ANALYSIS OF SOIL STRUCTURE INTERACTION FOR COMPOSITE STEEL AND RCC UNDER SEISMIC ZONE

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Abstract- The influence of soil-structure interaction in the analysis and design of a 6-storey and basement reinforced concrete frame building is investigated. Models simulating two different conditions: namely soil-structure interaction, and fixed-base behavior are considered. The influence of the soil structure interaction in the dynamic behavior of the structure is reflected in an increase in the vibration period as well as increase in the system damping in comparison with the fixed-base model, which does not consider the supporting soil. Conventional fixed-base analysis ignoring the effect of soil-flexibility carried out for the seismic design of buildings may result in unsafe design. Therefore, the effect of SSI is an important issue from the viewpoint of design considerations. Thus to evaluate the realistic behavior of structure the soil structure interaction (SSI) effect shall be incorporated in the analysis. In seismic analysis provision of bracing system is one of the important option for the structure to have sufficient strength with adequate stiffness to resist lateral forces. The different configuration of these bracing systems alters the response of buildings, and therefore, it is important to evaluate the most effective type and location of the bracing systems in view point of stability against SSI effect. In present study, two RC building frames, G+10 and G+15 with six different combinations of steel bracing system at alternate locations incorporating the effect of soil flexibility is considered in order to investigate the effectiveness of bracing system to control SSI. The seismic analysis is carried out using equivalent static method as per IS 1893-2002 The study is carried out using Elastic continuum approach(ECM) The influence of SSI on various seismic parameters and the flexural parameters are presented. The changes in all these parameters due to provision of steel bracing system are studied in order to evaluate its effectiveness in controlling the SSI effect. The study reveals that, steel bracing system plays important role to control SSI effect and it is observed that diagonal bracing placed at mid periphery are more effective, in resisting seismic load considering SSI.

Keywords: Steel Bracing System, Soil Structure Interaction, Elastic Continuum Approach, Natural Period**.**

1. INTRODUCTION

1.1 Soil Structure Interaction

Definition of soil structure interaction: The process in which the response of the soil influences the motion of the structure and motion structure influences the response of the soil is termed as soil structure interaction. Probably the most widely used value in a soil report is soil bearing capacity. The obvious reason is that basic examples given in most text books almost always use bearing capacity to calculate the plan dimension of a footing. Because of simplicity and ease of use, this method is still the fundamental soil parameter for foundation design. However, that simplicity assumes the footing will behave as a rigid body. That particular assumption works well in practice for small and single column footings. But for large and multi column foundations, most engineers prefer flexible analysis

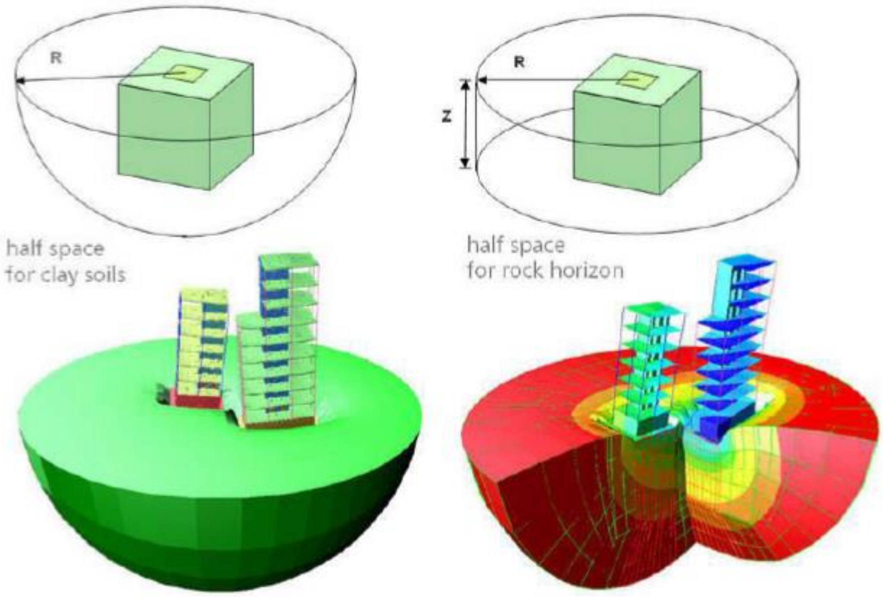

Fig 1.1: Behavior of Soil and Structures

Structural dynamics deals with methods to determine the stresses and displacements of a structure subjected to dynamic loads. The dimensions of the structure are finite. It is thus rather straightforward to determine a dynamic model with a finite number of degrees of freedom. The corresponding dynamic equations of motion of the discretized structure are then formulated, and highly developed methods for solving them are readily available. In general, however, the structure will interact with the surrounding soil. It is thus not permissible to analyze only the structure. It must also be considered that in many important cases (e.g., earthquake excitation) the loading is applied to the soil region around the structure; this means that the former has to be modeled anyway. The soil is a semi-infinite medium, an unbounded domain. For dynamic loading, this procedure cannot be used. The fictitious boundary would reflect waves originating from the vibrating structure back into the discretized soil region instead of letting them pass through and propagate toward infinity. This need to model the unbounded foundation medium properly distinguishes soil dynamics from structural dynamics.

1.2 Background

Most of the structures involve some type of structural element with direct contact with ground. When the external forces, such as earthquakes, act on these structures, neither the structural displacements nor the ground displacements, are independent of each other. 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). In conventional structural design it is assumed that building has a fixed base condition. However in reality it rests on flexible media (soil) which incorporates flexibility to the base resulting in to SSI phenomena. Neglecting effect of SSI in case of light structures resting on stiff soil is not significant. However, it becomes prominent for stiff structures resting on relatively soft soils In case of Tall buildings; the gravity load resisting system cannot resist lateral forces efficiently. It is well recognized that the incorporation of lateral force resisting systems in the form of shear walls, bracing systems etc. improve the structural performance of building subjected to lateral forces due to earthquake excitation.

Bracing systems are used to resist horizontal forces (wind load, seismic action) and to transmit to the foundation. The bracing members are arranged in many forms, which carry solely tension, or alternatively tension and compression. Bracings hold the structure stable by transferring the loads sideways (not gravity, but wind or earthquake loads) down to the ground and are used to resist lateral loads, thereby preventing sway of the structure There are different types of bracing systems in common use such as single diagonal bracing, X bracing, V bracing, K bracing, inverted V bracing. Further, the position of bracings in a building alters the response of structure. It is desirable to decide the position of the bracings, so that maximum benefit can be derived. Similarly, incorporation of SSI in the analysis is desirable to estimate the most realistic performance of the structure. In view of the above in the present study an attempt is made to investigate effect of SSI and also the effectiveness of alternate bracing system in the performance of the structure

1.3 Motivation

Most of the structures involve some type of structural element with direct contact with ground. When the external forces, such as earthquakes, act on these structures, neither the structural displacements nor the ground displacements, are independent of each other. 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). In conventional structural design it is assumed that building has a fixed base condition. However in reality it rests on flexible media (soil) which incorporates flexibility to the base resulting in to SSI phenomena. Neglecting effect of SSI in case of light structures resting on stiff soil is not significant. However, it becomes prominent for stiff structures resting on relatively soft soils In case of Tall buildings, the gravity load resisting system cannot resist lateral forces efficiently. It is well recognized that the incorporation of lateral force resisting systems in the form of shear walls, bracing systems etc. improve the structural performance of building subjected to lateral forces due to earthquake excitation. Bracing systems are used to resist horizontal forces (wind load, seismic action) and to transmit to the foundation. The bracing members are arranged in many forms, which carry solely tension, or alternatively tension and compression. Bracings hold the structure stable by transferring the loads sideways (not gravity, but wind or earthquake loads) down to the ground and are used to resist lateral loads, thereby preventing sway of the structure There are different types of bracing systems in common use such as single diagonal bracing, X bracing, V bracing, K bracing, inverted V bracing.

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1.4 Objective of the Study

1) To study the dynamic properties of building frame considering Soil Structure Interaction (SSI) effect.
2) To evaluate the effectiveness of alternate bracing system to reduce the SSI effect.
3) To identify the best possible type and location of bracing to control SSI and improve the overall performance of structure.

1.5 Problem statement

Conventional fixed-base analysis ignoring the effect of soil-flexibility carried out for the seismic design of buildings may result in unsafe design. Therefore, the effect of SSI is an important issue from the viewpoint of design considerations. Thus to evaluate the realistic behavior of structure the soil structure interaction (SSI) effect shall be incorporated in the analysis. In seismic analysis provision of bracing system is one of the important option for the structure to have sufficient strength with adequate stiffness to resist lateral forces.

1.6 Scope of the project

The scope of this project is to analyse, two RC building frames, G+10 and G+15 with six different combinations of steel bracing system at alternate locations incorporating the effect of soil flexibility is considered in order to investigate the effectiveness of bracing system to control SSI. The seismic analysis is carried out using equivalent static method as per IS 1893-2002 The study is carried out using Elastic continuum approach(ECM) The influence of SSI on various seismic parameters and the flexural parameters are presented.

2. REVIEW OF LITERATURE

1. Antonios K. Flogeras et al. This paper summarizes estimated seismic response results from three-dimensional nonlinear inelastic time-history analyses of some steel buckling-restrained braced (BRB) structures taking into account soil-structure interaction (SSI). The response results involve mean values for peak inter storey drift ratios, peak inter storey residual drift ratios and peak floor accelerations. Moreover, mean seismic demands in terms of axial force and rotation in columns, of axial and shear forces and bending moment in BRB beams and of axial displacement in BRBs are also discussed. For comparison purposes, three separate configurations of the BRBs have been considered and the aforementioned seismic response and demands results have been obtained firstly by considering SSI effects and then by neglecting them. It is concluded that SSI, when considered, may lead to larger inter storey and residual inter storey drifts than when not. These drifts did not cause failure of columns and of the BRBs. However, the BRB beam may fail due to flexure.

2. **Julio A. García et al** The influence of soil-structure interaction in the analysis and design of a 6-storey and basement reinforced concrete frame building is investigated. Models simulating two different conditions: namely soil-structure interaction and fixed-base behavior are considered. The influence of the soil structure interaction in the dynamic behavior of the structure is reflected in an increase in the vibration period as well as increase in the system damping in comparison with the fixed-base model, which does not consider the supporting soil. The influence of the soil-structure interaction in the seismic design of the structure is reflected in a decrease of the horizontal spectral acceleration values. The inclusion of the soil in the structural analysis provides results, stress and displacement values, which are closer to the actual behavior of the structure than those provided by the analysis of a fixed-base structure.

3. **Mr. Magade S. B et al.** A common design practice for dynamic loading assumes the building to be fixed at their bases. In reality the supporting soil medium allows movement to some extent due to its property to deform. This may decrease the overall stiffness of the structural system and hence may increase the natural periods of the system, such influence of partial fixity of structures at foundation level due to soil flexibility intern alters the response. Such an interdependent behavior of soil and structure regulating the overall response is referred to as soil structure interaction. This effect of soil flexibility is suggested to be accounted through consideration of springs of specified stiffness. Thus the change in natural period due to effect of soil structure interaction may be an important issue from the viewpoint of design considerations

4. **Zhenyun Tang et al.** Because of the limitations of testing facilities and techniques, the seismic performance of soil-structure interaction (SSI) system can only be tested in a quite small scale model in laboratory. Especially for long-span bridge, a smaller tested model is required when SSI phenomenon is considered in the physical test. The scale effect resulting from the small scale model is always coupled with the dynamic performance, so that the seismic performance of bridge considering SSI effect cannot be uncovered accurately by the traditional testing method. This paper presented the implementation of real-time dynamic sub structuring (RTDS), involving the combined use of shake table array and computational engines for the seismic simulation of SSI. In RTDS system, the bridge with soil-foundation system is divided into physical and numerical substructures, in which the bridge is seen as physical substructures and the remaining part is seen as numerical substructures. The interface response between the physical and numerical substructures is imposed by shake table and resulting reaction force is fed back to the computational engine. The unique aspect of the method is to simulate the SSI systems subjected to multisport excitation in terms of a larger physical model. The substructuring strategy and the control performance associated with the real-time substructuring testing for SSI were performed. And the influence of SSI on a long-span bridge was tested by this novel testing method.

5. **A.A. Gudadhe et al.** The majority of the structures are having enduring contact of one or more elements with the soil. Neither structural nor the ground displacements are independent of each other after the application of motions. Usually, the effect of Soil-Structure Interaction is avoided for the light structures and becomes important for heavy structures. This paper represents the comparative study of the effect of influence of Soil-Structure Interaction (SSI) on different structures like bridges, dam, laterally loaded pile, etc. An immeasurable loss is expected when the bridges or dam are damaged due to earthquakes which occurs due to break away of surrounding soil of the structures. This effect leads to the importance of study of Soil-Structure Interaction for heavy structures and the same is presented through comparative study of different structures 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 [1]. Almost all seismic structural response is caused by SSI forces, whereas in certain situations only the effect of SSI is considered. The analysis of SSI is a unique area of earthquake engineering. Substructure method and Direct method are the two main methods of analysis of SSI [3]. Though most of the codes have given the provisions for torsion resistant structures and asymmetry structures, but soil structure interaction can change the seismic behavior of the asymmetric structure [4]. That's why it has now been widely accepted that during analysis and design for seismic, the effect of SSI should be taken into consideration. The most important methods for understanding the behavior of structure with foundation and of foundation with soil are laboratory test and numerical simulation [5].

6. **Anantha Kavya Supriya et al.** In every structure, the super structure and the foundation executed on soil, represent an entire structural system. The analysis of a framed structure while not modeling its foundation system and its rigidity could mislead the axial forces, moments due to bending and due to settlement. It is, thus necessary to hold out the analysis considering the type of soil, foundation and above the sub structure i.e. (super structure). Hence the analysis of

the single bay single storied building frame resting on soil (Clayey Soil) is taken for present study. The analysis is carried out using "ANSYS 16.0". In this paper the effect of soil interaction on building frame design parameters as change of modulus of sub-grade reaction from 0.010 to 0.050 N/mm3.Shear force, Bending moment and settlements have been studied for different footing sizes of 1mx1m to 4.5mx4.5m the effect of SSI is quantified using finite element analysis. The following conclusions have been drawn from the study, the shear force and axial force value in the beam and column is constant from finite element analysis are not having considerable difference. The analysis is predicting that percentage difference in bending moment in beam, column and footings are at lower EFS value i.e 0.010N/mm3 at lower footing size 1mX1m is greater than when compared to higher EFS value i.e 0.050N/mm3 at higher footing size 4.5mX4.5m which considers soil interaction. But in case of the footings they undergo some settlement the percentage difference of settlement is 14.41% and 6.72% at lower EFS value i.e 0.010N/mm3 at lower footing size 1mx1m when compared to higher EFS value i.e 0.050N/mm3 at higher footing size 4.5mx4.5m respectively, which considers soil interaction.

7. Ponnala Ramaiah et al. One of the real difficulties for structural engineers is design and construction of structures with satisfactory performance under dynamic loading conditions actuated by strong wind or seismic tremors. SSI is a major problem in the construction process, which may alter the dynamic characteristics of the structural response altogether. The SSI system has two characteristic differences from the general structural dynamic system which are the unbounded nature as well as the non-direct characteristics of the soil medium. This study considering the SSI impacts in dynamic impacts of concrete moment opposing building frames resisting on Soil Pile Structure (SPS) is additionally anticipated. In SSI modeling, for diminishing the complexity and enhance the prediction accuracy, Adaptive Neuro Fuzzy Inference System (ANFIS) model with Opposition Based BAT Algorithm (OBAT) is proposed. It is demonstrated that the proposed model can foresee the dynamic response of the soil-structure system with great accuracy in much less time contrasted and the current strategies.

8. Dr. S.A. Halkude et al. Structural redundancy is constraint in the analysis which is of paramount importance from seismic consideration. The masonry in the framed structure is used primarily to create an enclosure and safety to occupants. Such masonry walls are known as infill walls. There will be structural interaction between framed members and infill walls. The combined behavior of the infill wall and structural frame is studied by many researchers from previous occurred earthquakes by modeling the masonry infill walls by compression strut elements. The steel frames with infill walls are general systems in the construction of usual residential buildings in some countries. It is obviously found that the seismic performance of structures is getting changed by considering the masonry infill walls in the analysis. In order to investigate the effect of infill walls on the steel frame, constructed with masonry infill walls, the seismic parameters like Time period, Base shear and Displacement were extracted for the frames with masonry infill's. The present research work aims to study the seismic analysis of steel and RCC plane frames with and without masonry infill walls. The Seven storeyed frames with varying number of bays are analysed by seismic coefficient method for obtaining Time period, Base shear and displacement. It is observed that consideration of brick infill indicates considerable effects on performance as compared to bare frames. It is found that infill wall reduces the time period, displacement for steel as well as RCC frames. The time period is found decreased for frames with infill walls. Base shear has substantially increased for frame with infill wall. The displacement and time period has been found to be reduced for bare frame and infill frame for steel as well as RCC frames when numbers of bays are increased from 2 bays to 10 bays. The inclusion of infill wall produces substantial improvement for steel frame whereas for RCC frames the improvement is marginal.

9. Ghalimath A.G et al. Earthquake in populated areas throughout the word causes intensive damage to the various structures that result in catastrophic loss of human life and enormous economic losses. However, the damage can be attributed to the inadequate design of the structures. This paper deals with seismic soil structure interaction analysis. It has conventionally been considered that soil-structure interaction has a beneficial effect on the seismic response of structure. Considering soil-structure interaction makes a structure more flexible and thus, increasing the natural period of the structure compared to the corresponding rigidly supported structure. The seismic waves circularize through soil during an earthquake, a discontinuity in the métier of wave propagation is clashed at the interface of soil and structural foundations. A structure subjected to an earthquake excitation, it interacts with the foundation and the soil, and thus changes the motion of the ground. The change in the material properties leads to scattering, diffraction, reflection, and refraction of the seismic waves at this soil-foundation interface thereby changing the nature of ground motion at that point from what would have otherwise been observed in the absence of structure and foundation.

10.Prof. Dr.B.R.Patagundi et al. In the construction of high rise structure the SOIL STRUCTURE INTERACTION (SSI) should be consider in evaluation of stiffness and strength of structure. Usually in the seismic design of ordinary bldg, soil structure interaction is neglected. But the lateral loads (Seismic & wind forces) work as an main role in the construction of high rise structures. The structure is analyzed for its structural behavior assuming base condition as fixed base. it is observed that effect of soil structure interaction is changes as the flexibility of soil varies. i.e., for fixed as well as for various flexible base conditions, i.e., for hard, medium and soft soil. In this study G+20 structure is analyzed with the help of STAAD-Pro V8i software, by equivalent static method with Winkler's approach method. considering three different soil types and compared with different arrangements of bracings system. This study reveals that SSI significantly affects the response of structure. The different parameters like Base shear, roof Displacement, Drift-ratio are considered to evaluate the output of plane frame and structures with different bracing system of models. and it is represented in the form of tables & graphs which will help us to understand the behavior of braced structure under the effect of soil structure interaction and also to suggest the better performance among the structures.

11.Lavanya. N et al. Owing to the difficulties involved in making dynamic analytical models of the soil system, it is common practice to ignore soil structure interaction (SSI) effects, simply by treating structures as if they are rigidly based, regardless of the soil condition. However, to evaluate the seismic response of a structure at a given site the dynamic properties of the combined soil-structure system must be examined. To understand the effect of SSI on structural behaviour of building supported on isolated foundation. A total of 14 models consisting of five and eight stories building structures supported on isolated footing such as Square & Rectangular footings are created. The parameter varied includes soil types like Hard, Medium and Soft Soil. Effect of SSI is accounted by means of point spring element and fixed support condition. Based on Comparison of time period for point spring element and fixed support it is observed the magnitude of time period for Soft Soil Condition is higher in comparison to Fixed Support, Medium and Hard Soil types. The Story Response values such as Displacement, Base Shear and Overturning moment was always higher for Soft Soil. Thus Soft Soil condition is more crictical in all cases.

3. RESEARCH METHODOLOGY

3.1 Soil Idealization

Present study is done to focus on mainly SSI effect on various parameters of building frame. In the past many researchers have developed different approaches such as Winklerian approach, Elastic continuum approach to investigate SSI effect. Elastic continuum approach (ECM) is considered in present study as it is possible to incorporate much complex condition in the analysis with high degree of realism.

ECM is a physical representation of the infinite soil media. In this method whole soil mass below the foundation which is under the influence of loading is considered. The soil mass, foundation and structure are discretized in small elements. The governing equations of motion for the structure incorporating foundation interaction and the method of solving these equations are relatively complex. Therefore, direct method is employed in this study and finite element software, SAP2000, is use to model the soil structure system and to solve the equations for the complex geometries and boundary conditions. According to Rayhani and Naggar (2008), horizontal distance between soil boundaries is assumed to be five times the width of structure and bed rock depth is assumed to be 30 m. The whole soil mass, foundation and structure is idealized using finite element method (FEM).

3.1.1 Discretization of Structure for FEM Analysis

1) Beam and Column

Beam and column is modeled as a frame element. The element is defined by two nodes, the cross-sectional area, and the material properties. It is a uniaxial element with tension, compression and bending capabilities. The element has six degrees of freedom at each node, translations in the nodal x, y, and z directions and rotation about the nodal x, y, and z-axis.

2) Slab

Slab is modeled as plate element. A plate is a planer structure with a very small thickness in comparison to the planer dimensions. It has four corner nodes with three degrees of freedom (u_z, θ_x, θ_y) at each node.

3) Footing and Soil Mass

Footing and soil mass is modeled as solid element. The foundation discretized as eight-noded brick element with 3 DOF at each node with translations in the nodal x, y, and z directions. The soil mass beneath the footing is also discretized as eight-noded brick element. The soil mass is assumed to be linear, elastic and isotropic material. The typical elastic continuum model is shown in figure 2.

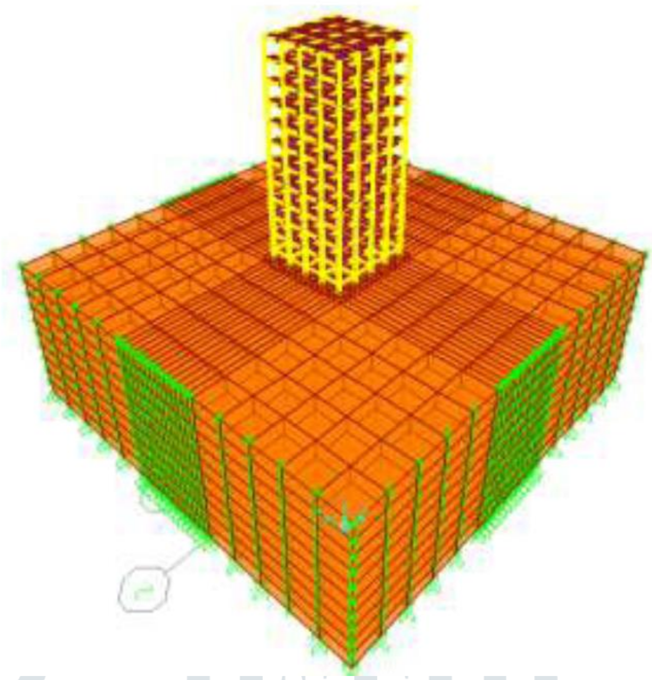

Fig -2: Typical view of Elastic Continuum Model

3.2 Structural Idealization

In this study two building frames, G+10 and G+15 representing mid-rise ordinary moment resisting frame resting on medium soil is considered. The parameters of soil considered for this study are given in Table no 1. The structural sections of frame are designed as per IS-456; 2000.The details of building frame are given in Table. The storey height is kept uniform of 3.5m. Different types of bracing arrangement such as diagonal, X and V at different location such as mid and corner have been considered for the analysis. Steel bracings are used in the present study and are designed as per IS-800; 2017. The building with different bracing position and orientation is shown in Figure no 2. The sizes of beams, columns, bracings and slabs are kept same in all cases. The various parameters for all cases are evaluated by using SAP-2000 software.

Table -1: Properties of soil

Sr No	Properties	Values
1	Modulus of Elasticity	50,000 kN/m²
2	Poisson's ratio	0.3
3	Unit weight	16 kN/m³
4	S.B.C	350 kN/m²

Conclusion

1) Soil Structure Interaction (SSI) increases time period due to incorporation of flexibility at the base. It is also observed that increase in storey height increases the time period. Enlarged time period will lead to P-Δ effect and causes the excessive forces/ moments in the members which get magnified further with the increase in the flexibility of soil. Therefore SSI shall be considered in the analysis of structures especially when resting on relatively soft soil.
2) The provision of bracing is effective in high rise structure for controlling and reducing the damage during Earthquake. The study reveals that majority of parameters are reduced due to provision of diagonal mid bracing therefore it is more effective than the remaining combinations. Thus it is recommended to provide the bracing at mid location to minimize the SSI effect. The above conclusion is valid for symmetric building; however for unsymmetrical building there is need to carry separate analysis.
3) Provisions of bracing in the structure controls the SSI and in addition minimizes lateral displacement and storey drift, which will help to improve the performance of structure under seismic load.

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