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# Soil-Structure Interaction Analysis on Pile Foundation in Sandy Soil

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**ABSTRACT:** Soil–structure interaction (SSI) analysis research has been acknowledged as an essential step in the design of significant structures. Powerful computers have led to a sudden increase in the capabilities of SSI analysis. The study on dynamic SSI analysis of pile-supported structures utilizing direct- and substructure-based numerical approaches is presented in this publication. Examining a building structure in touch with soil involves an interactive process of stresses and strains induced within the structure and the soil field. Due to the substantial interaction that exists between the soil field and the building structure's components, the Pile Foundation system reacts to the structure in an extremely complicated manner. This analysis of soil-building interaction is based on the Pile Foundation and has been evaluated with SAP 2000. It is usually very challenging to regulate and analyze the complex procedures involved in evaluating the SSI effects in experimental setups. Furthermore, it is harder to study the SSI impact when the kind of foundation for the building calls for the use of pile caps connected to piles. Because of this, most studies on SSI use trials with extremely simple geometric arrangements under conditions of monotonic stress. The development of new numerical methods that would enable the realistic capturing of this phenomenon is seen as being of utmost importance.

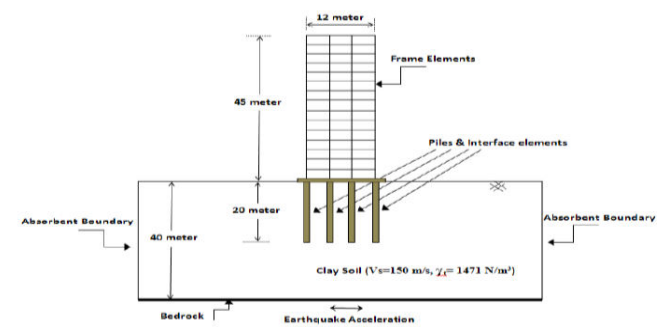
The investigation was carried out using models of structures both with and without soil. It is concluded that the structure is significantly impacted by the interaction of the superstructure, soil field, and building foundation.

**KEYWORDS:** Soil structure interaction, Pile foundation, SAP 2000, Lateral Displacements, and Storey Drifts.

## I. INTRODUCTION

Soil-structure interaction is related to the field of earthquake engineering. An earthquake is the shaking of the surface of the Earth, Due to earthquakes, the structures are subjected to lateral forces that may alter the generally expected response of the structure. It is important to note that the structural response is mainly due to the soil-structure interaction forces that bring an impact on the structure. Deep foundations consisting of frictional or end-bearing piles are routinely employed to transfer structural loads through soft soils to deeper layers to increase the bearing capacity and reduce the settlement of the superstructure. Numerical methods, adopting finite element or finite difference methods, have become more popular in studying complex and complicated interactive behavior giving the researcher the ability to model complicated conditions of the ground with a high degree of accuracy. Designing and modeling any structure across two engineering disciplines. There is the structural engineer who designs the structure and the geotechnical engineer who is concerned with the geotechnical aspects of the soil. The strength of the building and foundation are the two things to be considered while studying the behavior of the structure. The foundation is part of the structure to transmits loads from the structure into the subsoil.

When a structure is embedded in a weak soil layer, pile foundations are used to transmit the weight from the structure to the earth. Earthquake vibrations are a common dynamic stress on a soil-pile-structure system, thus it's critical to analyse the foundation system's performance when developing and evaluating new and existing structures for seismic safety. Several research papers analysing the impact of SSI on the dynamic response of structures including high-rise buildings, elevated roadways, and nuclear power plants have been published in the literature. Therefore, the numerical soil structure interaction analysis of pile foundation is necessary to be conducted by using various software with different parameters.



**Figure.1.** Components of soil-pile-structure model

Important industrial buildings are typically supported by pile foundations, particularly those that are situated in coastal locations where the majority of the area is covered by loose soil deposits. They are often subjected to lateral dynamic loads, primarily as a result of earthquakes, wind, equipment, and sea waves. Therefore, proper study and design of pile foundations should take into account the interaction between the soil, piles, and structures. In most cases, seismic analysis and superstructure design neglect the impacts of soil-structure interaction. However, the soil-foundation system has a negative impact on the structural behavior. The main goal of this study was to look at how the interaction between the soil, piles, and structures affected how reinforced concrete building frames behaved during earthquakes.

The storey lateral displacements and inter-storey drift values were significantly reduced because of the increased pile lateral displacement and shaking of the raft foundation carried on by an increase in the number of storeys, decreased relative soil density, and decreased pile spacing. The major influence of soil-pile-structure interaction on storey displacement and inter-storey drift is mostly observed at lower and upper storey levels when high-rise buildings are built on loose soil deposits with closely spaced pile foundations.

## II. LITERATURE REVIEW

In this chapter, the studies carried out on soil-structure interaction analysis of buildings, RC frames on pile foundations under various conditions have been presented.

**Ahmed Abdel-Mohti and Yasser Khodair (2014)** carried out a parametric study to examine the impact of important design parameters, such as the variation in values of the modulus of elasticity, the amount of soil surrounding the pile, and the number of soil springs, on the bending moment and lateral displacements resulting from an applied lateral displacement of 2 cm at the top of the pile. The modulus of elasticity has been changed to show an increase in the clay's stiffness from soft to hard. As the magnitude of the modulus of elasticity increases, there is a steady decrease in the difference between the values of the bending moment and lateral displacements induced along the depth of the pile estimated by Abaqus/CAE and those measured by LPILE.

**Dongmei CHU and Kevin Z. TRUMAN (2016)** conducted a study on the impacts of pile group configurations on seismic soil-pile kinematic interaction. This study examines both 2\*2 and 3\*3 pile groups with various soil characteristics and pile spacing ratios. The dynamic properties of both 2\*2 and 3\*3 pile foundation systems are first studied using natural frequency extraction. Following that, influences of soil characteristics and pile spacing to diameter ratios ( $S/D$ ) on kinematic interaction are investigated in nonlinear assessments of soil-pile foundation systems under harmonic excitation.

The number of piles' impacts on the seismic reactions of soil-pile systems are finally taken into consideration using the motion of the El Centro earthquake.

**Pulikanti Sushma and Ramancharla Pradeep Kumar, (2010)** carried out studies on how a high-rise structure responds differently when there are several nearby pile-supported structures within. For each example, they compared the SSSI response to the traditional fixed base response. High-rise structures supported by pile foundations have a distinct seismic behavior than rigid base structures. From the reactions of various examples, it has been determined that

a key factor in dynamic analysis is the group effect of nearby pile-supported structures. To create a secure and cost-effective design, high-rise structures supported by pile foundations must undergo a suitable seismic analysis.

**Chandrasekaran and Visuvasam Joseph Antony, (2019)** examined to investigate the the impacts of soil-pile-structure interaction on the seismic behaviour of moment-resisting reinforced concrete building frames. According to Indian standards, three different building types—low-rise (5 stories), mid-rise (10 stories), and high-rise (15 stories)—were created. Using a direct approach, equivalent static seismic analysis was carried out. For this experiment, a geotechnical finite element software called PLAXIS 3D was used. 30%, 50%, and 70% soil relative densities are taken into account. A 4x4 pile group layout with 2D, 4D, and 6D pile-to-pile spacing is used. The seismic response characteristics, including story lateral displacement, pile lateral displacement, raft foundation rocking, and inter-story drift, were evaluated and contrasted with rigid base constructions.

**Aslan S. Hokmabadi and Behzad Fatahi, (2018)** explain how a 15-storey full-scale (prototype) structure with various types of foundations, such as a fixed base, a shallow foundation, a floating pile foundation, and a pile-raft foundation, was subjected to a series of parametric studies using a 3D numerical simulation. The 3D numerical simulation has taken material (soil and superstructure) and geometric nonlinearities into account.

The findings of this study could eventually help practicing engineers in choosing the best form of foundation for their projects by taking into account the rocking dissipation. As a result, the kinds of foundations that shook a lot during an earthquake dispersed a lot more seismic energy than other kinds of foundations, which proved that the rocking-dissipation method reduced the amount of shear pressures directed towards the superstructure.

**Youngho Kim, Sangseom Jeong, (2010)** were studied to investigate numerically lateral load-transfer curve with respect to steel pile and drilled shaft, which are constructed on soil profiles encountered in Korean offshore deposits. In this study, the continuity of the soil pile has been taken into consideration when discussing and demonstrating the nonlinear 3D finite element modeling. In terms of pile deflection, bending moment, and p-y curves along the length of the pile, the full-scaled field load test in marine clay effectively supported the simulation approaches and analysis results. A number of parametric tests were also carried out to assess the impact of a lateral load shift.

**Aslan Sadeghi Hokmabadi, Behzad Fatahi, S. Hamid Reza Tabatabaiefar and Bijan Samali, (2018)** were carried out in this study for the 15storey moment resisting building resting on Loose sand class Ee, it was found that the base shear of the structure for shallow and pile foundations was less than the base shear of the structure modeled as fixed-base excluding the effects of soil-structure interaction. In other words, compared to the case when the system is supported by a shallow foundation, the installation of pile foundations increases the structural demand of the system.

**Amr Farouk Elhakim , Mohamed Abd Allah El Khouly, Ramy Awad. (2016)** performed three-dimensional finite element modeling is used to evaluate the load-movement response of laterally loaded piles embedded in the sand. The three-dimensional Plaxis model is validated by centrifuge test results of laterally loaded piles surrounded in sand. An analysis is carried out to confirm that the finite element software of Plaxis 3D Foundation can forecast the load-displacement relationships for pile groups with various configurations. A parametric analysis is conducted to evaluate how the behavior of laterally loaded piles in groups buried in dense and loose sand formations is influenced by the relative density of the sand (soil modulus and angle of shearing resistance), row location, and pile spacing.

**Zhaohui Yang and Boris Jeremic, (2002)** investigated how one pile behaved in elastic-plastic soils. Single pile behavior in stratified soils, clay, and sand was included in the analysis. Based on the results, it is concluded that extremely basic elastic-plastic soil models can be used in three-dimensional finite element analysis to calculate the pile head deflection with high accuracy.

Additionally, there is often consistency between the bending moments, shear forces, and lateral resistance when centrifuge data is compared. Additionally, a comparison of the data with those from the widely used program LPILE reveals notable differences in the final pressures in shallow soil layers.

**Zamri H. Chik and Jasim M. Abbas, (2009)** worked on the analysis of the pile at different water table elevations and combined loads to determine the lateral soil resistance concerning the pile width and depth. The amount of the load and how far it is from the surface are other factors.

Depending on the strength of the load and the elevation of the water level, the lateral soil pressure in the case of a pure lateral load changed with pile breadth and depth. Under various conditions of water elevation, a slight change in lateral soil pressure with pile width was calculated for small values of pure lateral load. Under heavyweight, the lateral soil resistance distribution became more complex and uneven, and it generally increased from the pile's edge to its center.

**Wattamwar Mayur Kishan Rao and Arun Prasad, (2016)** explained the behavior of a single pile under axial stress in two-layered soil in terms of settlement and transfer of load processes. Several theoretical and mathematical approaches are used in the design of axially loaded piles due to the load from the structure. Another good method for examining the interaction between the soil and the pile and the behavior of the pile under axial loading carried by the structural load is finite element analysis. The output of modeling using a 2D finite element program is presented in this paper. Plaxis for the case of an axially loaded single pile with two layers of soil and axis-symmetric circumstances two-layered soil. The outcomes are shown as Load vs Settlement graphs for various pile slenderness ratios ( $L/D=7.5, 10,$  and  $12.5$ ). Additionally, two different layering systems—soft clay on top of stiff sand, and vice versa—are taken into account.

### III. OBJECTIVE

- To perform an analytical investigation of the seismic behavior of structures with and Without SSI using a group of piles as the foundation using SAP 2000.
- Study the parameter and comparison between the results with and without SSI such as lateral displacement, Storey Drifts, Base shear, modal, and frequencies.

#### 3.1. Steps for achieving the objectives:

The current study focuses on the analytical investigation of the seismic behaviour of structures with and Without SSI using a group of piles as the foundation.

1. This study considered models as fixed base and flexible base (which includes different sand types I, II, and III are loose, medium, and Dense sands respectively) with a group of piles configuration.
2. The study was performed in SAP2000 V22 utilizing equivalent static and response spectrum methods by IS 1893:2016.
3. This study discovered parameters: Base shear, Lateral displacements, storey drift, and modal and frequencies.

### IV. METHODOLOGY

#### 4.1 General

In this chapter, various types of methods of analysis have been discussed and suitable methods have been adopted.

#### 4.2. Methods of Seismic Analysis:

To determine the seismic responses, a seismic study of the structure is crucial. Static analysis, either linear or equivalent, may be used to regular buildings with height limitations. One method for doing linear dynamic analysis is response spectrum analysis. The main distinctions between linear static and linear dynamic analysis are the forces' magnitude and distribution along the structure's height. Nonlinear static analysis is better than linear static analysis or dynamic analysis because it allows for more rigid behavior of structures. A nonlinear dynamic analysis is the only method that can fully capture the behavior of a structure during an earthquake.

There are various methods of analysis of building out of which the following methods are explained below:

##### 4.2.1. Equivalent Static Force Method:

This method uses the assumption that the dynamic loading and the horizontal lateral force are equivalent. Based on the structure's mass, fundamental period of vibration, and associated shape, this method calculates the base shear. In accordance with the provisions of the rules, the base shear is finally provided along the height of the building.

This method is predicated on the idea that a building is a rigid structure with perfect rigidity between the foundation and supports. There are equivalent accelerations experienced at every location of the structure. The primary influence of the earthquake is thought to be its horizontal forces. Using this technique, you may roughly calculate the horizontal force or base shear on the building.

**4.2.2. Response Spectrum Analysis Method:**

It is a technique for linear dynamic statistical analysis. The greatest feasible seismic response of a structure is determined by measuring the response from each natural mode of vibration.

When modes other than the fundamental modes have significant effects on how the building responds, this method is crucial. They are employed for the construction of irregular people in accordance with the code. The response-spectrum analysis correlates with the decision of structural type to dynamic performance, which is helpful for design decision-making. Longer structures undergo greater displacement, and shorter structures have greater acceleration. Prioritized design and response-spectrum analysis should consider structural performance objectives. In conclusion, both ESM and RSA are used to analyze the behaviour of structures under seismic loading conditions, although they have different levels of accuracy, applications, and processing demands. ESM is appropriate for earthquake hazard levels that are low to moderate and for simple structural systems, whereas RSA is appropriate for seismic hazard levels that are high and for complex structural systems.

Depending on the specific requirements of the analysis and the available resources, the appropriate method must be chosen. However, RSA is the preferable method and must always be used to assure the safety and effectiveness of the structure when analyzing the nonlinear response of buildings and other structures.

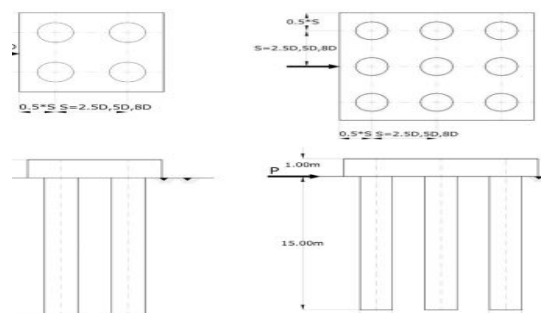
**V. MODELING AND ANALYSIS**

**5.1. Computational Modelling of Building:**

The process of modeling a building involves reducing a real-world, practical building model to create a mathematical model that can be used in software to perform all necessary calculations and determine the required response that corresponds to the real-world response.

**5.2. Pile configuration:**

In conditions when soil strata are poor or open foundations are not feasible, we frequently provide a pile arrangement. The piles should ideally be uniform, there shouldn't be a pile directly under the column, the piles should not be arranged off-centrally, and the horizontal stresses within the piles should be kept to a minimum because they also enhance the reinforcement within the heaps.



**Figure.2.** Different types of Pile configurations

**5.2.1. Material Properties:**

For the objective of computational modeling, spring, concrete, and reinforcing bars can be used as materials. For each of the materials listed above, the material properties can be considered to be the mass, unit weight, elastic modulus, Poisson's ratio, shear modulus, and thermal expansion coefficient. Below is a list of the materials' mentioned characteristics.



**Table-1.** Properties of the materials

Properties of material	Concrete (M30)	Rebar (Fe500)
Weight per unit volume (kN/m <sup>3</sup> )	25	76.97
Modulus of Elasticity (Mpa)	27386.13	2x10 <sup>5</sup>
Poisson's Ratio	0.2	-
Co-efficient of thermal expansion (C-1)	55x10 <sup>-7</sup>	117x10 <sup>-7</sup>
Shear Modulus(Mpa)	11410.89	-

**5.2.2. Overall Characteristics:**

**Table-2.** Structural Characteristics of Building Model

Type of Building	Multistorey building (G+15)
Typical Storey Height	3
Seismic Zone	1.5
Type of Soil	Sandy soil (High, medium, low)
Importance Factor	1.5
Response Reduction Factor	5
Damping ratio	5%
Types of Structure	Special Moment Resisting Frame

Modeling is carried out with the help of SAP2000 version 22.0.0 requirements. To develop a soil model with the structure, use the following measurements: unit weight ( $\gamma$ ), mass per unit volume modulus of elasticity (E), Poisson's ratio ( $\mu$ ), and shear modulus (G). The following table lists characteristics of sandy soil, including Medium-density, dense, and loose.

**Table -2.1.** Geotechnical inputs of sand properties for modeling in SAP2000

Soil Type	Sands		
Classification	Loose sand	Medium dense sand	Dense sand
Young's Modulus (E) (N/mm <sup>2</sup> )	2x10 <sup>5</sup>	4x10 <sup>5</sup>	7 x10 <sup>5</sup>
Unit Weight of Soil(γ) (KN/m <sup>3</sup> )	15	18	20
Mass per unit volume (kg/m <sup>3</sup> )	1.53	1.84	2.04
Poisson's Ratio (μ)	0.3	0.3	0.3
Shear Modulus (G) pa	76923.08	153846.15	269230.77

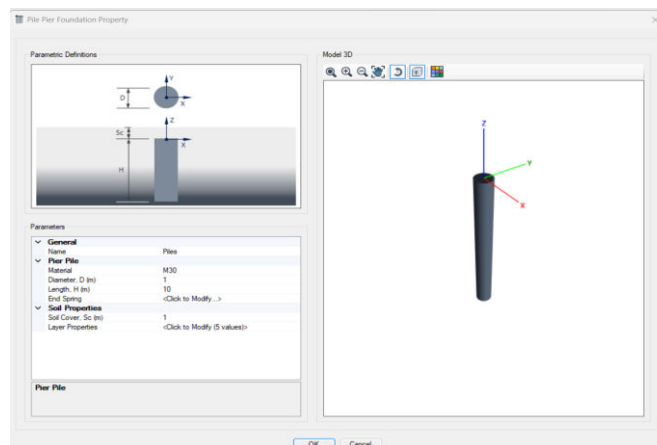
**5.2.3. Structural Configuration:**

**Table-3.** Properties of structural components

components	Dimension(mm)	Material	Shape
<b>Beam</b>	300x450	M30	Rectangular
<b>column</b>	400x400	M30	Square
<b>slab</b>	150	M30	Rectangular

The building model frame consists of G+15 storey with 4 bays in x and y directions respectively with floor height of 3.5m where the slab thickness is 150mm, beam size is 300\*400mm and column size is 400\*400mm.

The below figure displays the parametric definitions of a Pile foundation in which circular pile Length and diameter are 10m and 1000mm respectively.



**Figure.3.** pile foundation properties



5.3. Building Models and Analysis:

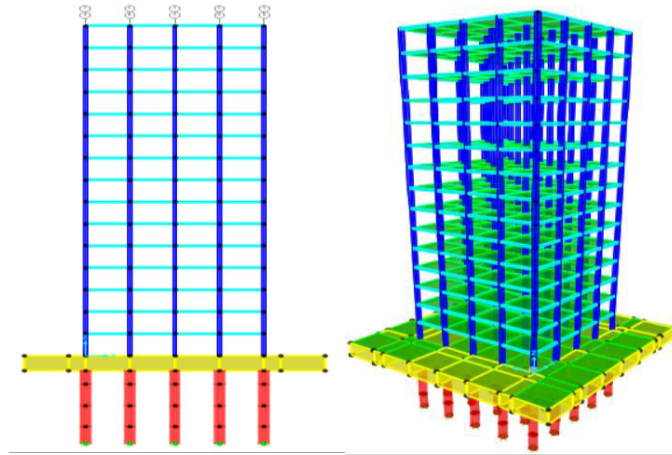


Figure.4.1.Rigid base structure with piles without SSI

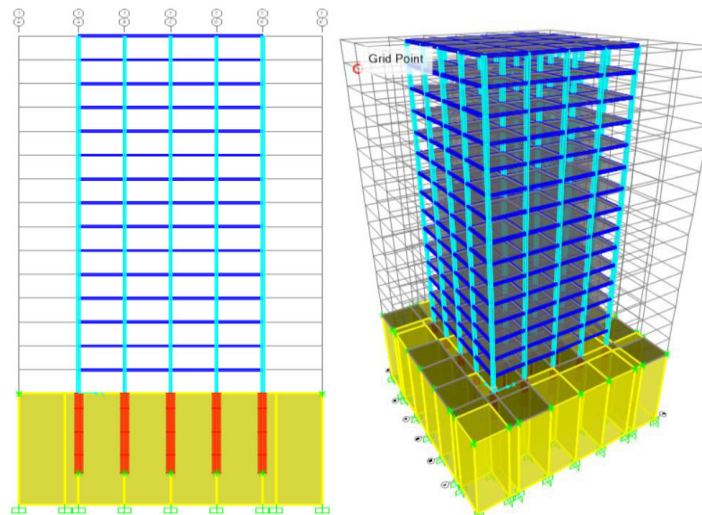


Figure.4.2.Flexible Base structure with piles SSI

5.4. Lateral Displacement Results:

The below table shows displacement values of the rigid base with a group of piles for a G+15-storey building.

Table-4.Comparison of Displacement Values due to ESM:

Storey no.	Rigid Base	Loose sand	Medium Dense sand	Dense sand
0	0	0	0	0
1	21.39	92.65	85.39	61.67
2	51.92	157.34	115.96	92.2
3	85.8	223.18	148.97	126.08
4	118.62	288.75	181.76	158.9
5	149.22	320.83	213.88	189.5
6	181.55	353.83	245.055	221.83
7	210.95	380.9	274.95	251.23
8	239.58	410.2	303.28	279.86



9	265.7	430.8	366.7	305.98
10	289.8	457.25	390.85	330.08
11	311.34	515.28	412.35	351.62
12	329.8	569.76	430.8	370.08
13	344.9	619.94	445.8	385.18
14	355.92	665.03	456.95	396.2
15	363.55	678.23	464.17	403.83

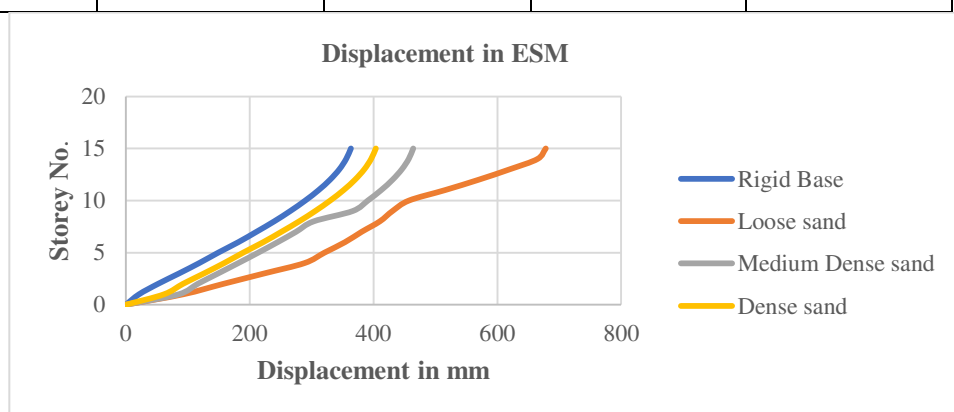


Figure.5.1.1. Comparison of Displacement Values due to ESM

Table-5. Comparison of Displacement Values due to RSM

Story no.	Rigid Base	Loose sand	Medium Dense sand	Dense sand
0	0	0	0	0
1	27.6	102.5	72.5	52.6
2	67.69	132.6	102.6	92.69
3	108.56	213.56	183.56	133.56
4	147.89	252.89	222.89	172.89
5	185.09	290.09	260.09	210.09
6	220.1	395	295	245.1
7	242.54	427.54	327.54	277.54
8	282.65	457.65	357.65	307.65
9	310.65	485.65	385.65	335.65
10	335.15	510.15	410.15	360.1
11	357.25	532.25	432.25	382.25
12	376.1	551.1	451.1	401.1
13	391.5	566.65	466.65	416.5
14	402.98	577.98	477.98	427.98
15	410.5	585.5	485.5	435.5

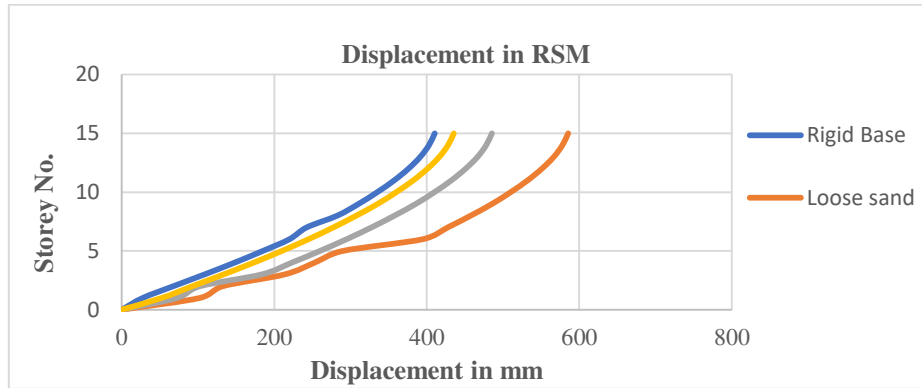


Figure.5.1.2. Comparison of Displacement Values due to RSM

5.5. Storey Drift Results

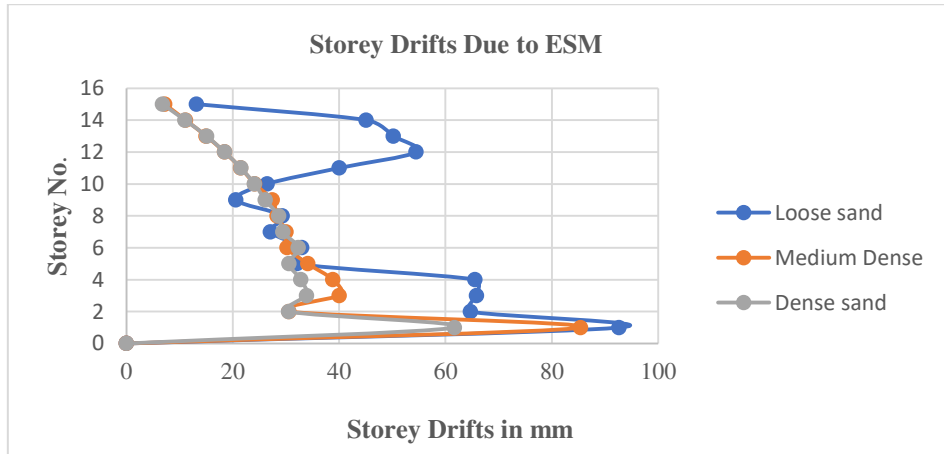


Figure.5.2. Comparison of Storey Drifts due to ESM for flexible base

From the figure there was a sudden increase in the storey drifts upto 3rd storey of the structure for hard soil and then increased more spike in storey drift for soft soil than the medium or hard soil. Overall, it can be considered that the Storey drift is in increasing order as the flexibility of the soil is increased and hence maximum drift occurs in case of soft soil in each type of building.

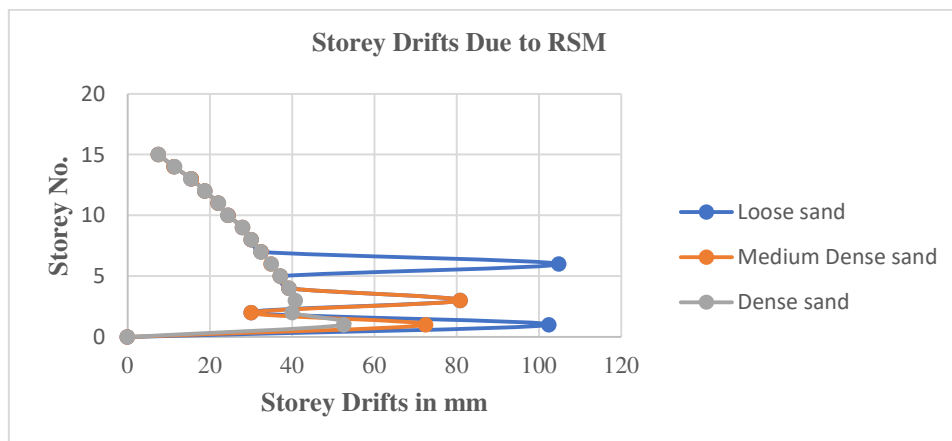


Figure.5.2.1. Comparison of Storey Drifts due to RSM for Flexible base

From the figure, there was a sudden increase in the storey drifts upto 2nd storey of the structure for hard soil and then linear upto top storey when compared to soft and medium soils. When we observe storey drift for medium and soft soil, we can see that there is the sudden increase in drift in 3<sup>rd</sup> and 6<sup>th</sup> storey level respectively. Overall, it can be considered that the Storey drift is in increasing order as the flexibility of the soil is increased and hence maximum drift occurs in the case of soft soil in each type of building.

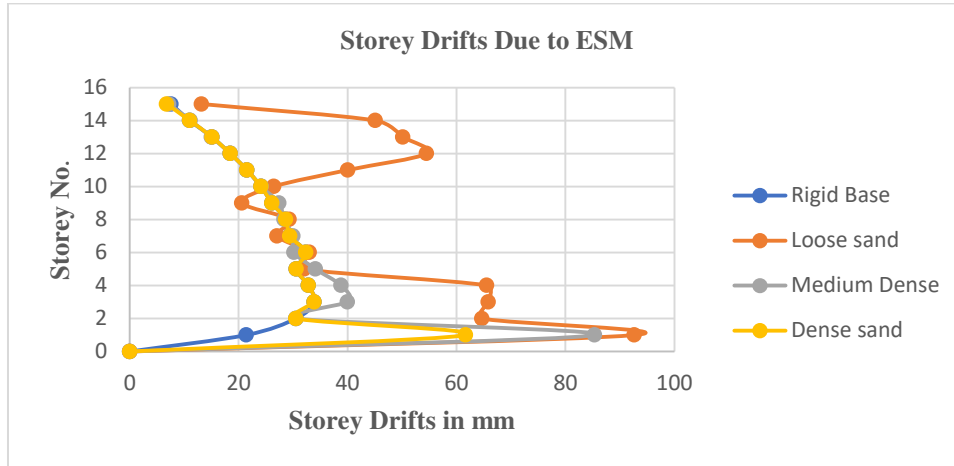


Figure.5.2.2. Comparison of Storey Drifts due to ESM

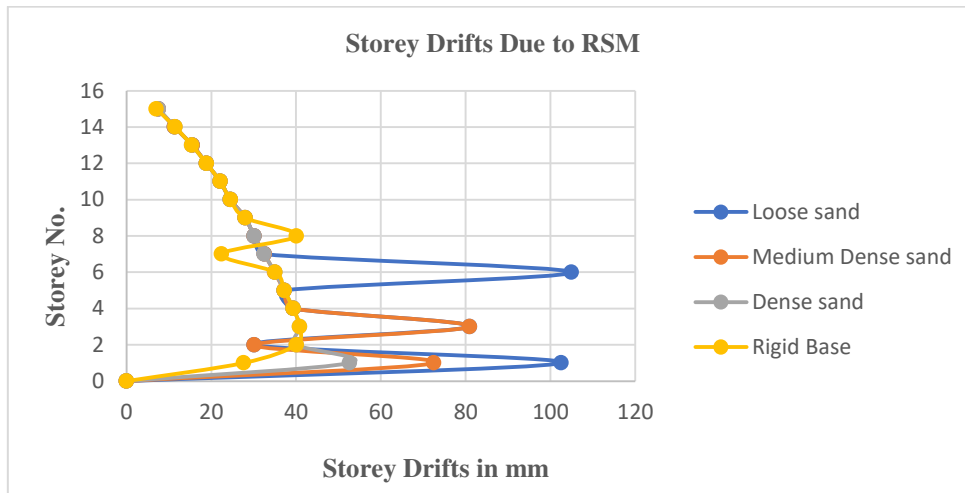


Figure.5.3. Comparison of Storey Drifts due to RSM

**5.6. Base shear Results:**

Base shear was calculated by analyzing models with rigid and flexible bases with and without SSI. For a better understanding of the variance and differences, a graph is included in Table 6.11 along with the results of the four G+15 storey models.

Table-6. Base shear Variations for different soils

Model Type	Base shear (KN)
Rigid Base	10515.066
Dense sand	9007.397
Medium Dense	8467.892
Loose sand	7472.323

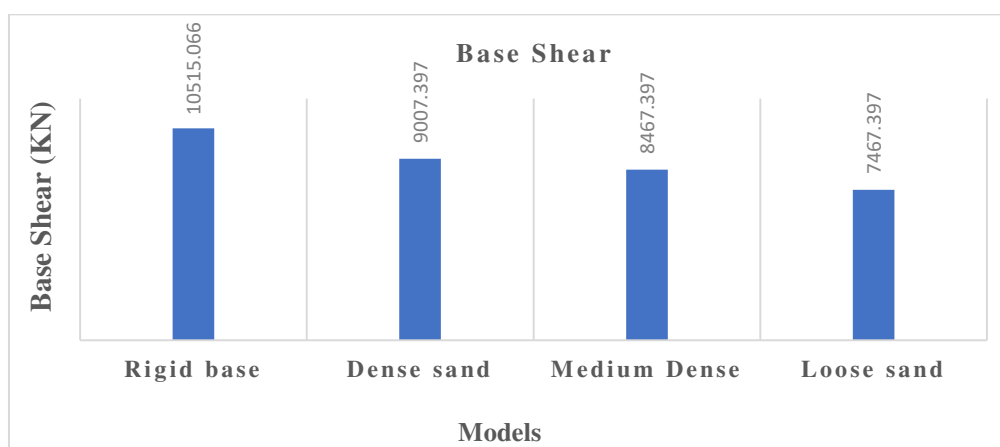


Figure.5.4. Comparison of Base shear values

From the figure.5.4. The base shear was found to decrease as the flexibility of the soil increases i.e., the fixed base condition has base shear 10515.066 KN and goes on decreasing from Hard soil to soft soil as 9007.397 KN ,8467.397 KN ,7467.397 KN respectively.

**5.7. Time periods:**

The differences in time periods and frequencies in cases of fixed basis and flexible base conditions are shown in Table.8 of analysis findings from soil structure interaction using SAP2000 software. Natural Frequencies (Hz) are the reciprocals of the natural period and time period of a building. The structural stiffness and mass, which can vary between rigid and flexible conditions, are the main parameters that influence the time period and frequencies of the structure.

Table-7. Time period Variations for different soils

Model Type	Time period(sec)
Rigid Base	2.125
Dense sand	2.466
Medium Dense sand	2.536
Loose sand	2.645

The time periods of structures increased as the flexibility of the building increased, i.e., the building with the largest value of time period occurs in soft soil rather than in a fixed base condition as 2.645s and 2.125s respectively as shown in Table 7.

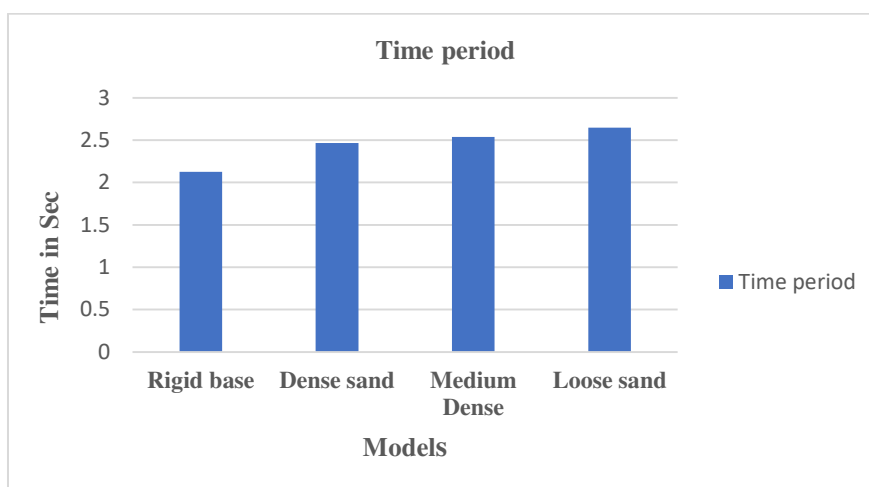


Figure.5.5. Comparison of Time periods for Rigid and Flexible base

Table-8. comparison of Time period values:

Base conditions Mode no.	Time periods (Seconds)			
	Rigid base	Hard soil	Medium soil	Soft soil
1	2.125827	2.466631	2.536631	2.645531
2	2.125795	2.46663	2.53663	2.64553
3	1.995928	2.350435	2.420435	2.530435
4	1.069912	0.809378	0.879378	0.988378
5	0.793795	0.809376	0.879378	0.988376
6	0.793471	0.772911	0.842911	0.951911
7	0.661019	0.469419	0.539419	0.648419
8	0.660963	0.469419	0.539419	0.648419
9	0.644348	0.451458	0.521458	0.451458
10	0.393417	0.32637	0.39637	0.50537
11	0.393417	0.32637	0.39637	0.50537
12	0.37845	0.3123	0.3823	0.4913
13	0.274295	0.245697	0.315697	0.424697
14	0.274295	0.245697	0.315697	0.424697
15	0.262636	0.233766	0.303766	0.412766
16	0.206914	0.194341	0.264341	0.373341
17	0.206914	0.19434	0.26434	0.37334
18	0.1972	0.191122	0.261122	0.370122
19	0.164469	0.183469	0.253469	0.362469
20	0.164469	0.170543	0.240549	0.349549

5.8. Modal Time Periods of G+15 Storeyed Building without SSI:

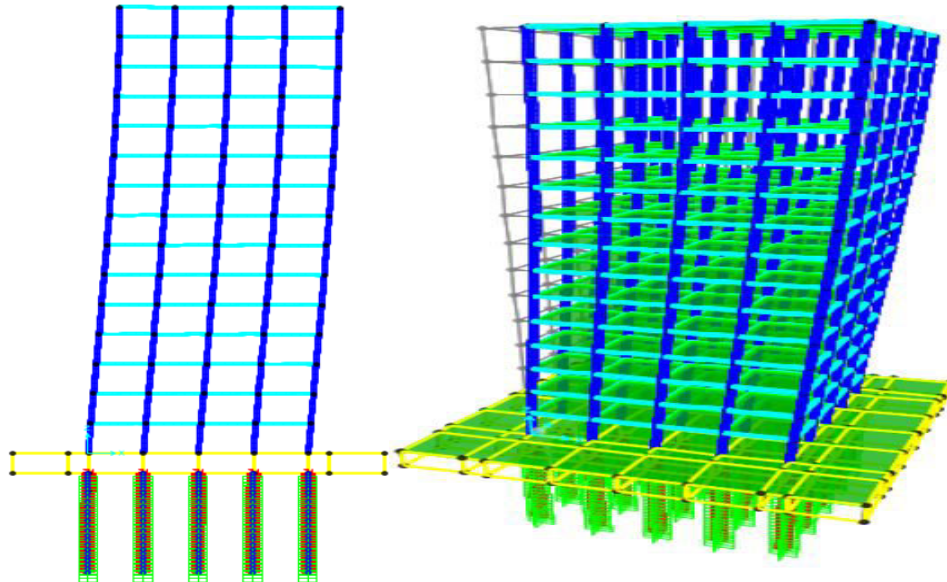


Figure.5.6.1. The deformed mode shape of structure with a time period of 2.125 seconds at 1st mode Resting on Rigid base.

5.9. Modal Time Periods of G+15 Storeyed Building with SSI:

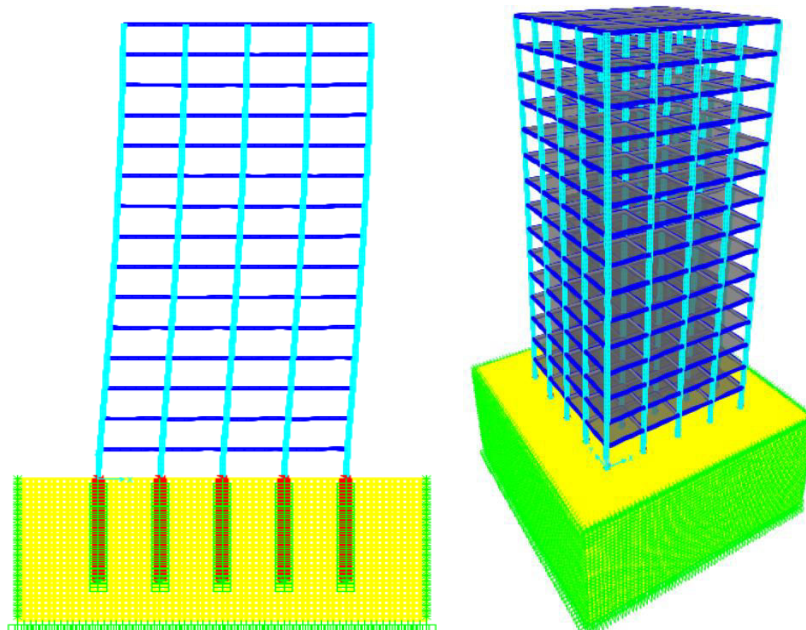
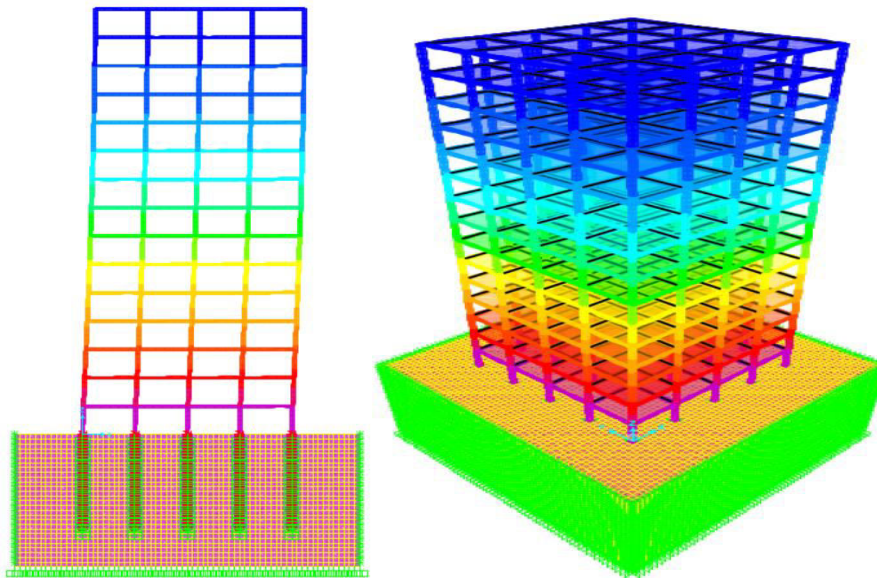


Figure.5.6.2. The deformed mode shape of structure with a time period of 2.645 seconds at 1st mode Resting on Loose sand



**Figure.5.6.3.** The deformed mode shape of structure with a time period of 2.536 seconds at 1st mode Resting on Medium Dense.

## VI. CONCLUSIONS

The results of the seismic analysis of the G+15-story structures that were previously described in this study and that had various geometrical conditions, as well as various soil-structure interaction conditions, are reported in the next section. Charts and figures are used to compare each type of building within the context of its geometrical variations, sub-structure variations, and method of analytical changes. The results are discussed in terms of time intervals, frequencies, base shear, storey force, and storey displacement and drift. The results that are produced below are entirely computed from the modal analysis performed using the CSI SAP2000 v22.

1. It was observed that the value of displacement is increased as the type of soil goes from Dense sand to Loose sand as compared to the fixed base condition in both ESM and RSM. i.e. Dense and loose sand have displacements of 40% and 54%, 25% and 70% respectively in ESM and RSM which means the Loose sand in RSM as 16% more displacement when compared to ESM.
2. The base shear was found to decrease as the flexibility of the soil increases i.e., the fixed base condition has a base shear of 10515.066 KN and goes on decreasing from Dense sand to Loose sand as 7472.323 KN.
3. The Time period of buildings was increased as the flexibility of the building was increased i.e., the building has the highest value of Time period located in Loose sand rather than in fixed base condition therefore after a complete evaluation of the structure, the Time period in rigid base assessed as 2.125s and increased in the flexible base having loose sand to 2.645s.
4. Values of Story Drifts increased with soil structure interaction i.e., flexible base as more compared to fixed base case in both RSM and ESM. So after comparison, the Loose sand and Rigid base have 13.2% and 7.63% of storey drift.
5. Since longer piles do not always result in a safer design under strong ground motions when the interaction between soil and structure is taken into consideration, the findings of this study may help in determining the size and type of pile foundation best suited to the seismic performance of buildings sitting on Loose sand while aiming to achieve an optimized design.
6. High-rise constructions supported by pile foundations behave seismically differently than rigid base structures. Dynamic analysis is known to depend significantly on the group impact of nearby pile-supported structures based on the responses of various conditions.
7. To create an efficient and cost-effective design, high-rise structures supported by pile foundations need to undergo a suitable seismic analysis.
8. Due to the complexity of the interactions between the components of the building structure and the soil field, evaluating combination piled-raft foundations for multi-story buildings is highly difficult. The interaction of the structure, foundation, and soil should be included in the analysis of a high-rise structure with a complicated foundation system in a uniform soil field. In this study, the interaction between a building structure with a pile foundation and a soil model is analyzed with and without the use of a soil model.



## VII. FUTURE SCOPE

- Several other factors like water table level, pile configuration, and height of superstructure also affect the substructure condition of the pile foundation which in turn affects the response of structure. Therefore the need for the necessity of modeling and analysis of pile foundation.
- Different forms of earthquake zones also affect both substructure and superstructure where seismic analysis is required to be done.

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