Evaluation of the effects of soil structure interaction on a multistorey RC building

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Abstract. When a structure undergoes seismic excitation, the displacement caused in the structure and the ground are not independent of one another, this dependency of each other causes noticeable changes in the structure. In order to study this interdependency, a phenomenon called soil structure interaction (SSI) comes into existence which has been neglected during design process but omitting it leads to unsafe design. Henceforth it’s important to consider the effect of SSI although its effect is negligible for buildings that are low rise. In the current study 6 models of G+13 multi-storey symmetrical RC building with storey height 3m is modelled using ETABS which is assumed to be located in Hard-soil, Medium-soil and Soft-soil of zone-IV is subjected to response spectrum analysis. The structure is analysed without SSI and also the behaviour of the structure is studied by considering SSI effect using spring elements. The variation of systematic parameters such as storey displacement, storey drift, Storey shear, base-shear, natural period, Storey stiffness and overturning moment has been studied and compared. It is observed that response of the structure is higher under SSI condition and soft soil is more critical, it’s important to consider the effects of SSI during design process.

1. Introduction

Since the early ages as the man evolved, it is also seen that there is evolution in his habitat. Apart from the evolution of mankind, as and when the society, economy developed and population explosion occurred, construction of large number of buildings and high rise building came into existence parallelly due to increase in density of population, and the need for their habitat. When earthquake occurs in these populated areas it causes huge damage to the structures, life and economic condition. This type of structural damage is a direct result of improper scientific design of the structure.

Due to the movement of the earth crest energy will be relished known as earthquake, structure will respond to this energy and undergoes changes. Therefore it is not only important to understand the properties of the structure but also important to understand the properties of the soil in the site. Most of the design codes omit the inclusion of soil structure interaction during the design process as it makes the design tedious due to its complexity at same time it leads to unsafe design of both substructure and superstructure.
1.1. Soil structure interaction
We know that either the entire structure or any of the elements of the structure is in direct contact with ground, this emphasises the need to understand the structural and soil properties. When a structure undergoes seismic excitation, the displacement caused in the structure and the ground are not independent of one another, this dependency of each other causes noticeable changes in the structure. In order to study this interdependency, a phenomenon called soil structure interaction comes into existence. Soil structure interaction is defined as a process where the seismic excitation that occurs in the underground soil not only causes the movement of soil but also affects response of the structure above the soil, in turn this change in the structure causes changes in the soil movement.

Although the effect of SSI on the rigid soil, buildings that are low rise is negligible it is a very important aspect under consideration for soft soil, high rise buildings, highways, heavy structures (nuclear power plants, hydraulic structures).

2. Idealization of methodology
Here the type of method that is used for simulation of soil structure interaction and how it is carried out is been discussed.

2.1. Simulation of soil structure interaction
There are two different methods in which soil structure interaction can be simulated, they are

2.1.1. Soil is Modelled as Spring Element. Spring element behaves like a mediator, it is inserted between the foundation of the structure and the soil resting below which alters the flexibility of the soil. The effect of soil flexibility is well understood by observing the movement of foundation and its rotation in vertical direction and two mutually perpendicular principal horizontal directions.

2.1.2. Elastic Continuum Method. Soil is modelled using Solid Element Type (based on Finite Element Method). All the possible mechanical properties of soil such as elastic modulus, passion’s ratio are assigned to the solid element. The interface between the soil and foundation is modelled using Gap elements available in the software packages.

2.2. Assigning spring to the base

**Figure 1.** Spring system at the foundation.

Here the method mentioned in section 2.1.1. is adopted, Springs are provided at the footing, three translational springs and three rotational springs are provided in X, Y, Z direction as shown in figure 1. The stiffness of the springs are obtained from the equations given in FEMA 356 which is as shown in figure 2. The equations in figure 2(a) gives the stiffness of the foundation at surface of the ground, if the foundation is embedded then a correction factor in the figure 2(b) should be multiplied (K_{emb} = \beta K_{surface}). Table 1 gives the information about the material properties of the soil that is used in calculating the stiffness of the equivalent soil spring.
Figure 2. Stiffness and correction factor for spring. (Reference FEMA 356).

Where,
G is shear modulus of soil in m.  
μ is Poisson’s ratio. 
B is Breadth of footing in m. 
L is Length of footing in m. 
D is depth of foundation in m. 
d is depth of footing in m. 
h is height from the ground level to the centre of the depth of footing in m.

Table 1. Mechanical properties of the soil.

| Soil type | Modulus of elasticity (KN/m2) | Shear modulus (KN/m2) | Poisson's ratio |
|-----------|-------------------------------|-----------------------|-----------------|
| Hard      | 65000                         | 25000                 | 0.3             |
| Medium    | 35000                         | 12500                 | 0.4             |
| Soft      | 15000                         | 5357.14               | 0.4             |

3. Characteristic of the employed structural model
In the current study 6 models of G+13 multi-storey symmetrical RC building is modelled using ETABS which is assumed to be located in Hard soil, Medium soil and Soft soil of zone IV is subjected to response spectrum analysis. The structure is analysed with and without SSI effects.
3.1. Structural details
Plan dimensions = 20 m x 20 m
Number of storey = G+13
No of bays in X and Y direction = 4
Length of each bay = 5m
Height of each floor = 3.0 m
Slab thickness = 150 mm
Beam size = 230 x 450 mm
Column size (M30) = 300 x 600 mm
Footing size = 3.5x3.5 m
Depth of footing = 0.6 m
Depth of foundation from ground level=2.0 m
Wall thickness = 0.23 m
Zone = 4
Zone factor = 0.24
Importance factor = 1
Response reduction factor = 5
Damping ratio = 0.05
Grade of Steel (F_y) = 500 N/mm^2
Density of brick = 20 KN/m^3
Density of concrete = 25 KN/m^3
Live load = 3 KN/m^2
Wall load = 5.2 KN/m^2
Floor finish = 1.5 KN/m^2

3.2. Model details
Model-1 Fixed base with hard soil
Model-2 Fixed base with medium soil
Model-3 Fixed base with soft soil
Model-4 Soil structural interaction with hard soil
Model-5 Soil structural interaction with medium soil
Model-6 Soil structural interaction with soft soil
Figure 3 shows the plan and elevation of the symmetrical rc building considered for the analysis.

Figure 3. Plan and elevation of symmetrical rc building.
4. Results and discussion
The variation of systematic parameters such as Storey displacement, Storey drift, Storey shear, Base shear, Natural period, Storey stiffness and Overturning moment has been studied and compared for structures with and without soil structure interaction (spring base and fixed base respectively).

4.1. Storey displacement

![Displacement Along X-Direction](image)

**Figure 4.** Storey displacement along x direction.

![Displacement Along Y-Direction](image)

**Figure 5.** Storey displacement along y direction.

The figures 4 and 5 shows that the displacement is higher in case of SSI system for all the three types of soil compared to fixed condition and it increases as the flexibility of the soil increases. The storey displacement is highest for soft soil for SSI system in both the directions. It is also seen that as the storey height increases the displacement also goes on increasing.
4.2. **Storey drift**

The figure 6 and 7 shows that storey drift in case of the hard soil is lesser when compare to the other two types of soil. It slightly increases in SSI system compared to fixed base system and it is maximum in soft soil condition. The storey drift increases in the lower storey which further increases in a larger extent at the middle storey levels and it is decreased in the higher storeys in all the soil types along x and y direction.
4.3. Overturning moment

The figure 8 and 9 shows that Overturning moment in case of the hard soil is lesser when compare to the other two types of soil, it increases in SSI system compared to fixed base system and it is maximum in soft soil making it a critical condition. It is also seen that the Overturning moment decreases with increase in the height of the storey.
4.4. Storey shear

The table figure 10 and 11 shows that storey shear in case of the hard soil is lesser when compare to the other two types of soil, it is high for soft soil in the both cases such as with SSI and without SSI system in both x and y directions. Storey shear increases in SSI system compared to fixed base system and it is maximum in soft soil condition. It is also seen that Storey Shear decreases with increase in the height of the storey.
4.5. Storey stiffness

The figure 12 and 13 shows that storey Stiffness in case of the hard soil is greater when compare to the other two types of soil, it is less for soft soil in the both cases such as with SSI and without SSI system. Storey stiffness decreases in SSI system compared to fixed base system and it is minimum in soft soil condition. It is also seen that Storey stiffness is high at bottom storey level decreases with increase in the height of the storey.
4.6. Time period

![Figure 14. Modal time period.](image)

The figure 14 shows that the natural time period is higher in case of SSI system in all the soil conditions compared to fixed base condition. The time period increases from hard to medium to soft condition in both the cases and it is highest in the flexible base soft soil making it a critical condition. It is seen that as the flexibility of the soil increases there is increase in time period.

4.7. Base shear

![Figure 15. Base shear along x direction.](image)
The figure 15 and 16 shows that base shear in case of the hard soil is lesser when compare to the other two types of soil, it is high for soft soil in the both cases such as with SSI and without SSI system. Base shear slightly increases in SSI system compared to fixed base system and it is maximum in soft soil condition.

5. Conclusion

- The time period in the hard soil is lesser when compared to the other two medium of soil and is highest for soft soil under SSI effect.
- The maximum displacement is seen in soft soil than other soil types in both the cases such as with SSI and without SSI system and it is maximum for SSI system.
- The storey drift in the hard soil is lesser when compared to the other two medium of soils, and is high for soft soil in the both cases such as with SSI and without SSI system and it is maximum for SSI system.
- Storey drifts of the structure are found within the limit as specified by code (IS: 1893-2002, part-1).
- Storey shear in the hard soil is lesser when compared to the other two medium of soil.
- Storey shear is higher in case of soft soil condition for SSI system.
- The base shear in the hard soil is lesser when compared to the other two medium of soil and is highest for soft soil under SSI effect.
- Overturning moment in the hard soil is lesser when compared to the other two medium of soil.
- Overturning moment is higher in case of soft soil condition for SSI system.
- Storey stiffness is greater in the hard soil when compared to the other two medium of soil. It is the least in soft soil condition for SSI system.
- The response of the structure is higher in flexible-base condition with SSI effect in comparison to fixed-base condition without SSI effect.
- The buildings designed without the consideration of SSI effects will be less safe during the time of earthquakes.
- The soft soil condition is considered to be more critical and unsafe, therefore it is necessary to consider SSI effects while designing a structure.
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