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Analysis of Soil-Structure Interaction of Framed Structure

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Abstract - This study examines the soil-structure interaction (SSI) effects on the seismic behavior of G+7 and G+12 reinforced concrete buildings. Using finite element modelling in SAP2000, we assess key seismic parameters, including base shear, time period, lateral displacement, and footing settlement, across three soil types: soft, medium, and hard. This comparative analysis provides insights into how building height and soil flexibility influence structural stability, suggesting optimal design considerations for enhancing earthquake resilience.

Key Words: Soil-Structure Interaction (SSI), Base Shear, Lateral Displacement, Seismic Analysis, G+7, G+12, SAP2000, Soft Soil, Medium Soil, Hard Soil.

1. INTRODUCTION

The soil-structure interaction (SSI) is an important consideration in the seismic design of buildings, especially in regions with varying soil conditions. Traditional seismic design assumes fixed-base support, which neglects the influence of soil flexibility. However, buildings respond differently depending on the underlying soil type, making SSI a critical factor for medium- to high-rise buildings. This paper compares the SSI effects on two buildings of different heights—G+7 and G+12—analyzing parameters such as base shear, natural frequency, time period, lateral displacement, and settlement for various soil types.

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 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 two different height (G+7, G+12) multi-storey building with different foundation 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 SSI) using Finite element Analysis.
(iv) MAT 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) Comparing results obtained from all the above fixed base models with their respective flexible base models

3. MODELLING AND ANALYSIS

3.1 MODELLING OF RC BUILDINGS

An 8-story and 13- storey reinforced concrete (RC) building was modeled in SAP2000. The building dimensions were 16m x 16m with 4 bays in both X and Y directions. The building was analyzed under seismic loading using Response Spectrum Analysis (RSA), with and without considering SSI.

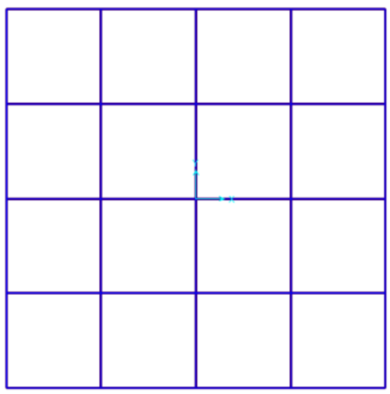

Figure 1 Dimensions of Buildings

Table 1:Structure Data

Structure	G+7	G+12
No. of Storey	8	13
Height(m)	3	3
Column Dimension(mm)	400*400	500*500
Beam Dimension(mm)	300*400	300*500
Slab Thickness(mm)	200	200
Grade of Concrete	M30	M30
Rebar	Fe500	Fe500

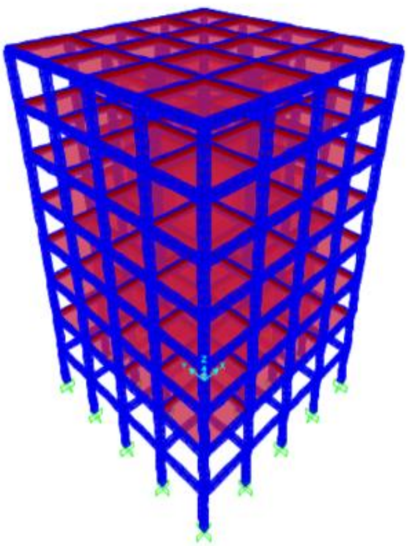

Figure 2: G+7 without SSI

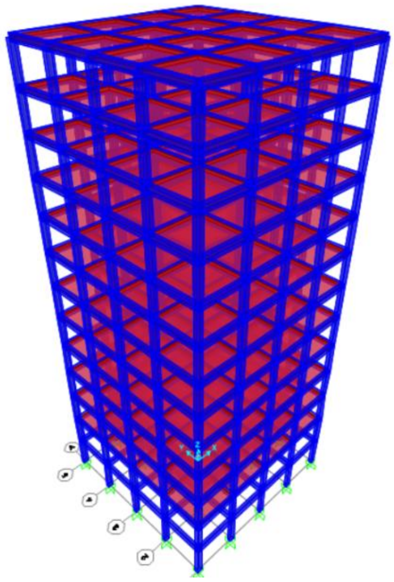

Figure 3: G+12 without SSI

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	2 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 Mat Foundation

Dimension of building is 16mX 16m and height of building is 24m and 39 m respectively, building are modelled as fixed (without SSI) and Flexible base(with SSI), which is modelled and merged with the soil using Finite Element Method and applied to the Mat or Raft foundation of dimension 19mX19m to emulate the soil behavior at the time of seismic activity.

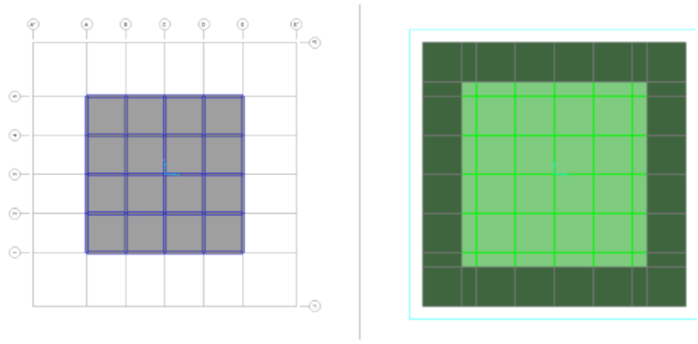

Figure 4: Mat Foundation

3.4 Soil Modelling

The present study involves all three major categories of soil, i.e., Category I (Hard soil), Category II (Medium soil) and Category III(Soft soil), all the soil parameters are considered as per the standard practices and reviewed literatures .For each category of soil and values are used in the Respective models for all the Flexible base models which are then assigned to the Mat foundation.

3.5 Soil Profile Data

Dimensions - 40m*40m

Depth-30m

Table 3: Soil Data

Soil		Soft(Clay)	Medium(Sand)	Hard(Rock)
Modulus of Elasticity(E)(MPa)		28	39	52
Shear Modulus(G)		10	15	20
Poisson's Ratio		0.4	0.3	0.25
Coefficient of Thermal Expansion		1.5*10^-6	1.75*10^-6	3*10^-6
Cohesion		30	0	350
Friction Angle		20	35	40

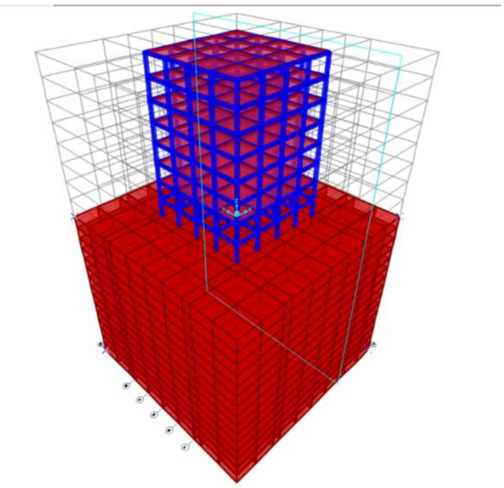

Figure 5: G+7 with SSI

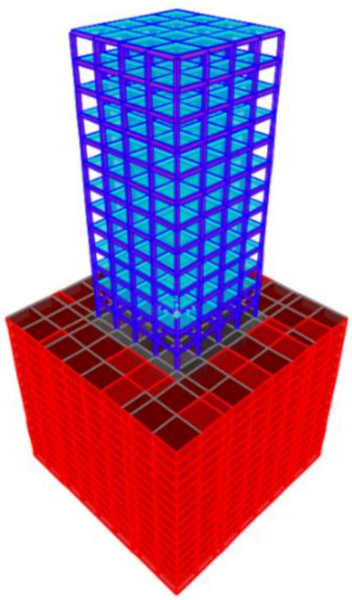

Figure 6: G+12 with SSI

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 SSI for clay, sand, and rock.

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**

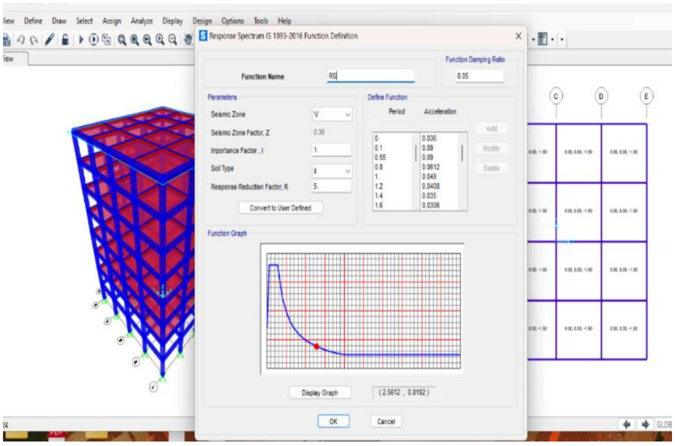

Figure 7: Response Spectrum

5. Results and Discussions

5.1 G+7 and G+12 without SSI

5.1.1 Natural Frequency and Time Period

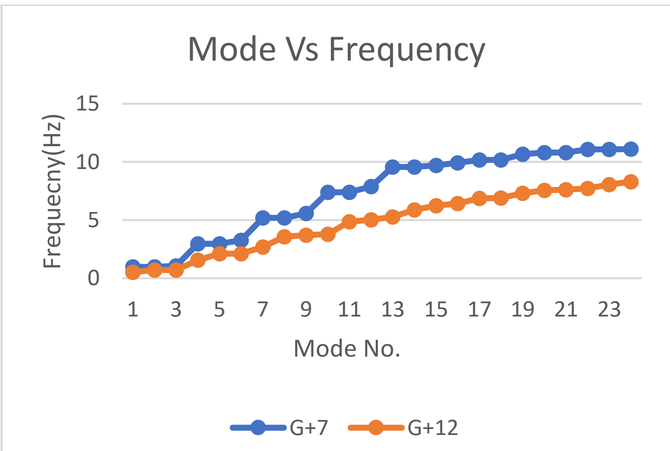

Figure 8: Mode vs Frequency of G+7 and G+12 without SSI

As the height of the building increases **Natural Frequency** decreases which we can see in the above Fig. as G+7 shows more frequency than G+12 which means the flexibility of G+12 is more than G+7. G+7 shows **33.74%** more frequency than G+12.

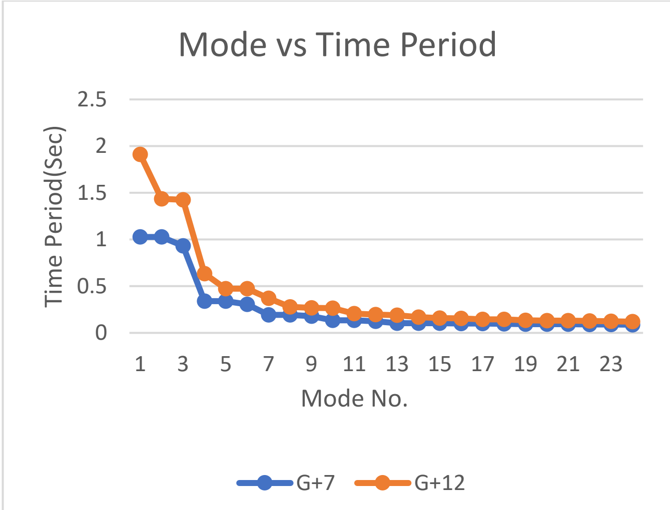

Figure 9: Mode vs Time Period of G+7 and G+12 without SSI

In the case of **Time Period** as we can see from above figures as the Height of the building increase the time period also increases which high rise building takes more time to perform the one full cycle of vibration. G+12 takes **86.17%** more time than G+7 to complete the one full cycle of vibration.

5.1.2 Lateral Displacement

Lateral displacement is shown in the fig.10

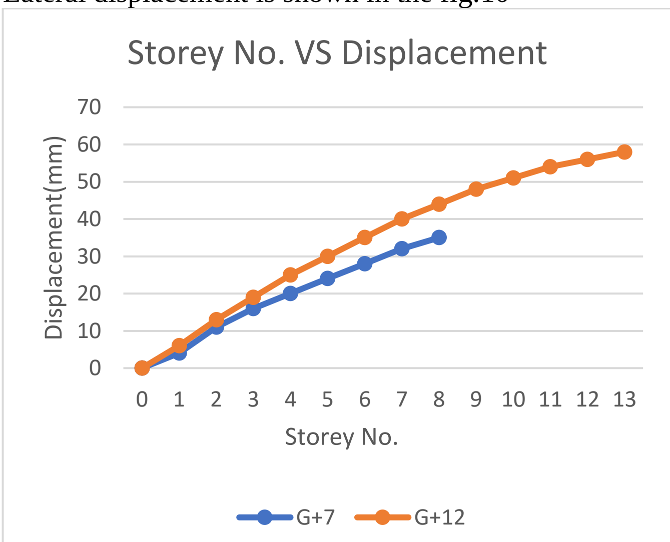

Figure 10: Displacement of Storey without SSI

From the above fig. it is clear that greater the height of structure the more displacement of the storey as G+12 shows the **65.71%** more lateral displacement than G+7 in the fixed base conditions.

5.1.2 Base Shear

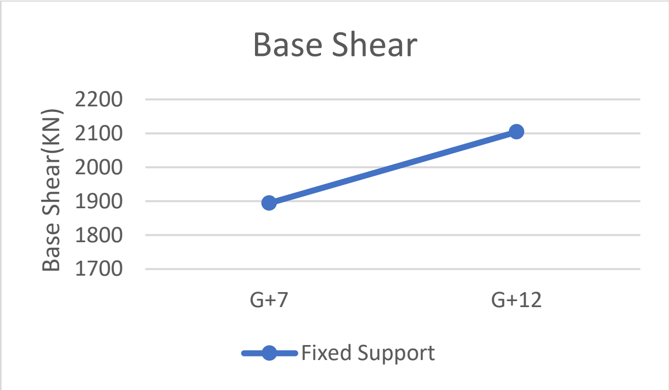

Figure 11: Base Shear without SSI

5.2 G+7 and G+12 with SSI

5.2.1 Natural Frequency and Time Period

As the height of the building increases Natural Frequency decreases which we can see in the above table. **G+7(Hard soil)** shows the **highest** frequency while **G+12(Soft)** shows the lowest frequency of all the other structures. **G+7 (Hard Soil)** shows the **14.18%** more than **G+12 (Hard Soil)**, while **G+7(Soft Soil)** shows **69.23%** more frequency than **G+7(Soft).**

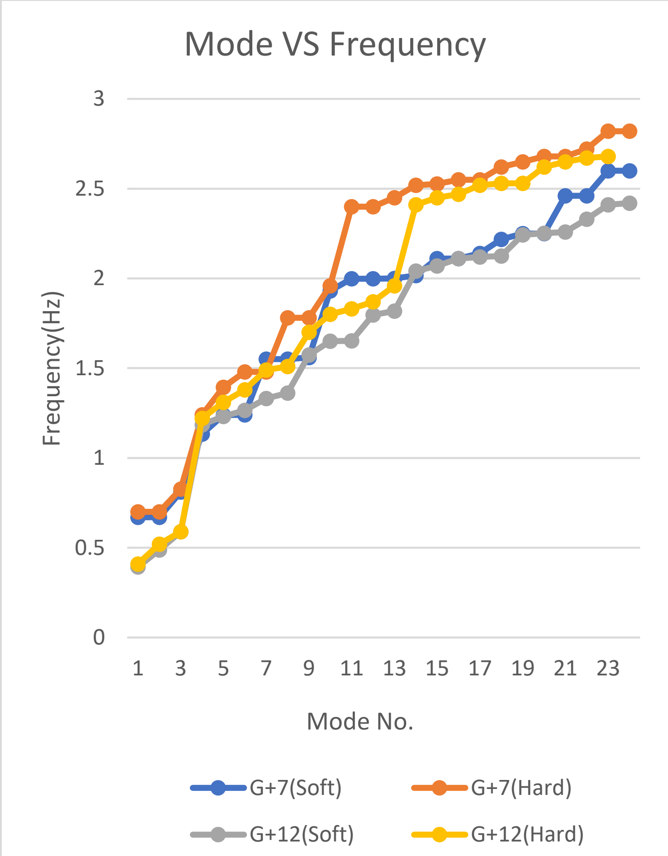

Figure 12 Mode vs Frequency with SSI

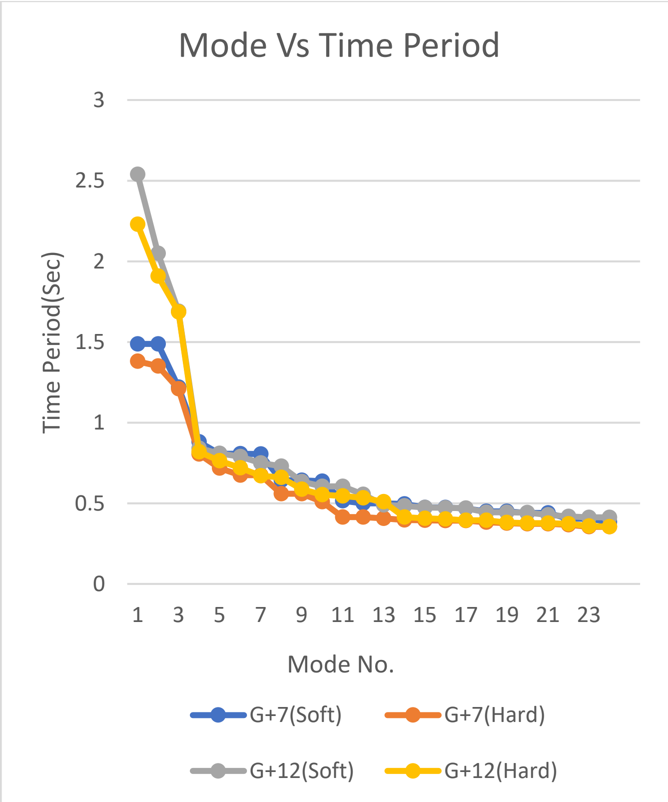

Figure 13 Mode vs Time Period with SSI

In the case of Time Period which is inversely proportional to Frequency , we can see from above tables as the Height of the building increase the time period also increases which means high rise building takes more time to perform the one full cycle of vibration. **G+12 (Soft Soil)** shows the **maximum time period** which shows that the **flexibility** of the **G+12(Soft)** is more than any other Structure. **G+12(Soft)** takes **41.73%** more time than **G+7(Soft)** to complete the one full cycle of vibration while **G+12(Hard)** takes **36.09%** more times than **G+7(Hard).**

5.2.2 Lateral Displacement

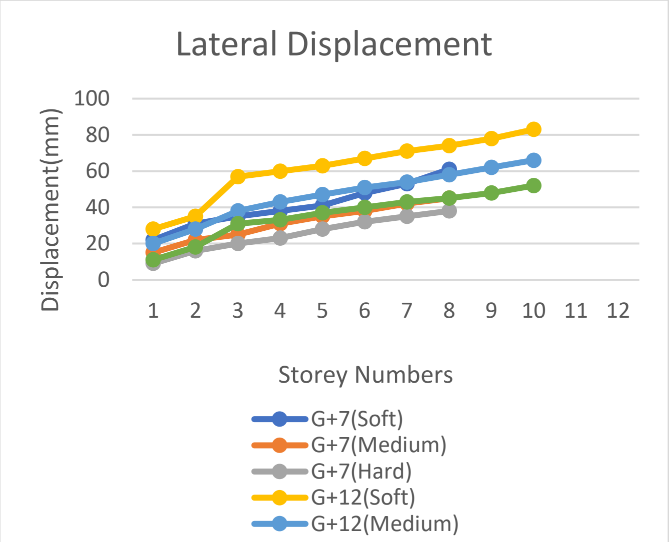

Figure 14 Displacement of Storeys with SSI

So, from the results and the above Fig 5.7 it is clearly seen that displacement of **G+12(soft soil)** is maximum than any other structure. **G+12(soft)** shows **50.8%** more displacement than **G+7(soft).** On the other hand **G+12(Medium and Hard)** shows **68%** and **63%** more displacement than G+7(Medium and Hard)

While **G+12(soft)** shows **50.38%** more displacement than **G+12(Hard)** and **21.05%** more than**G+12(Medium)** and on the other hand **G+7(Soft)** is **60.5%** more than **G+7(hard)** and **35.5%** more than **G+7(Medium).**

5.2.3 Base Shear

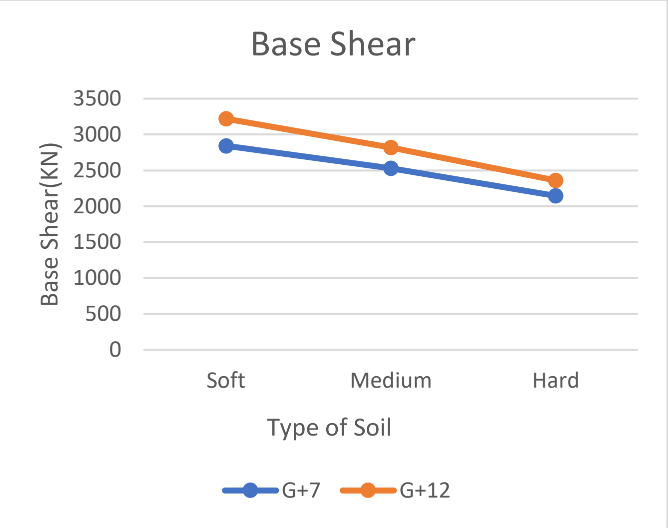

Figure 15 Base Shear with SSI

So, from above figure it is clearly show that Base shear is grater in the G+12 building than G+7 it means that height influence the base shear as the height of the building increases base shear also increases. Here base of G+12(Soft Soil) is increased by 14.28% than G+7.

5.2.4 Settlement of Footing

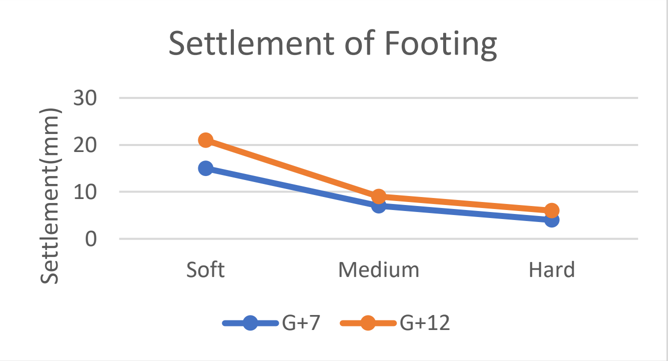

Figure 16 Settlement of Footing

From above table it is clearly seen that G+12(Soft Soil) shows the maximum settlement of footing than any other structure. There is variation **40%** in the settlement of G+7(Soft Soil) and G+12(Soft Soil). While other settlement are very negligible compare to the soft one.

6. Conclusion

➢ **Base Shear Analysis:**

The base shear is higher for the G+12 building compared to the G+7, with values increasing with building height and softer soil conditions. This indicates the higher seismic forces experienced by taller structures, especially when resting on soft soil.

The G+12 building shows 11.08% more base shear than the G+7 building in the fixed base condition.

When considering different soil types:

For soft soil, the G+12 structure experiences 13.26% more base shear compared to the G+7 building.

On medium soil, the G+12 structure shows an increase of 11.45% in base shear over the G+7.

On hard soil, the base shear in the G+12 building is 10.02% higher than that in the G+7 structure.

For both G+7 and G+12 buildings, the base shear decreases as the soil stiffness increases (soft > medium > hard). This demonstrates that softer soils lead to higher seismic demand on the structure due to greater deformation and flexibility.

➢ **Lateral Displacement:**

The lateral displacement increases with the number of stories, as expected. The G+12 building shows greater lateral displacement compared to the G+7 structure.

Under different soil conditions, lateral displacement is highest for buildings on soft soil and lowest for hard soil, which highlights the importance of soil stiffness in controlling displacement during seismic events.

In the fixed base condition, the lateral displacement of the G+12 building is 65.71% higher at the top floor compared to the G+7 building.

In terms of soil types for the G+7 building:

The displacement in soft soil is 35.5% higher than in medium soil, and 60.5% higher than in hard soil.

For the G+12 building, the displacement in soft soil is 21.01% higher than in medium soil, and 50.38% higher than in hard soil.

➢ **Footing Settlement:**

The settlement values for the footing also show a clear relationship with soil type, with the highest settlement occurring on soft soil and the lowest on hard soil. This indicates that buildings on softer soils are more prone to differential settlement, which could affect the structural integrity.

The settlement of the G+12 building on soft soil is 40% more compared to the G+7 building.

For medium soil, the G+12 building shows a 28.6% increase in settlement compared to the G+7 building.

On hard soil, the G+12 building experiences 50% more settlement than the G+7 building.

➢ **Frequency and Time Period:**

The fundamental frequency is lower and the time period is longer for buildings on soft soil, reflecting the increased flexibility of the structure-soil system. Conversely, hard soils lead to higher frequencies and shorter time periods, indicating a stiffer system.

The fundamental frequency of the G+12 building on soft soil is 3.5% lower compared to the G+7 building, indicating increased flexibility.

On hard soil, the G+12 building's frequency is 6% lower than that of the G+7 building, showing that soil stiffness helps reduce flexibility.

Conclusion Summary:

Influence of Soil-Structure Interaction:

- SSI has a significant impact on the overall dynamic behavior of both **mid-rise (G+7)** and **high-rise (G+12)** buildings. For buildings with a flexible base, an increase in the **natural period**, **base shear**, **lateral displacement**, and **settlement** is observed when compared to fixed-base models.
- The **percentage increase** in these parameters is more pronounced in **soft soils**, where the building's flexibility and soil deformation contribute to a substantial change in the dynamic response. For instance, the **natural period** increases by **12-27%**, and **lateral displacement** increases by **18-36%**, indicating that ignoring SSI in soft soils can lead to non-conservative designs.

Seismic Performance: Buildings on soft soil experience higher base shear, greater lateral displacement, and increased footing settlement, which makes them more vulnerable during seismic events compared to those on medium and hard soils.

Height Impact: Taller structures (G+12) exhibit higher base shear and lateral displacement than shorter buildings (G+7), indicating the importance of height in seismic design.

Soil-Structure Interaction: The comparison between fixed and flexible foundations across different soil types highlights the critical role of soil stiffness in influencing the seismic response of buildings, with soft soils significantly amplifying the dynamic effects.

The G+12 building exhibits 10-13% more base shear compared to the G+7 building, with softer soils amplifying the seismic forces.

The lateral displacement is significantly higher (up to 65% more) in taller buildings, especially on soft soil where flexibility dominates.

Footing settlement increases by 28.6% to 50% for taller buildings across various soil types, highlighting the importance of foundation design.

The frequency decreases with building height, especially on softer soils, reinforcing the importance of soil-structure interaction in seismic design.

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