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# Parametric Study on Soil Structure Interaction Effects on Multistory RC Buildings

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**ABSTRACT:** A phenomenon known as soil structure interaction (SSI), which is often disregarded during the design process but is crucial to understanding this interdependency, has emerged in order to be studied. In the current work, models of a G+8, G+10 and G+12 multi-storey symmetrical RC building with storey heights of 3m are simulated using ETABS version 2018 package and are then subjected to response spectrum analysis. It is expected that these buildings will be located in all seismic zones ii, iii, iv and v resting on hard-soil, medium-soil, and soft-soil. The structure is analysed both with and without SSI by calculating spring values from FEMA 356:2000 for flexible base. Studies and comparisons have been done on the parameters including storey displacement, storey shear, base-shear, storey stiffness, and overturning moment. It is observed that the buildings resting on soft soil and situated in higher seismic zones have more soil structure interaction.

**KEYWORDS:** Soil structure interaction, response spectrum, flexible base, fixed base, FEMA 356:2000, ETABS V.2018.

## I. INTRODUCTION

Soil-structure interaction is the process wherein the motion of the structure is affected by the response of the soil, and the response of the soil is affected by the motion of the structure. The main element in this relationship that will affect forces and deformation in the foundation and superstructure are soil deformations. Since the beginning the design of earthquake-resistant structures has been widely accepted and is still the practice that a building's supports should be kept fixed. In earthquake design, soil structure interaction effects on structures were disregarded.

Although the impacts of soil structure interaction have been studied for more than 50 years, there are still many gaps in the comprehensive specification and standard code requirements for SSI. When designing and analyzing structures, simplified dynamic analysis techniques are frequently utilized as a starting point. Following a thorough review of the literature on the subject, it became evident that the response of a structure which is resting on a flexible base may differ significantly from that of a building supported on a fixed base, and that factor such as the type of soil, the variation in the height of the building, and the stiffness of the structure are very crucial in determining the degree or severity of the effect of soil structure interaction on a structure.

## II. RELATED WORK

“Evaluation of R.C Multi-storey Building Response under the Effect of Soil-Structure Interaction”<sup>[1]</sup>, Published by - *International Research Journal of Engineering and Technology (IRJET)* Volume:06 Issue: 04, April 2019

The author of this paper uses the SAFE foundation design software to create a raft foundation, which is then used in the analysis of the structure while taking into account soil-structure interaction. The raft foundation is supported by soil springs, whose stiffness values are calculated using deflecting at a node and the total force acting on it. The author also uses the G+12 story building model with and without soil-structure interaction and analyzes the structure.

“Effect of Soil-Structure Interaction on High Rise RC Building”<sup>[2]</sup>, Published by IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE). 2016

In this work, the author examines a pre-existing G+42-story high-rise residential building in Mumbai, India. He analyses the structure utilizing time history analysis with ELCENTRO seismic data and the ETABS software package. It is assumed to have a structure in Earthquake Zone IV and Zone in the MIDAS GTX X modelling software. Response spectrum method using V with soil type class iii (soft soil) for structural analysis author is taking into consideration two possible model configurations: 1) Fixed base model 2) and a model that uses springs at the soil surface to simulate soil structure interaction with a raft foundation. (Richter and Lysmer’s approach).

“Effect of Seismic forces on Multi-storey Building for different Zones and Soil condition”<sup>[3]</sup>, Published by International Journal for Technological Research in Engineering, 2016.

As per Indian standards, the author of this paper used STADD Pro software to compare the force and moment formed in the structure's columns and beams at the aforementioned cases. He did this in order to study the variation in the effect of seismic forces on the same building model located in different soil conditions and seismic zones. The maximum moment (Mx) in the X, Z, and Y directions, as well as the maximum force (Fy), were observed by the author for Zone-V.

### III.METHODOLOGY

Modelling and analysis of the buildings is done in ETABS 2018 software package. Federal Emergency Management Agency, FEMA 356 ,2000 is used to calculate the stiffness of foundation at the surface for hard, medium and soft soil. The building chosen for the earthquake analysis is a reinforced concrete frame structure with 4 bays that are 3 meters wide in both X and Y directions with a typical story height of 3 meters for G+8, G+10 and G+12 story. Base dimension of the building is 12m X 12m and height of the building is 28.95m, 34.95m and 40.95m respectively. Structures are modeled as fixed (without taking into account interactions with the soil) and flexible bases (with Soil structure interaction). The point spring stiffness values for the flexible base is calculated by using the equations given in FEMA 356,2000 code book and the values are applied to the base of the structure and modelled accordingly.

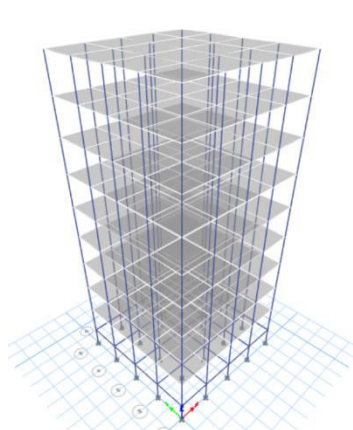


Fig.1.Fixed base

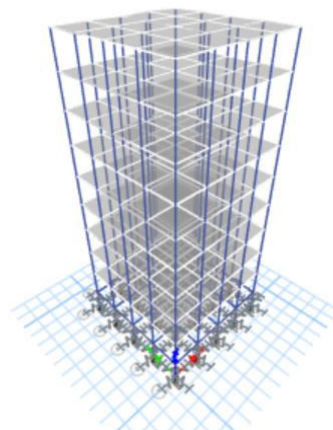


Fig.2.Flexible base

**Table 1: Materials used and members dimensions**

| Soil parameters                     | Formulas            | Hard soil | Medium soil | Soft soil |
|-------------------------------------|---------------------|-----------|-------------|-----------|
| SPT no.<br>(As per IS 1893)         | N                   | 40(>30)   | 26(10-30)   | 7(<10)    |
| Shear wave velocity(m/s)            | $V_s=100*N^{(1/3)}$ | 341.995   | 296.249     | 191.293   |
| Unit weight<br>(kg/m <sup>3</sup> ) | $\gamma$            | 2000      | 1800        | 1600      |
| Mass density<br>(N/m <sup>3</sup> ) | $\rho=\gamma/g$     | 203.873   | 183.486     | 163.098   |
| Shear modulus(kN/m <sup>3</sup> )   | $G=\rho V_s^2$      | 23845.104 | 16103.368   | 5968.247  |
| Poisson's ratio                     | $\mu$               | 0.3       | 0.4         | 0.4       |

The equations given in FEMA356:2000 for the spring stiffness values for different types of soil are used for modeling flexible base. Three translational and three rotational springs are provided at the footing in X, Y and Z directions. In this study, all three major categories of soil, Category I (Hard soil), Category II (Medium soil), and Category III (Soft soil) are included. All of the soil parameters are taken into account in accordance with standards to calculate the soil spring stiffness values for each category of soil, and those values are then used in the corresponding models by defining point springs for all of the flexible base models.

**Table 2: Stiffness factors for the point springs (reference FEMA 356,2000)**

| Structure            | G+8     | G+10    | G+12    |
|----------------------|---------|---------|---------|
| No. of storeys       | 10      | 12      | 14      |
| Column dimension(mm) | 350X350 | 400X400 | 450X450 |
| Beam dimension(mm)   | 300X400 | 300X450 | 300X500 |
| Slab thickness(mm)   | 200     | 200     | 200     |
| Grade of concrete    | M40     | M40     | M40     |
| Rebar                | HYSD500 | HYSD500 | HYSD500 |

where,

$G$ =Shear modulus of soil in kN/m<sup>3</sup>

$\mu$ = Poisson's ratio

$B$ =Breadth of footing

$L$ = Length of footing

Using the below values of soil parameters for different type of soil and taking dimension of foundation as 20m length and breadth the stiffness for the point springs are calculated for translational and rotational movements along x, y and z axis.

**Table 3: Soil parameters for different soil types**

| Degrees of freedom         | Stiffness of foundation at surface           |
|----------------------------|----------------------------------------------|
| Translational along x-axis | $K_x=GB/2-\mu[3.4(L/B)^{0.65}+1.2]$          |
| Translational along y-axis | $K_y=GB/2-\mu[3.4(L/B)^{0.65}+0.4(L/B)+0.8]$ |
| Translational along z-axis | $K_z=GB/1-\mu[1.55(L/B)^{0.75}+0.8]$         |
| Rotational along x-axis    | $K_{xx}=GB^3/1-\mu[0.4(L/B)+0.1]$            |
| Rotational along y axis    | $K_{yy}=GB^3/1-\mu[0.47(L/B)^{2.4}+0.034]$   |
| Rotational along z axis    | $K_{zz}=GB^3[0.53(L/B)^{2.45}+0.51]$         |

The values which are calculated in the below table are defined and assigned to the point springs in ETABS for flexible base models for hard, medium and soft soil for translational and rotational in X, Y and Z axis.

**Table 4: Soil spring values**

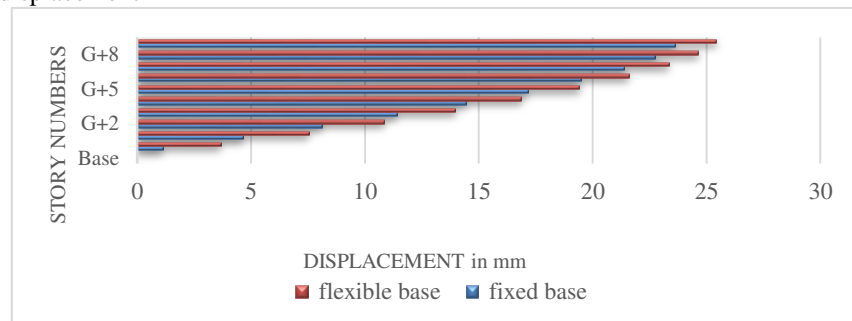
| Direction                          | Point Spring | Hard soil   | Medium soil | Soft soil   |
|------------------------------------|--------------|-------------|-------------|-------------|
| Translational along x axis (kN/m)  | $K_x$        | 1161396.822 | 833349.294  | 308856.782  |
| Translational along y axis (kN/m)  | $K_y$        | 1161396.822 | 833349.294  | 308856.782  |
| Translational along z axis (kN/m)  | $K_z$        | 1440925.57  | 1135287.444 | 420760.92   |
| Rotational along x axis (kN-m/rad) | $K_{xx}$     | 99331890.4  | 78262368.5  | 29005646.4  |
| Rotational along y axis (kN-m/rad) | $K_{yy}$     | 100126545.5 | 78888467.45 | 29237691.57 |
| Rotational along z axis (kN-m/rad) | $K_{zz}$     | 144627232.4 | 97671435.87 | 36199046.71 |

**Table 4: Loads and seismic factors applied to the models**

| Sl.no | Parameters                | Values                                |
|-------|---------------------------|---------------------------------------|
| 1.    | Live load                 | 3 kN/m <sup>2</sup>                   |
|       | Live load on roof         | 1.5 kN/m <sup>2</sup>                 |
| 2.    | Floor finish              | 1.5 kN/m <sup>2</sup>                 |
| 3.    | Wall load                 | 0.3(3-0.5) * 0.3 * 2.5 * 20 = 15 kN/m |
|       | Parapet wall load         | 0.15 * 1 * 20 = 3 kN/m                |
| 4.    | Earthquake load           | As per IS 1893:2016                   |
| 5.    | Zones                     | ii, iii, iv, v                        |
| 6.    | Zone factor               | 0.1, 0.16, 0.24, 0.36                 |
| 7.    | Response reduction factor | 5                                     |
| 8.    | Importance factor         | 1.2                                   |
| 9.    | Damping ratio             | 5 %                                   |

#### IV. EXPERIMENTAL RESULTS

##### 1. Maximum story displacement

**Fig 3. Maximum storey displacement of G+8 building, soft soil, zone v.**

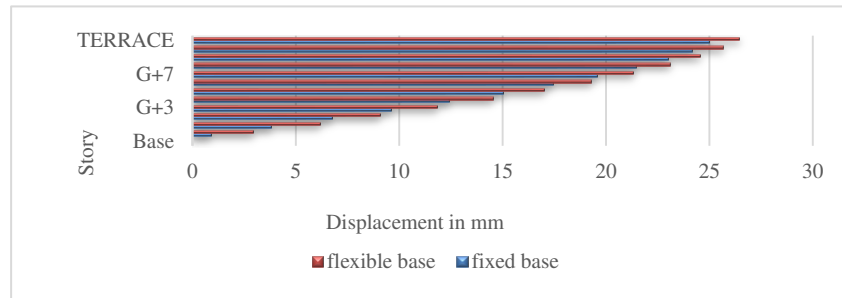


Fig 4. Maximum story displacement of G+10 building, soft soil, zone v.

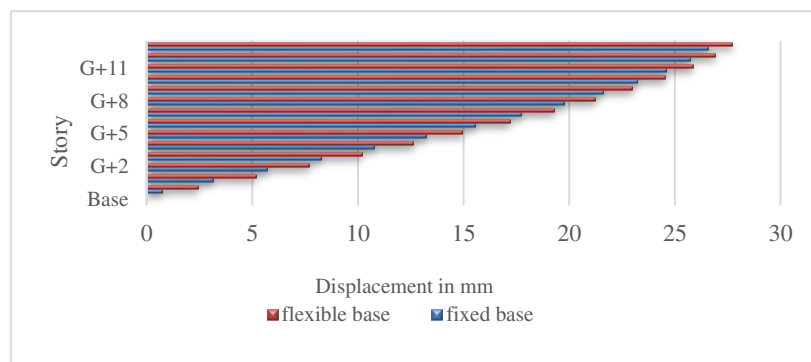


Fig.5. Maximum story displacement of G+12, zone v, soft soil

It is observed from analysis results that the story displacement increases as the elevation increases for flexible base for the soft soil which is situated in seismic zone v. It is concluded that soil structure interaction is higher in higher number of story.

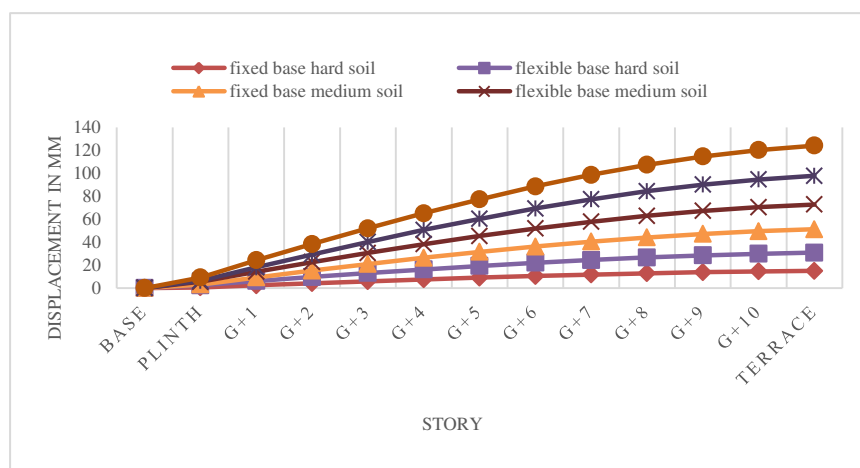
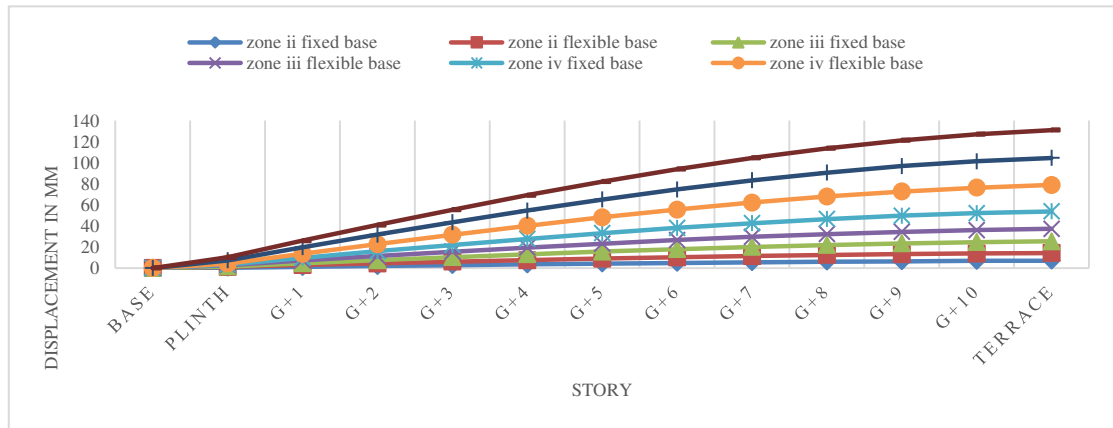


Fig.6 Story displacement in varying soil condition, G+10 model, zone v

It is observed that the response and influence of the soil structure interaction is more in soft soil flexible base for G+10 building situated seismic zone v rather than hard soil and medium soil. Therefore, its concluded that soil structure interaction is more in buildings which are situated in soft soil.



**Fig.7. Maximum story displacement in different seismic zones, G+10, soft soil.**

It is observed that the response and influence of the soil structure interaction is more in zone v flexible base for G+10 building soft soil rather than zone ii, iii, iv, v. Therefore, it is concluded that soil structure interaction is more in buildings which are situated in higher seismic zone i.e., zone v.

## 2. Story shear



**Fig 8. Story shear for G+12 building zone v, soft soil**

Story shear decreases in flexible base while compared to fixed base for soft soil situated in zone v. It is maximum at the base rather than top story. It increases with decreases in height of story.

## 3. Base shear

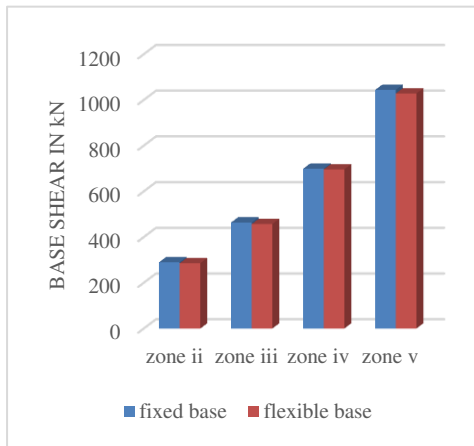


Fig.9. Base shear for model with different zones, G+10, soft soil foundation

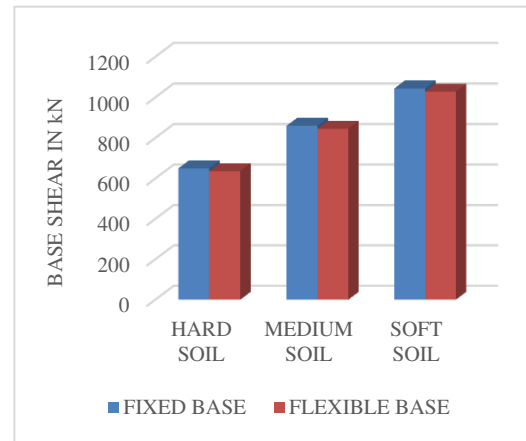


Fig.10 Base shear for model with different seismic soil, G+10, zone v

## 4. Story stiffness

Hard soil has greater stiffness than the other two categories of soil, while soft soil exhibits less stiffness in both situations, such as those with and without an SSI system. When opposed to a fixed base system, story stiffness is reduced in SSI systems and is at its lowest in state of soft soil. Additionally, it can be observed that story stiffness, which is strong at the lowest story level, declines as a rise in the number of storeys.

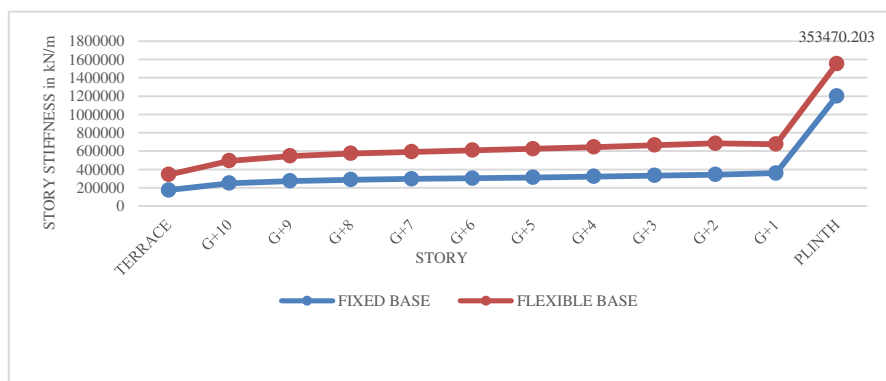


Fig.11 Story stiffness for hard soil, G+10, Zone v

## 5. Overturning moment

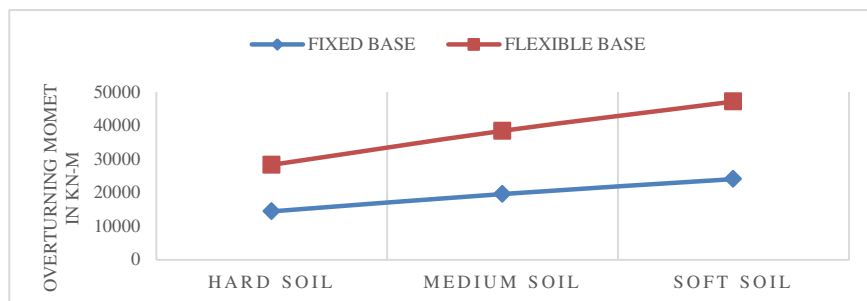


Fig.12 Overturning moment for different soil condition, zone v, G+10 model

Hard soil has a lower overturning moment than the other two types of soil, the SSI system has a higher overturning moment than the fixed base system, and soft soil has the highest overturning moment, making it a key condition.

## V.CONCLUSION

1. When compared to the corresponding fixed base models, an increase in top story displacement is seen in all flexible base building models with soil structure interaction.
2. As the stiffness of the earth increases from soft soil to medium soil to hard soil, the SSI impact will be greater for structures erected on soft soil than on medium and hard soil.
3. Story shear decreases in flexible base while compared to fixed base for soft soil. It is maximum at the base rather than top story.
4. Hard soil has a lower overturning moment than medium and soft soil.
5. When the buildings are designed which is resting on soft soil in seismic zone v without considering soil structure interaction there is vulnerable chances of damages due to earthquake to the buildings.

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