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# Analysis of Performance Point of the 15-Storey Framed Structure Considering Soil Structure Interaction

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**Abstract - As there is need have basic deeds in the man's life to accomplish, their specializations are very dedicated in their field. Among one of that basic needs is shelter and for construction the structural designers work with very specific designs to resist all the forces or loads coming on that structure. As the building resists all, the self-weight and imposed load with specific sectional elements, but can they resist the lateral forces coming on it. This is evaluated by some analytically or programmatically solutions. The building analyzed with considering earthquake vibrations as per the codal reference IS-1893:2002. The 15-storey building analyzed considering soil structure interaction for different types of soils. The building performance is evalated by nonlinear static analysis method and the respective performance points for various structural elements are expressed in different levels like immediate occupancy, life safety, and collapse prevention defined in ATC-40 at their respective performance point. The various parameters, fundamental natural periods, performance points, storey displacements are noted in the paper and the respective conclusions are explained.**

## I. INTRODUCTION

There are many methods for designing a structure for lateral forces (earthquake vibrations and wind loads) to get the various result parameters. Nevertheless, a designer or structural engineer during design or analysis of structure assume the foundation as fixed condition which mean all the three translation in both direction and rotation are restricted after all the loads acted upon it. However, nobody knows the behavior of the soil how it reacts on the structure during the self-weight of the structure and due to lateral loads, which is seismic vibrations. Even for blast load, the behavior of the soil on structure is unpredictable.

So to know the behavior of the soil the consideration of soil structure interaction where the foundations are referred as stiffeners, dampers and sliders. As in this paper, the soil type considered is stiffeners or springs. This type of soil helps in determining soil behavior during lateral vibrations acting on the structure.

The seismic vibrations intensity as defined in code IS-1893:2002, as defined in the code there are different zones categorized such as zone II, zone III, zone IV, and zone V. for evaluating the lateral seismic forces there are different methods and they are programmed as per the codal provisions. The structure is analyzed in the SAP2000 programmed software.

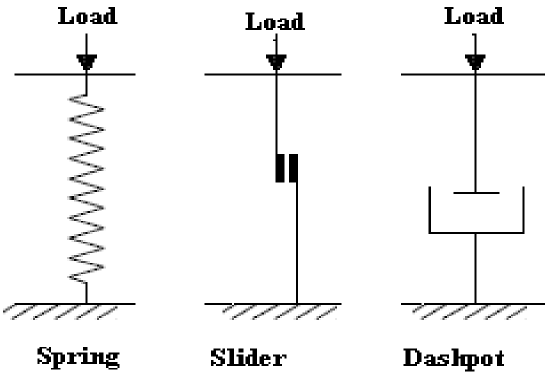


Figure 1: Different types of soil properties

## II. OBJECTIVES OF THE STUDY

The main objectives of the present study are;

a. To produce an easier design procedure for practical purpose.

b. To evaluate the structure with soil flexibility and without soil flexibility.

c. To assess the structure with soil flexibility and without soil flexibility for different soil types.

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## III. METHODOLOGY AND MODELING

There are many methods for analyzing or evaluating the seismic vibrations on the structure to get the behavior of the soil on the structure. Among them direct and substructure approaches are some methods which assists for the evaluating the soil flexibility. In the direct approach, the structure and the soil will be assessed in a single system or whole unit. However, in the substructure approach, the super structure is considered as different unit, sub structure with soil is considered as another unit, and the assessment is differently operated. In this paper, the direct approach has mentioned for the assessment. The following figure explains the direct approach of the soil structure interaction on the structure.

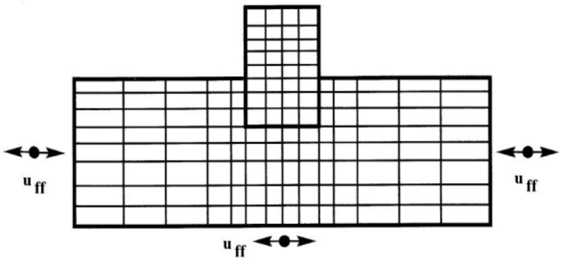


Figure 2: Modeling the structure with consideration of soil structure interaction by direct method

In the present study, a regular building with size 36mX36mX46m with beam size 0.3mX0.6m and column size 0.6mX0.9m. This 15-storey building is analyzed for fixed and flexible base condition. The slab thickness is taken as 150mm and analyzed as membrane. Firstly, the structure is analyzed as fixed base condition and then the springs are applied as per footing size as in the fixed base condition for counteracting the soil structure interaction. The structure is analyzed for different load cases as per code specification in SAP2000 software.

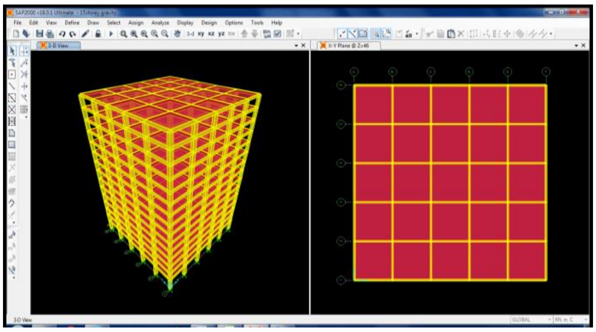

Figure 3: Plan and 3d cross sections of different elements of a 15-storey building

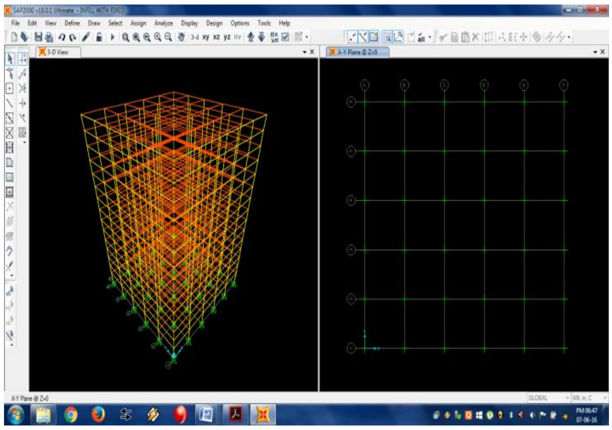

Figure 4: Plan and 3d view of the storey with fixed end condition

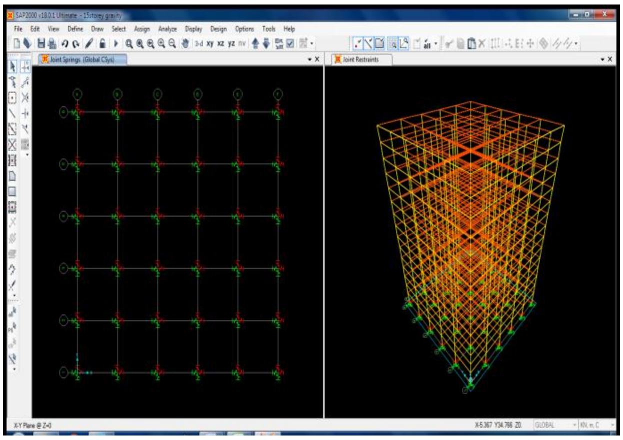

Figure 5: Plan and 3d view of the storey with flexible end condition

The different models are explained below;

Model I- Building with no walls in the structure supported on stiff clay;

Model II- Building with no walls in the structure supported on medium clay;

Model III- Building with no walls in the structure supported on soft clay;

Model IV- Building with open storey in the ground storey supported on stiff clay;

Model V- Building with open storey in the ground storey supported on medium clay;

Model VI- Building with open storey in the ground storey supported on soft clay.

The behavior of the soils is evaluated by different testing procedures. The results after the testing are tabulated in the following table for different parameters.

| Properties \ Soil type | Hard soil | Medium soil | Soft soil |
|---|---|---|---|
| Poisson's ratio, μ | 0.5 | 0.5 | 0.5 |
| Mass density, ρ | 2000 kG/m³ | 1700 kG/m³ | 1500 kG/m³ |
| Shear wave velocity, v | 1500 m/s | 800 m/s | 200 m/s |
| Shear modulus, G | 68965.89 kN/m² | 17241.51 kN/m² | 5147.92 kN/m² |
| Safe Bearing Capacity, SBC | 250 kN/m² | 150 kN/m² | 100 kN/m² |

Table 1: Different Types of Soils And Its Parameters

## IV. PERFORMANCE ASSESSMENT OF THE BUILDING

Pushover analysis is a one of the methods in seismic analysis, which helps in understanding the behaviour of the structures subjected to a seismic forces or lateral disturbances. As the name explains, this procedure of application of some amount of horizontal load with incremental pattern until the framed structure reaches a limit state (ATC-40, 1996). This is a static non-linearity approximation, which is designed previously or an existing structure; consists of vertical distribution of lateral forces to a model and monitoring the incremental of the loads until the peak response of the structure is obtained on base shear vs. Roof displacement.

To know the roof displacement due to the lateral forces is explained from the equivalent static method, response spectrum method, nonlinear static method and nonlinear dynamic method with respect to the natural period calculated. The base shear is evaluated as per the codal provisions.

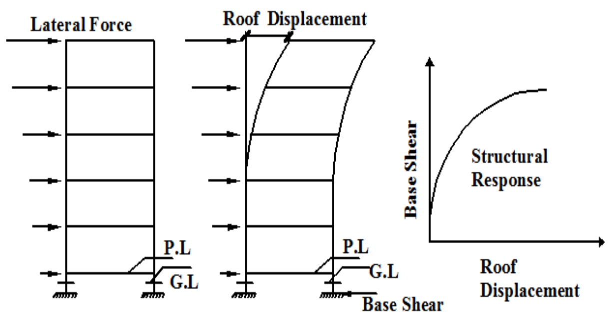


Figure 6: Pushover curves due to seismic forces

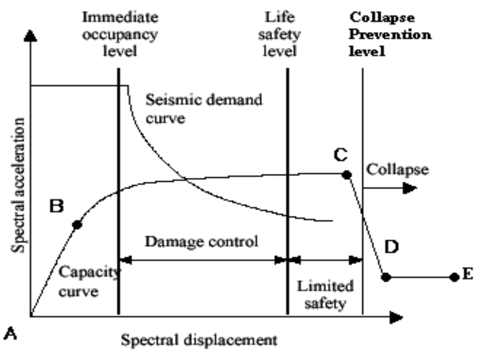


Figure 7: Typical graph for showing performance points as per ATC-40

There are many levels for the structure after the application of the nonlinear static analysis and are explained in the following.

Operational level: Backup utility services maintain functions, very little damage.

Immediate occupancy: Building remains safe to occupy, any repairs are minor.

Life safety: Structure remains stable and has significant reserve capacity, hazardous nonstructural damage is controlled.

Collapse prevention: building remains standing, but only barely, any damage or loss is acceptable.

## V. RESULTS AND DISCUSSIONS

In this main concentration is kept for the various outcomes from the various models used for analysis such as bare frame structure with fixed base condition and with flexible base condition and soft storey building with fixed condition and flexible condition. The different types of analyses completed viz, equivalent static analysis, and nonlinear static analysis (push over analysis). An attempt is made to concentrate on effect of soil structure interaction in the earthquake analysis even in the presence of infill in the model or structure.

➢ *Fundamental natural periods*

Fundamental natural periods are calculating based on which type of frame is considered. For different types of frame viz, concrete bare frame, infill frame and steel frames the code IS 1893(Part-I): 2002 has provided equations and mention in the above chapter.

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| Soil type | Mode | Fixed | | Flexible | |
|---|---|---|---|---|---|
| | | Bare frame | Infill frame | Bare frame | Infill frame |
| Hard soil | 1 | 2.1114 | 2.4673 | 2.3736 | 2.6905 |
| | 4 | 0.6862 | 0.802 | 0.7609 | 0.8589 |
| | 7 | 0.3913 | 0.4573 | 0.4258 | 0.4805 |
| | 12 | 0.2164 | 02581 | 0.2342 | 0.2690 |
| Medium soil | 1 | 2.3853 | 2.4673 | 2.3736 | 2.6905 |
| | 4 | 0.7859 | 0.802 | 0.7609 | 0.8589 |
| | 7 | 0.4295 | 0.4573 | 0.4258 | 0.4805 |
| | 12 | 0.2360 | 02581 | 0.2342 | 0.2690 |
| Soft soil | 1 | 2.4829 | 2.4673 | 2.3736 | 2.7109 |
| | 4 | 0.7886 | 0.802 | 0.7609 | 0.8681 |
| | 7 | 0.4356 | 0.4573 | 0.4258 | 0.4853 |
| | 12 | 0.2367 | 0.2581 | 0.2342 | 0.2710 |

Table 2: Natural period of 15 storey structure fixed and flexible foundation for different soils and modes

The fundamental natural periods found for all the three types of soils and for both rigid and flexible base conditions are tabulated in the above table. As considering the flexible base condition, the fixed base condition natural period is 8.5% is lesser for all type of soils.

- ➢ *Performance point and location of hinges*

As the structure is analyzed for seismic loading, the results are the storey displacements and drifts. The nonlinear static analysis is performed to know the plastic hinges formed in the beams and columns and to know the collapse prevention level for the given seismic loadings.

| Performance point | | | Hinges state | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Model | Base shear (kN) | Displacement (mm) | A - B | B - IO | IO - LS | LS - CP | CP - C | C - D | D - E | > E | Total |
| I | 2878.9 | 583 | 1944 | 342 | 594 | 0 | 0 | 0 | 0 | 0 | 2880 |
| II | 3833.6 | 583 | 1944 | 342 | 594 | 0 | 0 | 0 | 0 | 0 | 2880 |
| III | 4696.3 | 583 | 1944 | 342 | 594 | 0 | 0 | 0 | 0 | 0 | 2880 |
| IV | 2868 | 851 | 1944 | 0 | 586 | 350 | 0 | 0 | 0 | 0 | 2880 |
| V | 3816.5 | 851 | 1944 | 0 | 586 | 350 | 0 | 0 | 0 | 0 | 2880 |
| VI | 4656 | 851 | 1944 | 0 | 586 | 350 | 0 | 0 | 0 | 0 | 2880 |

Table 3: Plastic hinges and its performance point for the load case push for 15-storey fixed condition building

| Performance point | | | Hinges state | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Model | Base shear (kN) | Displacement (mm) | A - B | B - IO | IO - LS | LS - CP | CP - C | C - D | D - E | > E | Total |
| I | 1747.42 | 800 | 1980 | 276 | 264 | 310 | 0 | 2 | 48 | 0 | 2880 |
| II | 2591.10 | 800 | 1980 | 276 | 264 | 310 | 0 | 2 | 48 | 0 | 2880 |
| III | 3102.20 | 800 | 1980 | 276 | 264 | 310 | 0 | 2 | 48 | 0 | 2880 |
| IV | 1743.36 | 812 | 1980 | 248 | 292 | 310 | 0 | 2 | 48 | 0 | 2880 |
| V | 2582.38 | 812 | 1980 | 248 | 292 | 310 | 0 | 2 | 48 | 0 | 2880 |
| VI | 3090.22 | 812 | 1980 | 248 | 292 | 312 | 0 | 48 | 0 | 0 | 2880 |

Table 4: Plastic hinges and its performance point for the load case push for 15-storey flexible base building

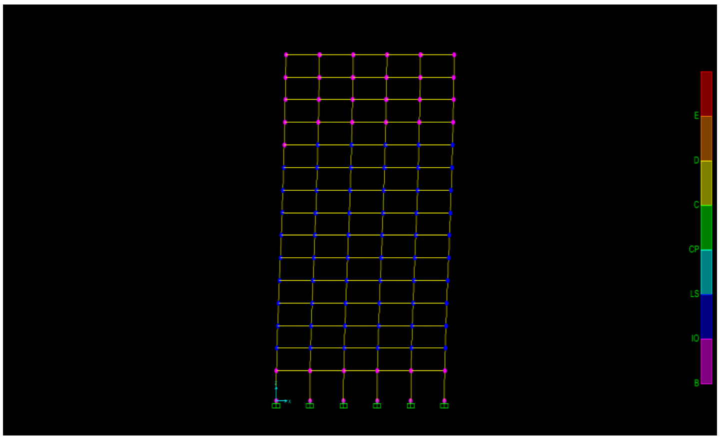

Figure 8: Formation of plastic hinges due to pushover analysis with fixed support condition

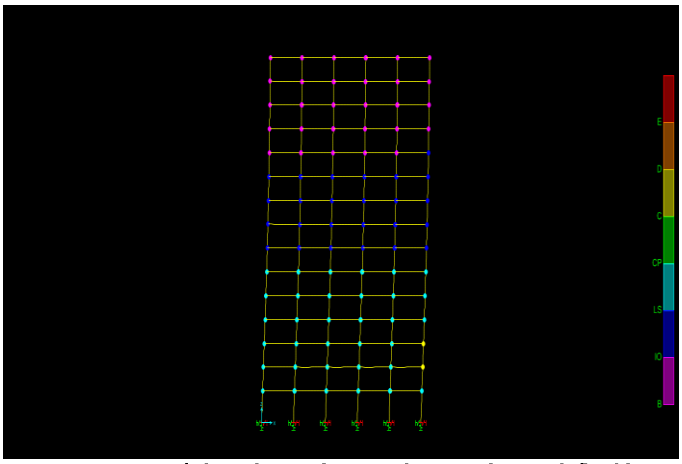

Figure 9: Formation of plastic hinges due to pushover analysis with flexible support condition

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- *Storey displacement*

Displacement of any structure is calculated by the difference between the deflection at roof to the deflection at the base, just like calculation of deflection of cantilever beam or a column. The displacements of any structures are explained for all types of soils with and without considering SSI in the following figures.

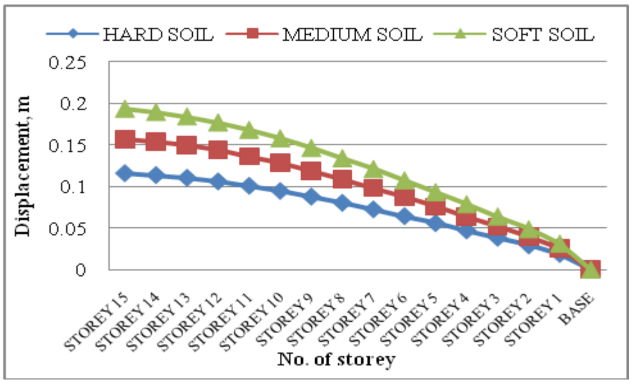


Figure 10: Graphical representation of Storey displacement for bare frame fixed base

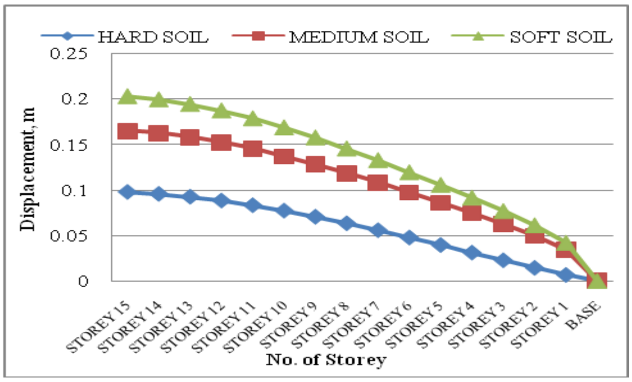


Figure 11: Graphical representation of Storey displacement for infill frame fixed base

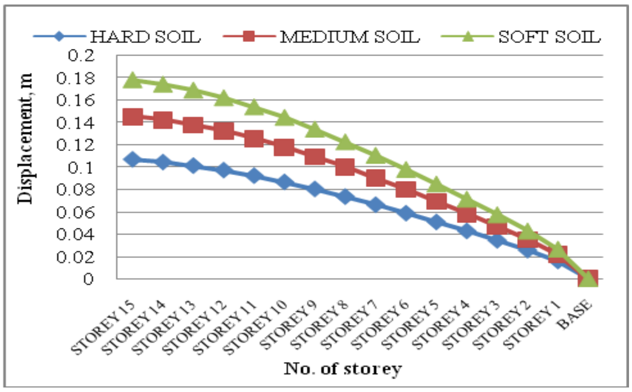


Figure 12: Graphical representation of Storey displacement for bare frame flexible base

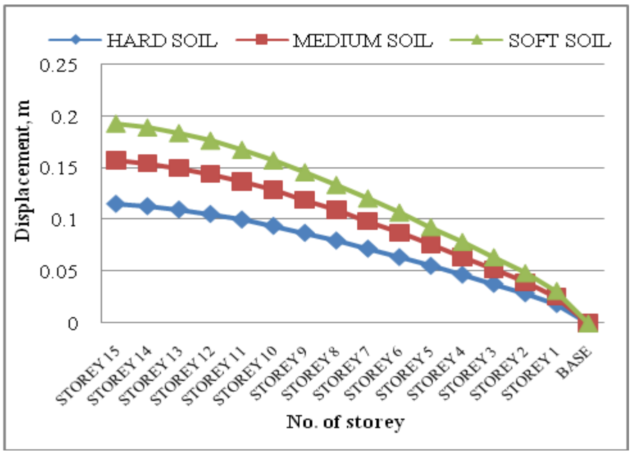


Figure 13: Graphical representation of Storey displacement for infill frame flexible base

There is not so much difference in storey displacements with and without considering soil structure interaction. However, as per the codal provisions the limiting value is H/250, which the soft soil type is crossing the limit for both fixed and flexible base.

- *Storey drifts*

Drift of any structure is calculated by the ratio of difference between the storeys to the total deflection. The drifts of any structures are explained for all types of soils with and without considering SSI in the following figures.

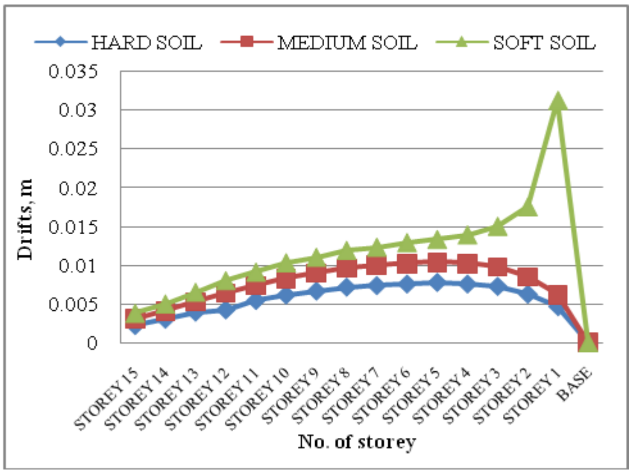


Figure 14: Graphical representation of Storey drift for bare frame fixed base

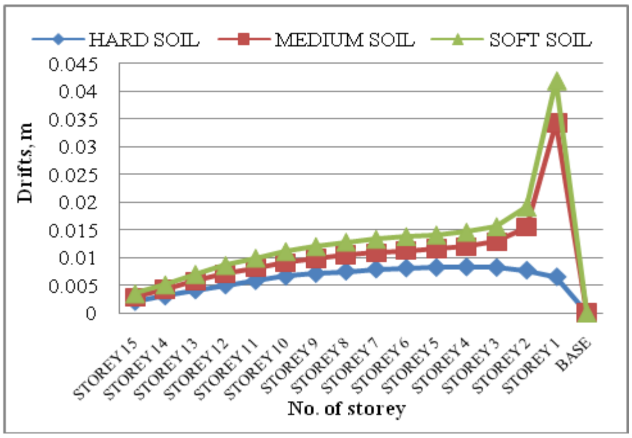


Figure no 15: Graphical representation of storey drifts with infill frame fixed base

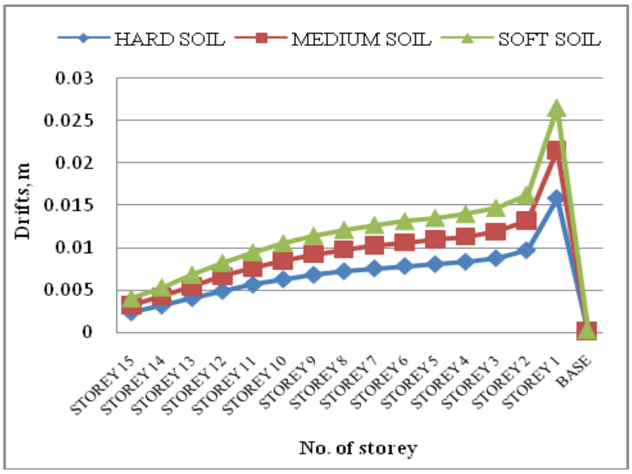


Figure no 16: Graphical representation of storey drifts with bare frame flexible base

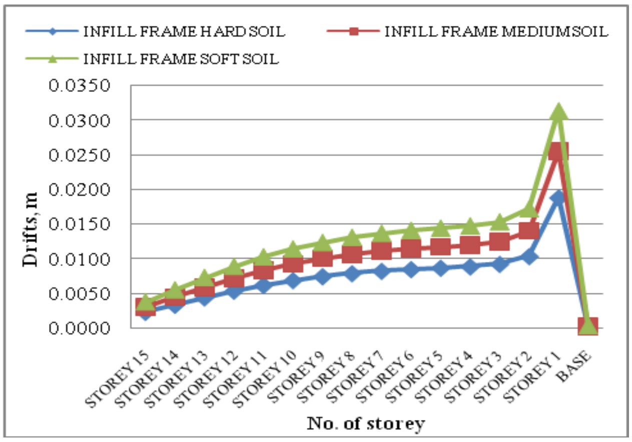


Figure no 17: Graphical representation of storey drifts with infill frame flexible base

## VI. CONCLUSIONS

In this present study, the reinforced 15-storey building is analyzed by including and not including soil structure interaction. The results are lead in the following conclusions.

1) Fundamental natural period for flexible base is much more than the fixed base framed structure, which tends to conclude that for the lateral forces the frame with flexible base takes maximum load than that of the fixed base frame.
2) As per the results, the structure is elastic for fixed base and the structure forms plastic hinges for flexible base, which mean the structure, need to do retrofitting for flexible base condition.
3) Storey displacement is more in case of bare frame building with respect to codal limiting value, with or without soil structure interaction.
4) Storey displacement even more in case of infill frame building with respect to the bare frame, with or without soil structure interaction.
5) Storey drift is more in case of bare frame building with respect to codal limiting value, with or without soil structure interaction.
6) Storey drift for infill building is more with respect to bare frame, with or without soil structure interaction.

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