Study of Soil Structure Interaction on Framed Structure using ETABS

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Abstract - *The response of a structure to earthquake shaking is affected by interactions between three linked systems: the structure, the foundation, and the soil underlying and surrounding the foundation. Soil-structure interaction analysis evaluates the collective response of these systems to a specified ground motion. The terms Soil-Structure Interaction (SSI) and Soil-Foundation-Structure Interaction (SFSI) are both used to describe this effect in the literature. In this paper, the foundation is considered part of the structure, and the term SSI has been adopted.*

***Key Words*: Soil structure interaction, framed structure, Behavior of foundation, ETABS**

1. INTRODUCTION

Soil-structure interaction, basically, can be defined as a collection of phenomena in the response of structures resulted from the flexibility of soil under the foundation, as well as in the response of soils caused by the presence of structures. A complete soil-foundation-structure system is composed of a frame in superstructure, its foundation and the soil on which it rests as illustrated in Figure 1. Both the axial forces and the moments in the structural members may change with the differential settlement (caused due to soil properties) among various parts of the structure.

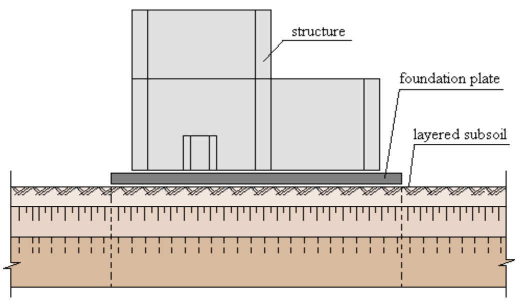


Fig -1: Interaction between structure, foundation plate and soil

Most civil structures contain some type of structural element that makes direct contact with the ground. When the external forces, such as earthquakes, act on these systems, the structural displacements and ground displacements are not remained independent of each other. The process by which soil response influences structural movements and structural movements affect soil response is called soil-structure interaction (SSI).

Rigidity of the structure and the load-settlement characteristics of soil affect the amount of redistribution of loads acting on the constructional members of the structure. Subsequently, there exist several studies in the literature conducted to estimate the effect of this factor. Conventional structural design methods neglect this SSI effects. Ignoring SSI is reasonable for light structures with relatively hard soil, such as low-rise buildings and simple rigid retaining walls. However, the effects of SSI are more pronounced on heavy structures resting on relatively soft soils such as nuclear power plants, skyscrapers, and highways.

Soil-structure interaction analysis is a method of evaluating the collective response of the above three linked systems to a specified earthquake motion. Soil-structure interaction can be defined as the process by which the response from the soil influences the movement of the structure and the movement of a particular structure influences the response from the soil. This is a phenomenon in which the structural displacements and the ground displacements are independent to each other.

Chaitanya Patel, Noopur Shah, (2016) studied the seismic behavior of reinforced concrete buildings with multiple underground stories. While the current research is primarily aimed at understanding the effects of changes in soil subgrade coefficients, the ultimate goal of this study is to make good recommendations for including underground stories in models for seismic analysis is to find out. To achieve this objective, the methodology involves the computer modelling by two alternate approaches, namely, building frame with fixed supports, building frame with supports accounting for soil-flexibility using STAAD.Pro. A comparison of the displacements of the frame and time period of the whole structure is done. They concluded that FEMA spring model gives higher time period compared to Fixed based model and Winkler model when soil subgrade modulus is 2750 kN/m3 and then winkler model gives higher value when soil subgrade modulus is 4500 kN/m3 and 6250 kN/m3. Winkler model gives higher value of maximum nodal displacement compared to other to models. Also says that with increasing number of storey variation in soil subgrade modulus effects is reduce. Soil subgrade modulus effects is more on softer soil and plays a significant role in increasing the storey shear and moment demand for relatively low rise building. Soil subgrade modulus effect depend on the stiffness of the foundation and the number of underground storey.

M Roopa et. al. (2015) mainly concentrated on in situ clayey soil conditions. The RC building measured to analyze SSI is a G+12-story apartment with an elevation of 40.15m and a plan shape of 28.2mX16.1m, proposed in Manbachham, South Chennai, Tamil Nadu, India. The study has used the finite element tools ETABS 9.7.4 for modeling and SAP2000 ver17 for SSI analysis. They concluded that Variation of storey drift in both the cases is parabolic with middle storeys showing maximum drift. Considering the SSI, the floor drift increases in the middle floor. Base shear for maximum flexible base conditions compared to fixed base conditions. Considering the effect of SSI, we can see that it has almost doubled from 1845.74 KN to 3475.90 KN. Natural time when building with a fixed base on soft soil in the first mode is 2.551 seconds, and when using a flexible base on clay soil increases by 37.39% to 3.505 seconds. A similar amount of increase in natural duration is understood in all 10 modes. The response of the tall building founded on clayey soil has shown significant increase compared to conventional approach of assuming fixed base and founded on soft soil. Significant increase in response of tall building when SSI is considered is because of flexibility induced to the base by the softness of clayey soil.

Aslan S. Hokmabadi et. al. (2015) intended to study the effects of the seismic soil-pile-structure interaction (SSPSI) on the dynamic response of buildings with various heights by conducting a series of shaking table tests on 5-, 10-story, and 15-story model structures. Two types of foundations for each case are investigated, including (1) a fixed-base structure, representing the situation excluding the soil- structure interaction; and (2) a structure supported by an end-bearing pile foundation in soft soil. An advanced laminar soil container has been designed that uses three dimensional numerical modeling to minimize the boundary effects and to simulate free-field motion during the shaking table tests. Four real earthquake events, including Kobe 1995, Northridge 1994, El Centro 1940, and Hachinohe 1968, are imposed to each model. According to the experimental measurements, it is observed that the SSPSI amplifies the maximum lateral deflections and in turn inter-story drifts of the structures supported by end-bearing pile foundations in comparison with the fixed-base structures. They concluded that considering the effects of the SSPSI can alter the dynamic characteristics of the soil-pilestructure system. In addition, the lateral deflections of structures sitting on end-bearing pile foundations were amplified in comparison with the fixed-base model. Generally, this amplification, which is mainly a result of the rocking component, is more severe for taller buildings, considering the range of the buildings investigated in this study. Moreover, by increasing the height of the model structure, more bending moments were generated in the pile elements. This is because of the fact that the 15-story model structure, as a result of its larger mass, attracts more inertial force from the same seismic excitation in comparison with the 10- or 5- story modelstructures.

Jui-Liang Lin et al. (2014) the proposed approximate method transfers the frequency independent equation of motion for the SSI system into a set of MDOF modal equations of motion. There are four advantages to this method at the expense of increasing degrees of freedom for each vibration mode. The first two advantages are similar to those of conventional modal response history analysis, whereby there is a significant decrease of the degrees of freedom required in the analytical work and the use of only the first few vibration modes to achieve satisfactory analytical results. On the other hand, another advantage is the preservation of the characteristics of non-proportional damping in the MDOF modal equations of motion. This would appeal to practicing engineers instead of performing calculations of the complicated equivalent modal damping. The final advantage is the transformation of the soil springs and dashpots into modal level. Thus, the impedance functions and their influences for each vibration mode can be explicitly quantified. The limitation of the proposed method is that the soil–structure systems must be simulated approximately as frequency independent systems. The extension of this study to more sophisticated models for the SSI problem, e.g., frequency-dependent inelastic systems with embedded foundations, will be carried out in the future.

Barış Sevim et.al 2019 [5] studied the blasting response of a two-storey reinforced concrete (RC) building under different charge weight of TNT explosives. In this study, a two-storey RC building was numerically modeled involving RC columns, beams, floors as structural elements, & walls and windows as non-structural elements. A blast modeling was constituted using ANSYS AUTODYN (2016) software, also the explicit analysis of the building was performed in this software for a duration of 3 m-sec. Simulation is performed for a model of an existing building in Istanbul, Turkey bombed in August 2015 using ANSYS Workbench. Three explicit analyses were performed considering 0.1 ton, 0.25 ton and 0.5 ton TNT explosives. The results showed that the different charge weight of TNT explosives considerably affected blasting response of the two-storey RC building. Also, the main damages are obtained on the first storey slab. The pressure values obtained show that the building can resist against blast loading of 0.1 ton TNT explosive.

1.1 Nonlinear Behavior of Soils

Soil, as a flexible material, behaves nonlinearly after the primary loading. This behavior is so complex that its mathematical simulation has always been a challenging task to the engineers. This behavior is also time-dependent. This nonlinearity is the main factor of the uncertainties of static behavior of soil foundation-superstructure system after construction. From the physical point of view, it is clear that when an external load is applied on the soil mass, the soil particles show a tendency to attain such a structural configuration that their potential energy will be a minimum and hence stability is achieved. Until a certain stress level is reached, strain passed onto the soil mass in this process is elastic. After a while, depending on the magnitude of applied load, it may enter the plastic range. This is followed by a visco-plastic deformation due to viscous inter-granular behavior, by which strain with passage of time is implied. Some of the factors that affect the behavior of soil are as follows;

a) Heterogeneous distribution
b) Anisotropy
c) Geometric differences (large displacements)
d) The nonlinear behavior between the interfaces
e) Cracks
f) Underground water consolidation

1.2 Effect of soil structure interaction on structural response

Traditionally, soil-structure interaction has been thought to have a beneficial effect on a structure's seismic response. Many design standards rationally show that seismic analysis of structures can neglect the effects of SSI. This myth about SSI seems to stem from the false perception that SSI reduces the overall seismic response of a structure, thus leading to improved safety margins. Most design codes use a simplified design spectrum. It achieves a certain acceleration up to a certain period and then decreases monotonically with time. During traditional designing of a structure, sub-structure is considered as rigid. When soil structure interaction is considered the sub- structure becomes less rigid or more flexible. Therefore, considering the soil-structure interaction, the structure will be more flexible and the natural period of the structure will be longer compared to the corresponding fixed support structure. In addition, considering the SSI effect increases the effective damping ratio of the system. The smooth idealization of the design spectrum suggests a smaller seismic response due to the natural period increase due to SSI and the effective damping ratio. With this assumption, it was traditionally being considered that SSI can conveniently be neglected for conservative design.

In addition, ignoring SSI significantly reduces the complexity of structural analysis and allows designers to ignore the impact of SSI on their analysis.

This conservative simplification is useful for certain classes of structures and soil conditions, such as lighter structures on relatively hard soils. Unfortunately, this assumption does not always hold. In fact, SSI can have a detrimental effect on structural response, and ignoring SSI in the analysis can be dangerous for both superstructure and foundation designs.

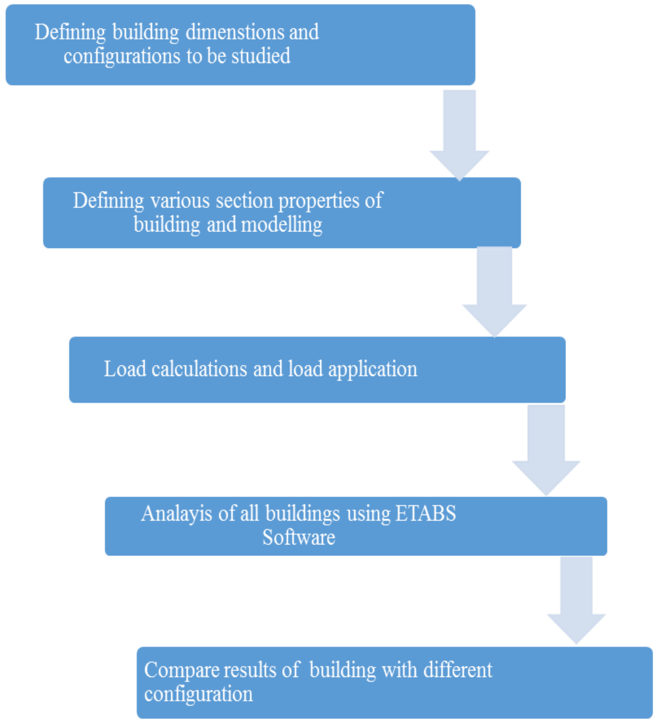
1.3 Objectives of investigation

1. To check the stability of structure with seismic load in seismic zones IV.
2. To understand the effect of soil structure interaction.
3. To find the effect of SSI on structure.
4. To establish guidelines to prevent the effect of soil structure interaction

2. METHODOLOGY

For present work seismic analysis is carried out for reinforced concrete moment resisting building frame G+12 Storey, is considered for the present study to investigate SSI effects on tall buildings. The plan dimension of the building is 28.20 m by 16.10 m and the height of the building is 43 m from the ground level. The stilt height is 4m from the base level and all other stories are 3 m. Two types of buildings considered in the study, which are

1) Buildings without fixed base (soft and hard)
2) Buildings with flexible base with SSI



A 12-story building modeled using ETABS 9.7.4 software to facilitate modeling. The entire building is modeled as a 3D RC frame model. Beams and columns are modeled using R.C 3-D beam elements with 6 degrees of freedom at each node. The slab is modeled as an infinitely rigid membrane in its own plane to provide diaphragm action for transferring horizontal loads to columns and shear walls. Shear walls are modeled using R.C 3-D shell elements.

The 3D R.C beam element is used for modeling the frame of the structure. Steel is modeled as a bar element and concrete as a beam element, assuming a perfect bond between the two materials. The frame section ofthe modeling process contains beams and columns. Sections of various columns used in modeling. All columns are made of M35 grade concrete and Fe 500 grade steel. Details of beam and column sections used in modeling are shown in Table1

Table 1 Sections properties of all structural members

Beams	Columns	slab	shear wall
230mm0x450mm for all floors	350x750 for first 5 floors	125mm for all floors	150mm for all floors
	350x450 for remaining floors		

Slabs and shear walls are modeled with R.C shell elements. The shell element is a stack of monolayer membranes with different thickness and eccentricity. The shell element can withstand bending, shearing and membrane forces. Floor slabs are modeled with membrane elements because they are assumed to be rigid diaphragms. Seismic walls are modeled using 3D quadrilateral shell elements, with M35 grade material assigned to all shell elements

2.1 Buildings with fixed base

The co-ordinate points are the placements of columns according to the base plan layout of the structure. All the points will be constrained with ux, uy, uz, rx, ry and rz coordinates for fixed base condition, which means no linear and rotational displacements are allowed. Storey 1 being a Master storey, remaining stories modeled according to it. The complete building has been modeled using appropriate elements of beams, columns, slabs and shear walls in each storey. The 3-Dimensional view of the tall building is as shown in Fig. 2.

2.2 Building on Raft foundation

The 29.8x17.7x0.5m raft foundation is modeled using a thick R.C. Shell elements, to facilitate simulation of Soil Structure Interaction effects for the clayey soil. The building with raft foundation model is as shown in the Fig.

3. The properties of clayey soil have adopted and calculated, are shown in Table-2. Spring stiffness values for vertical, horizontal, rocking and twist motion are calculated according to the Richart and Lysmer models. The entire area is meshed with quad shell elements and a soil spring is applied.

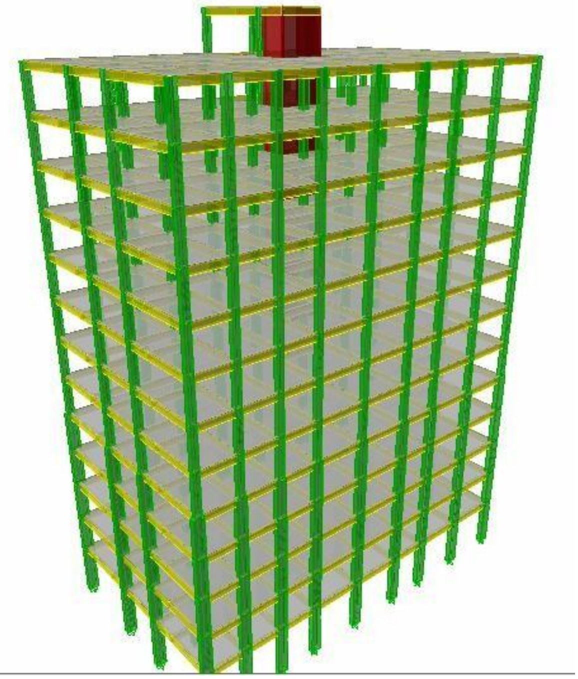


Fig. 2: 3D rendering view of building with fixed base in ETABS

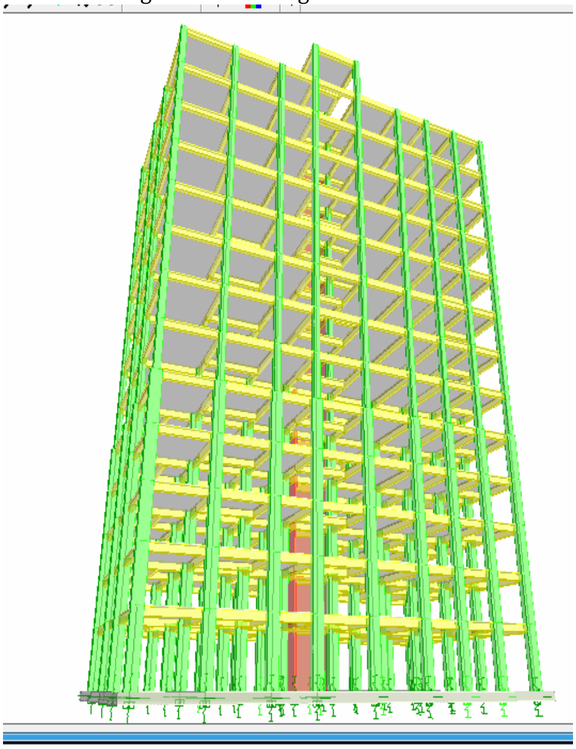


Fig. 3: 3D rendering view of building with raft foundation and applied soil springs in ETABS

Table 2: Soil Spring Values as Per Richart and Lysmer

Direction	Spring Values	Equivalent Radius
Vertical	$K_z=\frac{4Gr_z}{(1-\theta)}$	$r_z=\sqrt{\frac{LB}{\pi}}$
Horizontal	$K_x=K_y=\frac{32(1-\theta)Gr_x}{(7-8\theta)}$	$r_x=\sqrt{\frac{LB}{\pi}}$
Rocking	$K\omega_x=\frac{8Gr^3_{x\varphi}}{3(1-\theta)}$	$r_{\omega x}=\sqrt[4]{\frac{LB^3}{3\pi}}$
	$K\omega_y=\frac{8Gr^3_{y\varphi}}{3(1-\theta)}$	$r_{\omega y}=\sqrt[4]{\frac{LB^3}{3\pi}}$
Twisting	$K\varphi_z=\frac{16Gr^3_{z\varphi}}{3}$	$r_{\omega z}=\sqrt[4]{\frac{LB^3+BL^3}{6\pi}}$

3. RESULTS AND DISCUSSIONS

After analyzing all the models with response spectrum analysis we found that values of lateral displacement (mm) with floor level in X direction increased slightly around 5- 10% with soil structure interaction as compared to fixed base. The values of lateral displacement (mm) with floor level in Y direction increased slightly around 4-5% with soil structure interaction as compared to fixed base. Values of time period of building with mode no for zone IV increased slightly around 1-2% with soil structure interaction as compared to fixed base. Values of Story Drift with floor level in X direction for zone IV increased by 5-10% with soil structure interaction as compared to fixed base case. Values of Story Drift with floor level in Y direction increased by 6- 8% with soil structure interaction as compared to fixed base case. It is found out that, base shear in X and Y direction is almost similar in both cases as there is no increase in seismic weight of the building.

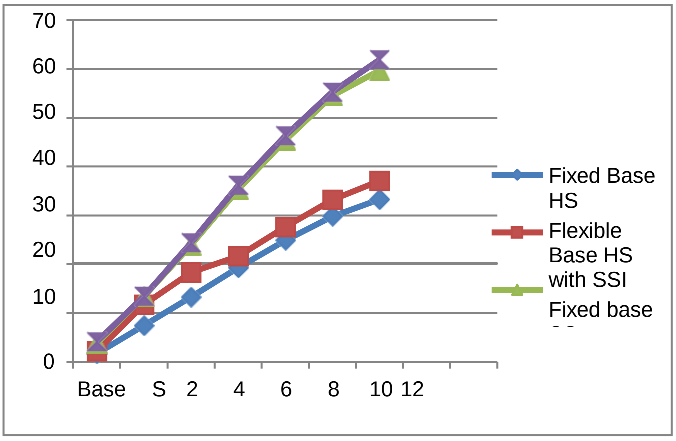


Chart-1: Variation of lateral displacement (mm) with floor level in X direction

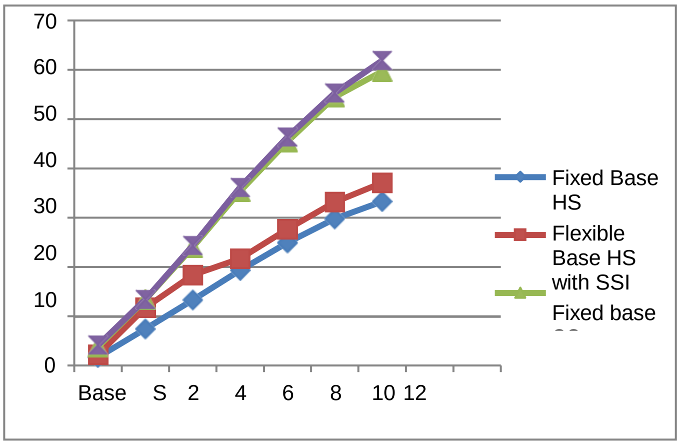


Chart-2: Variation of lateral displacement (mm) with floor level in Y direction

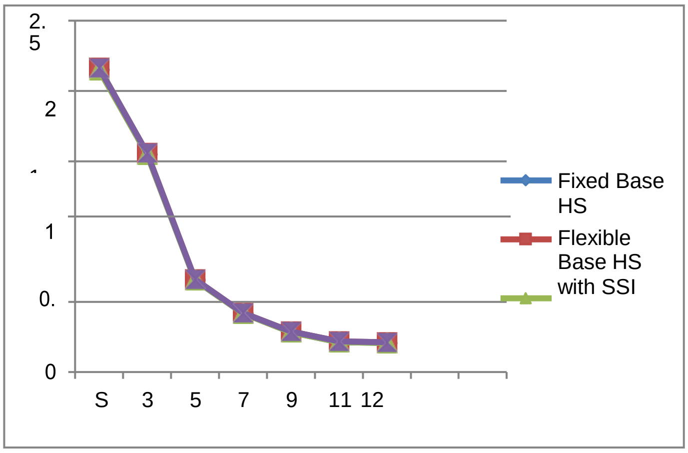


Chart-3: Variation of time period of building with mode shape no

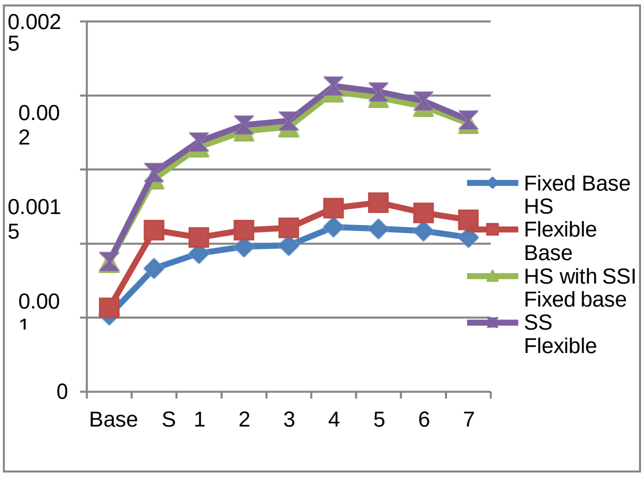


Chart-4: variation of Story Drift with floor level in X direction

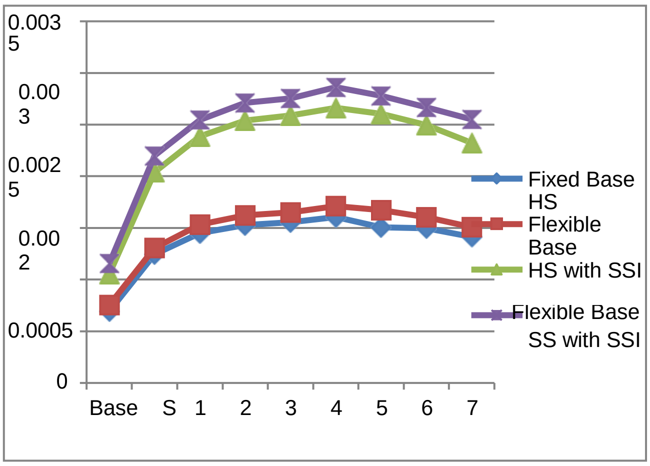


Chart-5: Variation of Story Drift with floor level in Y direction

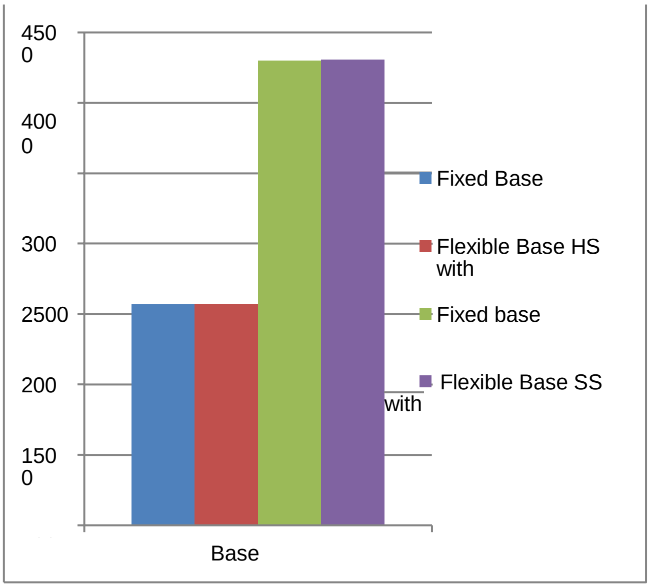


Chart-6: Variation of base shear (kN) of buildings in X direction

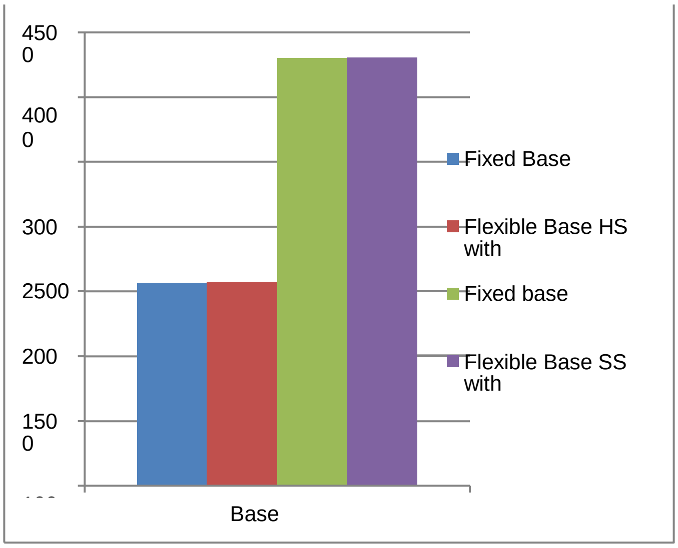


Chart-7: Variation of base shear (kN) of buildings in Y direction

4. CONCLUSION

Variation of storey drift in both the cases is parabolic with middle storeys showing maximum drift. When SSI is considered there is a magnification of storey drift in the middle storeys. Variation of lateral displacement in both the cases is maximum at top stories showing maximum displacement. The displacement value increases when SSI is taken into consideration. The base shear for with soil structure interaction case is almost same as compared to fixed base case as there is no increase in seismic weight of the building. The natural time period in case of building with soil structure interaction is increased a little as compared to fixed base case. The response of the tall building founded on soft soil has shown significant increase compared to hard soil for both fixed base and SSI case. The significant increase in skyscraper response when considering SSI is due to the flexibility induced in the base.

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