SEISMIC ANALYSIS OF SOIL STRUCTURE INTERACTION OF PILE FOUNDATION USING FEM

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Abstract- *Seismic Soil-Structure Interaction (SSI) is a fundamental aspect of civil engineering and structural dynamics, particularly in the design and analysis of structures subjected to earthquake excitations. Understanding the behavior of structures in seismic events requires more than just analyzing the structural components in isolation; it necessitates the incorporation of the surrounding soil's properties, as well as the interaction between the soil and the structure. This complex interplay can significantly alter the dynamic response of both the structure and the soil, leading to a more comprehensive understanding of seismic performance. This study investigates the phenomenon of SSI using the finite element analysis (FEA) software ANSYS, a powerful tool for simulating the interaction between structural and geotechnical systems. The main objective of this research is to develop a robust computational model within ANSYS to simulate seismic SSI and analyze its effects on structural responses during earthquake loading. The methodology adopted integrates the dynamic properties of soils, including non-linear behavior, damping, and wave propagation, alongside detailed structural modeling. By focusing on the interaction at the interface between the soil and structure, this study explores how seismic waves traveling through the soil medium affect the structural response, considering the mutual feedback mechanisms.*

Keyword: Soil structure interaction, Seismic analysis, wave propagation, finite element analysis.

1. Introduction-

Seismic analysis of soil stands as a pivotal domain within geotechnical engineering, illuminating the intricate interplay between seismic forces and the geological substratum upon which infrastructure rests. Spanning an array of methodologies, from laboratory testing to sophisticated computational models, this discipline plays a fundamental role in ensuring the safety and resilience of structures in earthquake-prone regions worldwide. To embark on a comprehensive exploration of seismic analysis of soil, it is essential to first comprehend the seismic hazard faced by a particular region. Earthquake hazard analysis involves assessing the likelihood of seismic events of varying magnitudes occurring over a specified period, often informed by historical seismicity, fault mapping, and probabilistic models.

One prominent method employed in seismic analysis of soil is the use of numerical modeling techniques, such as finite element analysis (FEA) and boundary element method (BEM), to simulate soil-structure interaction under seismic loading. These models discretize the soil mass into finite elements or boundary elements, allowing for the calculation of stresses, strains, and displacements within the soil and adjacent structures. By coupling these models with earthquake ground motion records, engineers can simulate the dynamic response of soil-structure systems, assessing factors such as foundation settlement, soil liquefaction potential, and structural deformations.

2. Problem Statement-

The primary challenge in seismic analysis of soil foundations is the accurate prediction of the dynamic interaction between soil and structure under seismic loading. This involves understanding and modeling the nonlinear behavior of soils, accounting for soil heterogeneity, and incorporating the effects of soil-structure interaction in numerical simulations. Key issues include:

Nonlinear Soil Behavior: Soils exhibit highly nonlinear behavior under seismic loading, characterized by variations in stiffness, damping, and potential for liquefaction. Current models often oversimplify these behaviors, leading to inaccurate predictions of soil and foundation responses.

3. Methodology-

Seismic analysis of pile and soil foundations assesses the structural integrity and performance of foundation systems when subjected to seismic forces. Utilizing ANSYS, a robust finite element analysis (FEA) software, this methodology provides a systematic approach to model and simulate the complex interactions between the pile, soil, and seismic inputs, ensuring a thorough understanding of the foundation behaviour under earthquake loading.

3.1. Preliminary Considerations

Before initiating the analysis, it is crucial to gather comprehensive data and set clear objectives:
Site-specific geological data: Information about the soil stratigraphy, including soil types, layers, and their respective properties.
Pile specifications: Details about the pile material, geometry, and installation method.
Seismic input data: Ground motion records or response spectra tailored to the site conditions.

3.2 Setting Up the Model in ANSYS

3.2.1 Define the Geometry

The first step in ANSYS is to create a precise 3D model of the soil domain and the pile(s):
Modeling the Soil Domain:
Create a 3D model that represents the soil domain, ensuring it extends sufficiently in all directions to minimize boundary effects. Typically, the domain should extend at least five times the pile length horizontally and vertically.
Divide the soil into distinct layers according to the geological data, assigning each layer an appropriate thickness.
Modeling the Pile:
Develop a detailed 3D model of the pile within the soil domain, ensuring accurate representation of the pile's length, diameter, and any variations in cross-section.

3.2.2 Material Properties

Accurate material properties are vital for realistic simulation results:
Soil Material Properties:
Define the properties for each soil layer, including density, Young's modulus, Poisson's ratio, damping ratio, and shear strength parameters.
Utilize nonlinear material models (e.g., Drucker-Prager, Mohr-Coulomb) to capture the soil's behavior under seismic loads.
Pile Material Properties:
Define the pile material properties, typically using linear elastic models. For concrete piles, include properties such as Young's modulus, Poisson's ratio, and compressive strength.

3.2.3 Meshing

Effective meshing is crucial for accurate and efficient simulations:
Meshing the Soil and Pile:
Use a finer mesh around the pile to capture detailed interactions and a coarser mesh further away to save computational resources.
Ensure proper connectivity between soil and pile elements to accurately simulate their interaction.
Element Types:
Use solid elements suitable for 3D modeling, such as SOLID185 or SOLID186 for both soil and pile.

3.2.4. Defining Boundary Conditions

Accurate boundary conditions ensure realistic simulation results:
Soil Boundary Conditions:
Apply fixed boundary conditions at the base of the soil model to simulate bedrock.
Use transmitting or absorbing boundaries on the sides to minimize seismic wave reflection, simulating an infinite domain. Elements like COMBIN14 in ANSYS can serve this purpose.
Pile Boundary Conditions:
Fix the pile at the connection with the superstructure or at the pile head as per the actual boundary conditions.

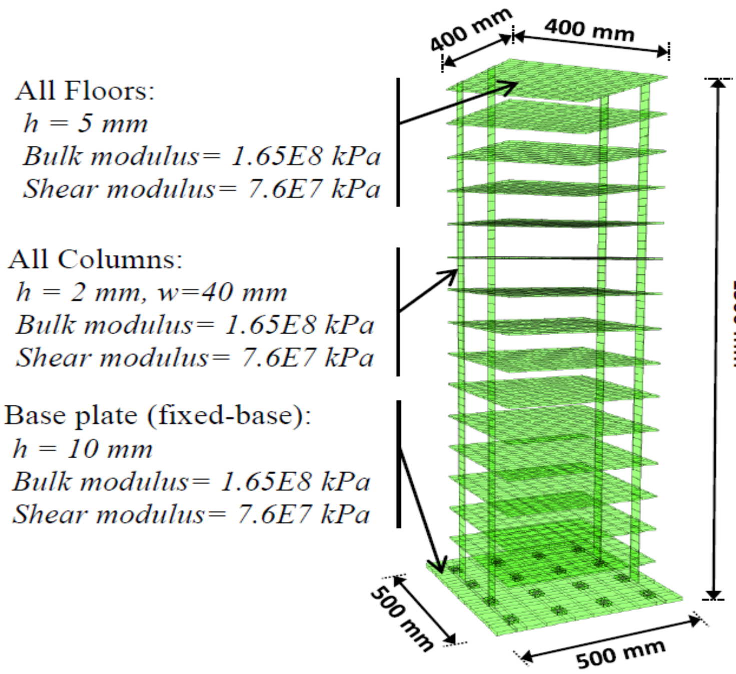

Fig. 1 Numerical model of the soil and pile foundation

4. Results and discussion

High rise buildings were subjected to seismic loading conditions. OMRF and SMRF are the two different conditions of the buildings which were subjected to high dynamic seismic loads with the conditions of the soil were also estimated. Normal rise buildings, single step building and stepped rise buildings are the three types of buildings on the different conditions of soil conditions like that were simulated in terms of seismic loading using ANSYS.

It was observed that when the structure was subjected to high intensity seismic loads in different directions it was essentially visible that a enhanced bending moment was developed in the structure mainly due to the presence of gravity load acting at the centre and due to the vibratory motion of the body a distance was created of the centroid from the regular axis of the building leading to generation of a moment in a body.

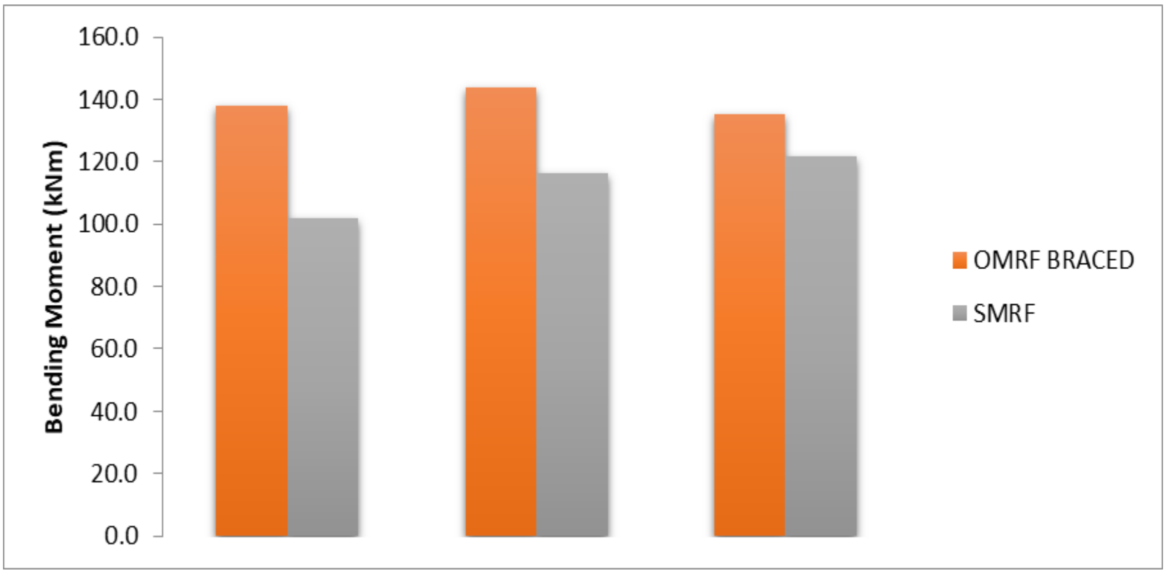

Fig.2. Bending moment in buildings in zone III

It was observed from fig. 2 that bending moment of stepped frame tends to have maximum bending moment on comparison to other two types of structure. Stepped frame therefore starts to behave more unstable on exposure to high dynamic seismic loads, while other two types of frames remain more stable. It was also observed from the figure that OMRF braced building have subsequently more bending moment as compared to SMRF braced building frame. It was the outcome of all three different types of buildings. SMRF building was observed to be highly efficient and earthquake resisting structure as compared to that of OMRF building.

When the magnitude of the seismic loads applied were as per that of time acceleration graph of zone III. All three different types of the structure normal, single step and stepped building was subjected to same earthquake load as per zone III according to IS codes. It was evident that stepped frame tends to have maximum shear force on comparison to other two types of structure.

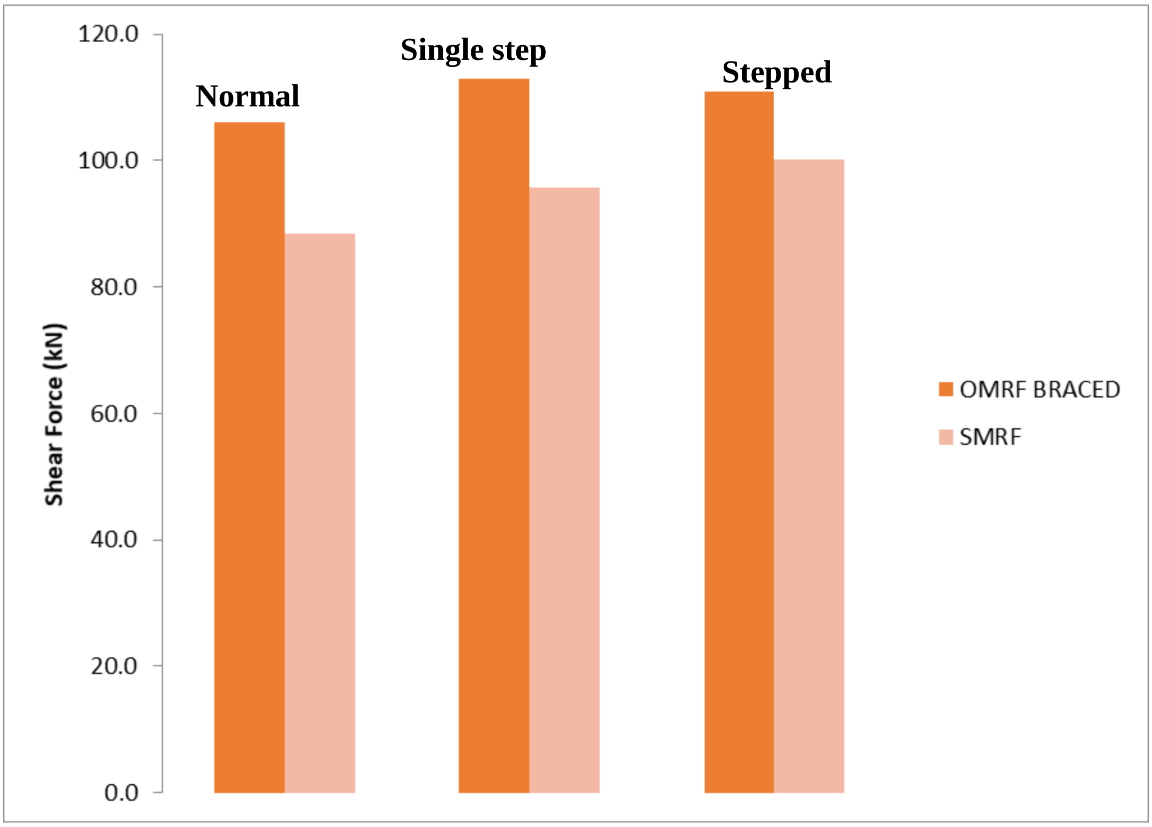

Fig.3 Maximum shear force in zone III

It was observed from fig. 3 that maximum shear force of stepped frame tends to have maximum shear force on comparison to other two types of structure. Stepped frame therefore starts to behave more unstable on exposure to high dynamic seismic loads, while other two types of frames remain more stable. It was also observed from the figure that OMRF braced building have subsequently more maximum shear force as compared to SMRF braced building frame. It was the outcome of all three different types of buildings. SMRF building was observed to be highly efficient and earthquake resisting structure as compared to that of OMRF building.

5. Conclusions-

This study underscores the critical role of soil-structure interaction in the seismic analysis of high-rise buildings. The incorporation of SSI using ANSYS revealed significant differences in natural frequencies, displacements, accelerations, and stress distributions compared to fixed-base models. The findings emphasize the need for comprehensive SSI consideration in the design and analysis of high-rise buildings to ensure their safety and performance during seismic events. Enhanced foundation design, careful structural detailing, and consideration of SSI effects are essential for resilient high-rise structures in earthquake-prone areas.

The seismic analysis of high-rise buildings, incorporating soil-structure interaction (SSI), reveals critical insights into the behavior and safety of such structures under earthquake loading. This comprehensive study, performed using ANSYS, underscores the significant influence of SSI on the dynamic response of high-rise buildings.

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