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Comparative Analysis of Soil-Piles Structure Interaction of Framed Structure

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Abstract - This study presents a comparative analysis of a 15-story building with two foundational approaches: a fixed-base foundation and a pile foundation incorporating soil-structure interaction (SSI) in sandy soil conditions. The research investigates the dynamic behavior of each foundation type under varying conditions, specifically examining the effects of different pile spacings and relative densities of sandy soil on the building's fundamental frequency, time period, lateral displacement, and overall structural stability. The SAP2000 software is used for numerical study.

Key Words: Soil-Structure Interaction (SSI), frequency, time period, displacement, Lateral Displacement, Seismic Analysis, G+14, SAP2000, sandy soil

1. INTRODUCTION

Soil-Pile-Structure Interaction (SPSI) plays a pivotal role in determining the seismic response of tall buildings, especially those built on pile foundations in areas with loose soil conditions. Traditional seismic designs often assume buildings have a rigid base; however, these assumptions may overlook significant soil-structure interactions that can influence lateral displacements, inter-story drifts, and stability during an earthquake. For high-rise structures, where the interaction between soil, pile, and building is magnified under seismic loading, SPSI is essential to accurately predict performance and design buildings capable of withstanding seismic forces. The reviewed thesis focuses on these dynamics within high-rise RC buildings on sandy soil and provides valuable insights into optimizing pile configurations and understanding SPSI's role in seismic resilience.

Soil-Structure Interaction

All the Civil engineering structures consist of structural elements which are directly supported on ground. When an external force such as Earthquake act on the structure neither the structure nor the ground responds independent of each other, the process in which the response of the soil due to earthquake influences the motion of the structure and the motion of the structure due to earthquake influences the response of soil is called Soil-pile Structure Interaction (SSI).

2. METHODOLOGY

In this project we are trying to study and understand the Effect of Soil structure interaction on high rise Reinforced concrete building by considering all important parameters like Height of structure, type of soil and Different seismic zones according to Indian standard codes, we are analyzing response and behavior of the structure using Response spectrum analysis in SAP 2000 V24 software package.

(i) Modelling multi-storey building with foundation sandy soil condition in same seismic zones using SAP 2000 Software.

(ii) Analyzing all the building models using Response spectrum seismic analysis method with fixed base support without considering Soil structure interaction in SAP 2000 software.

(iii) Modelling all buildings with flexible base (considering SPSI) using Finite element Analysis.

(iv) pile foundation is selected as common foundation for all the flexible base models, which will be designed and checked for all structural checks as per IS 456: 2000

(iv) Analyzing all the flexible base models using SAP2000 software.

(v) Comparison of fixed base building with pile foundation with ssi in sandy soil.

3. MODELLING AND ANALYSIS

3.1 MODELLING OF RC BUILDINGS

An 15- storey reinforced concrete (RC) building was modeled in SAP2000. The building dimensions were 12m x 12m with 3 bays in both X and Y directions. The building was analyzed under seismic loading using Response Spectrum Analysis (RSA), with considering SPSI.

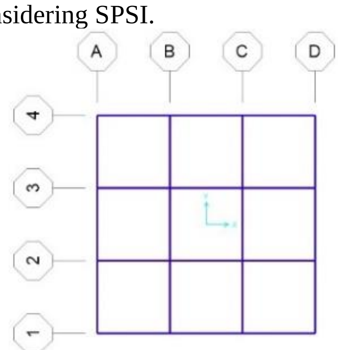

Figure 1 Dimensions of Buildings

Table 1:Structure Data

Structure	**G+14**
No. of Storey	14
Height(m)	3.5
Slab Thickness(mm)	150
Grade of Concrete	M30
Rebar	Fe550

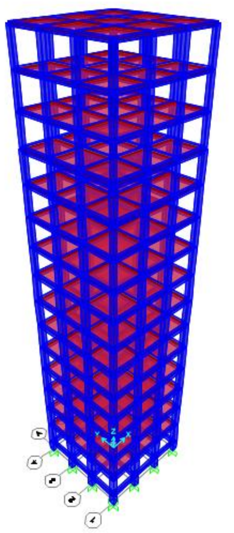

Figure 2: G+14 without SPSI

3.2 Data Used

Different loads on structure is taken as per IS 875 (part I) for dead load and IS 875 (part II) for live load and load combination is taken as per IS 1893:2016. (Table II)

Table 2: Data Used

No.	**Parameters**	**Values**
1.	Imposed Load	4 KN/m2
2.	Floor Finished Load	1.5 KN/m2
3.	Wall Load	3 KN
4.	Earthquake Load	As per IS 1893: 2016
5.	Seismic Load	Zone V
6.	Zone Factor	0.36
7.	Response Reduction Factor	5
8.	Importance Factor	1
9.	Damping	5%

3.3 Designing of Pile Foundation

Dimension of building is 12mX 12m and height of building is 52.5m respectively, building are modelled Flexible base(with SPSI), which is modelled and merged with the soil using Finite Element Method and applied to the pile or deep foundation of dimension Pile slenderness ranging from short to slender (20, 30, 40 and 50), spacing of piles ranging from close to large (3D, 5D, 7D and 9D), relative densities of sandy soil ranging from loose to dense (35%, 50%, 65% and 80%) and number of piles in a group 9 (3×3) to semulate the soil behavior at the time of seismic activity.

3.4 Soil Modelling

Due to project constraints, site-specific soil testing was not conducted. Therefore, the soil parameters used in this analysis were adopted from standard IS codes and published literature. These values represent typical ranges in this study (sandy soil, rock) and are widely used for preliminary structural analysis in cases where soil test data is unavailable.

3.5 Soil Profile Data

Due to project constraints, site-specific soil testing was not conducted. Therefore, the soil parameters used in this analysis were adopted from standard IS codes and published literature. These values represent typical ranges in this study (sandy soil) and are widely used for preliminary structural analysis in cases where soil test data is unavailable.

Dimensions – 36m*86m
Depth-Two times the pile length

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Table 3: Soil Data

Parameters	Soil	Sandy soil
1.	Modulus of Elasticity(E)(MPa)	40
2.	Shear Modulus(G)	15
3.	Poisson's ratio	0.3
4.	Coefficient of Thermal Expansion	1.75*10^-6
5.	Cohesion	0
6.	Friction Angle	31
7.	Unit Weight(KN/m3)	16

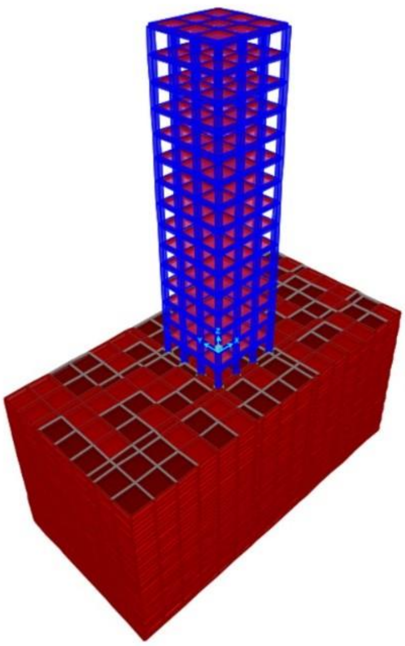

Figure 3: G+14 with SPSI

4. Seismic Analysis

The seismic loading was applied using the Response Spectrum Analysis (RSA) as per the relevant seismic code (IS 1893:2016) provisions. The building's response, in terms of natural frequencies, mode shapes, story displacements, and base shear, was analyzed under the following conditions:

1. Fixed foundation without SSI.
2. Flexible foundation considering SPSI for sandy soil

4.2 Response Spectrum

- It is the representation of maximum response of a spectrum of idealized single degree of freedom system of different natural periods but having the same damping, under the action of the same earthquake ground motion at their bases. The response referred to here can be maximum absolute acceleration, maximum relative velocity or maximum relative displacement.
- A Response Spectrum is a graphical representation of the peak response (such as displacement, velocity, or acceleration) of a set of oscillators of varying natural frequencies, all subjected to the same base excitation. It's a crucial tool in earthquake engineering and structural dynamics for understanding how different structures will respond to seismic events

- **Data used in performing Response Spectrum is according to Code IS 1893 :2016**

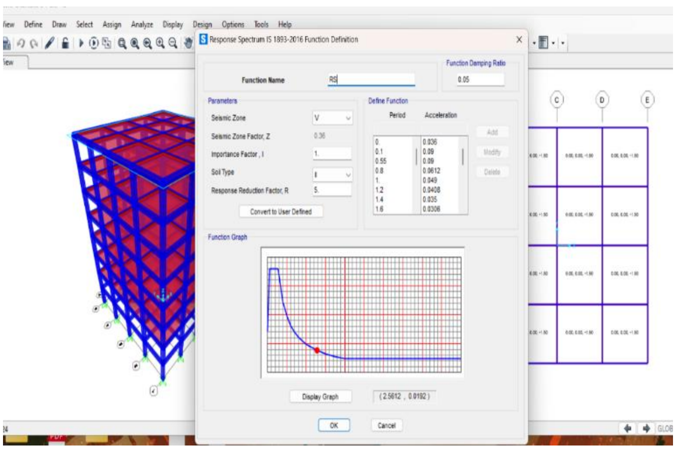

Figure 4: Response Spectrum

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5. Results and Discussions

5.1 G+14 without SSI

5.1.1 Natural Frequency and Time Period

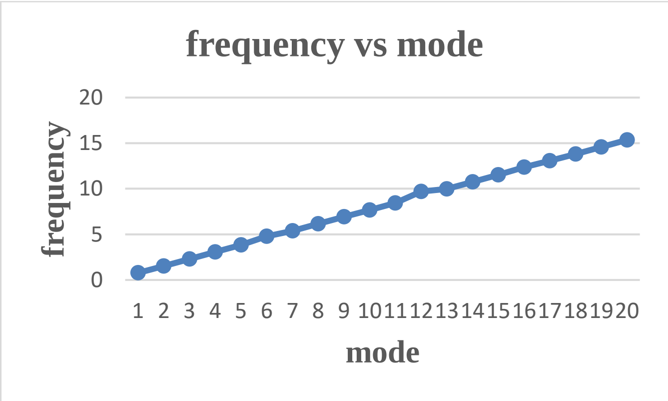


Figure 5: Mode vs Frequency of G+14 without SSI

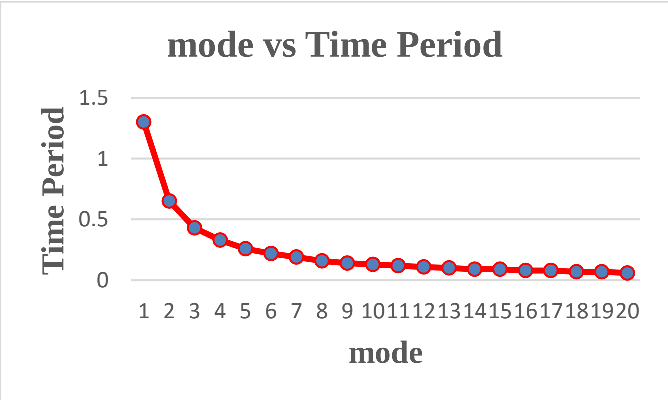


Figure 6: Mode vs Time Period of G+14 without SSI

5.1.2 Lateral Displacement

Lateral displacement is shown in the fig.10

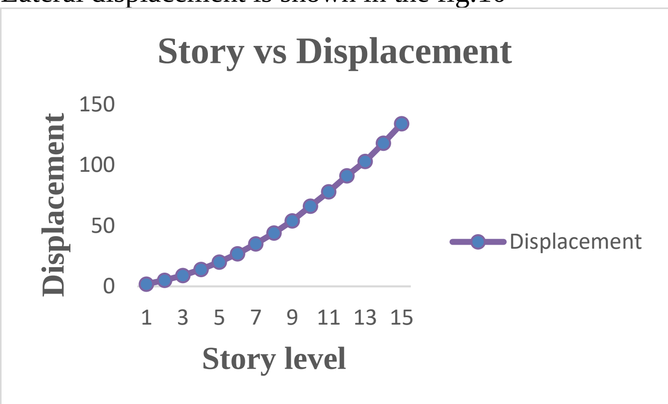


Figure7: Displacement of Storey without SPSI

5.2 G+14 with SSI

5.2.1 Natural Frequency and Time Period

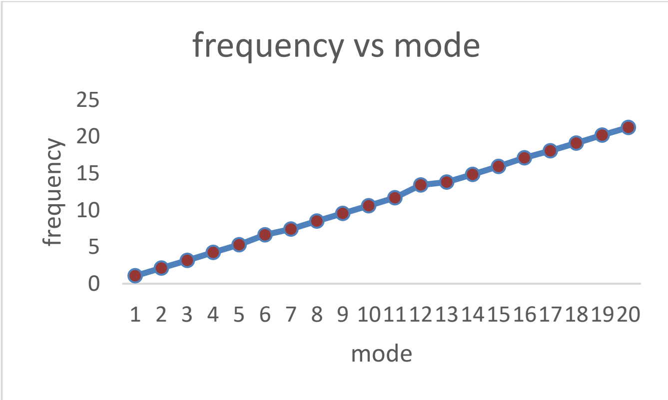


Figure 8 Mode vs Frequency with SPSI

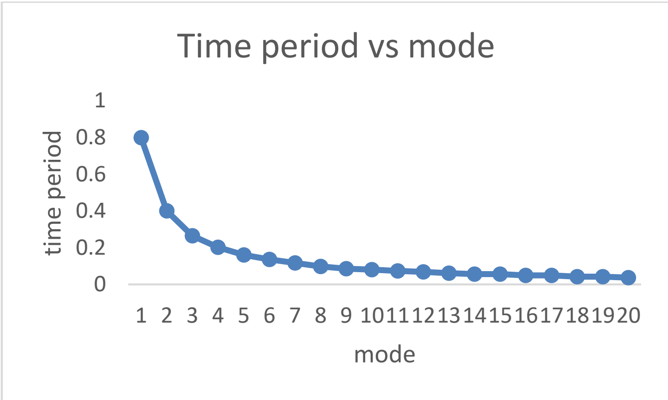
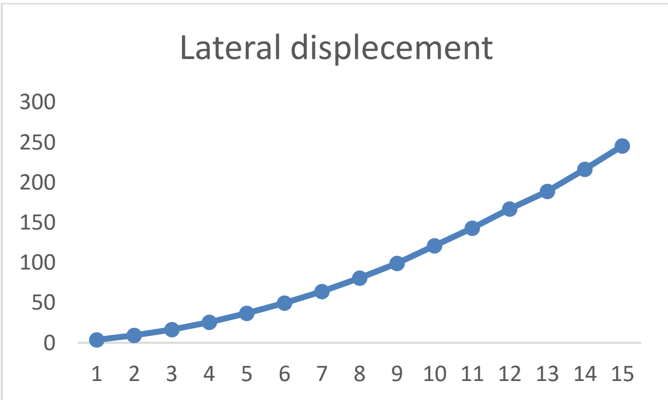


Figure 9 Mode vs Time Period with SPSI

- **Lateral Displacement:**



The lateral displacement increases with the number of stories, as expected. The G+12 building shows greater lateral displacement compared to fixed structure.

Under different story conditions, lateral displacement is highest for buildings on 9th story and lowest for 1st story, which highlights the importance of soil stiffness in controlling displacement during seismic events.

The lateral displacement of the G+14 building is 83.26% higher at the top floor compared to fixed building.

- **Frequency and Time Period:**

for buildings with a pile foundation on sandy soil, the fundamental frequency is lower, and the time period is longer due to the increased flexibility of the soil-pile interaction. This behavior highlights the importance of considering soil conditions in the design and analysis of structures, as the dynamic response can significantly differ based on the characteristics of the underlying soil. Proper evaluation of these factors is crucial for ensuring the structural integrity and safety of buildings subjected to dynamic loads.

The fundamental frequency of the G+14 building on sandy soil is 38.5% higher compared to the fixed building, indicating increased flexibility.

Conclusion Summary:

Influence of Soil-Structure Interaction:

The analysis of soil-pile interaction in the context of a 15-story building situated on sandy soil compared to a fixed foundation reveals significant differences in dynamic behavior, stability, and overall structural performance. Here are the key findings:

- Buildings with fixed foundations exhibit a higher fundamental frequency and a shorter time period due to the increased stiffness provided by the rigid base. In contrast, the pile foundation in sandy soil results in a lower fundamental frequency and a longer time period. This indicates a more flexible response to dynamic loads, which can lead to increased lateral displacements during seismic events or high winds.
- The lateral displacement experienced by the building on a pile foundation in sandy soil is generally greater than that of a fixed foundation. The flexibility of the soil-pile system allows for larger movements, which may necessitate careful design considerations to ensure that the displacements remain within acceptable limits as prescribed by relevant codes and standards.

Safety and Performance: The performance of the building on a pile foundation in sandy soil must be thoroughly assessed to ensure safety and serviceability. This includes evaluating the potential for increased lateral displacements and the implications for structural integrity, especially under dynamic loading conditions**.**

Soil-Structure Interaction: The incorporation of soil-structure interaction in the analysis of the pile foundation is crucial, as it reveals the importance of considering the effects of the surrounding soil on the overall performance of the structure. SSI leads to changes in effective stiffness and strength of the system, which must be accounted for in design calculations.

The lateral displacement is significantly higher (up to 83.25% more) in G+14 buildings, on sandyt soil where flexibility dominates.

In conclusion, while a fixed foundation offers a stiffer and more predictable response, the use of pile foundations in sandy soil introduces a different set of dynamics that must be carefully analyzed. Understanding the differences in fundamental frequency, lateral displacement, and the implications of soil-structure interaction is essential for ensuring the structural safety and performance of tall buildings in varying soil conditions. As such, advanced analysis techniques, including dynamic response simulations and consideration of site-specific soil properties, are vital for effective design and risk management in geotechnical and structural engineering

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