	16.6	M30,	3.0 m c/c	16	Square 12 x 12 m
Details of superstructure						
Bay Width and height	Beam and columns	Ht. of building	Steel Grade Frame	Young's modulus (E, map)	Tensile Strength	shape
4.0 m	15 mm steel plates	45.0 m	250 ASTM	280 Mpa	4100 Mpa	Square 12 x 12 m
Unit Wt. (kN/m ³)	Cohesion (kN/m ²)	Poisson's Ratio	E (kN/m ²)	V _s (m/s)	Mass Proportionate	
76.5	-	0.21	2.00x10 ⁸	180 0	Mass Proportionate	

In the three-dimensional numerical model, the floors are made up of fifteen steel plates that are horizontal, and the columns are made up of four steel plates that are vertical. The design utilizes steel plate grade 250, which meets Australian specifications. This grade has a minimum tensile strength of 410 MPa and a yield stress of 280 MPa. This material has been included into the design. Several iterations of trial and error were used in the design process to ascertain the thickness of the steel plates. The goal was to make sure the model's construction met the mass and natural frequency requirements. The foundation's steel plate is complete and measures 500 x 500 x 10 millimeters. The flooring is made of 400 x 400 x 5 mm plates, and the columns are four 500 x 40 x 2

mm steel plates apiece. The flooring is fastened to the columns using stainless steel metal screws that are 15 millimeters long and have a diameter of 2.5 millimeters. It is recommended to apply the competing scale model criteria to the collection of models in a manner analogous to the model structure. A well-executed model pile design considers the primary elements that influence the pile's reaction, such as the slenderness ratio L/d , correlations between moments and curvature, flexural stiffness EI , relative soil/pile stiffness, yielding behavior/mechanism, and natural vibration frequency. This is essential if you want to achieve your goal. Figure 3.10 shows the deconstructed model details, including the building's geometry and the piles.

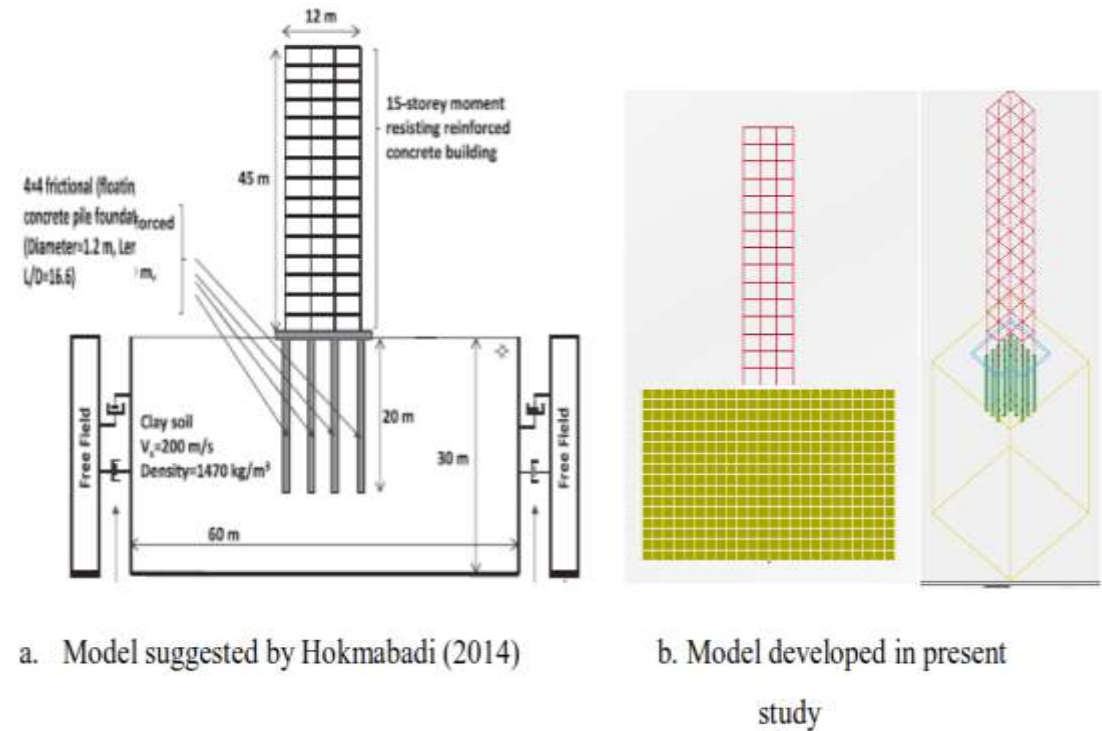


FIGURE 3. 10 Specifics of the validated Finite Element model

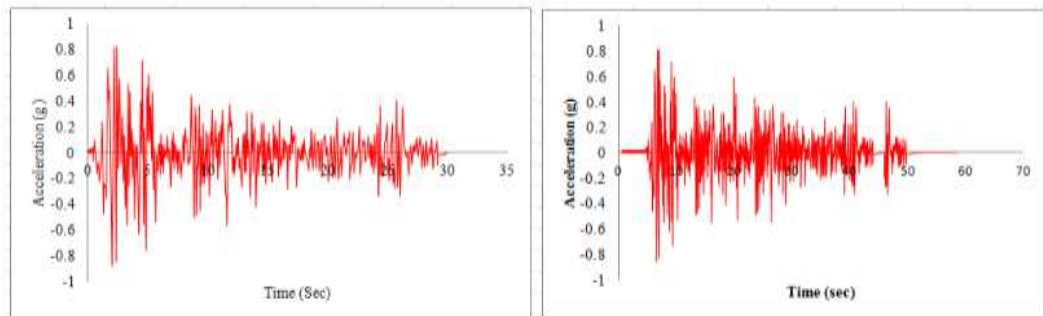
Validations that take dynamic loading into account

In the course of the dynamic study, the structure was put through three ground motions: the Northridge earthquake of 1994 ($M_w = 6.7$), the Kobe earthquake of 1995 ($M_w = 6.8$), and the El Centro earthquake of 1940 ($M_w = 6.9$). For your convenience, Table 3.5 includes the exact information of the earthquakes that were utilized in the study.

TABLE 3. 5 Data from earthquakes used to verify the current research

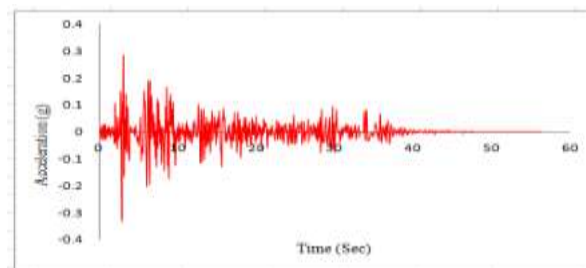
Earthquake Name	Northridge	Kobe	El Centro
Country	USA	Japan	USA
Year	1994	1995	1940
PGA (g)	0.843	0.833	0.349
M_w	6.7	6.8	6.9
Duration	30.0	56.0	56.5
Type	Near Field	Near Field	Far Field
Hypocentre Distance (km)	9.2	7.4	15.69

Figure 3.11 (a-c) displays the temporal acceleration spectra of the aforementioned rotational ground movements.



a. The 1994 Northridge (PGA = 0.84)

b. The 1995 Kobe (PGA = 0.83)



c. The 1940 El Centro (PGA = 0.34)

FIGURE 3. 11 The current investigation's input ground movements

Validation of results

This is where the SSI model begins, we run the El Centro earthquake through its paces. We compared the results from the previous studies to the ones at each level of the superstructure.

An asymmetrical structure with a height of 45.0 meters and the dynamic nonlinear analysis was performed on a pile with an aspect ratio of 16.6.

The numerical model's findings were contrasted with those of the current investigation, the experimental prototype responses created by Hokmabadi, and the superstructure.

The floor-specific responses to the interaction effect and time history analyses have been received. Figure 3.12 displays the change in the observed displacement at the superstructure's base and top over time.

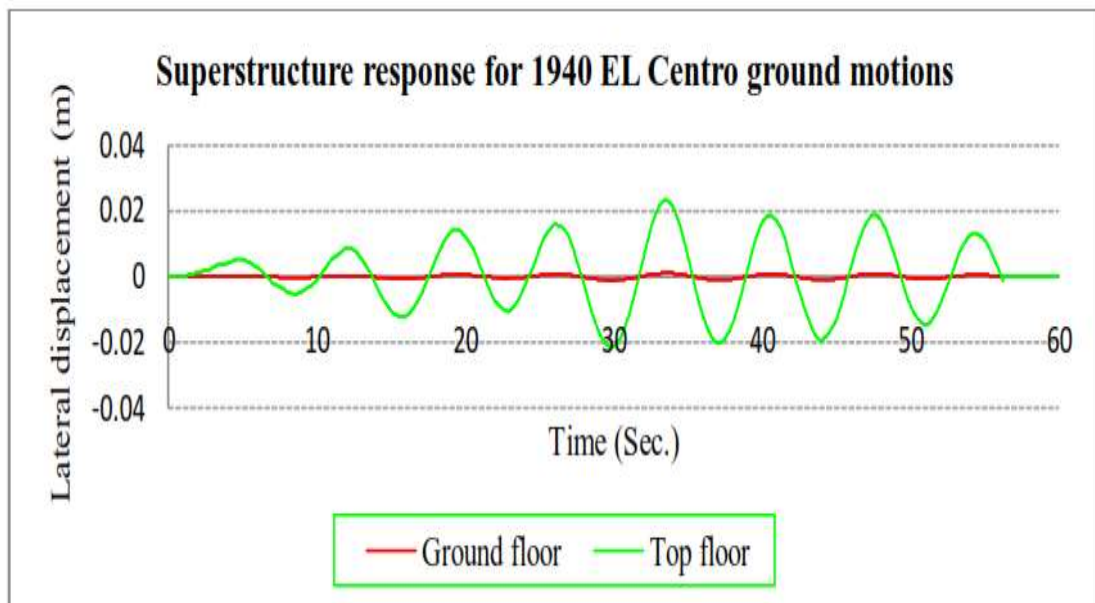


FIGURE 3. 12 The chronology, change in elevation of the superstructure at the top and bottom

Our results from the nonlinear dynamic analysis were compared to those from the experimental and numerical model developed by Hokmabadi (2014) to investigate the SSI impact. Figure 3.13 displays the comparative reactions, at different retailers, acquired from the present inquiry and the experimental model.

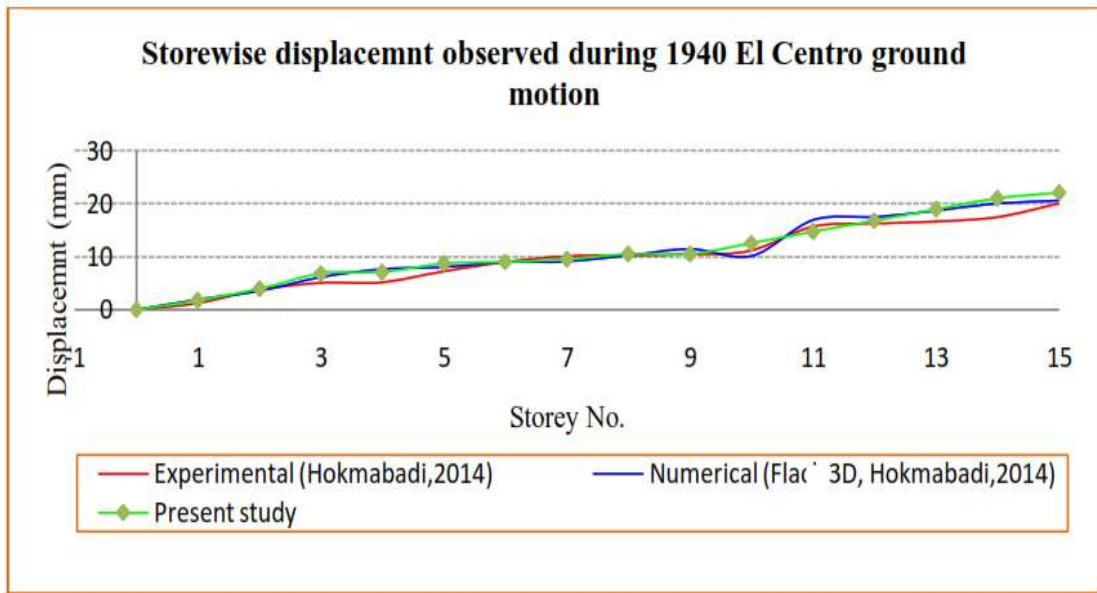
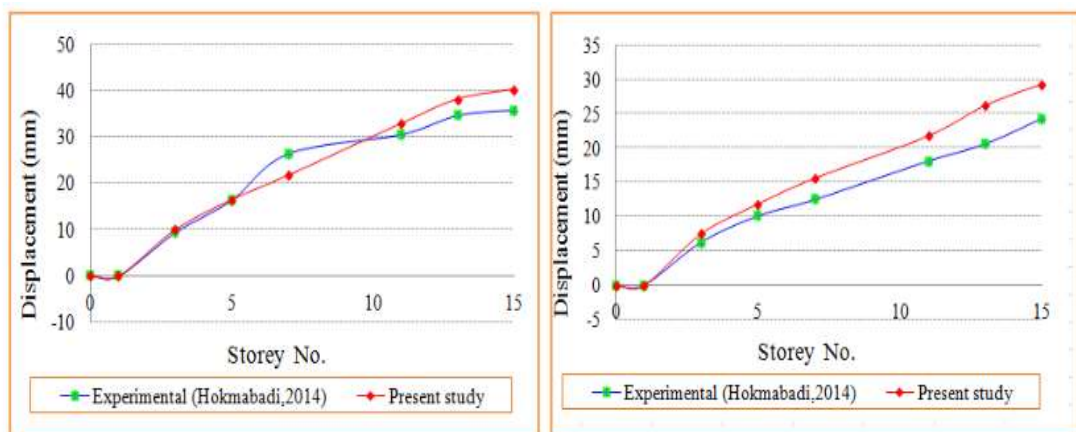


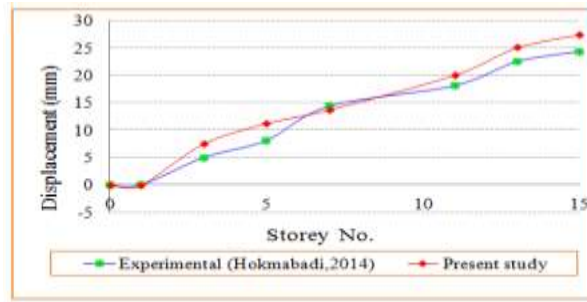
FIGURE 3. 13 Verification of Floor-by-floor displacement detected during the 1940 El Centro earthquake

Furthermore, for the 1994 Northridge earthquake and the 1995 Kobe earthquake, the time history responses were obtained. The greatest lateral reactions were investigated by Hokmabadi (2014) as part of his study on soil pile structure interaction analysis. The researcher contrasted his findings with experimental and numerical data. Figures 3.14 and 3.15 show the results of the response comparisons for different ground movements and explain how the present research was validated. The 1940 El Centro, 1994 Northridge, and 1995 Kobe earthquakes are all part of these ground movements.



a. The 1994 Northridge ground motion

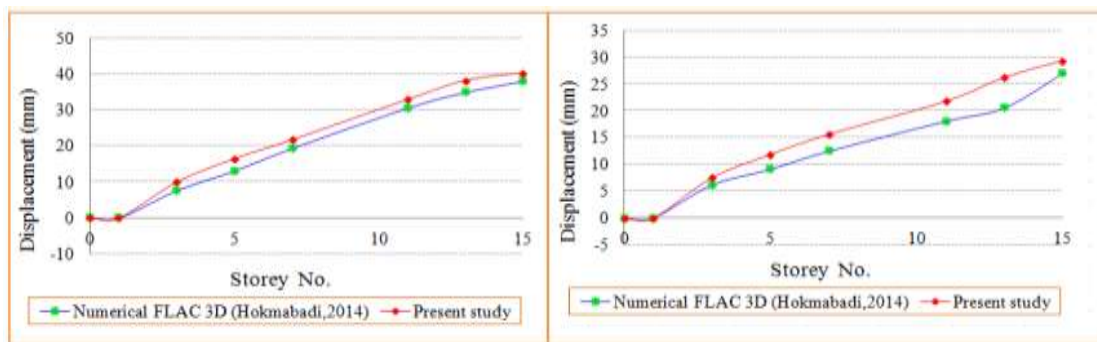
b. The 1995 Kobe ground motion



c. The 1940 El Centro ground motion

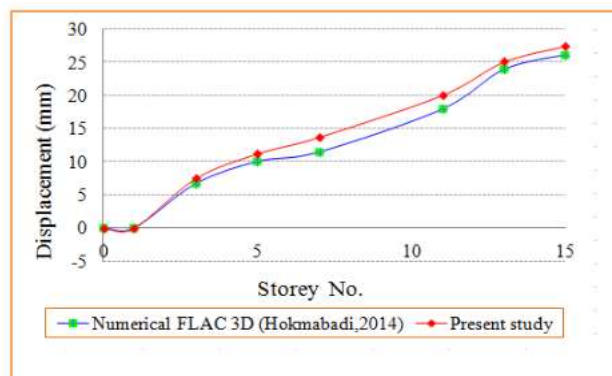
FIGURE 3. 14 Experimentally analyzing diverse ground movements, the present work verifies peak lateral displacement.

Furthermore, experimental responses for different ground motions were used to validate the current study's storey-wise maximum lateral displacement. This was done in order to gain an understanding of the functionalities and precision of the program that was constructed in the present study.



a. The 1994 Northridge ground motion

b. The 1995 Kobe ground motion



c. The 1940 El Centro ground motion

FIGURE 3. 15 The current work validates the peak lateral displacement by numerical analysis of different ground motions.

To further comprehend the superstructure's performance in terms of safety, the story is contrasted with the experimental and numerical analyses (Fig. 3.16).

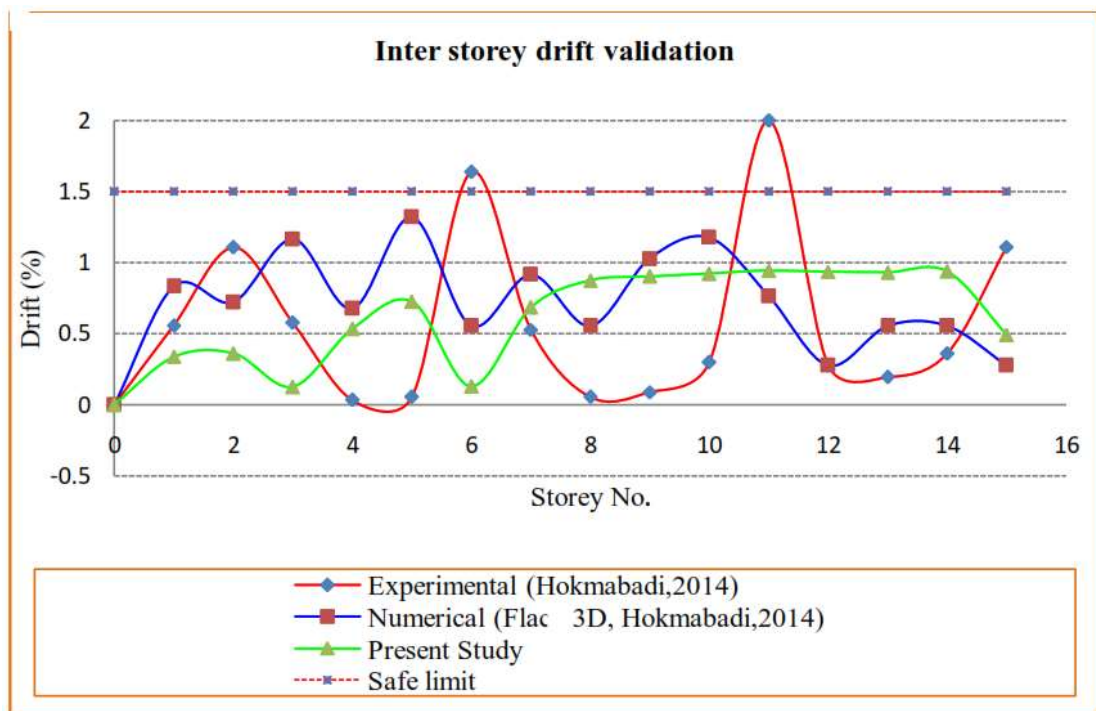


FIGURE 3. 16 Confirmation of Inter-story Drift in 1940 El Centro Earthquake

When lateral loads are applied, the performance-based engineering design standards consider the inter-story drift to be between 1.0 and 4.0%. Doing so guarantees the building will remain safe even when exposed to seismic activity.

According to the studies that were considered for this study's validation, a level of drift of 1.5% was considered acceptable. The predicted interstorey drift did not beyond the safe limit of the structure, according to the findings of the program's dynamic nonlinear analysis. The data shown in Figure 3.16 supports the conclusion that the building has an appropriate amount of interstorey drift. There was a 3.5% discrepancy between the findings of the numerical study and the current research, and an average discrepancy of 7.0% between the results of the experimental study and the present study. The numerical findings obtained by solving the SSI system using FLAC-3D showed a greater agreement with the results obtained from this study's analysis than the ones obtained from experiments. It was necessary to compare the experimental and numerical results for each of the ground motions considered in the study with the deviation in the peak response in order to carry out the validation evaluation of the

program that was built to examine the dynamic piling soil structure system. Table 3.6 displays the results of the validation tests and their analysis.

TABLE 3. 6 Evaluation of the current study's validity

Ground Motion	Experimental (Hokmabadi,2014)	Numerical FLAC 3D (Hokmabadi,2014)	Present study	Deviation w.r.t. Experimental (%)	Deviation w.r.t. Numerical (%)
Northridge	35.88	38.125	40.32	11.01	5.76
Kobe	24.37	27.11	29.375	17.04	8.35
El Centro	24.68	26.14	27.5	10.25	5.20

In order to test the finite element program that was created for this study, a 45 m tall and 12 m wide building frame was used. The frame was placed on clayey soil with a shear wave velocity of 200 m/s and a unit weight of 14.40 kilonewtons per cubic meter. To account for the laminar soil container proposed by Hokmabadi (2014), a geometric scaling factor of 1.30 was used. A 15-story steel structural model with a 0.20 m cross section was used to construct the building's structure.

- Using the tool established for this study, the same SSI model has been generated for the 1940 El Centro (M=7.0). Results from both the FLAC-3D numerical model and the shaking table experimental model have been used to compare and contrast the results of completely nonlinear time history dynamic studies.
- The present study's top storey response differs from the experimental study by 10% for the ground motion of the Northridge earthquake in 1994 (PGA = 0.84) and the El Centro earthquake in 1940 (PGA = 0.34), but by 17% for the Kobe earthquake (PGA = 0.83), according to the experimental average values of maximum lateral displacement of pile-supported buildings.

Both the present study and the numerical analysis reveal a 5% deviation in the maximum lateral displacement for the ground motions in 1994 at Northridge (PGA = 0.84) and 1940 at El Centro (PGA = 0.34), but an 8% deviation for the Kobe earthquake (PGA = 0.83).

- The drift shows a better agreement with the numerical studies and the experimental results when considered with the El Centro ground motion.
- The numerical forecasts and the facts from the lab seem to be in perfect harmony with each other. Consequently, the numerical model of the soil-structure system may, with some degree of success, reproduce the real system's behavior. It follows that the suggested numerical soil-structure model is a suitable and practical simulation approach with sufficient precision for future numerical dynamic soil-structure interaction studies.

CHAPTER 4

RESULT AND DISCUSSION

4.1 DSSI FOR PILE SUPPORTED ASYMMETRICAL BUILDING

The material a structure is constructed from determines how it responds to earthquakes. The dynamic reactivity of soil differs significantly from that of a rock-based superstructure and even changes with the kind of soil and its current condition. Despite the fact that almost every construction has some kind of foundation in the ground, fixed base analysis is often included throughout the design and analysis phases. In seismic analysis, the structure is informed about the soil's dynamic reactivity. Without a doubt, the answer produced from the fixed base reaction is different from the real response. Considering the influence of soil-structure interaction throughout the investigation is strongly advised for a better response from the superstructure. The structural response is determined by the interaction between the soil properties, the structure, and the input motion, according to a research called Soil Structure Interaction under Dynamic Loading Conditions (DSSI). In the event of free-field seismic ground movements, its purpose is to determine the true stresses acting on the soil-structure system. Buildings undergo seismic excitation, local site impacts, and DSSI phenomenon effects as a result of earthquake features and transit route effects.

As to Chandler's definition, mid-rise buildings are clusters of five to fifteen-story residential complexes. The G + 10 pile supported L-shape R.C.C. building is considered to cover this range in relation to this specification. When deciding on the initial pile arrangement, both the critical load condition during an earthquake and the frame gravity load are considered. The selected bridge width in megacities is in line with the norms and practices of conventional building design and construction.

4.1.1 METHODS FOR ESTIMATION SETTLEMENT OF PILE GROUP

Several methods have been detailed in the literature for the aim of determining pile foundation settling. Empirical approaches, simple methods of manual computation, and advanced numerical methods like finite element and finite difference evaluations are all part of this category. An approach that appropriately considers the pile-soil interaction has been prioritized, while still allowing for some approximations in soil modeling, in an effort to trace the development of rational techniques for estimating

pile group settlements. All previous approaches to estimating group settlement have focused in on the connection between group and individual pile settling. The settling of stacked raft foundations and the usefulness of the simpler analytical approaches have also been briefly addressed. Finally, it will be shown that misleading findings may be produced by using group settlement analysis carelessly, and it will be underlined how important it is to precisely estimate geotechnical parameters. An attempt will be made to close some of the gaps between research and practice using this strategy.

Many piles' settling rates may differ substantially from one pile's settling rate, even while the average load level remains constant. There are a variety of methods used to estimate the amount of settlement that pile groups face:

- **Interaction factor method:** It makes use of interaction factors and the superposition principle to determine the total number of piles in the group.
- **The settlement ratio method:** A modification to a single pile load-settlement curve is necessary to account for the impacts of group interaction. This is carried out so that this goal may be fulfilled. This approach uses a group settlement ratio multiplied by the average load level settlement of a single pile. To determine the individual pile settlements, this ratio takes into account the effects of group interaction;
- **The equivalent raft method:** Here, a comparable raft operating at a typical depth along the piles stands in for the pile group.
- **The equivalent pier method:** Here, a pier around the piles and the space between them stands in for the pile group. The pier is considered as one uniformly stiff pile for the purpose of calculating the average settling of the group.

When compared to other empirical methodologies, the similar pier approach's ability to precisely implement the soil pile interaction effect is its strongest suit. Consequently, this research assessed the piling group's and the superstructure's dynamic displacements.

Achieving this was made possible by consolidating the piling group into a single, similarly rigid pier.

4.1.2 PROJECT DETAILS FOR THE FIRST PILE

Utilizing the finite element program SAP200V14, a generalized understanding of the reaction forces communicated from the superstructure to the foundation was conjured up. There are three kinds of forces that are taken into account: horizontal, vertical, and moment. A dynamic fixed base linear analysis has been performed on the superstructure as a result of this. In Table 4.1, you can see the provided structural setup for this study.

TABLE 4. 1 Specifics of the investigation and the structural parameters taken into account in this investigation

Structural details						
Bay Width and height	Cross section of floor beam and columns	Ht. of building	R.C.C Grade Frame and rebar	Young's modulus (E)	Concrete density	Asymmetry shape
3.0 m	0.23 * 0.23m	33.0 m	M20,Fe415	2.0×10^7 kN/m ²	2400 kg/m ³	L-shape
Analysis details						
Analysis Type	Ground motion	PGA	Type of element	Load case	Output	Damping
Linear dynamic time history fixed base analysis	ground motion (Mw= 7.6)	0.31g	1D bar element	Modal (EQ + Self wt. of superstructure)	Lateral, vertical and moment at the end of base of column	5%

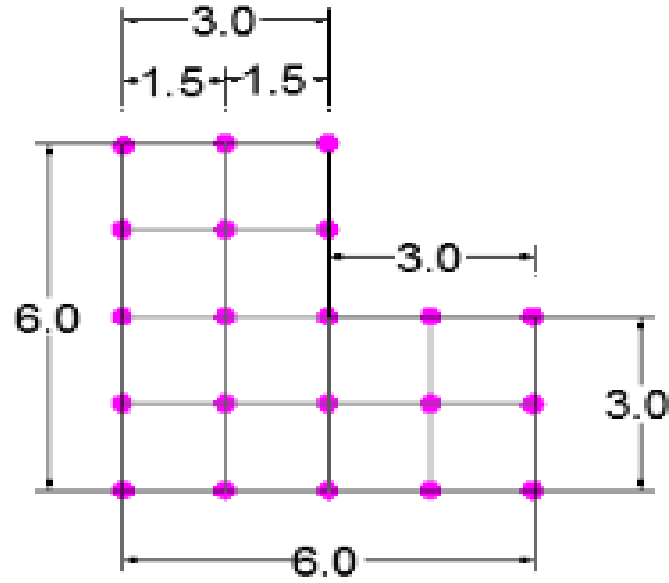


Figure 4. 1 Specifics of the linear programming model for heaps

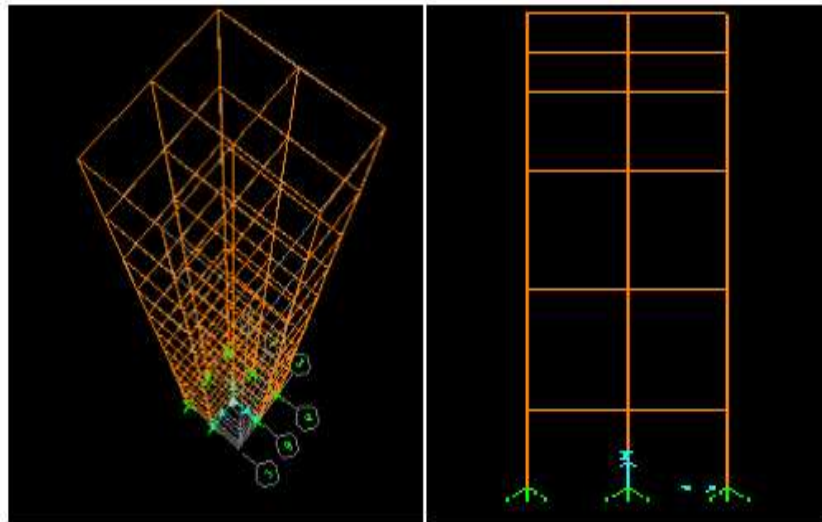


Figure 4. 2 Fragmentation of the FE model

When replies were visible at the base of the building's column, the first pile measurements were established manually. We did all this while keeping an eye on the replies. The design requirements for the single pile were taken into account, and a starting pile diameter of 0.45 meters was determined. This determination was based on responses gathered from the linear dynamic analysis. We verified the data to the soil type found there to ensure accuracy. When it comes to design and construction, the common rule of thumb is that the floating pile settles at a pace 60% higher than the

bearing pile. Taking these two factors into account for a specific kind of soil yields an L/D ratio of 20 (Figure 4.3). Because of this, we settled on a 9.0 meter length and a 0.45 meter breadth for the pile.

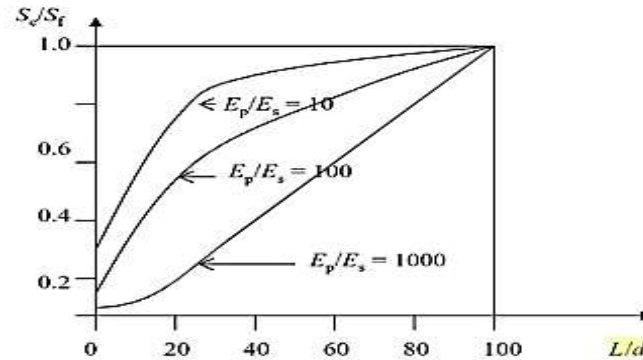


Figure 4. 3 The correlation between pile aspect ratio and settling factor

One recommendation is to leave at least three times the pile shaft's diameter between each set of cast-in-situ friction piles, as stated in clause 6.6.2 of International Standard 2911 (Part 1 Section 1, Rev. 2010). This will guarantee that there will be spaces between the piles where dirt may be found. Hence, in accordance with this study's suggestion, the piles are 1.5 meters apart, which is more than three times the diameter of the pile. This spacing has been included into the parametric for all soil types. The lack of defined standards about spacing in relation to soil type is the reason behind this. When d is the diameter of the friction pile, the optimal spacing between them is three times that number. By carefully planning the spacing of three-dimensional piles, we may ensure that the stress zones of nearby friction piles are kept to a minimum, resulting in optimal group efficiency. A current s/d ratio of 3.33 was determined to accommodate the 21 provided piles, which have a diameter of 0.45 meters, a length of 9.0 meters, and 1.5 meters of space between each pile in the L-shaped arrangement.

4.1.3 THE G+10 DSSI SYSTEM MODELING ASPECT

The DSSI system has been analyzed using C++ finite element software. It is possible to use the application to do static and dynamic nonlinear analyses, as well as studies of node interactions. The input must be provided in the format of the text files as described. You will need the following input in order to execute the C++ program:

- Geometry (including elements and nodes)

- Contact details
- Boundary constraints
- Material data
- Constraints and
- Load data with respect to the DOFs.

As output, at integration locations, the software produces nodal displacement and element stresses. The text files now include all of the required output data. Also, for making elevation and sectional elevation views, the application creates binary files in the LSDYNA PrePpost (LS-PP) format. The graphics may be made with the help of the freely available software LS-PP, which is accessible online. It generates views and accepts files in the key format.

A generalized piling plan G+10 L-shaped structure has its DSSI system modelled in great detail. Symmetry characterizes the structure. The DSSI study's finite element software makes use of two kinds of elements: three-dimensional beam elements with two nodes and three-dimensional brick elements with eight nodes. Applying the soil structure interaction analysis to asymmetrical design, this study assumes a uniform soil condition. Table 4.2 delves into the engineering qualities of the primary modeling factors that were considered for the superstructure, soil, piles, and interface/contact.

TABLE 4. 2 Soil engineering features taken into account by the FE model

Engg. Properties	Unit Wt. (kN/m³)	Friction angle, ϕ' (°)	Poisson's Ratio	E(kN/m²)	Vs(m/s)	Damping
Soil type: Medium sand	18	35	0.35	445,872	300	Mass Proportionate
Super structure	24	0	0.15	2.0×10^7	1200	Mass Proportionate
Pile	24	0	0.15	2.0×10^7	1200	Mass Proportionate
Raft	24	0	0.15	2.0×10^7	1200	Mass Proportionate

Drucker-Prager data model for materials	Friction angle = 35° Cohesion C (kN/m ²) = 0 Poisson's ratio = 0.35	For linear: The dampening of mass proportion The nonlinearity occurs when the stress-strain curve exhibits hysteresis as the material begins to plastify following the attainment of yield stresses..
Interface data	Friction angle (δ) = $1/3 \phi' = 11.4^\circ$	Coefficient of friction = 0.7

Superstructure modeling

These two-nodded three-dimensional beam elements have been used to simulate the components of the G+10 superstructure, which include the beams and the column. It is generally accepted that the joints that connect the beam and the column are stiff. Rigid connections are used to model the connection that exists between the raft and the column that is located on the first floor.

Soil modeling

Table 4.2 provides a more detailed description of the engineering characteristics of the soil domain, and sandy silt is employed for half space modeling. The soil model was developed using the elastic continuum methodology. It was assumed that bedrock was present twenty meters below the soil layer. So, apart from the direction of application of the earthquake, all movements of the soil layers were contained to the bedrock level. It is essential that the finite element platform accurately depicts the boundless domain of the soil media. This is an essential part of it. A suitable minimal space was maintained between the soil's lateral border and the surface to prevent waves from the soil reflecting back. Three to four times the width of the foundation's worth of soil was included in the examination. To further mimic the impact of an endless soil media, viscous dashpots were used to establish bounds in the lateral borders.

The DSSI analysis takes into consideration a volume of 20 x 20 x 20 meters, which is given by the equation ($3 \times 6.5 = 19.5$ say 20.0 m), to meet the requirements of this particular soil domain. In order to account for this nonlinear behavior of the supporting soil, the Drucker-Prager material model was used.

Predicting raft and piling

The three-dimensional brick pieces were used to model the raft, which has a thickness of 0.4 meters and is 1.0 meters off the edges of the superstructure foundation. Both the

0.45-meter and 9.0-meter circular heaps have been modelled using three-dimensional brick components. It is possible to fit the 21 piles with a spacing of 1.5 meters c/c by using an L-shaped pile plan. A representation of the raft and piling joints has been created using the stiff connections.

Meshing

In the current investigation, For meshing the FEM, Oasys used their GSA 2-D mesher (GSA V8.6). It is necessary to provide the tool with the coordinates of each model component, such as the coordinates of the dirt block, the pile, and the raft, in order to accomplish the task of creating the mesh in two dimensions, which has then been extruded into the third dimension.

Material model

In their elastoplastic material model, Drucker and Prager characterized the nonlinear behavior of soil subjected to seismic stresses.

The model is fed information about the soil's dilatancy angle, internal friction angle, and cohesiveness. Here, the model is built using the associative flow rule, with no hardening influence and equal yield and potential functions.

Boundary conditions

Avoiding several reflections over the dynamic analysis span is essential, a viscous barrier has been modelled as part of this inquiry. One relevant measure for assessing the viscous border's ability to absorb elastic waves impinging on It is the energy ratio, which measures the difference between the incident wave's transmitted energy and the reflected wave's energy. By factoring in the energy flowing into and out of a unit area at the border, we may calculate this ratio when wave amplitude ratios are included. A viscous barrier has been represented on each of the four sides of the isolated domain in this experiment. An additional force equal to the force calculated at the beginning of each time step is applied to the extreme element nodes in order to equalize the forces at the node. There is the base element of the soil domain and the earthquake boundaries, which both contribute to displacement in the same direction as the seismic input to the research. With this change, the degrees of freedom of every other element will be zero.

The purpose of this research was to examine how the DSSI system handled the 0.31 g E-W (x-direction) earthquake that occurred in 2001.

Interface modeling

The frictional contact between nodes has been used to depict the pile-earth interface via the application of the Lagrange multiplier approach. Entering the relevant node IDs directly into the interface data file's input file is necessary for the finite element program to evaluate the DSSI system. The contact forces are computed as part of the analysis of the contact node pair. Assuming the node's contacts behave as expected, one may estimate the response of the next time step by adding their displacement to the total node displacement.

Analysis

The model is tested in two different loading scenarios: static and dynamic. Assessment of statistics to establish the starting point for stress, the DSSI system is first tested for static load. In this specific stress state, the foundation system's and the superstructure's self-weight are considered. The static analysis might be performed by applying the fixed boundary condition in the normal direction. Given the soil volume, any displacements could only occur in a straight line, starting from the surface and ending at the nodes of the extreme element. Nodal forces are applied at the corner nodes of each level in the design to account for the influence of the slabs' self-weight on the 0.15 meter thick superstructure. Using the iterative initial stiffness approach, we were able to estimate the nonlinear response of the DSSI system.

Dynamic analysis

Initially, the dynamic analysis's response was based on the stresses and displacements gathered from the static analysis. Ground motion from 2001 (PGA = 0.31G, E-W) was delivered at the soil domain's lowest locations, and the reaction peak in the 15-second time frame was evaluated (Figure 4.4). The nonlinearity of the material has been taken into account using the associative Drucker-Prager material model. This dynamic study now includes data from the 15-second earthquake, which captures the highest ground motion.

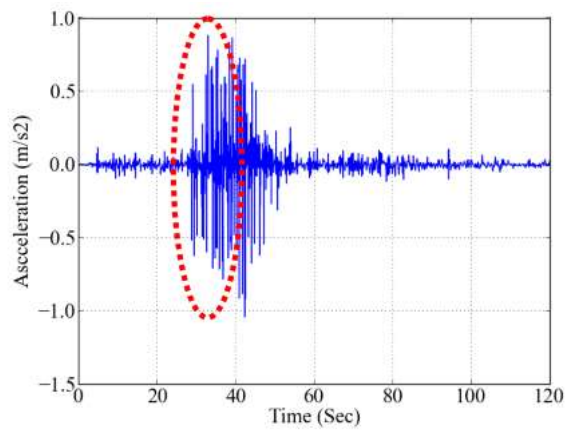


Figure 4. 4 Evaluating the ground motion in 2001 over time (PGA = 0.31g).

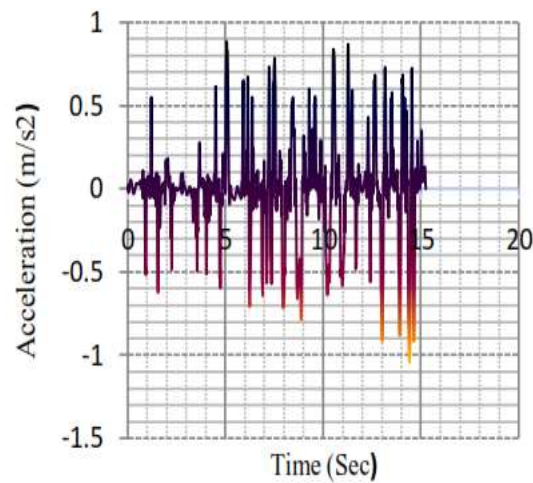


Figure 4. 5 component of ground motion that is being studied

Program Output

A text file contains the results of the C++ program that was developed to understand the DSSI system's response. The model's visuals were created using the LS-PP tool to make the research more preventive and to aid with visualizing.

File output

A comprehensive set of data, including nodal displacement, velocities, accelerations, and elemental stresses, is produced by the application. Graphs comparing the various scenarios have been constructed using this file data. To have a clearer picture of how it reacts when subjected to dynamic loading and assess the problem's importance, this research focuses only on nodal displacements.

Graphical output

In this experiment, we use LS-PP to display the DSSI system's output. A freeware program called LS-DYNA-Pre-Post may be used to manage the pre- and post-processing stages of the LS-DYNA (FE analysis software) program. The only aim of this tool is to create building views and render them. The visuals in this inquiry are created using LS-Pre-Post. This software will create a binary file for you in the d3plot format. The LS-PP tool takes this file as its input. The binary file contains data such as points' locations, displacements, speeds, accelerations, to the strains of each ingredient at each stage. With the LS-PP tool, we were able to create building elevations and sections with a more preventative approach. Looking at the finite element model in isometric perspective, Figure 4.6 shows the first pile construction. You can view the pile's initial configuration here.

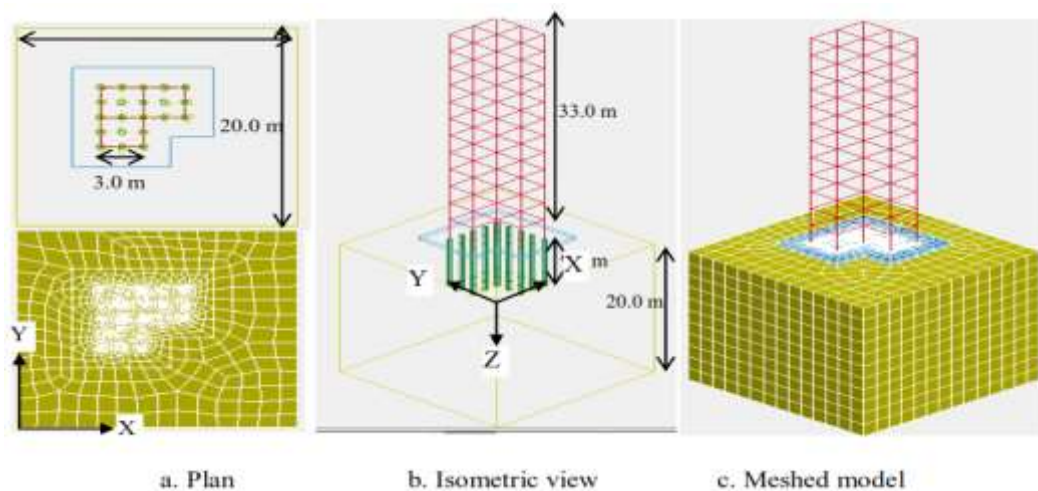


Figure 4. 6 Detailed structural model for G+10 construction in DSSI

4.1.4 POLYGROUP WITH ASYMMETRIC LAYOUT EXTENSION USING THE EQUIVALENT PIER METHOD

The soil domain that supplies support, the building's foundation, and the building's individual parts all add up to make the dynamic soil structure interaction problem quite large. This soil-structure interaction problem has to be three-dimensional if the building's base size and deep foundation system need to be taken into account in order to prevent wave reflection. The DSSI is an exceptionally difficult work to complete because of the nonlinear behavior of the soil under dynamic stress and the nonlinear

behavior of the interface between the soil and the foundation, which includes the slide, shrink, and gap between the soil and the pile components. For an appropriate simulation of the DSSI problem, it is essential to include the slide, shrink, and expansion phenomena into the interface behavior. Numerically implementing such interfaces is known to be a difficult and computationally costly task. The number of interfaces in a pile foundation system is increased because it is essential to provide at the soil face, pile cap, and structural nodes. The study's processing cost goes up because of this, and getting the lowest possible convergence level requires a lot of time steps. Minimizing the interface problem is critical for improving efficiency in computation cost, effort, result accuracy, and realism in model simulation.

If you want to know when the symmetrical pile group will settle under static loads, the equivalent pier approach is a tried-and-true way to do so. We were able to predict the settling of the pile group by taking into account the induced load at the pile tops, which is a consequence of the superstructure. Using varying piling group sizes and soil types as examples, many researchers examined the effectiveness of the similar pier method. A thorough description of the technique underlying an integrated superstructure and foundation system is lacking in the present literature. The asymmetrical pile group isn't getting its settlement assessment done, as someone else has noted. As of this writing, no one has investigated the potential effects on the superstructure's responses of switching the piling group to a comparable pier. The purpose of this research was to investigate, while taking into consideration the potential interaction effect, the consequences of replacing the asymmetrical piling group with an equivalent pier on the reactions of the superstructure and foundation under seismic loading conditions.

The present pile group of the structure has been modelled using an equivalent pier approach and interfaces attached to the equivalent pile in order to make the modeling of the large domain problem easier. The primary objective of this study is to use this approach in order to lower the cost of computing.

Concept of Equivalent Pier Method for Theory

For the purpose of analyzing massive, heavy superstructures that make use of a large piling group, The Equivalent Pier approach was introduced by Paulos and Davis. This was the approach Horikoshi used when he needed to do the settlement analysis for the

big pile group. The settlement of the pile groups may be more easily determined by merging them into a single pier and using load-transfer functions; this approach is equivalent to determining the settlement of a single pile. To implement this approach, we substitute the piles with a pier of comparable length (Figure 4.7) and calculate its diameter (D_{eq}) using the same formula.

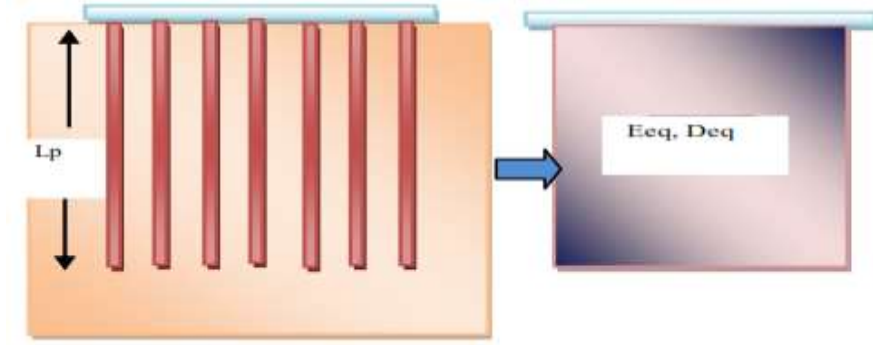


Figure 4. 7 The notion of the comparable pier technique

This equation gives the comparable pier's diameter.

$$D_{eq} = 2\sqrt{\frac{A_g}{\pi}} \quad \text{OR} \quad 1.13 \text{ to } 1.27 \sqrt{A_g} \quad (4.1)$$

In such case, A_g maps out the whole pile cluster, including the ground in between.

The value that is bigger is more appropriate for piles that are mostly frictional or floating, whereas the number that is smaller is more appropriate for piles that are mainly end bearing in Equation 4.1. Since the equivalent pier takes the soil trapped in the piling space into account, it is crucial to alter the Young's modulus before to doing the analysis. For the same pier, the Young's modulus may be expressed as follows:

$$E_{eq} = \frac{(E_p - E_s)}{A_g} + E_s \quad (4.2)$$

Where E_p represents the pile's Young's modulus,

E_s represents the soil's Young's modulus as it is pushed through the piles

A_{np} is the aggregate cross-sectional area of all the piles in a given set.

A_g encompasses the whole pile group's plan area, including the soil that lies between each pile.

Research by Poulos and Randolph on the consistency of the comparable pier approach to group forecasting settlements has shown that it yields good results. The correlation between pile count and end bearing pile group settling has been the subject of Poulos's study. A comparison of the solutions provided by the computer software DEFPIG, the equivalent raft method, and the equivalent pier techniques showed that for over nine piles, they were all quite comparable with each other. Thus, EPM has shown to be beneficial for symmetric stacks; however, no effort has been made to confirm its usefulness for asymmetrical piles.

Discovering the Same Pier via Trial and Error

This study's findings show that a comparable pier with changed diameter and modulus of elasticity has replaced the previous piling group (Table 4.3). Although the system works well for symmetric pile groups, it has to be adjusted to work with asymmetrical pile groups using a trial-and-error setup of the same pier site (Figure 4.8).

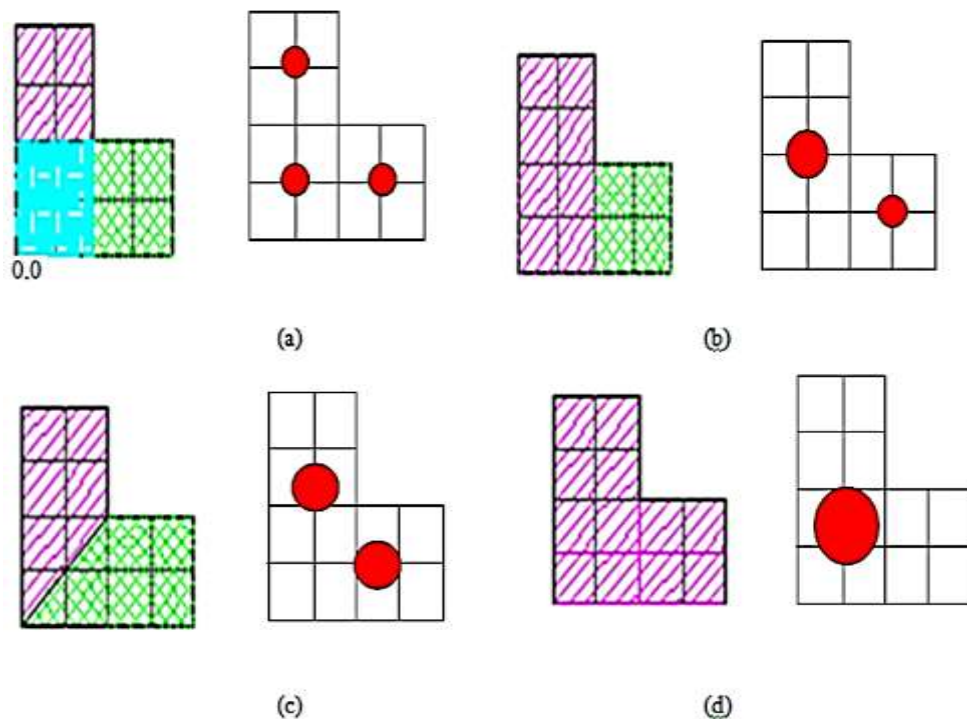


Figure 4. 8 The current investigation examined several experimental layouts for Equivalent pier.

TABLE 4. 3 Figure 4.8 shows the details of an analogous pier for each of the four configurations: EPM 1, EPM 2, EPM 3, and EPM 4.

Are a no.	L(m)	B(m)	No. of Piles participat ing	A_g (m^2)	Deq (m)	E_s (kN/m ²)	E_p (kN/m ²)	E_{eq} (kN/m ²)	Location (x,y) (m,m)
EPM 1									
1	3	3	7.5	9	3.2	445872	2.93×10^7	3.93×10^6	(1.5 ,4.5)
2	3	3	6.5	9	3.2	445872	2.93×10^7	3.41×10^6	(1.5,1.5)
3	3	3	7.5	9	3.2	445872	2.93×10^7	3.93×10^6	(4.5,1.5)
EPM 2									
1	3	6	13.5	18	4.5	445872	2.93×10^7	3.54×10^6	(1.5, 3.0)
2	3	3	7.5	9	3.2	445872	2.93×10^7	3.93×10^6	(4.5, 1.5)
EPM 3									
1	3	3	10.5	13.5	4.2	445872	2.93×10^7	3.67×10^6	(1.67,3.67)
2	3	3	10.5	13.5	4.2	445872	2.93×10^7	3.67×10^6	(3.67,1.67)
EPM 4									
1	6	3	21	27	5.8	445872	2.93×10^7	3.67×10^6	(2.5,2.5)

The current investigation is carried out by means of a custom-built C++ program that models the G+10 L-shape pile-supported structure. In order to replicate the system and base, we employ an eight-node three-dimensional brick element. To account for the soil's nonlinearity, the model of elastoplastic materials employed is the Drucker-Prager model.

Rocking of the pile group

When the pile group is subjected to lateral stress, it undergoes what is known as rocking, which is a cross-coupled horizontal movement. Figure 4.9 shows that this occurs due to the fact that the location at the base that corresponds to the centroid of the foundation cannot be approximated. The rocking impact is often very invisible on shallow foundations. However, the rocking impact becomes more apparent as the embedment depth increases. Therefore, the rocking effect must be considered throughout the pile foundation system design process. This is because both the foundation depth and the magnitude of the lateral load are much higher.

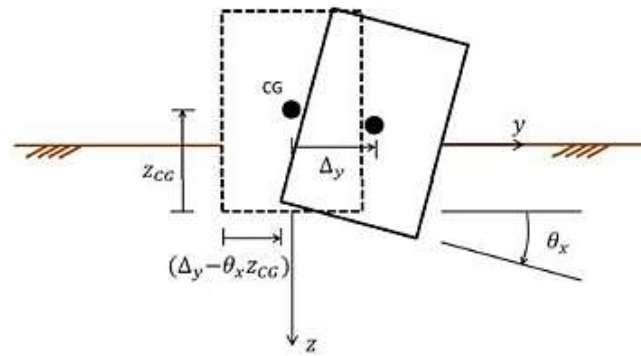


Figure 4. 9 Combined oscillations in the horizontal and rocking planes

For the study of the finite element formulation being discussed, eight noded brick elements with three degrees of freedom each are used. There are three independent degrees of freedom (DOFs) that allow rotations to be shown in the analysis. To get the three parts of shear strains (rotations) and normal strains, one has to know these displacements. Part of this analysis involves assuming that the raft is rigid in all three dimensions (x , y , and z). If the raft's rigid body movement at the connections of the piled raft is analyzed, the connected pile's rotation—the rocking of the pile—may be revealed. This seems to be a fair assumption to make since, in practice, stacked rafts behave more like rigid bodies, particularly when they are thrust to one side. The raft is positioned appropriately and the overall configuration of the pile is seen in Figures 4.10 and 4.11.

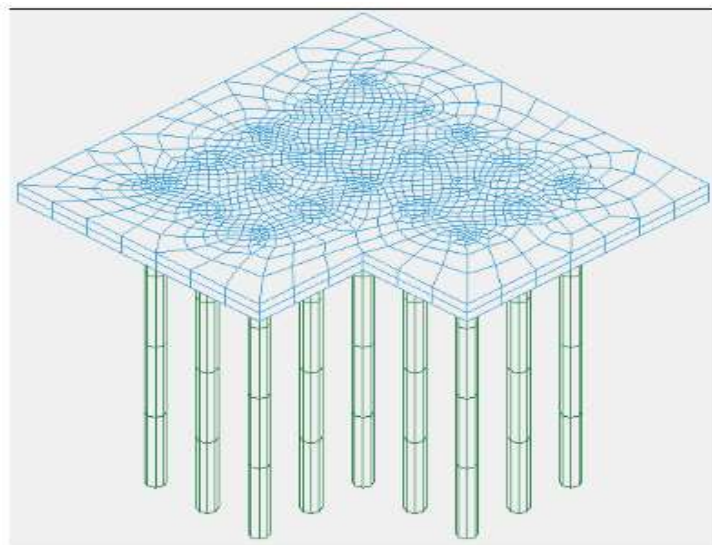


Figure 4. 10 A raft-filled L-shaped pile arrangement

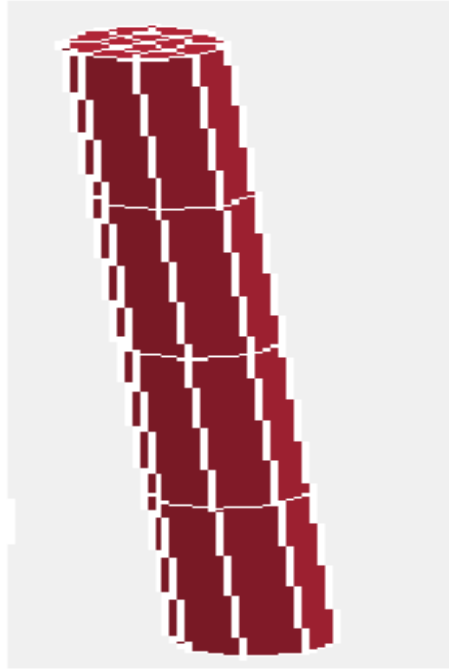
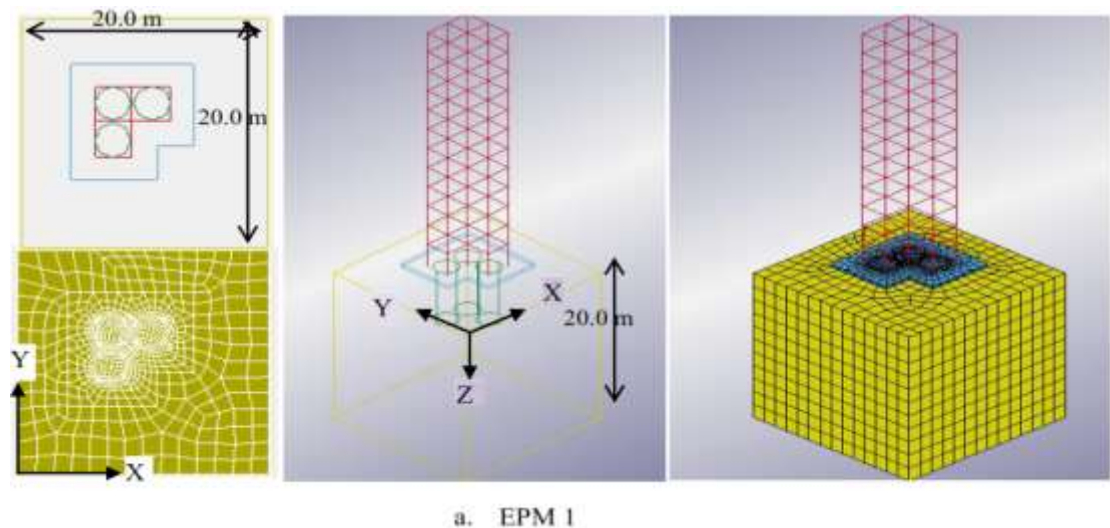
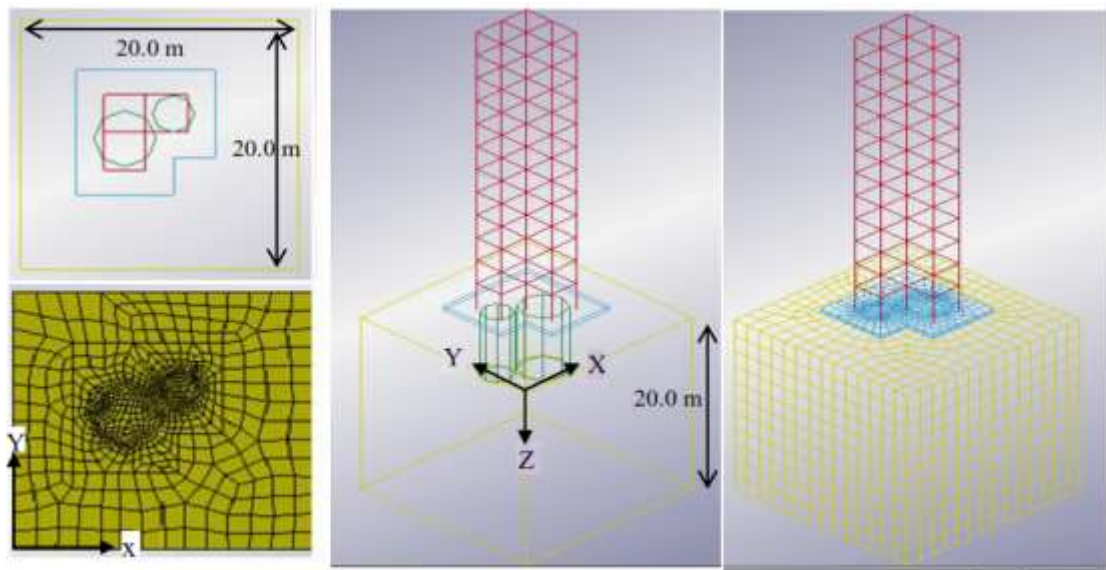


Figure 4. 11 FE model of a group's lone pile

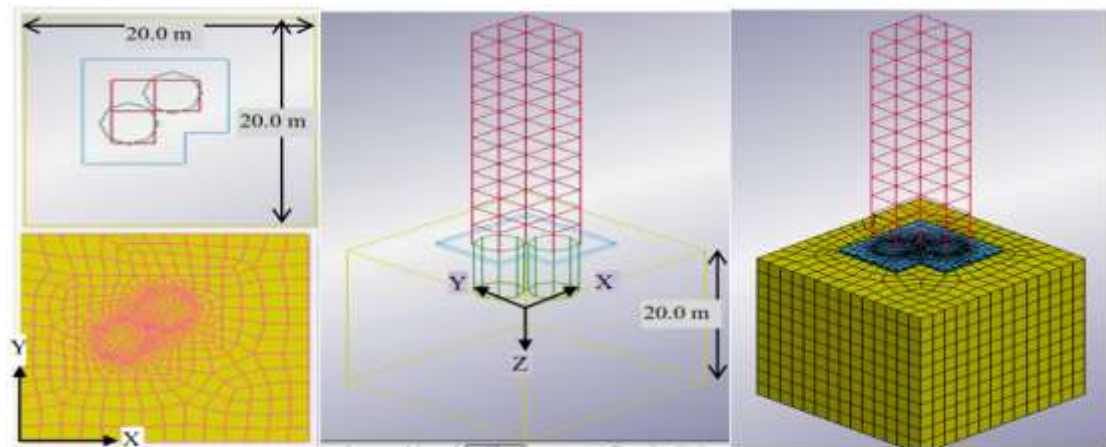
Model for EPM setup using Finite Element Technique

The LS-PP graphical tool played a significant role in developing the FEM. To do this, we imported the mesh coordinate file in the.key format. All of the model's EPM variants are shown in Figure 4.12, namely EPM1, EPM2, EPM3, and EPM4. All of the dimensions, material properties, and pier placements are derived from the data shown in Table 4.3. The exact dimensions of the raft, the structural arrangements, and the amount of soil that has to be filled have all been meticulously maintained, along with the basic or current pile pattern.

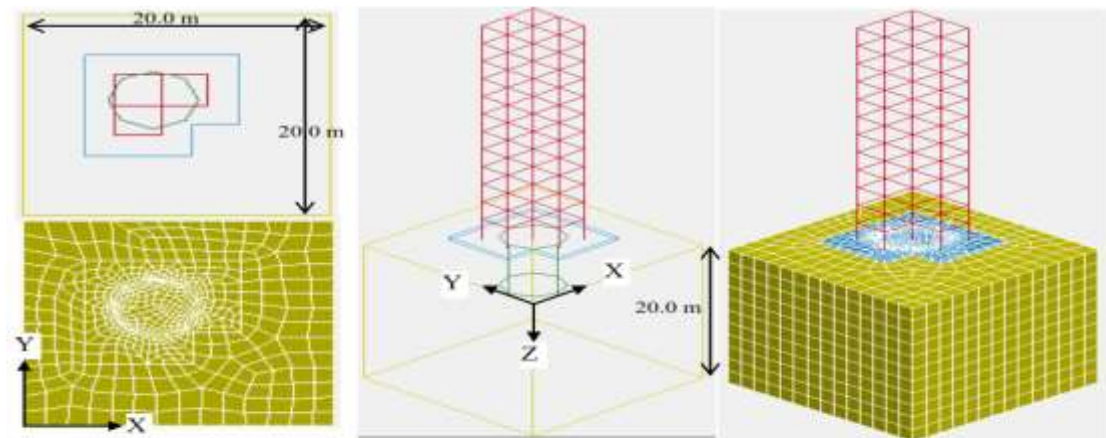




b. EPM 2



c. EPM 3



d. EPM 4

Figure 4. 12 Modeling finite elements for various EPM setups

4.1.5 RESULTS

The 2001 ground motion analysis of the G+10 R.C.C. L-shaped asymmetrical structure, which was supported by a pile foundation system on uniform soil layers, yielded a PGA value of 0.31g. While making an educated guess, we factor in things like how the Equivalent Pier Method can cut down on computational work and modeling complexity, how the pier's diameter and length affect the superstructure's response, and how the structure acts and reacts to different dynamic loadings. This way, we can get a good idea of what the results will be.

In the sections that before this one, we examined each issue independently and discussed the results of the investigation.

Construction response, incorporating DSSI for standard pile layout

Figure 4.13 shows the estimated system reaction for a generic pile design at the building's corners. This answer considers both the structural framework and the base systems. Every corner (A, B, C, D, E, and F) and every main axis (X, Y, and Z) of the superstructure, as well as every story height, has had its reaction evaluated. What you see in Figure 4.14 are the X, Y, and Z replies. The reactions are shown at several points on the upper floor for the standard layout of the piles. At each building corner, The reaction has been contrasted with the mandated ground shifts(Figure 4.15), with the goal of gaining an understanding of the influence that asymmetry has.

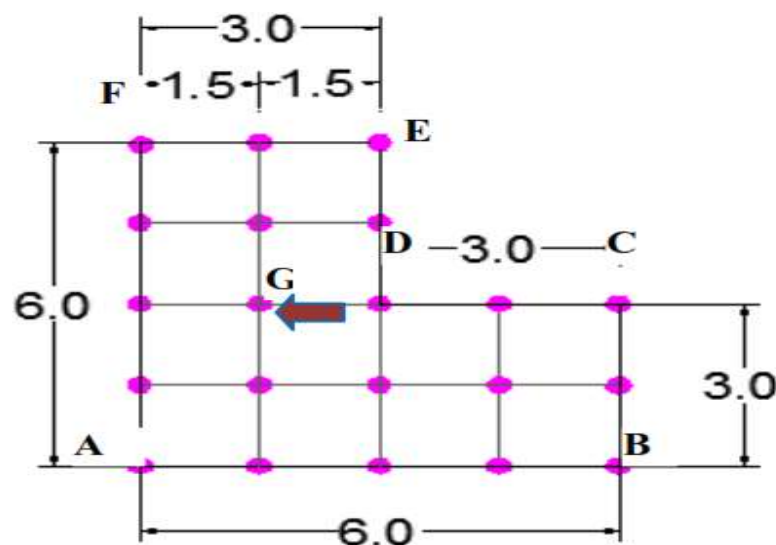


Figure 4. 13 Displacement histories for Response Location

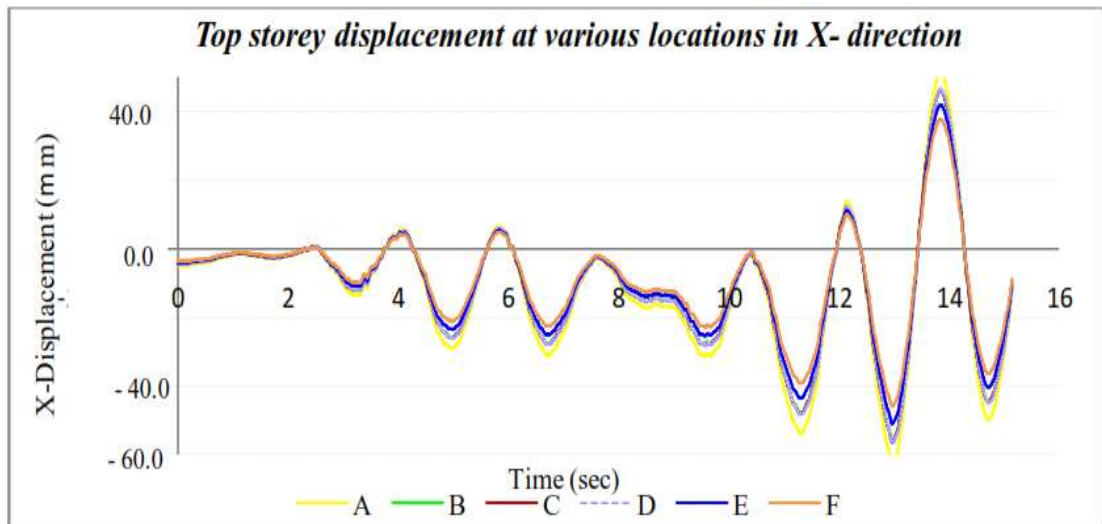


Figure 4. 14 Top floor reactions in the X direction at different top floor locations

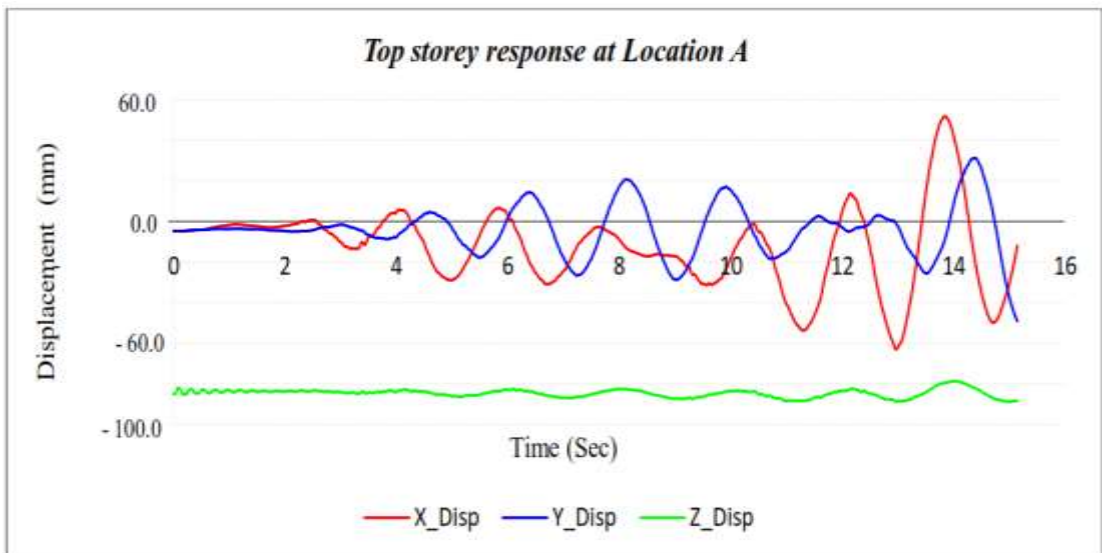


Figure 4. 15 Top storey responses at in different principal directions

They may be moving in the same general direction, but the magnitude varies somewhat at each corner. The time history displacements that were recorded and analyzed at different locations on the top floor are reported. The motions at each corner were determined to be within 4% of each other. The responses of the Y and Z directions have also been found. Because of the asymmetry introduced by the building's design, shoppers are able to roam freely across the whole megastore. The reaction in the soil mass underneath the raft has also been modeled using piling soil interaction in order to understand the influence of soil interaction on the structural component. The

displacement that occurred at point G below the raft level reached a depth of 20 meters, as seen in Figures 4.16 and 4.17.

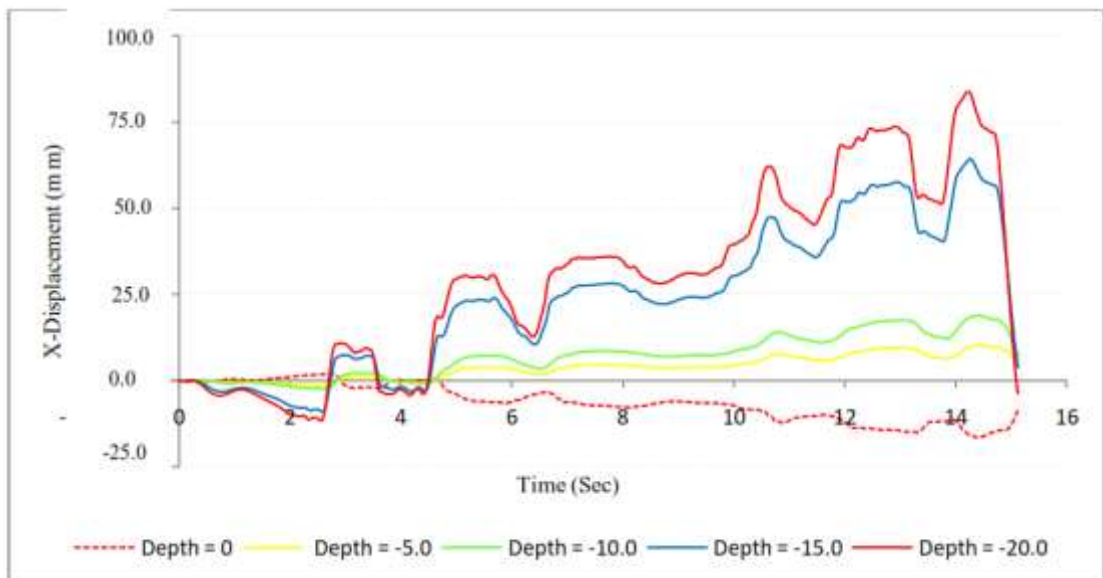


Figure 4. 16 Soil displacements in X-direction at location G

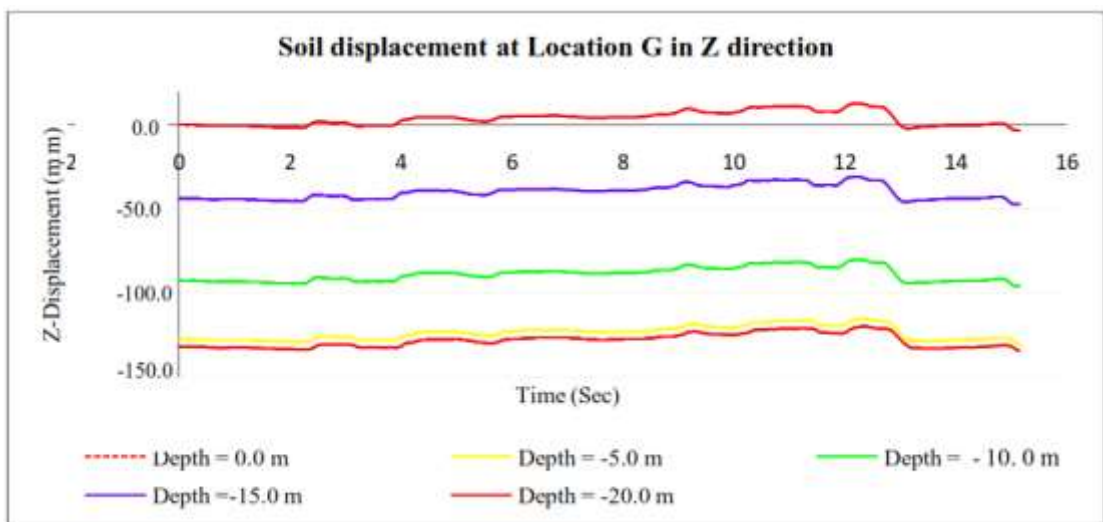


Figure 4. 17 Historical context of foundation system displacement

As previously mentioned, the dynamic analysis is ongoing along with the foundation system's mobility. Some have pointed out that tracking the point's motion in relation to the central pile could provide information on the analysis's kinematic interactions, represented by the letter G. After looking at the displacement along the ground motion's direction of application, we determined that the biggest displacement was close to the shaking point. Displacements are less at the lowest position (15.0 m), while they are

larger at the highest points (10.0 m), and 5.0 m. The spot with the least displacement is the one at the very top of the raft. You can see that the wave's energy drops as it moves through the material from its place of application because of the damping that happens there. Therefore causes the wave's amplitude to decrease as it travels toward the upper layer. However, because dead weight is the main component in deciding displacements, this assertion does not hold water when it comes to settlement. The settlement is found to be highest under the soil layers at the superstructure's base and lowest at its farthest point from the building.

Building reaction as a result of DSSI

Incorporating the impact of interaction, both the flexible foundation condition and the fixed base condition are considered when the structure is inspected. Doing so is essential for the researcher to assess the effects of DSSI. Thus, the structure is put under the same dynamic loading at its base with $PGA = 0.31\text{ g}$, and the temporal domain contains the answer. This particular instance also makes advantage of the same dynamic loading. A comparison of the building's response under the fixed base and flexible base situations is shown in Figure 4.18, with the former being explained in more detail.

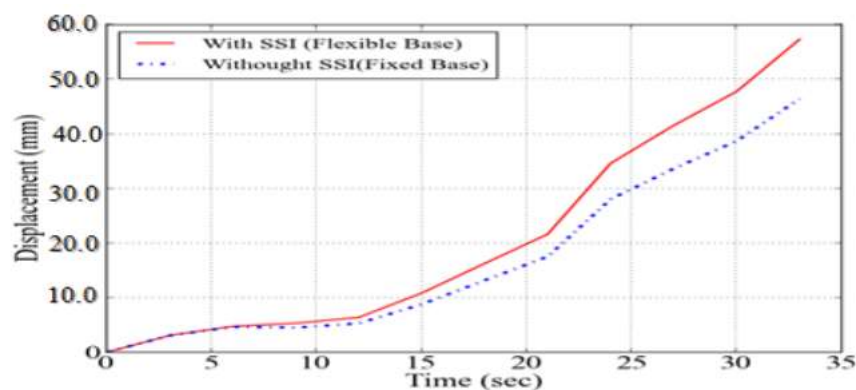


Figure 4. 18 Reaction of the G+10 structure to dynamic loading in the presence of a fixed base and DSSI

For every narrative level, displacement estimates have been computed taking into account both the fixed base condition and the DSSI condition. Along with the soil and raft node connections, the G+10 building is also furnished with a raft in the DSSI model. Because these surfaces are touching, Interactional effects are now included into the raft

level. In terms of the raft and the soil domain, three-dimensional brick pieces with eight nodes are used.

The two-noded 3D beam components are used to model the superstructure. Applying the static loading-obtained starting stress condition allows the dynamic nonlinear analysis to run. We estimate the answer iteratively until we find a solution that converges.

The effect of EPM on building response

The results of this study indicate that the existing piling group has been replaced with a similar pier with modified diameter and modulus of elasticity (Table 4.3). We need to use a trial-and-error setup of the similar pier site to broaden the method's applicability to an asymmetrical pile group, but it's adequate for the symmetric pile group.

By observing the superstructure's response, one may ascertain whether the corresponding piling approach is suitable. To do this, the current piles are substituted by a combination of similar piers; the precise quantity of similar piers is dictated by the specific region into which the asymmetrical structure was partitioned.

The four trials, namely EPM1, EPM2, EPM3, and EPM4, have been identified in this way, and the structure's reaction has been estimated for each of these trials.

The displacements acquired at each storey level and at different pile positions are compared with the response that was attained for the general pile layout.

By include interfaces at the piling soil nodes and the structural raft site, the interaction impact is integrated into the finite element model.

We have documented the length of time it takes for the CPU to acquire the convergent nonlinear dynamic solution for each EPM setup.

This was done so that we could find out how much money was spent on each mode that the different EPM setups produced. Based on the direction, the superstructure responses derived for the general pile architecture are shown in the X, Y, and Z directions in Figures 4.19–4.21.

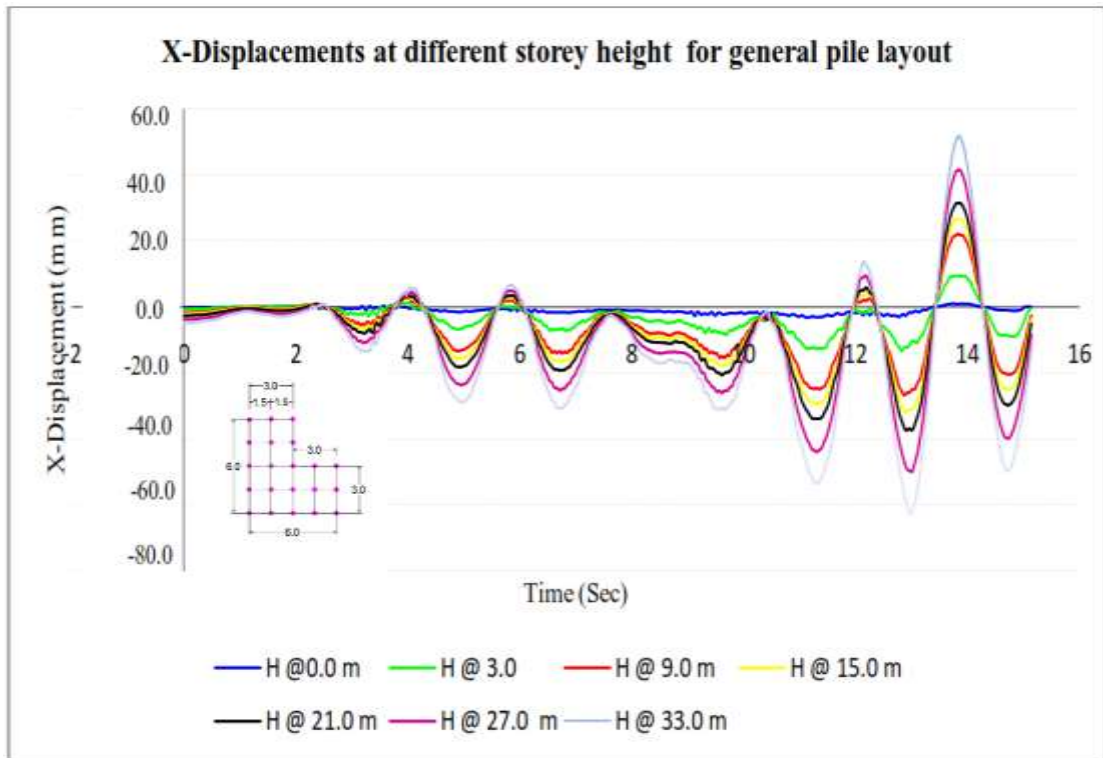


Figure 4. 19 X-Displacement at different storey height for general pile layout

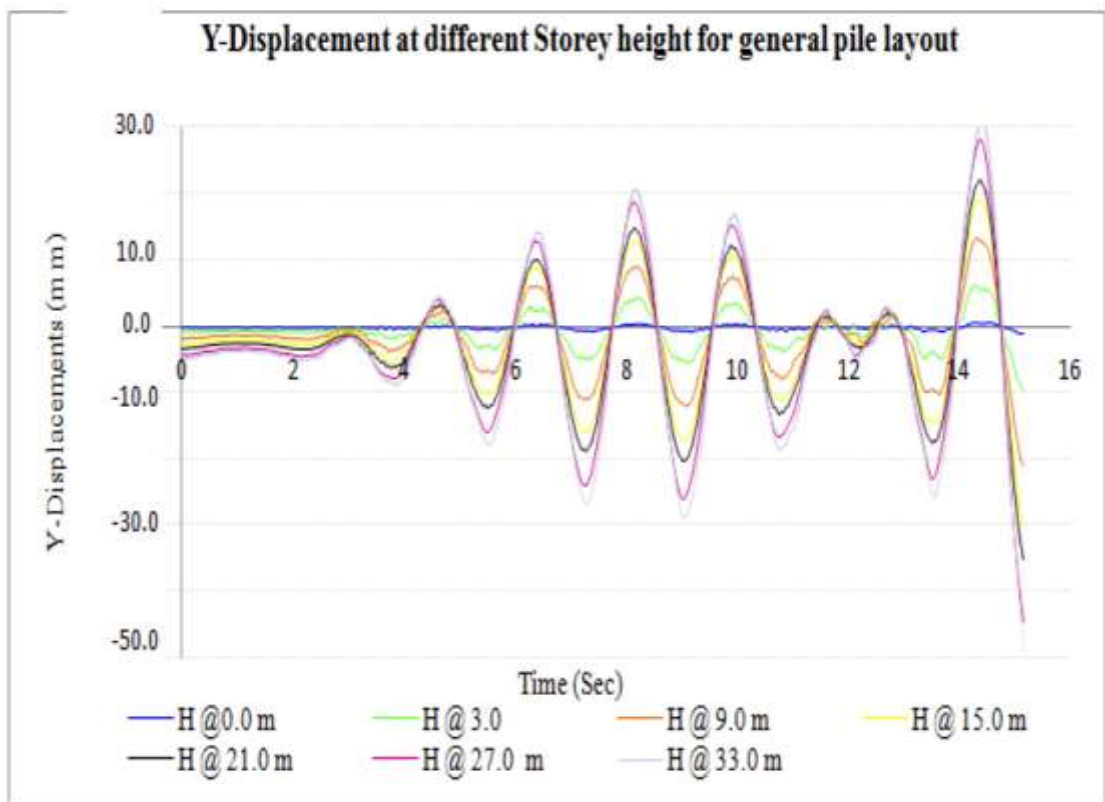


Figure 4. 20 General pile layout Y-displacement at varying story heights

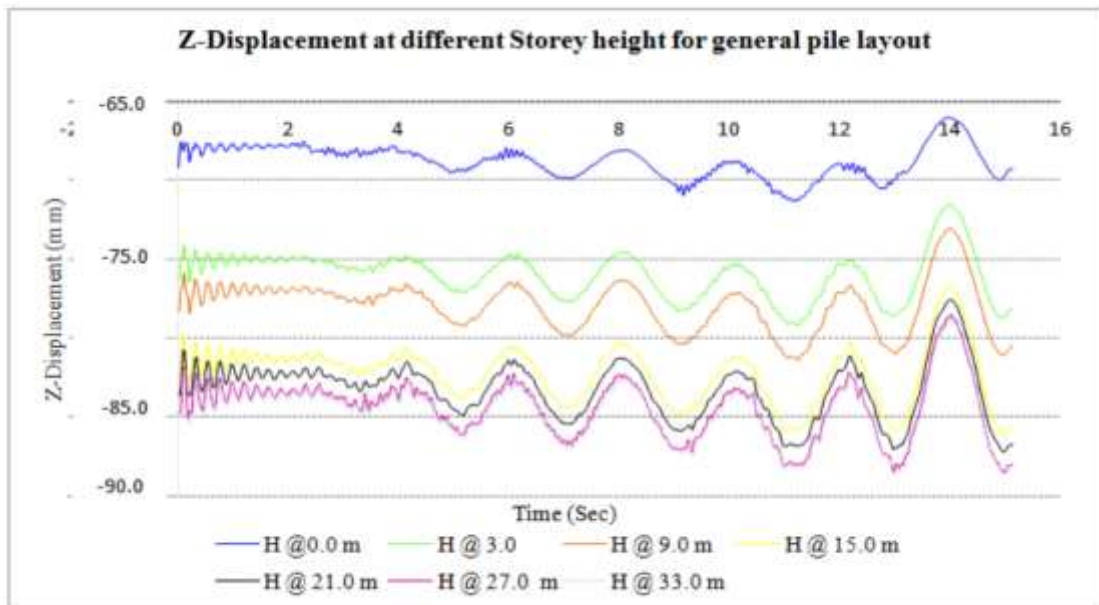


Figure 4. 21 Z-Relocation on varying floor levels for standard pile design

Figure 4.22–4.33 shows the displacement histories for ground motion at the crucial corner for each of the four EPM configurations, namely EPM1, EPM2, EPM3, and EPM 4. Each of the three axes represents a different displacement history.

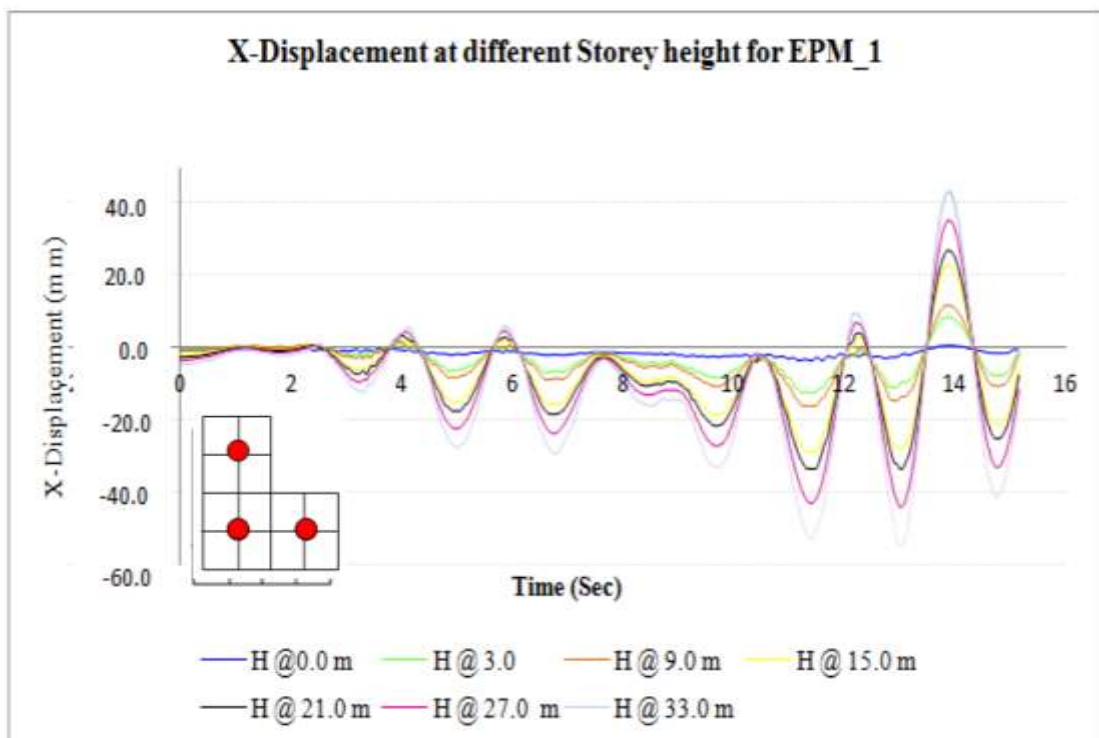


Figure 4. 22 History of X-Directional superstructure displacement under dynamic loading for an EPM1 setup

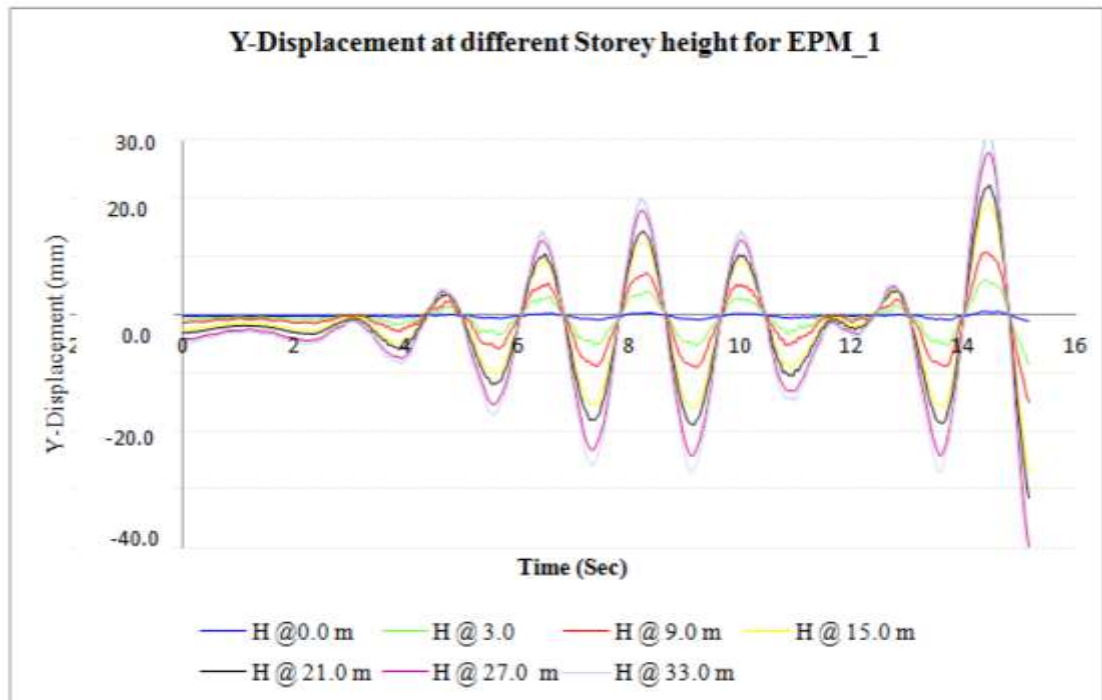


Figure 4. 23 Dynamic loading of an EPM1 and its effect on the Y-direction superstructure displacement history

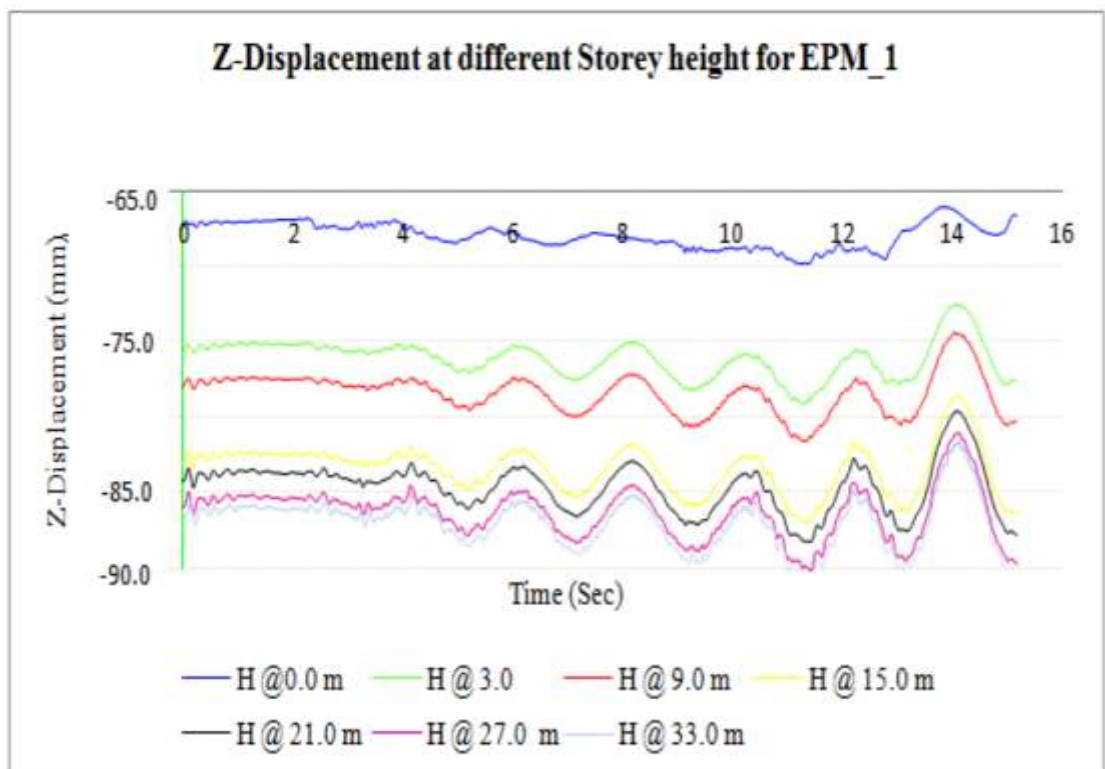


Figure 4. 24 Dynamic loading of an EPM1 and its effect on the superstructure's displacement in the Z-direction

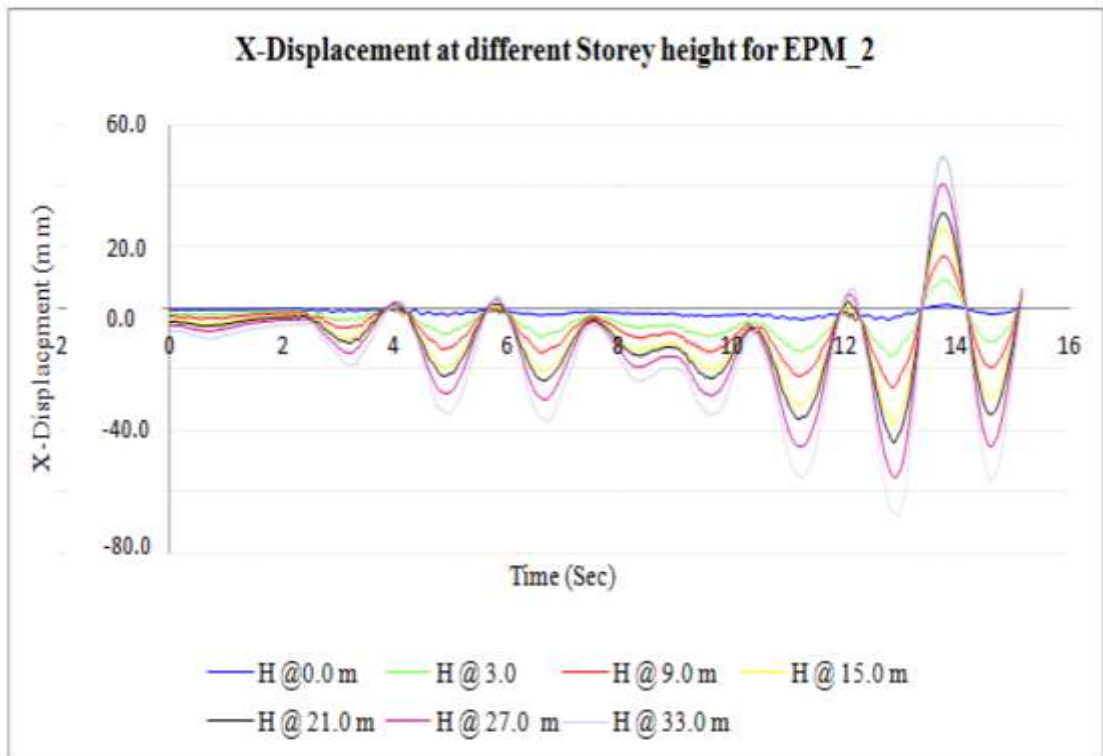


Figure 4. 25 Evolution of the superstructure's X-direction displacement under dynamic loading in an EPM2 setup

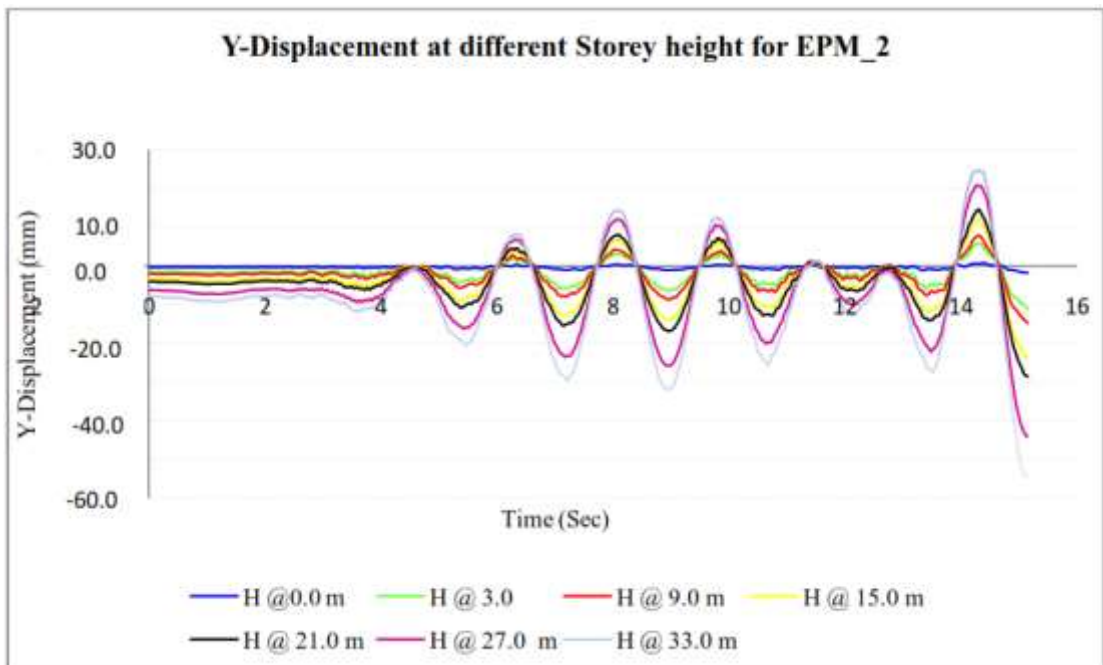


Figure 4. 26 The X-Direction displacement history of the superstructure under dynamic loading in an EPM2 setup

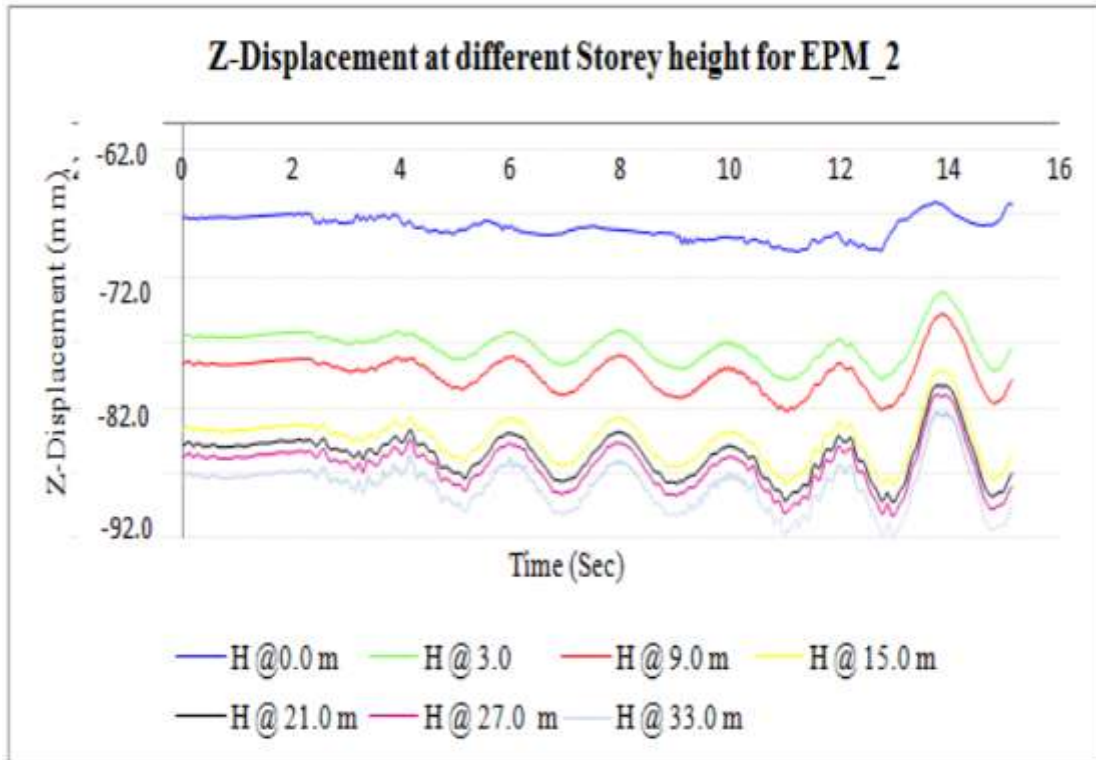


Figure 4. 27 ynamic loading of an EPM2 configuration: the history of superstructure displacement in the Z-direction

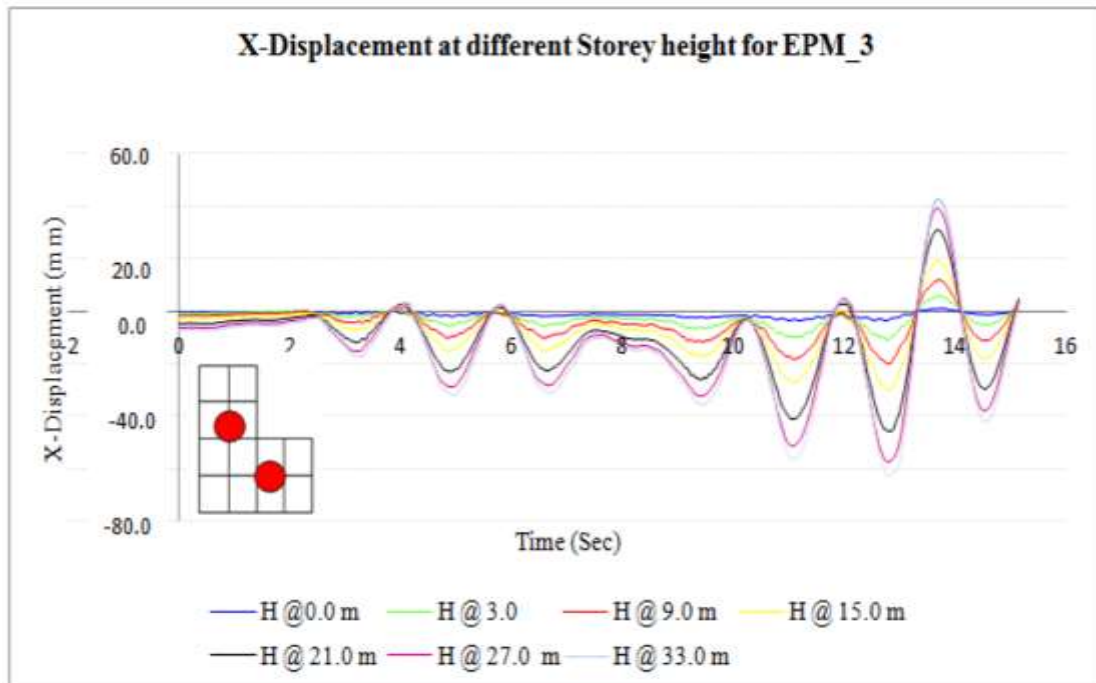


Figure 4. 28 Dynamic loading of an EPM3 configuration: the X-direction displacement history

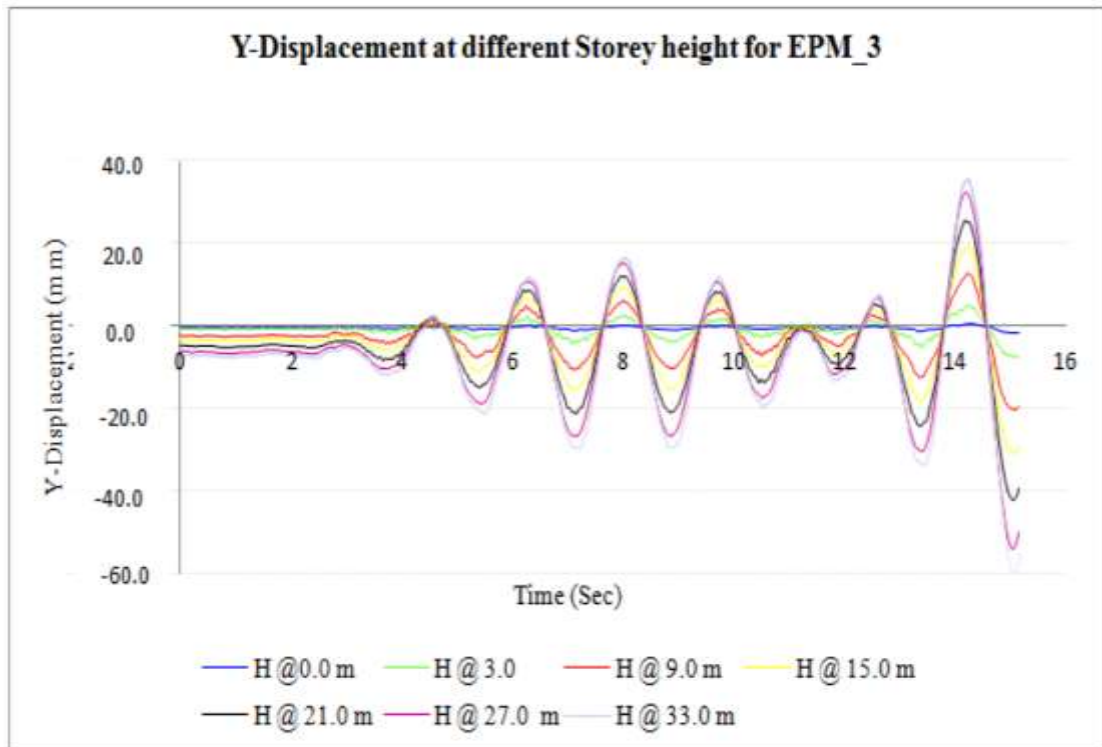


Figure 4. 29 Dynamic loading of an EPM3 configuration: the Y-direction displacement history

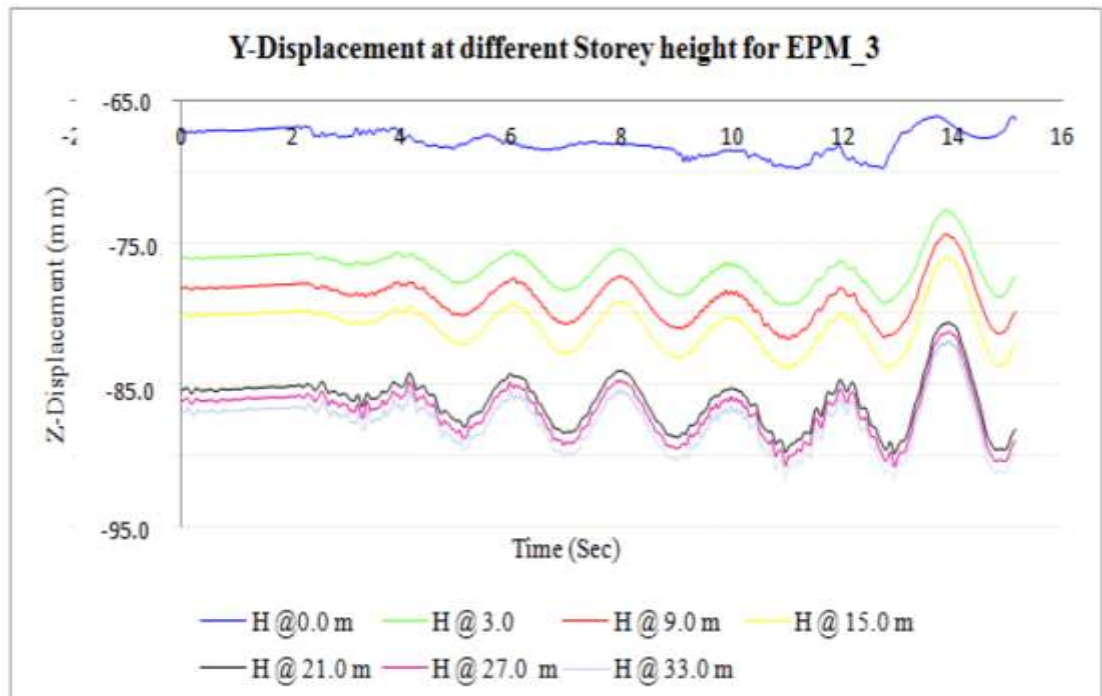


Figure 4. 30 The evolution of the EPM3's Z-Direction superstructure displacement under dynamic loading

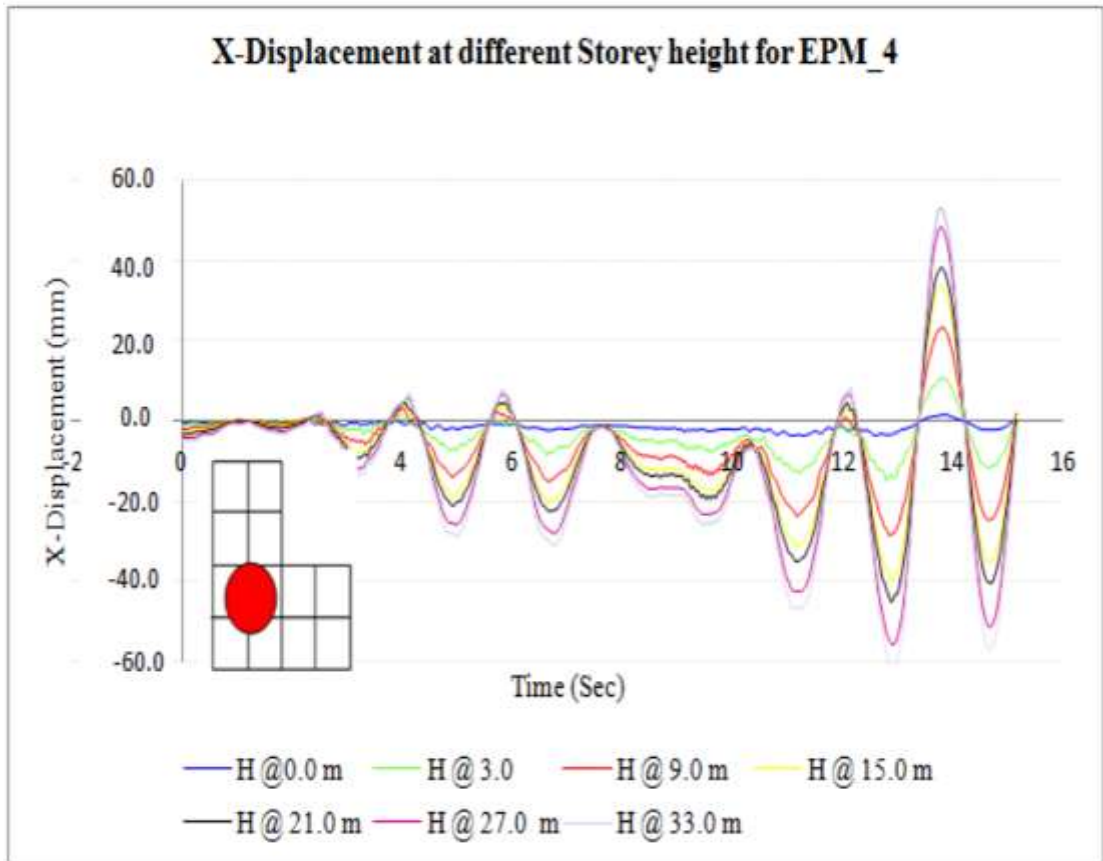


Figure 4. 31 Superstructure X-Direction displacement history under dynamic loading for an EPM3 setup

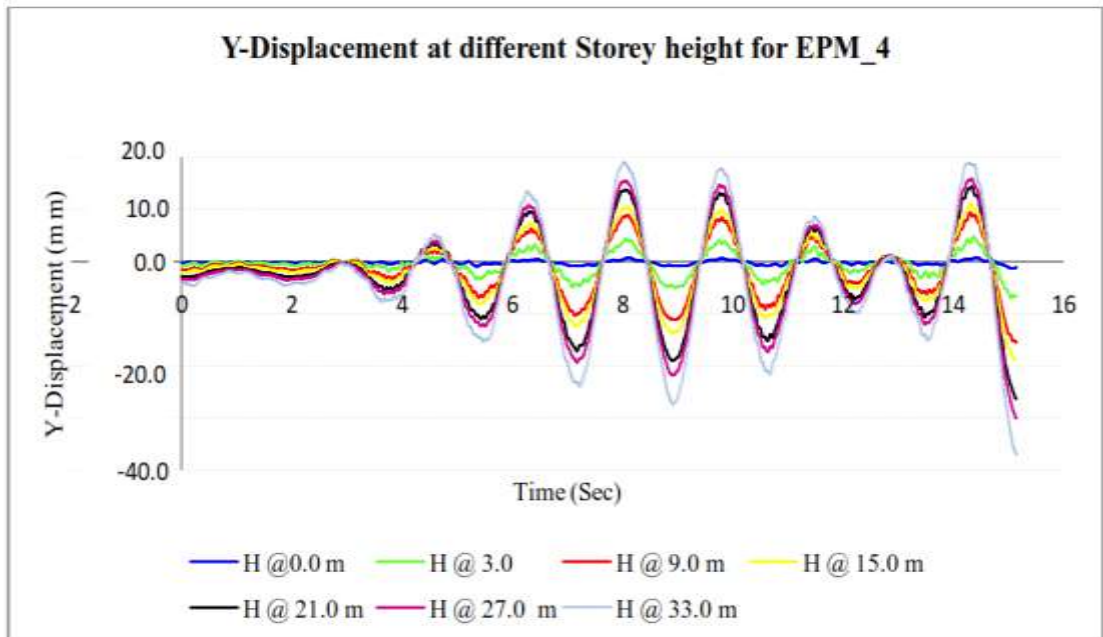


Figure 4. 32 Dynamic loading of an EPM4 configuration: the Y-direction displacement history

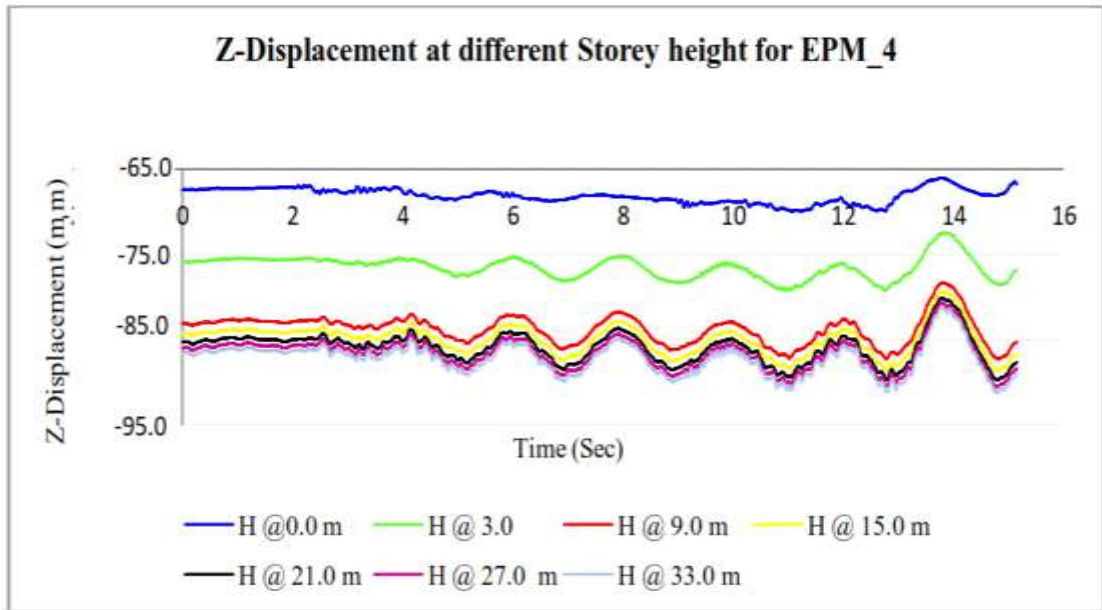


Figure 4. 33 Dynamic loading of an EPM4 configuration: the history of superstructure displacement in the Z-direction

To test the applicability of the equivalent pier approach to asymmetrical pile groups, we compared the results obtained from each EPM arrangement. Figures 4.34–4.42 show the results for all main directions for each EPM design and overall pile arrangement. You can see these reactions at different levels of the superstructure, from the base (H= 3.0 m) to the center (H= 15.0 m) to the peak (H= 33.0 m).

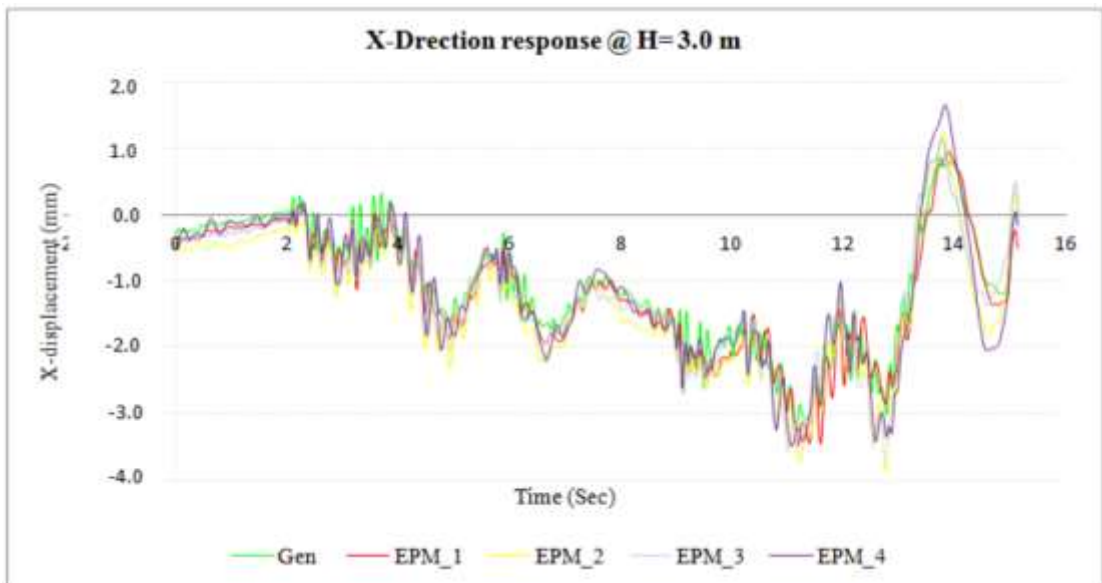


Figure 4. 34 Displacement over time for various EPM configurations at ground level in the X-direction

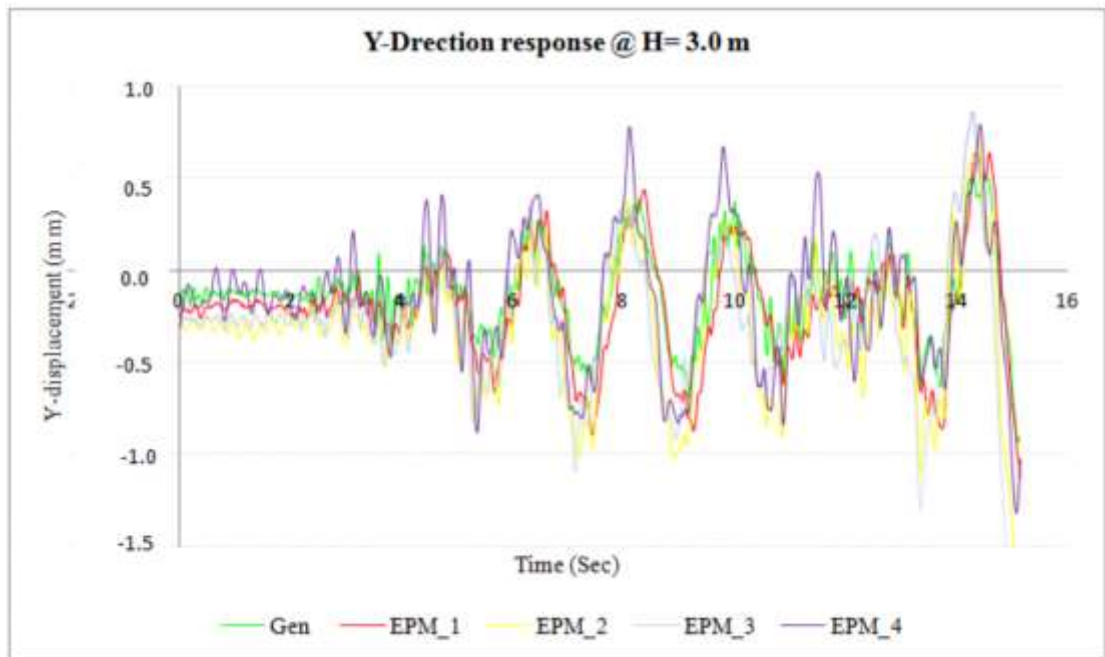


Figure 4. 35 The Y-axis displacement over time for various EPM configurations on the ground level

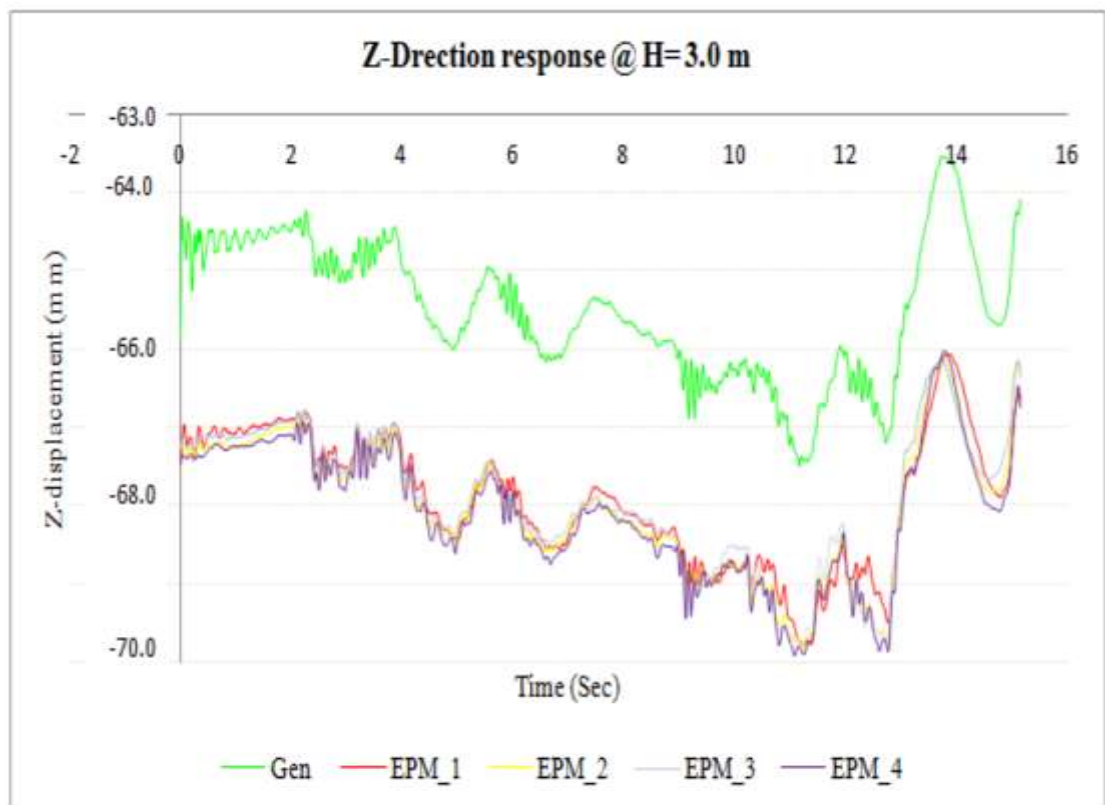


Figure 4. 36 Time series comparison of ground-level displacement in the Z-direction for various EPM configurations

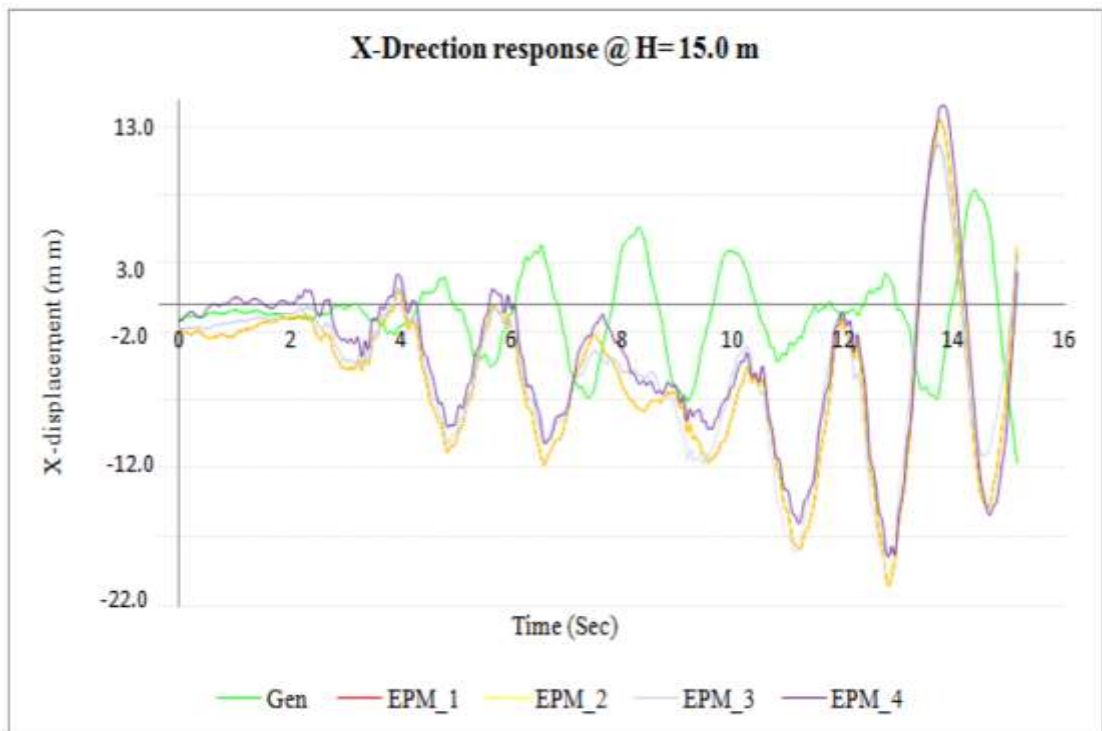


Figure 4. 37 Change in X-directional displacement at the building's midway over time for different EPM setups

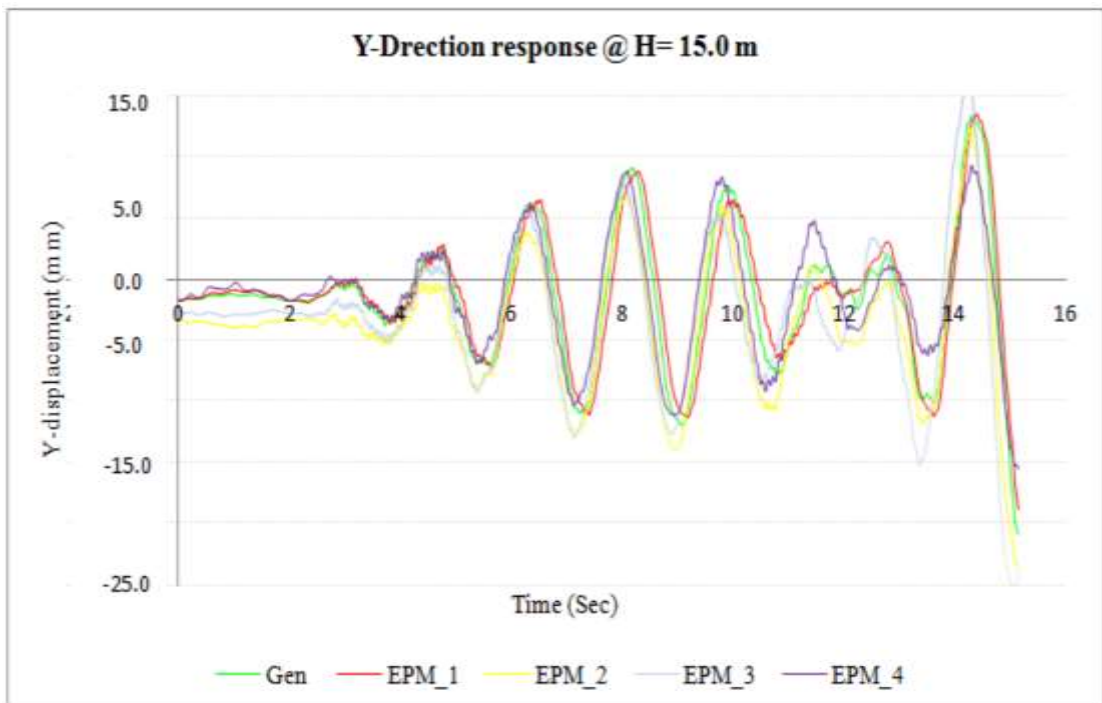


Figure 4. 38 A comparison of the Y-axis displacement histories of several EPM configurations at the building's midpoint

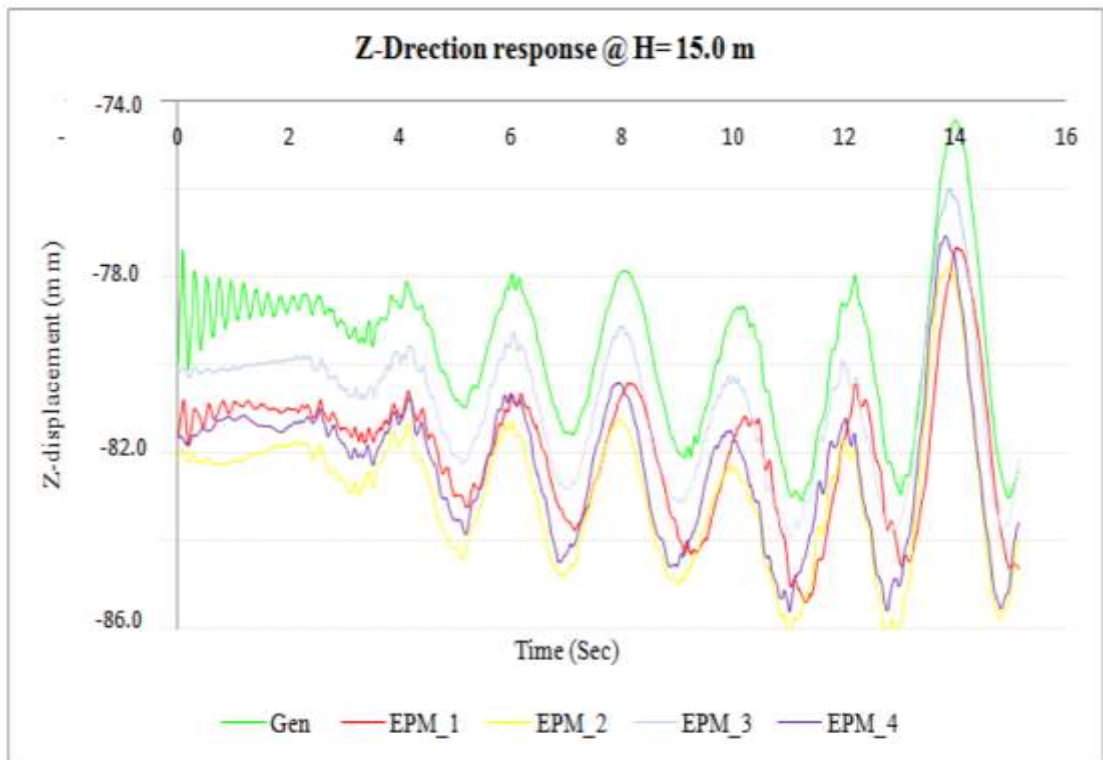


Figure 4. 39 Time series comparison of displacement in the Z-direction at mid-floor for various EPM configurations

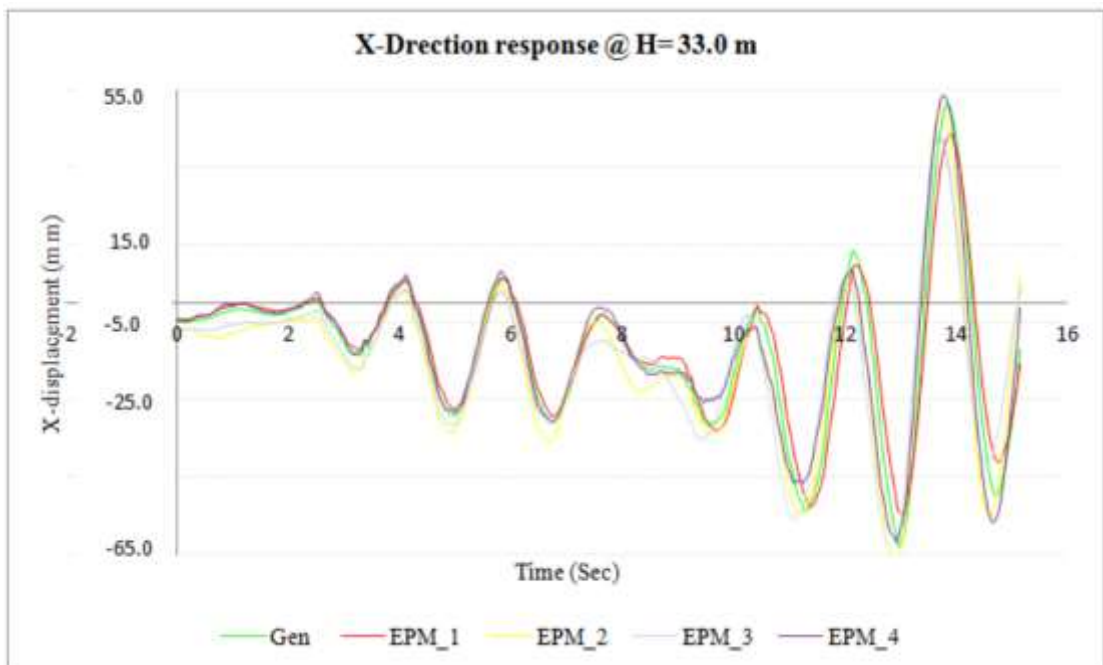


Figure 4. 40 Time series comparison of X-direction displacement at building top across a range of EPM setups

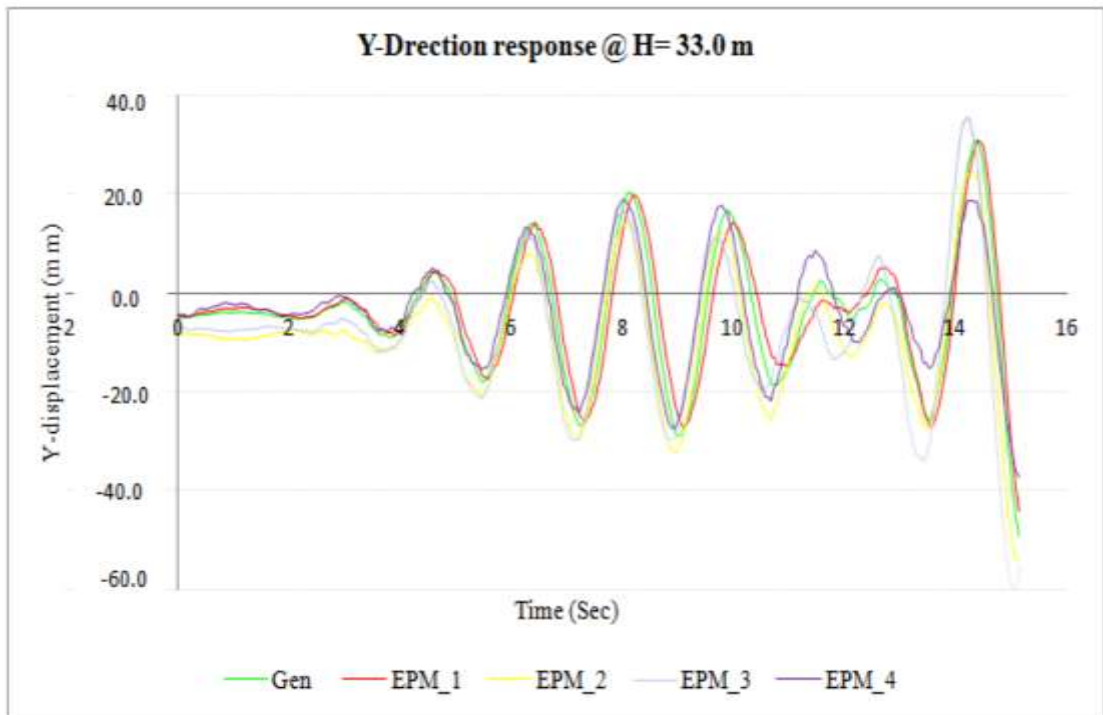


Figure 4. 41 The Y-axis displacement over time for various EPM configurations at the building's peak

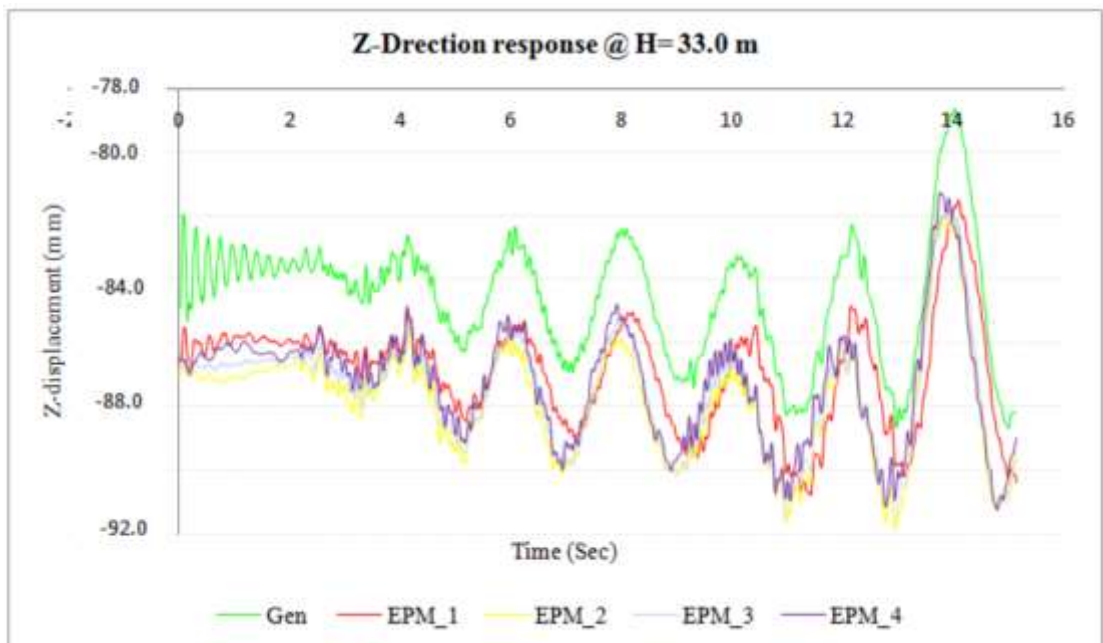


Figure 4. 42 Time series comparison of displacement in the Z-direction at the building's peak for various EPM configurations.

To get a quick look at the results, we examined the peak reactions at each at the superstructure level for various EPM layouts and standard pile designs. Time histories are obtained and compared for each arrangement, as illustrated in Figures 4.43–4.45.

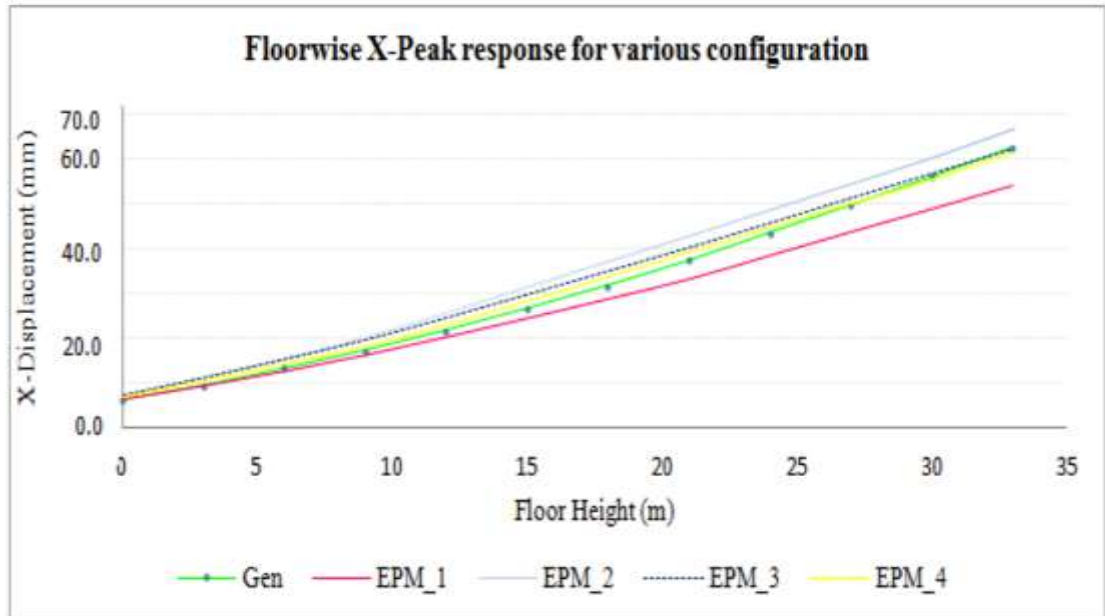


Figure 4. 43 Response comparison for several EPM designs in the X-direction at different building heights

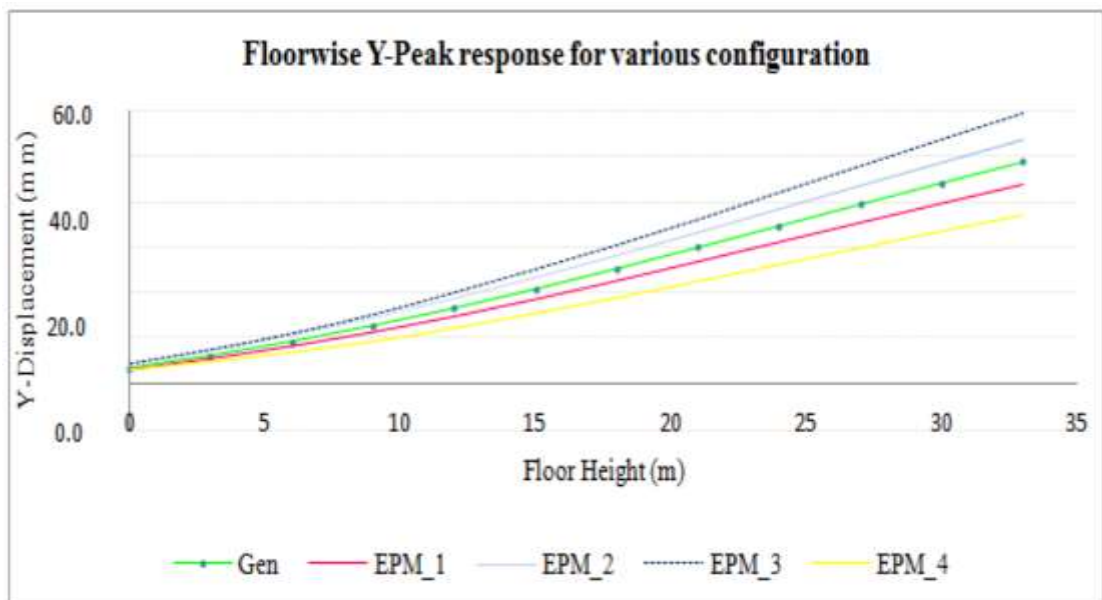


Figure 4. 44 Response comparison for several EPM designs in the Y-direction at different building heights

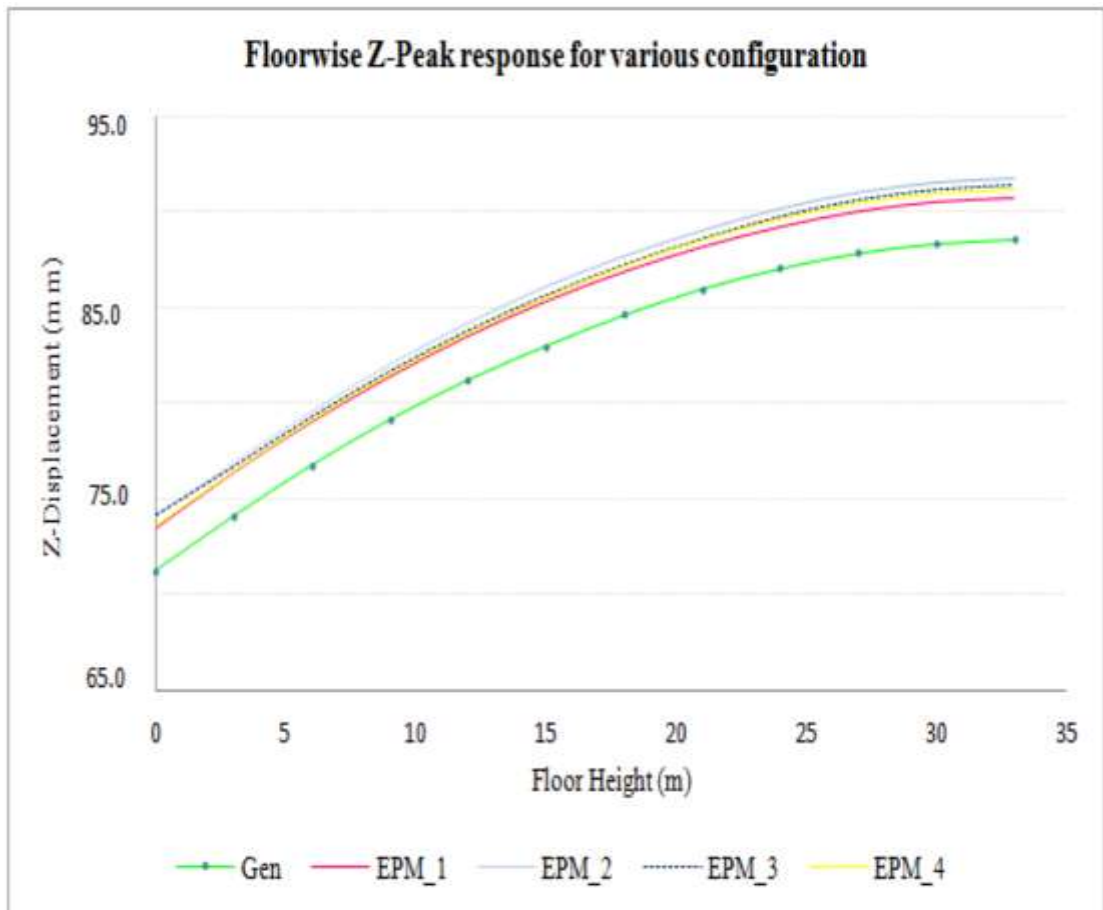


Figure 4. 45 Comparison of floor-wise responses in the Z-direction for various EPM setups

Computed utilizing CPU running time, the converged solution evaluated the computational flexibility of the suggested approach for pile-supported structure soil-structure interaction.

The goal was to guarantee that the approach is flexible enough. All of the EPM configurations' quantitative measures are shown in Table 4.4, allowing one to better grasp the numerical expenditure linked with each model.

For every one of the EPMc models—EMM1, EPM2, EPM3, and EPM4—that were shaken to their foundational roots, Tables 4.5 and 4.6 detail the superstructure's peak reactions.

You can see in the tables how these peak reactions vary from the overall piling scheme's responses as well.

TABLE 4. 4 A quantitative measure for every EPM setup

Configuration	Dof s	Element	No. of Nodes	No. of Nodes in Contact	Least element size in FE model (m)	Critical time step taken	CPU time to get the response
General	73,927	22515	24665	1505	0.11	5 x 10⁻⁵	51.17
EPM 1	39,012	11310	13016	495	0.15	8 x 10 ⁻⁵	20.10
EPM 2	32,275	9875	11389	397	0.15	8 x 10 ⁻⁵	17.50
EPM 3	32,725	10015	11539	407	0.15	8 x 10 ⁻⁵	18.05
EPM 4	30,653	8872	10227	328	0.15	8 x 10 ⁻⁵	15.35

TABLE 4. 5 Maximum reaction at the superstructure's apex for various EPM layouts

Configuration	Gen	EPM 1	EPM 2	EPM 3	EPM 4
X-Disp. (cm)	6.29	5.46	6.74	6.26	6.16
Y-Disp. (cm)	4.91	4.39	5.41	5.96	3.72
Z -Disp. (cm)	8.87	9.08	9.19	9.15	9.13

TABLE 4. 6 Variation in response percentage for different EPM configurations relative to the overall pile arrangement

Configuration	EPM 1	EPM 2	EPM 3	EPM 4
X-Disp. (%)	14.50	-6.91	0.48	2.09
Y-Disp. (%)	11.40	-9.69	-19.32	19.58
Z -Disp. (%)	-2.34	-3.54	-3.11	-2.89

As shown in Figure 4.46, the time needed for each analytical setup is displayed. The numerical expenditure analysis needed an approximation of the time difference between the conventional pile layout and EPM procedures.

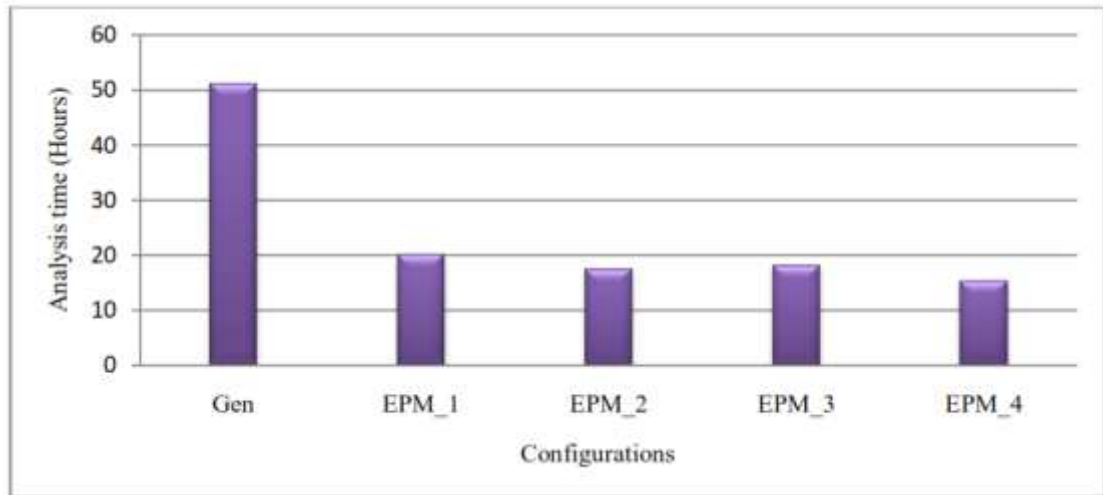


Figure 4. 46 Quantitative expense for various EPM setups

Studying soil structure is difficult and time-consuming, requiring a lot of computational power and human effort. Specifically, the direct technique requires modeling of the foundation and superstructure in addition to the soil half area. This causes the analysis to become computationally expensive and, in rare occasions, the solution may go beyond the memory of the computer. The complexity of the DSSI models is another obstacle. If the DSSI problem is to be shown correctly, it must imitate the interfaces that might compress, slide, or cause a separation between the foundation and the building. The accurate capture of the friction and contact between the pile and the soil material while dealing with piles and soil requires simulating the interfaces around the pile area. Using the iterative method to characterize the behavior of the interface is crucial for designing an earthquake-resistant DSSI assembly. The soil, structure, and interfaces exhibit non-linear behavior, as shown by a real-time interaction research. The modeling gets quite tedious and challenging to do this. It is crucial to provide some easy-to-understand approaches that streamline the modeling process while reducing the demand on computational resources. Applying the Equivalent Pier Method to the present piling group, this study aims to quantitatively minimize the issue size. In order to get over the added complexity, this is done. This simplifies the modeling process, reduces the amount of time needed for computing, and decreases the number of piles.

Ground motion analysis was performed on the G+10 R.C.C. L-shaped asymmetrical structure in 2001, with a PGA value of 0.31g. It rested on a foundation of uniformly distributed piles. Building on top of a piling foundation that was originally 0.3 meters in diameter and 10 meters long seems to be the norm. The R.C.C. building's framework consists of M 20 concrete grade beams and columns with a 0.23 by 0.23 prismatic cross section. Soil with a shear wave velocity of 300 m/s and a young's modulus of 7900 MPa forms the basis of the L-shaped pile-supported structure. The estimated bulk density and shear strength of the soil are 18 kN/m³ and 35 kN/m², respectively; while the expected angle of internal friction (ϕ) is 35°. In this particular area, the Poisson's ratio is thought to be 0.35.

Following the conclusion of the present academic inquiry, the following are the outcomes of the assessment of the dynamic soil structure.

Effect of DSSI on response

The research was conducted using both the condition that includes the interaction effect and the one that excludes it, which is called fixed base analysis. It has been discovered that in both instances, the response of the superstructure is distinct. Compared to the fixed base condition, displacements at each floor level or above might be detected by including the interaction impact into the investigation. According to what the DSSI investigation found, that the average response is between fifteen and twenty percent. Lower levels have a smaller difference in reaction, but the gap stays the same up to around 18-20 percent as you go higher in the building. All this points to the fact that interaction has a major role in the superstructure's response.

At each time step, the contact displacement vector shows positive values for the nodal displacement. This contributes to the increased digits needed to update the nodal displacement. Therefore, one component that aids the DSSI analysis in providing a bigger response volume is the interface effect. The DSSI study shows that the pile top deflects and the elements next to the raft distort. The higher displacement in dynamic interaction analysis is mostly caused by this deformation, which is communicated to the base of the superstructure. Fixed base analysis, on the other hand, gets around this problem by modelling the fixed support (i.e., zero restrictions) at the superstructure's column bases. Researchers have shown that the higher up a building is, the more

responsive it is. This is because the whole reaction includes the lower series' inertial weight.

An empirical approach first proposed in 1983 was used to manually estimate the basic time period, which was found to be 0.48 seconds (part 2, 2000). Over time, the DSSI calculation considers the soil in addition to the superstructure. The $4H/V_s$ is the soil's basic time period, according to the research. This research considers a uniform soil with a shear wave velocity of 300 m/s, prolonging the system's basic time period to 0.75 seconds. For this reason, By comparison to the permanent base structure, the DSSI system boasts a duration that is 27% longer. It takes twenty seconds to do the fixed base analysis, while it takes fifty-two hours to finish the DSSI analysis. This is mainly because many more finite elements representing the soil domain and pile volumes are now included in DSSI analyses. The time it took for a step to complete increased somewhat as the nodes became closer together. Thus, the most critical factor impacting the time needed for DSSI analysis is, unsurprisingly, interface response estimate..

The impact of the building's asymmetry

When subjected to dynamic loading, the structure's displacement was measured at every corner of every level. While the answers at the corners are the same as those at the asymmetrical constructions, there seems to be some little variation in the answers as they are different at each corner.

It has been noted that the leftmost corner of the L-shape stands out more with a larger degree of torsional translation in the base system. Analysis revealed that the Z-axis had more displacements than the X and Y-axes, even though the earthquake was felt in the X-direction.

The reason for this is because the soil and foundation system have an impact on the applied gravitational load. You may determine the percentage using the displacement from the static examination; hence, the self-weight is just a factor in vertical displacements. It was discovered that the sum of the X and Y components of earthquake forces was greater than the vertical component alone.

Potential of EPM in asymmetrical pile configurations

By dividing the asymmetrical area into many symmetrical halves, the number of options in the pile group was reduced to four. Every floor level of the superstructure has had its response estimated for each EPM configuration, with the interaction effect taken into account. Everything points to the X, Y, and Z axes being the ones employed to measure the displacements of the EPM models. In terms of vertical response, studies have shown that all EPM designs are almost identical to the conventional pile construction. With a response differential in the 2–4% range, the EPM arrangement is the safer and more practical option here.

The X-direction response of the superstructure is almost identical for EPM3 and EPM4, however there is a 13% difference for EPM1. The pile's central location in the midst of the uneven area might be to blame. Relative to the entire pile design, the displacements of EPM1 (-13.20%) and EPM 3 (-0.45%) are fewer in this particular situation. First, EPM 1 divided the plan area in half and then built up three piers of the same diameter. According to EPM 3, the floor plan may be divided into two halves, with each half having two piers of the same diameter. This led researchers to conclude that combining the EPM with the area's equal division makes for a more stable system. This layout, in comparison to the current pile configuration, has a lower response since there are fewer interface pairs and this structure contributes less to nodal responses. As a result, we learned that the stability of the existing pile group is inadequate compared to other EPM designs. But since they don't trigger as many reactions from the superstructure as the conventional pile design, the responses may be muted.

Research has shown a 10% to 20% variation in reactions between EPM and conventional pile designs when the Y direction reaction is included. Therefore, this EPM design ensures the building will be safer during earthquakes since it is more conservative than the other setups.

With a maximum variation of 20% to 20%, the solution is generally delivered by all EPM arrangements. Consequently, it may be effectively adjusted to address DSSI issues, where the analysis time is a crucial component in deciding the system's reaction.

The Impact of Numerical Expense and Complexity

In order to facilitate communication across the many components involved, dynamic interaction analysis employs intricate fundamental system modeling. As a result, adding

more of these factors makes the problem more complicated. Based on the findings of EPM's applicability for asymmetrical pile groups, the cautious approach is to apply interaction effects. Based on the asymmetrical region in the superstructure's plan geometry, the EPM mechanism requires modeling a decreased number of piles, which may be three, two, or one. The enhanced range for decreasing the location of interface applications leads to a noticeable reduction in modeling complexity. As the contact displacements were iterated, the average number of nodes decreased from 1,505 to 430. The time and effort saved by simplifying things is clearly seen here. To our knowledge, this is the only tangible benefit of EPM approaches at this time. The quantity of parts and the degrees of freedom are two important characteristics that impact the numerical cost. Using the EPM method reduces the number of components from 22,515 to 11,000 (on average) and the number of degrees of freedom from 73,000 to 35,000, proving that the method is numerically efficient.

To get the answer to this question, an explicit solver was used. The very small time step was determined by the lowest element size in the finite element model. The matching piers of the EPM technique increase the diameter at the conclusion of the meshing phase, resulting in larger components. One of the key aspects that minimizes the time necessary to address the problem is the longer time step, and this makes it an easier option. The usual lowest element size in models is 0.11 m, which corresponds to a pile diameter of 0.45 m. To account for this, the critical time step must be set at 5×10^{-5} seconds. This is the case with the majority of pile designs. The solution found after applying the fifteen-second-period dynamic load to the general pile arrangement is fifty-one hours. For EPM configurations 1-4, on the other hand, the average element size has to be between 0.9 and 1.5 meters, with a diameter of 0.9 to 3.5 meters and a diameter of 5.0 to 1.5 meters, respectively. We can get the same findings for dynamic loading duration in an average of 16 hours by changing the crucial time step to 8×10^{-5} seconds. Hence, it is shown that any EPM configuration yields the answer more quickly than the initial pile arrangement, demonstrating that EPM is a reliable approach to decrease the time required for DSSI-style large-scale problem analysis. The time it takes to acquire the answer is 68% shorter with all EPM designs compared to traditional pile architecture. Furthermore, the EPM approach works well with DSSI problems, which need a large amount of CPU memory and numerical cost.

4.2 AN ANALYSIS OF NONLINEAR DSSI FOR C AND T BUILDINGS

Scientists analyzed the seismic damage and conducted surveys to have a better understanding of the various types of building collapses that occurred during previous earthquakes. There is evidence to show that buildings with asymmetrical architecture are more prone to damage. The features of the structures are to fault in this regard. Systems that exhibit a linked torsional translational seismic response are characterized as asymmetrical plan buildings. These buildings are defined by their asymmetrical mass and strength distributions within the plan. In today's built environment, asymmetrical structures are almost inescapable because of the broad range of architectural and functional standards used. Combined lateral and torsional vibrations are more likely to occur in buildings when the planar stiffness and strength are not uniformly distributed. The mass and resistance centers are often in conflict with one another in these formations. Utilizing the histories of base torsion and displacements, the seismic behavior of asymmetrical buildings is taken into account. For buildings to hold up successfully during earthquakes, it's important to design a failure mechanism that works for both the building and the quake. One consideration is required to reduce the torsional effect. The most prevalent of the several possible reasons for torsion in buildings that are susceptible to earthquakes is an uneven distribution of mass and rigidity. As can be seen in Figure 4.47, the torsional effects are known to increase as the eccentricity between the mass and stiffness centers develops.

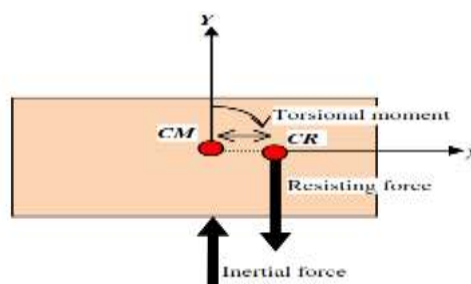


Figure 4. 47 Seismic excitation-induced torsional moment generation in unevenly distributed structures

When an earthquake hits a structure that is elastic, the parts that resist lateral stresses may experience substantial extra displacements and forces due to torsional vibrations. But most building designs rely on the principle of inelastic reaction. This means that

ductility and displacement requirements for the material are both increased when subjected to torsional motion. Modern building standards address torsion in two ways: first, by limiting the construction of structures with irregular layouts; and second, by introducing an unintentional eccentricity that had to be addressed during design. Torsional vibration may also be seen in asymmetrical building structures as a result of the lateral torsional coupling that arises from the eccentricity between the CM and CR. Whether the ground shaking is entirely translational or not, this trembling occurs. There are two points at which seismic shaking might impact a system's structural integrity: the mass center, where the inertia force acts, and the rigidity center, where the resistive force acts.

When it comes to seismic concerns, asymmetrical building designs are more susceptible than symmetrical ones. Researchers have been laser-focused on a wide range of issues due to this sensitivity, including, but not limited to, earthquake characteristics, structural factor assessment, and system model validity. Instead, researchers focused on the effects of soil-structure interaction and the way these systems react after the 1985 Mexican earthquake caused many asymmetrical structures to collapse. Multiple researchers have so far sought to find ways to include basic flexibility into models of asymmetric systems. With the goal of approximating the frequency-dependent foundation impedance functions in an unstable multi-story building, Balendra used simple springs. Values that did not rely on frequency were represented by these springs. Following that, a thorough investigation of the steady-state behavior of torsionally connected structures supported by flexibility and exposed to harmonic ground movements was carried out by Tsicnias and Hutchinson. This was made possible by using dashpots and frequency-independent springs. Chandler and Hutchinson investigated the seismic response to several earthquake types using the same simple model of a one-story building. Foundation impedance functions that are almost frequency independent were also investigated. Sivakumaran and Balendra proposed a method that uses approximate frequency independent foundation impedance functions to analyze the seismic response of three-dimensional asymmetric multi-story building foundation systems. This method was first suggested by Sivakumaran and Balendra. Wu et al. conducted research on the effects of soil-structure interaction and torsional coupling on asymmetric buildings, which included transferring the frequency-dependent foundation impedance functions to the frequency domain. In order to

comprehend the behavior of complicated systems, including torsionally connected systems, it is anticipated that an appropriate model must include the significant effects of soil-structure interaction.

Olariu and Movila, Lin and Miranda, and others have studied the reaction of asymmetrical structures by using analytical methods like the spectral acceleration and arithmetic sum techniques. In order to comprehend the behavior of shallow foundations, they set out to comprehend the interaction between dashpots and springs. To investigate how soil-structural interaction affects a building's seismic response, Mason and Bui conducted an experimental research utilizing a scaled-down model of an asymmetrical dwarf structure. Asymmetrical buildings were also supported by techniques that did not extend to the pile. The interaction of soil structures may be most accurately and effectively studied using numerical approaches, as mentioned by Chopra and Gutierrez. Afterwards, Wegner and other researchers conducted SSI analyses on an asymmetrical building that was supported by a raft and a shallow foundation system. This work also examined two- and three-dimensional nonlinear analysis. Using a shallow foundation and an asymmetrical building, Venkatesh assessed the nonlinear dynamic SSI system. The usage of the spring and dashpot allowed us to demonstrate the effects of their interaction. Since asymmetrical structures are common and will always be there, we need a better analysis that takes interactions into account. However, the modeling becomes very challenging when the interaction effect is included in the numerical analysis. In addition, the analysis time grows exponentially as soil components are included, and this tendency persists until the infinite domain is reached. Therefore, it is crucial to provide a method to reduce analysis time while simplifying the SSI system's modeling. Using the Equivalent Pier Method (EPM) on various symmetrical pile-supported building designs, this study aims to streamline SSI modeling and cut down on analysis time.

4.2.1 INFLUENCE OF PLAN GEOMETRY

Examining the building's fundamental geometries is the best way to understand how the plan geometry affects the building's seismic performance. Structures that are straight in height and plan are more likely to withstand earthquakes because they can convey inertia forces without bending. However, constructions with central apertures and setbacks impose geometric limits on the flow of inertia forces, forcing the courses

of these forces to curve before they reach the ground. Both the symmetrical and asymmetrical buildings' load transmission systems are shown in Figures 4.48 and 4.49, respectively.

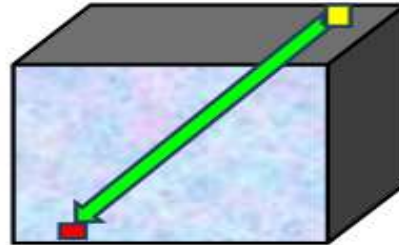


Figure 4. 48 Classification of buildings Simple

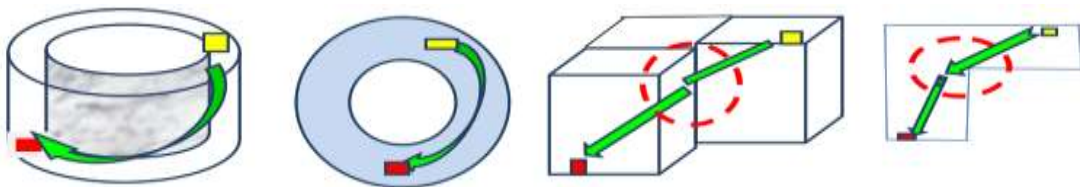


Figure 4. 49 Classification of buildings Complex

For structures with conventional geometry, such as rectangles and squares, direct load channels are used to transport seismic inertia pressures to the foundation. In contrast, buildings with complicated plans, like X, Y, L, T, V, or irregular plan forms, need indirect load paths. Stress concentrations occur at the sites where these indirect load channels curve, as seen in Figures 4.50 and 4.51v.

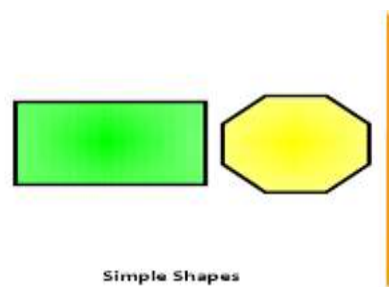


Figure 4. 50 Simple, planar building forms exhibit seismic behavior that is both acceptable and predictable.

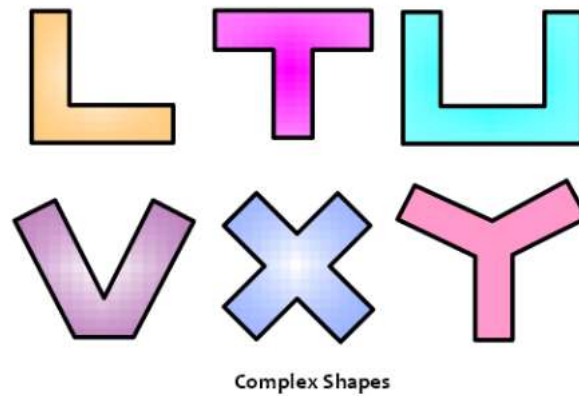


Figure 4. 51 Buildings with complicated forms that are planar exhibit structurally problematic seismic behavior.

As a result, it is safe to say that all asymmetrical structures are complicated plan systems that collapse catastrophically during earthquakes. It is critical to focus on doing an accurate study of the structure, which should use all available approaches, in order to maximize the performance of the uneven building during seismic events. The fixed base study of any building does not account for the interaction effects since they are too complicated to model and too time-consuming. Buildings that are irregular or asymmetrical, such as those with C-shaped plans were the focus of an investigation into the earthquake safety requirements and T-type plans, to determine their dynamic nonlinear interaction. The building's asymmetrical piling configuration was modelled using the Equivalent Pier Method (EPM) in an effort to reduce modeling complexity. The steps to implement the suggested EPM method for asymmetrical pile placement in construction designs depicting the C and T forms are detailed in the next section.

4.2.2 IDENTIFYING TRIAL-BASED EQUIVALENT PIER

This study aims to explain the behavior of the superstructure when a single pier is used in lieu of a pile group by considering "C" and "T" shaped structures that are supported by piles. Here, we have determined the number of piles that contribute to each region and divided the asymmetrical arrangement of the construction design into the number of symmetrical portions. We have also estimated the comparable pier diameter. How rigid the matching pier was when connected into the preexisting piling group. The approach works well for the symmetric pile group, b Figures 4.52 and 4.53) show the trial-and-error setup required to fine-tune it for an asymmetrical pile group.

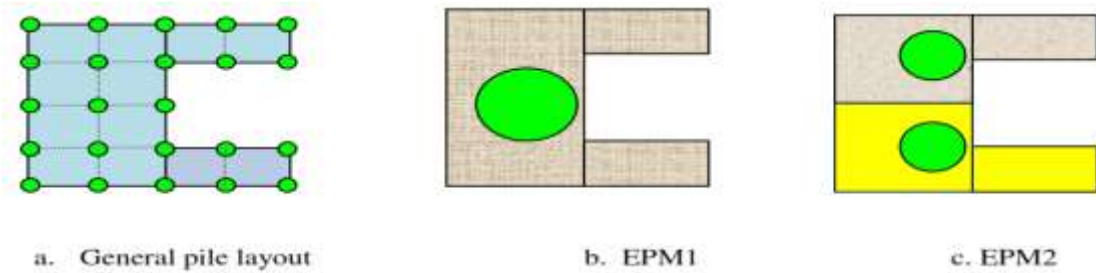


Figure 4. 52 Alternative trial setups for the Equivalent Pier in a C-shaped structure

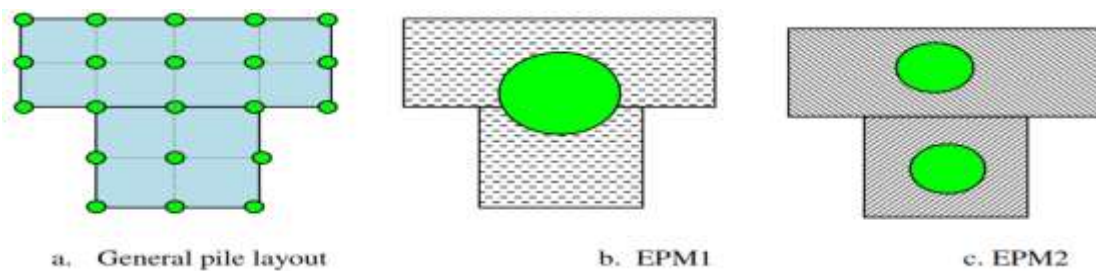


Figure 4. 53 Variations in trial setup for the Equivalent Pier in a T-shape structure

The C-shaped building is split into two different configurations, which are referred to as EPM1 and EPM2. Within the framework of EPM1, the entire area is regarded as a single entity, together with the comparable pier's shape and stiffness being computed. In EPM2, the asymmetrical area is split into two equal pieces, denoted as L, and the amount of piles that contribute to each region determines the features of the associated pier.

The first configuration, or EPM1, is considered while building a T-shaped structure by considering the whole area. Also calculated are Young's modulus and the diameter of a single pier. The upper and lower rectangles are the two halves of the asymmetrical region that are divided in EPM2. The amount of piles that go into each section defines the corresponding pier's features. In Table 4.7, we can see the details of each EPM arrangement that was considered for the T-shaped and C-shaped buildings.

TABLE 4. 7 Information on the setup that was looked at for the research

Attributes of the configurations	C-SHAPE			T- SHAPE		
	EPM1	EPM2		EPM1	EPM2	
Area no	1	1	2	1	1	2
L (m)	6	6	6	6	6	3
B (m)	3	2.25	2.25	4.5	3	3
No. of Piles participating	23	11.5	11.5	21	13.5	7.5
A_g (m ²)	27	13.5	13.5	27	18	9
D_{eq} (m)	5.8	4.2	4.2	5.8	4.5	3.2
E_s (kN/m ²)	445872	445872	445872	445872	445872	445872
E_p (kN/m ²)	2.93 x 10 ⁷	2.93 x 10 ⁷	2.93 x 10 ⁷	2.93 x 10 ⁷	2.93 x 10 ⁷	2.93 x 10 ⁷
E_{eq} (kN/m ²)	4.35 x 10 ⁶	4.35 x 10 ⁶	4.35 x 10 ⁶	4.01 x 10 ⁶	3.89 x 10 ⁶	4.27 x 10 ⁶
Location (x,y) (m,m)	(2.5,3.0)	(2.5,1.25)	(2.5,4.75)	(3.0,3.5)	(3.0,4.5)	(3.0,1.5)

This study models a G+10 C and T form pile supported structure using internal C++ software. We use a three-dimensional brick element with eight nodes to represent the foundation and structure. Using an elastoplastic material model developed by Drucker and Prager, the nonlinearity of the soil material is considered.

4.2.3 SSI MODELS THAT HAVE BEEN COMMONLY USED

"Mid-rise buildings" are a collection of residential structures that range from five to fifteen stories in height, as stated according to Chandler. In accordance with this criteria, In order to span this range in the present research, the mid-C and T-shaped G+10-story structure has been chosen.

The selected span width is consistent with the architectural standards and construction procedures used for typical structures in megacities, which is an essential consideration. Table 4.8 details the different EPM configurations' SSI element specifications, including the structure, foundation system, soil, and stacked raft, which were used to construct the finite element model.

TABLE 4. 8 Characteristics of adopted model for the study

Structural details						
Bay Width and height	Cross section of floor beam and columns	Ht. of building	R.C.C Grade Frame	Young's modulus (E)	Concrete density	Asymmetry shape
3.0 m	0.23 x 0.23m	33.0 m	M20	2.9×10^7 kN/m ²	2400 kg/m3	C and T
Raft details						
Depth	Plan Area	Ht. of building	R.C.C Grade Frame	Young's modulus (E)	Concrete density	shape
0.5 m	8.0 x 8.0 m	33.0 m	M20	2.9×10^7 kN/m ²	2400 kg/m3	Square
Pile details						
Length	Diameter	R.C.C Grade		Young's modulus (E)	Concrete density	shape
9.0 m	0.45 m	M20		2.9×10^7 kN/m ²	2400 kg/m3	Square
Soil details						
Plan area	Depth	Young's modulus (E)		Unit Wt.		shape
20.0 x 20.0m	20.0 m	445,872 kN/m ²		18 kN/m ²		Square

4.2.4 CT AND TT-SHAPE BUILDING MODELING DSSI SYSTEM

For the purpose of analyzing the SSI system, A C++ software for finite elements is currently being developed. Node interactions may be investigated using the program, among other nonlinear static and dynamic investigations. The input text files must adhere to the prescribed format. The DSSI-shaped C and T system's finite element model follows the same methodology as the prior model.

4.2.5 FINITE ELEMENT MODELS

The construction of the mesh finite element model is being undertaken to accurately depict the G+10 C and T shape SSI system. To allow waves to propagate through soil, the supporting soil domain is considered, which is 20 by 20 by 20 meters. At each node, the three-dimensional beam element that describes the structure has six degrees of freedom. The foundation system, consisting of the raft, piles, and earth, is modeled

using a three-dimensional brick element. For the purpose of simulating sliding and penetration, the Lagrange multiplier method is used to represent the earth-pile interface. To create the model, participants in this research input the coordinates of several elements, including structural nodes and frame connections, into the study's associated software. The general pile arrangement system's finite element model is presented in Figure 4.54 and Figure 4.55, respectively, for the T-shaped building and the C-shaped building. The 21st and 23rd piles of the C-shaped structure are laid out in a C pattern with 1.5 meters of c/c spacing (3.5 directions), respectively. The piles, which are nine meters long and have a diameter of 0.45 meters, have an aspect ratio of twenty.

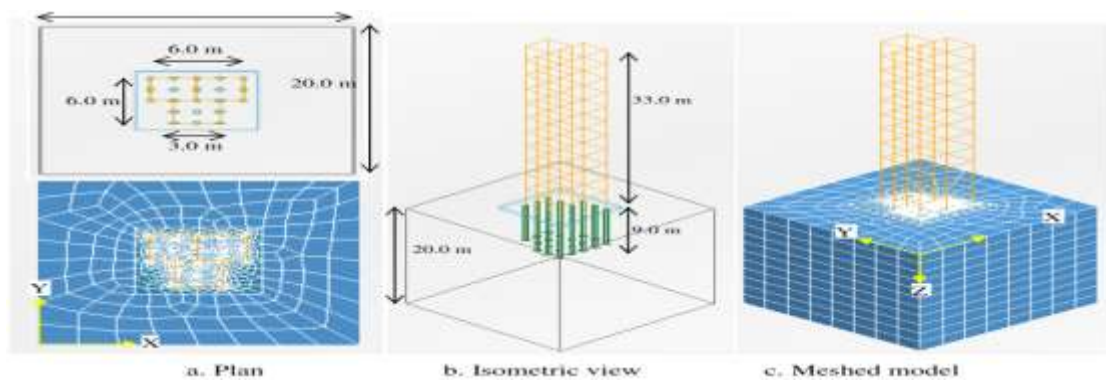


Figure 4. 54 General piling arrangement finite element model for T-shape G+10 buildings using DSSI

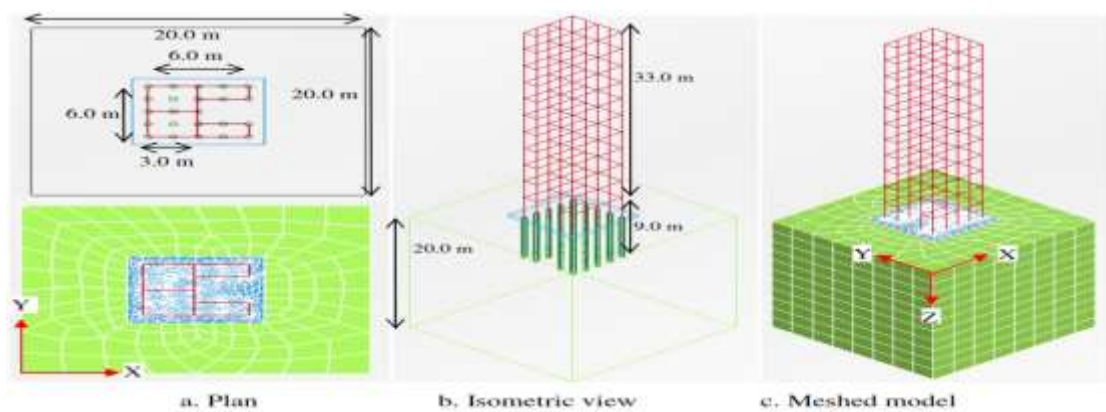


Figure 4. 55 The C-shaped G+10 building's finite element model for DSSI in EPM1

It was suggested in the research that the number of piles in the group should be reduced to one or two. The equivalent pier approach makes this feasible; it only requires calculating the diameter and stiffness using the methods given in chapter 4. An

approximation of the quantity of comparable piers has been made by dividing the uneven sections into equal halves. From 4.56 to 4.59, we can see the finite element model of the building's most likely EPM layout in both the C and T versions. Below, we'll go into further depth about these settings.

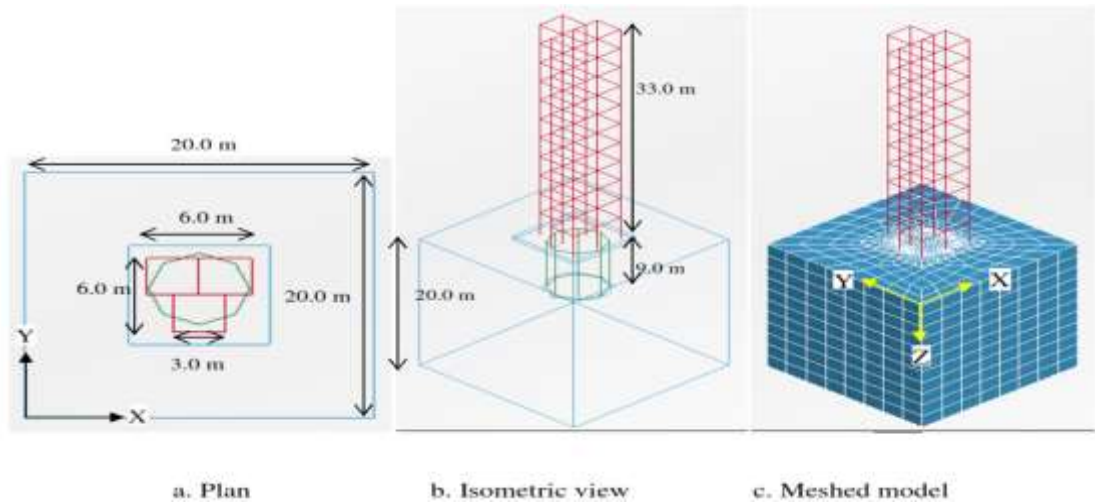


Figure 4. 56 Simulation using finite elements for a T-shaped G+10 structure in EPM1's DSSI

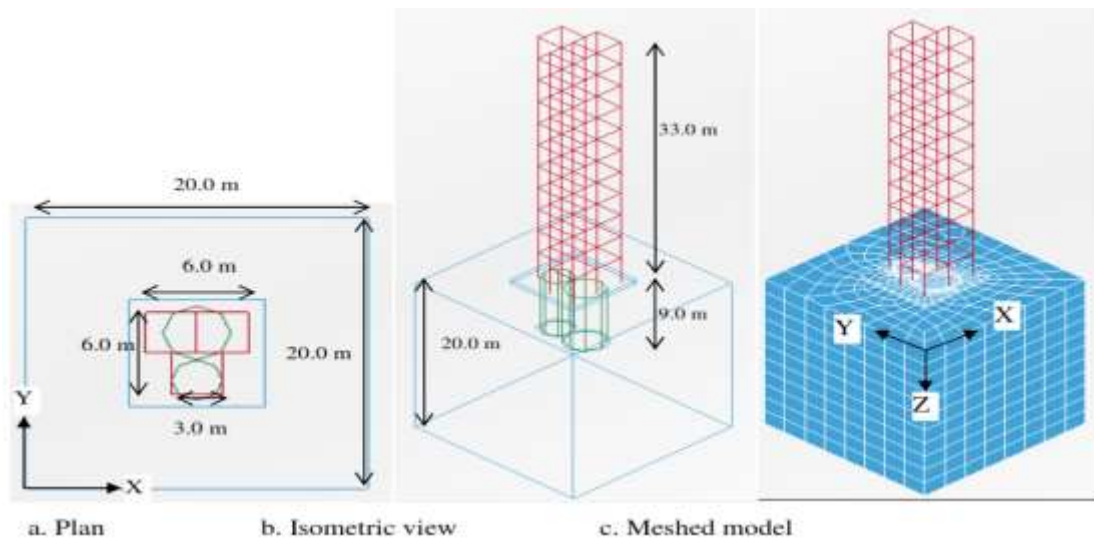


Figure 4. 57 Models using finite elements for T-shape G+10 buildings in DSSI for EPM2

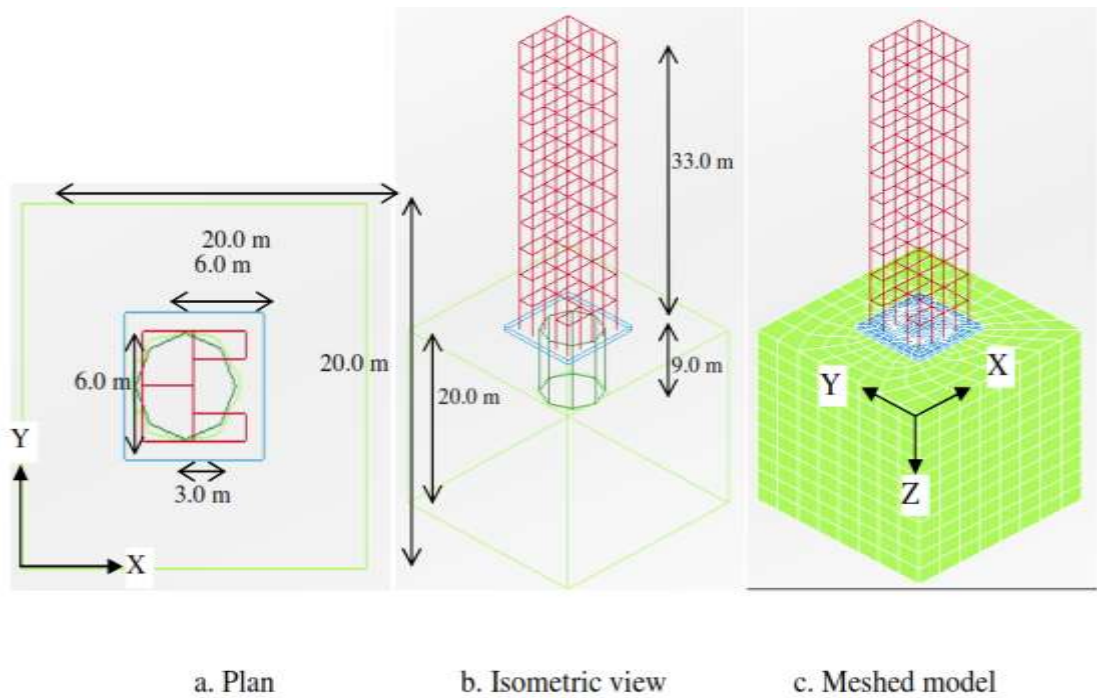


Figure 4. 58 Modeling finite elements for a C-shaped G+10 building in EPM1's DSSI

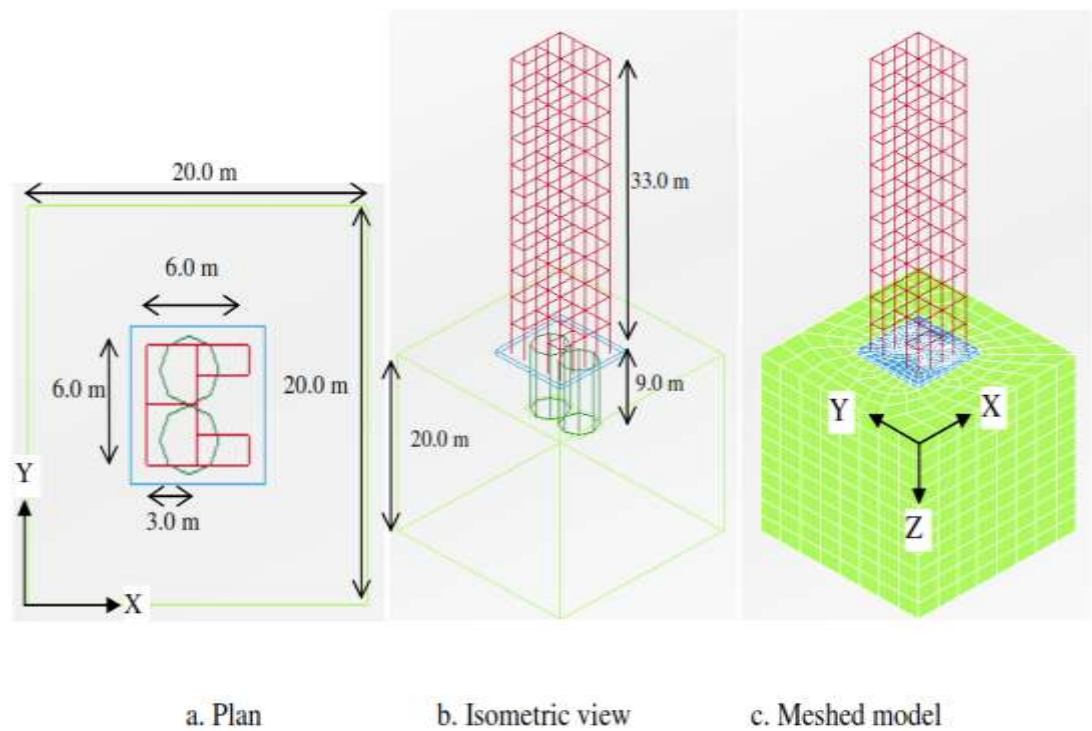


Figure 4. 59 The C-shaped G+10 building's finite element model for DSSI in EPM2

4.2.6 RESULT

The asymmetrical G+10 R.C.C. T and C-shaped structure was set up on a pile foundation method in a uniform layer of soil. In 2001, the ground motion study was conducted using a 15-second period and a PGA value of 0.31g. Estimating the results involves considering the following factors: the significance of SSI analysis for the specific loading and the local soil condition; the applicability of the Equivalent Pier Method to reduce computational efforts and complexity in modeling; the effect of the pier's diameter and length on the superstructure response; and the behavior and response of the structure for numerous dynamic loadings. In the sections that before it, we examined each issue independently to understand the study's results.

Identifying the critical corners of the C and T layout

Figure 4.60 shows the estimated response of the system, which comprises the foundation system and the superstructure, for a general pile arrangement at the building's corners. The response at each story height of the superstructure has been estimated in all essential directions (X, Y, and Z) and in all corners (A, B, C, D, E, F, G, and H). The X, Y, and Z reactions at different locations on the top floor for the usual pile pattern arrangement are shown in figure x to x. We conduct this to learn how asymmetry affects the building's reaction to ground vibrations. Both the C and T building plans should provide the same result.

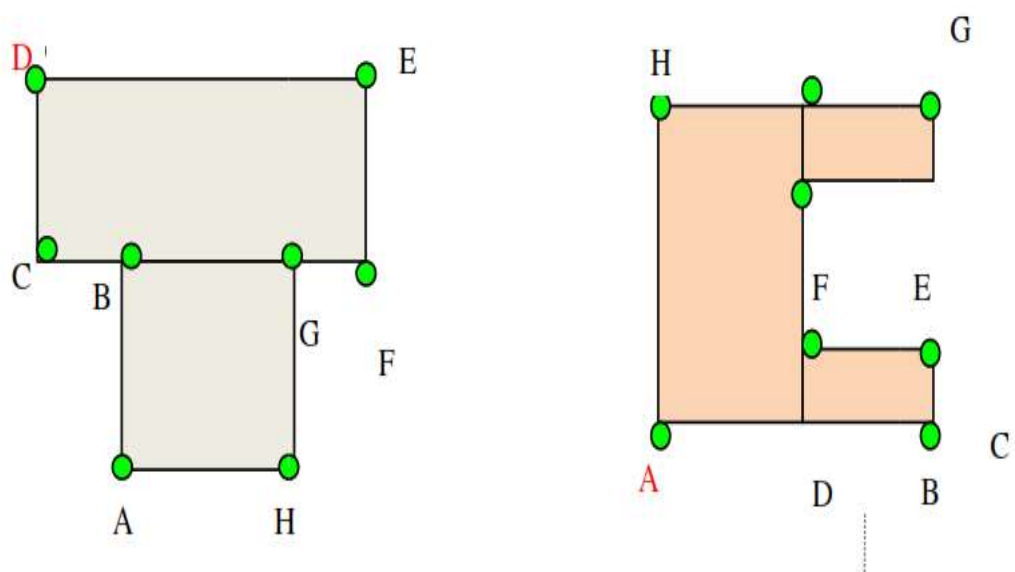


Figure 4. 60 Superstructure Response Site

The nonlinear displacement history for the applied ground motion in 2001 for a C-shaped building is depicted in Figure 4.61 to 4.63 this history is shown for various corners in the X, Y, and Z directions, respectively, for the points A, B, C, and D, which are symmetric about the horizontal axis.

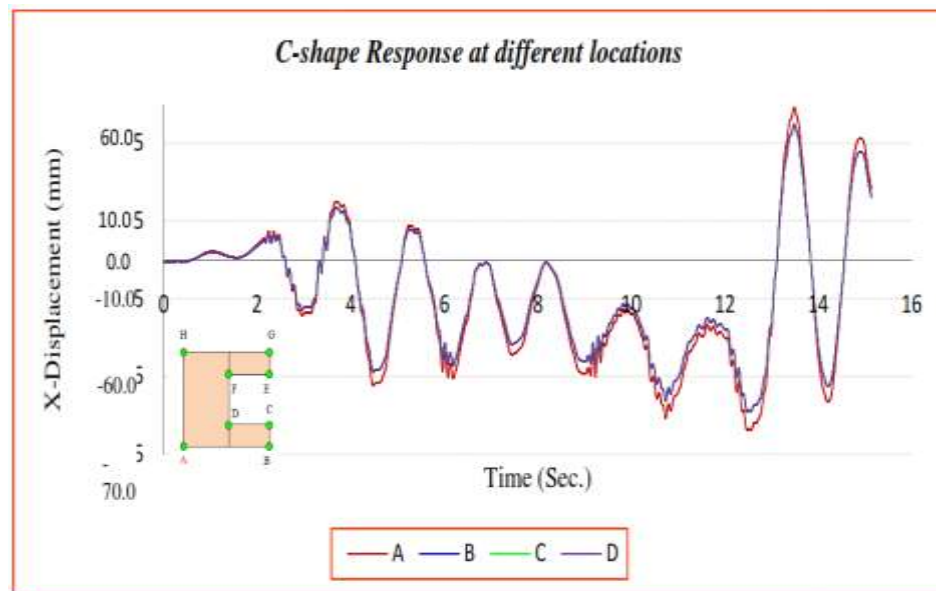


Figure 4. 61 The displacement of a C-shaped structure over time at different points in the X-direction

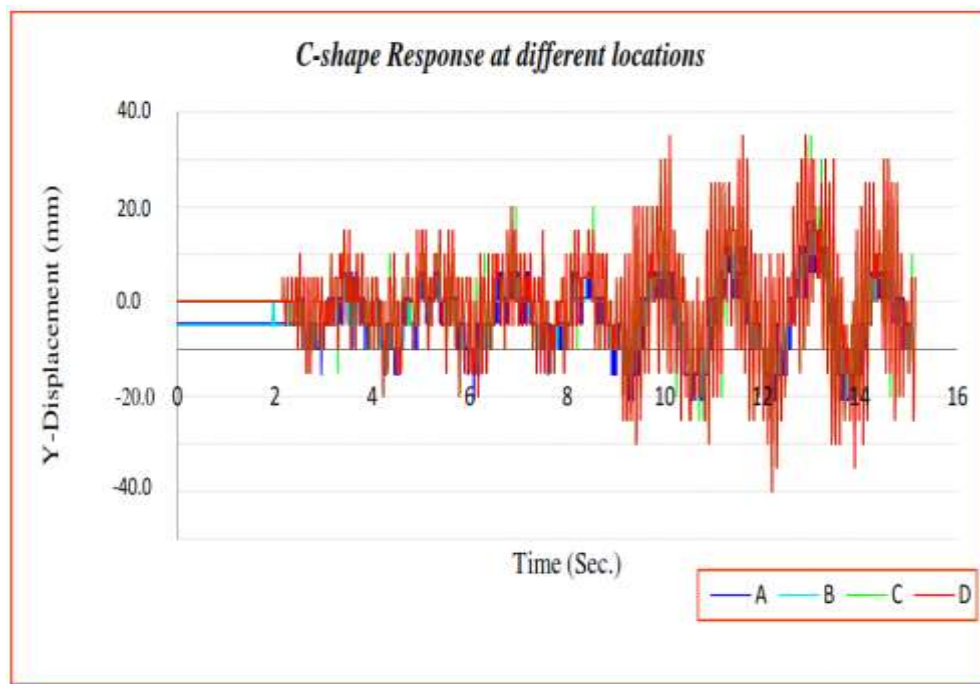


Figure 4. 62 C-Shape building time history displacements at different Y-locations

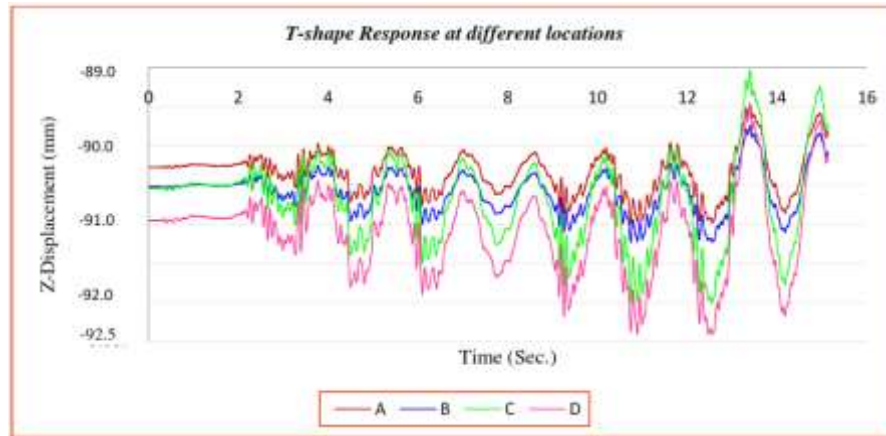


Figure 4. 63 Different points along the Z-axis of a C-shaped building's temporal history of displacements

Noting and observing the time history displacements acquired at the top storey at different places reveals that, while they are following the same movement profile, the magnitude varies somewhat at each corner. We have also seen the same thing with the Y and Z directions' replies. Consequently, the asymmetry associated with the building's design causes the movement, which is not limited to any one spot inside the superstore. Someone also wrote a note on the T-shaped building's displacement history. A thorough analysis of the building's behavior during an earthquake has been conducted by plotting each of the T-shaped corners: A, B, C, D, E, F, G, and H. Because of the asymmetry in the building's design, this is done to study the building's transient reaction. Figures 4.64–4.66, which cover the main directions, show the structure's reaction at different corners.

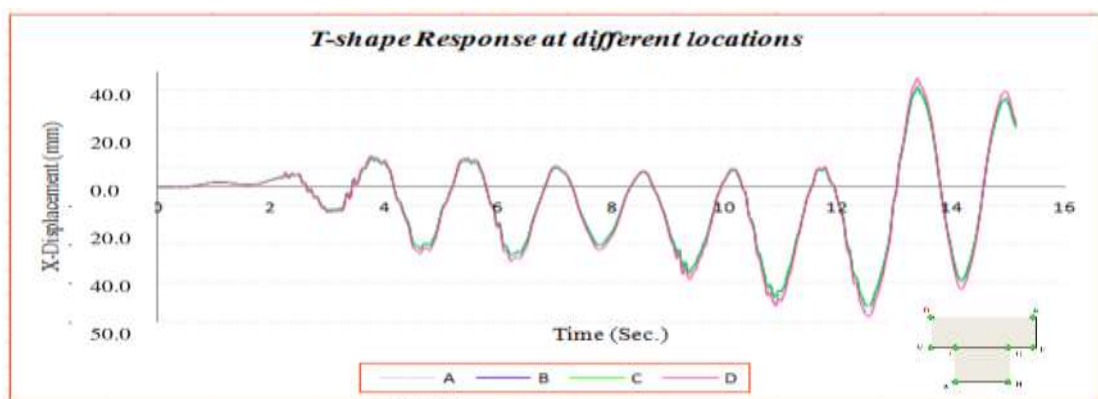


Figure 4. 64 The X-direction displacements during time at different sites for T-shaped construction

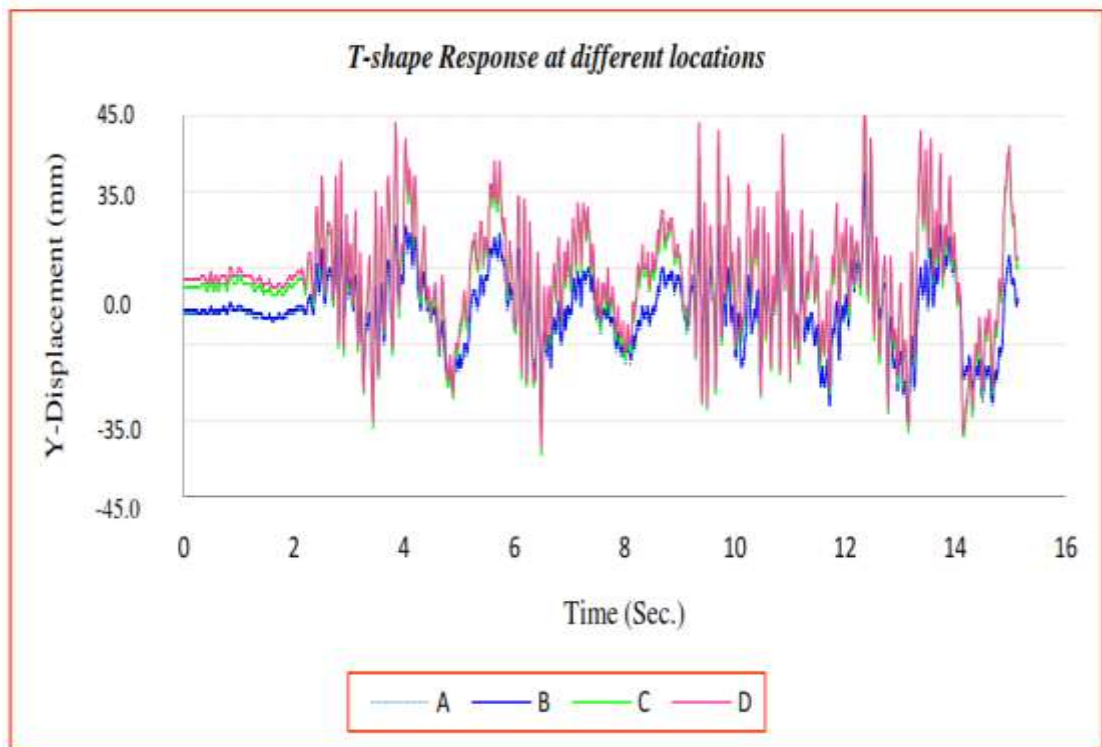


Figure 4. 65 the Y-axis displacements over time and space for T-shaped structures

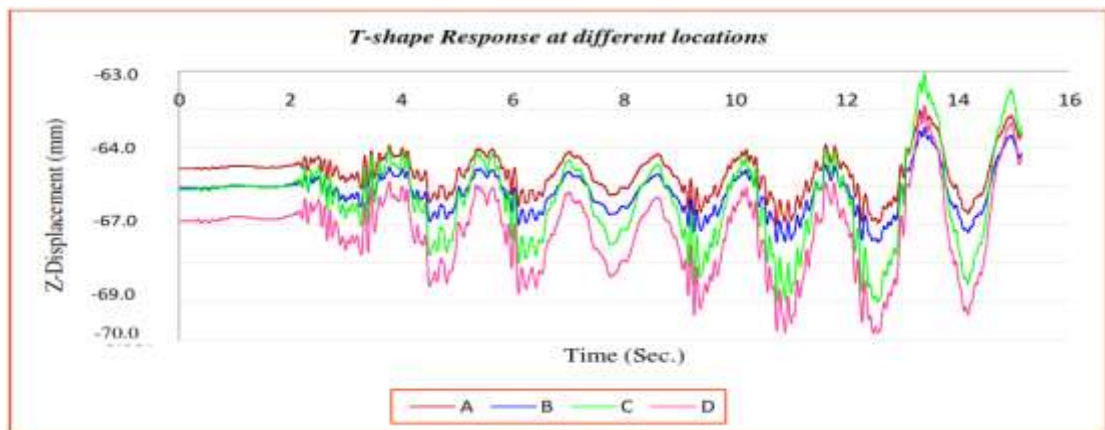


Figure 4. 66 the displacements in time and space at different points along the z-axis of a T-shaped structure

The gathered time history displacements at the top floor show a consistent pattern of movement; nevertheless, the magnitude of the movement differs somewhat at each corner. The similar discovery has been made about the Y and Z directions' reactions. The form of the structure causes an asymmetry, which in turn causes movement that is not limited to any one spot in the superstore.

Where reactions to the seismic stress have been detected at each level is where the crucial corner has been determined to be. Figures 4.67 to 4.69 show the displacement of one level at the most important corner of the C-shaped structure. The nonlinear seismic analysis revealed this displacement in X, Y, and Z. The base of the soil domain was where the ground motion was applied.

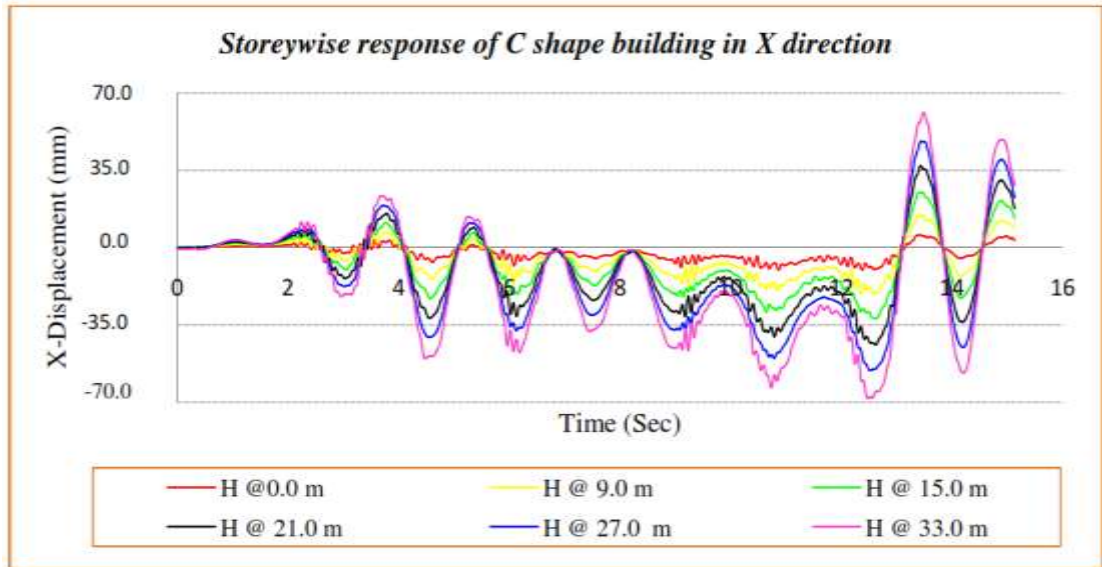


Figure 4. 67 The X-direction essential corner displacements across the building's storeys

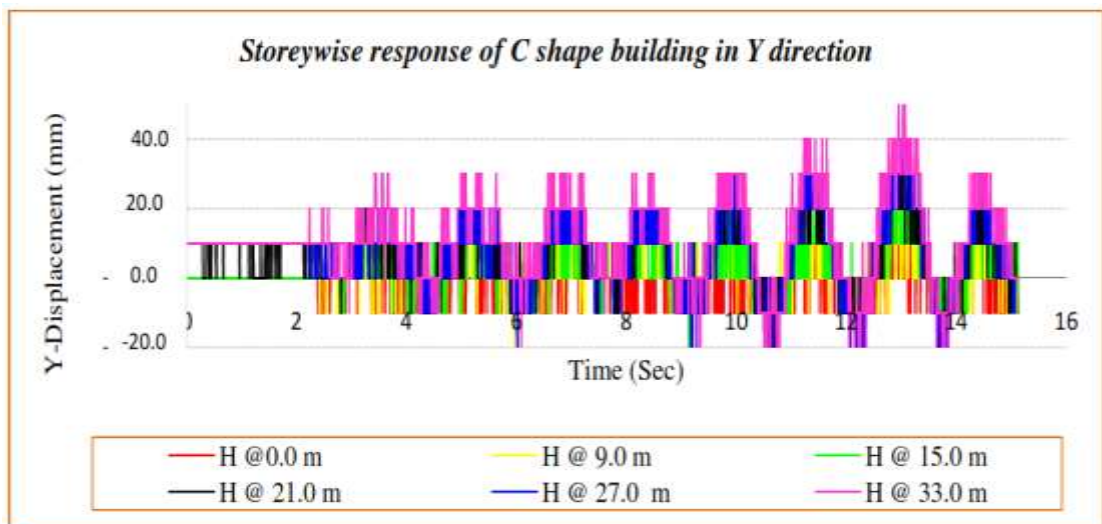


Figure 4. 68 Changes in floor-by-floor displacements at key corners in the Y-direction for a C-shaped building

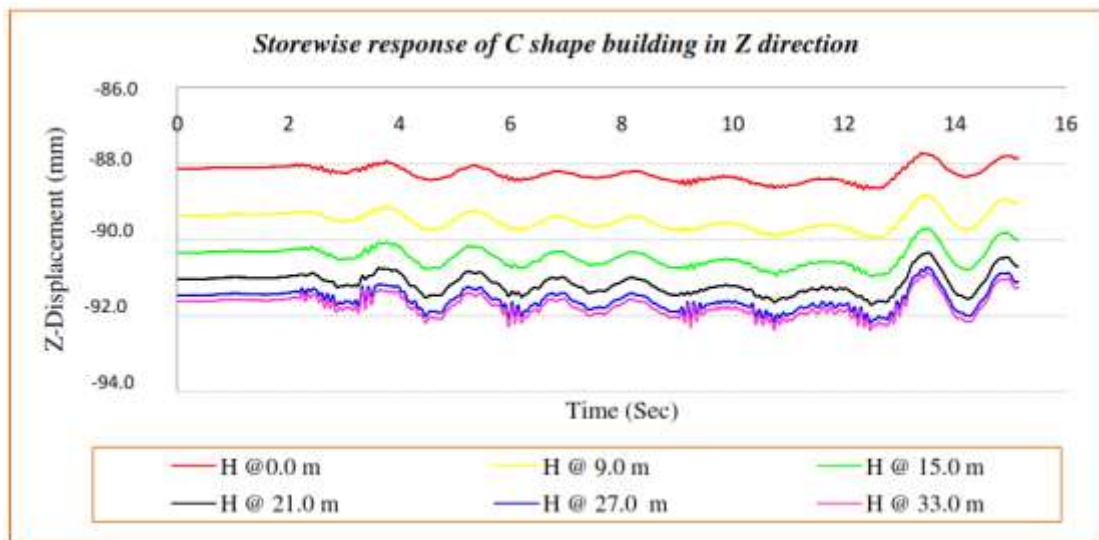


Figure 4. 69 The X-direction essential corner displacements across the building's storeys

The rising store-wise displacements, which are more pronounced with increasing storey height, are caused by the inertia participation effect. Whereas the lowest level shows the least amount of movement, the highest floor shows the most. The T-shaped building has also been the subject of relocation reports. The X, Y, and Z-directional displacement of the superstructure at the crucial corner of the T-shaped building is seen in Figures 4.70 to 4.72. Various floors of the building experience this displacement.

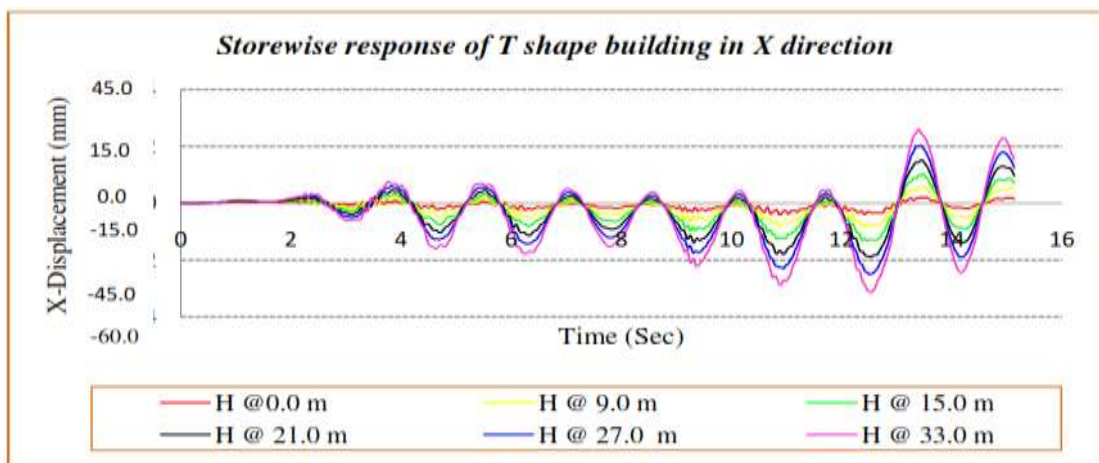


Figure 4. 70 For a T-shaped structure, the X-direction storey-wise displacements at key corners

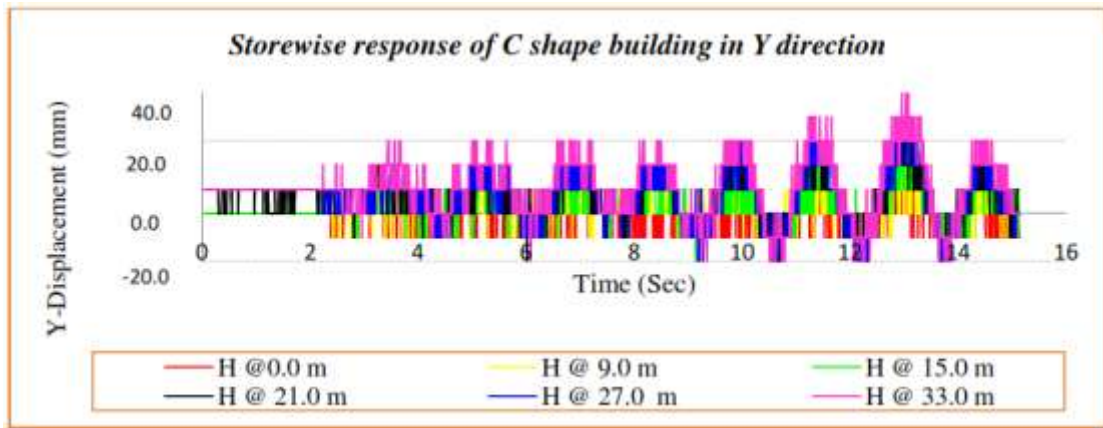


Figure 4. 71 The Y-direction crucial corner displacements in the storey-wise time history of a T-shaped building

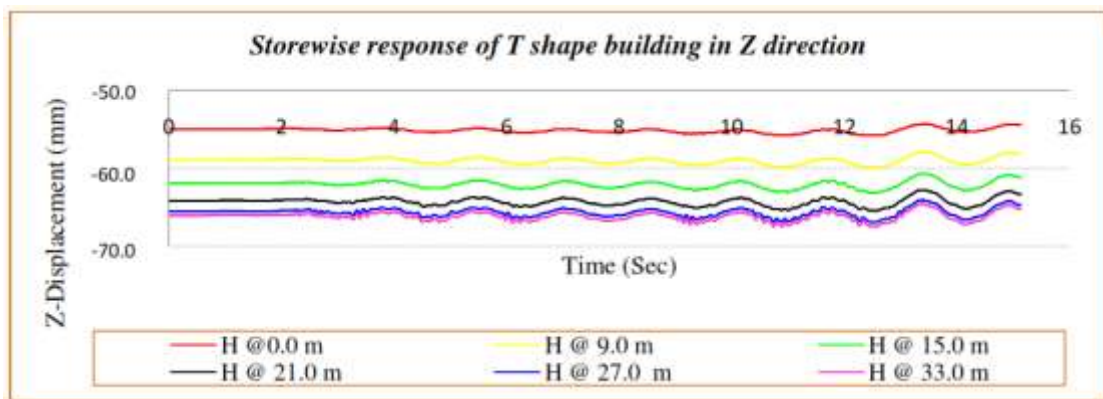


Figure 4. 72 The displacements in the Z-direction at important corners of a T-shaped building's history, broken down by storey

Regarding the store-wise displacements, the same finding has been drawn as for the C-shaped structure; nevertheless, the amount of movement experienced by the T-shaped building is lower than that of the C-shaped building.

Foundation system behavior under earthquake

There have also been displacements detected in the systems of the foundation. Figure 4.73 shows the results of the foundation system's measurements taken at the site of the central pile. At the critical corner location, we have seen that both the C and T structures have shifted (responses in X and Y directions) and settled (responses in Z direction) the pile and the raft. For both sets of structures, these notes were taken.

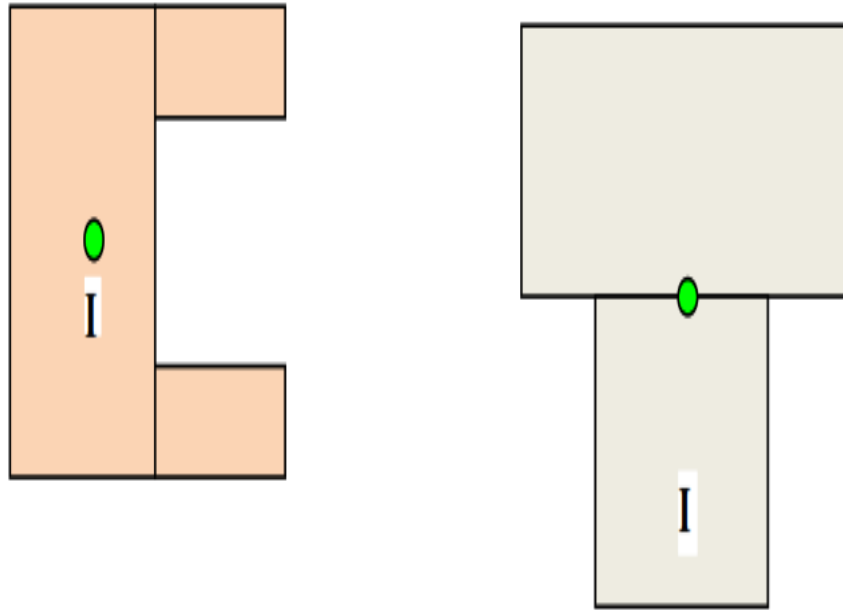


Figure 4. 73 Response location of pile settlement for C and T shape building

From the dynamic study, we have derived the pile's lateral displacements and settlement at the pile head, center, and tip/bottom depths, among others. In order to investigate the pile's settling, the displacement history is studied in the gravity (Z) direction.

Both the C-shaped pile arrangement and the T-shaped pile pattern show signs of these reactions. We have approximated the reactions in the direction of the applied dynamic load for C and T shape buildings using the general pile arrangement foundation system. The figures 4.74 and 4.77 show these estimations, respectively.

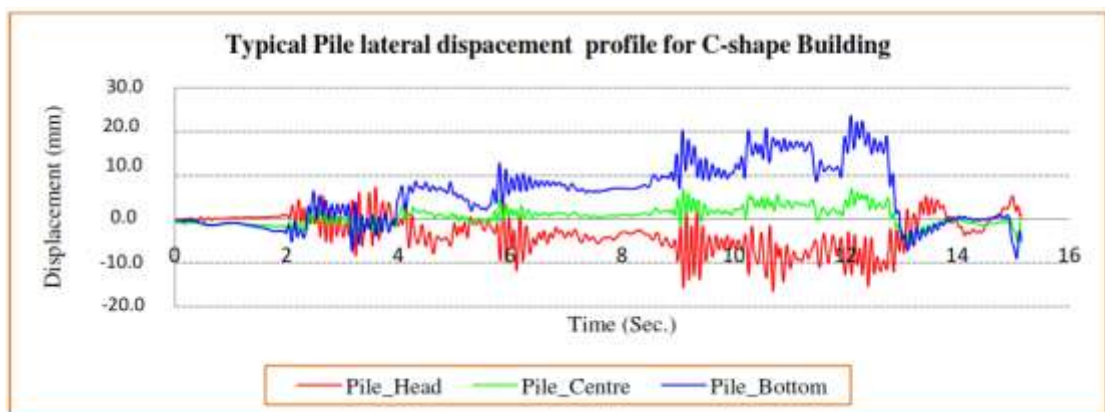


Figure 4. 74 Pile displacements over time for a C-shaped structure with a generic configuration

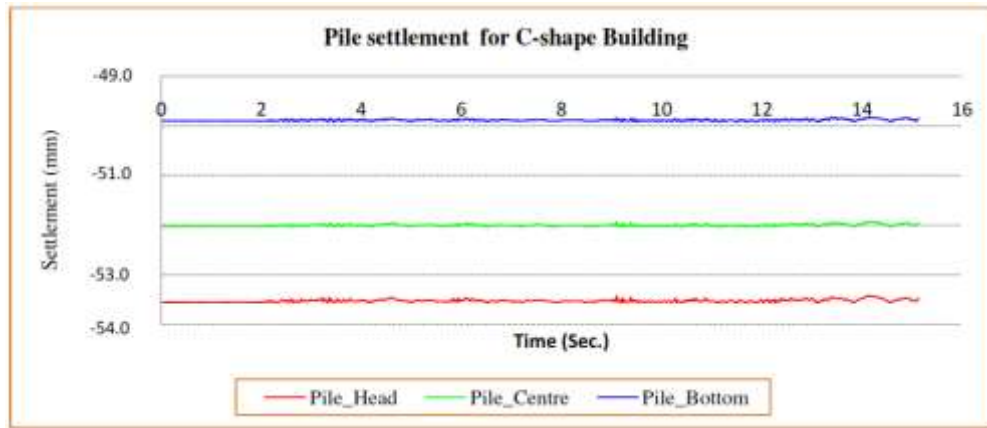


Figure 4. 75 General pile layout time series for C-shaped buildings

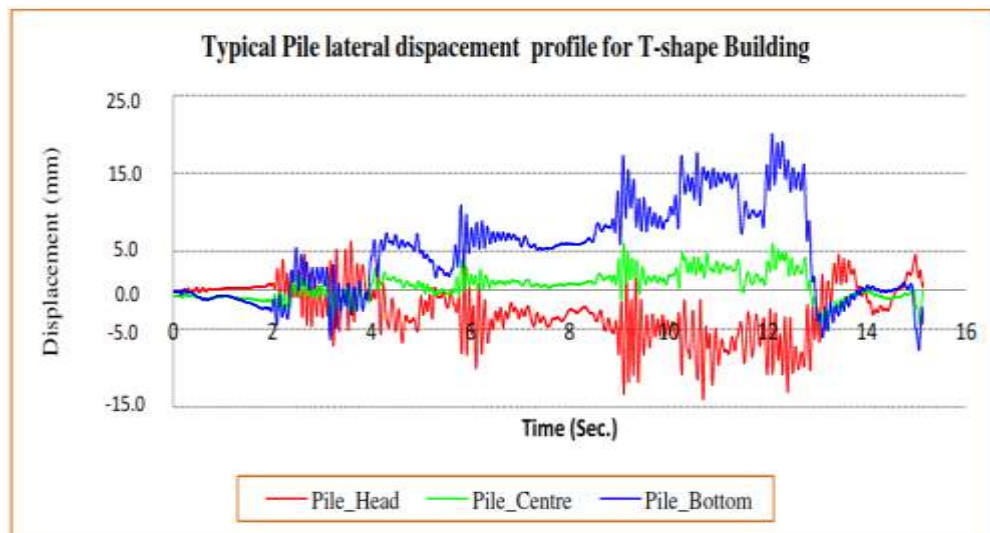


Figure 4. 76 Pile lateral displacement time series for T-shaped buildings with standard pile configuration

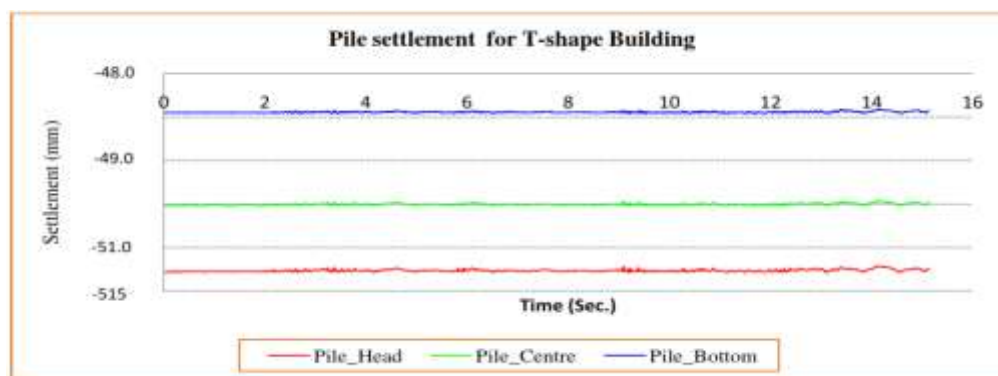


Figure 4. 77 The C-shaped building's time-history pile settling for the basic pile layout

The time history profiles show that the lowest point in the pile experiences the least amount of displacement relative to the direction of the earthquake's application, while the highest point in the pile experiences the most displacement. When looking at the settlement trend at a particular pile location, the pile head is where the most settlement occurs, and as one approaches closer to the bottom of the piles, the settlement becomes less. Whereas, compared to a C-shaped structure, a T-shaped building has a much lower population density.

Studies of the raft's motion have been conducted. Displacement at the crucial corner has been shown for all asymmetrical layouts, including C and T forms, for the purpose of examining the raft's behavior while dynamic loading different asymmetrical designs (Figure 4.78 to 4.80).



Figure 4. 78 for a typical pile structure at a crucial corner, the X-direction displacement of the raft over time for various asymmetrical forms

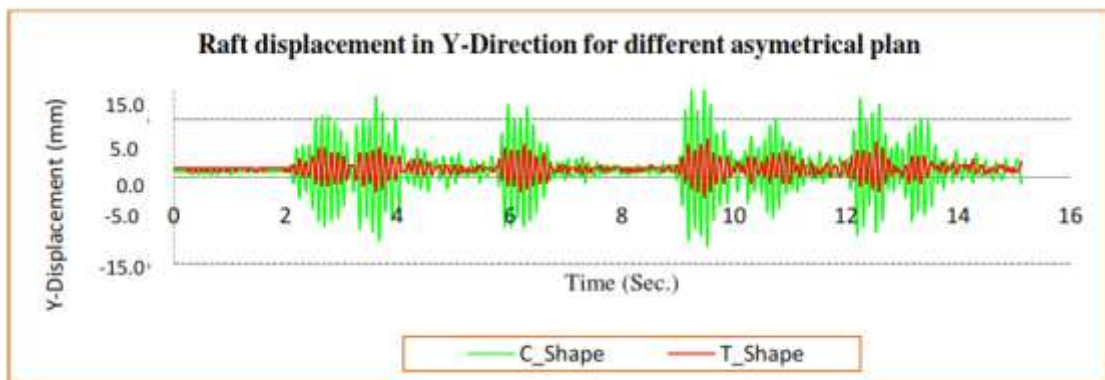


Figure 4. 79 For a standard pile configuration at a crucial corner, the following time series and raft displacement in the Y-direction are presented:

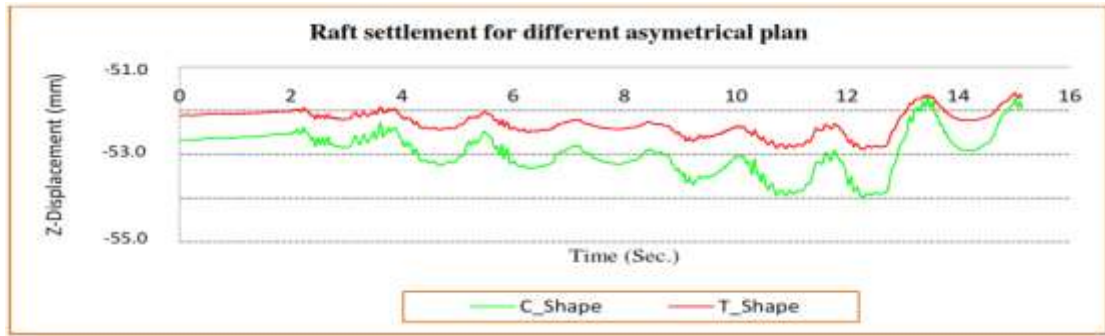


Figure 4. 80 Various asymmetrical forms for the overall pile arrangement at the key corner and their time history of raft settling

According to the patterns shown in the picture, the raft displacement is larger for the C-shaped structure than for the T-shaped one. Another finding is that, when subjected to an earthquake, structures with a C or T form experience more displacement in the X direction than ones with a Y or Z shape. The Z displacements look larger due to the superstructure's gravity weight, although the contribution of the displacement due to earthquake vibration is much less than the X-Y plane value.

Response of the buildings for EPM configurations

The Equivalent Pier has been lowered from the general piling group of both structures, which includes the C and T forms, using the modified diameter and stiffness. After accounting for the interaction effect, the nonlinear dynamic analysis for the C and T building yielded the answers shown in Figures 4.81–4.83. All three primary directions (X, Y, and Z) show these replies.

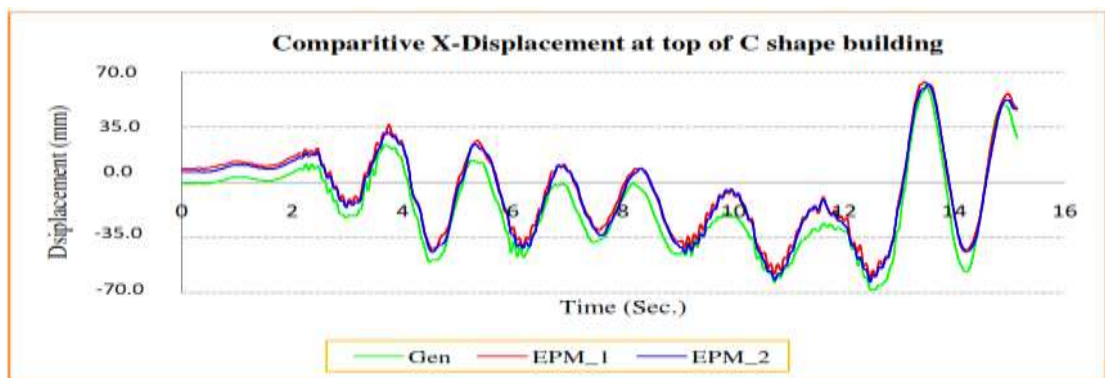


Figure 4. 81 The X-direction time history displacements at the vital corner of a C-shaped building at the top floor

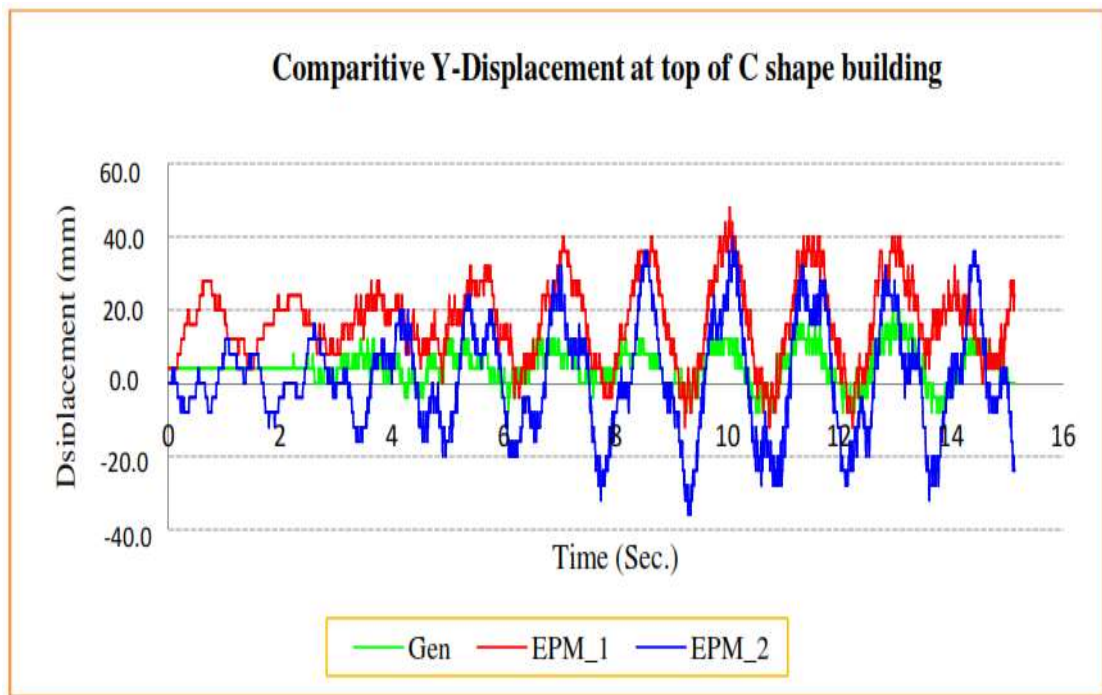


Figure 4. 82 The Y-direction time history of top-story displacements for a C-shaped structure at a crucial corner

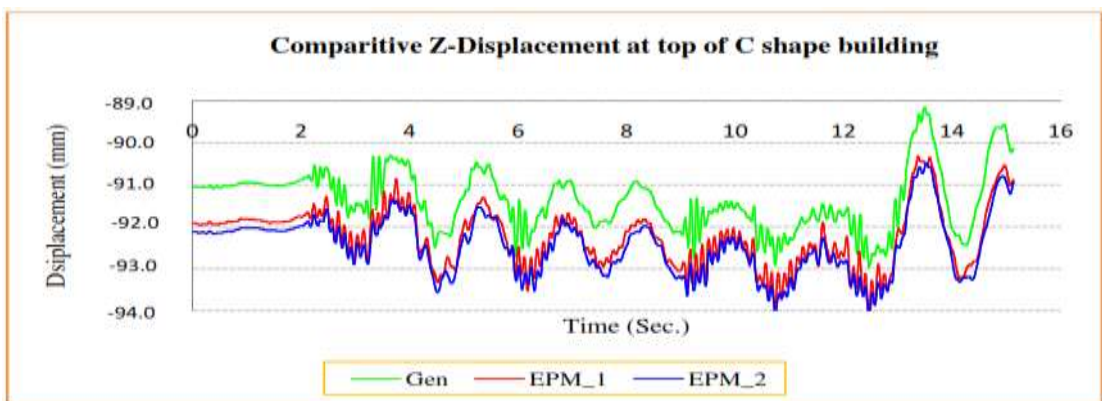


Figure 4. 83 displacements at the top floor in the Z-direction over time for a C-shaped structure at a key intersection

In light of the trends shown by the presented results, it has been noted that the decreased DSSI system's EPM model exhibits responses that are somewhat closer to the reference model, namely the General pile arrangement. There is no lag in the X direction where the earthquake has been applied, and the smaller model's movement follows the same profile as the original model. However, at the first stages of the earthquake application, the Y-axis does not support the same finding. The reference model and the reduced model do not move in tandem throughout the whole shaking, even if the results are

found to agree well in the Y-direction. Upon comparing the reference model's Z displacement with that of the decreased EPM models, it was found that the movement followed the same profile. The EPM model, in contrast to the standard pile arrangement method, shows a larger settlement. The relevant pier may not be as strong as the general piling, which might explain the situation. See Figures 4.84 and 4.86 for the same observations on the T-shaped building.

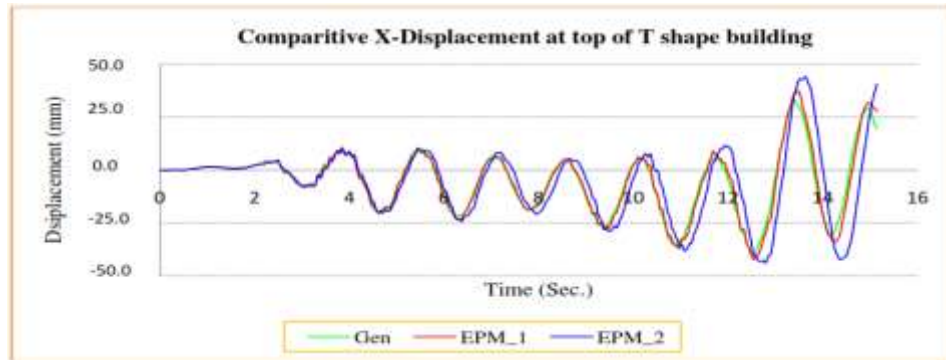


Figure 4. 84 for a T-shaped structure at a crucial corner, the X-direction displacements at the top floor over time

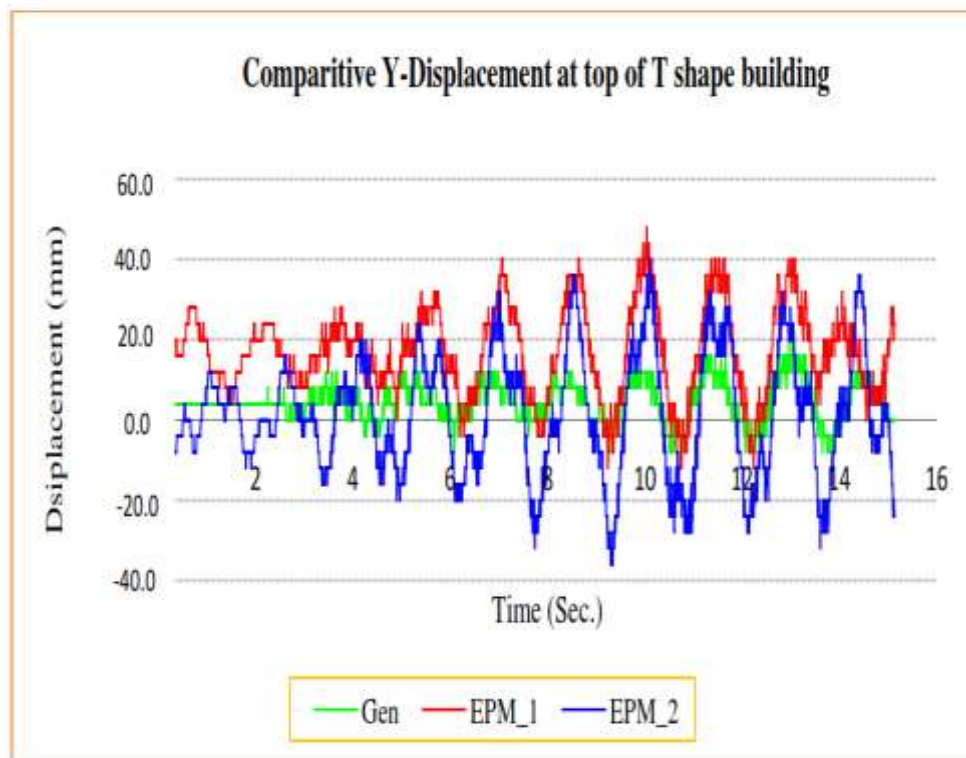


Figure 4. 85 the Y-axis displacements with time at the top floor of a T-shaped structure at a key intersection

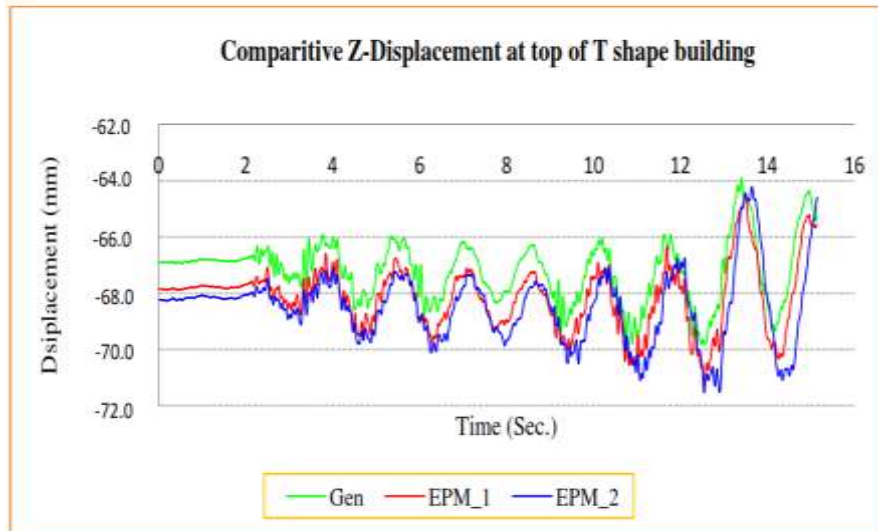


Figure 4. 86 For a T-shaped structures at a crucial corner, the time history displacements at the top level in the Z direction

We compare the displacements obtained at each configuration—the general pile layout, EPM 1 (with one pier), and EPM 2 (with two piers)—to learn how the EPM technique works with the asymmetric pile group, which includes C and T designs. From 4.87 to 4.92, you can see the X, Y, and Z axes showing the storey-wise peak displacements that were measured for the C and T shape designs during the earthquake.

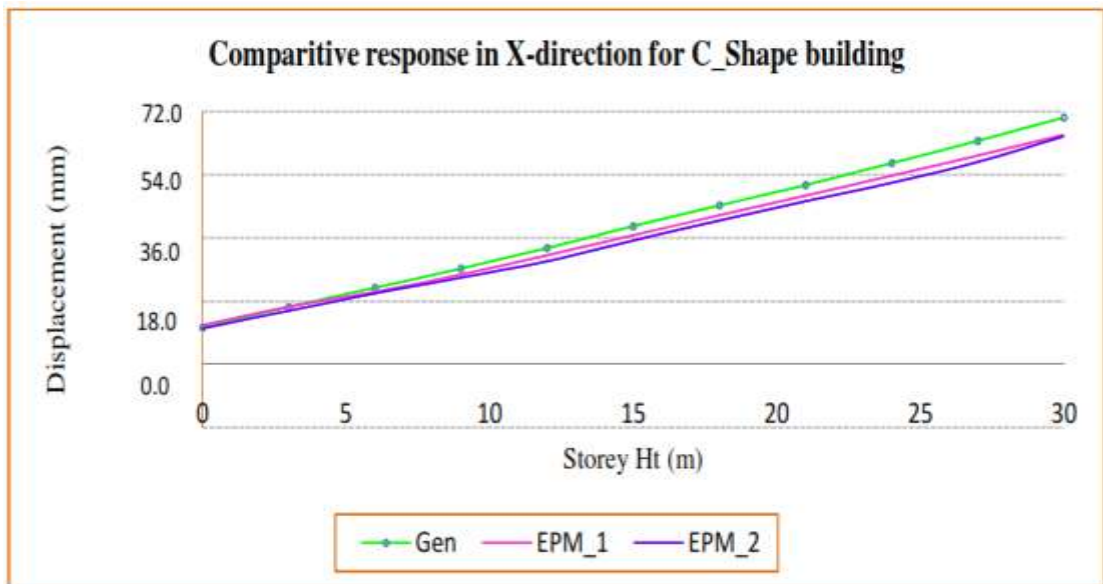


Figure 4. 87 C-Shape building response comparison for several X-direction combinations

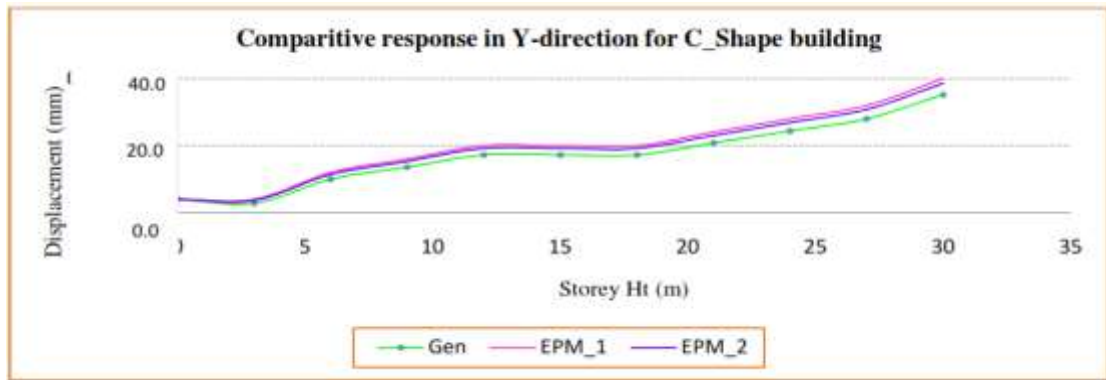


Figure 4. 88 Comparison of responses for different Y-direction setups for C-Shape construction

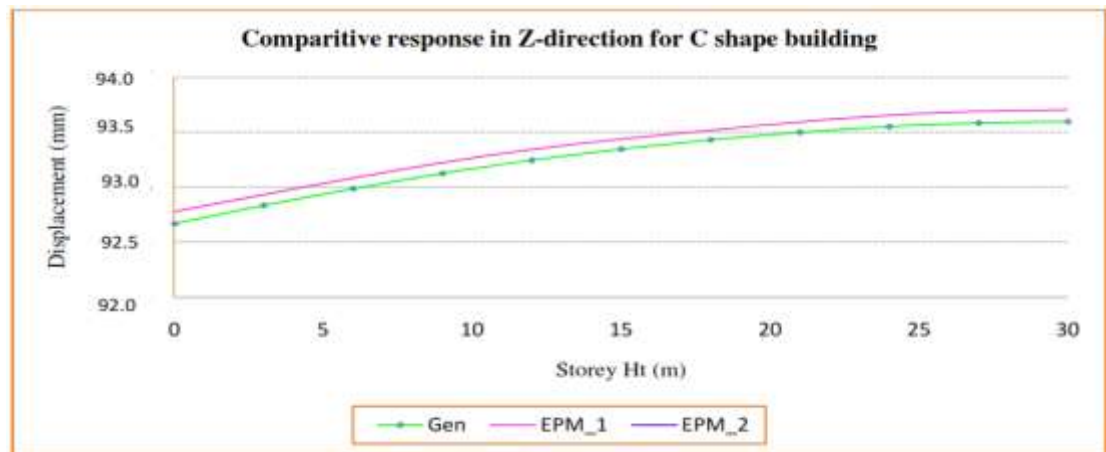


Figure 4. 89 Various setups in the Z-direction for C-Shape constructing response comparison

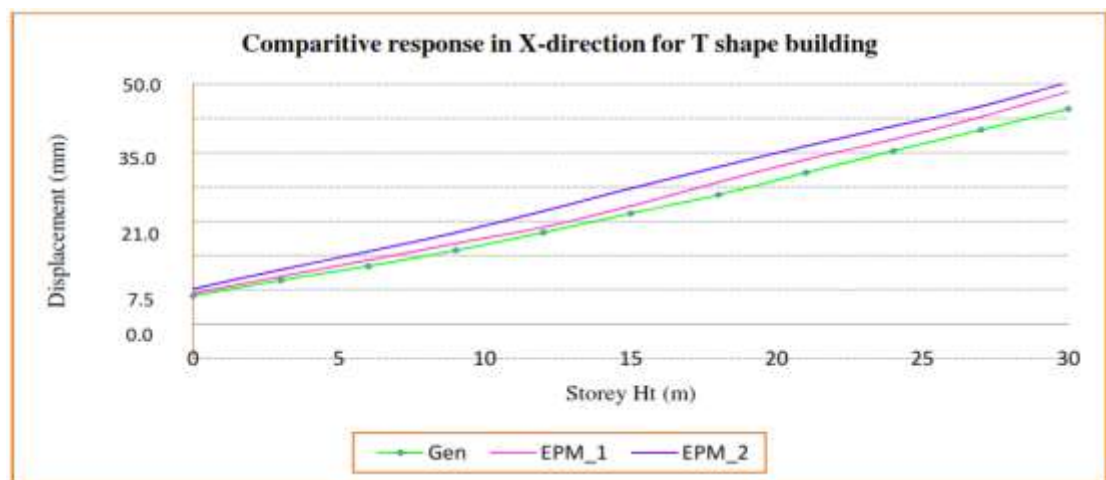


Figure 4. 90 Comparing the reaction of several X-direction layouts for T-shaped buildings storey by storey

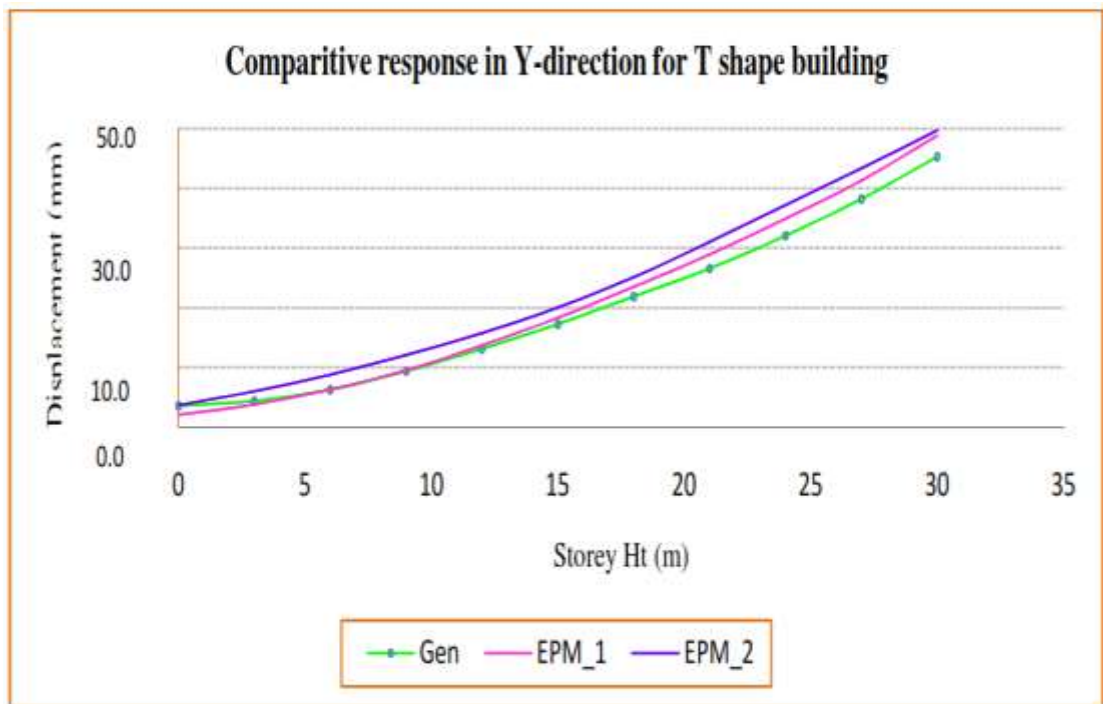


Figure 4. 91 Analyzing the Y-axis reaction of several T-shape building layouts storey by storey

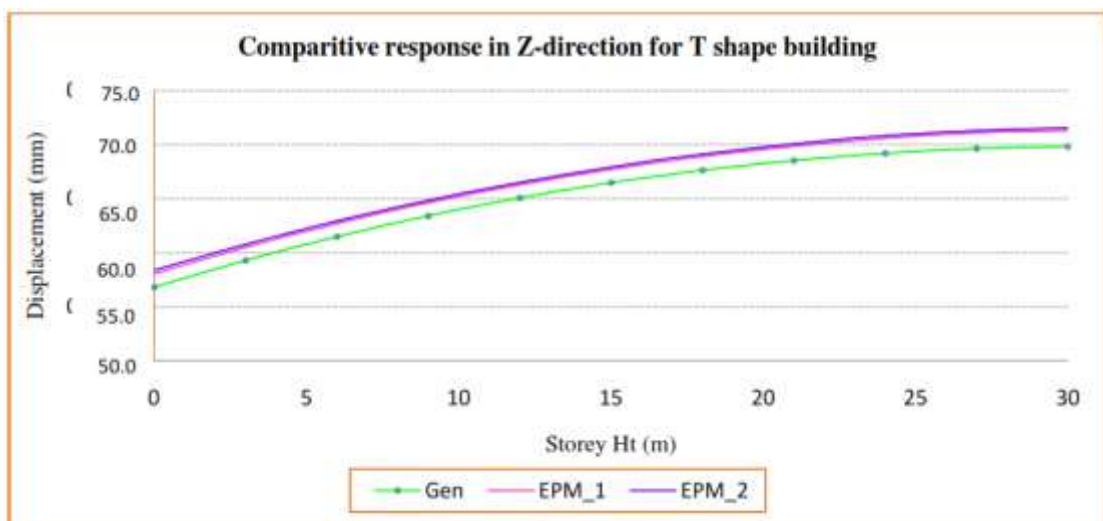


Figure 4. 92 Various layouts in the Z-direction for T-shaped buildings were compared storey-wise in terms of response.

Notably, when taking the general pile arrangement into account, the story-wise displacement for reduce models agrees quite well with the solutions of the reference models.

When compared with the reference model, the responses provided by the reduced model are often more conservative.

A similar principle holds true for T-shaped constructions.

We have compared the EPM setup, the pile's movement, and the pile's general design. It was accomplished by comparing the lateral displacement and settlement of the pile group and the pier in the EPM 1 configuration, which entails substituting the whole pile group with a single pier.

It was done in this way because, mathematically speaking, the center of the pile group and the similar pier are in the same position.

Figures 4.93 and 4.94 indicate that for varied pile lactations, the settlement profile for both the traditional and EPM foundation systems for C and T shape buildings is same.

In contrast. The figures show comparisons at the tip, top, and center. A comparison is used to display these numbers.

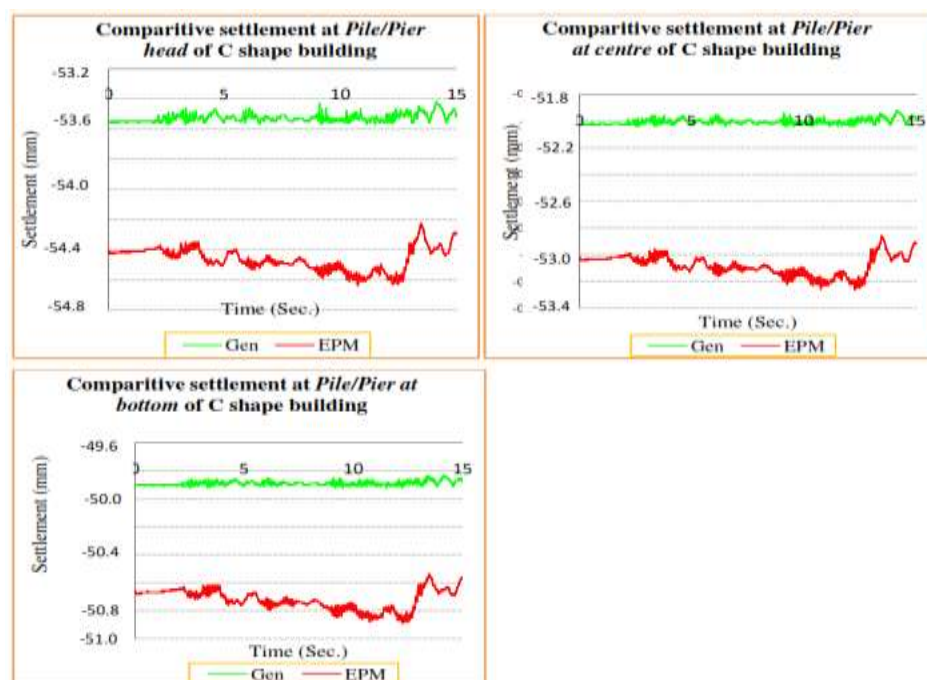


Figure 4. 93 Pile and pier settling profiles compared at various locations for a C-shaped pile arrangement

Figure 4.93 shows that the pile settles at different points along the reduced EPM model, which disagrees somewhat with the reference model that describes the pile's overall layout. Regarding the T-shaped building, the same conclusion has also been reached.

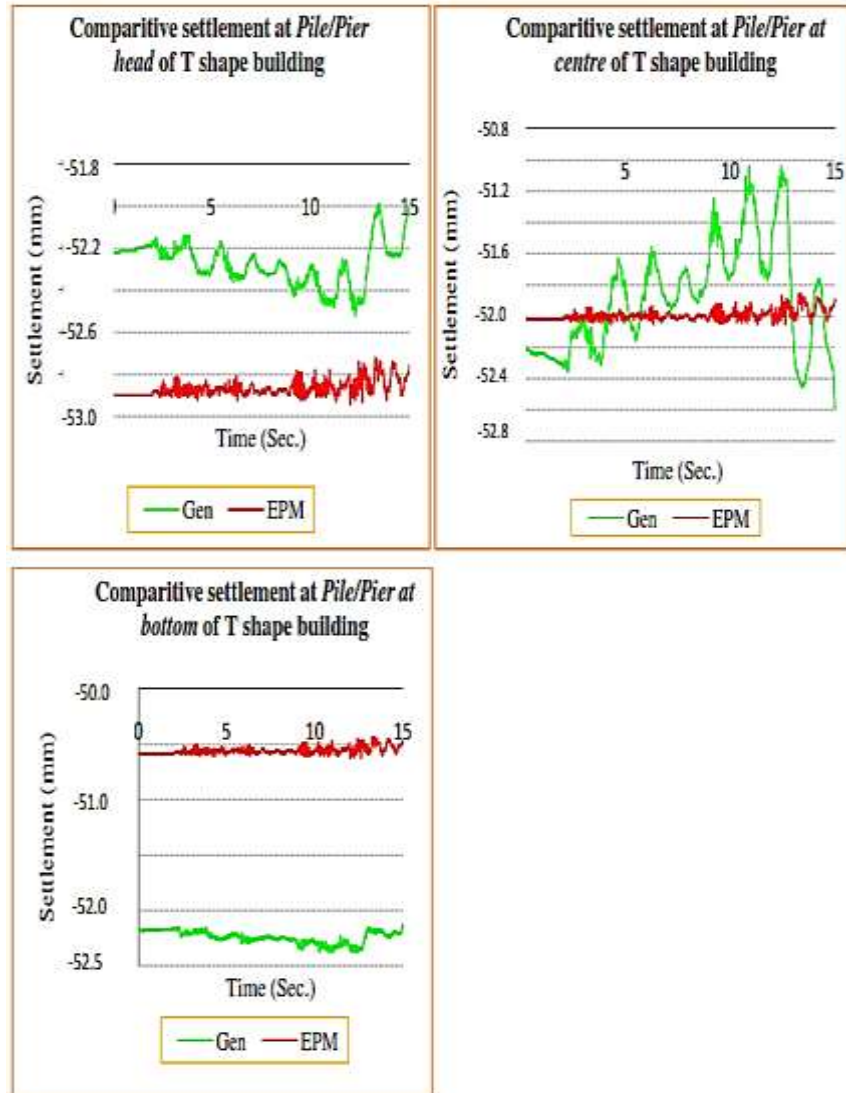


Figure 4. 94 Settlement profiles of piles and piers at various locations using a T-shaped configuration

Additionally, we have compared the general configuration and EPM architectures' lateral displacements of the piles. In Figures 4.95 and 4.96, we can see how the pile or pier head, tip, and center moved laterally in the direction of the earthquake for both C and T shape structures, compared over time. The figures that correspond to these numbers show them.

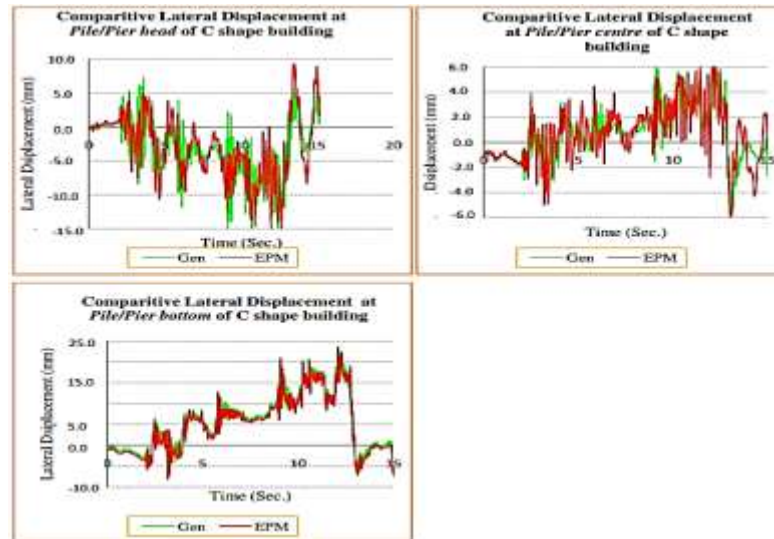


Figure 4. 95 Various locations for a C-shaped pile and its pier, compared for lateral displacement profile

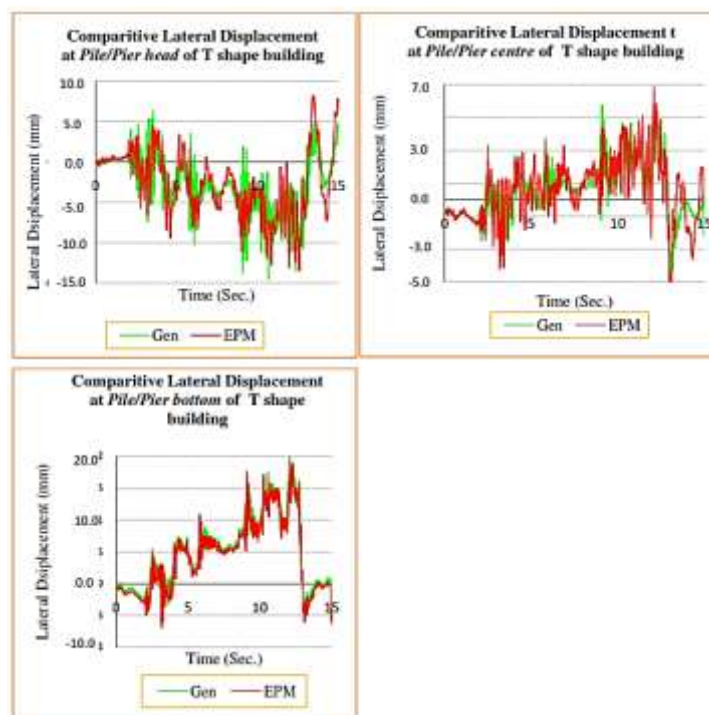


Figure 4. 96 Comparison of the pile's and the pier's lateral displacement profiles at various locations using a T-shaped pile arrangement

When comparing the EPM model to the conventional pile arrangement technique, one noticeable difference is the amount of lateral displacement along the dynamic load's direction of application. Because of this, the EPM shows that the foundation systems of the C- and T-shaped buildings react in a very synchronized manner.

A comparative maximum primary stress analysis was conducted on the foundation system, comprising the raft and piles, to evaluate how the system responds when reduced to the matching pier of the proper stiffness and diameter. Comparative stresses produced in the raft at the critical corner for various pile types are shown in Figure 4.97. This includes layouts such as traditional piles, EPM1 and EPM2 for T-shaped building systems, and others. The usual stress profile for the T-shaped asymmetrical arrangement is shown in this chapter (Fig. 4.97), although research has been undertaken for both C-shaped and T-shaped constructions.

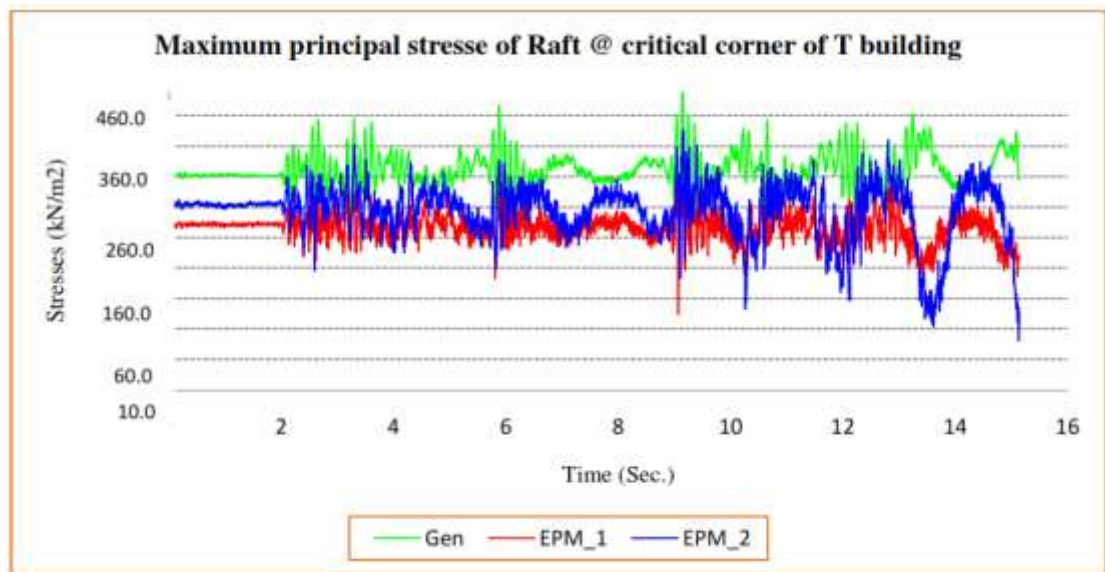


Figure 4. 97 for various T-shape arrangement configurations, the stress profile of the raft at the crucial corner

As a result of measuring the stresses at It was found that the simplified models, EPM1 and EPM2, generate less stress than the reference model, which is the regular pile plan, at the raft position, which is the precise site of the building's crucial corner. However, since the range difference is rather considerable, it was determined that the deviation is not comparable.

Using ground motion at the base of the SSI system, we have measured the maximum primary stresses at the top, middle, and bottom of the pile for both the group's central pile and the comparable pier. The goal was to find out how big these strains may become. Relative to ground shaking; Figure 4.98–4.100 shows the typical stress profile. The three levels of the T-shaped SSI system's pile display this stress profile.

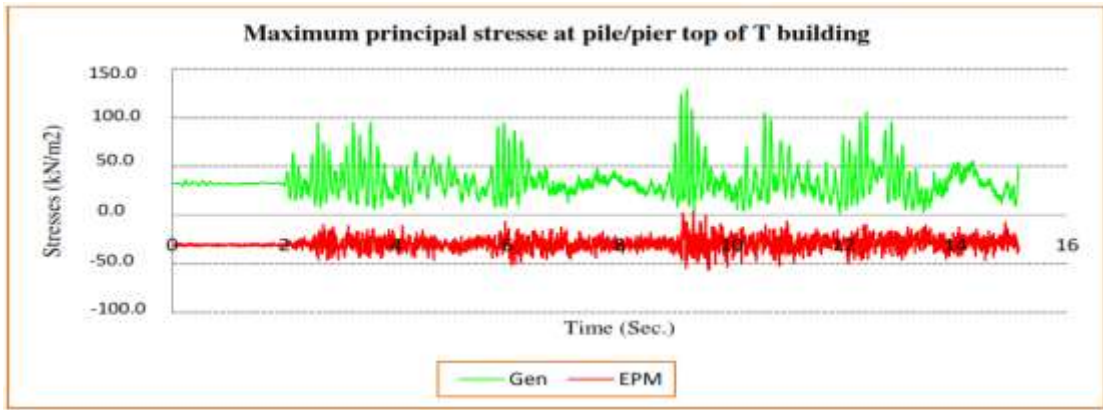


Figure 4. 98 Top of pile/pier stress profile in T-shaped configuration

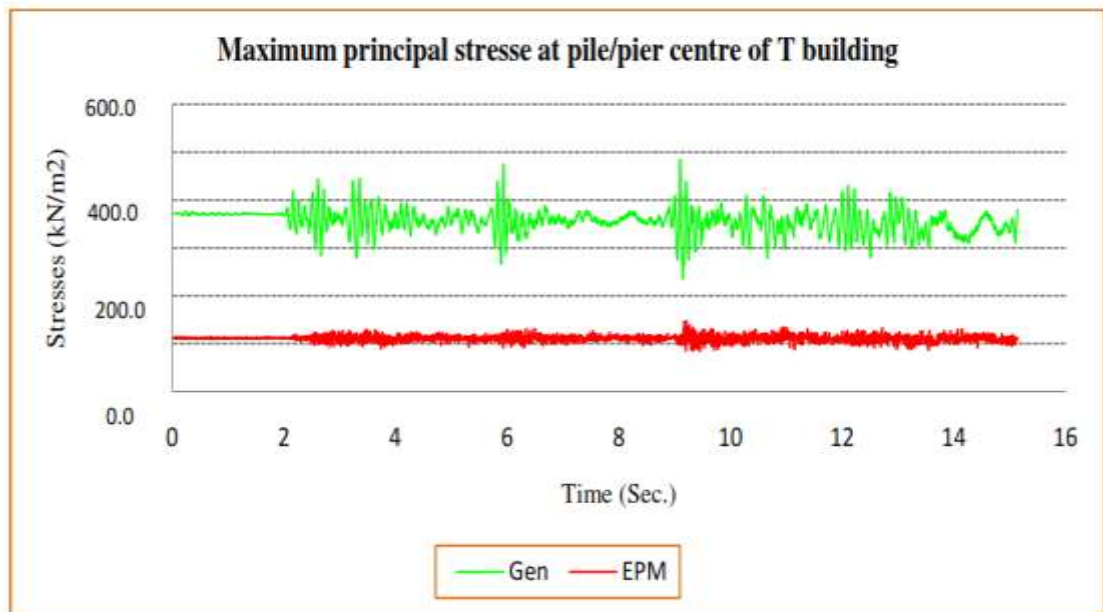


Figure 4. 99 Profile of stress at T-shaped layout's central pile/pier

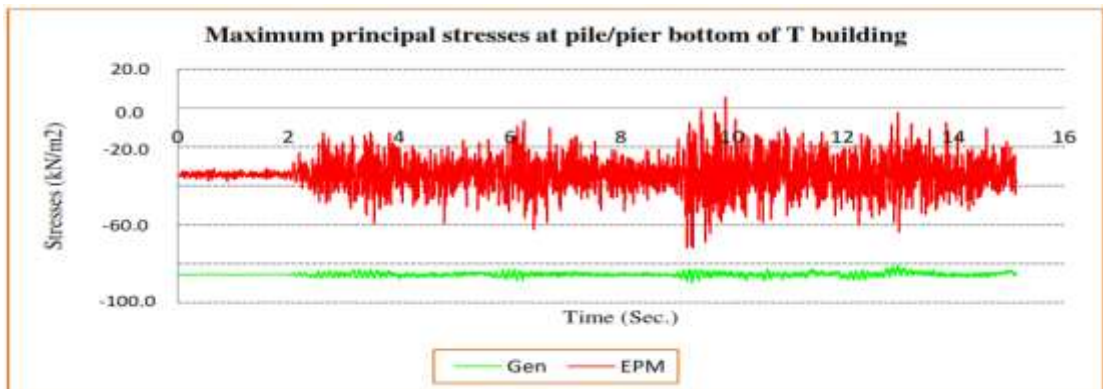


Figure 4. 100 Top of pile/pier stress profile in T-shaped configuration

Numerical statistics

For each design, a finite model was constructed to estimate the numerical expense. This includes the General pile arrangement, EPM 1, and EPM 2. The numerical cost has been indicated for each model in terms of degrees of freedom (DOFs), number of nodes, lowest element size, elements formed after meshing the model, and total number of elements. The quantitative measure that is shown in Table 4.9 is associated with each possible configuration of the C and T shape building design.

TABLE 4. 9 Metrics that quantify each EPM setup

Configuration	Dofs	No. of Elements	No. of Nodes	No. of Nodes in Contact	Least element size in FE model (m)	Critical time step taken	CPU time to get the response
C-Shape							
General	72,792	22,695	24,264	1,974	0.11	5×10^{-5}	50.45
EPM 1	27,372	8,376	9,124	309	0.15	8×10^{-5}	18.97
EPM 2	28,047	8,575	9,349	357	0.15	8×10^{-5}	19.45
T-Shape							
General	65,016	19,777	21,672	1,669	0.11	5×10^{-5}	47.16
EPM 1	26,985	7,743	8,995	278	0.15	8×10^{-5}	18.70
EPM 2	27,720	7,978	9,240	370	0.15	8×10^{-5}	19.25

Comparing the displacement departures with the overall pile arrangement allowed us to assess the applicability of the approach proposed in this study. Table 4.10 displays the maximum building reactions assessed during the earthquake, and Table 4.11 shows the percentage discrepancy between each EPM model for each C and T shape pile arrangement.

TABLE 4. 10 Different EPM configurations show peaks in response at the top of the superstructure.

Asymmetric al shape	Peak X-Displacement (mm)			Peak Y- Displacement (mm)			Peak Z- Displacement (mm)		
	Gen	EPM 1	EPM 2	Ge n	EPM 1	EPM 2	Gen	EPM 1	EPM 2
C	68.3 9	63.59 5	63.17 5	33. 5	40.1	39.8	92.1	93.8	92.2
T	46.5	48.9	50.54	45. 1	48.4	41.9	69.8 2	71.29	71.53

TABLE 4. 11 Variation in response percentage for different EPM configurations relative to the overall pile arrangement

	C-Shape		T-Shape	
Response Direction	EPM1	EPM2	EPM1	EPM2
X	7.53 %	8.25 %	-4.91 %	-7.99 %
Y	-16.46 %	-15.83 %	-6.82 %	7.64 %
Z	-1.81 %	-0.11	-2.06 %	-2.39 %

Tables 4.12 and 4.13 describe the response of the foundation system. For comparable pier designs, these tables include the peak raft and settlement. They also provide the pile lateral displacement and the general pile group for both C and T shape layouts.

TABLE 4. 12 Raft maximum settling and critical site lateral displacement

Building plan	Settlement (mm)			Lateral Displacement (mm)			Max. Principal stresses (kN/m ²)		
	Gen	EPM 1	EPM2	Gen	EPM 1	EPM2	Gen	EPM 1	EPM 2
C-shape	54.91	56.38	56.27	18.1	16.7	16.7	514.45	329.5	326.2
T-Shape	53.08	55.52	55.34	17.2	22.2	22.4	501.5	386.9	435.9

TABLE 4. 13 various asymmetry conditions maximize pile settling and lateral displacement at various locations

Building plan	Pile location	Settlement (mm)		Lateral Displacement (mm)	
		Gen	EPM	Gen	EPM
C-shape	Top	53.57	54.64	16.5	15.3
	Centre	52.04	53.26	7	8.2
	Bottom	49.92	50.89	23.6	23.2
T-Shape	Top	52.52	52.94	14.5	13.4
	Centre	52.6	52.06	5.8	6.8
	Bottom	52.38	50.62	20.06	19.72

Every one of the three building layouts—CPM1, EPM2, and L—had their own numerical evaluation associated with it. These evaluations included the basic piling arrangement, EPM1 (with a similar single pier), and EPM 2 (with two comparable piers). We have thoroughly reviewed the numerical evaluation in terms of degrees of freedom (DOFs), number of nodes in contact, and number of elements in the finite model that was built for each configuration for the study.

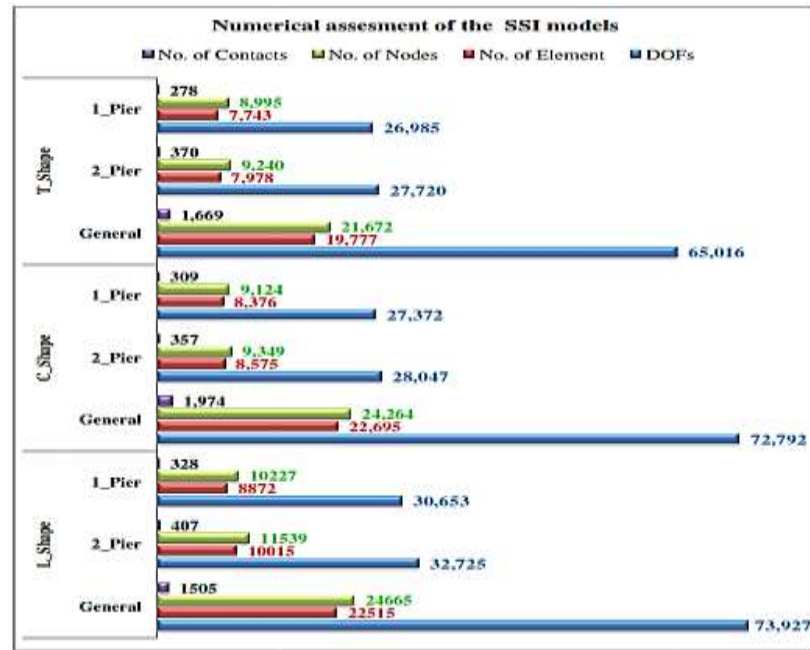


Figure 4. 101 Quantitative evaluation of L-, C-, and T-shape construction

Based on Figure 4.101, it is clearly visible that lowered EPM algorithms, in contrast to the full pile architecture, can significantly reduce numerical controlling parameters like element count, node count, interface pair in contact, and degrees of freedom. The average reductions for all EPM setups are more than twice as large as these reductions. Considerations for indicated asymmetrical building designs in this study, including C, T, and L, support the same conclusion.

Studying soil structure is a laborious and computationally demanding process that calls for powerful computers and plenty of processing capacity. The direct approach requires not only soil half space but also foundation and superstructure modeling. Failing to do so might lead to the analysis being very computationally expensive, or even beyond the memory limitations of the system. The SSI modeling is complex, which is an additional obstacle. We need to include interfaces that may compress, slide, or create a gap between the ground and the structure if we want to mimic the SSI problem to the letter. Modelling the interfaces around the piling area is necessary when dealing with soil and piles in order to accurately depict the contact and friction between the two materials. If the SSI assembly is subjected to an earthquake, it is important to use the ideological process to identify the interface's behavior. The soil, structure, and interfaces all exhibit non-linear correlations when doing SSI analysis in real-time. This calls for modeling that is both difficult and time-consuming. Providing some simple, easy-to-understand

solutions to simplify modeling and decrease computational resource requirements is of the utmost importance.

To try to quantitatively reduce the problem, we used the Equivalent Pier Method to the current piling group in this research. In order to get over the extra complexity, this is done. This not only decreases the number of piles, but it also simplifies the modeling process and cuts down on computation time.

In order to fulfill the requirements of this chapter, a G+10 R.C.C. C and T-shape asymmetrical structure was examined for ground motion (2001, PGA =0.31g) on platforms supported by a pile foundation system on uniform soil strata.

The following measurements are typical of the piling foundation that supports the structure in question: has a length of 9.0 meters, a starting diameter of 0.45 meters, and an aspect ratio of 20. Beams and columns of M 20 concrete grade, with prismatic cross sections of 0.23 x 0.23, formed the structure of the R.C.C. building.

Constructed on soil with a young's modulus of 7900 MPa and a shear wave velocity of 300 meters per second, this building's foundation is a C and T shape pile supported structure. It is anticipated that the soil has shear strength of 35 kN/m² and a bulk density of 18 kN/m³. Additionally, the projected angle of internal friction (ϕ) is 35°. The Poisson's ratio is 0.35 in the relevant domain.

This scholarly investigation into the dynamic soil structure is now complete, and the results are as follows.

The impact of the building's asymmetry

In this section, we explore the asymmetrical structures of the C and T shapes along one of the main axes. These structures are not balanced with one another. The displacements at each corner of every level may tell you a lot about the effects of asymmetry on a structure. To do this, the SSI system is subjected to seismic stress. It has been noted by someone that the responses at the symmetrical structures are different from those at each corner. This points to a little amount of response variance, but it's still noticeable. It has been observed that a structure shaped like a C has two very important corners. Regarding the construction of T-shaped structures, two critical corners have been

found. As a result, various building designs may exhibit varying asymmetrical reactions to seismic loads. In both C-and T-shaped constructions, the reaction variance between the critical and non-critical corners is between 0.5 and 6.5 percent. Modulating the inertial stress may amplify the amount of this shift.

The research revealed that the Z-direction had bigger displacements than the X and Y-axes, despite the fact that the earthquake was felt in the X-direction. Because of how the soil and foundation system affect the applied gravitational force, this is indeed the situation. The percentage may be determined using the displacement from the static analysis, which indicates that the self-weight simply influences vertical displacements. When calculating earthquake forces, it was discovered that the vertical component is less than the sum of the X and Y components. The torsion at the base is a crucial characteristic because it allows the asymmetrical structure to adapt to dynamic stress.

Impact of asymmetrical layouts' complexity

All buildings with L and T shape plan geometry had their dynamic time history responses evaluated in this study. Peak displacements are bigger in the C form as compared to the T and L shapes, according to the findings. The sequence's most responsive regions are C, L, and T, in that order. The average number of displacements per level in a C-shaped building is 9.0% more than in an L-shaped building, whereas in a T-shaped structure it is roughly 20.5% lower. In terms of the building plan, C and T shape designs are more involved, but they are symmetrical in X-direction. So, the amount of planar asymmetry is proportionate to the structural displacements.

The load that the L, C, and T constructions all send to the ground is identical. With an average variance of around 0.5% to 1.5%, all three constructions caused the raft to settle when it came to displacement at the piling location. The kinematic interaction caused by an earthquake stays the same, but the way it reaches the superstructure is affected by its shape. In order to build an uneven construction that can withstand earthquakes without sustaining damage, this must be considered.

Use of EPM for groups of asymmetrical piles

Now that the asymmetrical area is separated into several symmetrical portions, the pile group is reduced to two different configurations with each other. Every floor level of

the superstructure has had its response estimated for each EPM configuration, with the interaction effect taken into account. For every EPM model of a C- or T-shaped structure, the X, Y, and Z axis displacement has been calculated. The displacement has allegedly taken place. In terms of vertical response, studies have shown that all EPM designs are almost identical to the conventional pile construction. With a response differential in the 2–4% range, the EPM arrangement is the safer and more practical option here. The two numbers EPM 1 (1 Equivalent Pier) and EPM 2 (2 Equivalent Piers) denote the structure's reduced piling configuration. The EPM 2 layout divides the planned space in half, with each half having two piers of the same diameter. Observations show that structures with an X-direction response are both C-shaped and T-shaped. For both C and T shape structures with the EPM 1 arrangement, the peak response of the superstructure is found to be typically off by 4 to 8 percent when the X direction is considered. The two buildings' EPM2 levels are around 8 percent different. Increase the stability of the SSI system with EPM1 by erecting comparable piers and splitting the area into equal halves. As we go on to the Y-direction response, we see that 16% of the C-direction structures and 8% of the T-direction buildings have different answers for EPM and general pile arrangement. This EPM design has shown to be more stable for the C building and more conservative for the T structure compared to the associated general pile arrangement.

Z displacement varies by 1% to 2% across all C and T building EPM configurations. Thus, the responses are under-estimated in comparison to the conventional pile structure, even if the system becomes more inflexible when the EPM design is considered. The most notable variation, measured in absolute terms, often ranges from 2% to 16%; nonetheless, the answer is typically provided by any EPM system. Since the analysis time is a key factor in determining the system's behaviors in SSI situations, this technique may be adjusted accordingly.

Stresses and displacements inside the base

At the most important location on the raft, researchers studied the settlement and stress levels of C-shaped and T-shaped components. When dynamic loads are applied, the superstructure displays the maximum displacement at this point. For C and T-shaped structures, the general EPM configuration did not significantly vary from all EPM (1 and 2) configurations with respect to settlement and stresses. If we compare this pile to

the general pile design's center pile and the one matching pier—both situated in the same position inside the asymmetrical configuration—we may get a clearer idea of its deflection and stress behavior. The investigation discovered that the settlement and displacement at the top, tip, and center of the pile were almost comparable (with a little fluctuation of 0.5 to 2%), in both the normal pile arrangement and the EPM configuration foundation system. We constructed a pier that closely resembles the one in the pile group's center pile after studying its comparative major maximum stress profiles. The area of action of the single pile differs from the equivalent region, making stress comparisons impossible.

Effect of Complexity and Numerical Expense

As a result of the need to establish a connection between the interdependent components, SSI analysis offers a very intricate representation of the underlying system. Consequently, the issue becomes more complex as more of these components are included. The best EPM for asymmetrical pile groups is the one that takes interaction effects into consideration, as it produces workable results with a reasonable degree of uncertainty. According to the EPM mechanism, the degree of asymmetry in the superstructure's plan geometry and the asymmetrical area determine whether two or one piles are reduced. Reducing the modeling complexity to a manageable level is achieved by expanding the variety of available sites for interface applications.

In both the C and T shape constructions, the average number of contact nodes was reduced from 1900 to 320 throughout the iterative process of contact displacements. The time and effort saved by simplifying things is clearly seen here. To our knowledge, this is the only tangible benefit of EPM approaches at this time. In particular, the numerical cost is affected by the number of components as well as the degrees of freedom. Since the EPM methodology reduces the number of components from 20,000 to 9,000 (on average) and the number of degrees of freedom from 70,000 to 20,000, this method is numerically efficient. To get the answer to this question, an explicit solver was used. The very small time step was determined by the lowest element size in the finite element model. The matching piers of the EPM technique increase the diameter at the conclusion of the meshing phase, resulting in larger components. One of the key aspects that minimizes the time necessary to address the problem is the longer time step, and this makes it an easier option. The usual lowest element size in models

is 0.11 m, which corresponds to a pile diameter of 0.45 m. To account for this, the critical time step must be set at 5×10^{-5} seconds. This is the case with the majority of pile designs. The total number of hours that the C and T buildings' piling arrangements can withstand a fifteen-second dynamic load is 49. For EPM 2 (with an equivalent diameter of 5.0 meters) and EPM 1 (with an equivalent diameter of 3.5 meters), the average element size while talking about the EPM configuration should be 0.9 to 1.5 meters, respectively. This means that the critical time step may be completed in 8×10^4 seconds, which works out to 16 hours on average for the same dynamic loading period. Thus, all EPM configurations provide the solution more quickly than the original pile design, demonstrating that EPM is a dependable approach to decreasing the time required to evaluate SSI and other large-scale difficulties. The results show that across all EPM configurations, the time needed to get a solution is cut in half to three quarters. This goes against the grain of the typical pile pattern seen in T-and C-shaped floor designs. The EPM approach is adequate for dealing with SSI difficulties, regardless of how much memory and processing power the CPU needs.

4.3 NUMERICAL PARAMETRIC STUDY

Recent years have seen a proliferation of research and practice devoted to performance-based seismic design principles, which include soil structure interaction among its many components. This method evolved from the assessment and improvement procedure for preexisting structures. Unpredictable movements in every direction, emanating from the core, are the result of an earthquake. The building vibrates due to the inertia forces induced by the ground movements. Due to its primary design for gravity loads alone, most of the existing reinforced concrete structures in India's seismic zone do not fulfill the current seismic criteria.

Buildings' responses to earthquakes are conditional on a wide range of factors, including the foundation's behavior, the soil's and infill's stiffness, the severity of the earthquake, and many more. While buildings placed on medium-stiff or stiff soil should be able to resist some of the lateral strains caused by earthquakes, the exact opposite is true for buildings positioned on too-soft soil, which may cause them to collapse. Examining the impact of each controlling parameter is the only way to grasp the key requirement of the soil structure system during seismic circumstances. If the integrated DSSI system passes its parametric testing, this may happen. This chapter lays out the

steps for conducting an inelastic analysis-based, completely nonlinear time history dynamic analysis, which includes the interaction effect. Predicting the structural reaction of the mid-rise asymmetric building by changing characteristics of the supporting system is the primary focus. A G+10 mid-rise C-shape asymmetric building, which was shown to be more susceptible to seismic damage, was the subject of a thorough parametric investigation in this chapter. This will be accomplished by foreseeing how the structure will react to various soil types, seismic loads, and L/D pile foundation configurations.

4.3.1 SSI MODELLING OF ASYMETRICAL BUILDING

By incorporating the method into the C++ code, the finite element model of C-shaped pile-supported buildings was generated. Everything from the superstructure and soil to the pile and raft—the many components that comprise the SSI system—are accounted for in the model. To see the model in action, we utilize the LS-PP tool. It is feasible to simulate the G+10 asymmetrical arrangement of C, L, and T by analyzing the impact of interactions by modeling the connections between the pile's nodes and the ground. We could observe the superstructure's reactions and investigate the effects of the aforementioned variables by manipulating them during the investigation: soil type, dynamic loading, and pile L/D ratio. Drucker and Prager's soil material model was used to conduct a dynamic nonlinear analysis that takes material nonlinearity into consideration. Buildings supported by piles are shown in Figures 4.102–4.104 using the extended SSI model.

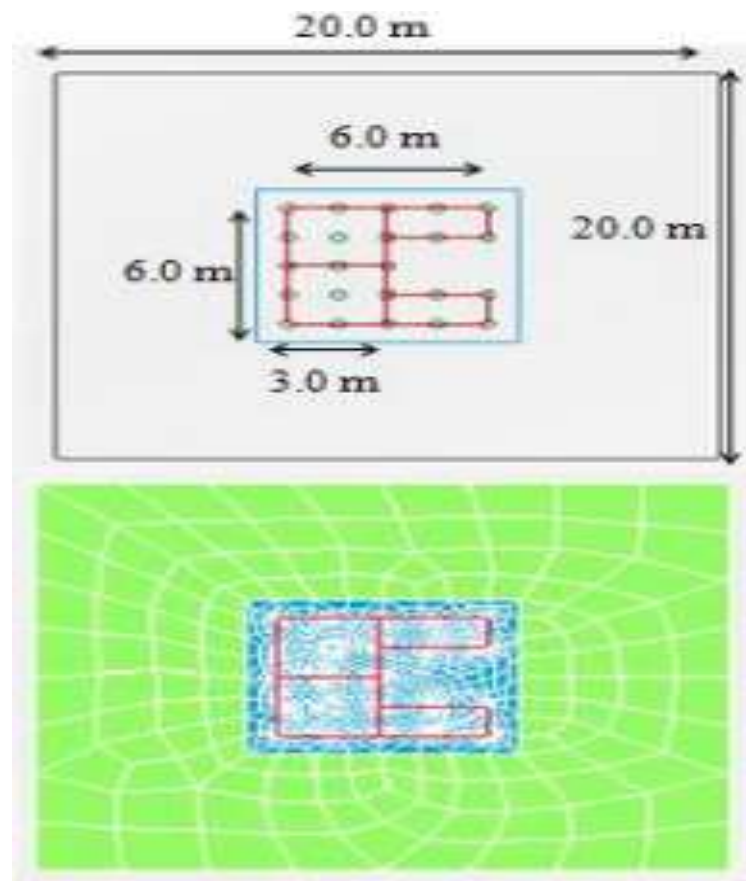


Figure 4. 102 Design for the DSSI system's C-shaped G+10 structure

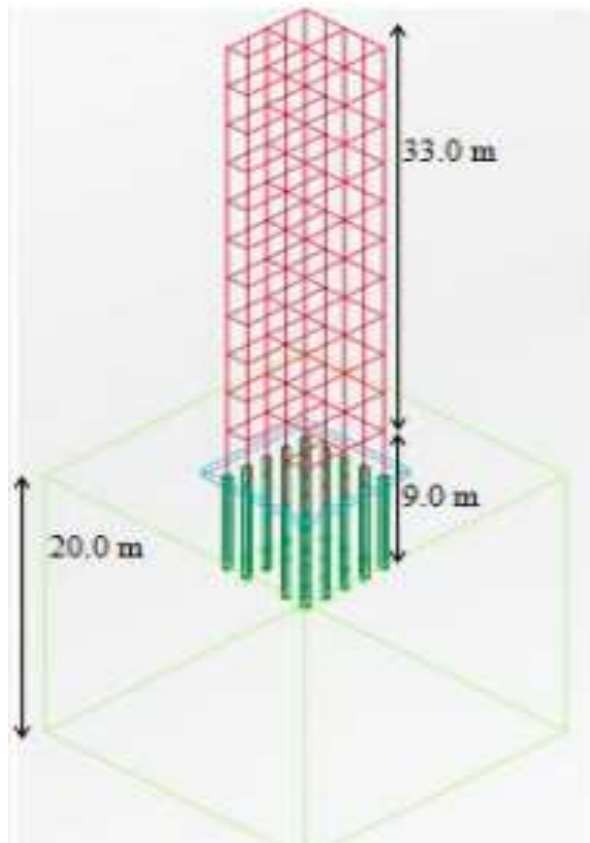


Figure 4. 103 3D model of a C-shaped G+10 structure with a DSSI system

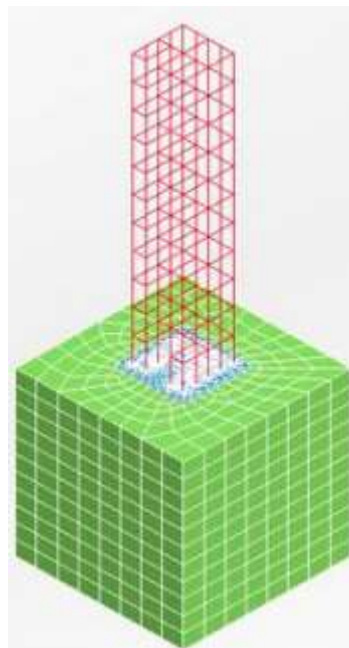


Figure 4. 104 Meshed model for C-shape G+10 building for DSSI system

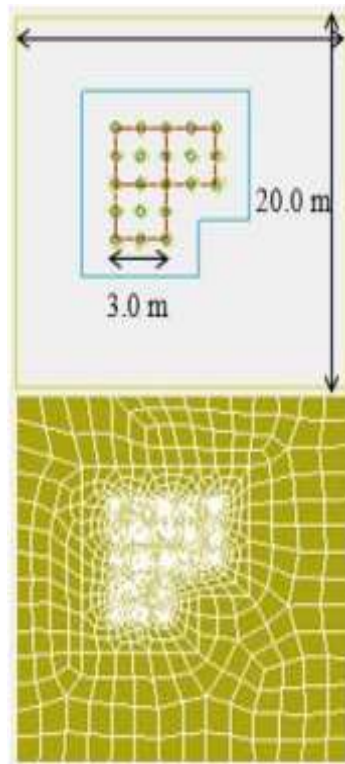


Figure 4. 105 Plan for L-shape G+10 building for DSSI system

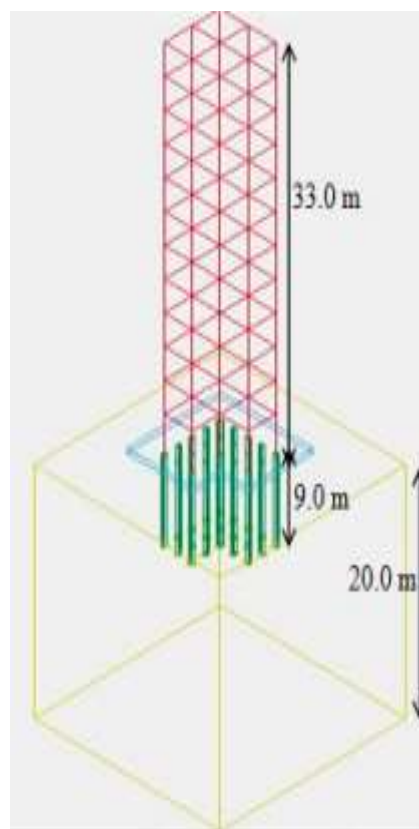


Figure 4. 106 Isometric view for L-shape G+10 building for DSSI system

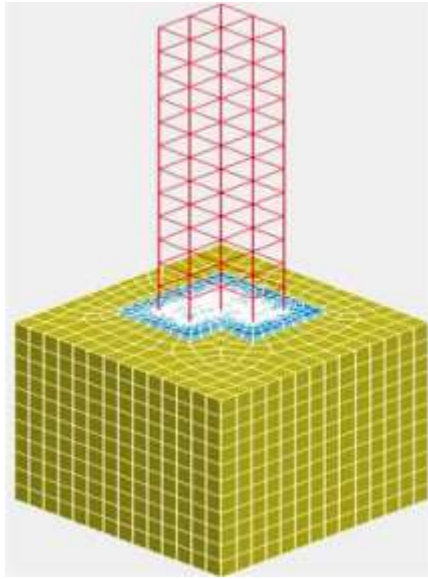


Figure 4. 107 Meshed model for L-shape G+10 building for DSSI system

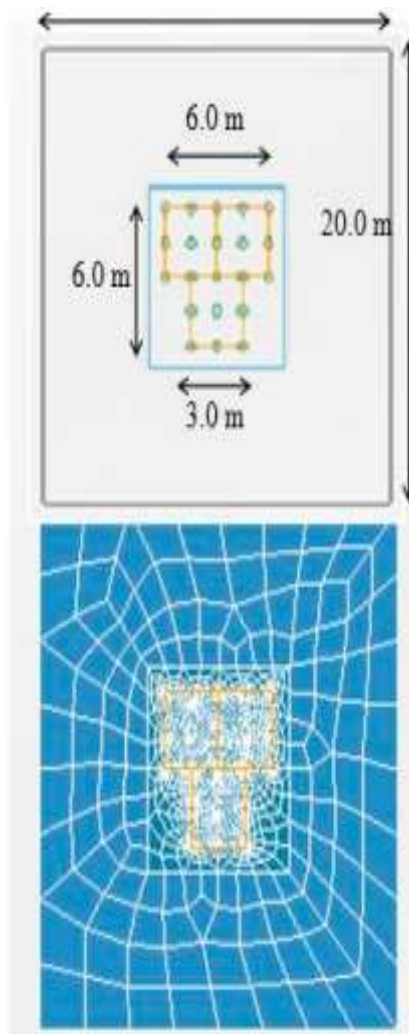


Figure 4. 108 Design for the DSSI system's T-shaped G+10 structure

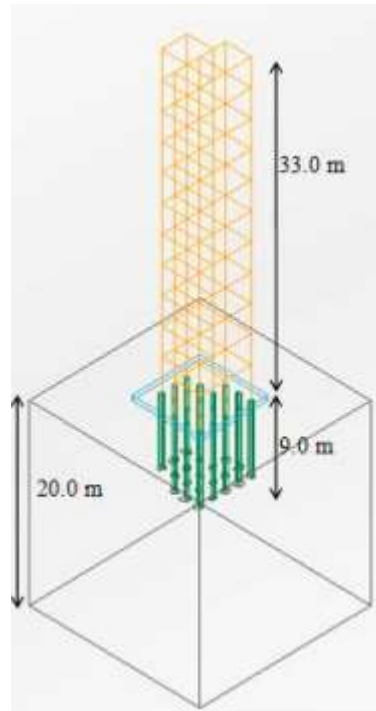


Figure 4. 109 The DSSI system's isometric representation of the T-shaped G+10 building

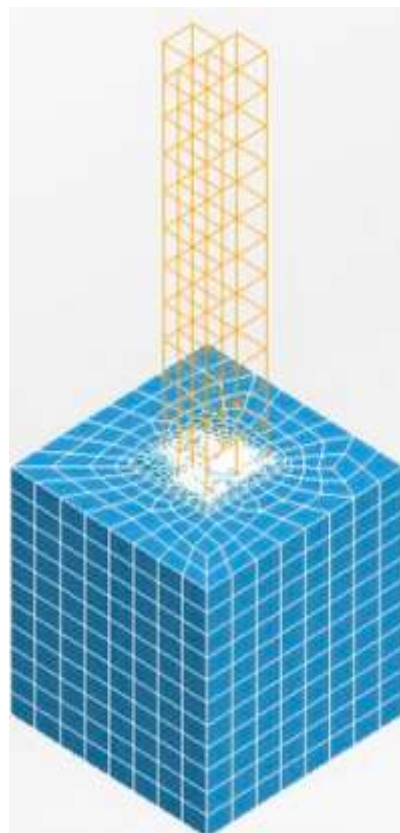


Figure 4. 110 Integral model for DSSI system T-shape G+10 building

4.3.2 EFFECTS OF LOCAL SOIL TYPES THAT SUPPORT DEVELOPMENT

The characteristics of seismic waves are greatly affected by how the Earth's crust behaves. Understanding the dynamic reaction of soil deposits is essential for building structures that can resist earthquakes. This kind of behavior plays a pivotal role in earthquake engineering. Most of the time, the way dirt particles move through and structure is totally dependent on the soil type, which in turn is determined by the engineering features and state parameters of the soil.

Both the soil's vibration and the superstructure's reaction are crucial factors in interactions analysis. For this reason, Recognizing the impact of soil type and condition on the superstructure's ability to withstand seismic pressures is of the utmost importance. As a result, we're doing this research to try to predict how various soil types will influence the G+10 structure's reaction to the C shape that the piling group can sustain. A few examples of the soils that belong here include sandy clay (S2), clay (S3), and sandy soil (S1).

In accordance with IS 1904-1978, the results of soil testing should be used to determine the soil's safe bearing capability.

Table 4.14 shows the safe bearing capacity values for various types of soil and rock. Since no such data is available, it is appropriate to assume that these values are the same as the presumptive bearing capacity values. Also, cut the values for non-cohesive soils in half if the water table is anywhere near or above the footing's base.

TABLE 4. 14 Presumptive bearing capacity values as per IS 1904-1978

Type of soil/rock	Rock	Soft rock/ Coarse sand/ Fine sand	Medium sand	Soft shell / stiff clay/ Soft clay	Very soft clay
Safe/allowable B.C (kN/m2)	3240	440	245	100	50

Based on the criteria set by the IS IS 1904-1978 for the kind of soils utilized, this study's parametric analysis (Table 4.15) assumes bearing capacity.

TABLE 4. 15 Soil engineering characteristics taken into account in the parametric analysis

Sr. No.	Soil Type	Young's Modulus (kN/m ²)	Poisson's ratio	Density (kN/m ³)	Shear wave velocity (m/s)	Angle of friction (°)	Cohesion (kN/m ²)	Bearing capacity (kN/m ²)
1	S1	645,872	0.30	20	300	42	0	240
2	S2	545,872	0.30	20	200	30	20	350
3	S3	445,872	0.35	18	100	0	30	150

This study examines the effects of varying soil conditions on a C-shaped G+10 structure that is supported by a pile foundation system (the general configuration). By applying ground motion to the soil domain's base, the dynamic analysis is executed. We compute the building's reaction at each floor and compare the peak response for each soil type.

Applying Ground motion to the base nodes of the soil model allowed for the dynamic analysis to be carried out. We compared the X, Y, and Z displacements of the top level of the superstructure for each soil type for a C-shaped building. Figures 4.111–4.113 show the results of our analysis of the effects of soil type on the behavior of the superstructure.

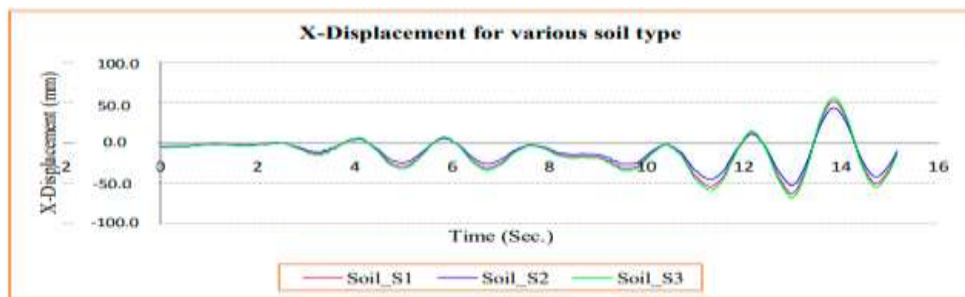


Figure 4. 111 Time series of soil displacement in the X-direction of a C-shaped building's upper floor

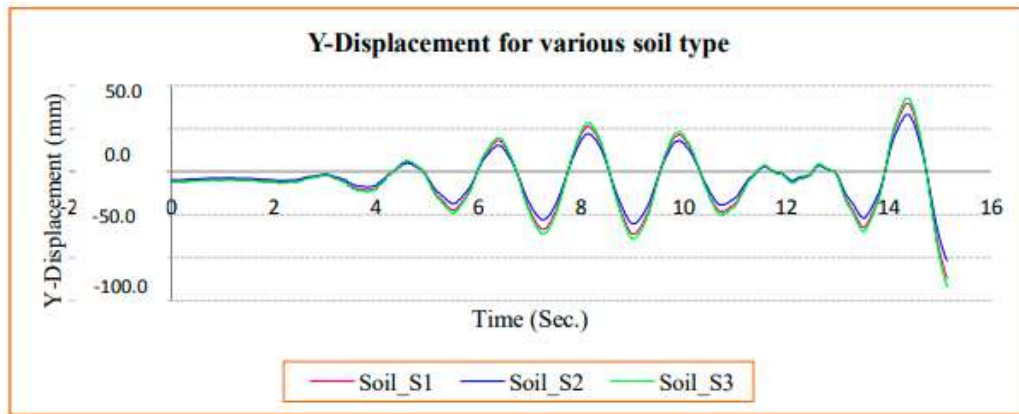


Figure 4. 112 The Y-axis displacement history of several soil types at the upper story of a C-shaped structure

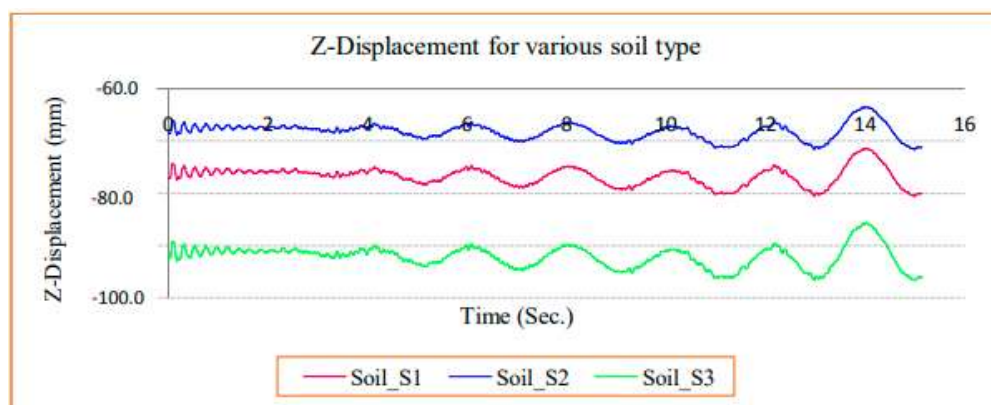


Figure 4. 113 Chronology of soil displacement in the Z-direction of a C-shaped structure with the top floor

In all types of soil, the X and Y axes of the displacement time histories of the superstructure follow a consistent pattern with varying magnitudes. The figures show the pattern. This is due to the fact that the X-Y plane has been used for the shaking, and the vibration spectra regulate the movement trend or profile. The amplitude or resistance to the vibration, however, is determined by the strength properties of the soil. This indicates that the x-Y displacement of the structure is regulated by the vibration profile, which remains consistent regardless of the different kinds of soil in terms of their technical characteristics. Every displacement profile of the structure exhibits the same trend. Unlike the X-Y plane, where vibrational displacements are significant, shaking has a little effect on a Z-shift. Gravitational force of the superstructure on the ground is a major factor in determining the size. The settlement will have a greater impact on a lower-class stratum than on a strong one. This is evident from the soil's

characteristics. Cohesionless soil exhibits less movement compared to cohesive soil in this instance. The C-Ø soil, however, experiences the least amount of settlement. Soil type and the plane of vibration application both significantly impact soil movement.

The patterns shown in figures 4.114 to 4.116 for the movement of the foundation system under dynamic loading are also indicative of this.

This is quantitatively explained in relation to the peak displacement values in Table 4.16.

Core pile displacement is assessed for this set of C-shaped piles. Getting the pile head's and pile tip's displacement profiles may help understand the piles' overall movement during the earthquake.

For different supporting soil conditions in the X, Y, and Z directions, the displacements at the pile's head and tip over time are shown in figures 4.114 to 4.116

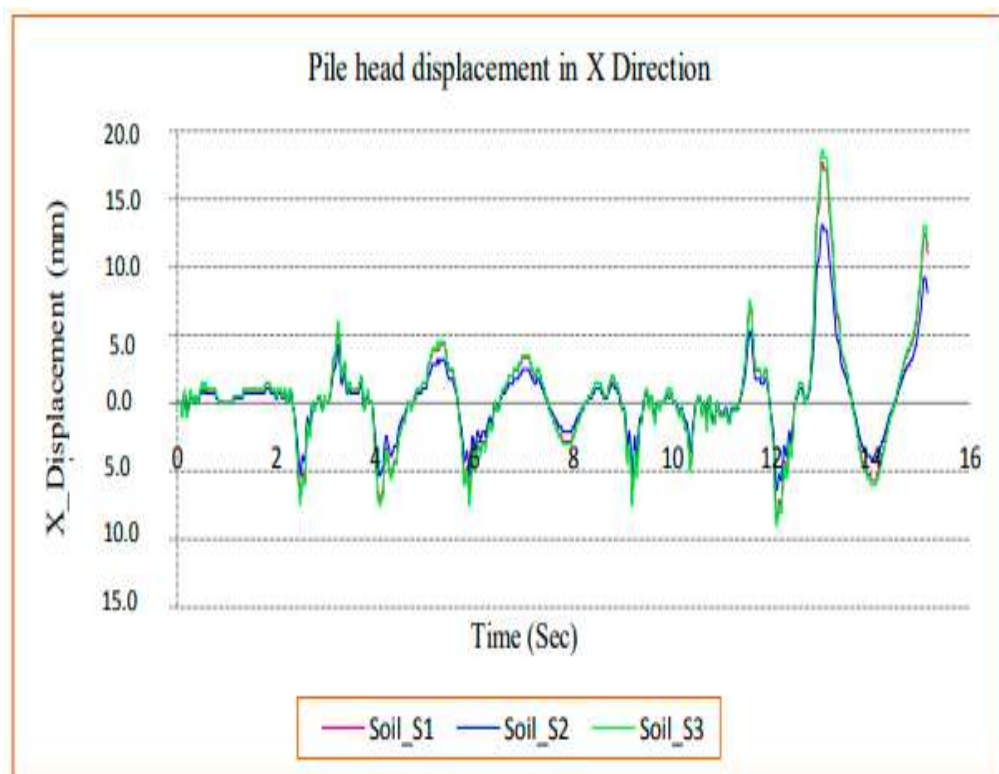


Figure 4. 114 Time series of soil displacements in the X-direction at the central pile head

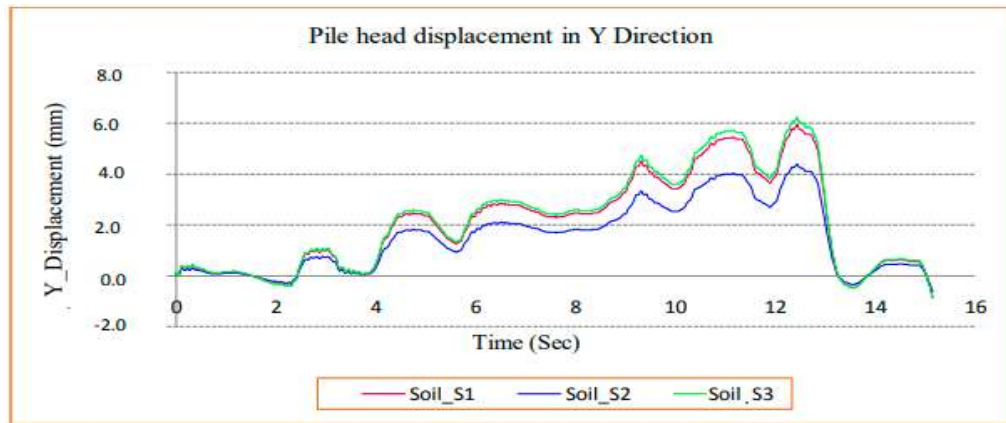


Figure 4. 115 Chronology of Y-axis displacement at the central pile head for different soil types

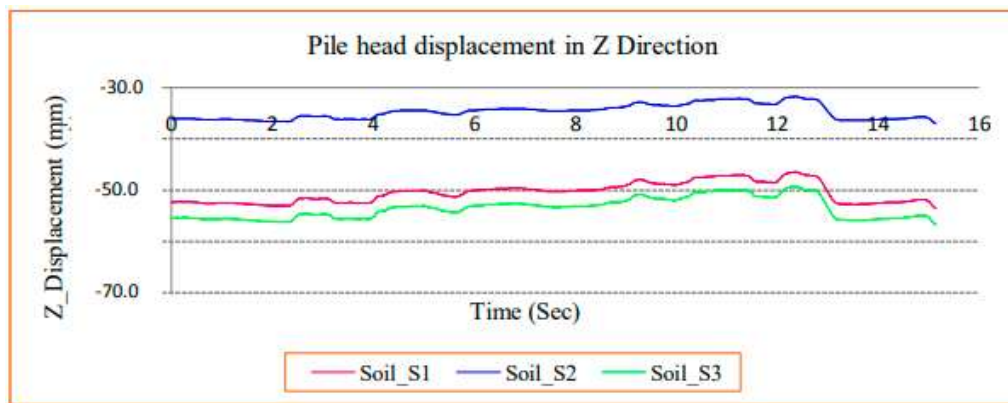


Figure 4. 116 Chronology of Y-axis displacement at the central pile head for different soil types

Figures 4.117–4.119 illustrate the X, Y, and Z-axis displacement profiles at the pile tip subjected to dynamic loads applied to the SSI system.



Figure 4. 117 The Y-axis displacement time history of several soil types near the tip of the central pile

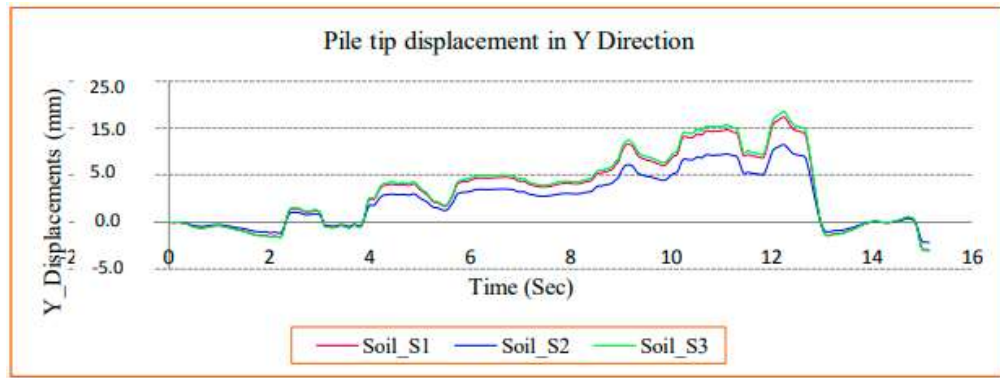


Figure 4. 118 Chronology of Y-axis displacement at the central pile tip for different soil types

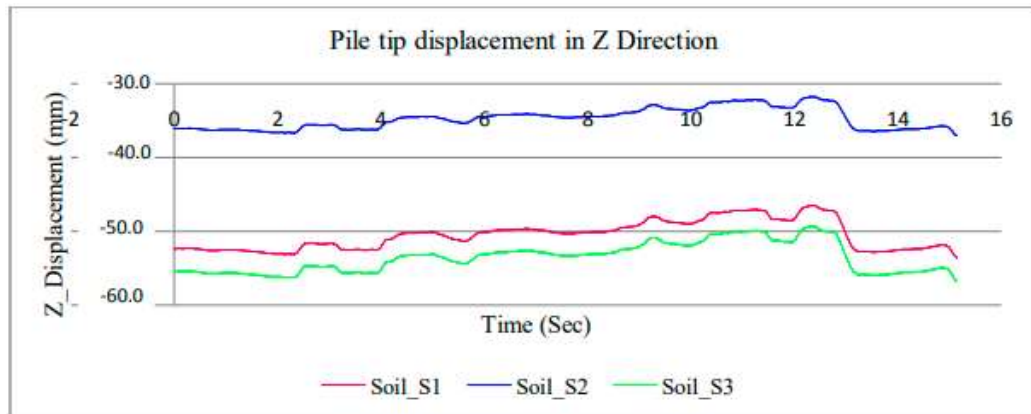


Figure 4. 119 Temporal variations in soil displacement along the Z-axis at the central pile tip

Furthermore, the quake Researchers looked at how soil and L and T-shaped structures interacted. Soil types such as S1, sandy clay, and clay were examined, and the peak responses of each were compared.

Table 4.16 displays the peak reactions at different places of the foundation and superstructure system, which were calculated for different building types and soil conditions.

Looking at the SSI system under lateral seismic stress and in its settled condition vertically for the top and bottom of the superstructure allowed us to compare the responses for all three asymmetrical geometries (C, L, and T). Furthermore, we recorded the head, center, and tip/bottom of the pile, which are located in the middle of the geometry.

TABLE 4. 16 Superstructure and pile peak lateral displacement and settling for various soil types and foundation systems

Description of the response		Location	Soil Type								
			Soil _S1			Soil _S2			Soil _S3		
Building Response	Displacement (mm)	Building Shape	C	L	T	C	L	T	C	L	T
		Top	62.91	45.17	42.78	60.18	43.21	40.92	68.39	49.10	46.5
		Bottom	7.55	5.42	5.136	7.22	5.185	4.91	8.20	5.89	5.58
	Settlement (mm)	Top	81.96	65.61	62.13	81.04	64.88	61.44	92.1	73.72	69.82
		Bottom	65.61	52.49	49.71	64.88	51.90	49.15	73.72	58.98	55.85
			C	L	T	C	L	T	C	L	T
Pile Response	Displacement (mm)	Top	15.18	13.67	13.34	14.52	13.06	12.76	16.5	14.85	14.5
		Center	6.44	5.80	5.34	6.16	5.544	5.104	7.00	6.31	5.8
		Bottom	21.71	19.54	18.45	20.76	18.69	17.65	23.6	21.24	20.06
			C	L	T	C	L	T	C	L	T
	Settlement (mm)	Top	48.74	43.87	47.79	47.14	42.42	46.21	53.57	48.21	52.52
		Center	47.35	42.62	47.86	45.79	41.21	46.2	52.04	46.83	52.6
		Bottom	45.42	40.88	47.66	43.92	39.53	46.09	49.92	44.92	52.38

Between the three kinds of foundation soil, this research revealed that type S3 (C soil) transmitted more vibrations to the superstructure than types S2 (C- Ø) and S1 (Ø). When employed as a supporting stratum, soil type S3 exhibits greater floor wise peak displacement values compared to soil types S1 and S2. The findings reveal a range of peak displacement values of 12% to 15%.

Soil characteristics, such as Poisson's ratio and Young's modulus, impact the reaction, which in turn affects the peak displacement, which differs between soil types. There is a stronger relationship between the soil's strength (as measured by Young's modulus) and the superstructure's reaction. Soil type S1 (Ø soil) has a much higher Young's modulus and bearing capacity, which is why soil type S3 (C soil S3) has a lower reactivity. Superstructure reactivity to supporting soil conditions is lower for soil type S2 (Ø) compared to soil type S1, despite the fact that Young's modulus of soil type S2

(C-D soil) is lower.

Although peak responses vary across L and C building types, the generalization indicated before is still valid. Soil types S2 and S3 both have bearing capacity, but S2 has a much higher capacity. Soils with a higher carrying capacity will have lower displacement values. According to the study, the carrying capacity of the supporting strata, rather than the young's modulus, governs the reactions of the superstructure.

On average, the superstructure of C-shaped buildings responds 28% better to all soil types than L-shaped structures, whereas the superstructure of T-shaped buildings responds 31% better. From a foundational standpoint, C-shaped structures show a 9 percent higher pile top compared to L-shaped buildings and a 12 percent higher pile top compared to T-shaped buildings in all soil types. At the bottom of the heap, however, the difference narrows to around 4%. Soil types are both mirrored and distinguished by the kinematic interaction. Even though the wave is symmetrical, it enters the structure in various ways depending on the kind of soil. Soil type and superstructure shape are two important factors that affect reactivity to dynamic loads.

4.3.3 EFFECT OF L/D RATIO OF PILES

Piles behave differently depending on their characteristic length, L . As a general rule, a pile is said to be long if its length is more than $5L$, and short rigid if its length is $2L$ or below. Piles may experience axial stresses, moments, and lateral loads. The most common sources of lateral loads are earthquakes, waves, and wind.

When the weight exceeds the lateral resistance of the soil, a short, rigid pile will collapse. Information posts, transmission towers, and advertising pillars are all supported by short piles with a large diameter. Vertical loads, which are frequently disregarded, are as important as lateral pressures and toppling moments when it comes to these structures. How the pile acts is dictated by the nonlinear, three-dimensional soil interaction issue. The behavior of short piles is greatly affected by the soil's militancy and elastic modulus.

Short stiff piles composed of loose sands saw a deflection increase of more than 58% when exposed to water after being dry.

A lengthy, pliable pile will fail if the moment at any one or more points is greater than. Fig. 4.120–4.121 shows that along the length of the pile, one or two plastic hinges develop, which causes the moment of resistance and collapse.

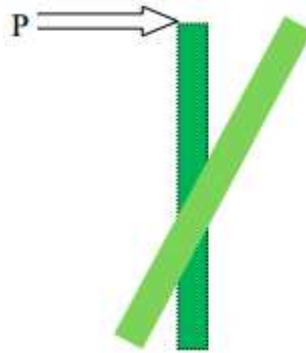


Figure 4. 120 Short pile failure under later loading

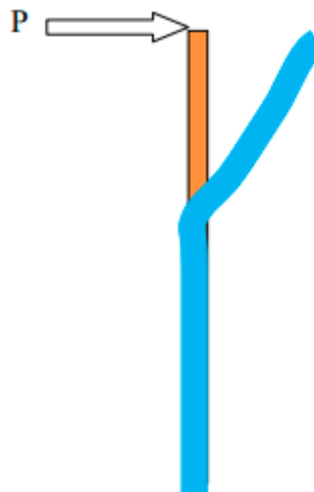


Figure 4. 121 Long pile failure under later loading

Several pile bearing capacity tests found that when clay stiffness increased, Additionally, the piles' ultimate lateral resistance rose. There would be little to no change in ultimate bearing capacity as a function of pile diameter.

The capacity of a pile group to support loads is affected by several factors. The dimensions, dimensions, length, and spacing of the piles are all part of this. What kind and condition of soil is supporting it also matters. To meet the design criteria, it is advised to expand the pile instead of the foundation depth. Creating the most cost-

effective and technically sound pile group should be a top priority for every geotechnical engineer. Interactions between heaps in a pile group have complex and critical consequences. This is why, before design, you need to make an educated guess as to how the pile group's personality might affect their actions. Rather of relying just on pile diameter or length, the L/D ratio is often used to examine how heaps within a pile group interact with one another. To get the most out of the superstructure's response, think of an L/D ratio somewhere from 10 to 50.

In this work, we tested the responsiveness of the superstructure in dynamic environments with different L/D ratios. Ratios ranging from ten to fifty are covered here. Table 4.17 shows the basic pile design for the C-shaped construction, which is the sum of the pile length and diameter. The foundation system's L/D ratio is connected to the pile's critical relative stiffness (K_{cr}), which is analytically determined as $E_p I_p / E_s L^4$. The finite element approach, in contrast, determines the piles' stiffness by combining their aspect ratio with their elemental stiffness.

TABLE 4. 17 The study's consideration of the L/D ratio in detail

Sr. no.	Pile Length (m)	Pile Dia. (m)	L/D Ratio
1	5	0.5	10
2	9	0.45	20
3	8	0.28	30
4	10	0.25	40
5	6	0.12	50

By doing dynamic soil structure interaction assessments for various L/D ratio combinations ranging from 10 to 50, we were able to assess the impact of pile diameter and length on the responsiveness of the superstructure. During the 2001 earthquake ($M=7.7$), researchers looked at how variations in sandy soil type affected displacements on various floors. The scope of the study includes piles with L/D ratios ranging from 10 to 50 and all asymmetrical construction geometries, including C, L, and T. Despite a consistent pile spacing of around $3.5D$, the number of heaps differs throughout the different asymmetrical pile groupings. The reaction of the superstructure is affected by the overall stiffness, which is in turn affected by the diameter, spacing, and number of piles. Figures xx to xx show the results of a comprehensive study on how these factors affect the behavior of the superstructure. Structures of the L, C, and T kinds are shown in Figures 4.122-4.124, together with the displacement on each level for various L/D

ratios, measured in the direction of the applied ground motion. This research utilizes data from a fifteen-second earthquake to determine how the superstructure's reaction is affected by the L/D ratio.

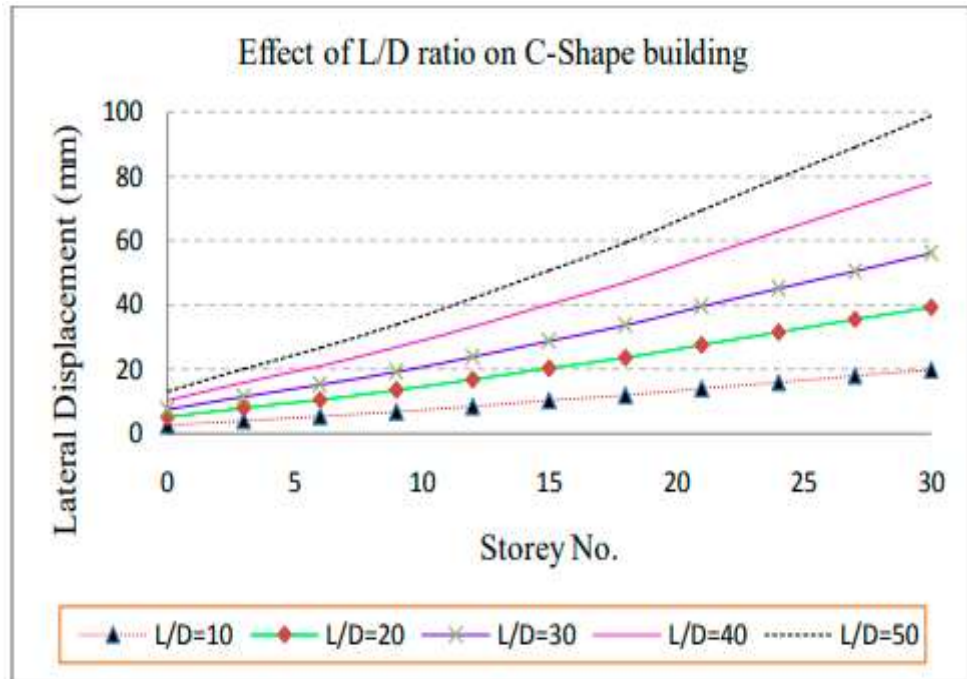


Figure 4. 122 The reaction of a C-shaped building's superstructure

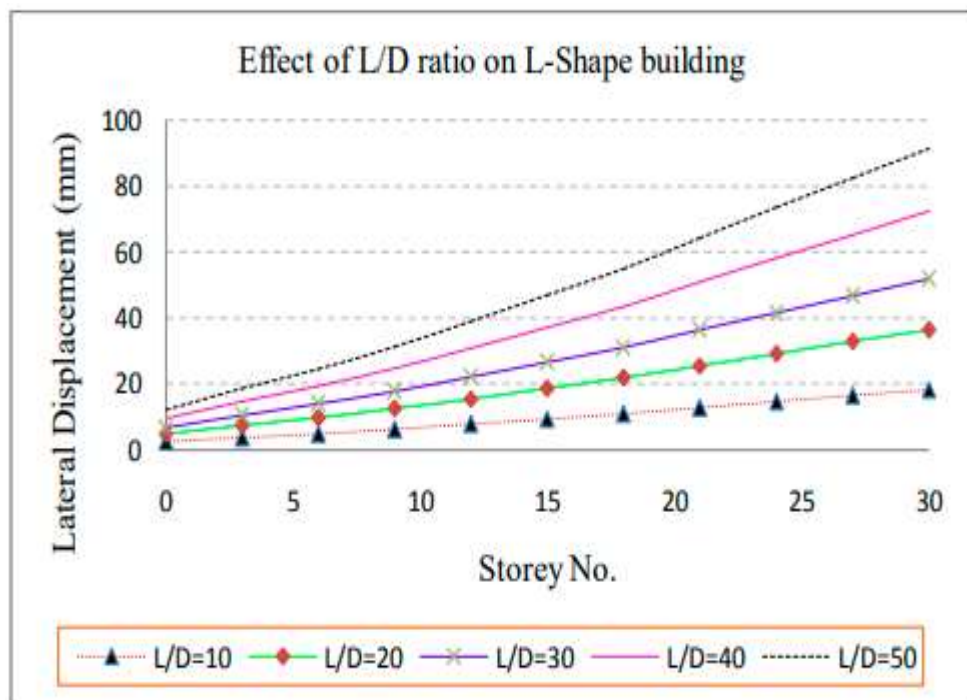


Figure 4. 123 Superstructure response of L shape building

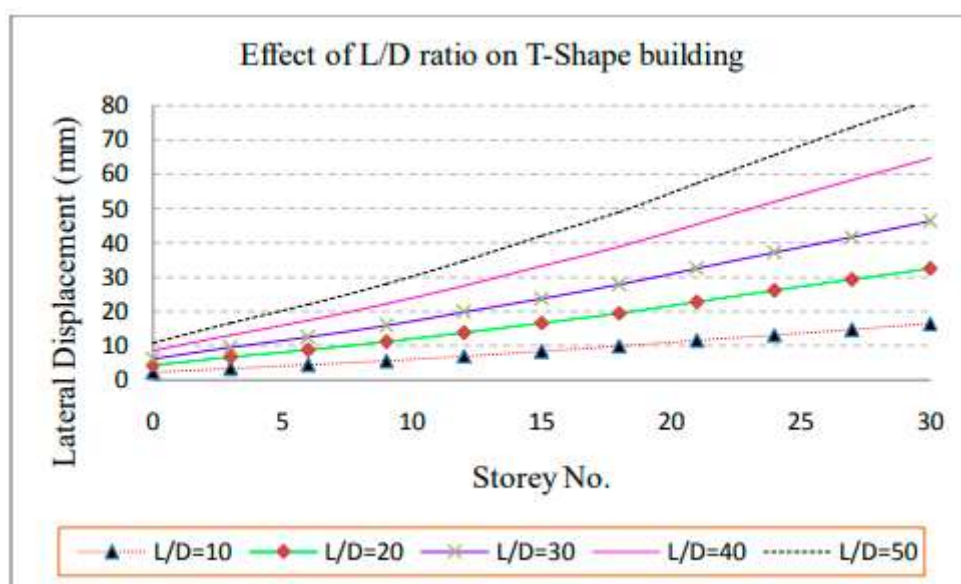


Figure 4. 124 The reaction of a T-shaped building's superstructure

The settlement in the pile, situated in the geometric center of each asymmetrical shape, may be revealed by seismic soil structure interaction analysis, which may provide light on soil failure. Table 4.18 shows the results of the dynamic analysis for the foundation and superstructure systems' peak lateral displacement and settlement.

TABLE 4. 18 the foundation system's and the superstructure's peak responses to varying L/D ratios

L/ D Ratio	Superstructure response (mm)						Pile response at top (mm)					
	Lateral displacement			Settlement			Lateral displacement			Settlement		
	C	L	T	C	L	T	C	L	T	C	L	T
10.00	19.76	81.59	16.33	17.15	12.19	10.65	3.86	3.47	3.35	13.77	12.39	11.98
20.00	39.26	39.26	32.45	48.52	34.51	30.14	11.02	9.91	9.58	39.34	35.41	34.23
30.00	55.97	55.97	46.26	83.03	59.05	51.57	18.85	16.97	16.40	67.32	60.60	58.58
40.00	78.09	78.09	64.54	137.54	97.82	85.43	31.18	28.06	27.12	111.33	100.21	96.87
50.00	98.72	98.72	81.59	196.18	139.53	121.85	44.50	40.05	38.72	158.94	143.05	138.28

It is quite clear from the data and pattern in Table 4.18 At L/D ratios of 10, 20, 30, 40, and 50, the displacement values tend to cluster closer together, according to the research. The normal diameter of other L/D ratios is 0.2 m, whereas the average diameter of L/D ratios 10 and 20 is 0.5 m. It follows that a larger pile diameter results in a more rigid pile, since less structural movement is caused by a more rigid pile. Since 0.45 m is the average pile diameter, increasing the diameter causes the superstructure to respond three times more forcefully, despite the fact that the pile is longer with a lower diameter. bigger areas incur bigger displacements as a function of this L/D ratio, which are proportional to the area in contact with the soil compared to the interfaces. The L/D ratio ranges from 30 to 40 to 50, and larger top-side displacements are caused by stronger contact displacements in the nodal displacements. Standard dimensions are 8.0 m in length and 0.25 m in diameter. Consequently, due to the interactions effect, the superstructure's reaction to changes in the L/D ratio and the foundation area in contact with the ground are altered. This discovery is also valid for a wide variety of structures with L and T shapes. Still, C's system responses are 21% more than L's. Because of the imbalance, the three L/D layouts have different system responses; the C-shaped structure has 32% greater responses than the T-shaped building.

An eleven-story asymmetrical building with C, L, and T-shaped piling supports was subjected to dynamic loading considerations using dynamic nonlinear interactions analysis. Soil type, various earthquake loadings, and the pile L/D ratio are some of the aspects that researchers are considering as they explore the effect of each parameter on the response of the superstructure and the movement of the piles. We have examined the effects of each parameter on the structural response in detail.

Results from the dynamic soil structure analysis formed the basis of this study's conclusions.

In order to convey vibration to the structure, dynamic analysis prioritizes wave propagation and the influence of attenuation on wave amplitude as it travels through solid media. From the three kinds of soil examined in this research, cohesive soil is the one that transmits more vibrations to the superstructure compared to neither cohesive nor C-Ø or Cohisionless (Ø) soil. There are two more kinds of soil: cohesive soil and cohesionless soil. When cohesive soil is used as a base layer, the floor-wise peak displacement values are larger.

There is a relationship between the maximum displacement and the soil. This study's findings demonstrate that soil matrix strength influences the reaction of the superstructure. According to the research, every kind of soil displays a unique and almost similar kinematic interaction. Nevertheless, the outcomes differed when the wave pierced the structure owing to its asymmetry, even if the soil type was same. The response of a superstructure under dynamic loading conditions is significantly influenced by the kind and form of the soil.

Based on the findings, the impacts on the superstructure are amplified for larger earthquakes as a consequence of enhanced kinematic interaction. In SSI analysis, the magnitude of the earthquake is a key component of the kinematic interaction.

The length of the pile with respect to the ground has a greater impact on load displacement than the diameter. Despite having greater area to carry the load, a shorter pile with a bigger diameter will have lower contact displacement values compared to a longer one with a smaller diameter. The shorter string on the smaller stack is for that reason. Consequently, due to the interactions effect, the superstructure's reaction to changes in the L/D ratio and the foundation area in contact with the ground are altered. While studies show that shorter lengths and greater diameters increase foundation system stability, these configurations alter displacement behavior depending on superstructure asymmetry.

CHAPTER 5

CONCLUSION, RECOMMENDATION AND FUTURE SCOPE

5.1 CONCLUSION

In order to better prepare for earthquakes, a research in Hyderabad, Telangana, examined soil-structure interaction (SSI). The findings illuminate the complex interplay between built structures and the ground underneath them. So that the area's seismic risk may be reduced, engineering practices and policy suggestions should be based on the findings of this kind of research. Growing urbanization and the presence of different soil profiles have made Hyderabad vulnerable to earthquakes, despite the city's notoriety as a low-risk area. In order to make infrastructure more resistant to possible earthquake risks, this study's results highlight the need of including SSI concerns into the local seismic preparation framework.

Conventional design rules may fail to appropriately account for the substantial impact of soil-structure interaction on building seismic response, according to the main result of this work. Seismic stress causes distinct soil types in Hyderabad, which range from sandy loam to more compacted rock. Particularly vulnerable to magnified ground motion, which may cause higher displacement and stress on buildings, the research indicates, are structures constructed on soft soils. In metropolitan areas that are likely to see future growth, our results highlight the significance of conducting site-specific soil studies throughout the planning and design stages of construction.

Moreover, the research highlights how conventional seismic design methodologies often fail to capture or accurately depict the true seismic demand in cases when SSI effects are substantial, since they frequently presume a fixed-base condition for buildings. Resonant effects during an earthquake may be worsened if the building's foundation interacts with the underlying soil in a way that changes the structure's inherent frequency. The soil's pliability caused more lateral movement and, in turn, more substantial structural stress, which was most apparent in buildings with bigger footprints and higher frames. Consequently, the research suggests that current construction rules should be revised to more thoroughly account for the consequences

of soil-structure interaction. This is particularly important for vital infrastructure buildings in Hyderabad, such hospitals, schools, and emergency services.

In addition to being technically necessary, design solutions that include SSI impacts also provide economic benefits. According to the research, more cost-effective designs may be achieved by accurately considering SSI. An example of this would be the potential reduction in the need for costly and excessively cautious structural reinforcements via the use of more adaptable foundation designs that cooperate with the soil's natural reaction. More sustainable urban development in earthquake-prone places like Hyderabad is possible when engineers optimize designs to account for SSI. This balances safety, functionality, and cost-efficiency.

The research also highlights the need of sophisticated computational models for seismic event behavior prediction of soil-structure systems. In areas with complicated geotechnical conditions, such as Hyderabad, Conventional analysis techniques can miss some of the SSI implications. By revealing the mechanics of interaction between soil layers and the structures they support, numerical simulations—like finite element modeling—have been very helpful in this work. These findings show how important it is for engineers and academics to use these sophisticated modeling tools more often. Creating computational models tailored to the Telangana area that account for its distinct seismic and soil features is an important proposal.

The study's most important finding is that various building types are differently vulnerable to seismic events. SSI impacts are different in low-rise buildings than in high-rise or more contemporary structures since these buildings are often built with less seismic design concerns. The research found that older structures might be made much more earthquake resistant by modifying them to accommodate SSI. In order to lessen the negative impacts of soil-structure interaction, methods like base isolation—which separates the building from ground motion—are very successful. It would be wise for the city to include retrofitting measures like these into its earthquake preparation efforts to protect the built environment.

The results have important ramifications for society and public policy. Many different kinds of buildings have sprung up in Hyderabad due to the rapid development of the city, and it's possible that many of them weren't planned with modern seismic

regulations or SSI issues in mind. This research highlights the need of lawmakers making it a top priority to assess and upgrade old buildings, especially in heavily inhabited or heavily traveled regions. Building codes and emergency preparations that take SSI into account may help municipalities greatly lessen the impact of seismic disasters. The research concludes that city officials, engineers, and planners should work together to compile a database of all the soil profiles in the city. Building projects in the future will benefit from this database since it would allow for more precise earthquake resistance measures tailored to specific geotechnical conditions.

The influence of regional groundwater conditions on soil-structure interaction is another significant finding of the research. Changes in groundwater levels have the potential to impact the stiffness and damping qualities of the underlying soils in Hyderabad, which are heavily influenced by the city's aquifers. This is of the utmost importance in earthquake-prone regions where shallow groundwater tables increase the risk of liquefaction and other soil stability problems. As part of the city's earthquake preparation plan, the research suggests continuously monitoring the levels of groundwater. Foundation designs that can adjust to variations in soil moisture content should be considered for future building projects in places where groundwater fluctuations are known. There will be less chance of structural damage as a result of this.

Looking at SSI through a larger lens, Engineering is shown via this careful scrutiny, urban design, and disaster management is all interdependent. Based on the results, it seems like Hyderabad has to think about its infrastructure as a whole, not just individual buildings, while preparing for earthquakes. Important lifeline constructions' contact with the soil greatly affects their performance during earthquakes. This includes bridges, roads, and power lines. In order to identify and address risks connected to SSI, the report suggests conducting an assessment of such infrastructure across the whole city. The city's transportation and utility networks are crucial for earthquake response and recovery, and maybe, if they do this, they will develop more overall resilience.

Finally, this critical research of soil-structure interaction for better earthquake preparation in Hyderabad, Telangana, offers vital insights that might govern future urban planning and building practices in the area. Importantly, SSI has a major impact on how well buildings withstand earthquakes, and underestimating earthquake risks is

possible when this interaction is not taken into consideration. To make Hyderabad more earthquake resistant, city officials should prioritize upgrading at-risk buildings, use cutting-edge computer modeling tools, and include SSI impacts in construction rules. In addition, the research highlights the need of taking a comprehensive strategy to urban earthquake preparation, which takes into account the interaction between soil, water, and infrastructure. If city planners, engineers, and policymakers want to build a resilient metropolis that can weather future earthquakes and adapt to its ever-changing geotechnical landscape, they'll need to collaborate.

A future-oriented foundation for earthquake preparation is provided by this all-encompassing knowledge of soil-structure interaction in Hyderabad. Urban areas in the region may become safer and more robust in the face of seismic risks and other threats to sustainable development if research, technology, and proactive policy measures are maintained and expanded.

5.2 RECOMMENDATIONS OF THE STUDY

Critical insights into the complexity of seismic risk management in urban contexts are provided by the research on soil-structure interaction (SSI) for increased earthquake preparation in Hyderabad, Telangana. In light of the results, we suggest the following measures to strengthen the infrastructure and make the area more earthquake-proof:

- 1. Incorporate Soil-Structure Interaction into Building Codes** Recommendation: Hyderabad municipal construction regulations should be revised to include implications of soil-structure interaction during seismic occurrences. Especially in areas with complicated geotechnical profiles, the fixed-base assumption of conventional seismic design methods leaves a lot of room for variance in soil reaction. Engineering models of building performance under real-world seismic conditions may be improved by the incorporation of SSI into building standards. Particularly for essential facilities like schools, hospitals, and emergency services, this is of the utmost importance.
- 2. Conduct Comprehensive Soil and Geotechnical Assessments** The research shows that the response of structures to seismic loads is affected by the diverse soil conditions found in Hyderabad. In order to enhance building practices, a comprehensive mapping of the city's soil profiles is required. City planners and

officials should compile information on the city's soil types, groundwater levels, and seismic characteristics into a comprehensive geotechnical database. In order to facilitate site-specific design solutions for future building projects, this database will be an essential tool for urban development in the future.

- 3. Implement Retrofitting Strategies for Existing Buildings** It is possible that many of Hyderabad's older structures were not built to meet current seismic standards or SSI requirements. Older and more susceptible buildings, especially those on sandy or gravelly soils where seismic amplification is greater, should be retrofitted, according to the research. To lessen the likelihood of structural collapse in the event of an earthquake, it is recommended to investigate methods such as seismic dampers, foundation reinforcing, and base isolation.
- 4. Encourage the Use of Advanced Computational Modeling** The intricate behavior of soil-structure systems may be better predicted with the use of sophisticated numerical simulations like finite element modeling. In both theoretical and practical engineering contexts, these methodologies should be extensively used. Because of this, earthquake-resistant designs may be fine-tuned and SSI impacts can be studied in more depth, leading to more reliable seismic risk assessments.
- 5. Monitor Groundwater Levels and Soil Stability** In regions where water tables are subject to frequent fluctuations, groundwater conditions greatly affect how soil behaves during earthquake occurrences. It is advised that groundwater levels in Hyderabad be monitored constantly to avoid problems like liquefaction and instability in the case of earthquakes. Foundation designs should be considered in construction projects in locations with shallow groundwater to provide stability during seismic loads by accounting for variations in soil moisture content.
- 6. Focus on Lifeline Infrastructure Resilience** It is essential to consider the resilience of the city's vital infrastructure, such as its bridges, roads, and utility networks, in addition to individual buildings. In the event of an earthquake, these buildings are crucial for retrieval efforts and emergency services. The research suggests that in order to find potential vulnerabilities associated to SSI, the city's

lifeline systems should be audited. Then, the relevant mitigation measures, such as strengthened foundations and flexible joint systems, should be put in place.

These suggestions will help Hyderabad become far more earthquake-proof, which would lessen the likelihood of property damage, economic losses, and casualties in the case of a seismic disaster. According to the research, the city can enhance its future resilience and promote sustainable growth by actively integrating SSI into its planning and building processes.

5.3 FUTURE SCOPE OF THE STUDY

Research on soil-structure interaction (SSI) in Hyderabad, Telangana, with the goal of improving earthquake readiness has tremendous promise for bolstering urban resilience and seismic safety. The creation of sophisticated computer models capable of simulating the dynamic interactions between different kinds of soil, buildings, and seismic forces is an important subject that needs further investigation. In regions with varied soil profiles, like Hyderabad, these models may get more complex as computer power rises, enabling more precise forecasts of the seismic behavior of various buildings.

Examples of critical infrastructure include transportation networks (including highways, railroads, and subways), water treatment facilities, electrical grids, and telephone or internet service providers. It is important that future research seek to expand the scope of these domains' use of SSI ideas. To ensure that these critical systems continue to function properly during and after an earthquake, it is essential to comprehend their response to seismic stresses and their interaction with the ground below. Research might also look at ways to make older buildings more earthquake resistant by modifying them or using new building materials and methods.

The use of sensor technologies and real-time seismic monitoring is another interesting area of study. Future research might investigate the possibility of collecting data in real-time during seismic occurrences by embedding smart sensors in soil and buildings. This would provide light on the complex interaction between soil and structures during earthquakes. A potential outcome of this research might be the creation of systems for buildings that are sensitive to seismic activity and can adjust or fortify themselves in response.

In addition, urban planners in Hyderabad may benefit from more regional building regulations and earthquake preparation plans if the study is expanded to include a comprehensive, site-specific evaluation of soil profiles across the city. Making the city more robust to seismic occurrences may be achieved by guiding future building and retrofitting activities toward locations with a greater vulnerability to soil liquefaction and other detrimental SSI impacts.

This study has the potential to be extended to other cities in India and throughout the world that face comparable soil-structure difficulties. Working together with professionals from across the world may pave the way for groundbreaking research and the establishment of new benchmarks for seismically safe building practices. Research in this area may also look at ways to make cities more environmentally friendly and seismically resilient by combining SSI factors with green building techniques.

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ANNEXURE

LIST OF PUBLICATIONS

LIST OF INTERNATIONAL/NATIONAL CONFERENCE

1. V Rohith Reddy, A Study Of Soil-Structure Interaction For Enhanced Earthquake Preparedness, International Conference on Advances In Science, Engineering, Management AND Humanities (ICASEMH – 2023), Gandhibagh, Nagpur, Maharashtra, India, 26th February, 2023
2. V Rohith Reddy Londhe, Influence Of Numerical Parametric On Soil structure Interaction, National Conference on Recent Advances in Science, Engineering, Humanities, and Management (NCRASETHM - 2024), Banquet, Noida, India, 28th January, 2024

LIST OF JOURNAL PUBLICATIONS

1. V Rohith Reddy & Dr. A. Mahesh Babu Published the paper titled “A Comparative Study On Ground-Based Ceilometer And Satellite Observations For Enhancing Fog Detection” in Nanotechnology Perceptions, ISSN 1660- 6795, Volume 20 No. S16, 2024
2. V Rohith Reddy & Dr. A. Mahesh Babu Published the paper titled “A Comparative Analysis of Bare Frame and Brick Infill Frame Structures Considering Soil Flexibility”, in International Journal of Enhanced Research In Science Technology & Engineering (IJERSTE), ISSN: 2319-7463, Issue: Volume 13, Issue 10, October 2024

REPRINT OF THE RESEARCH
PAPER & CONFERENCE
CERTIFICATES



IARF Conferences

International Conference on Advances in Science, Engineering, Management and Humanities (ICASEMH- 2023)

ICASEMH/2023/C02232-33

. CERTIFICATE .

This is to Certify that V Rohith Reddy, Research Scholar, Ph.D.in Civil Engineering,
P.K. University, Shivpuri, M.P.

has presented a paper on A study of Soil - structure Interaction for Enhanced
Earthquake Preparedness.

at **International Conference on Advances in Science, Engineering, Management and Humanities (ICASEMH - 2023)** organized by the **International Academic Research Forum (IARF)** at Hotel Siddhartha Inn, Gandhibagh, Nagpur, Maharashtra, India. On 26th February, 2023

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Dr. Rayess Ahmad Dar

Organizing Secretary



Shenhe

Dr. Shabnam Arora

Convener



CERTIFICATE NO : **ICASEMH /2023/C0223233**

**A STUDY OF SOIL-STRUCTURE INTERACTION FOR
ENHANCED EARTHQUAKE PREPAREDNESS**

V ROHITH REDDY

Research Scholar, Ph. D. in Civil Engineering
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ABSTRACT

Soil-structure interaction (SSI) plays a critical role in enhancing earthquake preparedness, as it affects how buildings and structures respond to seismic activity. When an earthquake occurs, the motion of the ground interacts with the structure above, altering the distribution of forces and deformation. SSI involves the dynamic exchange of energy between the soil and the structure, influenced by factors such as soil type, foundation design, and structural characteristics. Understanding these interactions is essential for designing resilient structures that can withstand seismic forces. Traditional building codes often treat soil and structures as separate entities, leading to potential underestimation of seismic demands. However, incorporating SSI into earthquake-resistant design enables engineers to anticipate the amplified effects of ground motion, resulting in more accurate predictions of structural behavior. Techniques such as base isolation, soil improvement, and advanced foundation designs can be employed to mitigate adverse SSI effects, reducing building damage and enhancing safety. Furthermore, numerical modeling and experimental studies of SSI contribute to the development of performance-based design approaches, making earthquake preparedness more robust. By accounting for SSI, engineers can improve the resilience of infrastructure, ultimately safeguarding lives and minimizing economic losses in seismic-prone regions.



IJESTI CONFERENCES



NCRASETHM/2024/CO124/44

**National Conference on Recent Advances in Science,
Engineering, Humanities and Management
(NCRASETHM-2024)**

CERTIFICATE

This is to certify that V Rohith Reddy, Research Scholar,
P.H.D. in civil Engineering, P.K. University, Shivpuri, M.P.

has presented a paper in **NCRASETHM-2024** held on 28th January 2024
at Hotel Krishna Residency & Banquet, Noida, India.

Title of the paper Influence of Numerical Parametric on
Soil - Structure Interaction.

Syrdhar
Dr. Syed Imtiyaz
convenor



NV Krishna Prasad
Dr. N. V. Krishna Prasad
Conference Chair



**National Conference on Recent Advances in Science, Engineering,
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28th January, 2024, Banquet, Noida, India.

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**INFLUENCE OF NUMERICAL PARAMETRIC ON SOIL-
STRUCTURE INTERACTION**

V ROHITH REDDY

Research Scholar, Ph. D. in Civil Engineering
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ABSTRACT

The influence of numerical parametric analysis on soil-structure interaction (SSI) is crucial for understanding and predicting the behavior of structures during seismic events. Numerical parametric analysis involves varying parameters such as soil properties, foundation stiffness, structural mass, and damping characteristics to assess their impact on SSI. These parameters significantly influence the dynamic response of the soil and structure, affecting factors like displacement, acceleration, and internal forces. By systematically altering these variables in numerical models, engineers can gain insights into the complex interactions between the ground and structures, enabling more precise predictions of seismic performance. The choice of soil model, for instance, whether elastic, elasto-plastic, or nonlinear, directly affects the accuracy of SSI analysis. Similarly, foundation types (e.g., shallow versus deep foundations) and soil conditions (e.g., soft clay versus dense sand) exhibit distinct behaviors under seismic loading. Numerical parametric studies allow for the optimization of design strategies, such as the implementation of base isolators, modification of foundation systems, or soil stabilization techniques, to enhance earthquake resistance. These analyses also aid in developing performance-based design criteria that account for SSI effects. Consequently, numerical parametric analysis serves as a valuable tool in advancing SSI research, leading to safer and more resilient structural designs.

A Study To Evaluate The Performance Of Multi-Storeyed Buildings Reinforced Concrete Structures Under Seismic Loading

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Both symmetric and asymmetrical building types are prevalent in both urban and rural regions these days. This is because of the growing population, the skyrocketing cost of land, and the issue of land shortage. Many constructions cannot be symmetrical or regular in size, form, rigidity, etc. for a variety of reasons, including but not limited to: site circumstances, barriers, operating demands, and countless more. In order to fulfill all of the code requirements, a building with an asymmetrical or otherwise irregular layout might be planned or built. In contrast to regular and symmetrical layouts, asymmetrical constructions will behave and perform poorly. Although it is generally recommended that designers and contractors steer clear of asymmetrical and irregular designs, there are a number of reasons why design and structural component irregularities may be impossible to eradicate. The purpose of this article is twofold: first, to compare the seismic performance of regular and irregular buildings in plan, and second, to provide a way to mitigate the effects of seismic load on asymmetrical structures. In order to conduct analyses, Etabs software takes into account square, L-shaped, and T-shaped G+10-story building models.

Keywords: Seismic, Symmetric, Buildings, Reinforced concrete, Storey displacement

I. INTRODUCTION

A multi-story structure is a realistic answer to the problems of housing, commerce, and industry brought about by the fast expansion of cities and the resulting increase in population density. For these types of buildings, reinforced concrete (RC) constructions are now the go-to because of their adaptability, longevity, and affordability. It is nevertheless very important to ensure that these buildings can withstand seismic activity without compromising their safety or function. Structures are subject to dynamic loads during earthquakes, which may cause significant damage or even collapse if these forces are not properly accounted for during design and construction. Earthquakes are defined by the abrupt release of energy that causes ground shaking. Achieving a balance between strength, flexibility, and energy dissipation is the goal of seismic resistance design for RC

structures, which requires combining concepts of structural dynamics, material science, and engineering mechanics. Seismic loads, in contrast to static ones, are dynamic and can change in period, frequency, and intensity. Vibrations, torsional effects, and resonance are some of the complicated reactions that result from the interplay between the inertia forces induced by these loads and the mass and stiffness of the building. Because of their height, mass distribution, and structural stiffness across floors, multi-story structures are especially vulnerable to seismic forces. Many elements, such as the design, materials, details, and interaction between soil and structure, determine how well these structures hold up during seismic loads.

The design philosophy of RC structures has changed considerably throughout the years, and this has a major impact on how these structures behave during seismic events. Structures are constructed to satisfy specified performance targets under varying degrees of seismic intensity, according to modern building regulations and standards that stress performance-based design. Among these goals is the assurance of quick occupation following small earthquakes, the mitigation of damage in moderate earthquakes, and the prevention of collapse in severe earthquakes. Accomplishing these objectives calls for expert knowledge of seismic risks, structural behavior, and state-of-the-art computational and analytical resources. Making sure the RC structure is ductile is one of the first things to do while constructing it to withstand seismic forces. A structure is considered ductile if it can sustain large deformations without weakening or breaking. It lessens the possibility of catastrophic failure by absorbing and dissipating seismic energy. Ductility in reinforced concrete structures is attained by correctly specifying the reinforcement, which includes using closely spaced stirrups in key areas, having enough anchoring length, and avoiding brittle failure mechanisms. Because of the enormous shear and bending forces experienced by beams, columns, and beam-column joints during earthquakes, ductile detailing plays a crucial role in these structural components.

A multi-story building's seismic performance is greatly affected by its architecture and design. Soft stories, vertical discontinuities, and mass eccentricities are examples of architectural imperfections that can lead to stress concentrations and an amplified seismic response. For example, a soft story, which is typical in buildings with open ground floors for parking, has much lower rigidity than the higher floors, which can cause uneven deformation and even collapse. In a similar vein, structures with non-normal distributions of mass or stiffness are unstable due to torsional vibrations; hence, engineers and architects need to work closely together to find the sweet spot between seismic safety and practicality. Modern methods for improving RC buildings' seismic performance include base isolation and energy dissipation devices. Placing isolators, such as elastomeric bearings or friction pendulum systems, at the foundation level allows for base isolation, which decouples the building from ground motion. By reducing the transmission of seismic pressures to the building, these isolators lessen the likelihood of damage. Structures may absorb seismic energy and lessen vibrations by installing energy dissipation devices like dampers. Both methods have been successful in reducing the likelihood of seismic damage to important structures, such as government buildings, hospitals, and bridges.

II. REVIEW OF LITERATURE

Abd-Alghany, Mariem et al., (2021) A building with a soft floor is a kind of high-rise that has an open floor plan on the ground level. The building's seismic performance is greatly impacted by this level. The reason for this is because such a story causes sudden variations in the strength and stiffness on the sides. Here, we use the finite element approach to look assess how RC structures with soft storeys do during seismic events. The position of the soft storey in relation to the building's height, the irregularity of the building's plan dimensions, and the soft storey's height are the criteria taken into account in this study. This study aims to determine, by means of the building's height, the best spot for the soft story in order to lessen its impact. Furthermore, without drastically altering the building's design or use, the effects of using basic strengthening procedures to increase structural safety are studied. The results include the results of the modal response spectrum (MRS) and the equivalent static load approach for stiffness, displacement, and storey drifts, as well as the impacts of the elements that were analyzed. Included in the research are the cracked stiffness ratio and the P-Delta effect. The results show that several architectural parameters, including the ratio of length to breadth and the height of the soft story, considerably impact the resistance and rigidity. The findings also show that shear walls are efficient in decreasing displacements and enhancing stiffness. In addition, the behavior of these structures may be improved by installing a bracing system during the retrofitting process.

Garg, Ankit et al., (2020) Steel bracing systems are the best option for improving the resistance of reinforced cement concrete (RCC) frames to lateral stress. When compared to alternative engineering solutions, steel bracing offers many advantages, including increased strength and stiffness, lower cost, smaller footprint, and much less overall weight. Different types of bracing—X type, X type tension alone, Eccentric-K type, and Inverted-V type—were examined in this seismic analysis of RCC frame buildings. A six-story (G+5) structure in seismic zone IV on medium-density soil was proposed for this objective. Then, using Resist, we conducted similar static analysis on the building models in accordance with IS code 1893:2002. Stability coefficient, P-delta, lateral displacement, storey drift, and inter-storey drift ratio were the primary metrics used to compare the structures' seismic performance. Research has shown that X-type steel bracing is superior to conventional bracing methods in reducing inter-storey drift and greatly increasing structural stiffness in reinforced concrete buildings.

Sardiwal, Devendra et al., (2019) This research updates a previous literature review on the topic of employing Soft Storey for performance-based seismic analysis of non-linear multi-story structures. A method for elastic design known as performance-based seismic design, "performance based plastic design" is another description. Each part of a structure has a strength and deformation capacity that contribute to its total capacity. One definition of a soft storey is a story in a building that is not strong enough to withstand an earthquake. Another name for this is a weak storey. A soft story is one with plenty of natural light and air. Building on undeveloped land may be very risky if not planned and executed correctly.

Hosseini, Mahmood et al., (2017) Buildings are required to meet the Life Safety (LS)

Performance Level (PL) according to most seismic design rules. This is happening at the same time that several structures have failed to meet expectations and have even fallen in recent earthquakes, especially those that were close to their points of origin. Based on this, it seems that there is still room for improvement in the code provisions to inspire enough trust among engineers. Finding out how well the LS PL provisions in the ACI 318-2014 code and the Reinforced Concrete Multi-Story Regular Building Code of 2009 work with the unique moment frame lateral load bearing system was the main goal of this study. In the heart of Tehran's most seismically vulnerable neighborhood, a string of sixteen-story buildings conforming to building codes were intended to do this. Next, a collection of code-compliant near-source three-component accelerograms were used, and each building underwent a battery of nonlinear time history studies. In order to assess the seismic performances, we computed the acceleration and displacement of the roof as well as the base shear pressures. We also looked at the distribution and development trend of plastic hinges in the constructions. The results demonstrate that during some earthquakes, the performance of the structures surpasses the LS PL and, in extreme circumstances, reaches the collapse level.

Haque, Mohaiminul et al., (2016) While Bangladesh is one of the most earthquake-prone countries in South Asia, Sylhet is particularly vulnerable. This study intends to conduct static and dynamic analyses, such as equivalent static analysis, response spectrum analysis (RSA), and time history analysis (THA), on a range of RCC building frames with equal span, considering both regular and irregular shapes, in compliance with the Bangladesh National Building Code (BNBC)-2006. This research evaluates four different ten-story RCC building frames in Bangladesh's seismic zone 3 (Sylhet) using ETABS v9.7.1 and SAP 2000 v14.0.0: W-shape, L-shape, rectangle, and square. Scientists have examined the dynamic response spectrum and the maximum displacement that different building designs can endure under static loads. The effects of seismic force on static load analysis are practically same for all models, with the exception of model-1 (the W-shape), according to the results. When it comes to seismic stresses, the W-shape is the most vulnerable. Also, structures having non-standard shapes in their frames are subject to greater displacements, according to the response spectrum analysis. In terms of overall performance, regular structures are superior to their irregular counterparts.

Seo, Junwon et al., (2015) A twelve-story reinforced concrete moment-resisting frame structure with shear walls will be evaluated for seismic performance using 3D finite element models. The assessment will be conducted in accordance with seismic design regulations, including those set out by the Federal Emergency Management Agency (FEMA) and seismic building codes. Here we are talking about the LATBSDC code, which stands for Los Angeles Tall Building Structural Design Council. Seismic Zone 4, the most dangerous seismic zone according to the USGS, is where the building is situated. We used widely accessible finite element software to generate the 3D model. Seismic performance assessment made use of two industry-standard methods for seismic analysis of structures: nonlinear time-history analysis and response spectrum analysis. The structure's inter-story drift ratios were calculated using both methods. Seismic fragility curves were generated for each floor based on the ratios derived from the time history research and the FEMA

standard in order to evaluate the building's seismic vulnerability. In light of the limitations imposed by FEMA and LATBSDC, we contrasted the two approaches' ratios. The findings demonstrated that floor-level fragility decreased with increasing building height throughout all FEMA performance categories, and that the ratios obtained from the two approaches largely fulfilled the given constraints.

III. RESEARCH METHODOLOGY

Etabs was used to generate a G+10 reinforced concrete structure with a symmetrical plan model. Additionally, L-shaped and T-shaped replicas were made using the identical floor space. Loading the structures according to IS 875: 1987 and analysis according to IS 1893: 2002 were both carried out. We used both the response spectrum approach and the seismic coefficient method to conduct our seismic study. The software's early design dictated the frame's dimensions. The model's characteristics are shown below:

Grade of concrete	M25
Grade of steel	Fe415
Height of each storey	3m
Area of plan	324 m2
Size of columns for G+10 structure	450mmx450mm
Size of beams	300mmx500mm
Thickness of staircase slab and landing	150mm
Depth of foundation for G+10 structure	2.5m

Figure 1: Details of Model

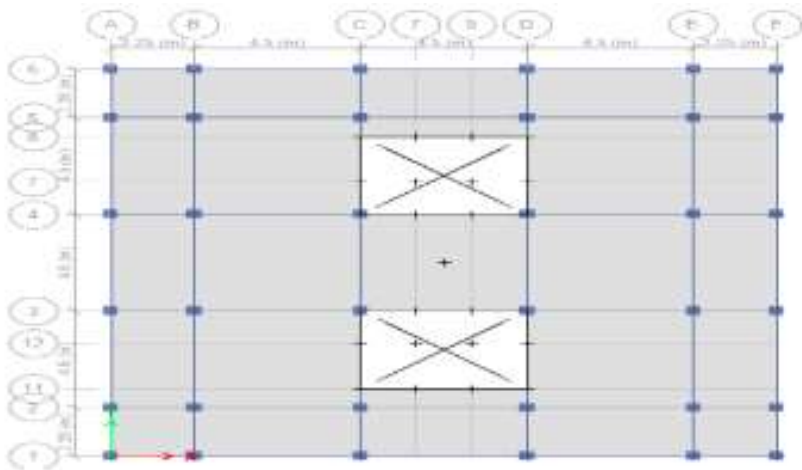


Figure 2: Plan of symmetric structure

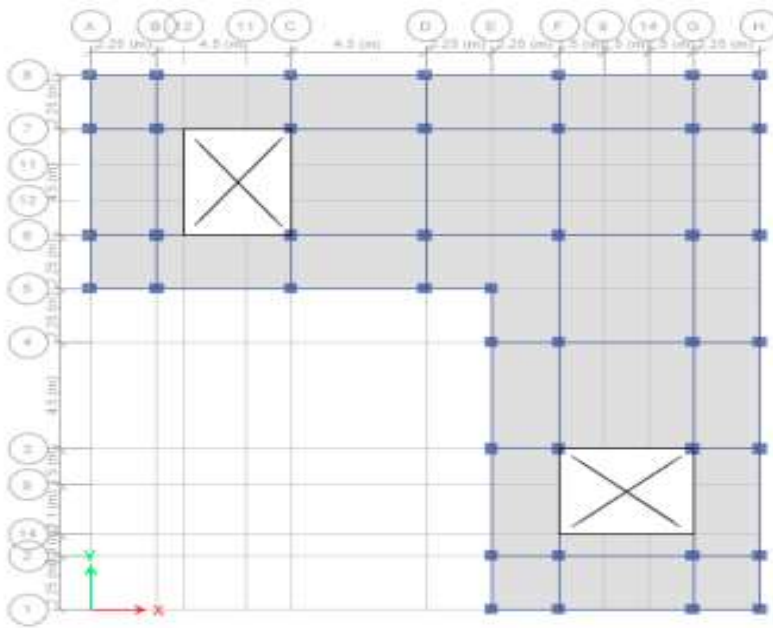


Figure 3: Plan of L shaped structure

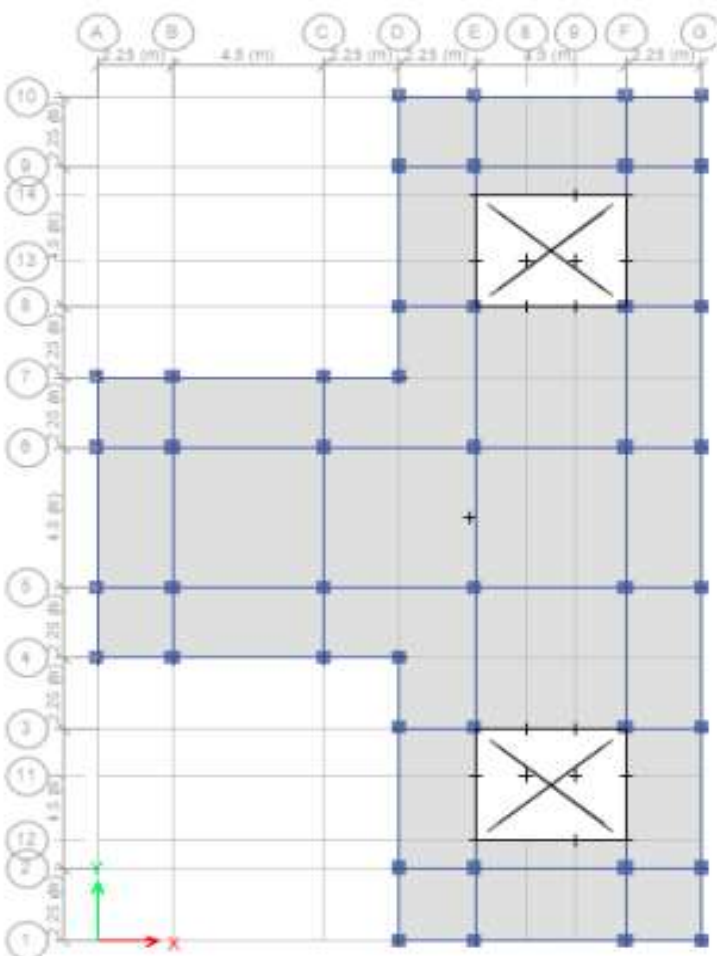


Figure 4: Plan of T shaped structure

The seismic analysis made use of the following parameters.

Type of frame	Special moment resisting frame
Response reduction factor	5
Importance factor	1
Seismic zone	Zone V (very severe)
Zone factor	0.36
Soil type	Medium (Type-2)
Damping	5%
Modal Combination	Complete quadratic combination

Figure 5: Seismic loading parameters

IV. RESULTS AND DISCUSSION

Figure 6 shows the earthquake coefficient method's variation of overturning moment throughout the height of symmetric, L-shaped, and T-shaped G+10 structures, whereas Figure 7 shows the response spectrum method's variation. Using the static technique, the overturning moment is 11.06% more in an L-shaped structure compared to a symmetrical one, and when using the dynamic method, it's 28.39% higher. In a similar vein, a T-shaped building shows an increase of 17.40% when examined using the static approach and 28.7% when assessed using the dynamic method. Additionally, in symmetric, L-shaped, and T-shaped buildings, the overturning moment calculated using the dynamic technique is 20% lower, 8% lower, and 16% lower than that obtained using the static method, respectively.

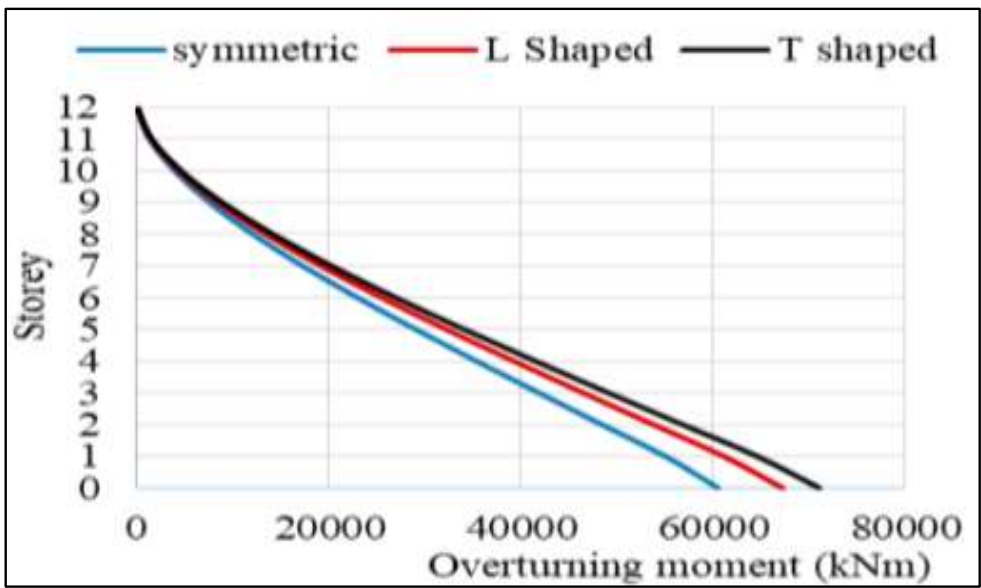


Figure 6: Seismic coefficient technique for G+10 overturning moment

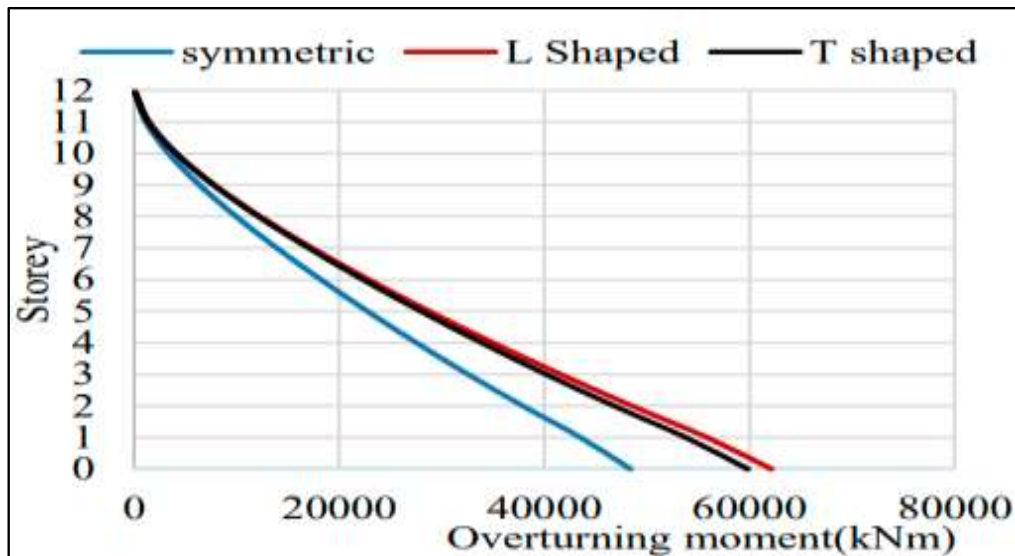


Figure 7: Response spectrum method for G+10 overturning moment

Both Figure 8 and Figure 9 show the variance in storey displacement for the G+10 models. In static analysis, the maximum storey displacements of L- and T-shaped buildings are nearly identical to those of symmetric structures; however, in dynamic analysis, they are 12.62% and 7.55% higher, respectively, than those of symmetric structures. Furthermore, in symmetrical, L-shaped, and T-shaped structures, the maximum storey displacement using the dynamic technique is about 21.3% lower, 10.5% lower, and 15.4% lower than that obtained using the static method, respectively.

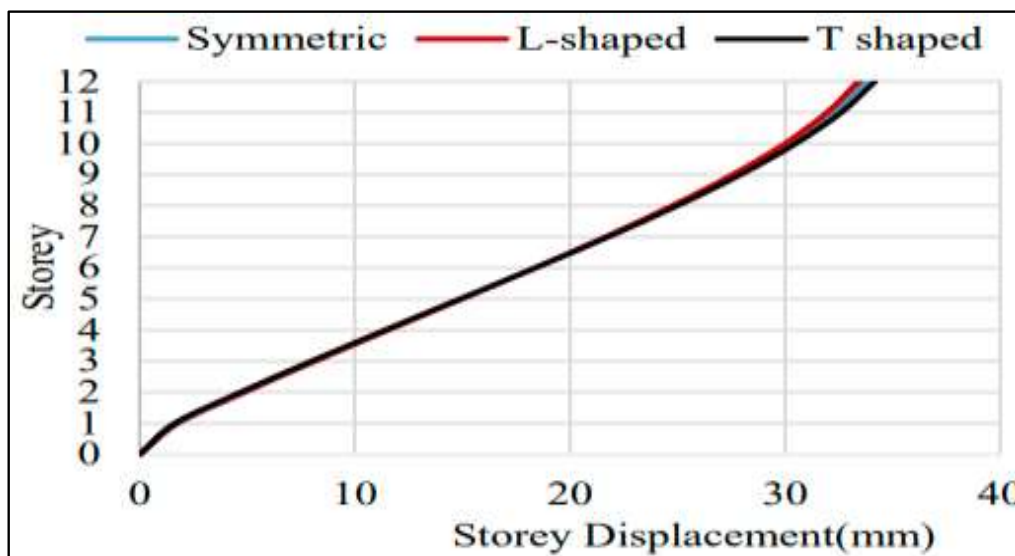


Figure 8: Seismic coefficient method for storey displacement of G+10 building

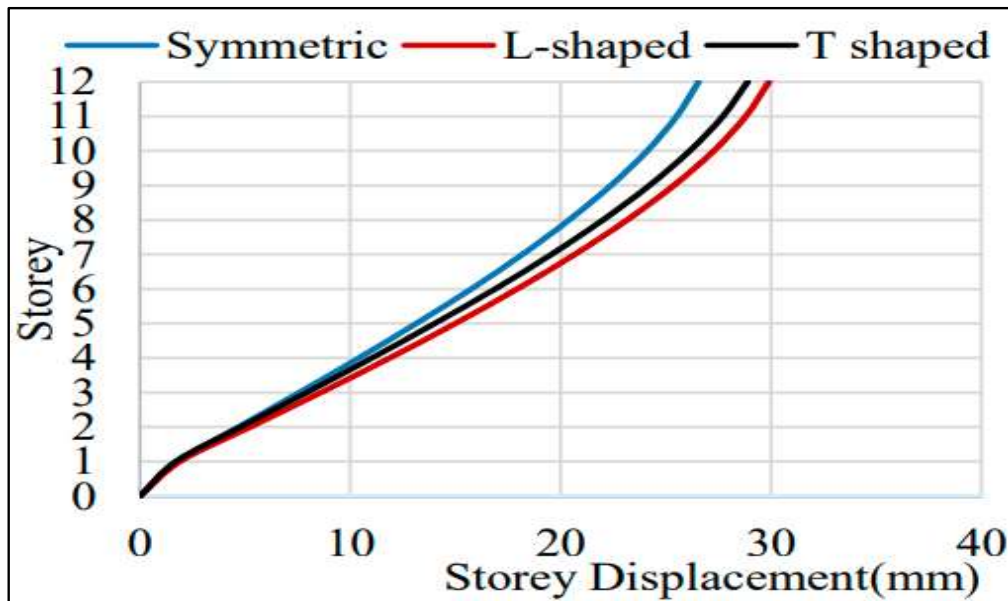


Figure 9: Response spectrum method for storey displacement of G+10 structure

V. CONCLUSION

Variations in seismic response are shown to be considerable when G+10 reinforced concrete buildings with symmetric, L-shaped, and T-shaped plan geometries are analyzed. Using the dynamic response spectrum approach in particular, the research showed that symmetric structures had lower overturning moments and storey displacements than L-shaped and T-shaped buildings. When compared to symmetrical buildings in dynamic analysis, L-shaped and T-shaped structures demonstrated an increase in overturning moments of up to 28.39% and 28.67%, respectively. Additionally, the maximum storey displacements for the former were 12.62% higher, while for the latter they were 7.55% higher. It is important to address dynamic effects for correct seismic design, since dynamic analysis often led to reduced overturning moments and displacements compared to static analysis.

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A Comparative Analysis of Bare Frame and Brick Infill Frame Structures Considering Soil Flexibility

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ABSTRACT

The benefit of soil-structure interaction (SSI) to structures subjected to seismic loads is often believed. This assumption may have been erroneous, as we learnt from the most recent earthquakes; SSI may affect the seismic response of various structural systems in different ways. Examining the effects of soil-structure interaction on multi-story buildings using different foundation systems is the goal of this effort. An examination of the seismic reaction of multi-story buildings with both rigid and flexible bases also took into account various soil types, including hard, medium, and soft. For our research, we have chosen a conventional G+6 storey building that is situated on several kinds of soils. In this case, we contrast the results that come about when soil-structure interaction is taken into account with those that happen when the structure is thought of as being fixed at its base.

Keywords: Soil structure, Base shear, Bare Frame, Brick Infill, Soft

INTRODUCTION

Built to resist a wide range of stresses and to support people within, structures are an essential part of today's infrastructure. The design and material qualities of these structures do not, however, determine their performance in isolation. The underlying soil's flexibility is a key but sometimes overlooked component affecting their behavior. Soil flexibility, a component of soil-structure interaction (SSI), is crucial in determining a structure's dynamic and static responses. When subjected to natural disasters like earthquakes or even just regular operational loads, a building's resilience depends on its foundation and the soil underneath it. The concept of soil-structure interaction is based on the fact that neither the foundation nor the soil underneath it can be completely incompressible. The outer weights of a structure are borne primarily by its foundation and, in the long run, by the soil itself. In response to these loads, the soil's kind and characteristics determine how the structure behaves. Soil deformation affects the structural reaction, which in turn affects the structure, creating a feedback loop. When buildings are constructed on loose or soft soils, the dependency between these factors becomes much more important since the soil's flexibility can increase displacements and vibrations, which could weaken the structure.

In order to build buildings that are both safe and efficient, it is essential to understand the soil's elasticity. In order to make calculations easier, structural designers have traditionally assumed fixed or rigid supports. Although this may be true in some cases, it fails to take into account how soil actually behaves when subjected to a load. The composition, moisture content, and density of soil are three of the many variables that affect the material's damping properties and the degree to which it is stiff. Soils with low stiffness and high deformability, such loose sands and soft clays, make structures built on them more likely to settle and tilt. On the other hand, even while thick sands and hard clays are more rigid, they could nonetheless behave nonlinearly when subjected to heavy loads. In dynamic events, like earthquakes, the impact of soil elasticity becomes most apparent. The structural reaction to seismic waves is directly affected by the soil's absorption and dissipation capabilities. Higher ground acceleration is caused by the quick transmission of seismic waves by inflexible soils like granite or tightly packed materials. But, towering structures' inherent frequencies can be amplified by flexible soils, which magnify lower-frequency waves. This can make their reaction much more apparent. Soil amplification is a real thing, and it shows how important it is to consider soil flexibility while making seismic plans. The local and global performance of a building are both impacted by the pliability of the soil. As an example, irregular stress distribution in structural components can result in cracking, deformation, and, in the worst-case scenario, failure, due to differential settlement, a prevalent problem in mobile soils. Similarly, the stability of the superstructure can be further affected by lateral loads, which can cause the foundation to rock or slide. Engineers may ensure long-term performance and safety by include soil flexibility into design calculations. This helps them to forecast and mitigate such concerns. Because of developments in both computer modeling and experimental methods, research

into the soil-structure interaction has been picking up speed. One effective method for modeling the dynamic relationship between building foundations and structures is Finite Element Analysis (FEA). Engineers can assess the impact of soil pliability on several structural characteristics including natural frequencies, stress distribution, and stiffness by depicting the soil as a continuum or by employing discrete models like Winkler or Pasternak foundations. Validating theoretical models and directing design approaches, experimental methods like centrifuge modeling and shake table testing have also offered useful insights into SSI occurrences.

The importance of soil flexibility extends beyond conventional structures. Bridges, offshore platforms, and towers are specialized constructions that are especially vulnerable to soil-structure interactions. As an example, the combined impacts of axial, lateral, and torsional stresses create complicated interactions for bridge piers supported by pile foundations. Oil platforms and wind turbines are only two examples of offshore constructions that need to consider how the seafloor and superstructure react to environmental pressures including wind, waves, and currents. Soil flexibility should be considered in such instances to avoid underestimating design loads and possible failure. In light of the interplay between urbanization and climate change, the importance of soil flexibility is amplified. Tall structures and infrastructure have been erected on marginal areas with poor soil conditions as a result of rapid urban expansion. Soil flexibility is already a problem, and it's getting worse due to climate change and its related phenomena like higher sea levels and more frequent extreme weather events. Soil shrinkage and cracking can result from extended droughts, while flooding can reduce the soil's ability to support heavy loads. A comprehensive knowledge of soil-structure interaction is essential for designing robust buildings in these changing settings.

Soil adaptability is an important factor in sustainable and cost-effective design, along with other practical factors. It is possible to waste materials and incur more expenses by overdesigning foundations to account for soil uncertainty. Foundation designs may be optimized for safety, performance, and economic efficiency by precisely simulating soil-structure interaction. To reduce material consumption while maintaining stability, pile foundations can be constructed with different lengths and diameters to accommodate soil heterogeneity. Soil flexibility is an important factor to include in structural analysis, but there are a number of obstacles to overcome. It is challenging to simulate soil behavior effectively due to its intrinsic nonlinearity and substantial unpredictability. Complexity is further increased by factors such as anisotropy, heterogeneity, and time-dependent effects such as creep and consolidation. In addition, several factors, such as the kind of foundation, the load characteristics, and the environmental circumstances, affect the soil-structure interaction. These intricacies may elude simpler models, which are good for initial design but may call for more sophisticated analytical and numerical methods.

REVIEW OF LITERATURE

Rehal, Jasdeep Singh et al., (2021) Buildings in seismically active regions, such as India, often have frameworks made of reinforced concrete with walls filled with brickwork. In structural assessments, masonry infill walls are usually considered nonstructural and their mass is taken into account rather than their structural properties like stiffness and strength. Seismic zones make buildings there very susceptible to harm. In addition to the force of gravity, the structure must also be able to resist lateral loads, which may cause significant stress. To this day, reinforced concrete frames continue to dominate the global building industry. Brick infill walls or panels are often used to fill the vertical gap that is generated with the use of reinforced concrete beams and columns. Analyses will be conducted once diagonal struts are used to replace these infill walls in this research. Examining the outcomes of G+ 15 constructions with and without infill using computerized model analysis. We check the following (base shear, lateral floor displacement, story drift by buildings) so that we may compare the results.

Kiani, Kianoosh et al., (2020) Finding the basic period of vibration is one of the most important elements in structural analysis and design. How the structure's mass and stiffness are distributed determines the basic period. Consequently, the building regulations include a number of empirical formulae that are derived from testing measuring ambient vibration and the periods that actual structures experience during earthquakes. In most cases, the building type and height are the variables that determine these equations.

The analytical approaches' exclusion of non-structural factors explains why they differ from the code equation in determining the basic era of buildings. This is why it's important to think about how non-structural components, like infill panels, might affect these qualities. How Soil-Structure Interactions (SSI) affect the basic period is another important element. Soil pliability obviously lengthens the foundational stage of the building. Taking soil-structure interaction (SSI) into account, this study examines how moment-resisting frames' fundamental periods are impacted by infill panels.

For this reason, we compared 3, 6, 9, 12, 15, and 18 store 2-D frames with different infill opening percentages and infill panel layouts. We used Seismo Struct to model and analyze the frames that were under study. We compare the computed basic period values to those from the seismic code's recommended equation. Key criteria affecting the basic period of steel building frames, according to the findings analysis, several factors: the kind of soil, the amount of stores, the percentage of infill opening, and the stiffness of infill panels.

Elwardany, Hytham et al., (2019) In this study, we will examine how masonry infill panels, whether present or not, and soil-structure interaction (SSI) affect the reaction of nearby buildings to earthquake-induced pounding. With an emphasis on the dynamic behavior of individual frames, the research was further expanded to compare the behavior of structures engaged in pounding with that of structures that did not experience collisions. The assumption In order to examine the impact of SSI, the foundation level was equipped with linear springs and dashpots. The infill panels were symbolized by diagonal compression struts that were similar to the actual ones.

The underlying premise was that the steel frames would display a linear strain hardening of 1% and elastic-plastic behavior. To make it seem like the buildings were slamming on one other, the dynamic contact method was used. Two nearby multi-story buildings were subjected to nonlinear finite element analysis, with four possible configurations reflecting real-world scenarios. Seismic response in the situations analyzed typically showed those nearby buildings' responses may be drastically changed if soil flexibility and/or the infill panels' contributions are ignored. Buildings subjected to structural pounding during earthquake excitation may have their seismic behavior misrepresented as a consequence.

Jayalekshmi, B. et al (2014) The foundation is often assumed to be fixed in conventional structural assessments. Nevertheless, the lateral forces acting on the building and the earthquake loading are both affected by the soil below the foundation. So, it's not practical to evaluate the building as if it were fixed at the foundation. This study examines the variations for multi-story reinforced concrete framed structures, as a consequence of seismic regulations in both the European and Indian standard codes, as well as in the spectral acceleration coefficient, base shear, and storey shear. Raft foundations, with or without shear walls, sustain the structures of varied heights. The impact of soil pliability is further considered. According to the research, symmetrical structures with shear walls at each of the four corners had the lowest amount of base shear.

Jinya, Mohammad. (2014). Architects often design masonry walls as partitions or infills in reinforced concrete frame buildings; however, these walls are not meant to add to the building's vertical gravity load-bearing capability. By separating the inside of a structure from outside elements, infill walls shield occupants from potential dangers. On top of that, infills possess substantial stiffness and strength, which greatly influences the structural systems' seismic reaction. When earthquakes strike, brick infill walls often create two types of structural damage: weak stories and short columns. Used in business or residential buildings, You may find these holes on the outside.

This sample follows IS: 1905-1987 and makes use of bricks with compressive strengths of 5.0 and 12.5 N/mm² and masonry strengths of 0.50 and 1.06 N/mm². Central apertures are cut into the perimeter wall at various percentages of 15% and 25%, respectively. G+9 R.C.C framed building models were subjected to seismic coefficient method (SCM) and time-history (TH) studies in the ETABS program, in compliance with IS 1893:2002. This research takes into account the following parameters: axial force with and without soft story, story drift, base shear, and story displacement, all while evaluating the influence of infill walls with varied percentages of opening. In order to determine the strut width for the macro model, the The FEMA approach method is utilized in tandem with the equivalent diagonal strut (EDS) technology.

Bhattacharya, Koushik et al., (2004) The natural periods of the system are increased when the earth medium below the foundation is flexible, since this reduces the total rigidity of the structure frames. Changes in lateral natural periods may significantly impact seismic lateral response, as is well-established. As a result, this research aimed to determine how Building frames supported by grid or isolated foundations varied in their lateral natural periods due to soil-structure interaction. There are a lot of variables that might affect the results, including (a) soil type, (b) floor count, (c) bay count, (d) column to beam flexural stiffness ratio, and (e) ground excitation frequency.

In this type of study, four different building models are considered: (1) a (1) a framework with fixed supports; (2) a framework with supports that account for soil flexibility; (3) a framework with brick infill and fixed supports; and (4) a framework with brick infill and supports that account for soil flexibility. We examine two possible outcomes in each category: one without tie beams and one with them installed at plinth level. Based on variables such as shear modulus, soil Poisson ratio, and footing form and size, the soil-flexibility for different kinds of soil and foundations may be calculated using methods outlined in widely-accepted literature.

By physically simulating the system, we can examine how different building frames' lateral natural periods vary over time as a result of changes in a variety of parameters. Based on the results, any building frame may have the influence of soil-structure interaction evaluated quite accurately using the given variation curves for dynamic features and some basic linear interpolation.

MATERIALS AND METHODS

Figures 1, 2, and 3 depict the plan and elevation, respectively, for the current seismic research.

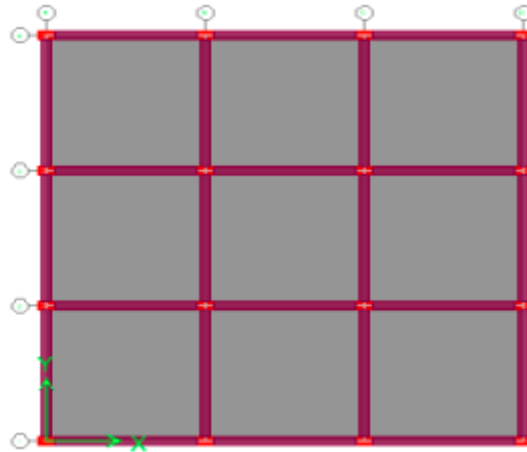


Figure 1: Plan of the building

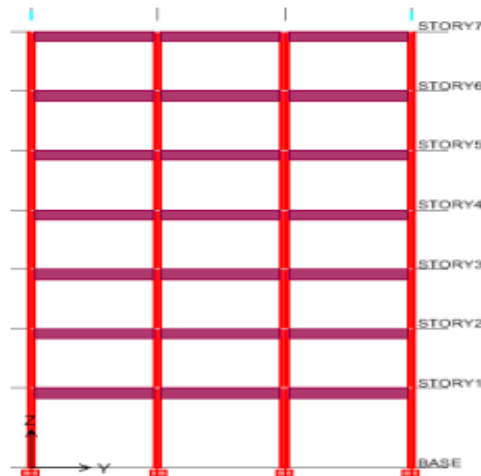


Figure 2: Elevation for Bare Frame

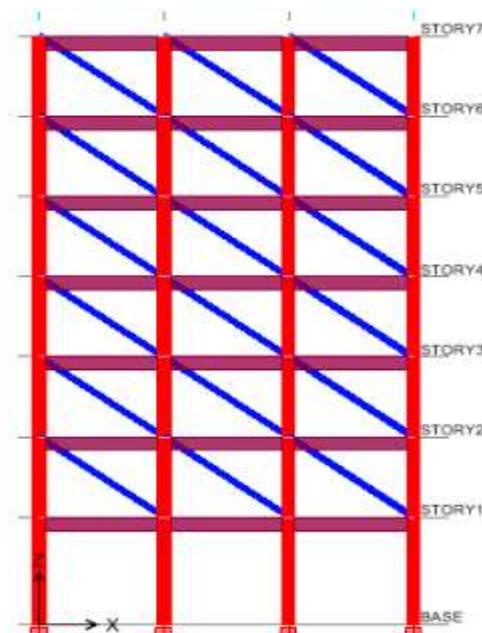


Figure 3: Elevation for Brick Infill Frame

The current investigation models the slab as a stiff diaphragm and the beams and columns as frame elements. In order to achieve in-plane stiffness, the slab is given membrane-type behavior. Assuming the beam-column joints are rigid, the floor's masses are consolidated at the center of rigidity. The models have all been developed and tested under the

conditions of a gravity load, namely 1.5(DL+LL). We were successful in recreating this soil behavior by modeling it using a network of linear elastic springs. Two rotating springs on each side of the globally perpendicular axes and three translational springs along them are positioned underneath the foundation's center of gravity to mimic the impact of soil-flexibility. The method for simulating and computing the stiffness of analogous soil springs along the several axes of rotation has been defined by ATC-40. Multiplying the surface stiffness variables by the embedding stiffness factors takes bearing depth into consideration. Finally, the coefficients of translational and rotational stiffness are determined by dividing the total embedded stiffness by the area of contact and the moment of inertia, respectively, in the absence of coupling. The result is the distribution of stiffness intensities for each person. The ultimate stiffness with the appropriate units (kN/m for translational and kN/radian for rotational, respectively) is obtained by multiplying the separately distributed stiffness intensity parameters with the corresponding areas. The soil parameters that were used to identify these similar springs are shown in Figure 4.

Type of Clay	S.B.C of soil kN/m ²	Young's Modulus kN/m ²	Poisson ratio	Shear Modulus kN/m ²
Soft	120	15000	0.45	5172.41
Medium	160	50000	0.45	17241.37
Stiff	250	200000	0.45	68965.51

Figure 4: Soil Parameters for Performance Evaluation

RESULTS AND DISCUSSION

Base shear, storey drift, and lateral displacement results from various analysis are shown and compared for building models. Investigating the effects of nonlinear building behavior and soil-structure interaction is the primary goal of seismic studies. Furthermore, the nonlinear static pushover analysis is used to assess the performance of the building models during the design earthquake. Included in this evaluation are models with and without brick filling.

Base Shear

A building's base shear is affected by its mass, stiffness, height, and natural period. The equivalent static method uses the horizontal acceleration value from the code's natural period to inform design decisions. Its underlying premise is that the dynamics are controlled by the building's first mode of vibration and that higher modes do not have a significant impact. For both gravity and seismic design, Figures 5 and 6 show Using different kinds of soil, the base shear of models of buildings with and without brick infill may be calculated.

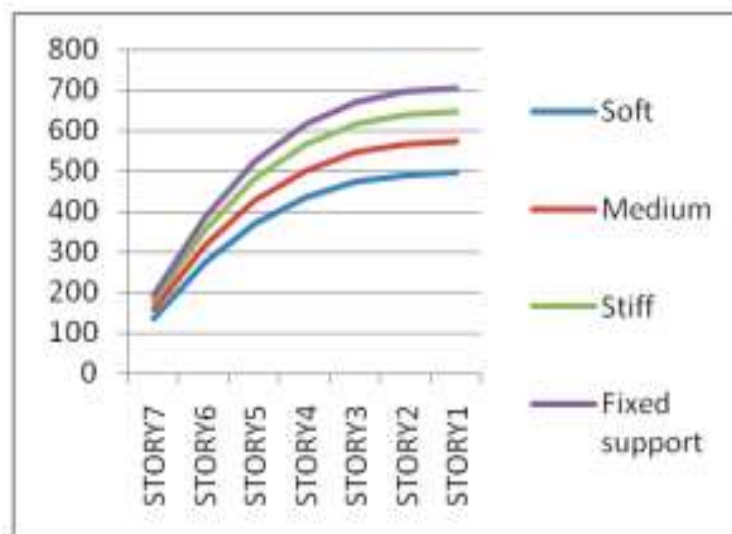


Figure 5: Base shear for Bare Framebuilding models on Different Soil Types

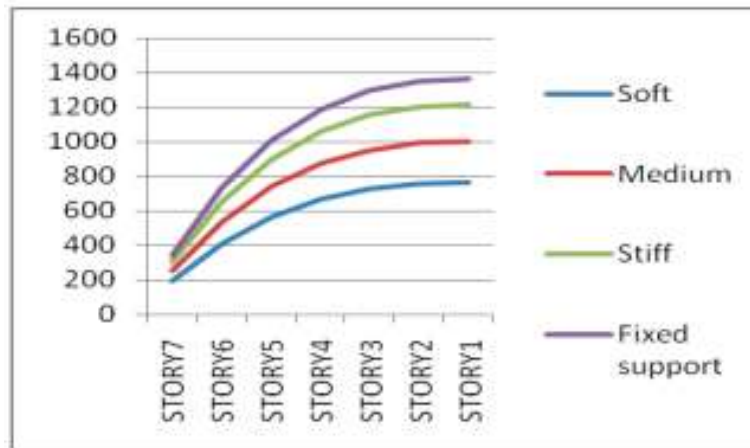


Figure 6: Base shear for brick infill Different soil types frame building models

Lateral displacements

Figures 7 and 8 display tabular data along the longitudinal axis representing lateral displacements for various soil types. The statistics clearly show that when the soil type goes from hard to soft, the displacement values go up.

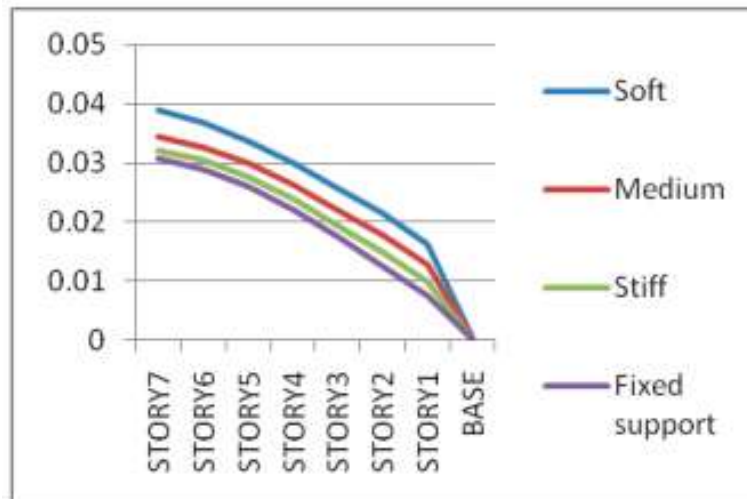


Figure 7: Bare Frame lateral displacement

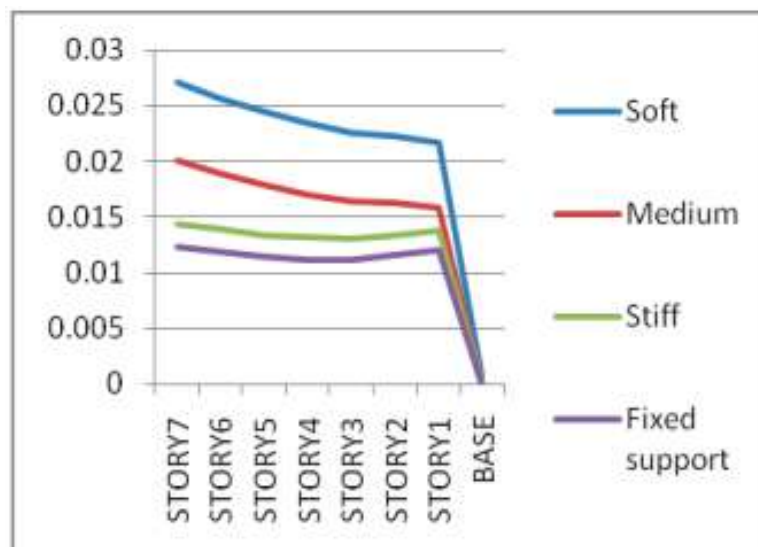


Figure 8: Lateral displacement for Brick infill Frame

Inter Storey Drift

In Figures 9 and 10, we can see the longitudinal variation of the interstorey drift for the building models. The inter-story drift was seen to be greater on the first floor in the longitudinal direction in model 2, possibly because of the open ground story. The storey drift must not be more than 0.004 times the storey height, as stated in article 7.11.1 of IS 1893 (Part 1): 2002. The storey drifts on the higher floors of model 2 are within the acceptable range, but on the first floor, which is exposed to the ground, the stiffness and irregularity are too much.

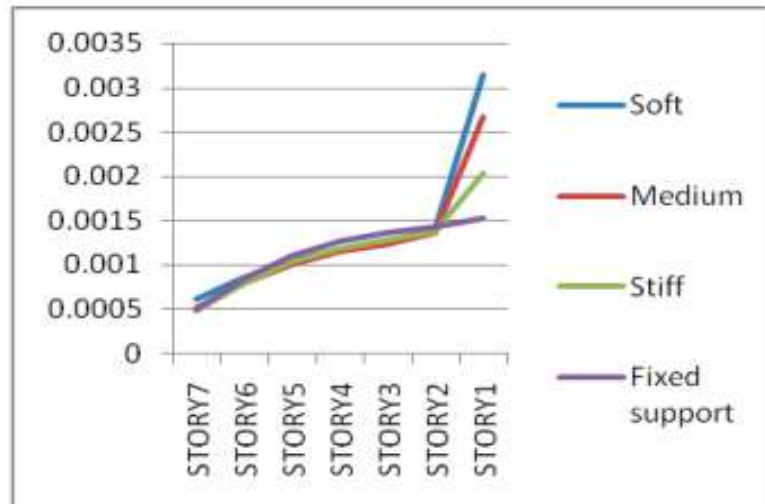


Figure 9: Storey drift for Bare frame

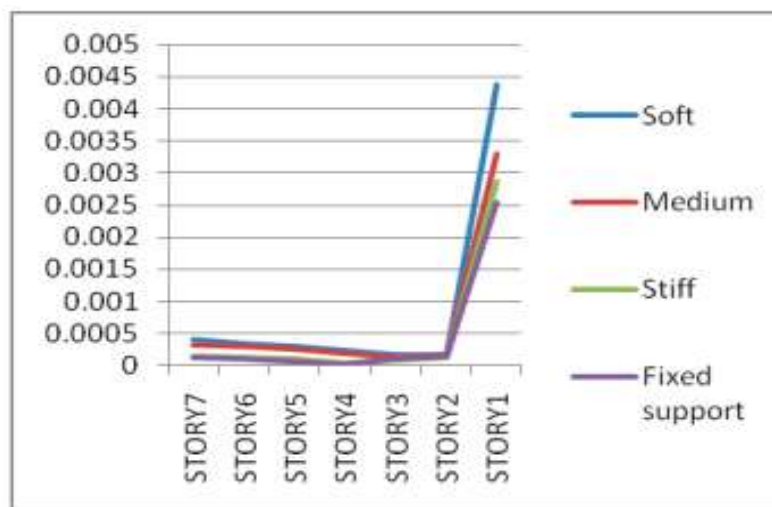


Figure 10: Drifts between storeys for brick infill frames

Performance Evaluation of Building Models

We use nonlinear static pushover analysis to evaluate all of the models based on their seismic performance. The most extreme combination of planned loads is used to assign default hinges for constructing models. There were eleven stages to the pushover study. Hinge formation in beams was noted to occur first with subsequent push to construction. The hinges started off in proceeded through the B-IO stage, IO-LS, and LS-CP. Table 2 displays the data for the performance measures used in model creation. The base shear is represented by V and the displacement by D in this context.

Table 1: Performance Evaluation of Building Models at Point V and

Soil Type	Bare Frame		Brick Infill Frame	
	V	D	V	D
Fixed base	1244.32	0.252	1634.39	0.077
Stiff soil	1241.25	0.258	1628.80	0.080
Medium Soil	1234.65	0.274	1603.71	0.093
Soft Soil	1178.07	0.288	1348.26	0.108

The results of the performance assessment of the Bare Frame and Brick Infill Frame models on different kinds of soil are shown in the table at Points V and D. All of the models exhibit a minor decrease in displacement values from a stable foundation to stiff earth, followed by an increase as the soil softens, and finally a maximum on very soft soil. In comparison to the Bare Frame, the Brick Infill Frame often experiences bigger displacements. At Point V, the displacement of the Bare Frame is somewhat lower in stiffer soils compared to the Brick Infill Frame, which exhibits a larger displacement in all soil types. The two models display a consistent upward trend in displacement with progressively softer soils at Point D, while the Brick Infill Frame once again shows the highest displacement values.

CONCLUSION

Consideration of soil flexibility in a comparative study of bare frame and brick infill frame constructions shows how soil-structure interaction significantly affects buildings' seismic performance. Soil type affects important building factors such lateral displacement, storey drift, and foundation shear; study shows that soft soils cause more displacements and drift. In addition, the degree to which both building styles are safe during seismic events varies; bare frame constructions, with their open ground floor, are particularly prone to plastic hinges developing on the first story. Although both bare frame and brick infill frame buildings are capable of withstanding earthquakes, there is clear room for improvement in terms of seismic resilience, especially for structures situated on unstable ground.

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