# PERFORMANCE BASED ANALYSIS OF RC STRUCTURE WITH AND WITHOUT CONSIDERING SOIL STRUCTURE INTERACTION

**Dr. M Keshava Murthy[1], Harini R[2]**

[1]*Professor, Dept of Civil Engineering, University Visvesvaraya College of Engineering, Bengaluru, India*
[2]M.tech student, *Dept of Civil Engineering, University Visvesvaraya College of Engineering, Bengaluru, India*

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**Abstract -** *There are considerable exchanges amongst structural engineers about structural modelling but not important about the modelling of foundation. While modelling any structure, the foundation is modelled in a truly simplistic manner. It's assumed as fixed, roller support. Still, in reality, analogous idealized foundations are truly rare. Ultimate of the foundations are footings, mat, piles, or other bedded structures. In fact, foundations are constantly huge structures by themselves. It may not always be good to simply convert them into single point and also assume them to be fixed or roller. The effect of soil structure interaction (SSI) on the Reinforced Concrete framed structures is directly told by the soil properties of the site. Pushover analysis which is also stated as Non linear static analysis is considerably accustomed procedures for the seismic assessment or evaluation of the structures. In the present work, the pushover model is used to measure the new structures seismic demand or for current structures. Pushover review is carried out by considering G+8 multi- storeyed structure in Zone II, III, IV, and V using ETABSv20 software in all soil types i.e., Hard, Medium and Soft soil.*

***Key Words***: **Soil structure interaction, Modal analysis, Equivalent static analysis, Response spectrum analysis, Performance point.**

## 1. INTRODUCTION

The failure of land compels masterminds to construct structures at site with lower favourable Geotechnical conditions in seismically active regions. Earthquake produces strong ground movements the impact on a structure during an earthquake relies upon the properties of the ground soil, intensity of earthquake and structural system. During an earthquake seismic waves are transmits through soil from the origin of disturbance to the structure the wave motion of the soil excites the structure, which in turn modifies the input motion by its movement relative to the ground. The movements of soil under foundation will interact with the distortions of the structure itself. Thus, a performance- grounded design is needed, which is incompletely satisfied through pushover analysis. Generally for seismic analysis, structures are assumed to be strictly restrained at the foundation position, and thereby neglecting the effect of SSI. But in reality, when a structure is in contact with an earthquake excitation it interacts with the soil, and therefore, this commerce affects the structural response. Thus, due to the consideration of interaction of soil and the structure remains a very crucial issue in earthquake design. Present study aims to understand the effect of soil inflexibility on various response parameters of erecting frames with and without considering the soil structure interaction.

### 1.1 Soil Structure Interaction

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, structures that are low rise is negligible it's a very important aspect under consideration for soft soil, high rise structures, roadways, heavy structures nuclear power plants, hydraulic structures. This conservative simplification is valid for certain class of structures and soil conditions, similar as light structures in fairly stiff soil. Unfortunately, the supposition doesn't always hold true. In fact, the soil structure interaction can have a mischievous effect on the structural response, and neglecting SSI in the analysis may lead to unsafe design for both the superstructure and the foundation.

### 1.2 Approaches for Soil-Structure Interaction analysis

1. Methods based on the half-space theory

a) Direct approach
b) Indirect approach

2. Analytical methods

a) Winkler approach
b) P-y method
c) Elastic continuum approach

3. Numerical Methods

a) Finite element method
b) Finite difference method
c) Boundary element method

### 1.3 Modelling of soil by Winkler model

The flexibility of soil is generally modelled by fitting springs between the foundation member and soil medium. While modelling, the number of degree of freedom should be named precisely considering the ideal of the analysis. During earthquake a rigid base may be under displacement in six degrees of freedom, and thus resistance of soil can be expressed by the six corresponding resultant force factors. Hence to make the analysis most general restatements of foundation in two mutually perpendicular principle horizontal directions and vertical direction as well as rotation of the same about these three directions are considered in this study.

Where, G = dynamic shear modulus of soil and is calculated by G=E/2(1+μ)

μ=Poisson's ratio of the soil

K= equivalent spring stiffness of the soil

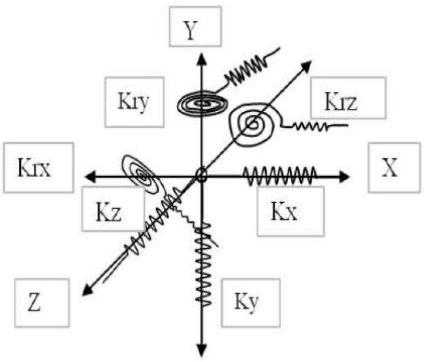



Figure: 1 spring system at the foundation

## 2. OBJECTIVE

To study the behaviour of structure with and without the Soil structure interaction with Raft foundation resting on different type of soil using Winkler model. The reinforced concrete frame structures is analysed by linear i.e., Response spectrum analysis and non linear static analysis i.e., push over analysis using ETABSv20 Software. It shows the performance levels, behaviour of the components and failure medium in a structure.

## 3. METHODOLOGY

1. In this study simple RC frame with Raft foundation, Slab is taken and is considered for 8 storey building.

2. Three type of soil i.e., Hard, Medium and Soft soil is considered as per IS code 1893:2016 for Zone II, Zone III, Zone IV and Zone V with soil springs proposed by Winkler.

3. Present study uses both Response spectrum analysis and Push over analysis with and without the consideration of Soil structure interaction and also the Performance levels, behaviour of the components and failure mechanism in a building.

4. Analysis by using ETABS v20 and generating the results.

## 4. SPECIFICATION OF THE MODEL

### 4.1 Plan Details

The study frame is 3 bay x 2 bay RC structure with storey height of 3m consisting of totally 8 stories. The first and the third bay length along X direction is 6m and the central bay length is 8m. The plan of the structure is rectangle. Along Y direction both the bays are 3m. The frame is assumed to be special moment resisting frame.

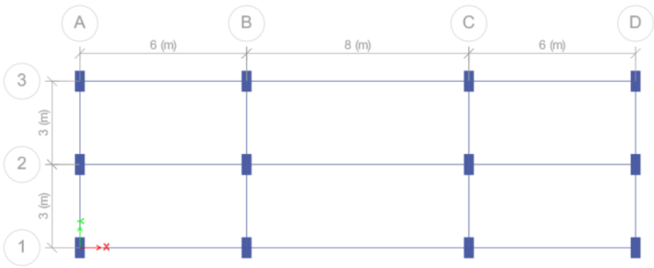



Figure: 2 2D Plan

Conventional analyses of structures are generally carried out by assuming the base of structure to be fixed. Fixed base model is done to compare with that of SSI model. 3D view of 8 storey structure with fixed base is given below.

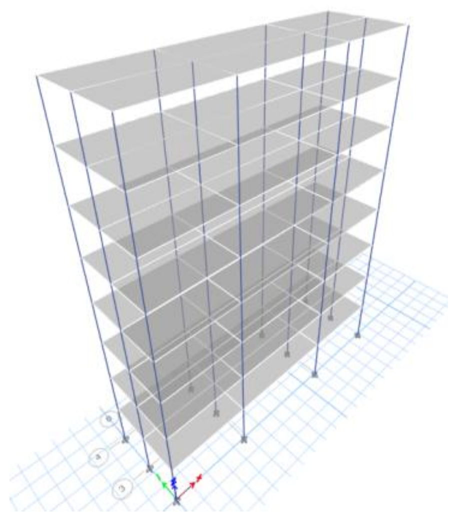


Figure: 3 fixed base

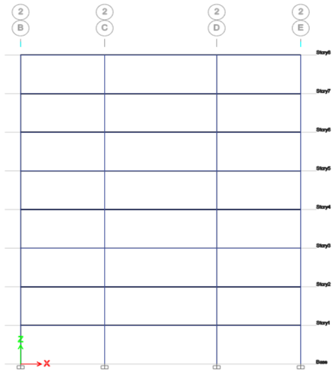


Figure: 4 3D Elevation

The various loads such as DL, LL, Wall load and FF was considered as per IS code provisions. DL consists of weight of floor slab, roof slab, beams and columns. The LL is 3 kN/m$^2$ at floor slab and 1.5kN/m$^2$ at roof slab. The FF load on all the floors is 1.5 kN/m$^2$. The wall load of 8.8kN/m$^2$ is applied on floor beams and 2 kN/m$^2$on roof. The structure is assumed to be situated in seismic Zone II, III, IV and V, with an I factor of 1.5 and response reduction factor R of 5. The slab thickness is 100mm. In order to account for seismic actions, IS: 1893 2016 Response Spectrum analysis was used to arrive at the Structural details adhering to the code guidelines. The live load is applied directly on slabs and while computing the mass source, 25% of live load is considered as per IS code provisions. The grade of the concrete is M25 and Steel is Fe500.

**Table-1**: Section and reinforcement details of beam

| Beam | Dimension (mm) | Top reinforcement | Bottom reinforcement | Transverse reinforcement |
|---|---|---|---|---|
| B-1 | 300 x 500 | 6-25 ϕ | 5-25 ϕ | 3L-8 ϕ @100mm C/C |
| B-2 | 300 x 500 | 5-25 ϕ | 5-25 ϕ | 2L-8 ϕ @100mm C/C |

**Table-2:** Section and reinforcement details of column

| Column Type | Dimension (mm) | Main reinforcement | Transverse reinforcement |
|---|---|---|---|
| C1-L | 500 X 800 | 12-25 ϕ | 5L-8ϕ@ 200C/C |
| C1-M | 350 X 750 | 12-25 ϕ | 5L-8ϕ@ 200C/C |
| C1-H | 350 X 750 | 12-20 ϕ | 5L-8ϕ@ 200C/C |
| C2-L | 500 X 900 | 14-25 ϕ | 6L-8ϕ@ 200C/C |
| C2-M | 350 X 750 | 14-25 ϕ | 6L-8ϕ@ 200C/C |
| C2-H | 350 X 750 | 14-20 ϕ | 6L-8ϕ@ 200C/C |

### 4.2 Loads

**1. Dead load** (Table 2 as per IS 875(part1):1987)
**2. Live load** (Table 1 as per IS 875(part2):1987)
**3. Seismic load**
Importance factor, I=1.5

Response reduction factor, R = 5

Zone factor, Z = 0.1, 0.16, 0.24, 0.36 for Zone II, Zone III, Zone IV and Zone V respectively.

Design response spectra constructed as per IS 1893:2016 for all the four zones and three types of soil.

### 4.3 Load Combinations

1. 1.5(DL+LL)
2. 1.2(DL+LL+EQX)
3. 1.2(DL+LL-EQX)
4. 1.2(DL+LL+EQY)
5. 1.2(DL+LL-EQY)
6. 1.5(DL+EQX)
7. 1.5(DL-EQX)
8. 1.5(DL+EQY)
9. 1.5(DL-EQY)
10. 0.9(DL)+1.5(EQX)
11. 0.9(DL)-1.5(EQX)
12. 0.9(DL) +1.5(EQY)
13. 0.9(DL)-1.5(EQY)
14. 1.0(DL+LL)

**Table-3:** Soil elastic constants

| Soil Type | Modulus of Elasticity -E (KN/m2) | Poison's Ratio (μ) | Unit weight (KN/m2) | SBC (KN/m2) | Shear modulus-G(KN/m2) |
|---|---|---|---|---|---|
| Hard soil | 65000 | 0.3 | 18 | 250 | 25000 |
| Medium soil | 35000 | 0.4 | 16 | 150 | 12500 |
| Soft soil | 15000 | 0.4 | 16 | 100 | 5357.14 |

**Table-4:** Soil spring value as per Richart and Lysmer.

| Direction | Spring values | Equivalent radius |
|---|---|---|
| Vertical | $K_z = \frac{4Gr_z}{1-\nu}$ | $r_z = \sqrt{\frac{LB}{\pi}}$ |
| Horizontal | $K_x = K_y = \frac{32(1-\nu)Gr_x}{(7-8\nu)}$ | $r_x = \sqrt{\frac{LB}{\pi}}$ |
| Rocking | $K\phi_x = \frac{8Gr_{\phi x}^3}{3(1-\nu)}$ | $r_{\phi x} = \sqrt[4]{\frac{LB^3}{3\pi}}$ |
| | $K\phi_y = \frac{8Gr_{\phi y}^3}{3(1-\nu)}$ | $r_{\phi y} = \sqrt[4]{\frac{LB^3}{3\pi}}$ |
| Twisting | $K\phi_z = \frac{16Gr_{\phi z}^3}{3}$ | $r_{\phi z} = \sqrt[4]{\frac{LB^3+BL^3}{6\pi}}$ |

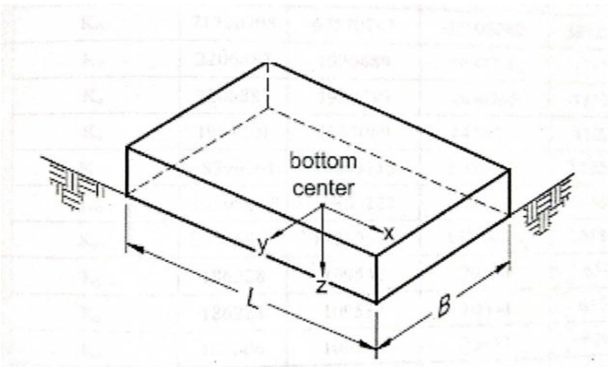



Figure: 5 orientation of axes such that L > B

L=Length of the foundation

B= width of the foundation

The whole area is meshed with quad shell elements and soil springs are applied.

**Table-5:** Calculated soil spring values as per Richart and Lysmer

| Soil type | Equivalent radius | Spring values |
|---|---|---|
| Hard | rz=6.84 | Kz=977140 |
| | rx=6.84 | Kx=Ky=832690 |
| | røx =5.257 | Køx=13836000 |
| | røy =5.257 | Køy=13836000 |
| | røz =7.862 | Køz=64790000 |
| Medium | rz=6.84 | Kz=570000 |
| | rx=6.84 | Kx=Ky=432000 |
| | røx =5.257 | Køx=8070000 |
| | røy =5.257 | Køy=8070000 |
| | røz =7.862 | Køz=32390000 |
| Soft | rz=6.84 | Kz=244280 |
| | rx=6.84 | Kx=Ky=185140 |
| | røx =5.257 | Køx=34450000 |
| | røy =5.257 | Køy=34450000 |
| | røz =7.862 | Køz=13880000 |

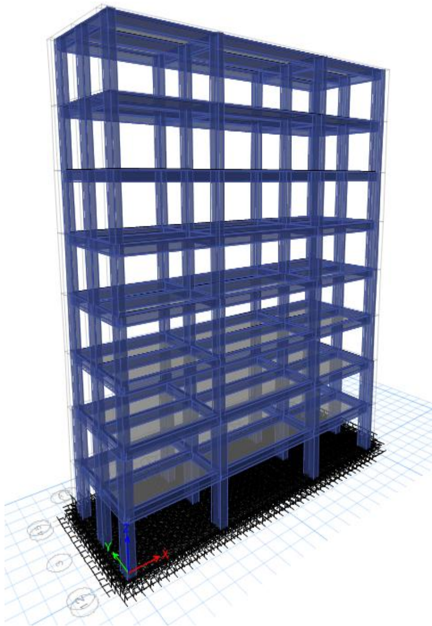
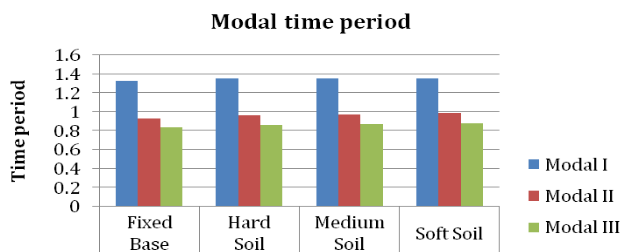


Figure: 6 Flexible Raft foundation considering soil flexibility

## 5. RESULTS AND DISCUSSION

The comparison results of systematic parameters such as Modal Time period, Base shear, Roof displacement, Storey drift and Performance of building has been studied and compared for 8 storey structures with and without soil structure interaction.

**Table-6:** Modal Time Period




| | Fixed Base | Hard Soil | Medium Soil | Soft Soil |
|---|---|---|---|---|
| Modal I | 1.332 | 1.352 | 1.354 | 1.358 |
| Modal II | 0.933 | 0.969 | 0.977 | 0.994 |
| Modal III | 0.837 | 0.863 | 0.869 | 0.881 |

Modal time period for frames with flexible base is higher than frames with fixed base i.e., the soil having less stiffness have longer time period. The time period of soft soil is greater than that of other soils. The study shows that average time period increases 1.7% with soil flexibility by the inclusion of SSI when compared to fixed base model.

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## 5.1 RESPONSE SPECTRUM ANALYSIS RESULTS

### Base shear

**Table-7:** Base shear (Vb) in KN

| Sl. No | Zones | Fixed Base | Hard Soil | Medium Soil | Soft Soil |
|---|---|---|---|---|---|
| 1 | Zone II | 268.508 | 273.821 | 372.38 | 457.282 |
| 2 | Zone III | 429.613 | 438.114 | 595.836 | 731.625 |
| 3 | Zone IV | 644.419 | 657.172 | 893.755 | 1097.477 |
| 4 | Zone V | 966.629 | 985.754 | 1340.635 | 1646.207 |

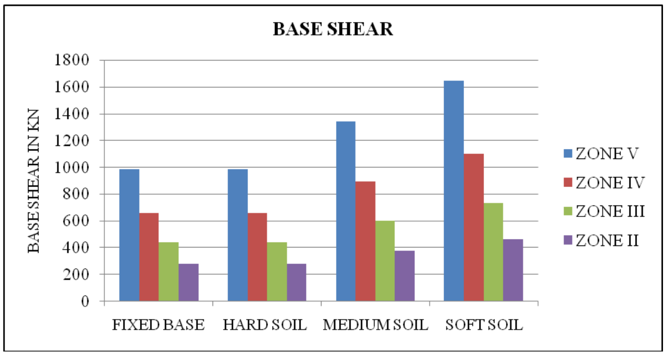


Figure: 7 Base shear for different types of soil for various zones

The graph shows that the base shear in SSI are increased for building on soft ground conditions, and for firm ground conditions i.e., hard soil, they are decreased and can be neglected when compared to fixed condition. Therefore this study shows the soil flexibility at the rate of 2%, 38.5%, 70% with respect to the fixed to considering SSI in Hard, Medium, and Soft soil models respectively.

### Roof displacement

**Table-8:** Roof displacement (mm)

| Sl. No | Zones | Fixed Base | Hard Soil | Medium Soil | Soft Soil |
|---|---|---|---|---|---|
| 1 | Zone II | 14.04 | 14.15 | 19.295 | 23.82 |
| 2 | Zone III | 22.46 | 22.64 | 30.87 | 38.11 |
| 3 | Zone IV | 33.69 | 33.96 | 46.31 | 57.17 |
| 4 | Zone V | 50.54 | 50.94 | 69.46 | 85.75 |

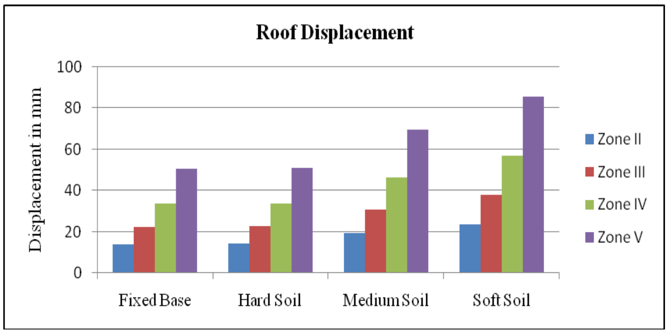


Figure: 8 Roof displacements for various zones and soil types

### Storey drift

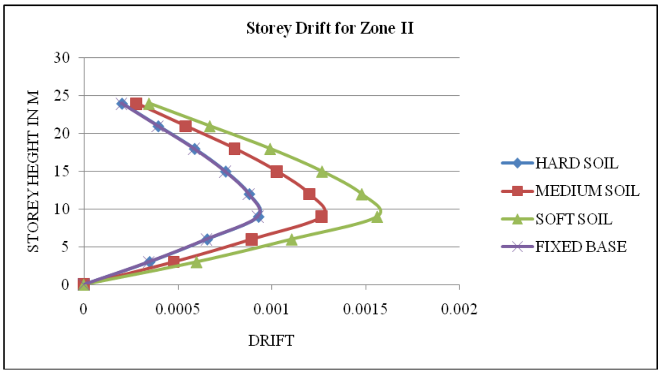


Figure: 9 Storey Drift for Zone II

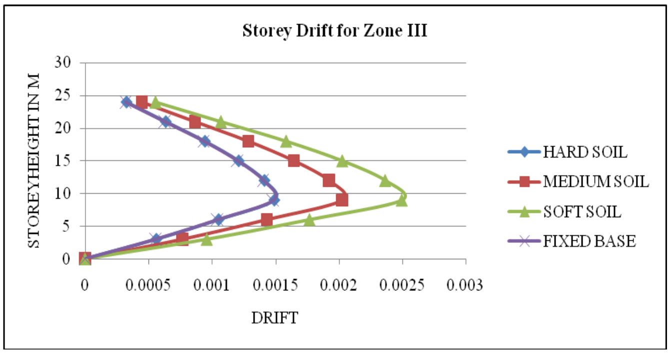


Figure: 10 Storey Drift for Zone III

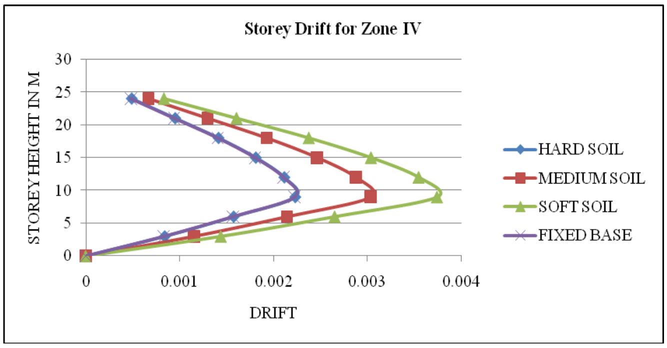


Figure: 11 Storey Drift for Zone IV

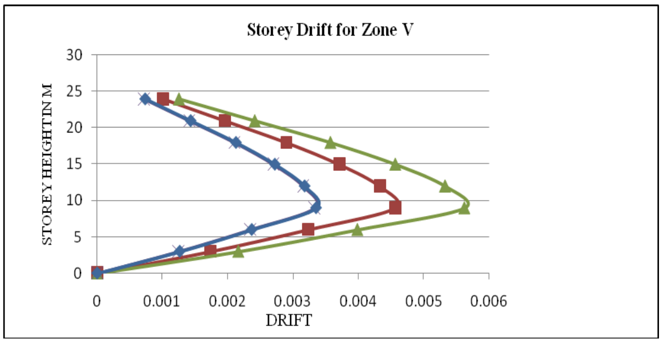


Figure: 12 Storey Drift for Zone V

The storey drifts in case of hard soil, it is less when compared to the other two types of soil. Drift slightly increases in SSI model when compared to fixed base, and maximum in case of 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. It reaches critical limit values when the number of story increases whereas the soil rigidity decreases because of the flexibility of soil especially in frame systems.

### 5.2 PUSHOVER ANALYSIS

**Table-9**: Performance point and Base Shear values of Pushover analysis

| Category | Zone II | | Zone III | | Zone IV | | Zone V | |
|---|---|---|---|---|---|---|---|---|
| | Vb (kN) | D (mm) | Vb (kN) | D (mm) | Vb (kN) | D (mm) | Vb (kN) | D (mm) |
| Fixed Base | 4110.54 | 204.00 | 4110.42 | 204.00 | 4110.55 | 204.00 | 4111.60 | 204.01 |
| Hard Soil | 4308.76 | 201.92 | 4280.51 | 201.19 | 4303.12 | 201.45 | 4303.46 | 201.72 |
| Medium Soil | 4303.91 | 202.25 | 4279.26 | 201.57 | 4278.77 | 201.76 | 4292.31 | 201.80 |
| Soft Soil | 4300.40 | 202.92 | 4276.69 | 202.29 | 4273.43 | 202.38 | 4275.10 | 202.24 |

Above table shows that there is an average increase in base shear by 4.6 % in spring base condition while compared with fixed base condition. And also there is decrease in deflection by 1% while compared with fixed base condition. The base shear at the performance point of the structure is affected by different soil conditions for different support conditions. The performance point for frames with flexible base is lower than corresponding values for frames with fixed base. The base shear obtained by pushover analysis is much higher than base shear obtained by linear analysis. This shows that the value of base shear increases in the consideration of spring base system. Therefore there is more chance for the building to act more vigorously when SSI is considered.

## 6. CONCLUSIONS

- The time period of soft soil is greater than that of other soils. The study shows that average time period increases 1.7% with soil flexibility by the inclusion of SSI when compared to fixed base model.
- 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 high for soft soil for SSI system. It is also seen that as the storey height increases the displacement also goes on increasing.
- Roof displacement is observed to be increasing due to SSI for soft soil in Winkler approach (spring model). The average increase in top displacement is about 53% along the zones from lower to higher level of seismicity.
- 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.
- 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. Base shear was increased at the rate of 2%, 38.5%, 70% with respect to the fixed to considering SSI in Hard, Medium, Soft soil models respectively.
- The soft soil condition is considered to be more critical and unsafe with the consideration of SSI. Therefore it is necessary to consider SSI effects while designing a structure. The buildings designed without the consideration of SSI effects will be less safe during the time of earthquakes.
- From the results of the study it was discovered that the hinges are established between Immediate Occupancy and Life Safety suggesting that the building is secure. The structural model analysed in this state is safe.

Obtained results clearly show that interaction between soil and the structure affects both calculation of displacement capacities and demands in different types of soils in various zones. This situation implies that seismic performance of these buildings should be also examined since the performance is determined by comparing both capacity and demand.

## 7. SCOPE FOR FURTHER STUDY

- Irregularity in elevation and plan of RC buildings.
- The earthquake resisting elements such as core wall, shear wall and bracings can be incorporated.
- Dynamic SSI analysis can be continued with different foundation models and different layers of soil.
- This study can be extended to a non-linear time history analysis of the building.

- This study can also extend for underground structures open storey structures, water tanks etc.
- Effect of Ground water table on SSI can be analyzed.

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