# Seismic Response of Structure Considering Soil Structure Interaction for Soft Soils in Different Zones

**Akshay N[1], Dr. Manjunath N Hegde[2]**

[1]Mtech, Structural Engineering, Dr. Ambedkar Institute of Technology, Bangalore, Karnataka, India
[2]Professor and Dean (Academic), Dr. Ambedkar Institute of Technology, Bangalore, Karnataka, India

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**Abstract -** *The finite element method (FEM) is widely used for the fixed base condition, in which the majority of the work done is by applying an equivalent static load and the linear analysis of a structure is carried out. Contrary to many similar research efforts, in which the aim of the seismic analysis is to get the dynamic response of superstructure, this work is primarily concerned with changes in the response of superstructure by taking into consideration the soil structure interaction effects. As the static analysis approximates the response to a large extent. A detailed dynamic analysis is necessary to understand the real behavior of the superstructure.*

***Key Words*: Soil Structure Interaction, Response Spectra, Base Shear, Lateral Displacement, Storey Drift, Modal Time Period**

## 1. INTRODUCTION

In the contemporary world the rapid development towards social trend urbanization, new structures are often built on available relatively soft soil which are otherwise deemed to be unsuitable for construction in the past, as cities grow to accommodate the influx of residents and commerce. Earthquakes are the most destructive of all natural hazards. There are several case histories of earthquakes that have shown the intensity of earthquake is directly related to the soil type and the soil stratification. "If a flexible structure is constructed on a very rigid base (hard strata), theory is that the input motion at the bottom of the structure is similar to the free-field motion. If the structure is rigid (huge weight), and base is flexible (Soft soil), the motion at the bottom of the structure may fluctuate from that of free-field surface motion". Thus the dynamic effects of earthquake excitations to structure on different type of soil deposit has gained attention.

## 1.1 SOIL STRUCTURE INTERACTION

"The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as "Soil-Structure Interaction (SSI)". Soil-Structure interaction makes a structure more flexible increasing the natural period of the structure compared to the corresponding rigid supported structure.

## 1.2 OBJECTIVE

The objectives of the present work are enlisted below.

- Study on seismic responses of structure with fixed base for all seismic zones by response spectrum analysis method.
- Study on seismic responses of structure founded on sandy silty clay soil around the foundation for all seismic zones.
- Comparison of responses in both the cases.

## 1.3. METHODOLOGY

The G+10 Storey building has been modelled as three dimensional R.C. frame. Finite element software SAP 2000 v14.0 is used for the modelling of the structure and performing finite element analysis to determine the seismic responses. Modeling, material properties, frame sections, loads applied, and analysis method used in present study are described below.

**Table -1:** Material Properties

| Properties | M 25 | M 30 |
|---|---|---|
| Mass per unit volume (Kg/m$^3$) | 2500 | 2500 |
| Weight per unit volume (KN/m$^3$) | 25 | 25 |
| Modules of elasticity (KN/m$^2$) | 25x10$^6$ | 27.38x10$^6$ |
| Poisson's ration | 0.2 | 0.2 |
| Co-efficient thermal expansion (/$^o$C) | 9.9x10$^{-6}$ | 9.9x10$^{-6}$ |
| Shear modules (KN/m$^2$) | 10.42x10$^6$ | 10.42x10$^6$ |
| Compressive strength (KN/m$^2$) | 25000 | 30000 |
| Yield stress for reinforcement (KN/m$^2$) | 415000 | 415000 |

**Table 2:** Frame Sections

| Properties | Beam | Column |
|---|---|---|
| **Size (mmxmm)** | (200x450) | (200x600) |
| | | (200x750) |
| | | (200x900) |
| | | (300x900) |
| | | (300x1000) |
| **Material** | Concrete | Concrete |
| **Grade of Concrete** | M25 | M30 |
| **Grade of steel** | Fe415 | Fe415 |

**Table -3:** Soil Properties

| Soil Parameter | Notation | Formula | Values |
|---|---|---|---|
| SPT No. | N | | 5 |
| Shear Wave Velocity | Vs | $100xN^{0.33}$ | 170.99 m/s |
| Unit Weight | γ | | 18 KN/m³ |
| Mass Density | ρ | γ/g | 1834.86 Kg/m³ |
| Shear Module | G | $\rho Vs^2$ | 53653 KN/m² |
| Poisson's Ratio | μ | 0.3-0.35 | 0.3 |
| Modulus of Elasticity | E | 2G (1+μ) | 139497.8 KN/m² |

**Table -4:** Loading Details

| Load (KN/m²) | Floors | Terrace |
|---|---|---|
| Live Load | 2 | 1.5 |
| Floor Finish | 1.5 | 1.5 |

## 2. MODELLING

### 2.1 DESCRIPTION OF BUILDING

In the current study, a G+10 storey reinforced concrete moment resisting frame structure is considered to investigate the effect of flexibility of soil. The structure is assumed to be a residential apartment structure and it has plan dimension of 20 m x 20m and the height of 40.5m from the ground level. The ground floor is of 4 m height and all other storeys are of 3.65m height. The structure is symmetrical. Plan of the proposed structure is shown in the Fig. 1

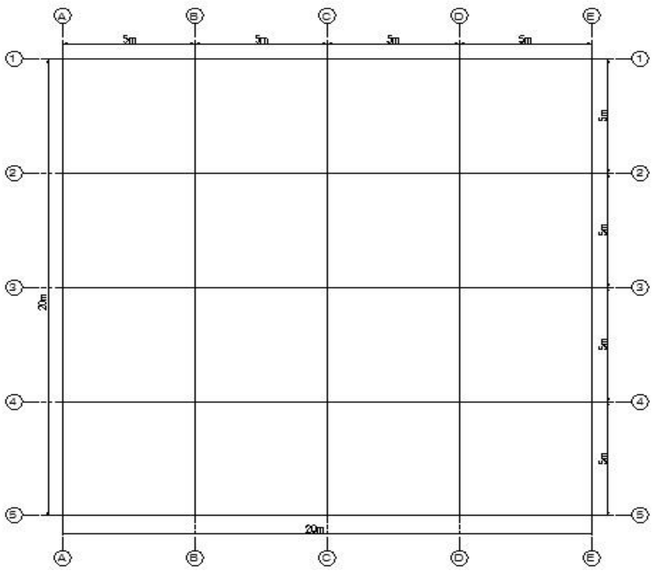

**Fig -1**: Plan

### 2.2 FIXED BASE MODEL

The 11 Storey structure considered for study has been modelled as 3-Dimensional R.C. frame structure. The frames were idealized and modelled with standard 3D beam element having three translational and three rotational degrees of freedom at every node. All the slabs at various storey levels are modelled with R.C shell elements with consideration of adequate thickness. The base of the columns are assumed as fixed at the ground level.

### 2.3 FLEXIBLE BASE MODEL

Raft foundation of area 21.5m x21.5m and depth of 0.9 m is taken which is designed for gravity loads. It is idealized and modelled using continuous three dimensional 8 noded elastic solid element having three translational degrees of freedom at each node

### 2.3.1 MODELLING OF SOIL MASS

Finite element method or Elastic Continuum method is used to model the soil mass. The soil mass is idealized using three dimensional 8 noded elastic solid elements with three degrees of freedom at each node. Soil mass considered is a homogeneous, isotropic, elastic medium and mass less for soil- structure interaction for the present study. The linear elastic analysis is governed by Young's modulus ($E$) and Poisson's ratio ($\mu$)

The horizontal width of soil mass considered is 1.5 times the width of the mat foundation and vertical depth of soil mass considered is 30m. This assumption is made referring to pressure bulb diagram given by Bowles (1982). Vertical movement has been restricted at the bottom boundary while the lateral movement has been restricted along the vertical boundaries.

## 3. ANALYSIS

### 3.1 METHODS OF SEISMIC ANALYSIS

There are different methods of analysis which provides different degrees of accuracy and can be performed on the basis of the external action, the behavior of the structure or structural materials, and the type of structural model selected. In the present study Response Spectrum analysis and Modal analysis has been carried out.

### 3.1.1 RESPONSE SPECTRUM METHOD

The peak response of a structure during an earthquake is obtained directly from the earthquake response spectrum. This procedure gives an approximate peak response, but this is quite accurate for structural design applications. In this approach, the multiple modes of response of a building to an earthquake are taken into account. In response spectra analysis Base shear, lateral displacement and storey drift are obtained.

### 3.1.2 MODAL ANALYSIS

Modal analysis uses the overall mass and stiffness of a structure to find the various periods at which it will naturally resonate. The goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration. The response in each mode of natural vibration can be computed independently with respect to the other modes. The structure can be modelled as a discrete or continuous system and depending on this ordinary differential equations or partial differential equations can be used as governing equations respectively.

## 4. RESULTS AND COMPARISON

Comparative study is carried out with respect to seismic responses such as lateral displacement, storey drift, base shear and modal time period obtained in different Seismic Zones for the following two cases.

- Building with fixed base condition without Soil Structure Interaction
- Building with Soil Structure interaction founded on sandy silty clay.

### 4.1 LATERAL DRIFT

The lateral displacement values from the response spectrum analysis of structure from the two cases with their variation in each zone is studied and graphs have been plotted. Comparisons made in each zones are as follows.

The maximum lateral displacement is obtained at terrace level for both the conditions. The value in structure with SSI is 1.50 times greater when compared to fixed base condition without SSI.

**Table -5:** Lateral Displacement for Fixed Base

| Storey | Lateral Displacement (mm) | | | |
|---|---|---|---|---|
| | Zone II | Zone III | Zone IV | Zone V |
| Terrace | 35.55 | 56.90 | 85.34 | 128.01 |
| Storey 10 | 34.27 | 54.83 | 82.24 | 123.36 |
| Storey 09 | 32.11 | 51.38 | 77.07 | 115.61 |
| Storey 08 | 29.41 | 47.06 | 70.59 | 105.88 |
| Storey 07 | 26.09 | 41.75 | 62.62 | 93.94 |
| Storey 06 | 22.38 | 35.82 | 53.73 | 80.60 |
| Storey 05 | 18.27 | 29.23 | 43.84 | 65.77 |
| Storey 04 | 13.93 | 22.30 | 33.43 | 50.15 |
| Storey 03 | 9.45 | 15.13 | 22.70 | 34.04 |
| Storey 02 | 5.15 | 8.23 | 12.35 | 18.53 |
| Storey 01 | 1.67 | 2.68 | 4.02 | 6.02 |
| Base | 0 | 0 | 0 | 0 |

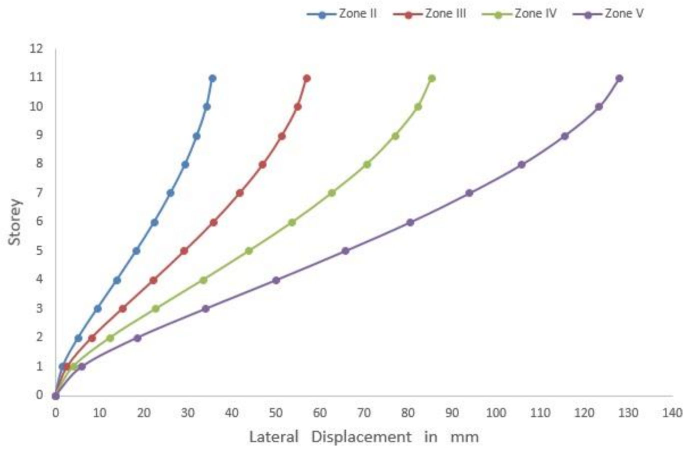


**Fig -2**: Lateral Displacement for Fixed Base

**Table -6:** Lateral Displacement for Flexible Base

| Storey | Lateral Displacement (mm) | | | |
|---|---|---|---|---|
| | Zone II | Zone III | Zone IV | Zone V |
| Terrace | 53.15 | 85.04 | 127.56 | 191.34 |
| Storey 10 | 51.80 | 82.88 | 124.33 | 186.50 |
| Storey 09 | 49.57 | 79.31 | 118.96 | 178.45 |
| Storey 08 | 46.72 | 74.75 | 112.13 | 168.20 |
| Storey 07 | 43.16 | 69.05 | 103.58 | 155.38 |
| Storey 06 | 39.10 | 62.56 | 93.83 | 140.76 |
| Storey 05 | 34.45 | 55.11 | 82.67 | 124.01 |
| Storey 04 | 29.32 | 46.91 | 70.37 | 105.56 |
| Storey 03 | 23.60 | 37.77 | 56.66 | 84.98 |
| Storey 02 | 17.14 | 27.43 | 41.14 | 61.72 |
| Storey 01 | 9.64 | 15.43 | 23.15 | 34.73 |
| Base | 0.16 | 0.26 | 0.39 | 0.59 |

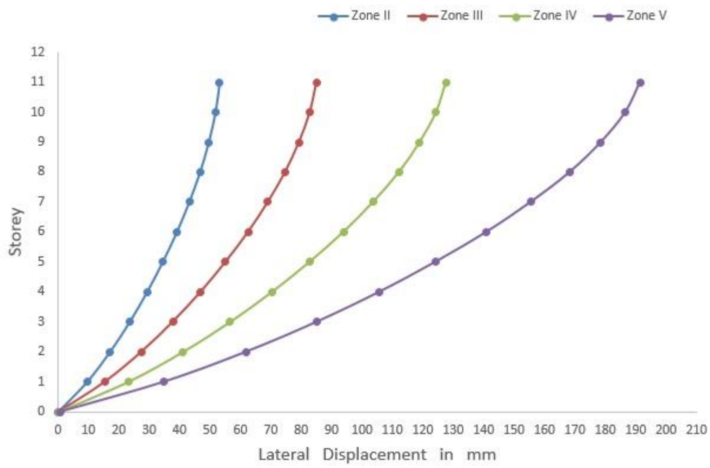


**Fig -3**: Lateral Displacement for Flexible Base

### 4.2 STOREY DRIFT

The storey drifts values for response spectrum analysis of the two cases with their variations in each zone is studied and graphs have been plotted. Comparisons made in each zones are as follows.

Maximum drift has occurred at storey 1 in both conditions and in all zones. The drift in structure with SSI is 5.6 times greater when compared to fixed base condition without SSI.

**Table -7:** Storey Drift for Fixed Base

| Storey | Storey Drift (mm) | | | |
|---|---|---|---|---|
| | Zone II | Zone III | Zone IV | Zone V |
| Terrace | 1.28 | 2.07 | 3.10 | 4.65 |
| Storey 10 | 2.16 | 3.45 | 5.17 | 7.75 |
| Storey 09 | 2.70 | 4.32 | 6.48 | 9.73 |
| Storey 08 | 3.32 | 5.31 | 7.97 | 11.94 |
| Storey 07 | 3.71 | 5.93 | 8.89 | 13.34 |
| Storey 06 | 4.11 | 6.59 | 9.89 | 14.83 |
| Storey 05 | 4.34 | 6.93 | 10.41 | 15.62 |
| Storey 04 | 4.48 | 7.17 | 10.73 | 16.11 |
| Storey 03 | 4.30 | 6.90 | 10.35 | 15.51 |
| Storey 02 | 3.48 | 5.55 | 8.33 | 12.51 |
| Storey 01 | 1.67 | 2.68 | 4.02 | 6.02 |
| Base | 0 | 0 | 0 | 0 |

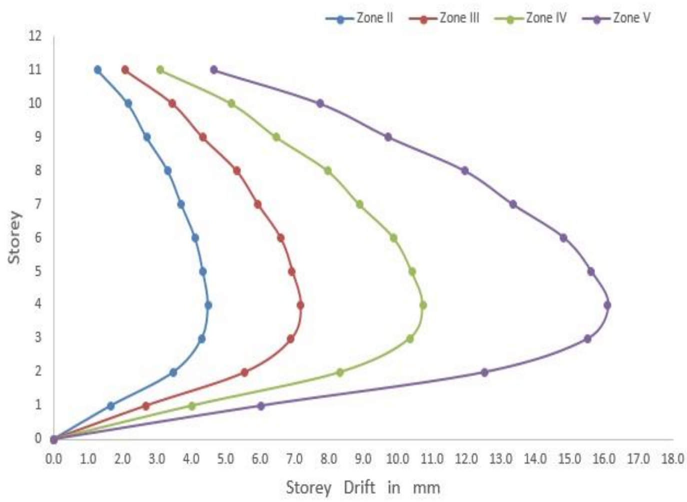


**Fig -4**: Storey Drift for Fixed Base

**Table -8:** Storey Drift for Flexible Base

| Storey | Storey Drift (mm) | | | |
|---|---|---|---|---|
| | Zone II | Zone III | Zone IV | Zone V |
| Terrace | 1.35 | 2.16 | 3.23 | 4.84 |
| Storey 10 | 2.23 | 3.57 | 5.37 | 8.05 |
| Storey 09 | 2.85 | 4.56 | 6.83 | 10.25 |
| Storey 08 | 3.56 | 5.70 | 8.55 | 12.82 |
| Storey 07 | 4.06 | 6.49 | 9.75 | 14.62 |
| Storey 06 | 4.65 | 7.45 | 11.16 | 16.75 |
| Storey 05 | 5.13 | 8.20 | 12.30 | 18.45 |
| Storey 04 | 5.72 | 9.14 | 13.71 | 20.58 |
| Storey 03 | 6.46 | 10.34 | 15.52 | 23.26 |
| Storey 02 | 7.50 | 12.00 | 17.99 | 26.90 |
| Storey 01 | 9.48 | 15.17 | 22.76 | 34.14 |
| Base | 0.16 | 0.26 | 0.39 | 0.59 |

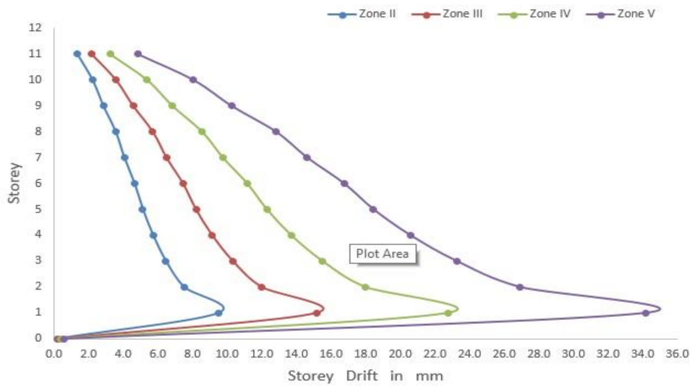


**Fig -5**: Storey Drift for Flexible Base

### 4.3 BASE SHEAR

The base shear values from the response spectrum analysis of the two cases with their variation in each zone is shown in Table 9 and graph has been plotted as shown in Fig. 6

Base shear has been greater consistently in all zones. Base shear of flexible base is 7.26 percent greater than that of fixed base condition.

**Table -9:** Base Shear for Different Zones

| Zone | Fixed Base | Flexible Base | Variation |
|---|---|---|---|
| II | 791.777 | 849.224 | 1.0726 |
| III | 1266.843 | 1358.759 | 1.0726 |
| IV | 1900.265 | 2038.130 | 1.0726 |
| V | 2850.397 | 3057.206 | 1.0726 |

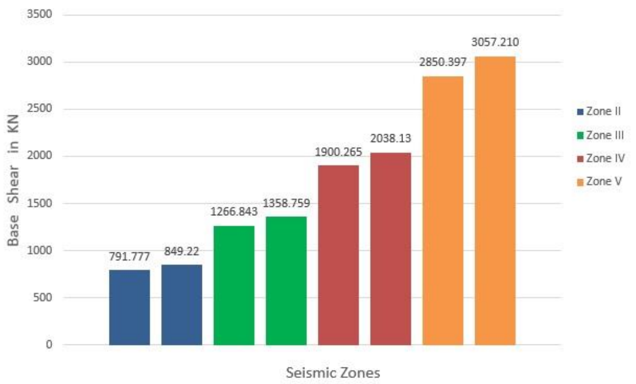


**Fig -6**: Base Shear for Different Zones

### 4.4 MODAL TIME PERIOD

The time period for different modes has been shown in Table 10 for both the cases and graphs have been plotted to study the behavior of building in different modes in Fig. 7

It is observed that mode 1 has the highest time period in both cases. It is 15.7 percent greater in flexible base in comparison with fixed base.

**Table -10:** Modal Time Period

| Mode Number | Modal Time Period | | Variation |
|---|---|---|---|
| | Fixed Base | Flexible Base | |
| 1 | 4.455 | 5.153 | 1.157 |
| 2 | 3.192 | 3.917 | 1.227 |
| 3 | 3.158 | 3.824 | 1.211 |
| 4 | 1.659 | 1.915 | 1.154 |
| 5 | 1.089 | 1.277 | 1.173 |
| 6 | 1.012 | 1.199 | 1.185 |
| 7 | 0.992 | 1.079 | 1.088 |
| 8 | 0.687 | 0.743 | 1.082 |
| 9 | 0.608 | 0.684 | 1.125 |
| 10 | 0.549 | 0.627 | 1.142 |
| 11 | 0.532 | 0.574 | 1.079 |
| 12 | 0.443 | 0.457 | 1.032 |

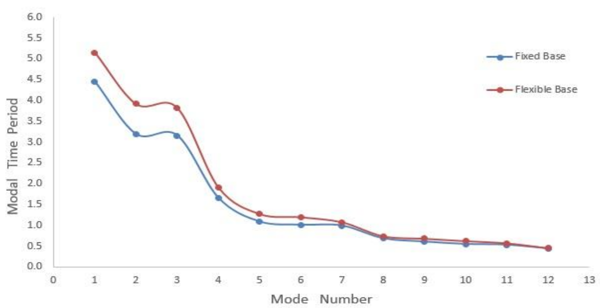


**Fig -7**: Modal Time Period

## 5. CONCLUSIONS

The response spectrum analysis of 11 storey structure with mat foundation for sandy silty clay soil condition considering the effect of SSI has been carried out to study the seismic responses such as lateral displacement, storey drift, base shear and modal time period. These responses are compared with analysis of structure with fixed base through finite element method using SAP.

Following conclusions are drawn after the comparison of seismic responses of both the cases.

### 5.1 LATERAL DISPLACEMENT

Lateral displacement is a function of stiffness, the flexable base structure has shown a significant amount of rotation at the base due to flexibility of soil. Maximum displacement is observed at the terrace level in both the cases.

Maximum lateral displacement is 1.50 times greater in flexible base structure compared to fixed base structure.

### 5.2 STOREY DRIFT

The storey drift is the highest in storey 1. Flexible base structure shows maximum storey drift values in all the storeys compared to fixed base structure. The maximum drift is about 5.68 times greater in flexible base case compared to fixed base case.

### 5.3 BASE SHEAR

Base shear is a function of mass, stiffness, height and modal period of the structure. The base shear for flexible base case is maximum compared to fixed base structure. The base shear is about 7.26% greater in flexible base case compared to fixed base case.

### 5.4 MODAL TIME PERIOD

The modal time period is about 15.7% greater in flexible base case compared to fixed base case for mode 1. Increase in the modal time period is found in all 12 modes.

## 6. SUMMARY

- Soil-Structure interaction plays an important role in altering the seismic response of buildings founded on sandy silty clay soil condition.
- Significant increase of response of structure with soil structure interaction is found compared to the analysis with the fixed base analysis due to effect of flexibility.

## 7. SCOPE OF FUTURE WORK

- Analysis can be further extended to time history and pushover analysis and compare the accuracy of results.
- Non homogeneous or layered soil below the foundation can be considered for the analysis.
- Evaluate the response of buildings with variable distances between two adjacent buildings with structure soil structure interaction.
- Asymmetric buildings with varying height of adjacent buildings can be considered using structure soil structure interaction.
- Buildings with deep foundations with the effect of water table can also be considered for the further study.

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## AUTHORS

Akshay N
Mtech, Structural Engineering, Dr. Ambedkar Institute of Technology, Bangalore, Karnataka, India

Dr. Manjunath N Hegde
Professor and Dean (Academic), Dr. Ambedkar Institute of Technology, Bangalore, Karnataka, India