International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 08 | Aug 2020 www.irjet.net p-ISSN: 2395-0072

Seismic Soil-Structure Interaction of RC-Frame Structure Supported by Different Foundation Type Resting on Clayey Soil

Sameer Kumar K[1], Ashwini G[2], Lokesha N[3], Mohan B[4]

[1]M.Tech Student, Civil Engg. Dept., East West Institute of Technology, Bangalore, Karnataka, India
[2]Associate Professor, Civil Engg. Dept., East West Institute of Technology, Bangalore, Karnataka, India
[3]Lecturer, Civil Dept., Government Polytechnic Immadihalli, Bangalore, Karnataka, India
[4]M.Tech student, Civil Engg. Dept., SKSJTI, Bangalore, Karnataka, India

---***---

Abstract - *The structural analysis and design in general are done by considering super-structure and substructure as separate entities and the super-structure is analyzed by assuming the base as rigid, but however in reality due to the presence of soil mass below and surrounding the foundation there will be interaction between soil and foundation during seismic activity, the response of soil particles to earthquake ground motion affects the motion of structure and the response of structure affects the motion of soil mass is referred as Soil-Structure Interaction (SSI) or Soil-Foundation Structure Interaction (SFSI). Code specifies for the analysis of structure considering SSI in soft soil and it is not necessary for the structure in hard strata or hard soil. In the present study, the seismic response of the super-structure and sub-structure is investigated for the fixed base and flexible base models in SAP-2000 for 6 storey and 8 storey RC framed structure with 2 bays in both X and Y directions. For the both framed structure two types of end conditions, they are a) Column base is fixed (ideally) b) flexible base in which SSI is considered*

Key Words: **SSI, SFSI, Flexible Base, Fixed base.**

1. INTRODUCTION

The seismic analysis and the design of a RC frame structure is assumed to be fixed at the base with zero flexibility which do not take into account the flexibility of the foundation and adjacent soil. The typical design of super-structure and sub structure is done as two independent systems considering constrained at base. As a consequence, the seismic performance of the building evaluated depends only on the superstructure. Damages in structure due to recent earthquakes have shown that the seismic behavior of a structure is mainly influenced not only by the response of the super- structure but also by the response of the foundation and ground as well. Considerable progress has been made in understanding the nature of earthquake and how they could cause structural damages. The investigation on the wave propagation transfer mechanism from ground to buildings during earthquakes is critical for the seismic design of frame structure and structural strengthening of existing buildings. Hence it is required to study the soil structure interaction effects while evaluating the behavior of the structure.

1.1 Soil-Structure-Interaction

The soil-structure interaction refers to effects of the flexibility of supporting soil-foundation system on the response of RC frame structure. When earthquake force acts on these structural elements, neither the displacement of the structure nor the ground motion, are independent of each other. The phenomenon in which the response of both soil and structure caused due to earthquake are interdependent on each other is termed as Soil-Structure Interaction (SSI) or Soil-Foundation Structure Interaction (SFSI). Soil-structure interaction may not be considered in seismic analysis of structure supported on rock or rock like material at shallow depth.

The response of a structure is affected by interactions between three linked systems under to earthquake load: the foundation, the structure, and the soil surrounding and underlying the foundation. Soil-structure interaction analysis evaluates response of these systems collectively to a specified ground motion.

Factors Affecting Soil Structure Interaction

The major factors which are responsible in influencing the behavior of framed structure foundation- soil interaction are

- Types of soil available surrounding and below the foundation at various depths.
- Stiffness between footing and soil, and also between super-structure and footing.
- Size, shape and types of footing/foundation.
- Stress-stain relationship and soil nonlinearity of foundation soil.
- Type of loading:
  a) Static
  b) Dynamic
- Water table depth from surface.

1.2 FOOTING / FOUNDATION

Columns are supported by the footings/foundation which are located below the ground level. The structural design of the footing, which includes the design of cross-sectional area of foundation, depth and reinforcement, is done by considering factored load for the limit state of collapse. Footings are designed for both one way and two way shear action. Types of foundations are.

SHALLOW FOUNDATION:
The depth of the foundation which is less than the width of the foundation /footing is known as Shallow foundation. Shallow are usually provided where the soil below the structure has more stiffness and higher SBC value.
Types of shallow foundation:

- Isolated footing
- Combined footing
- Strap footing
- Mat/raft foundation
- Wall footing

DEEP FOUNDATION:
The foundation that has greater depth than width is called as Deep foundation. When the soil beneath the foundation doesn't have enough bearing capacity for carrying structural load with allowable settlement, in such case deep foundation is preferred. Types of deep foundation are:

- Pile foundation
- Pier foundation
- Well foundation

Pile foundation is one of the type of deep foundation which are formed by slender members made up of RCC, steel or timber used as piles having cap to support the column to rest called as pile cap. In pile foundation system, the depth of piles is at least three times more than its breadth.

2. OVERVIEW OF LITERATURE SURVEY

By referring journals it was clear that effect of SSI in the response of a structure plays a vital role. To understand the exact concept of soil structure effect different methods are adopted by different researchers. Some choose the experimental method and some of them choose numerical methods. In experimental analysis the structure was scaled down and supported by pile foundation which was inserted in to a laminar container containing soil mass, series of shake table tests were conducted to study the behavior of super- structure. In analysis, software like ETABS, SAP-2000, ANSYS and Abaqus were most commonly used by researchers to do perform the simulation of SSI continuum models and to obtain the response under different conditions. From all literature it is clear that foundation type, soil condition and soil properties were the key factors which affect the behavior of the structure.

3. METHODOLOGY

In the present study earthquake loads is considered for analysis model with rigid base and flexible base (SSI model). A rigid foundation refers to base elements with infinite stiffness and a flexible base analysis considers both the foundation/footing elements and the surrounding soil and the mathematical model of SSI is as shown in figure.

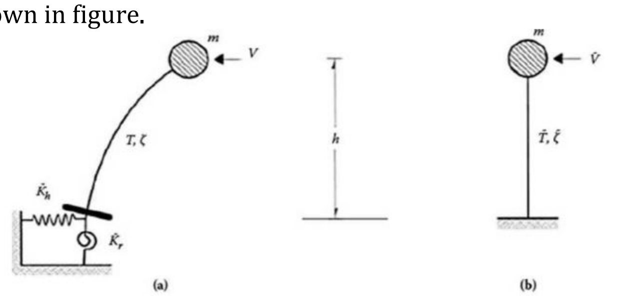

Fig -1:
(a)-Single degree of freedom model with flexible base (SSI),
(b)-Single degree of freedom model with fixed base.

Step by step procedure:

- RC framed structure is modeled and considered with two condition
- Fixed base condition
- Flexible condition
- In fixed base condition, the base is considered as 100% rigidity
- In flexible base condition soil body around the foundation is also considered
- The numerical method such as FEM-software is employed to model soil and foundation system
- 'SSI' effect of RC frame structure with different type of foundations are analyzed by earthquake loading using FEM based software SAP-2000
- Interpretation of results

STRUCTURAL CONFIGURATION

Table -1: Details of structure configuration

Sl.no.	Description	Details
1.	Number of stories	6 and 8
2.	Height between consecutive storey	3m
3.	Number of bays in both X and Y direction	2
4.	Bay width in both directions	4m
5.	Column dimension	0.45m x 0.45m
6.	Beam dimension	0.23m x 0.45m
7.	Slab thickness	0.15 m

8.	Concrete Grade	M30
9.	Rebar Grade	Fe-500
10.	Concrete density	$25kN/m^3$
11.	Live load applied for both floor and roof	$3kN/m^2$
12.	Floor finish/ wall load	$2kN/m^2$

SPECIFICATION OF SOIL

Type of soil - Soft soil (II) and Stiff soil (III)
Elastic modulus of soil - $25000kN/m^3$ and $50000\ kN/m^3$
Density of soils considered - $17.2\ kN/m^3$ and $20.31\ kN/m^3$
Poisson's ratio - 0.3

DESIGN CONCEPT OF ISOLATED SQUARE FOOTING

The isolated footing has been analyzed and designed as per codal provisions for the column reaction obtained from the software for soft and stiff soil and checked for the bending, one way shear and two way shear check.

DESIGN CONCEPT OF PILES AND PILE GROUP

The maximum load carried by the pile and at which pile continues to settle without further increase in the load coming on pile is known as the Ultimate load carrying capacity of the pile (**Q_{UP}**). The load that can be safely carried by a pile is referred as Allowable Load of pile (**Q_a**). The allowable load of the pile can be determined by dividing ultimate load carrying capacity by factor of safety (FOS), and allowable load is also affected by permissible settlement and overall stability of the pile group.

NOTATIONS

F - 6 storey RC frame structure with fixed base and 8 storey RC frame structure with fixed base
SF - Shallow Foundation (isolated footing)
PF - Pile Foundation
SF1 and PF1 - 6 storey RC frame structure supported by isolated footing and pile foundation respectively resting on soft soil
SF2 and PF2 - 6 storey RC frame structure supported by isolated footing and pile foundation respectively resting on stiff soil
SF3 and PF3 - 8 storey RC frame structure supported by isolated footing and pile foundation respectively resting on soft soil
SF4 and PF4 - 8 storey RC frame structure supported by isolated footing and pile foundation respectively resting on stiff soil
ESL – Equivalent Static Load
THM – Time History Method

FINITE ELEMENT METHOD OF ANALYSIS:

Complicated engineering problems involving complex and manual calculations which cannot be easily solved can be now solved easily by using FEM analysis

FEM BASED SOFTWARES

1) STADD PRO
2) E-TABS
3) ANSYS
4) SAP-2000
5) I-DEAS OR SDRC
6) NASTRUN

Modelled RC framed Structures in SAP-2000 software:

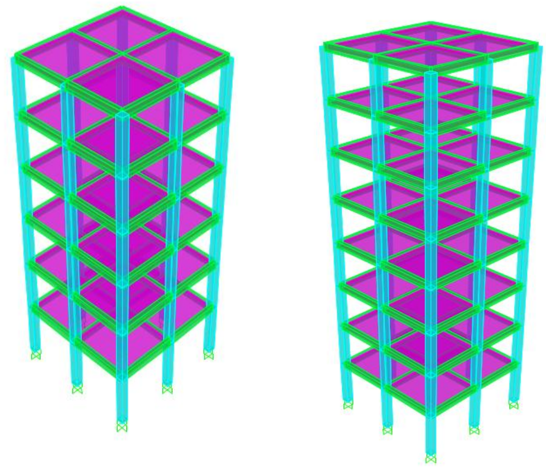

Fig -2: 6 Storey RCC frame structure with fixed base (left), 8 Storey RCC frame structure with fixed base (right)

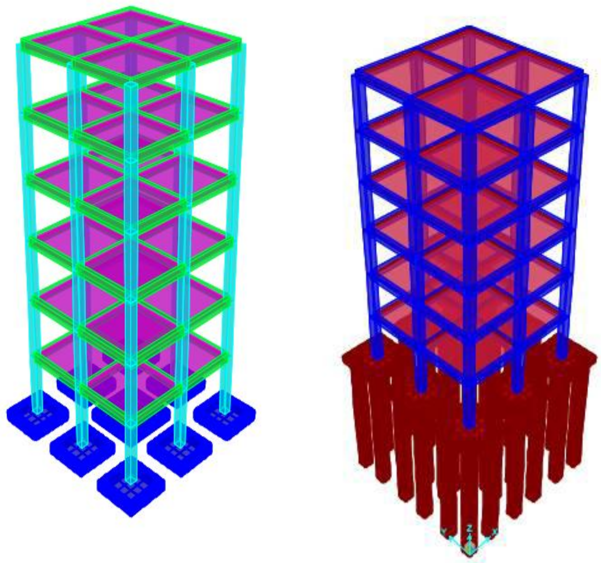

Fig -3: Extruded view of 6 storey frame model with isolated footing (left) and same model with pile foundation(right)

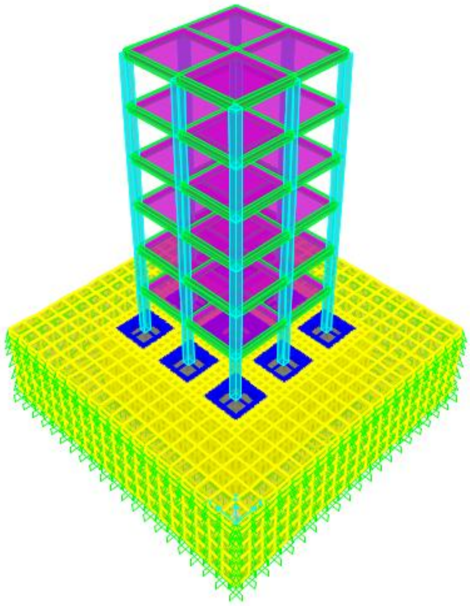

Fig -4: 3D view of 6 storey continuum model (SSI model)

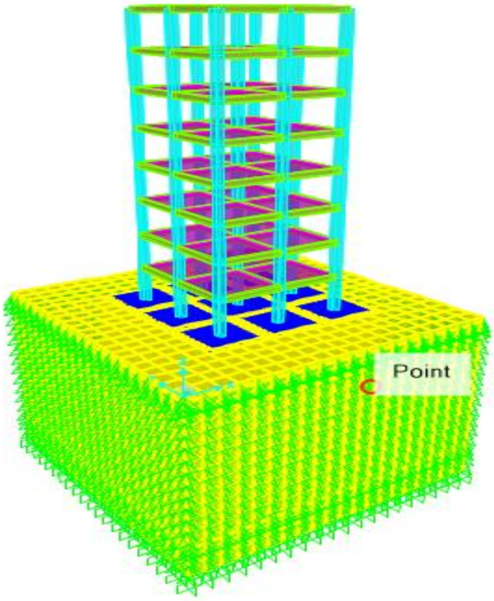

Fig -6: 3D view of 8 storey continuum model (SSI model)

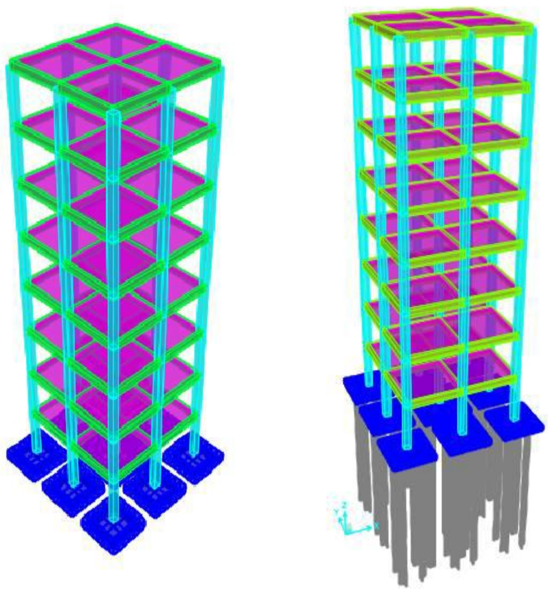

Fig -5: Extruded view of 8 storey frame model with isolated footing (left) and same model with pile foundation(right)

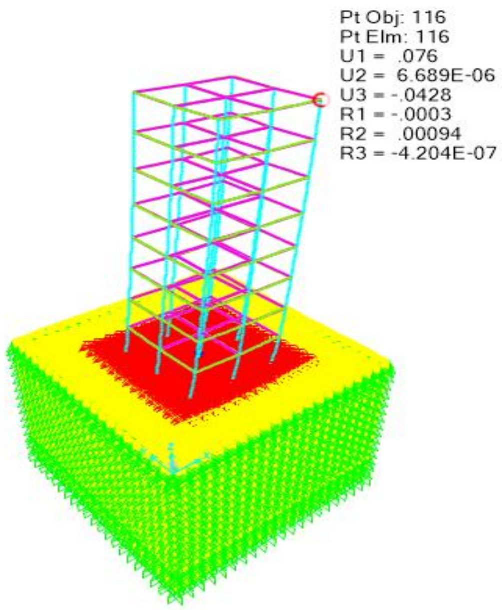

Fig -7: Top storey displacement due ESL in 8 Storey SSI model

4. RESULTS AND DISCUSSIONS

Equivalent static load analysis data:
Equivalent static seismic load of the following data is incorporated for both fixed base (rigid base) model and soil structure interaction 3D continuum models and response from the structure are collected.

- Soil type : III
- Earthquake Zone : 5
- Seismic zone factor (Z) : 0.36
- Response reduction factor (R) : 5
- Importance factor : 1

Variation in Storey Displacement and Inter-Storey Drift of the RC framed structure under Equivalent Static Load method (EQL):

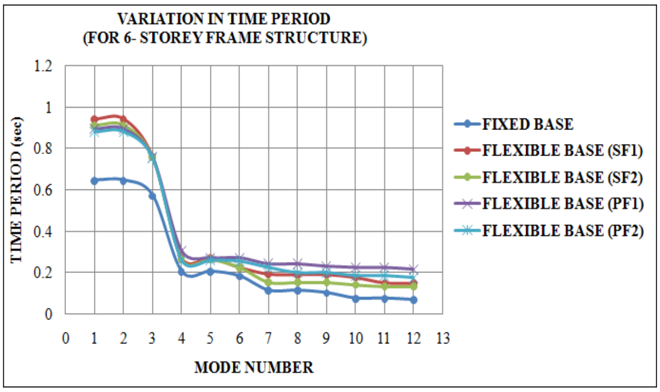

Chart -1: Graphical representation of time period (in seconds) for 6 storey structure for fixed base model and SSI models.

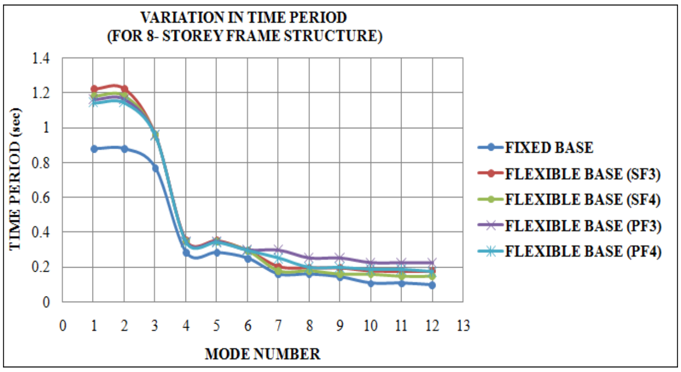

Chart -2: Graphical representation of time period (in seconds) for 8 storey structure for fixed base model and SSI models.

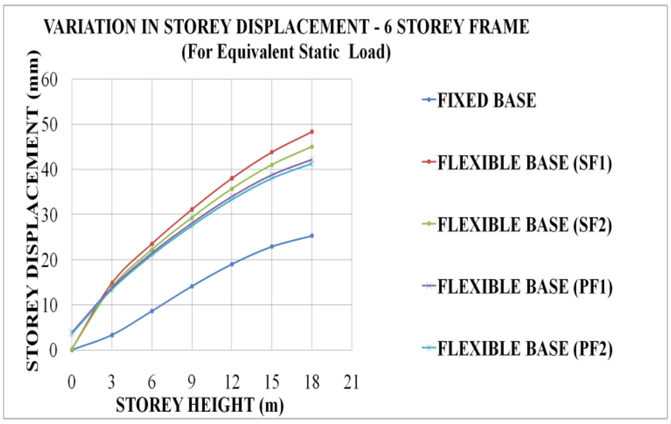

Chart -3: Graphical representation of Storey Displacement for 6 storey structure for fixed base model and SSI models.

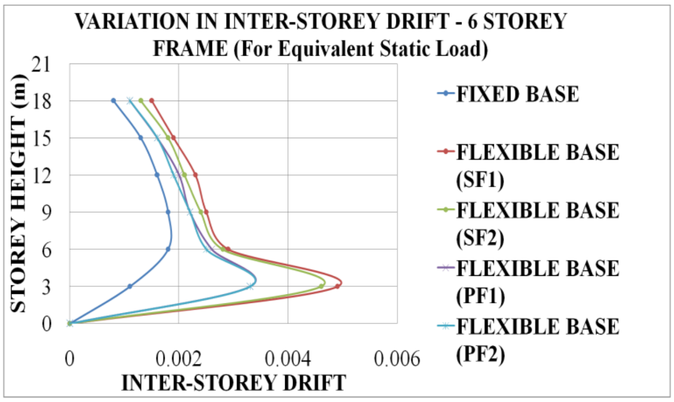

Chart -4: Graphical representation of Inter-Storey Drift for 6 storey structure for fixed base model and SSI models.

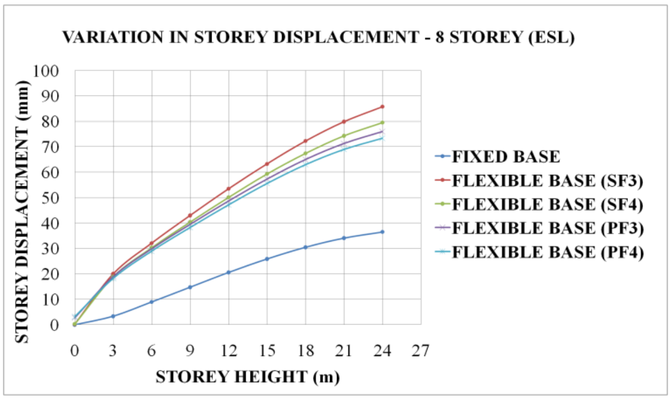

Chart -5: Graphical representation of Storey Displacement for 8 storey structure for fixed base model and SSI models.

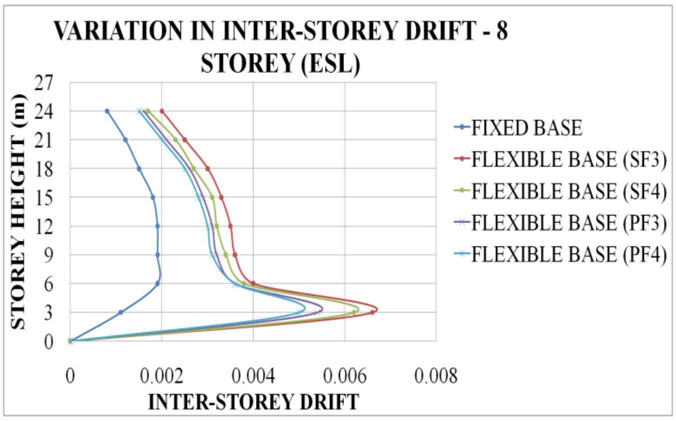

Chart -6: Graphical representation of Inter-Storey Drift for 8 storey structure for fixed base model and SSI models.

Variation in Storey Displacement and Inter-Storey Drift of the RC framed structure under Time History Method (THM)

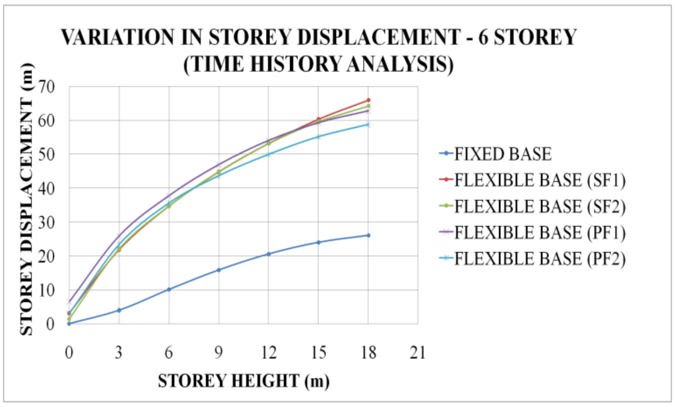

Chart -7: Graphical representation of Storey Displacement for 6 storey structure for fixed base model and SSI models.

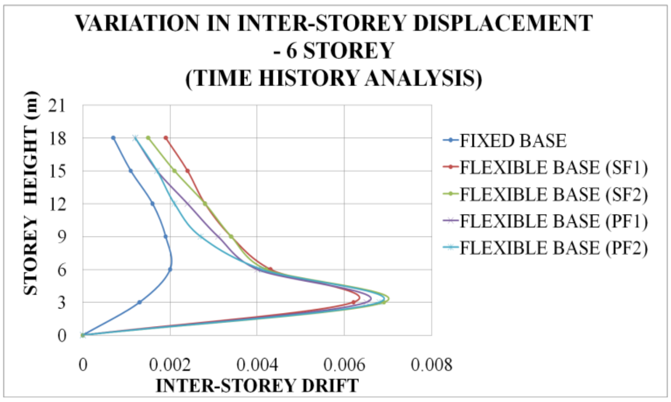

Chart -8: Graphical representation of Inter-Storey Drift for 6 storey structure for fixed base model and SSI models.

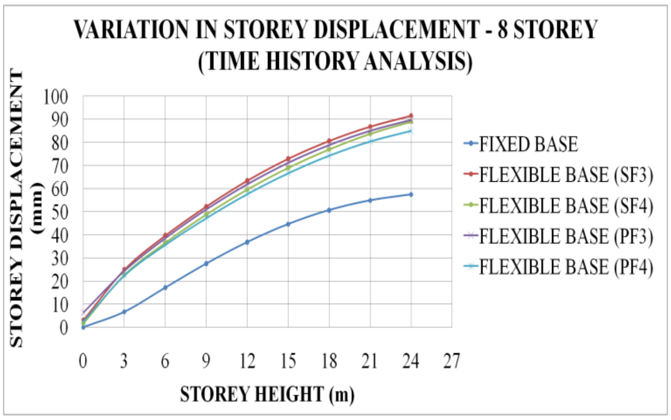

Chart -9: Graphical representation of Storey Displacement for 8 storey structure for fixed base model and SSI models.

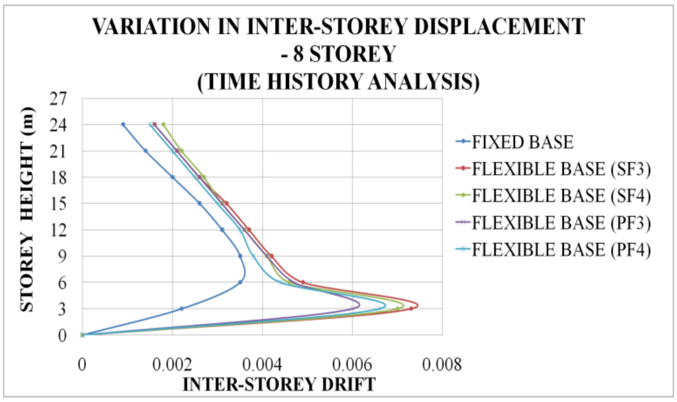

Chart -10: Graphical representation of Inter-Storey Drift for 8 storey structure for fixed base model and SSI models.

5. CONCLUSIONS

An attempt has been made in this work, to study of response of a regular super-structure having six and eight stories with fixed base (rigid base) model and SSI flexible base 3D continuum model condition with soft soil and stiff soil conditions, and the following conclusions are withdrawn from the obtained results.

- There is increase in time period in all SSI 3D continuum models compared to fixed base models
- The time period of RC-frame structure resting on soft soil is more when compared to RC frame structure resting on stiff soil
- Time period for a structure resting on a pile foundation is less when compared to structure resting on isolated square footing
- In case of equivalent static load analysis Storey-displacement for SSI models has increased 2.5 - 4 times compared to fixed base model
- Storey displacement for structure resting on pile foundation is less compared to structure resting on isolated footing in ESL analysis

- In case of time history analysis Storey-displacement for SSI models has increased 1.5 – 3 times when compared to fixed base model
- Storey displacement for time history analysis in structure resting on pile foundation is less when compared to the structure resting on isolated footing
- The Inter-Storey drift for ESL analysis in SSI models has increased 1.5 – 2.5 times when compared to fixed base model
- The Inter-Storey drift for time history analysis for SSI models is more when compared to fixed base model
- The Inter-Storey drift for structure resting on pile foundation is less when compared to the structure resting on isolated footing in both ESL analysis and time history analysis
- The storey-displacements of the structure for fixed and flexible base condition are within the limits for both ESL analysis and time history analysis

ACKNOWLEDGEMENT

Sincere gratitude for my guide Mrs. Ashwini G (Associate Professor EWIT, Bangalore), Mr. Mohan B for helping me in learning SAP-2000 software and Mr. Lokesha N for suggesting the topic to carry out the research

REFERENCES

[1] Hamid Reza Tabatabaiefar, Bijan Samali, and Behzad Fatahi (2010) "Effects of Dynamic Soil-Structure Interaction on Inelastic Behavior of Mid-Rise Moment Resisting Buildings on Soft Soils". Australian Earthquake Engineering Society Conference, Perth, Western Australia, Centre for Built Infrastructure Research, University of Technology Sydney (UTS), Australia (2010).

[2] Raksha J.K and H.S Chore, "Interaction of Building Frame with Pile" International Journal of Electrical, Electronics and Computer Systems ISSN 2347-2820, Volume-1, Issue -1, 2013.

[3] Y. Han (M. ASCE) and S.T Wang (M. ASCE), "Soil Pile Structure in Earthquake Engineering" ASCE journal published in 2013.

[4] V. M. Tormal, K.B. Ladhane, V.R Rathi, "Effect of Soil Structure Interaction on Response of Multistorey Building", International Journal of Engineering Research & Technology Vol. 3 Issue 8th August 2014 ISSN: 2278-0181 Page no : 412-418.

[5] Aslan S.H, Behzad Fatehi and Bijan S, "Physical Modelling Of Seismic Soil Pile Interaction For Building On Soft Soil", American Society of Civil Engineers (2014).

[6] Ruoshi Xu, Behzad Fatahi, and Aslan S. Hokmabadi, "Influence of Soft Soil Shear Strength on The Seismic Response of Concrete Buildings Considering Soil-Structure Interaction", Geo China 2016 GSP 259, ASCE journal published in 2016.

[7] Bakhtyar Saleh Ahmmad ,"Earthquake Analysis of 12 Storey Building Considering Built on Three Type of Soil Include Effect of Soil Structure Interaction" SCJCEA, Vol. 3, Issue. 1, December 2017.

[8] Q.V. Nguyen, B Fatehi and Aslan S.H, "Influence of Size and Load Bearing Mechanism of Pile on Seismic Performance of Building Considering Soil Pile Structure Interaction", (ASCE) American Society of Civil Engineers 2017.

[9] **IS 456-2000,** "Code of Practice for Plain and Reinforced Concrete", Bureau of Indian Standards, New-Delhi, India.

[10] **IS 1893 (part 1) - 2002**, "Criteria for Earthquake Resistant Design of Structures", part1- General provisions and buildings, fifth revision, Bureau of Indian Standards, New Delhi, India.

[11] **IS 2911 part 1/section 1 -1979**, "Code of Practice for Design and Construction of Pile Foundation", part 1 - concrete poles, section1 – driven cast in situ concrete piles by Bureau of Indian Standards.