ASSESSMENT OF R.C. FRAMED BUILDINGS WITH SOIL STRUCTURE INTERACTION: AS PER ETHIOPIAN AND INDIAN SEISMIC CODE

A DISSERTATION

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CANDIDATE'S DECLARATION

I, Berhanu Melkamu, Roll No: 2K18/STE/24. Regular student of M.Tech, Structural Engineering, hereby declare that the project Dissertation titled Assessment of R.C. Framed buildings with soil-structure interaction: As per Indian and Ethiopian seismic provisions which is submitted by me to the department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the project Dissertation titled Assessment of R.C. Framed buildings with soil-structure interaction: As per Indian and Ethiopian seismic provisions which is submitted by Berhanu Melkamu Mengistie, Roll No: 2K18/STE/24 Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project who carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this university or elsewhere.

Shilpa Pal

Place: Delhi **Dr. SHILPA PAL (Associate Professor)**

Date: 28/08/2020 **SUPERVISOR**

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ABSTRACT

The dynamic soil-structure interaction effects for RC framed buildings with or without shear wall on raft foundation is evaluated by explicit consideration of structural nonlinearity and soil-structure interaction as per Indian and Ethiopian seismic codes. In the current study, the finite element model (Elastic continuum approach) employed for soil-foundation-structure model. Hence, four and eight number of stories with or without shear wall on raft foundation found on rock, dense, stiff and soft soils are designed and modeled using SAP 2000 v 21. The building studied with or without incorporation of SSI effect. The analysis is carried out in 3 stages: (1) response spectrum analysis, (2) soil-structure interaction analysis, and (3) nonlinear structural analysis (pushover analysis). The response spectrum analysis is used to design the section sizes of the members and a comparison is made according to IS 456: 2000 and ES EN-2. The nonlinear static pushover analysis is used to observe proper structural behavior for defined push displacement. The resulting pushover curves are studied through performance-based design (PBD). Finally, a comparison is made between the behavior of each building in the fixed base condition and SSI condition. This work demonstrates ES ES-2 moments exceed that of the IS 456: 2000 by an average of about 15.58% for beam area of tension reinforcement for span and 15.4% for support. So, Indian code provides a more economical design than Ethiopian code ES EN-2. Moreover, the nonlinear response of buildings was determined and compared between two cases: fixed-base and SSI conditions. Response quantities such as SSI effects on the target displacement, SSI effects on the story drifts, SSI effects on the plastic hinge mechanisms and rotations obtained from pushover analysis of superstructure. The numerical findings indicate that incorporating the soil-structure interaction generally increases the top displacement and plastic hinge rotation, reduces the base shear. Hence, it is very important point is that soil-structure increases the plastic deformation.

Keywords: Seismic performance, response spectrum analysis, pushover analysis, soil-structure interaction, RC frame-wall structure

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

The soil structure interaction defined in (IS 1893 (Part 1) :, 2016) is impact of the flexibility of supporting soil-foundation system on the response of structure. According to Designers' guide to (ES EN 1992: 2015): Design of concrete structures on 2-1-1/clause 2.1.1 and 2-1-1/clause G.1.1(1) both that SSI be considered where the interaction has significant influence on the action effects in the structure. 2-1-1/Annex G gives in formation guidance on SSI for shallow foundations and piles. The basic statement in 2-1-/clause G.1.1. (2) requires soil and structure displacements and reactions to be compatible and the remainder of Annex G adds little to this. It could be added that serviceability limit state requirements should be met for both structure and soil, with realistic stiffness employed in analysis. At the ultimate limit state, allowable soil pressures should not be exceeded and all members should be sufficiently strong and possess sufficient rotation capacity to justify the distribution of forces assumed. In a similar way, the effect of SSI is usually ignored, in the earthquake design of structures. However, it has been demonstrated to be likely   harshness of ignoring the impact of the SSI in design of buildings (R. Roy, and S. C. Dutta. 2015).

Civil engineering structures are often found in soil layers. An exception is when a layer of rock supports a structure. Therefore, the structural supports subjected by the ground motions. This raises a number of questions regarding the changes produced by the soil layers to the seismic wave, the response of soil itself to such wave passages and about the possible interaction between the structure and soil layer in which case the soil and structural systems need to be analyzed together as mutually interacting systems. The seismic behavior of structures found on soft soil sites is also described by the following features (Kramer, 1996):

(a) The inability of the foundation to conform to the deformations of the free-field motion would cause the motion of the base of a structure to deviate from the free-field motion,

(b) The supporting soil induces deformation caused by the dynamic response of the structure itself.

Soil structure interaction involves the interaction between ground condition and structure built upon. It is predominantly an exchange of mutual stress, thereby in earthquake the response of the soil-structure system is significantly affected by both the type of structure and the type of soil condition. A structure supported on flexible soil often suffers more damage than a structure on stiff soil. The SSI can reduce the dynamic response of the structure and improves the safety of margins. A second interaction effect, related to the stiffness and strength of soil, causes the settlement of foundation, created by the action of earthquake loads. This phenomenon is called soil liquefaction.

Most civil engineering structures involving inclusion-substructure in direct contact with the supporting soil. When the structural components subjected to external loads, such as seismic forces, neither the ground (soil) displacements, nor the structural displacements, are mutually independent stresses. 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) (Tuladhar et al., 2008).

The characteristics of the conventional design procedure, imply ignores the impact of SSI, while ignoring SSI is acceptable for simple rigid retaining walls and low-rise buildings resting on stiff soil. The influence of SSI, however, will be prominent for huge structures found on relatively flexible soils such as tall buildings, nuclear power plants and elevated-highways (Wolf, J. P. (1985).

Most damage to life and property occurred in recent major earthquake, namely Kobe earthquake, occurred on January 17, 1995, revealed that the earthquake performance of a structure is powerfully affected by the response of the ground (soil) and structure (Mylonakis, Gazetas, et al., 2006). Hence, the modern provisions and seismic design, for instance Standard Specifications for Concrete Structures: Seismic Performance Verification JSCE 2005, recommend accounting for SSI impacts in the earthquake design of both superstructure and foundations.

The soil-structure interaction is analyzed through a parametric study that allows the separation of the effects caused by the foundation dimensions, the soil properties and the stress and strain levels. In particular, for three different sand deposits the Young's soil modulus is considered constant or linearly variable with the depth. At the same time the analyses are performed with both linear and non-linear soil constitutive laws.

The area of soil structure interaction maintains various design philosophy and analysis procedure which is so far uncommon practice in civil engineering. Soil structure interaction has manly applicable in the field of mechanics of interaction between structure and the soil.

1.2 CLASSIFICATION BASED ON METHOD OF ANALYSIS

Base on technical development, problems of SSI can be solved Numerically and Analytically.

1.2.1 Analytically Methods

In general, wide-ranging study has been available for the last several decades to provide a comprehensive mathematical model for considering the impact of the ground on the behavior of the structure in the analysis. In this case the problem of defining an appropriate mathematical model to represent the interaction between soil and structure have a well-defined solution. Taking in to account the deformation of soil medium and bending of the structure is critical for solving the problems of soil structure interaction in analytical studies. After defining the strength and stiffness of structure and soil, the problems of SSI are fundamentally targeted to the establishment of the contact stress distributions as the interface between a structure and the ground. So that, the displacements, stresses and strains in the soil medium and the moments, forces and deflections in structure can be easily estimated. Initially in analytical methods highly mathematical idealization of models comprising, say, rigid circular disks welded onto perfectly homogeneous half-spaces were analyzed.

1.2.2 Numerical Methods

Instead of continuing to solve the highly sophisticated mathematical models that concerning perfectly homogeneous half-spaces, rigid circular disks are responsible for even complex problems like flexible foundations supporting on inhomogeneous soil and irregularly shaped. With the advent of powerful computers software's there has been in the mid-1960s to mid-1970s fast development of numerical methods in solving mechanics and other engineering problems. Nowadays, there are available of versatile computational tools for solving structural mechanics problems such as FEM, finite strip method and boundary element methods. Finite element method is recognized as a powerful and versatile analytical tool, and is very effective in the analysis of structure which are subjected to a variety of loading conditions. Remarkably, FEM is widely used computer-based method of numerically solving a range of boundary problems, and can model the mechanics of ground and structures more suitable than other techniques, determine complex geometry, structural loads or actions, and nonlinear events.

1.3 CLASSIFICATION BASED ON TREATMENT OF SUPERSTRUCTURE AND SOIL

According to the treatment of the soil and superstructure SSI analyses may be categorized in to two types, viz. 1) Continuum approach 2) Field elimination approach

1.3.1. Continuum Approach

The easiest kind of modeling substructure is to consider the characteristics of ground as linear elastic continuum in which the implicit of reversibility and linearity of displacements. This is a conceptual approach of physical representation of the infinite soil media. It is a conceptual approach for dealing with boundary distances and loaded areas. It is very reasonable to use the theory of continuum mechanics for modelling the soil media. Although this modeling reduces complexity and produces less exact results as well as for design purpose when strains are little it gives valuable information.

1.3.2. Field Elimination Technique

Field elimination techniques is used when the soil media is represented by a spring element. For a long time, field elimination techniques have been favored over fully coupled analysis of soil-structure interaction problems, largely due to their computational simplicity. In this respect, numerous idealization and elimination techniques are representing either soil or structure, depending on their relative significance for the problem under consideration, have been employed and evaluated.

In static SSI analysis further idealization of soil behavior associated with the elastic continuum model include those proposed by shtaerma (1949) is essentially a linear combination of a Winkler medium and an elastic half-space. In Winkler model a linear relationship between the force on the foundation (pressure p) and the deflection w is assumed.

In dynamic SSI analysis, historically, the first field elimination technique was used in the study of foundation-soil system by considering the system to behave as a single mass supported by a weightless spring subjected to viscous damping, usually called as lumped parameter approach.

1.4. CLASSIFICATION BASED ON TREATMENT OF INTERACTIONS

Based on the treatment of interactions of sub-domains in a system SSI analyses may be classified as 1) Monolithic or direct approach or domain,

2) Substructure approach and

3) Hybrid or Coupled approach.

Direct analysis approach is used to estimate the response of soil-foundation interaction system at various points performed via FEM direct analysis. The specified ground motion formed at all boundaries as free-field motion. The time domain (direct numerical integration) is used to solve the problem. The approach accounts nonlinear soils and superstructures however needs an exceptional assumption of the external fictitious boundary of the soil model to apply earthquake actions and remove wave reflections. The required computational cost is high, particularly if the system comprises nonlinear behavior soils or structures and complex geometric.

Substructure approach in this approach the SSI problem is partitioned into distinct parts as soil, foundation, and superstructure. Their response is first obtained independently and then combined to satisfy compatibility of forces and displacements and to formulate the complete solution. Soil motions at free-field are calculated. It is obvious that the substructure approach is normally limited to linear behavior and results in frequency-dependent equations that are solved by using Fourier synthesis.

Based on substructure method, many **hybrid methods (coupling methods)** have been developed by the standard finite-element method while the unbounded soil is modeled by the boundary element method. Coupled methods provide the advantages of both methods combined together.

1.5. PRESENT STATUS OF SSI AND STATEMENT OF PROBLEM

Only with the earthquake design of nuclear power plants the field received more importance. Engineering mechanics experts accomplished the principal. The civil engineers were doing more on provision features of these structures. This resulted in gap between the state of art and knowledge applied by civil engineers who were practicing in the fields which involved human occupation. This led to omission of both static and dynamic SSI in the design process in regular practice of civil engineering. This tendency of discounting the impact of soil further increased as, for several standard structures, earthquake SSI can be ignored. In the early stages and to some extent as of now SSI problems are simplified by structural engineers by providing spring and dashpots in place of soil while geotechnical engineers simplify the structure by block mass or lumped mass and column System. Spatial impacts of the foundation and the structure cannot be estimated because of the simplifications in the sizes of the interactive models. Many of the previous models are insufficient in evaluating the realistic behavior under static / service loads or under seismic loads if considering irregular structures and soil is non-linear.

1.5.1. Static SSI

Few researchers have addressed the issue of considering the impact of SSI on 3D space frames. There is no vast amount of studies on the impacts of non-linearity of soil-structure-interaction system considering non-linearity of soil and yielding of structures the on the whole performance described as stresses and displacements.

Though the structural field and geotechnical field have advanced computational tools offering sophisticated non-linear modelling in their respective fields, they fail together, to model an SSI problem to the same degree of sophistication. It is therefore a real challenge to achieve the same amount of sophistication in modeling both the soil and the structure in a single soil structure interaction analysis. In this respect, existing advanced discipline-oriented computational tools are inadequate, on their own, for modeling a soil structure interaction problem that involves considerable nonlinearity in both the structure and the soil; rather such a problem needs an integrated interdisciplinary computational model combining the features of both structural and geotechnical modeling.

1.5.2. Dynamic SSI

Dynamic soil-structure interaction can sometimes modify significantly the stresses and deflections of the whole structural system from the values that could have been developed if the structure were constructed on a rigid foundation. It is important to bear in mind the key consideration behind all the approaches which have been concisely revised thus far is the superstructure elastic behavior and soil which is a major limitation. In these circumstances, the whole deformation of soil structure system affected by the nonlinear behavior of soil. Currently, this assumption also dealt approximately.

Direct method and substructure methods are the two main prevalent methods for analyzing SSI problems. These both approaches are until now improved to eliminate the short comings associated with each of other, particularly the unboundness and non-linearity of the problem.

Recent developments in the field of numerical modelling of dynamic soil structure interaction have shown the need for enhancements which is evident from the fact that it has been used least by practicing engineers and in civilian construction industry. There are still no standard numerical models available. The numerous existing models are no longer limited only in the frequency or the time domain especially in coupled methods.

1.6 RESEARCH GAP AND STATEMENT OF RESEARCH PROBLEM

1. A closer look to the literature on SSI in framed and shear wall-frame reinforced concrete structures, but, reveals a number of gaps and shortcomings. Most researchers adopt linear analysis techniques to solve problems of SSI. Currently, there is very little research that considers nonlinear behavior of structure and soil. However, this may be inaccurate assessment.

SSI impacts turn out to be important, and one immediate consequence is that erecting or dismantling a building or a group of buildings could damage the earthquake hazard for the neighborhood. This leads to significant conceptual change, particularly regarding earthquake micro zonation studies, land-use planning and insurance policies. This work will address the need for the effect of dynamic soil flexibility in RC framed buildings with shear wall should be analyzed by nonlinear analysis (Pushover), so far lacking in the scientific literature.

2. Previous work has been limited to investigate the earthquake behavior of framed and shear wall-frame reinforced concrete buildings considering dynamic soil flexibility: A comparative study of IS 1893(Part-1): 2016 and ESEN 1998-1: 2015. Work of this type is extremely important because there is no data that is available to validate the significance of SSI effects on buildings. Especially there is no clear distinction of the responses includes story drift, base shear, time period and story displacement between buildings of multistory R.C. frames building including shear wall located at core taking into account soil flexibility according to the two building codes i.e. Indian and Ethiopian building code.

1.7 RESEARCH OBJECTIVE

A considerable amount of literature has been published on the problem of SSI by adopting the method of linear analysis. However, there has been relatively little literature published on it using nonlinear analysis of structure and soil. Therefore, this may be inaccurate assessment.

Based on the research gap identified from the existing literature, this research focuses on the assessment of dynamic soil structure interaction effects for RC framed buildings with shear wall over raft foundation: A comparative study analyzed according to (IS 1893 (Part 1) :, 2016) and (ESEN1998-1: 2015).

Also, the ambition of this work is to put extra light on importance of including soil in numerical analyses of structures. Nonlinear linear analysis was carried out.

In order to achieve this building models are designed using SAP2000 v. 21 software by varying different parameters of the building and soil conditions. And analyzed the response of the building due to earthquake for corresponding conditions. Work of this type is extremely important because there is very little data that is available to validate the importance of SSI effects on buildings. Especially there is no clear comparison of the responses like base shear, time period, story drift, story displacement between with and without SSI for the tall building including basement with normal foundation and also with pile foundation according to the two building codes i.e. Indian and Ethiopian building code.

1.8 METHODOLOGY

In this work, the assessment of dynamic SSI effects for RC framed buildings with shear wall over raft foundation is evaluated by explicit consideration of structural nonlinearity and soil-structure interaction (SSI). The analysis is carried out in three stages:

(1) Response spectrum analysis,

(2) Soil-Structure Interaction analysis, and

(3) Pushover static analysis (nonlinear structural analysis).

Response spectrum analysis is a dynamic linear analysis performed to design the section sizes of the members of four story and eight story building with and without incorporation of the soil stiffness in **(IS 456: 2000)** and **(ESEN-2)** building codes for varying soil sites. The Response Spectrum Analysis were conducted as per (IS 1893 (Part 1) :, 2016) and **(ESEN 1998-1: 2015)**. All these results are compared with those obtained from Indian and Ethiopian Building code standards.

The nonlinear dynamic soil-structure interaction is analyzed using direct method of analysis using Finite element method.

Pushover nonlinear analysis is a simplified nonlinear static analysis used to observe the designed structure’s behavior. The structure and soil impact often exceed the linear elastic phase and requires an elastoplastic analysis. And in order to successfully solve the problems of SSI, need to be considered nonlinear analysis of structure and soil. This study is based on the major non-linear static (**Pushover)** analysis. Pushover is performed in which the magnitude of loading or displacement is monolithically increased until a collapse mechanism occurs as predefined pattern. Determining the real displacement demand and seismic force resisting capacity of structures get more significant to obtain performance level of structures when considering soil-structure interaction. Pushover analysis gives more realistic results when compared to linear analysis methods to achieve seismic performance level of structures.

SAP2000 v. 21 finite element software package is employed in all the numerical analysis. Pushover capacity of structures are calculated and studied according to the methodology of **Performance-Based Design (PBD)** design code. Story drifts, Target displacements, rotations and plastic hinge mechanisms obtained from pushover analysis of super structure are compared according to the analysis results. All these results from fixed base condition are compared with those from four and eight story and SSI condition.

1.8. OVERVIEW OF THE THESIS

Chapter 1 deals with introduction to SSI, brief review of literature, present status of SSI, objectives, scope and methodology nonlinear pushover analysis.

Chapter 2 consists with detailed literature related to soil structure interaction, frame-wall interaction, dynamic soil structure interaction, soil linearity and non-linearity, and constitutive models.

Chapter 3 contains Finite element modeling, Response Spectrum Analysis, SSI analysis and pushover analysis of three-dimensional structure resting on raft foundation.

Chapter 4 deals with Result and Discussion based on the IS and ESEN Standards

Chapter 5 contains detailed conclusions of the work done and suggestions for future

Work.

CHAPTER 2

LITRATURE REVIEW

2.1 GENERAL

Analytical research in this topic needs for to look for the study material available on this topic and to search the current different existing cases. To collect the important and necessary information, a literature study was conducted. Therefore, the study of topic and the related 52 literature published in various journals and papers are used in the current study.

2.2 LITERATURE STUDY

(Kausel, 2010) reported a brief literature review on the early history of SSI. The study found an exhaustive review of the main development of SSI. The SSI is an interdisciplinary field of endeavor which lies at the intersection of soil and structural dynamics, geophysics and geomechanics, soil and structural mechanics, earthquake engineering, computational and numerical methods, earthquake engineering, and diverse other technical disciplines. Due to needs for enhancements in seismic safety of structures especially the nuclear power and offshore industries the concept of SSI originated in the late 19th century, and gradually developed in the early decades of the 20th century with high powerful computers and simulation tools such as finite elements, and by the needs for improvements in seismic safety. This report also provides a brief review of some of the major developments that paved the way for the state of the art as it is known today. Static solutions are included in their study, hence for the purpose of considering the SSI impacts the code provisions and engineering analyses are broadly used static foundation stiffness.

(Karthika & Gayathri, 2018) reported the literature review on dynamic behavior of building including the effect of SSI. The study considers 10 and 20 story with ground floor. These multi-storied buildings located under different depth of raft foundation and fixed support. The SSI effect is incorporated while area springs are included into the local axis ‘z’ so that the foundation is flexible there. The performance of the proposed buildings measured in respect of story drift, seismic base shear, lateral displacement, lateral deflection and fundamental natural period. The main conclusion drawn from the study is that in the design of earthquake resistant buildings the designer should include SSI hence it affects significantly the seismic performance of the building.

(Stewart et al., 2012) reported an improvement in the SSI knowledge environment for engineers to practice. They present a synthesis of the soil structure interactions literature body, which contained a detailed summary in a consistent set of units and variables. The particular techniques described in this study are used to simulate the SSI phenomena in which engineering practice is considered and provided recommendations for modeling buildings including the effects of seismic SSI. The analysis soil structure interaction estimates the overall response of the three interconnected systems: the structure, the foundation, and the soil underlying and surrounding the foundation and it is a field of interaction involving structural and Geotechnical engineering.

(Jayalekshmi & Chinmayi, 2016) reported the influence of SSI and building configuration. This parametric study includes a building having various aspect ratios, different stiffness for supporting medium soil and configurations to examine the consequence of SSI. Considering linear elastic behavior of structure and soil, the integrated SSI analysis implemented by LS DYNA finite element software. The analysis outcomes are articulated with respect of base deflection, shear forces, bending moment, axial force and maximum response of base shear while comparing the results gained from conventional analysis assuming fixed support. To evaluate the influence of SSI the study considers multi-story buildings up to 16 story with 6 different positions of shear wall and 4 various soil types according to their shear wave velocity. The main conclusions drawn from the study: considering fixed support the response of the structure is very conservative. The minimum seismic force is attracted when the situation of shear wall located at the exterior corner of the buildings considering soil having shear wave velocity, $V_s \geq 300m/s$ whereas it is advantageous placing shear wall at the corner considering soil having shear wave velocity, $V_s \leq 300m/s$.

(Mylonakis et al., 1997) examined the seismic behavior of bridge piers built on flexible soil considering the significance of SSI, the key parameters and phenomena in relation with the interplay between superstructure, pile-foundation, soil profile, and seismic excitation. The sub structuring technique is performed for the bridge piers earthquake analysis built on pile groups and vertical piles in various soil profile. This method in a simple realistic way reproduces semi-analytically both the and inertial and kinematic SSI. They observe that this study is enormously different from those of the similar studied area of seismic excitations, soil deposits, and bridge piers. Though, the ground excitation of the dominant period and different systems of natural period can be of in estimating the results of numerical studies, or in interpreting qualitatively the response in other cases.

(S. H. R. Tabatabaiefar et al., 2013) investigated numerical assessments in the impact of SSI in the midrise building frames. They consider ten-story concrete MR frame buildings found on soil type Ee, De, and Ce. The analysis leads to the following conclusions: the base shear ratios decreased due to decreasing subsoil dynamic properties while relatively increased inter-story drifts of the MR frame buildings. The design of MR frames buildings found on Soil Classes Ee and De, which excludes the effect of SSI, is inadequate to guarantee structural safety of the buildings. Since most of the earthquake provisions fail to do clearly address SSI, a special section of these parameter is highly recommended considering the impact of SSI in design. In addition, it recommended structural engineers to consider the effect of SSI on MR building frames found on soft soils located in high seismic zone to ensure the design are reliable and safe.

(H. R. Tabatabaiefar & Massumi, 2010) presented analytical investigation of the earthquake performance of RC MR frame buildings including the impact of SSI. The building is modeled and designed according to Iranian Seismic Code (2800-05 Standard no.) with and without soil while the elastic behavior of the ductile RC frame structures studied. The simplified method introduced has the advantage for earthquake design of high-rise buildings found on soft soil. In their analysis a three-dimensional FEM is implemented to estimate the effect of SSI in the earthquake behavior of RC MR frames building. The main conclusion drawn from the study: for RC-MRF buildings higher than 3 and 7 stories they recommend taking into account the impact of SSI in the earthquake design of buildings resting on soil type IV and III respectively whereas it is not basic to consider the influence of SSI for buildings resting on the soil type II.

(Raychowdhury, 2011) studied the modeling and earthquake behavior of low-rise steel MR frame buildings including the impact of nonlinear SSI. A Beam-On-Nonlinear-Winkler-foundation (BNWF) method is implemented for the purpose of modeling the nonlinear SSI behavior. The influence of nonlinearity behavior of foundation on the structural performance expressed in respect of ductility demand, base shear, base moment, and story drift. The outcomes of the analysis are compared with those obtained from elastic-base models and fixed-base. This aspect of the research suggested that: the structural behavior is significantly influenced by the foundation compliance. When Considering the foundation nonlinearity in the analysis the displacement demands and forces are significantly reduced. In addition, displacement demands and forces is observed to significantly reduced when taking in to account nonlinear SSI analysis over elastic-base models and conventional fixed-base.

(Mylonakis & Gazetas, 2008) reported the behavior of inelastic and elastic structures incorporating the effect of SSI. They present a critical review of the presently seismic provisions about significance of taking into account the impact of SSI for the earthquake design structures. This aspect of the research suggested that: when predicting the earthquake behavior of bridge piers unsuitable generalization of geometric considerations and ductility concepts might lead to incorrect estimation of forces. Based on the features of the structure and the motion the ductility demand in the bridge piers observed significantly increased when the SSI included in the inelastic bridge piers found on soft soil. Due to SSI the structural period increased which is a basic parameter does not essentially result a lesser response in contrast to conventional code design spectra to actual response spectra.

(Mylonakis, Nikolaou, et al., 2006) reported a parametric investigation on the earthquake analysis and design of bridge bents on embedded foundations in layered soil. The study provides a simplified expression for estimating kinematic response both in rotation and translation while discussed about soil inelasticity and inhomogeneity, the contribution of foundation sidewalls and presence of rock at shallow depths. Hence a cross-coupling horizontal-rocking impedance exists, in addition to translational the horizontal forces induce rotational in embedded piles and foundations. Discounting the coupling stiffness results in underestimation of the fundamental period of a flexibly supported pier whereas coupling impedances can be neglected hence usually small in shallow foundations. The main conclusion drawn from the study: as compared with that of a stratified soil profile the damping of the system increased there is no point in the fact that implemented method using an equivalent linear half-space.

(Khalil et al., 2007) investigated the impact of the soil flexibility on the dynamic properties of buildings specifically the structural period of buildings. They used rotational and translational discrete springs for the purpose of modeling the soil-foundation system. It is considered elastic behavior of both the soil and structure in the analysis. The analysis is performed at the start for 1-story buildings and then extended for multi-story buildings. The main conclusion drawn from the study is that due to the effect of SSI the natural frequency of the system become reduced hence ignoring the effect of SSI bring about unsafe design.

(Bielak, 1975) reported the dynamics of building-SSI that incorporates material damping and embedding of the foundation. Considering with embedding observed increased the damping and the natural frequency in the system. Internal friction in the soil increased effective damping. Discounting the material damping and embedding of the foundation may underestimate. The peak amplitude of the steady-state overturning moment for lightly damped superstructures a building with base supported on rigid ground is considerably larger than that comparable to flexible soil. For seismic design this result gives a practical suggestion.

(Stewart, Fenves, et al., 1999) investigated simplified procedures for determining foundation damping factors and period lengthening ratios; and system identification techniques for estimating modal vibration parameters for various cases of base fixity. It was reported in literature that these procedures are similar to provisions in some building codes. The impact of shape on foundation impedance, flexibility, the foundation embedment and site conditions are included. The system identification techniques and analysis procedures proved by performing an earthquake struck Northridge during the 1994 building shaking. It is observed the influence of SSI estimated accurately using these analysis procedures. These analysis procedures applied to numerically estimate the impact of SSI seismic structural excitation and response by currently recorded strong motion from widely range of sites.

(Stewart, Seed, et al., 1999) investigated soil-structure interaction effects inertial interaction on the behavior of the structural for a variety of geotechnical and structural conditions. In this paper, the analysis procedures in (Stewart, Fenves, et al., 1999) applied for interpretation and analyze available seismic strong ground-motion data for 57 sites in Taiwan and California. The results of this study is used to prove the (Stewart, Fenves, et al., 1999) procedures modified from (Bielak,

1975) and (Veletsos and Nair 1975). The KI modifies foundation-level motions relative to free-field motions. In this study the kinematic interaction is not the primary subject which is P-Delta effect for several high-rise buildings.

(Bhattacharya & Dutta, 2004) reported the influence of SSI on the change in lateral natural periods of frame buildings frames supporting on isolated footings and grid foundation, and soil-flexibility takes into account in their FEM of analysis. The main conclusion drawn from the study: when a grid foundation is provided in place of strip foundations, the change in the column to beam stiffness ratio does not affect the change in lateral natural period because of this impact of SSI. The influence of SSI should be considered in earthquake design of structures in the estimation of the lateral natural periods of any building because it leads unsafe design. The change in lateral natural period fails to affected by addition of diagonal braces in the outer peripheral panels of the frame buildings found on strip foundation. The impacts of SSI may not be recognized if the impact of the infill brick wall is not bear in mind while examining the earthquake behavior of frame buildings. The impact of SSI on earthquake behavior of buildings to a limited magnitude could affected by excitation frequency of the forcing function.

(Saad et al., 2012) presented the analysis of twenty story RC building with underground stories including the effect of SSI on moments, inter-story shears and base shear. Existing building codes do not have clear recommendations on how earthquake performance can be simulated to multiple underground stories in high-rise buildings. Some models include analysis of the buildings that are all the underground floors, while, high-rise buildings include multiple underground stories, or cut the ground floor. The structural designers are basically laying the groundwork for their analysis of engineering judgment and practice. This study focuses on the earthquake performance of RC buildings with several basements. It clearly puts suggestions on the percentage or number of basements that should be considered in the design of RC shear wall buildings. The main conclusion drawn from the study considering low bearing soil the story moment and story shear become increased in low rise building.

(Goel & Chopra, 1997) investigated empirical formulas to determine the fundamental vibration period for moment-resisting fame buildings. This study assessed the formulas collected available data measured to this end by system identification approaches applied to an earthquake struck

Northridge during the 1994 building shaking. The main conclusions drawn from the study: measured natural vibration periods of a total of 21 RC frames, specifically those above 16 stories are larger than the code formulas reviewed by this paper provide natural vibration periods leads to an improvement for better performance of buildings. Then, improved natural vibration period empirical formulas to determine the fundamental vibration periods of steel MR frame and reinforced concrete frame buildings are formulated via regression analysis of the recorded natural vibration period information. Furthermore, this study puts a clear recommendation as a draw back a rational analysis, in particular Rayleigh's technique for calculation of period are factors to limit the fundamental period.

(Crowley & Pinho, 2004) investigated the period vs. height relationship for current European RC buildings using assessment of displacement-based. The code-based formula does not implement hence the latter give rise to a conservative estimation of the period for FBD, whereas for displacement-based assessment a conservative estimation of the period would bring about an underestimation of the displacement demands. They analytically derived for different heights of RC fames of the required yield period using analytical procedure have been developed such as dynamic, pushover and eigenvalue analyses. The main conclusions drawn from the study: they recognized the need take into account the impact of infill panels on the fundamental natural period of reinforced concrete frames. Furthermore, a simple empirical linear relationship T = 0.1H, should be taken into account as practically acceptable and exact solution for displacement-based susceptibility assessment procedures for seismic damage valuation.

(Halabian & Naggar, 2002) established a method used to taking in to account the nonlinearities of soil in 3D dynamic SSI analysis of adjacent tall slender structures, which is called an approximate hybrid approach. This adopted method were combined the FEM and the CIFECM. A serious of recent studies has indicated that the direct approach appears to be the more efficient with high performance computing devices. To consider secondary soil non-linearity dashpots and equivalent non-linear springs are used. An approximate hybrid approach is implemented to estimate the earthquake performance of an RC TV-tower and an intake–outlet tower. The main conclusion drawn from the study: according to the type of structure, dynamic behavior of the near-field soil and frequency, the base forces of tall slender structures might increase or decrease due to the soil secondary non-linearity

(Jaf & Gu, 2016) examined the influence of SSI in the bridge. They implemented a direct method of soil structure interaction analysis which is a three-dimensional time history analysis to assessing the impact of SSI in the bridge considering a historical masonry stone arch bridge as a case study. The direct method of configuration considers the nonlinearities of structure and soil, which is more accurate estimations than linear approach. The main conclusion drawn from the study: the stresses almost remain unchanged, while the impact of SSI important on the responses of base shear, frequency, acceleration, modal shapes, overturning moment, rotation, and displacement compared with the fixed base solution. This investigation could be useful for the exact assessment of the earthquake behavior for other historical structures in the country.

(Amorosi et al., 2017) reported the nonlinear soil behavior of a nuclear power plant in Lotung using the direct approach by considering the nonlinearities soil and structure.

This study addresses the HSsmall model used to simulated the response of soil in 3D PLAXIS. The main conclusion drawn from the study demonstrates that currently difficult dynamic soil structure interaction events could not be solved through direct technique, overlook the sound explanations of the deeply rooted substructure methods. Additionally, the dynamic behavior of the structure regarding natural frequency of the system becomes decreased considering the support fixed-base and the damping ratio becomes increased.

(Atik et al., 2017) investigated the difference between the behaviors of bracing systems in buildings: shear walls and frames. So as to estimate the earthquake behavior of shear wall structures by implementing a new single-run adaptive pushover technique considering the gradual variation in the structure dynamic behavior. The load pattern and that is originated from the base of the overturning moment is predominantly governs the plasticity of shear wall. This paper investigated the influence of both adaptation and base in the single-run adaptive pushover analysis The main conclusion drawn from the study: the key important of the new single-run adaptive pushover method comprises in its simple employment upholding the idea of the adaptive response spectrum analysis while can properly estimate the outcomes of the time history analysis(nonlinear). The distinction between the suggested technique of adaptive and non-adaptive form put emphasis on the significance of the adaptive aspect to include the progressive gradual n in modal and dynamic behavior.

(Karayannis et al., 1994) developed inelastic analysis of RC frames using adaptive analysis. This study proposed an adaptive analysis technique for the purpose of numerical and modelling limitations of conventional nonlinear analysis. Considering reinforced concrete and steel framed 2D structures computational savings often in excess of 80% due to adaptive analysis. The results achieved by the nonlinear analysis program ADAPTIC introduced the idea of automatic mesh refinement, confirmed and valuable comments regarding the accuracy of the proposed analysis technique.

(Pong et al., 2006) reported some appreciated overlooks into IBC 2003 and UBC 1997for the sake of earthquake analysis and design of special steel MRF buildings. This numerical investigation performed based on the concepts of ELFP instead of MRSA and the model buildings analyzed and compared well taken whichever important outcome difference. They discover differences in the outcomes found by two seismic provisions, specifically the drift ratios and seismic design base shear in regards to 4 different occupancy use and situation. Findings in this paper moreover demonstrates buildings designed and modeled by UBC 1997 seismic provision does not satisfy the IBC 2003 seismic provision for drift limits of hospital buildings, and requirements of redundancy factor.

(Doğangü & Livaoğlu, 2006) investigated some valuable insights into IBC 2003, UBC 1997, TEC, and Euro code 8 with regards to design spectra of reinforced concrete buildings. Six sample buildings of six and twelve story RC buildings consisting of shear walls and MR frames are considered. In order to estimate the earthquake performance of these buildings, response spectrum analysis implemented by SAP 200(2003) computer program. As the ground response and accordingly the shape of design spectrum is mainly affected from the local ground conditions. The site-dependent assessment of response spectra in any region of interest is important. In general, the evidence from this study implies that: in this paper a common conclusion is not possible because of limited number of (6) buildings. So that more buildings consist various periods values and structural systems have to be examined considering numerous design acceleration. Eurocode 8 shows the maximum base shear for similar soil types expressed into UBC and TEC. For the buildings UBC shows the minimum and EC 8 the maximum displacement value. The findings add to our understanding of when the soil becomes softer, the lateral displacements are increased this is confirmed using TEC considering all ground conditions

(Nahhas, 2011) studied a comparative research to estimate the earthquake forces produced from a modal response spectrum analysis using the 2000-2009 IBC and the 1997 UBC considering ordinary residential and office buildings. For this comparison, considering various layouts and heights of 4 buildings, located at 4 different geographical sample locations. The structural analysis implemented using response spectrum analysis by the ETABS software. The main conclusion from the study: the response of structural members using IBC as compared to UBC results the lesser magnitude of moment and base shear. For considering all the cases UBC considerably more conservative than the IBC. The design of ordinary residential and office buildings using UBC 1997 results overdesigned, beside hence based on the IBC codes buildings are quite safe.

(Yayong, 2004) reported a comparative investigation in the subject of seismic actions, structural analysis methods and design requirements according to both the International code ISO3010:2001 (E) and the Chinese Code GB50011-2001. Differences include: mode damping factors, seismic loading, seismic levels and structural control. Similarities exist in the following areas: conceptual design, energy dissipation and isolation, response spectra, ductility requirements and structural strength, deformation limits, site classification, nonstructural elements, seismic analysis procedures, and earthquake return period.

(Khose et al., 2012) developed the similarities and differences of selected seismic design codes of ASCE 7, Euro code 8, NZS 1170.5 and IS1893 governing the seismic design of RC buildings. Considering this building codes this study makes a distinction on the specification of minimum design base shear, response reduction factors, site and ductility classification, hazed, and design response spectrum while their cumulative effect on seismic base shear. The methodology used all provisions to consider for inelastic energy dissipation follow a common force- based using a response reduction factor and an elastic analysis. In favor of normalize the seismic base shear over strength contributed by the load factors and material is considered. The main conclusion drawn from the study: using the code NZS 1170.5 results seismic base shear coefficients gets larger while influence of natural period on the response reduction factor considered only in NZS

1170.5. Considering the ASCE 7 shows the lower base shear coefficients. Regard IS 1893 and Euro code 8 for tall buildings results less than 1% (very low) design base shear coefficients.

(Imashi & Massumi, 2011) studied the similarities and differences between the IS 2800-05-Iranian and IBC 2003 of seismic provisions stated to estimate the earthquake loads using the static analysis technique. Building response modification factor, spectral response acceleration, importance factor, and fundamental period are the factors specified to the seismic coefficient for the equivalent lateral force. These parameters are obtained through IS 2800-05 and are compared against those covered in the IBC 2003. The main conclusions drawn from the study: the story drift limitation in IS 2800-05 is dependent only on fundamental period of the building. The IBC 2003, however, in accordance with importance factor value and structural system type it offers the story drift limitation. The vertical load distribution is parabolic with period greater than 0.5s for all structures in accordance with in IBC 2003 and the additional force Ft is not considered. However, in IS 2800-05 for all structures the force distribution in the height is linear with all periods but to the top floor of long period buildings an additional force is applied. For all seismically active areas and for all soil profiles, shear force values calculated lesser magnitude in IBC 2003 as compared to the IS 2800-05.

(Santos et al., 2013) presented the earthquake design of buildings based on Romanian, Italian, Brazilian, American and Euro code-8 standards. This paper taken into account residential and commercial buildings to allow distinguishing among the provisions. These building has been modeled using SOFiSTiK and SAP2000 computer software's and analyzed according to the numerous earthquake codes. This study adds to the body of knowledge around: in the very instant case of the EC-8, differences in the shapes of the design spectra give rise to differences in the results, in some cases, higher to 50%. However, apart from the soil characteristics

this shape is governed by the peak ground acceleration and a single parameter in all the South American standards.

(Pong et al., 2007) studied a comparative study deals with the issue of comparing the design spectra and ESL using both IBC 2003 and MOC 1993 for seismic analysis. They used 6-story special RC moment fame building in varying soil conditions and seismic zones, located on the

San Diego/Tijuana border region. For this comparative study a static analysis procedure of both codes are used. In order to classify the essential MOC 1993 and IBC 2003 soil types, 4 random soil shear wave velocities selected and this established inelastic design response spectra. The main conclusion drawn from the study: the analysis shows MOC 1993 is considerably more conservative as compared to IBC 2003. The MOC 1993 design response spectra including larger seismic coefficients and longer periods in most cases.

(Malekpour et al., 2011) discussed the merits and demerits seismic provisions and evaluation of the seismic performances of steel MRF buildings according to Japanese (BCJ), Iranian code (Standard No. 2800), and EC8 including ATC-40 and FEMA-356 provisions. The study designed four 2D steel MRF buildings with intermediate ductility levels with 3, 6, 9 and 12 story implemented based on different countries earthquake design building codes. The analysis of the building performed using nonlinear static pushover analysis. This research has investigated: Iranian (Standard No. 2800) consider higher seismic forces for buildings with lengthy periods implies general speaking doesn’t satisfy safety requirement among the EC 8, Iranian code and BCJ. The earthquake design of structures with EC8, the structures has a better performance before and during yielding. The three codes are mostly corresponding to each other in case of yielding displacement. The whole strength of middle and short period buildings from strength point of view the three codes are almost identical whereas with relatively long periods varies for tall buildings.

(Marzban et al., 2012) investigated impacts of SFSI in earthquake performance of reinforced concrete shear wall fames. In their analysis, frames of three, six, ten and fifteen story supported on hard, medium and soft soils analyzed and designed in OpenSees. In ode to demonstrate the inertial SFSI impact in seismic behavior of concrete shear wall frames, “beam on nonlinear Winkler foundation” method implemented. The analysis is implemented by pushover analysis. The outcomes of pushover curves are studied according to FBD and PBD. The performance of reinforced concrete shear wall fames compared using flexible base and fixed base assumptions. The main conclusion drawn from the study that the assumption applied the fixed-base condition regularly in practice results some degree of inaccuracy. Furthermore, the design of the connected moment frame becomes underestimated and the design of the shear wall element becomes overestimated because of the fixed-base assumption.

(Chinmayi & Jayalekshmi, 2013) reported using Elastic Half approach the effect on asymmetric R.C. Buildings with shear by taking in to account SSI. In earthquake analysis, the performance of the building significantly affected by the situation of shear walls in a building. An important finding to emerge in this study is the performance of the building is significantly influenced by soil structure interaction and position of shear walls. Also, is shear wall is placed internally and externally it shows that axial force and bending moment becomes decreased.

(Tang & Zhang, 2011) investigated the evaluation of earthquake demand probability of long shear walls including SSI. To attain the main objective of this study needs considerations of the uncertainty and variability with regard to earthquake ground type, the nonlinear behavior and interaction of foundation and structural. For this paper a typical mid-rise tall shear wall considering flexible footing used. In their analysis the nonlinear time history was implemented. For assuming with and without the impact of SSI, the seismic response like drift ratio, foundation displacement, base shear, rotation and maximum inter-story are examined and corresponding the inelastic spectral displacement S_{di}. Subsequently, the influence of SSI is examined and derived the fragility functions of the SW. It was concluded that when considering soil nonlinearity, the loss probability of the shear walls decreased because of SSI. The soil friction angle becomes more sensitive because of soil structure interaction impacts in the maximum inter-story drift under strong ground shakings.

(V et al., 2015) reported the earthquake behavior of tall buildings due to the SSI is analyzed. The study considers a seismic analysis, a 14 storied MR building with 4 basement floors. The study was carried out by linear-dynamic analysis i.e. responses spectrum analysis using Etabs software. The building is located according to IS 1893 2002 code in seismic zone-II and designed according to IS 456 & IS 800 codes. The boundary conditions for the analysis: pile foundation with SSI, pile foundation without SSI, fixed-base with SSI, fixed base without SSI. The outcomes interpreted on story drifts, maximum story displacement, base shear, and time period. SSI alters the response characteristics of a structure because of soft soils softness and stiff and massive nature of structure. The research investigated: story drifts, time period, maximum story displacement, and base shear increased and also as depth of foundation increases because of contact area between the soil and the structure increases. Generally, designing buildings for its better performance while need to be considered soil-structure interaction effects.

(Kraus & Džakić, 2015) interpretation overlooks much of SSI effects on seismic behavior of RC frames. In this paper numerical modeling done on 3 different approaches by considering structure on half-space, conventionally fixed structure and structure on Winkler Springs. It is often the case that soil beneath the structure is ignored in numerical analyses. In most cases there are two reasons for neglecting the soil in analyses: complexity in modelling of the soil and, as mostly believed, beneficial effects of the soil on structures. The structure considered for the study are 3, 7, and 10 story 3-bay RC frames resting on flexible soil as described based on Euro codes. The Linear elastic analysis was carried using time history analysis. The findings of this study have a number of important implications for structural models taking into account SSI as stated by American and European earthquake codes and emphasized the influence of SSI on low-rise buildings. An important finding to emerge in this study, including soil in a model of structure does not always have beneficial effects, as often believed. Analyses conducted shows that structure models with soil included have much higher values of story drifts, especially when the soil is modelled using Winkler springs. Furthermore, a common assumption that including soil to a model of structure would elongate fundamental period of structure and thus reduce internal forces shows to be wrong. This research shows that this assumption is not valid for low-rise buildings resting on flexible soil. The analysis including soil, in contrast to conventional fixed base models, have 70 % higher fundamental periods of vibration but also up to 400 % higher base shear. Since this research was conducted using linear-elastic models, further investigation on nonlinear models is underway.

(Hatami et al., 2015) investigated the earthquake performance of base isolated in tall buildings considering the effect of SSI using a real 10-story base isolated structure selected as a case study and designed based on IBC, 2009 guidelines. 3 different soil types of the site (Sc, SD, and SE) are taken based on IBC, 2009. The base soil characteristics is modeled by half-space cone model theory for the purpose of analysis of buildings including SSI and base isolation impact as well as calculate the damping ratios and equivalent soil stiffness in the rotational and horizontal directions. The analysis was performed using time history analysis considering taking into account SSI and base isolation influence. The comparison has been realized based on analytical models of base shear, fundamental natural period, and total relative displacements of the building. This research investigated: when a building built on very stiff soil, the SSI has insignificant impacts on the base shear ratios. Whereas in spite of shear-wave velocity or height of the building, damped periods of base isolated buildings increased where buildings found on the soft soils.

(F Behnamfar & Banizadeh, 2016) explored impacts of nonlinear SSI distribution of seismic vulnerability of three, five, six, eight, nine story RC building. These buildings found on very soft and soft soil types, and the lateral load resisting system involved once with concrete shear walls and once with moment resisting are considered. The nonlinear dynamic analysis is once employed once for flexible-base and for fixed-based conditions indicates the points of greater drift shifts to the first story where the supreme severe susceptibility is seen when considering for soil structure interaction SSI. Furthermore, they found that the pattern of distribution of susceptibility of numerous members changed and considering SSI results increased, particularly for the beams of buildings.

(Menglin et al., 2011) introduced the idea of SSI and discussed the possible research approaches. For a researcher, a in depth literature review of the status and history of the dynamic interaction of structure–soil–structure investigation which take into account adjacent structures suggested as reference based on several documents. In this area of study finite element programs that help for analyze SSI is recommended while first phase implies its excessive simplification and complexity of the model for structures and soil, and need to be carried forward for its importance. Additionally, discussed about the advantages, disadvantages, and applicability of such programs. This recent review about SSI examined the future research trend and the existing problems.

In a similar way, (Karthika & Gayathri, 2018) reported a recent literature review that dynamic behavior of buildings affected by the SSI. The paper includes the performance of multi-storied buildings supported over raft foundation taking into account the impact of SSI. The behavior of the building expressed as regards seismic base shear, story drift, lateral displacement, lateral deflection and fundamental natural period. This study concluded that, dynamic behavior of the building significantly influenced by the SSI and need included in seismic analysis and design of buildings.

(Grange et al., 2011) investigated RC concrete viaduct considerably affected by SSI. An experimental study was carried out to model a pre-stressed concrete 3- pier viaduct for a numerical strategy while tested pseudo dynamically in ELSA laboratory (JRC Ispra, Italy). The behavior of the deck was modeled using the FEM, whereas the three piers were tested during the experimental campaign. The non-linear constitutive laws and the Timoshenko multi fiber beam elements considered for the first part a numerical model of RC concrete viaduct. A best performance of the method showed in comparisons with the experimental results. This parametric investigation is conducted in the second part showing that the effect of SSI. A recently developed macro-element for various types of soils describing a fixed shallow foundation. The macro-element takes in to account foundation uplift force, the plasticity of the soil, the radiative damping and P – effects and appropriate for seismic forces. The main conclusion drawn from the comparison study indicates using linear approach it is inaccurate to predict the performance of a structure as displacements and internal forces induced when taking into account the impact of SSI. Hence, the performance of a wider variety of configurations, it seems now possible to use this method according to the results obtained in this paper.

(Kumar et al., 2015) presented the effect of SSI on tall building reinforced concrete subjected to earthquake force. The study considers 30 story building is located at different seismic zones, and modulus of subgrade reaction ranging from 12,000kN/m^3 to 60,000kN/m^3. The structural analysis is performed using STAAD Pro-2007 by including SSI. Dead loads and earthquake load acting on a structure. In general, therefore, the results show that the maximum percentage of variation at seismic zone V concerning fixed-base condition at 12,000 KN /m^2/m sub grade modulus in x- trans is 337% and in y- trans is 1420%. The main conclusion dawn from the study the structure found on a soil that has low sub grade modulus at greater earthquake intensities has to be consider the effect of SSI.

(G & Reddy, 2016) investigated the seismic performance of tall buildings considering the impact of SSI. The building is assumed to locate at Amaravati of the state Andhra Pradesh which has different locations at different types of soil / rock profiles. Nowadays, the impact of SSI in the earthquake behavior of multi-storied buildings is a major concern to incorporate the necessary changes in designing such structures. It is assumed a 12-story building, with 10-stories for residential and commercial purpose and 2 basements (soft stories) for parking, and is chosen for the analysis. This region falls under seismic zone III. Earthquake analysis is performed when the same building found on various soils types. The results of displacements, base shears and fundamental time periods obtained from fixed base condition are compared with other ground conditions. The main conclusion drawn from the investigation indicates the necessity of analyzing a building considering the influence of SSI, specifically when the building found on loose soils.

(Azarbakht & Rajabi, 2012) evaluates the element demand modifier factor of gravity concrete beams considering the impact of the SFSI according to ASCE 41-06 standard. For this study, simple and efficient method is employed that is the beam on the nonlinear Winkler foundation method. The study uses 4 sets of three, six, ten and fifteen story concrete MRF rests on hard, medium and soft soils are analyzed and designed considering flexible-base and fixed-base conditions. The structures are analyzed using both nonlinear response history analysis and equivalent linear static approach. A comparison is then made between the results of fame in the fixed-base and flexible-base conditions in both approaches. This research has investigated forces for gravity concrete beams governed by deformation actions may result non-conservative estimates of earthquake demand using equivalent linear static approach. Final the study, for equivalent linear static approach a modified load combination is proposed to avoid this imperfection.

(Farhad Behnamfar et al., 2017) investigated the impact of uplift and SSI on earthquake behavior of structures. The study included several structural systems with multi-stories of steel and reinforced concrete buildings found on 2 soft soils. The buildings analyzed for various lateral load resisting systems found on soft soil. The analysis of the buildings implemented using nonlinear dynamic analysis which takes into account nonlinear behavior of both structure and soil strong shaking, and no tension transfer of the base soil. The findings of this study have a number of important implications for the magnitude of base shear reduced consistently as a result of uplift and SSI. Story drifts increased due to no-tension soil springs at the foundation level. As the period or building height increases, simultaneously total drift increased as a consequence of SSI and uplift. Hence, larger P–D effects because of higher rotation at flexible-base condition.

(Sharma et al., 2014) reported the influence of the SSI asymmetrical RC buildings with shear wall. The study uses a 3D multi-bay 12 storied R.C. consisting shear wall found on loose soil type and the columns and footings having either spring supports or fixed supports. But it is assumed that at the common boundary between the footings and soil where the soil gives flexibility to rotation and displacement (horizontal and vertical) at the nodded points. Elastic Half Space Method adopted for the structural analysis using STAAD PRO software. The proposed building is analyzed for various loads types and combinations of loads such as gravity load and seismic force. The main conclusion dawn from the study, generally the magnitude of member forces significantly changed for the analysis including SSI and Shear wall effect. When the influence of shear wall is included it is observed that a decrease in the axial force in columns. Because of not considering the shear effect in case of Winkler model, more are indicated bending moment once Winkler method conduct although elastic half space. For all frames, inner spans show the increase and end spans the decrease shear force values.

(Ghersi et al., 2000) examined the displacement response and M/φ ratio of a single shear wall with a significant soil volume. The whole soil-foundation-shear wall system is analyzed through the new finite element code SOFIA. In this way it is possible to evaluate the effects of the basement rotation of the shear wall. In multi-story buildings shear walls are often included to resist against seismic loads, due to their efficiency and their low cost. The soil flexibility cannot be neglected because of the high stiffness of these structural elements. It plays a fundamental role in the displacement response of the shear wall and could change significantly the behavior of this element in a building structure. The shear wall is then submitted to dead and live vertical loads and to simplified pseudo-static horizontal forces at different levels. An incremental load procedure allows the non-linear behavior of the subsoil to be considered. The SSI is analyzed through a parametric study that allows the separation of the effects caused by the foundation dimensions, the soil properties and the stress and strain levels. In particular, for three different sand deposits the Young’s soil modulus is considered constant or linearly variable with the depth. The structural analysis implemented using linear and non-linear soil constitutive laws. Considering the important role of the foundation rotation of shear wall structures, the behavior of a single shear wall resting on sand deposits is investigated by means of the finite element code SOFIA. In particular, the M/φ ratio and the displacement response of the structure is investigated for various foundation dimensions and geotechnical conditions, considering soil non-linearity. In the simple elastic-linear soil condition the comparison between the numerical static rocking stiffness $K_r=M/\varphi$ and the theoretical ones shows some agreement, reaching a minimum error of 5 % for square footing. In any case, it is possible to note a not-negligible increase of the rocking stiffness with the increasing of the relative density and with the decreasing of the L/B ratio, in the hypothesis of the same contact pressure at the soil-foundation interface. This aspect is amplified in non-linear soil conditions. In this last case, however, it is important to emphasize the evident degradation of the rocking stiffness with the foundation rotation level. The more evident the above degradation the smaller the relative density, as the soil deformability is higher, and cannot be neglected for accurate analysis of the soil-shear wall interaction. This interaction modifies significantly the displacement response of the shear wall if compared with the fixed base schematization. More precisely, comparing the shear wall resting on sand deposit with the fixed base shear wall, it is possible to find the maximum horizontal displacement at the top elevation is amplified 10 times, considering an elastic-linear soil behavior, and 50 times considering the soil non-linearity.

(Hayashikawa et al., 2004) presented the dynamic performance of the cable-stayed bridge tower including the influence of soil-foundation-superstructure interaction. The methodology developed for the study is a quite general nonlinear dynamic SSI analysis. A finite element model considers pier flexibility, tower geometry, soil nonlinearity and geometrical nonlinearity, the presence of a massive foundation are capable of capturing the essential feature of tower seismic response are considered. The soil, material and geometrical nonlinearity also included in the model. The main conclusion from the study: taking into account soil foundation interaction and different soil nonlinearities the response physical sub-structure stiffness tower model can be decreased. Hence, bearing stress beneath the footing base dramatically increases. The response of foundation rocking influenced by uplift force at the interface and soil yielding below the foundation. The massive foundation rocking has impact on the vertical response of footing base rather than from the vertical excitation. The spectrum amplitude at tower top contains only the dominant flexible super-structure frequency and all other frequencies, which present in the massive and rigid sub-structure base level, have been essentially filtered out.

Table 2.1:Contribution of different researchers in SSI

S. No	Researcher	Building Parameter	Soil Parameter	Model	Method	Conclusion
1	(Jayalekshmi & Chinmayi, 2016) Innovative Infrastructure Solutions	16 story buildings with shear wall	Soil type (soft, stiff, dense and rock)	3D	- Time history record of Elcentro ground motion Based on FEMA 273 and using finite element software LS DYNA	- The seismic performance of the structure is influenced by both the position of shear wall and SSI
2	(Mylonakis et al., 1997) Earthquake Engineering and Structural Dynamics	Bridge pier	Soft soil	2D	- Sub structuring technique	-Ground excitation of the dominant period and different systems of natural period can be of in estimating the results of numerical studies, or in interpreting qualitatively the response in other cases
3	(S. H. R. Tabatabaiefar et al., 2013) International Journal of Geomechanics	10-Story concrete MR building frame	Ce, De, Ee	2D	-Dynamic nonlinear time-history analysis Using Australian standard FLAC 2D	-It recommended structural engineers to consider the effect of SSI on MR building frames found on soft soils located in high seismic zone to ensure the design are reliable and

						safe.
4	(Bhattacharya & Dutta, 2004) Journal of Sound and Vibration	4-story building frame with isolated footing	Soft Medium Stiff	3D	FEM consistent mass matrix	-Estimation of the lateral natural periods of any building affected by SSI.
5	(Saad et al., 2012) 15th World conference on Earthquake Engineering	5, 10, 15 and 20 Story buildings With and without basements	Sc- very dense or soft soil and SD-Stiff soil	3D	-Response spectrum analysis According to ASCE 7-05	-Considering low bearing soil, the story moment and story shear become increased in low rise building.
6	(Goel & Chopra, 1997) Journal of Structural Engineering	21 EC shear wall buildings	Empirical research for Fundamental vibration period	Empirical research	-System identification approach Using U.S codes	-Improved natural vibration period empirical formulas for steel MR frame and RC frame buildings are formulated via regression analysis
7	(Crowley & Pinho, 2004) Journal of Earthquake Engineering	RC frames of varying height	-Empirical study of period vs. height relationship		-Dynamic, pushover and eigenvalue analyses Using Eurocodes	-Impact of infill panels on the fundamental period of RC frames should be considered
8	(Halabian & Naggar, 2002) Journal of Soil Dynamics and Earthquake	TV-tower MDOF and An intake-outlet tower	Homogeneous stratum	3D	-An approximate hybrid approach combined FEM and	-Base forces of tall slender structures might increase or decrease due

	Engineering				CIFECM	to the soil secondary non-linearity
9	(Jaf & Gu, 2016) Journal of Environmental Earth Science	Bridge	Soft soil Medium soil	3D	-Nonlinear response history analysis	-In the top of the bridge the rotation and displacement increase and the acceleration decreases due to the SSI effect
10	(Amorosi et al., 2017) Journal of Computers and Geotechnics	Linear viscos-elastic SDOF structure	Homogenous Linear viscos-elastic Medium soil	3D	Nonlinear finite element (FE)	-Currently complex SSI events could not be solved through direct technique.
11	(Atik et al., 2017) Seismic PBD of concrete structures and infrastructures-(Book)	Shear wall structure consists of 20 story building	Ground motions scaled until full plastic hinge in structure SF=1.95	2D	A new adaptive pushover method (OMAP) Using FEMA-356.A	-The proposed OMAP procedure is efficient
12	(Karayannis et al., 1994) Journal of Structural Engineering	2-Story RC frames with ground floor mezzanine	Nil	2D	Nonlinear analysis program ADAPTIC	-The ADAPTIC introduced the idea of automatic mesh refinement.
13	(Doğangü & Livaoğlu, 2006) Journal of Seismology	6 & 12 story RC building consisting shear wall and MR frames	-For UBC, IBC & FEA 368- (SA-SF) -For EC-8- (A-D, S1 &-S2)	3D	Response spectrum analysis Using IBC 2003, UBC 1997, TEC & EC-8	-For the buildings UBC shows the minimum and EC 8 the maximum displacement

						value -when the soil becomes softer, the lateral displacements are increased.
14	(Khose et al., 2012) Journal of Earthquake Engineering Research Institute	4, 6, 12 story RC buildings	-IS-1893 (I-III) -EC-8(A-D) -ASCE 7 & NZS- (A-E)	3D	- FBD using an elastic analysis Using ASCE 7, EC-8, NZS 1170.5 & IS 1893	-NZS 1170.5 results seismic base shear coefficients get larger -ASCE 7 shows the lower base shear coefficients while IS 1893 and Euro code 8 for tall buildings results very low design base shear coefficients.
15	(Santos et al., 2013) Journal of Mathematical modeling in civil Engineering	12 floors Residential and Commercial Buildings	-Varying from very stiff to stiff soil defined according to the codes	3D	Spectra analysis Using (American Standard, Eurocode 8, Italian Code, Romanian Code and Brazilian Standard)	- Encourages integration and revisions in the South American seismic codes.
16	(Pong et al., 2007) Advances in Structural Engineering	-6 story special RC moment fame building	-IBC 2003 (from B to E) And MOC-93 (I to III)	2D	-Static analysis Using (IBC 2003 and MOC-93)	-MOC-1993 is considerably more conservative as compared to IBC 2003. -MOC 1993 design

						response spectra including larger seismic coefficients and longer periods in most cases.
17	(Malekpour et al., 2011) Journal of Procedia Engineering	-Three, six, nine and twelve stories Steel MRF	-Ranging hard to soft	2D	-Nonlinear static analysis Using (Iranian, European (EC8), and Japanese (BCJ))	-Iranian (Standard No. 2800) consider higher seismic forces for buildings with lengthy periods doesn't satisfy safety requirement among the EC 8, Iranian code and BCJ. -The earthquake design of structures with EC8, the structures have a better performance before and during yielding.
18	(Marzban et al., 2012) 15th World Conference on Earthquake Engineering	3, 6, 10 and 15 story	-Hard soils, medium soil and soft soil	3D	-Pushover Analysis Using FEMA 450 guidelines (FEMA, 2004)	- The assumption applied the fixed-base condition regularly in practice results some degree of inaccuracy.

19	(Chinmayi & Jayalekshmi, 2013) IJSER	2, 3, 6 and 12 story Building frames with and without shear wall	-Rock, Dense soil, stiff soil, soft soil	3D	-Response spectrum analysis Using (IS1893:2002)	-Performance of the building is significantly influenced by place of shear walls and SSI.
20	(Tang & Zhang, 2011) Journal of Engineering Structures	-7 story office building with dual system	-Sand	3D	- Nonlinear response history analysis	- when considering soil nonlinearity, the loss probability of the shear walls decreased because of SSI.
21	(V et al., 2015) International Journal of Research in Engineering and Applied Sciences	14 Storied Moment Resisting Building with 4 Basement Floor	Zone-II (Medium Soil)- Soft Soil	2D	-Response Spectrum (linear dynamic) Analysis, Using (IS 456, IS 800 and IS 1893- 2002)	- Story drifts, time period, maximum story displacement, and base shear increased and also as depth of foundation increases because of contact area between the soil and the structure increases.
22	(Kraus & Džakić, 2015) Anniversary conference 50 SE-EEE 1963-2013	3,7 & 10 Story three-bay RC frames	Soft Soil	2D	-Linear Elastic Analysis i.e. Time History Analysis Using (Eurocodes: CEN, 2004b; 2004c; 2005)	-70 % higher fundamental periods of vibration obtained in contrast to fixed base models.
	(Hatami et al.,	10 story	3 different	2D	- Time history	-When a

23	2015) IJSCER	base isolated structure	soil types (Stiff soil, Very stiff soil, Soft soil)		earthquakes Using (International Building Code, IBC, 2009)	building built on very stiff soil, the SSI has insignificant but where buildings found on the soft soils.
24	(F Behnamfar & Banizadeh, 2016) Journal of Soil Dynamics and Earthquake Engineering	3, 5, 6, 8, 9 story RC building	Soft Soil and Very Soft Soil types	2D	-Nonlinear Dynamic Analysis using (ACI318-05 and ASCE7-10)	-SSI impact decreases the total plastic hinge rotation and increases for shear wall building
25	(Karthika & Gayathri, 2018) IRJET	(G+10) and (G+20) multi-storied building	Fixed support and over raft foundation of varying depth	3D	Dynamic analysis	-Earthquake resistant buildings should be designed by including the impact of SSI.
26	(Grange et al., 2011) Journal of Earthquake Engineering and Structural Dynamics	RC concrete three-pier viaduct	Soil (Class B and C)	2D	Experimental Method	-Linear method of approach is not perfect method of predicting member forces in the structure when considering SSI impact

27	(Kumar et al., 2015) IJRET	30 Story RC building located at different zones	Medium dense sand to loosen sand	3D	Dynamic analysis STAAD Pro-2007	-A building found on a soil that has low sub grade modulus at greater earthquake intensities has to be consider the effect of SSI.
28	(G & Reddy, 2016) International Journal of Science and Research (IJSR)	12 story building, with basement (2 soft stories)	Type (S1 – S5)	2D	-Free vibration analysis (SRSS) (square root sum of squares) Using (IS 1893 (2002))	-When the building found on loose soil the SSI should be considered
29	(Azarbakht & Rajabi, 2012) Journal of Structural Engineering and Geotechnics	-Three, six, ten and fifteen story frames with shear walls	-Soil class (hard, medium and soft)	2D	-Nonlinear Response time history using (ASCE 41-06 standard)	-Non-conservative predictions of seismic demand may result due to equivalent linear static approach loads.
30	(Farhad Behnamfar et al., 2017) Journal of Advances in Structural Engineering	3, 4, 5, 6, 12 Story steel moment frame, concrete moment frame, steel braced frame, concrete	Soil type (D & E)	2D	-Non-linear dynamic response analysis using (ASCE/SEI 7-10 (2010)	-P-D effects are larger due to large rotation at the base of a flexible-base system -Because to SSI and uplift, the base shear

		shear walls				decreased unanimously
31	(Sharma et al., 2014) (IOSR-JMCE)	12 story RC building with shear wall	Elastic Medium	3D	(Richart, Hall and Woods Approach) Elastic Half Space Approach	-Due to the inclusion of SSI in the analysis, there is a change in the member forces
32	(Ghersi et al., 2000) 12th WCEE	A single shear wall	Sandy soil	2D	Soil-foundation-shear wall system Using finite element coded SOFIA	The smaller the relative density, as the soil deformability is higher, and SSI should be included in analysis
33	(Hayashikawa et al., 2004) 13th WCEE	Cable Stayed bridge tower Structure	Rock	3D	Nonlinear Dynamic SSI analysis (time history analysis)	-Magnitude of sub-structure stiffness of tower structure can be reduced by considering soil foundation interaction and different soil nonlinearities .
34	(H. R. Tabatabaiefar & Massumi, 2010) Soil Dynamics and Earthquake Engineering	3, 5, 7, 10 stories RC- MRFs	Soil (II, III, IV)	2D	Time history analysis Using Iranian seismic code (Standard no, 2800-05)	-For buildings higher than 3 and 7 stories they recommend taking into account the impact of SSI in the

						earthquake design of buildings resting on soil type IV and III
35	(Raychowdhury, 2011) Engineering Structures	Low-rise steel moment-resisting frame	Base condition (Fixed base, Elastic SSI, Nonlinear SSI)	2D	Pushover analysis, nonlinear response history analysis	-The structural behavior is significantly influenced by the foundation compliance.
36	(Nahhas, 2011) Earthquake Engineering and Engineering Vibration	A sample of 4 buildings, ranging from 4 to 6 floor RC building	Soil class (A, B, C, D & E,)	3D	Modal Response Spectrum Analysis Using IBC, UBC	- The design of ordinary residential and office buildings using UBC 1997 results over designed, beside hence based on the IBC codes buildings are quite safe.

However, the dynamic structure, SSI of raft supported RC farmed building with shear wall is not being addressed. The complete building analysis, including full farmed structure with heterogeneous soil, material nonlinearity, nonlinearity in the superstructure is not being addressed so far a comparative study of (IS 1893 (Part 1) :, 2016) and (ES EN1998-1: 2015).

2.3 CODAL PROVISIONS ON SSI

2.3.1 Indian Standard

(IS 1893 (Part 1) : 2016) assumptions seem to be well-grounded for consideration the impact of SSI earthquake analysis of structures. However, there is still a need for guidelines for its consideration in the Indian provisions and it does not suggest the use of other standards and international guidelines for modeling of SSI. SSI is defined by Clause 6.1.5 of the (IS 1893 (Part 1) : 2016) to refer to:

"The effects of the flexibility of supporting soil-foundation system on the response of structure. The soil-structure interaction may not be considered in the seismic analysis for structures supported on rock or rock-like material at shallow depth."

2.3.2 The European Standard for Earthquakes

(ES EN 1998-1: 2015) The Ethiopian standards based on Euro Norms recommend it is necessary to pay special attention to the ground condition S1. Such deposits containing, or consisting a layer at least 10m thick, of soft clay/silts with a high plasticity index (PI > 40), high water content, a very low value of average shear wave velocity, Vs, 30(m/s) < 100m/s, low internal damping and an abnormally extended range of linear behavior. Hence, such ground conditions generate anomalous earthquake site amplification and SSI impacts. (ES EN 1998-5: 2015, section-6) reads the impact of dynamic SSI need to be considered in the following structures:

a) structures resting on soft soils (ground type S1);
b) tall structures (slender chimneys and towers);
c) structures with massive or deep-seated foundations, such as bridge piers, offshore caissons, and silos;
d) structures where second order or P-Delta effects play an important role.

EN 1998-5: 2004 (E) (Annex D): Euro code 8: reads evidence in the overall importance and impacts of dynamic SSI. The impact of SSI becomes more prominent for the most common building structure analysis, since they decrease the member forces (shear forces and bending moments) in several components of a building superstructure.

The seismic response evaluation of a structure using flexible-base condition and fixed-base condition assumption due to the influence of SSI are different in various ways for the same structure considering the same dynamic loading (free-field excitation), on the following grounds:

a) the dynamic properties (mode shapes, natural periods and modal participation factors) of the flexible-base condition becoming significantly different than those from the fixed-base condition;
b) the foundation motion of the flexible-base structure become differ from the free-field motion and may produce an essential rocking component of the fixed-base structure;
c) the total damping of the structure resting on a flexible-base condition will contain the internal damping and radiation damping created at the interface between foundation and soil, as well as damping of the superstructure;
d) the fundamental period of vibration of the flexible-base condition becoming significantly higher than that of the fixed-base condition.

CHAPTER 3

NUMERICAL MODELLING AND PARAMETRIC STUDY

3.1 SOIL-STRUCTURE INTERACTION ANALYSIS

Soil-structure interaction analysis is implemented on multistory RC framed buildings of four and eight story in the presence or absence of shear wall supported by mat foundation are assumed, as schematically shown in Figure 3.1. For the study purpose buildings assumed all are ordinary MR with the impact of infill being ignored. Review of literature suggests that the influence of SSI plus shear walls in structural earthquake performance is less studied. To evaluate the impacts of shear wall, the position and size taken as for the study purpose same sizes of structural walls located at the center and all 4 sides in the exterior frames of building at corners. Comparative study on earthquake provisions of Ethiopian seismic code, (ES EN1998-1: 2015) and Indian seismic code, (IS 1893 (Part 1) :, 2016) including soil-structure-interaction SSI are also rarely considered. The merits of placing shear wall at the center of a building in contrast to locating at corner of a building in the effective lateral force resisting system by reducing lateral displacements under seismic forces. For including the impact of soil stiffness, 4 soil classes categorized according to shear-wave velocity are taken into account in the current study. To determine the impacts of SSI, nonlinear analysis of 3D building models resting on different soil sites is implemented and importance of location of shear wall on seismic base shear lateral loads of buildings.

3.2 SYSTEM IDEALIZATION

3.2.1 Structural Idealization

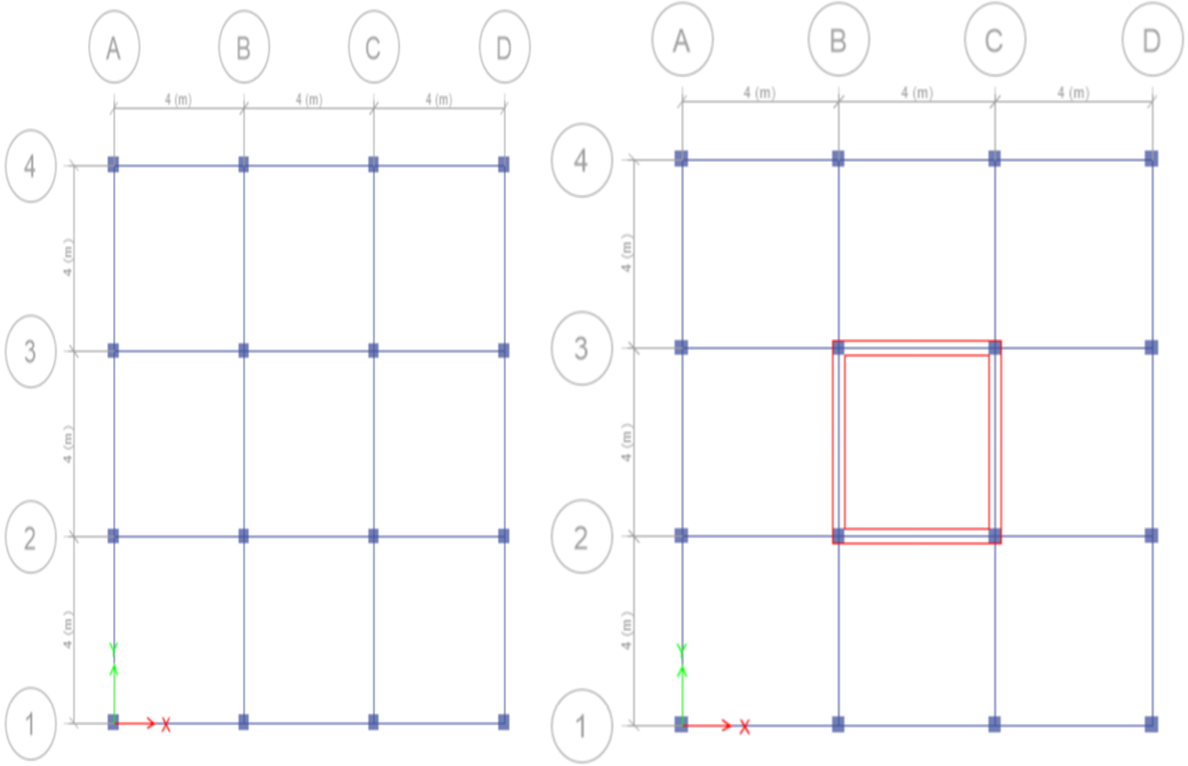
To study the impact of SSI in present analysis, 4 and 8 stories RC farmed buildings with and without shear wall on mat foundation are assumed. These multistory buildings consisting ordinary MRF of 3 bays of equal length in both direction and ignoring the presence of in-fill brick walls. Symmetric-plan buildings of the same sizes of shear walls located symmetrically along all 4 corners of the exterior frames and core to investigate the impacts of location of shear wall.

The building frames idealized as three-dimensional space frames using standard two-node beam element possessing 3 rotational and 3translational DOF at each node. Shear wall, Slabs at different story level, roof slab and the slabs of raft foundation are modeled using 4-noded plate elements by providing adequate thickness. Assuming the building function for small office building the length of each bas as well as the story height of all the building frames is chosen as 4m and 3m respectively. The layout of the buildings are shown in Figure 3.1.

Table 3.1: Dimensions of components of buildings (Jayalekshmi & Chinmayi, 2014)

1	Type of structure	MRF and Dual system
2	Zone	Very severe seismic intensity in both Indian and Ethiopian
3	Soil type	Rock (Sb), Dense (Sc), Stiff (Sd) and Soft (Se) soil
4	Base Condition	Fixed-base and Soil-structure-interaction conditions
5	Layout	As shown in fig 3.1
6	Number of stories	Four and Eight storied buildings with or without shear wall
7	Floor to Floor height	3m
8	Live load	3 KN/m^2
9	Material	Indian- M20 concrete and Fe415 steel Ethiopian- C20/25 and Fe-415
10	Seismic analysis	(1) Response Spectrum Analysis using ES EN 1998-1: 2015 and (IS 1893 (part-1): 2002 (2) SSI analysis (3) Pushover analysis
11	Design Philosophy	Limit state method conforming to ES EN-2 and IS 456: 2000
12	Size of column	(a) Four story- 0.32 x 0.32m (b) Eight story- 0.40 x 0.40m up to 3 story and 0.35 x 0.35 m above 3 stories
13	Shear wall thickness	0.15m for four story and 0.20 for eight story building
14	Dimension of beams	0.23 x 0.23 m
15	Slab thickness	0.15
16	Raft foundation slab thickness	0.3
17	Bedrock depth	30m

18	Size of raft foundation	15 x 15m
19	Confinement of the soil domain	22.5 x 22.5m
20	Response reduction factor	3- For MRF and 4-for ductile shear wall buildings
21	Importance factor	1



Bare fame(a).

SW1(b).

Figure 3.1: Plan of (a) bare frame and (b) frame with shear wall at the core (Jayalekshmi & Chinmayi, 2014)

3.2.2 Geotechnical Idealization

The main objective of the current study is to understand the influence of soil-structure interaction on buildings found on various types of non-cohesive soil, i.e., rock, dense, stiff and soft soils. (FEMA 273 -1997, 1997) and (FEMA 356-2000, 20000) classify such soil profile types from softest to hardest as Se, Sd, Sc and Sb. The specifications of various soil properties are presented in Table 3.1.

The inputs soil property for response spectrum analysis and non-linear static analysis are selected values from the recommended ranges are presented in Table 3.1 wherein Es modulus of elasticity, unit weight of soil, and poisons ratio of the soil. The soil is considered as a homogenous, isotropic, and elastic half space medium to examining the soil-foundation and structure interaction in the present study.

The bedrock assumed to be at depth of 30m. Size of raft foundation 15m x 15m x 0.3m. The total confines a finite domain for the soil is 22.5m x 22.5m.

Table 3.2: Details of soil parameters considered (FEMA 273 -1997, 1997) and (FEMA 356-2000, 20000)

Soil profile type	Description	Shear wave velocity (Vs) (m/sec)	Poisson's ratio μ	Unit weight (ρ) (kN/m^3)	Young's modulus (Es) (KN/m^2)
Sb	Rock	1200	0.3	22	8.40E + 6
Sc	Dense soil	600	0.3	20	1.91E + 6
Sd	Stiff soil	300	0.35	18	4.46E + 5
Se	Soft soil	150	0.4	16	1.03E + 5

Since classifications of soil sites are based on shear wave velocity or standard penetration test (SPT) values as per different seismic codes, they are mapped according to (FEMA 356-2000, 20000) classification for a uniform approach as shown in Table 3.2.

Table 3.3: Mapping of soil sites of IS and ES EN

Soil profile type	Description	Equivalent site class	
		IS	ES EN
Sb	Rock	Type I	A
Sc	Dense soil	Type I	B
Sd	Stiff soil	Type II	C
Se	Soft soil	Type III	D

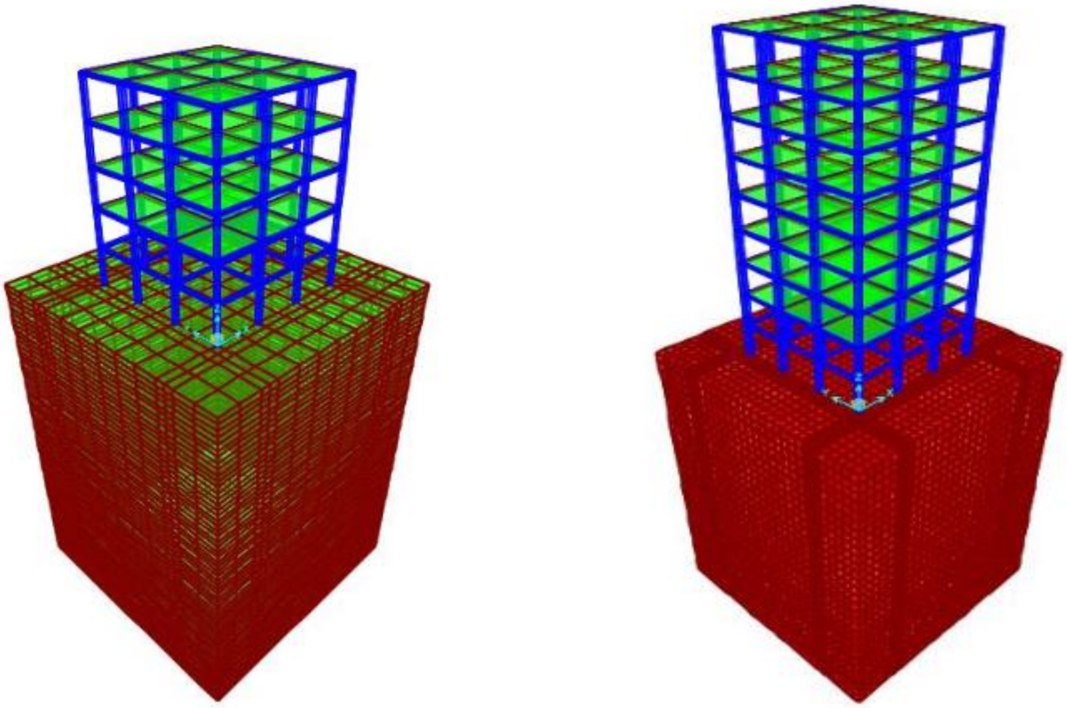
The finite element model of the idealized soil-foundation-structure system corresponding to the proposed buildings on raft foundation is shown in the Figure 3.2 and 3.3.

3.3 RESPONSE SPECTRUM ANALYSIS

3.3.1 Load Combinations of IS Code

According to (IS 1893 (Part 1) :, 2016), the load combinations shall be considered as specified in respective standards due to all load effects mentioned therein. In addition, those specified in this standard shall be applicable, which include earthquake effects.

Design Horizontal Earthquake Load-When lateral load resisting elements are oriented along two mutually orthogonal horizontal directions, structure shall be designed for effects due to full design earthquake load in one horizontal direction at a time, and not in both directions simultaneously.



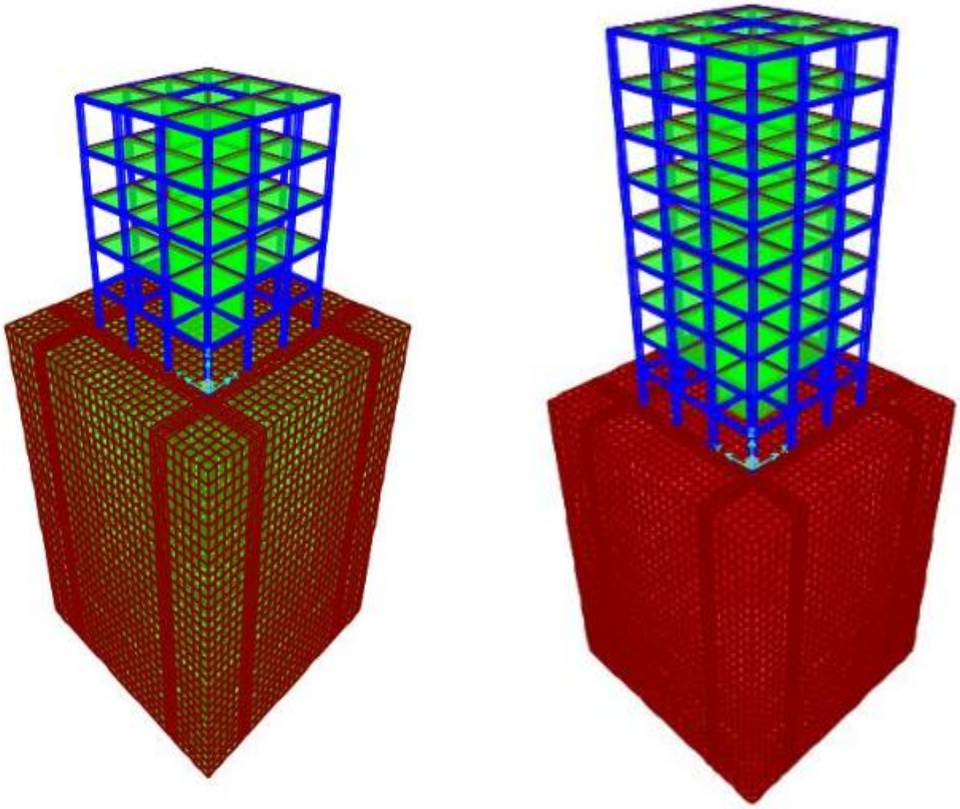
4-Storey

(a)

8-Storey

(b)

Figure 3.2: Finite Element Model of Idealized soil-foundation-structure model of bare frame a) 4-Storey and (b) 8-Storey.



4-Storey
(a)

8-Storey
(b)

Figure 3.3: Finite Element Model of Idealized soil-foundation-structure model of SW1 (a) 4-Storey and (b) 8-Storey.

Thus, structure should be designed for the following sets of combinations of earthquake effects:

a) $\pm EL_X \pm 0.3\ EL_Y$, and

b) $\pm 0.3\ EL_X \pm EL_Y$,

Where X and Y are two orthogonal horizontal plan directions. Thus, EL in the load combinations given in 6.3.1 shall be replaced by ($EL_X \pm 0.3\ EL_Y$) or ($EL_Y \pm 0.3\ EL_X$). Hence, the sets of load combinations to be considered shall be as given below:

1) $1.2\ [DL + IL \pm (EL_X \pm 0.3\ EL_Y)]$ and $1.2\ [DL + IL \pm (EL_Y \pm 0.3\ EL_X)]$;

2) $1.5\ [DL \pm (EL_X \pm 0.3\ EL_Y)]$ and
$1.5\ [DL \pm (EL_Y \pm 0.3\ EL_X)]$; and

3) $0.9\ DL \pm 1.5\ (EL_X \pm 0.3\ EL_Y)$ and $0.9\ DL \pm 1.5\ (EL_Y \pm 0.3\ EL_X)$.

Therefore, the load combinations used for the seismic analysis are:

1) 1.5(DL+LL)
2) 1.2(DL+LL+ (EQX1+ 0.3EQX3)
3) 1.2(DL+LL- (EQX1+ 0.3EQX3)
4) 1.2(DL+LL+ (EQX1- 0.3EQX3)
5) 1.2(DL+LL- (EQX1- 0.3EQX3)
6) 1.2(DL+LL+ (EQX3+ 0.3EQX1)
7)1.2(DL+LL- (EQX3+ 0.3EQX1)
8)1.2(DL+LL+ (EQX3- 0.3EQX1)
9)1.2(DL+LL- (EQX3- 0.3EQX1)
10) 1.5(DL+LL+ (EQX1+ 0.3EQX3)
11) 1.5(DL+LL- (EQX1+ 0.3EQX3)
12) 1.5(DL+LL+ (EQX1- 0.3EQX3)
13) 1.5(DL+LL- (EQX1- 0.3EQX3)
14) 1.5(DL+LL- (EQX3- 0.3EQX1)
15) 1.5(DL+LL- (EQX3 + 0.3EQX1)
16) 1.5(DL+LL+ (EQX3 - 0.3EQX1)
17) 1.5(DL+LL- (EQX3- 0.3EQX1)
18) 0.9DL + 1.5(EQX1 + 0.3EQX3)
19) 0.9DL - 1.5(EQX1 + 0.3EQX3)
20) 0.9DL + 1.5(EQX1 - 0.3EQX3)
21) 0.9DL - 1.5(EQX1 - 0.3EQX3)
22) 0.9DL + 1.5(EQX3 + 0.3EQX1)
23) 0.9DL - 1.5(EQX3 + 0.3EQX1)
24) 0.9DL + 1.5(EQX3 - 0.3EQX1)
25) 0.9DL - 1.5(EQX3 - 0.3EQX1)

According to (IS 1893 (Part 1) : 2016), to allow for cracking, gross value of moment of inertia for columns and beams should be reduced by a factor of 0.7 and 0.35 respectively.

3.3.2 Load Combinations of ESEN Code

1) Comb 1 = 1.35DL + 1.5LL
2) Comb 2 = 1.35DL + 1.5LL + EQXA + 0.3EQYA
3) Comb 3 = 1.35DL + 1.5LL + EQXA - 0.3EQYA
4) Comb 4 = 1.35DL + 1.5LL- EQXA + 0.3EQYA
5) Comb 5 = 1.35DL + 1.5LL - EQXA - 0.3EQYA
6) Comb 6 = 1.35DL + 1.5LL + EQYA + 0.3EQXA
7) Comb 7 = 1.35DL + 1.5LL+ EQYA - 0.3EQXA
8) Comb 8 = 1.35DL + 1.5LL - EQYA + 0.3EQXA
9) Comb 9 = 1.35DL + 1.5LL - EQYA - 0.3EQXA
10) Comb 10 = 1.35DL + 1.5LL + EQXB + 0.3EQYB
11) Comb 11 = 1.35DL + 1.5LL + EQXB - 0.3EQYB
12) Comb 12 = 1.35DL + 1.5LL - EQXB + 0.3EQYB
13) Comb 13 = 1.35DL + 1.5LL - EQXB - 0.3EQYB
14) Comb 14 = 1.35DL + 1.5LL + EQYB + 0.3EQXB
15) Comb 15 = 1.35DL + 1.5LL + EQYB - 0.3EQXB
16) Comb 16 = 1.35DL + 1.5LL - EQYB + 0.3EQXB
17) Comb 17 = 1.35DL + 1.5LL - EQYB - 0.3EQXB
18) Comb 18 (Serviceability) = DL + LL
19) Comb 19 = Envelope

According to (ES EN 1998-1: 2015), stiffness properties of slabs with shell properties, beams, columns, and walls has to be reduced to 50% for considering the effect of cracking.

3.3.3 Seismic Data

Indian seismic Data:

- Seismic zone= V (5), zone factor= 0.36 with an importance factor of 1.

- The response reduction factor of 3 was considered for moment resistant frames and 4.5 for ductile shear wall buildings as per IS code and equivalent parameters were considered as per Ethiopian ES EN-8 code.

Ethiopian seismic Data:

- The seismic hazard map is divided into 5 zones, where the ratio of the design bedrock acceleration to the acceleration of gravity g = α_o for the respective zones is indicated in Table 3.4.

Table 3.4: Bedrock acceleration Ratio αo

zone	5	4	3	2	1	0
$\alpha_o = ag/g$	0.20	0.15	0.10	0.07	0.04	0

- For very sever seismic intensity, the design bedrock acceleration $\alpha_o = ag/g = 0.20$ is selected from Table 3.4.
- The behavior factor “q”=1.5 and The lower bound factor β=0.2.

- Design Response Spectra as per ES EN 1998-1: 2015 is described in Table 3.5.

Table 3.5: Spectral shape controlling parameters according to ESEN 1998-1: 2015

Site class	S-Factor	TB (s)	TC (s)	TD (s)
A	1.00	0.15	0.40	2.00
B	1.20	0.15	0.50	2.00
C	1.15	0.20	0.60	2.00
D	1.35	0.20	0.80	2.00
E	1.40	0.15	0.50	2.00

3.4 PUSHOVER ANALYSIS

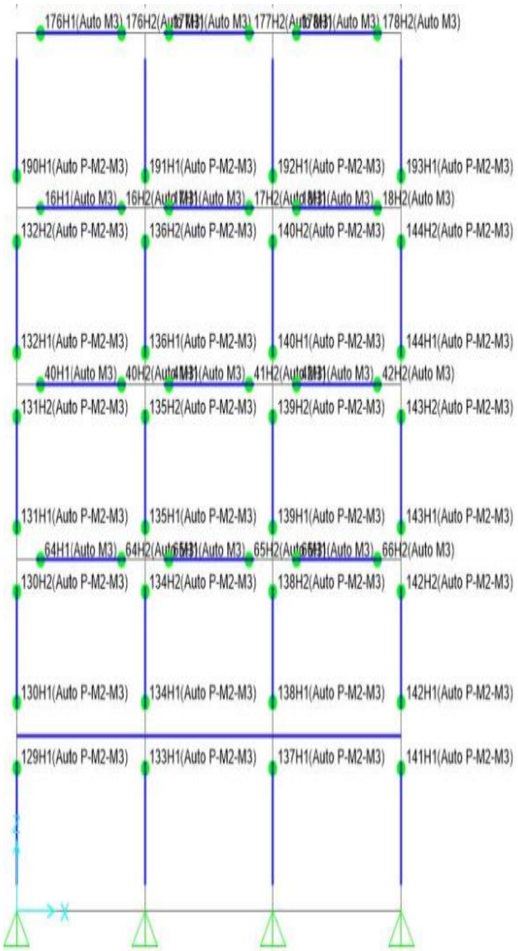
Pushover analysis is one of the performance-based design methods, recently attracting practicing structural engineers engaged in the field of seismic design. The objective of a performance-based design is achieved after the owner and the designer collectively select a target performance for the structure in question. The engineer carries out the conventional design and subsequently performs a pushover (elasto-plastic) analysis to evaluate if the selected performance objective has been met.

In this work Displacement Method is used. Displacement Coefficient Method is a non-linear static analysis procedure which provides a numerical process for estimating the displacement demand on the structure, by using a bilinear representation of the capacity curve and a series of modification factors or coefficients to calculate a target displacement. The point on the capacity curve at the target displacement is the equivalent of the performance point in the capacity spectrum method.

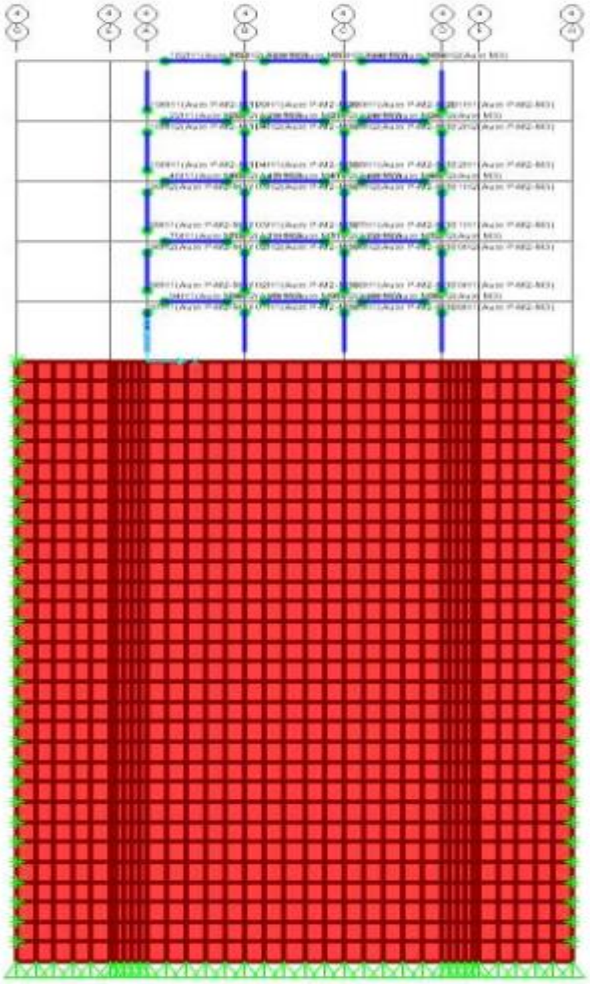
3.4.1 Plastic Hinge

- Point of Inelastic action of the structural member is called as Plastic hinge. In this state structural member starts losing strength to come back in previous position (As we know elasticity helps members to come back in its identical/safe/previous position, Plasticity starts after crossing elastic limit). Assign hinges to Model for observing the structural behavior of sequential loss of strength in different performance level of the structure due to seismic effect.

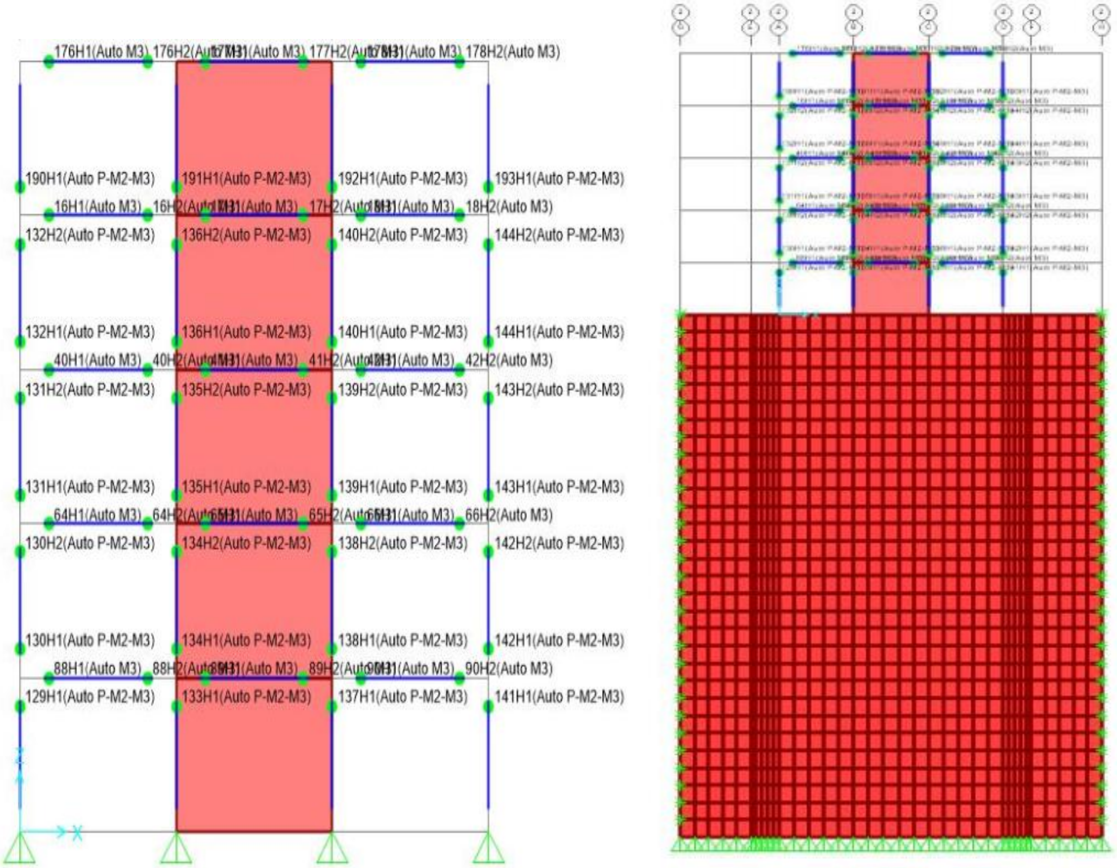
- A hinge property is a set of nonlinear properties that can be assigned to points along the length of one or more frame elements. Assigning Hinge properties of 5% and 95%. Hinge information: Beams- From Tables in ASCE 41-43, Table 10-7 (Concrete Beams-Flexure)- M3. And Columns- Auto Hinge Type- From Tables in ASCE 41-43, Table 10-8 (Concrete Columns)- P-M2-M3.



(a) 4- Story- Fixed base, Bare Frame

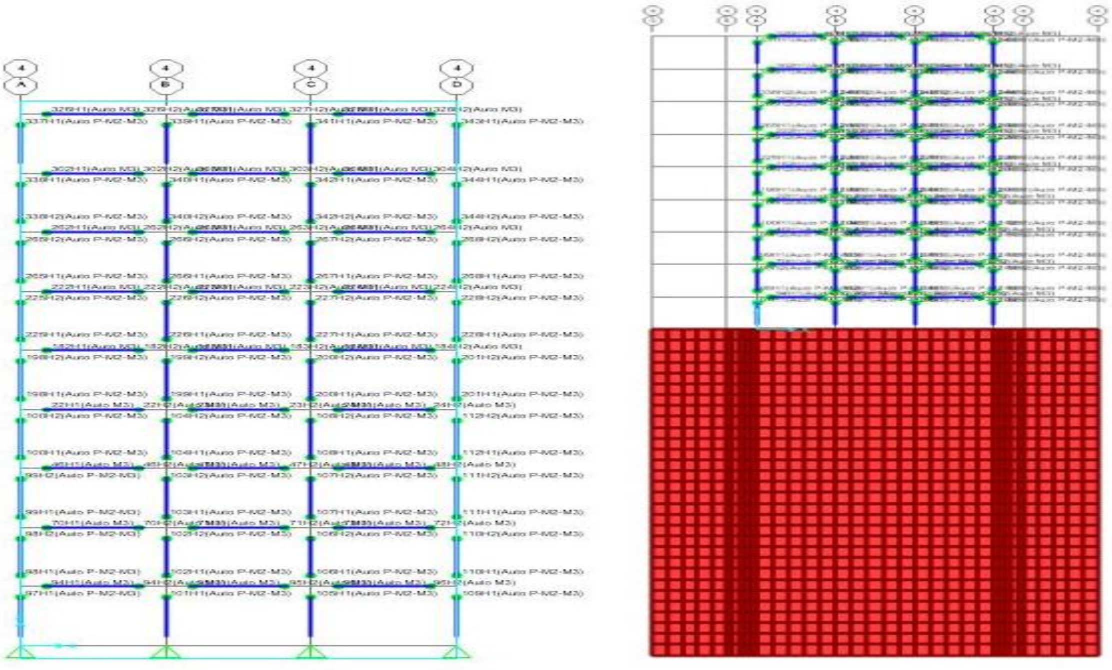


(b). 4-Story- SSI, Bare Frame



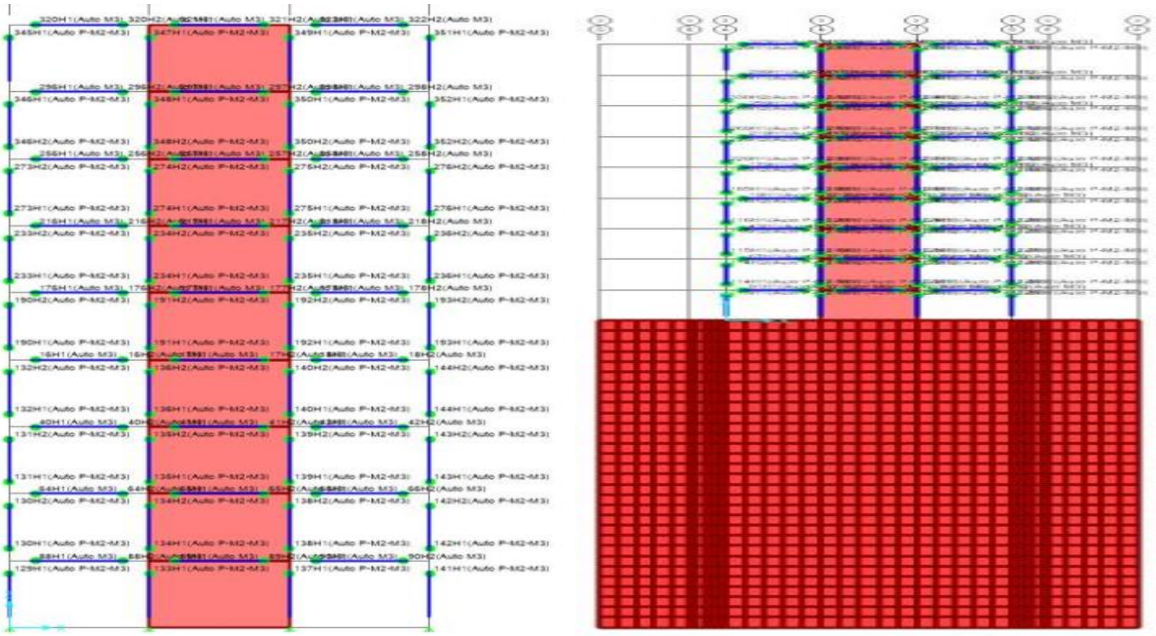
(c) 4-Story- Fixed, SW1 **(d). 4- Story- SSI, SW1**

Figure 3.4: Finite element model of superstructure of four story building with plastic hinges assignments at member end (a) Fixed base, Bare frame (b) SSI, Bare frame (c) Fixed,SW1 (d) SSI, SW1.



(a) 8-Story- Fixed, Bare Frame

(b). 8-Story- SSI, Bare Frame



(c)8 Story- Fixed, SW1

(d). 8-Story- SSI, SW1

Figure 3.5: Finite element model of superstructure of four story building with plastic hinges assignments at member end (a) Fixed base, Bare frame (b) SSI, Bare frame (c) Fixed,SW1 (d) SSI, SW1.

3.4.2 Building Performance Level

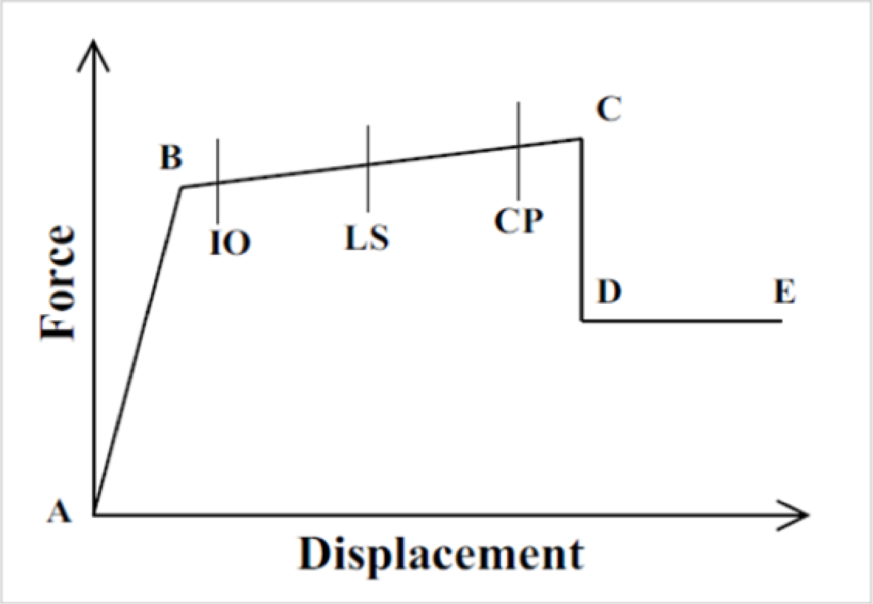


Figure 3.6: Force-Displacement curve of a Hinge.

- Point A is the original state (OL) of structure.
- Point B represents yielding. No deformation occurs in the hinge up to point B.
- Point C represents the ultimate capacity/limit for pushover analysis.
- Point D represents a residual strength limit in the structure After this limit structure initialize collapsing.
- Point E represents total failure of the structure. After this point hinges break down.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 RESPONSE SPECTRUM ANALYSIS RESULTS AND DISCUSSIONS

For the comparison of buildings in the absence/presence of the soil flexibility, first floor beams of four and eight storied buildings are selected in both principal directions. Design moments, M3, support moment, maximum span moment, positive moment rebar, negative moment rebar obtained from response spectrum analysis of superstructure are compared according to the analysis results of with or without incorporation of the soil stiffness. Two types of framing-systems considered moment-resisting frame and dual system (SW1) in the present study. The buildings compared for structures with fixed-base considered to be found on various soil sites (fixed) and including SSI effect.

4.1.1 Moment-Resisting Frame Results

(a) Four story

Table 4.1: Comparison of Design moment, M3 along Axis 1 & 4 of the beam section of four-story MR frame

Base condition	Soil type	Span (m)	Length (m)	Support Moment (kNm)			Maximum Span Moment (kNm)		
				ES EN-2	IS-456-2000	% difference	ES EN-2	IS-456-2000	% difference
Fixed	Rock soil	AB	4	15.74	12.59	-24.99	7.87	5.98	-24.02
		BC	4	13.52	12.05	-12.23	6.76	5.78	-14.49
		CD	4	15.74	12.59	-24.99	7.87	5.98	-24.02
Fixed	Dense soil	AB	4	17.68	12.59	-40.41	8.84	5.98	-32.36
		BC	4	13.43	12.05	-11.44	6.71	5.78	-13.89
		CD	4	17.68	12.59	-40.41	8.84	5.98	-32.36
Fixed	Stiff soil	AB	4	28.58	26.3	-9.41	14.29	12.9	-9.74
		BC	4	22.77	20.93	-8.78	11.36	9.43	-16.97
		CD	4	28.58	26.3	-9.41	14.29	12.9	-9.74
Fixed	Soft soil	AB	4	171.3	169.2	-1.23	85.63	83.1	-2.95
		BC	4	133.4	129.3	-3.16	66.69	65.52	-1.76
		CD	4	171.3	169.2	-1.23	85.63	83.1	-2.95

SSI	Rock soil	AB	4	15.74	12.59	-24.99	7.87	5.98	-24.02
		BC	4	13.52	12.05	-12.23	6.76	5.78	-14.49
		CD	4	15.74	12.59	-24.99	7.87	5.98	-24.02
SSI	Dense soil	AB	4	135.7	103.8	-23.53	72.84	58.9	-19.1
		BC	4	131.2	101.3	-22.74	68.59	57.7	-15.9
		CD	4	135.7	103.8	-23.53	72.84	58.9	-19.1
SSI	Stiff Soil	AB	4	418.2	380.0	-9.14	209.1	189.6	-9.3
		BC	4	366.4	320.4	-12.56	183.2	158.3	-13.6
		CD	4	418.2	380.0	-9.14	209.1	189.6	-9.3
SSI	Soft soil	AB	4	511.8	479.7	-6.27	255.9	220.9	-13.67
		BC	4	448.5	355.5	-20.74	224.3	217.5	-3.01
		CD	4	511.8	479.7	-6.27	255.9	220.9	-13.67
				Average		-15.6	Average		-15.5

Table 4.1 indicates that the values of the design support moments and maximum span moments increases due to increase in flexibility of building which indicated to be more in case of soft soil (Se) and less in rock soil (Sb). In addition, soil-structure-interaction impact is ignored in the case of buildings found in Rock soil (Sb). When a comparison is made between the Indian and Ethiopian building codes, remarkable differences are estimated between the design moment values calculated using both codes. The result shows that ESEN-2 moments exceed that of the IS 465: 2000 by an average of about 15.6% at span and 15.5% at supports.

Table 4.2: Percentage difference in area of Tension steel required for maximum span moments and support moments Along Axis 1 & 4 of four-story MR frame

Base condition	Soil type	Span (m)	Length (m)	Positive Moment Rebar (mm^2)			Negative Moment Rebar (mm^2)		
				ES EN-2	IS-456-2000	% difference	ES EN-2	IS-456-2000	% difference
Fixed	Rock soil	AB	4	154.8	117.5	-24.1	327.4	231	-29.44
		BC	4	131.9	111.6	-15.4	276.5	230	-16.73
		CD	4	154.8	117.5	-24.1	327.4	231	-29.44
Fixed	Dense soil	AB	4	190.3	117.5	-38.3	389.1	231	-40.64
		BC	4	165.7	111.6	-32.6	317.4	230	-27.47
		CD	4	190.3	117.5	-38.3	389.1	231	-40.64
Fixed	Stiff soil	AB	4	293.9	228.5	-1.85	668.2	661	-1.1
		BC	4	229.2	220.0	-4.02	502.9	497	-1.2
		CD	4	293.9	288.5	-1.85	668.2	661	-1.1
Fixed	Soft soil	AB	4	894.9	887.6	-0.82	1954	1949	-0.25
		BC	4	678.2	675.3	-0.42	1515	1510	-0.36
		CD	4	894.9	887.6	-0.82	1954	1949	-0.25
SSI	Rock	AB	4	154.8	117.5	-24.1	327.4	231	-29.44

	soil	BC	4	131.9	111.6	-15.4	276.5	230	-16.73
		CD	4	154.8	117.5	-24.1	327.4	231	-29.44
SSI	Dense soil	AB	4	743.5	527.6	-29.04	1515	1201	-20.7
		BC	4	118.9	97.3	-0.18	1490	1001	-32.84
		CD	4	743.5	527.6	-29.04	1515	1201	-20.7
SSI	Stiff Soil	AB	4	1710	1600	-6.42	3640	3235	-11.11
		BC	4	1472	1368	-7.01	3206	2600	-18.91
		CD	4	1710	1600	-6.42	3640	3235	-11.11
SSI	Soft soil	AB	4	2125	2009	-5.45	4478	4169	-6.89
		BC	4	1843	1700	-7.75	4129	3986	-3.5
		CD	4	2125	2009	-5.44	4478	4169	-6.89
				Average		-15.4	Average		-15.3

Table 4.2 shows that flexural reinforcement is least from IS 456: 2000 code and maximum for ESEN-2. ESEN-2 exceeds IS 465: 2000 by an average of about 15.4% for the area of tension reinforcement for span and 15.3% for support. So, IS 456: 2000 code provides a more economical design than ES EN-2.

(b) Eight story

Table 4.3: Comparison of Design moment, M3 along Axis 1 & 4 of the beam section of Eight story MR frame

Base condition	Soil type	Span (m)	Length (m)	Support Moment (KNm)			Maximum Span Moment (KNm)		
				ES EN-2	IS-456-2000	% difference	ES EN-2	IS-456-2000	% difference
Fixed	Rock soil	AB	4	19.31	16.91	-12.44	9.66	746	-22.75
		BC	4	17.75	16.9	-4.39	8.88	7.47	-15.84
		CD	4	19.31	16.91	-12.44	9.66	7.46	-22.75
Fixed	Dense soil	AB	4	28.98	16.91	-41.65	12.5	7.46	-40.27
		BC	4	26.64	16.9	-36.3	10.3	7.47	-27.63
		CD	4	28.98	16.91	-41.65	12.5	4.76	-40.27
Fixed	Stiff soil	AB	4	27.5	25.9	-5.65	13.7	12.93	-5.87
		BC	4	26.9	24	-10.78	13.5	13.29	-1.34
		CD	4	27.5	25.9	-5.65	13.7	12.93	-5.87
Fixed	Soft soil	AB	4	498.6	463.6	-7	249	245.5	-1.54
		BC	4	489.6	474.6	-3.07	245	243.9	-0.44
		CD	4	498.6	463.6	-7	249	245.5	-1.54
SSI	Rock soil	AB	4	19.31	16.91	-12.44	9.66	746	-22.75
		BC	4	17.75	16.9	-4.39	8.88	7.47	-15.84
		CD	4	19.31	16.91	-12.44	9.66	7.46	-22.75
SSI	Dense	AB	4	201.1	168.9	-15.97	106	82.34	-21.98

	soil	BC	4	197.9	129.6	-30.5	102	63.62	-37.61
		CD	4	201.1	168.9	-15.97	106	82.34	-21.98
SSI	Stiff Soil	AB	4	1122	985.3	-12.21	561	500.1	-10.87
		BC	4	1097	969.7	-11.61	537	484.6	-9.67
		CD	4	1122	985.3	-12.21	561	500.1	-10.87
SSI	Soft soil	AB	4	1628	1404	-13.78	814	725.2	-10.93
		BC	4	1603	1212	-24.41	789	726.6	-7.92
		CD	4	1628	1404	-13.78	814	725.2	-10.93
				Average		15.46	Average		15.31

From Table 4.3 shows that the values of the design support moments and maximum span moments increases due to increase in flexibility of building which indicated to be more in case of soft soil (Se) and less in rock soil (Sb). In addition, soil-structure-interaction impact is ignored in the case of buildings found in Rock soil (Sb). When a comparison is made between the Indian and Ethiopian building codes, remarkable differences are estimated between the design moment values calculated using both codes. The result shows that ESEN-2 moments exceed that of the IS 465: 2000 by an average of about 15.6% at span and 15.5% at supports.

Table 4.4: Percentage difference in area of Tension steel required for maximum span moments and support moments Along Axis 1 & 4 of Eight story MR frame

Base condition	Soil type	Span (m)	Length (m)	Positive Moment Rebar (mm^2)			Negative Moment Rebar (mm^2)		
				ES EN-2	IS-456-2000	% difference	ES EN-2	IS-456-2000	% difference
Fixed	Rock soil	AB	4	192.1	168.3	-12.39	413.5	336.6	-18.58
		BC	4	175.7	149.1	-15.11	375.1	338.3	-9.82
		CD	4	192.1	168.3	-12.39	413.5	336.6	-18.58
Fixed	Dense soil	AB	4	258.4	168.3	-34.86	579.7	336.6	-41.92
		BC	4	242	149.1	-38.38	512	338.3	-33.94
		CD	4	258.4	168.3	-34.86	579.7	336.6	-41.92
Fixed	Stiff soil	AB	4	281.3	258.5	-8.1	635.9	595.9	-6.29
		BC	4	275.3	252.5	-8.3	620.6	616.2	-0.71
		CD	4	281.3	258.5	-8.1	635.9	595.9	-6.29
Fixed	Soft soil	AB	4	2101	2011	-4.25	4315	4111	-4.72
		BC	4	2085	1999	-4.09	4242	4238	-0.10
		CD	4	2101	2011	-4.25	4315	4111	-4.72
SSI	Rock soil	AB	4	192.1	168.3	-12.39	413.5	336.6	-18.58
		BC	4	175.7	149.1	-15.11	375.1	338.3	-9.82
		CD	4	192.1	168.3	-12.39	413.5	336.6	-18.58
SSI	Dense soil	AB	4	837.5	648.2	-22.61	1658	1147	-30.83
		BC	4	812	543.6	-26.65	1632	1084	-33.61

		CD	4	837.5	648.2	-22.61	1658	1147	-30.83
SSI	Stiff Soil	AB	4	3086	2481	-19.6	6718	6315	-5.99
		BC	4	3060	2431	-20.57	6693	6189	-7.53
		CD	4	3086	2481	-19.6	6718	6315	-5.99
SSI	Soft soil	AB	4	3841	3451	-10.2	9851	9390	-4.68
		BC	4	3816	3413	-10.6	8473	8113	-4.25
		CD	4	3841	3451	-10.2	9851	9390	-4.68
				Average		-15.5	Average		-15.6

Table 4.4 shows that flexural reinforcement is least from IS 456: 2000 code and maximum for ESEN-2. ESEN-2 exceeds IS 465: 2000 by an average of about 15.5% for the area of tension reinforcement for span and 15.6% for support. So, IS 456: 2000 code provides a more economical design than ES EN-2.

4.1.2 Dual System (SW1) Results

(a) Four story

Table 4.5: Comparison of Design moment, M3 along Axis 1 & 4 of the beam section of four-story dual system (SW1)

Base condition	Soil type	Span (m)	Length (m)	Support Moment (KNm)			Maximum Span Moment (KNm)		
				ES EN-2	IS-456-2000	% difference	ES EN-2	IS-456-2000	% difference
Fixed	Rock soil	AB	4	6.34	5.19	-8.11	3.17	3.08	-2.87
		BC	4	2.42	1.52	-37.14	1.51	1.27	-15.64
		CD	4	6.34	5.19	-18.11	3.17	3.08	-2.87
Fixed	Dense soil	AB	4	7.03	5.19	-26.16	3.92	3.08	-21.38
		BC	4	3.67	1.52	-4.11	1.99	1.27	-36.2
		CD	4	7.03	5.19	-26.16	3.92	3.08	-21.38
Fixed	Stiff soil	AB	4	12.86	11.7	-14.37	6.43	5.54	-13.86
		BC	4	7.06	6.02	-14.69	3.03	2.81	-7.1
		CD	4	12.86	11.7	-14.37	6.43	5.53	-13.86
Fixed	Soft soil	AB	4	20.55	19.4	-5.59	6.8	5.9	-13.15
		BC	4	16.39	15.0	-8.33	3.93	3	-23.64
		CD	4	20.55	19.4	-5.59	6.8	5.9	-13.15
SSI	Rock soil	AB	4	6.34	5.19	-8.11	3.17	3.08	-2.87
		BC	4	2.42	1.52	-37.14	1.51	1.27	-15.64
		CD	4	6.34	5.19	-18.11	3.17	3.08	-2.87
SSI	Dense soil	AB	4	37.9	27.1	-28.76	20	15.2	-23.9
		BC	4	35.9	25	-30.37	17.97	14.5	-19.3

		CD	4	37.9	27.1	-28.76	20	15.2	-23.9
SSI	Stiff Soil	AB	4	186	173	-7.07	143	121	-15.31
		BC	4	161	158	-1.96	130	119	-9.12
		CD	4	186	173	-7.07	143	121	-15.31
SSI	Soft soil	AB	4	340	326	-3.87	170	143	-15.84
		BC	4	325	321	-0.97	163	157	-3.62
		CD	4	340	326	-3.87	170	143	-15.84
				Average		-15.68	Average		15.6

Table 4.5 shows that ESEN-2 moments exceeds that of the IS 465: 2000 by an average of about 15.68% at span and 15.6% at supports.

Table 4.6: Percentage difference in area of Tension steel required for maximum span moments and support moments Along Axis 1 & 4 of four-story dual system (SW1)

Base condition	Soil type	Span (m)	Length (m)	Positive Moment Rebar (mm^2)			Negative Moment Rebar (mm^2)		
				ES EN-2	IS-456-2000	% difference	ES EN-2	IS-456-2000	% difference
Fixed	Rock soil	AB	4	119.7	101.1	-15.55	123.4	121.1	-1.85
		BC	4	119.7	101.1	-15.55	119.7	101.1	-15.6
		CD	4	119.7	101.1	-15.55	123.4	121.1	-1.85
Fixed	Dense soil	AB	4	119.7	101.1	-15.55	137.5	121.1	-11.9
		BC	4	119.7	101.1	-15.55	119.7	101.1	-15.6
		CD	4	119.7	101.1	-15.55	137.5	121.1	-11.9
Fixed	Stiff soil	AB	4	119.7	101.1	-15.55	150.9	138.9	-7.9
		BC	4	119.7	101.1	-15.55	148.1	101.1	-31.7
		CD	4	119.7	101.1	-15.55	150.9	138.9	-7.9
Fixed	Soft soil	AB	4	119.7	101.1	-15.55	267.1	245.2	-8.2
		BC	4	119.7	101.1	-15.55	263.4	101.1	-61.6
		CD	4	119.7	101.1	-15.55	267.1	245.2	-8.2
SSI	Rock soil	AB	4	119.7	101.1	-15.55	123.4	121.1	-1.85
		BC	4	119.7	101.1	-15.55	119.7	101.1	-15.6
		CD	4	119.7	101.1	-15.55	123.4	121.1	-1.85
SSI	Dense soil	AB	4	401.4	340	-15.3	460.7	330.6	-28.2
		BC	4	401.4	340	-15.3	356.9	320.4	-10.2
		CD	4	401.4	340	-15.3	460.7	330.6	-28.2
SSI	Stiff Soil	AB	4	1176	960	-18.4	1492	1200	-19.58
		BC	4	1176	960	-18.4	1355	1132	-16.46
		CD	4	1176	960	-18.4	1492	1200	-19.58
SSI	Soft soil	AB	4	1229	1101	-10.5	2116	1800	-14.92
		BC	4	1176	1101	-6.4	2116	1750	-17.28
		CD	4	1129	1101	-10.5	2116	1800	-14.92
				Average		-15.56	Average		-15.5

According to Table 4.6 The result shows that flexural reinforcement is least from IS 456: 2000 code and maximum for ESEN-2. ESEN-2 exceeds IS 465: 2000 by an average of about 15.56% for the area of tension reinforcement for span and 15.5% for support. So, IS 456: 2000 code provides a more economical design than ES EN-2.

(b) Eight story

Table 4.7: Comparison of Design moment, M3 along Axis 1 & 4 of the beam section of Eight story dual system (SW1)

Base condition	Soil type	Span (m)	Length (m)	Support Moment (KNm)			Maximum Span Moment (KNm)		
				ES EN-2	IS-456-2000	% difference	ES EN-2	IS-456-2000	% difference
Fixed	Rock soil	AB	4	11.34	9.19	-18.95	7.7	6.8	-11.7
		BC	4	10.4	8.61	-16.87	7.2	5.85	-18.54
		CD	4	11.34	9.19	-18.95	7.7	6.8	-11.7
Fixed	Dense soil	AB	4	13.53	9.19	-32.1	8.76	6.8	-22.75
		BC	4	12.44	8.61	-30.8	8.21	5.58	-28.75
		CD	4	13.53	9.19	-32.1	8.76	6.8	-22.75
Fixed	Stiff soil	AB	4	16.75	15.6	-6.86	8.87	7.87	-11.25
		BC	4	12.63	11.5	-9.1	8.31	7.3	-12.61
		CD	4	16.75	15.6	-6.86	8.87	7.87	-11.25
Fixed	Soft soil	AB	4	26.72	25.6	-4.3	11.4	10.2	-10.1
		BC	4	20.54	19.5	-5.32	10.8	9.56	-11.2
		CD	4	26.72	25.6	-4.3	11.4	10.2	-10.1
SSI	Rock soil	AB	4	11.34	9.19	-18.95	7.7	6.8	-11.7
		BC	4	10.4	8.61	-16.87	7.2	5.85	-18.54
		CD	4	11.34	9.19	-18.95	7.7	6.8	-11.7
SSI	Dense soil	AB	4	104.9	89.1	-15.14	70.97	47.2	-33.48
		BC	4	898.3	78.2	-23.89	65.36	34.3	-47.45
		CD	4	104.9	89.1	-24.67	70.97	47.2	-33.48
SSI	Stiff Soil	AB	4	898.3	725	-19.3	311.6	289.7	-7.02
		BC	4	896.2	701	-21.76	310.1	278.5	-10.2
		CD	4	898.3	725	-19.3	311.6	289.7	-7.02
SSI	Soft soil	AB	4	1005	990	-1.51	552.6	542.8	-1.79
		BC	4	997.8	857	-14.14	549.4	537.6	-2.15
		CD	4	1005	990	-1.51	552.6	542.8	-1.79
				Average		-15.65	Average		-15.53

From Table 4.7 result obtained shows that ESEN-2 moments exceed that of the IS 465: 2000 by an average of about 15.65% at span and 15.53% at supports.

Table 4.8: Percentage difference in area of Tension steel required for maximum span moments and support moments Along Axis 1 & 4 of Eight story dual system (SW1)

Base condition	Soil type	Span (m)	Length (m)	Positive Moment Rebar (mm^2)			Negative Moment Rebar (mm^2)		
				ES EN-2	IS-456-2000	% difference	ES EN	IS	% difference
Fixed	Rock soil	AB	4	119.7	101.1	-15.55	143.7	121.8	-15.23
		BC	4	119.7	101.1	-15.55	123.8	120.1	-3.02
		CD	4	119.7	101.1	-15.55	143.7	121.8	-15.23
Fixed	Dense soil	AB	4	119.7	101.1	-15.55	189.4	121.8	-35.69
		BC	4	119.7	101.1	-15.55	166.2	120.1	-27.72
		CD	4	119.7	101.1	-15.55	189.4	121.8	-35.69
Fixed	Stiff soil	AB	4	119.7	101.1	-15.55	193.9	162.1	-16.44
		BC	4	119.7	101.1	-15.55	170.4	138.3	-18.83
		CD	4	119.7	101.1	-15.55	193.9	162.1	-16.44
Fixed	Soft soil	AB	4	119.7	101.1	-15.55	214.9	213	-0.87
		BC	4	119.7	101.1	-15.55	189.7	187.4	-1.24
		CD	4	119.7	101.1	-15.55	214.9	213	-0.87
SSI	Rock soil	AB	4	119.7	101.1	-15.55	143.7	121.8	-15.23
		BC	4	119.7	101.1	-15.55	123.8	120.1	-3.02
		CD	4	119.7	101.1	-15.55	143.7	121.8	-15.23
SSI	Dense soil	AB	4	665.5	519.9	-21.87	889.1	700.4	-22.02
		BC	4	662.6	507.9	-23.34	895.2	486.8	-45.62
		CD	4	665.5	519.9	-21.87	889.1	700.4	-22.02
SSI	Stiff Soil	AB	4	2147	1800	-16.16	4684	4101	-12.46
		BC	4	2077	1777	-14.47	4515	4012	-11.13
		CD	4	2147	1800	-16.16	4684	4101	-12.13
SSI	Soft soil	AB	4	2708	2205	-18.56	5863	5262	-10.26
		BC	4	2558	1985	-22.41	5509	5007	-9.12
		CD	4	2708	2205	-18.56	5863	5262	-10.26
				Average		-15.5	Average		-15.5

Table 4.8 shows that flexural reinforcement is least from IS 456: 2000 code and maximum for ESEN-2. ESEN-2 exceeds IS 465: 2000 by an average of about 15.5% for the area of tension reinforcement for span and 15.5% for support. So, IS 456: 2000 code provides a more economical design than ES EN-2.

4.2 NONLINEAR STATIC ANALYSIS RESULTS AND DISCUSSIONS

The impact dynamic soil-structure interaction impacts on seismic behavior of R.C. framed buildings in the presence or absence of shear wall on raft foundation by including soil-structure interaction and structural nonlinearity as per Indian and Ethiopian seismic codes. Reinforced concrete buildings being four and eight story found on rock, dense, stiff and soft soil types, once with MRF and once with frame-walls are analyzed. The nonlinear static analysis is once implemented for fixed-based and once for SSI assumptions to study the seismic behavior. The nonlinear response of buildings was determined and compared between two cases: fixed-base and SSI conditions. Response quantities such as SSI effects on the Target displacement, SSI effects on the story drifts, SSI effects on the plastic hinge mechanisms and rotations studied using nonlinear analysis was compared based on the analysis results.

4.2.1 Soil-Structure Interaction Effects On the Base Shear Force Versus Roof Displacement According to PBD Codes

Pushover capacity curve indicates the nonlinear behavior of the structure and is a load-deformation curve of the base shear force versus the horizontal roof displacement of the building. This is important estimate the force demand and structural demand. The relationship between base shear force and roof displacement of four and eight story buildings in the absence/presence of SSI obtained through pushover analysis are given in Table 23 &24 respectively.

Table 4.9: Pushover capacity of 4 Story buildings

Soil Type	Base Condition	Displacement (m)	Base Shear (KN)
ROCK SOIL	FIXED BASE, BARE FRAME	0.196	3270.13
	FIXED BASE, SW1	0.01	17212.71
	SSI, BARE FRAME	0.301	1916.56
	SSI, SW1	0.174	9804.5
DENSE SOIL	FIXED BASE, BARE FRAME	0.223	3010.61
	FIXED BASE, SW1	0.02	15013.14
	SSI, BARE FRAME	0.354	1743.12
	SSI, SW1	0.204	8564.6
STIFF SOIL	FIXED BASE, BARE FRAME	0.296	2950.12
	FIXED BASE, SW1	0.03	14104.3
	SSI, BARE FRAME	0.398	1731.36
	SSI, SW1	0.233	7958.94
SOFT SOIL	FIXED BASE, BARE FRAME	0.308	2755.12
	FIXED BASE, SW1	0.04	13974.92
	SSI, BARE FRAME	0.431	1605.89
	SSI, SW1	0.268	7683.35

According to Table 4.9 result shows the top displacements increased and the base shear decreased as the soil flexibility increases when pushover analysis is done for the buildings considering soil-structure-interaction.

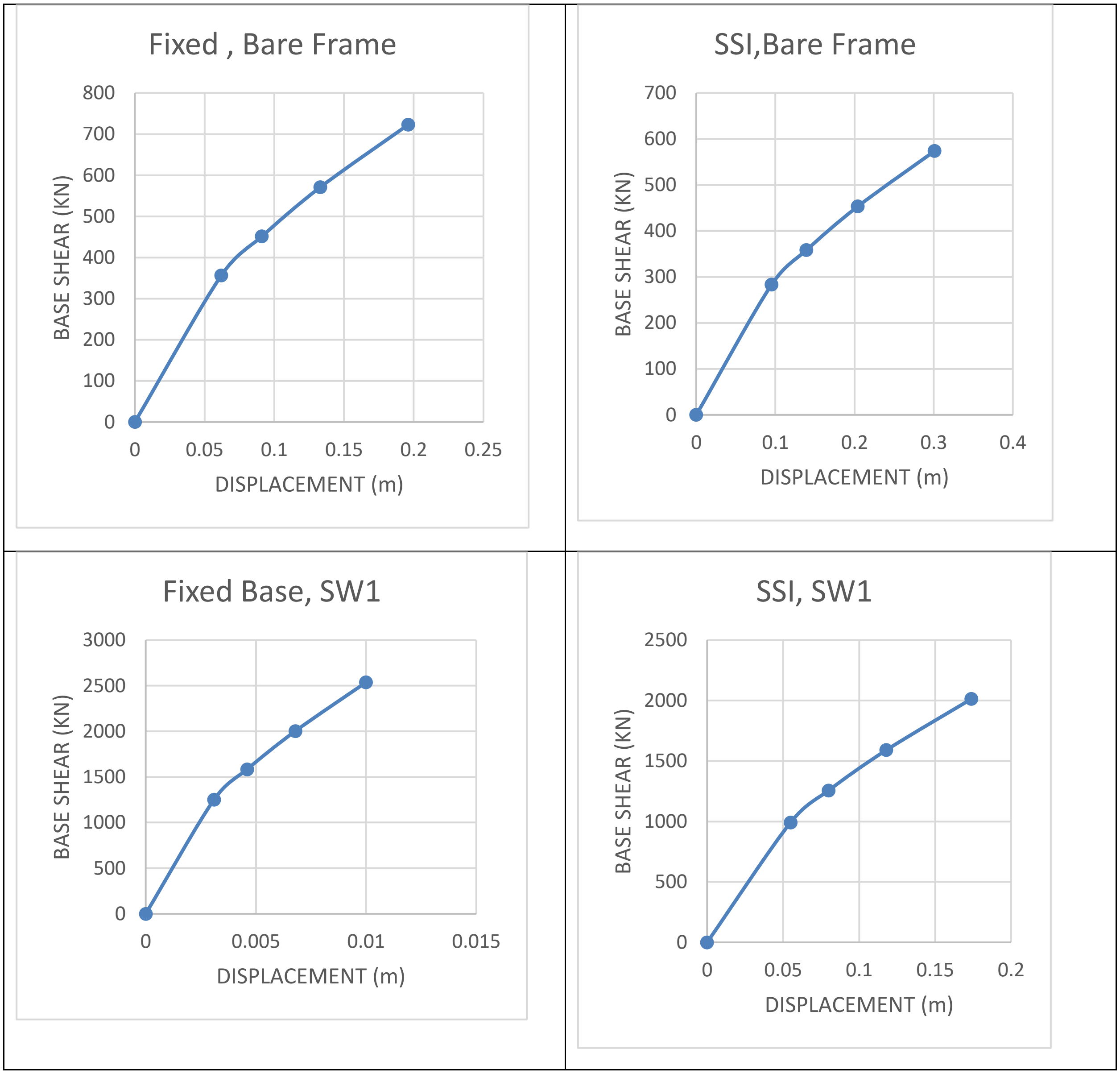


Figure 4.1: Pushover curves of four-story building found on rock soil.

Figure 4.1 & 4.2 shows that base shears observed significant difference with high values for buildings found on soft soils and low value in case of rock soil. The value of base shear in the absence/presence of soil-structure impacts is observed to be least in MRF and highest for building configuration with shear wall at core. Moreover, the value of base shear increases when an increase of soil flexibility and superstructure stiffness. As the SSI takes into account, the top horizontal displacement becomes increased.

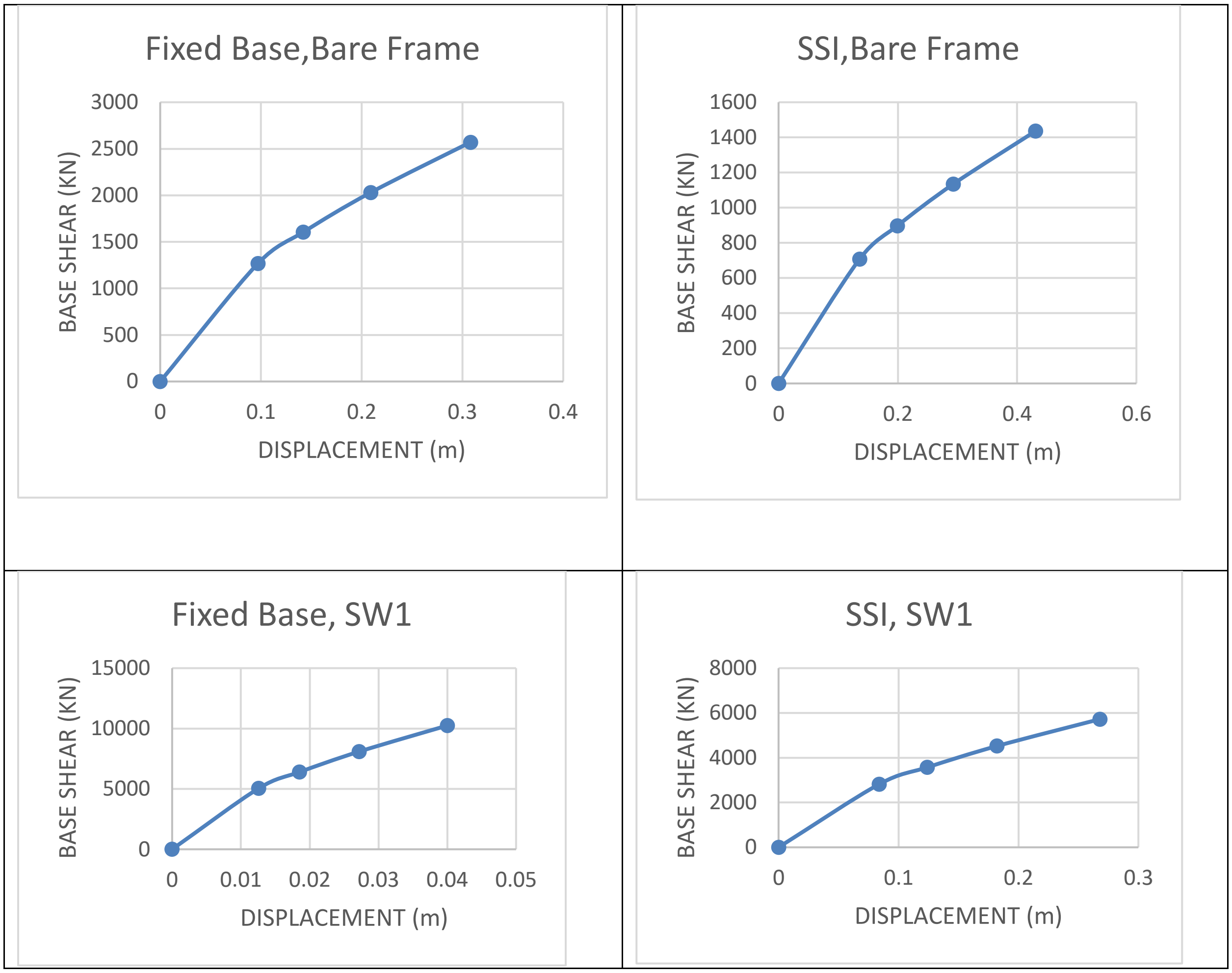


Figure 4.2: Pushover curves of four-story building found on soft soil.

Table 4.10: Pushover capacity of 8 Story buildings

Soil Type	Base Condition	Displacement (m)	Base Shear (KN)
ROCK SOIL	FIXED BASE, BARE FRAME	0.234	3660.13
	FIXED BASE, SW1	0.03	25820.14
	SSI, BARE FRAME	0.384	2136.56
	SSI, SW1	0.197	14718.34
DENSE SOIL	FIXED BASE, BARE FRAME	0.257	3010.61
	FIXED BASE, SW1	0.05	23342.48
	SSI, BARE FRAME	0.411	1643.12
	SSI, SW1	0.234	13318.62
STIFF SOIL	FIXED BASE, BARE FRAME	0.296	2620.12
	FIXED BASE, SW1	0.07	22123.64
	SSI, BARE FRAME	0.458	1531.36
	SSI, SW1	0.3	12356.25
SOFT SOIL	FIXED BASE, BARE FRAME	0.34	3455.12
	FIXED BASE, SW1	0.08	19395.2
	SSI, BARE FRAME	0.531	1885.89
	SSI, SW1	0.353	10643.53

From Table 4.10 it is found that incorporating soil-structure-interaction generally reduces the base shear and larger the lateral displacement.

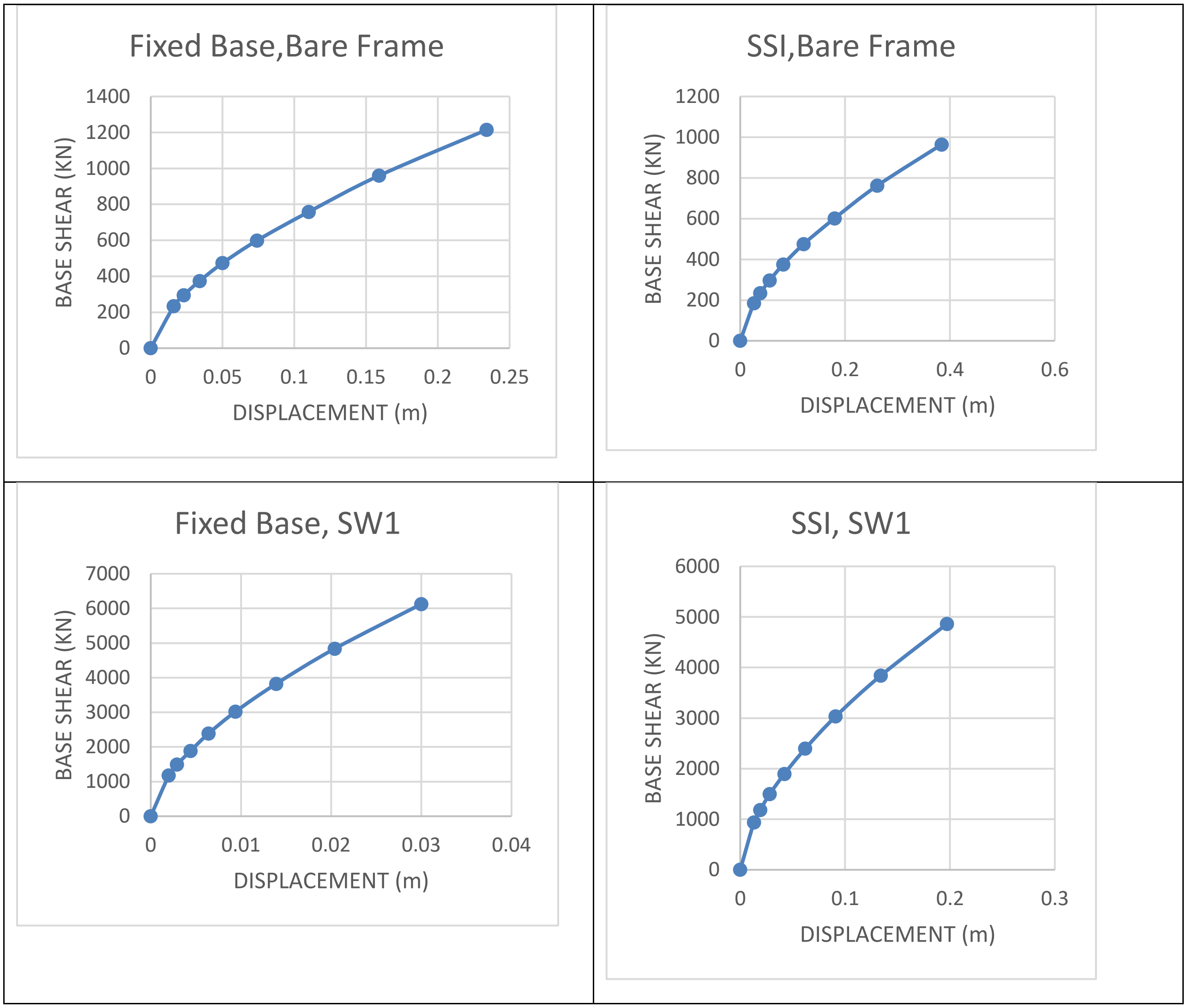


Figure 4.3: Pushover curves of eight-story building found on rock soil.

Figure 4.3 & 4.4 shows that base shears observed significant difference with high values for buildings found on soft soils and low value in case of rock soil. The value of base shear in the absence/presence of soil-structure impacts is observed to be least in MRF and highest for building configuration with shear wall at core. Moreover, the value of base shear increases when an increase of soil flexibility and superstructure stiffness. As the SSI takes into account, the top horizontal displacement becomes increased.

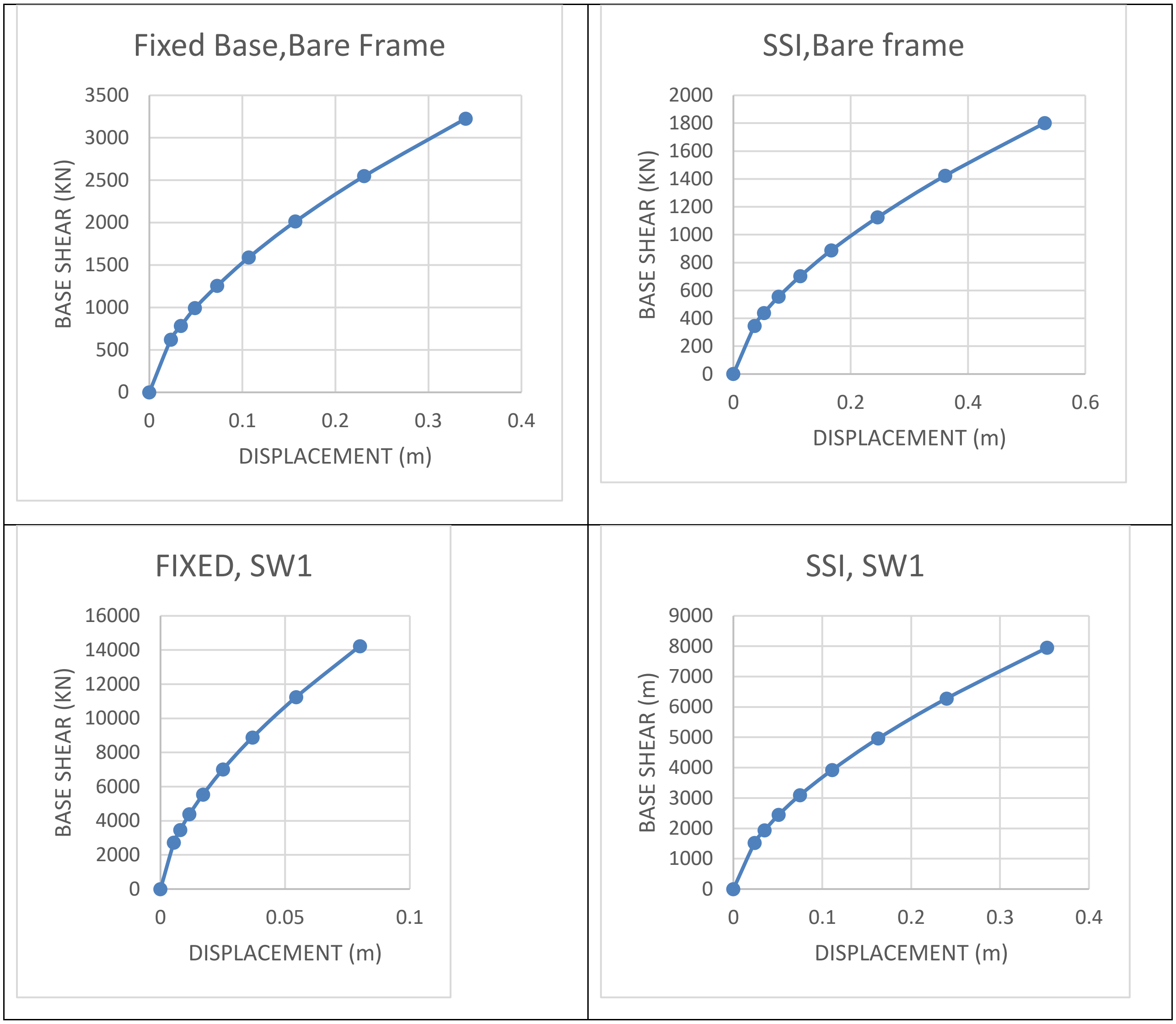


Figure 4.4: Pushover curves of eight-story building found on soft soil.

4.2.2 Soil-Structure Interaction Effects on the Structural demands

The structural demands studied by inelastic static analysis are given in Table 4.11 & 4.12. Target displacement demand used to determine the plastic hinge rotations.

Table 4.11: Variation of structural demands of 4 story building

Story	Framing Type	Soil Type	Pushover capacity	Base Condition		Variation (%)
				Fixed	SSI	
4	Frame System	Sb	Base Shear (KN)	3270.13	1916.56	41.39
		Sc		3010.61	1743.12	42.10
		Sd		2950.12	1731.36	41.31
		Se		2755.12	1605.89	42.55

4	Frame System	Sb	Roof Disp. (m)	0.196	0.301	-53.6
		Sc		0.223	0.354	-58.7
		Sd		0.296	0.398	-34.56
		Se		0.308	0.431	-39.9
4	Frame System	Sb	Period T (s)	0.85	1.00	-17.6
		Sc		0.85	1.00	-17.6
		Sd		0.85	1.00	-17.6
		Se		0.85	1.01	-18.8
4	Shear Wall	Sb	Base Shear (KN)	172121.71	9804.5	42.74
		Sc		15013.14	8564.60	42.95
		Sd		14104.30	7958.94	43.57
		Se		13974.92	7683.34	45.02
4	Shear Wall	Sb	Roof Disp. (m)	0.01	0.174	-900.1
		Sc		0.02	0.204	-505
		Sd		0.03	0.233	-380.3
		Se		0.04	0.286	-377.5
4	Shear Wall	Sb	Period T (s)	0.35	0.36	-2.8
		Sc		0.35	0.38	-2.5
		Sd		0.35	0.42	-20.1
		Se		0.35	0.52	-48.6

In Table 4.11, it is found that incorporating soil-structure interaction generally reduces the seismic demand. When soil-structure interaction considered in a building, the value of natural period becomes increased and it is found less in rock soil and more in soft soil. It was observed that while the base shear decreases in a building due to soil-structure interaction, it increases for the shear wall system.

Table 4.12: Variation of structural demands of 8 story building

Story	Framing Type	Soil Type	Pushover capacity	Base Condition		Variation (%)
				Fixed	SSI	
8	Frame System	Sb	Base Shear (KN)	3660.13	2136.56	41.62
		Sc		3010.61	1643.12	45.42
		Sd		2620.12	1531.36	41.60
		Se		3455.12	1885.89	45.42
8	Frame System	Sb	Roof Disp. (m)	0.234	0.384	-64.1
		Sc		0.257	0.411	-59.9
		Sd		0.296	0.458	-54.73
		Se		0.340	0.531	-56.2
8	Frame System	Sb	Period T (s)	1.50	1.72	-14.7
		Sc		1.50	1.72	-14.7
		Sd		1.50	1.73	-15.3
		Se		1.50	1.75	-16.7

8	Shear Wall	Sb	Base Shear (KN)	25820.14	14718.34	43.0
		Sc		23342.48	13318.62	43.0
		Sd		22123.64	12356.25	44.15
		Se		19395.20	10643.53	45.15
8	Shear Wall	Sb	Roof Disp. (m)	0.03	0.197	-556.7
		Sc		0.05	0.234	-368.7
		Sd		0.07	0.3	-328.6
		Se		0.08	0.353	-341.3
8	Shear Wall	Sb	Period T (s)	0.45	0.48	-6.7
		Sc		0.45	0.53	-17.8
		Sd		0.45	0.67	-48.9
		Se		0.45	0.90	-100

Table 4.12 shows that incorporating soil-structure interaction generally reduces the seismic demand. When soil-structure interaction considered in a building, the value of natural period becomes increased and it is found less in rock soil and more in soft soil. It was observed that while the base shear decreases in a building due to soil-structure interaction, it increases for the shear wall system.

4.2.3 Soil-Structure Interaction Effects On the Story Drifts

Story drift is defined as the displacement of one story with respect to the other story, used to determine the nonlinear performance level of a structure.

Story drift limitations:

- According to (IS 1893 (Part 1) :, 2016), story drift in any story shall not exceed 0.004 times the story height.

  Total drift to be limited to $\frac{H}{250}$, therefor according to the given data we can calculate four story building shall not exceed 0.048m and eight story building shall not exceed 0.096m.
- According to (ESEN-8) Damage limitation (story drift ratio < 0.5-1%) under the damage limitation earthquake (~50% of “design seismic action”), using 50% of uncracked gross section stiffness.

Table 4.13: Story displacements and Story drift ratios of 4 Story buildings

Soil Type	Base Condition	Story Number	Drift (m)	Base Shear (KN)	Story Drift	Story Drift Ratio (%)
ROCK SOIL	FIXED BASE, BARE FRAME	4	0.196	3270.13	0.021	0.7
		3	0.182	3110.24	0.016	0.53
		2	0.164	2742.58	0.029	0.96
		1	0.015	1345	0.015	0.5
		0	0	0	0	0
ROCK SOIL	FIXED BASE, SW1	4	0.01	17212.71	0.0093	0.331
		3	0.000071	16241.23	0.000071	0.0024
		2	0.0000003	11542.36	0.0000007	0.0000098
		1	0.000000005	7546.25	0.000000005	0.000000167
		0	0	0	0	0
ROCK SOIL	SSI, BARE FRAME	4	0.301	1916.56	0.016	0.53
		3	0.285	1816.67	0.016	0.53
		2	0.269	1352.63	0.026	0.87
		1	0.015	948.91	0.015	0.5
		0	0	0	0	0
ROCK SOIL	SSI, SW1	4	0.174	9804.5	0.017	0.567
		3	0.157	9642.35	0.016	0.53
		2	0.141	7541.63	0.015	0.5
		1	0.015	3847.36	0.015	0.5
		0	0	0	0	0
DENSE SOIL	FIXED BASE, BARE FRAME	4	0.223	3010.61	0.022	0.73
		3	0.201	2845.63	0.016	0.53
		2	0.185	2341.36	0.023	0.767
		1	0.015	1542.71	0.015	0.5
		0	0	0	0	0
DENSE SOIL	FIXED BASE, SW1	4	0.02	15013.14	0.0159	0.53
		3	0.0041	13214.25	0.0041	0.137
		2	0.00000001	9575.15	0.0041	0.137
		1	0.000000005	4375.45	0.000000091	0.00000303
		0	0	0	0	0
DENSE SOIL	SSI, BARE FRAME	4	0.354	1743.12	0.023	0.767
		3	0.331	1621.32	0.02	0.67
		2	0.311	1241.35	0.02	0.67
		1	0.015	879.65	0.015	0.5
		0	0	0	0	0
DENSE SOIL	SSI, SW1	4	0.204	8564.6	0.015	0.5
		3	0.189	8245.25	0.015	0.5
		2	0.174	7312.52	0.017	0.567
		1	0.015	4312.36	0.015	0.5
		0	0	0	0	0
	FIXED	4	0.296	2950.12	0.023	0.767

STIFF SOIL	BASE, BARE FRAME	3	0.273	2741.32	0.021	0.7
		2	0.252	2314.57	0.021	0.7
		1	0.015	1745.62	0.015	0.5
		0	0	0	0	0
STIFF SOIL	FIXED BASE, SW1	4	0.03	14104.3	0.015	0.5
		3	0.015	12342.35	0.0139	0.463
		2	0.0011	9847.95	0.00108	0.0359
		1	0.000021	4563.35	0.000021	0.0007
		0	0	0	0	0
STIFF SOIL	SSI, BARE FRAME	4	0.398	1731.36	0.027	0.9
		3	0.371	1542.12	0.03	1
		2	0.341	914.98	0.029	0.967
		1	0.312	397.34	0.015	0.5
		0	0	0	0	0
STIFF SOIL	SSI, SW1	4	0.233	7958.94	0.022	0.73
		3	0.211	7645.23	0.02	0.67
		2	0.191	6714.56	0.012	0.4
		1	0.015	3315.67	0.015	0.5
		0	0	0	0	0
SOFT SOIL	FIXED BASE, BARE FRAME	4	0.308	2755.12	0.025	0.83
		3	0.283	2612.32	0.021	0.7
		2	0.262	2132.14	0.021	0.7
		1	0.015	1452.31	0.015	0.5
		0	0	0	0	0
SOFT SOIL	FIXED BASE, SW1	4	0.04	13974.92	0.017	0.567
		3	0.023	12132.14	0.011	0.367
		2	0.012	9563.57	0.012	0.4
		1	0.000000051	4579.91	0.00000051	0.000017
		0	0	0	0	0
SOFT SOIL	SSI, BARE FRAME	4	0.431	1605.89	0.017	0.567
		3	0.414	1511.23	0.025	0.83
		2	0.389	918.94	0.026	0.867
		1	0.015	346.25	0.15	0.5
		0	0	0	0	0
SOFT SOIL	SSI, SW1	4	0.268	7683.35	0.017	0.567
		3	0.271	7463.16	0.014	0.467
		2	0.254	6342.54	0.018	0.6
		1	0.017	3987.47	0.015	0.567
		0	0	0	0	0

From Table 4.13, it is observed that the total displacement observed in the SSI case are more than an average of 51% of the same soil. For both fixed base and SSI over varying soil sites the drift ratio capacity of the shear wall (estimated at 0.5% on average). All drift values of four story building are lesser than the permissible values of 0.048m and the story drift ratios are less than 0.5-1%. As story of structure increases, the story drift reaches critical limit value.

Table 4.14: Story displacements and Story drift ratios of 8 Story buildings

Soil Type	Base Condition	Story Number	Drift (m)	Base Shear (KN)	Story Drift	Story Drift Ratio (%)
ROCK SOIL	FIXED BASE, BARE FRAME	8	0.234	3660.13	0.021	0.7
		7	0.213	3012.24	0.023	0.767
		6	0.19	2849.36	0.029	0.96
		5	0.161	2514.69	0.02	0.67
		4	0.141	2101.45	0.02	0.67
		3	0.121	1817.78	0.02	0.67
		2	0.101	1612.32	0.022	0.63
		1	0.015	1114.34	0.015	0.5
		0	0	0	0	0
ROCK SOIL	FIXED BASE, SW1	8	0.03	25820.14	0.015	0.5
		7	0.015	23612.41	0.0147	0.49
		6	0.0003	19723.74	0.00022	0.0074
		5	0.000078	16541.87	0.000031	0.00163
		4	0.000047	12431.78	0.0000014	0.0024
		3	0.0000045	9570.87	0.00000043	0.0000072
		2	0.0000041	7481.45	0.00000032	0.0000031
		1	0.000000035	4614.51	0.000000035	0.0000009
		0	0	0	0	0
ROCK SOIL	SSI, BARE FRAME	8	0.384	2136.56	0.023	0.767
		7	0.361	1825.31	0.019	0.633
		6	0.342	1542.31	0.022	0.733
		5	0.32	1214.78	0.03	1
		4	0.29	945.63	0.019	0.633
		3	0.271	611.23	0.021	0.7
		2	0.25	504.21	0.019	0.633
		1	0.016	246.54	0.016	0.53
		0	0	0	0	0
ROCK SOIL	SSI, SW1	8	0.197	14718.34	0.013	0.433
		7	0.184	1245.63	0.017	0.567
		6	0.167	1004.41	0.013	0.433
		5	0.154	818.74	0.014	0.467
		4	0.14	614.85	0.02	0.67
		3	0.12	457.96	0.02	0.67
		2	0.1	241.54	0.017	0.567
		1	0.015	112.6	0.15	0.5
		0	0	0	0	0
		8	0.257	3010.61	0.022	0.73

DENSE SOIL	FIXED BASE, BARE FRAME	7	0.235	2845.14	0.018	0.6
		6	0.217	2462.25	0.017	0.567
		5	0.2	2278.96	0.02	0.67
		4	0.18	1998.63	0.027	0.9
		3	0.153	1725.57	0.021	0.7
		2	0.132	1487.87	0.02	0.67
		1	0.015	987.69	0.015	0.5
		0	0	0	0	0
DENSE SOIL	FIXED BASE, SW1	8	0.05	23342.48	0.015	0.5
		7	0.035	21456.74	0.014	0.467
		6	0.015	18642.25	0..014	0.467
		5	0.0051	15632.14	0.006	0.26
		4	0.000047	11495.32	0.0149	0.49
		3	0.0000078	8346.54	0.0149	0.49
		2	0.00000013	6268.49	0.000056	0.09
		1	0.000000015	2678.14	0.0000014	0.087
		0	0	0	0	0
DENSE SOIL	SSI, BARE FRAME	8	0.411	1643.12	0.021	0.7
		7	0.39	1445.36	0.019	0.63
		6	0.371	1002.47	0.019	0.63
		5	0.352	845.36	0.019	0.63
		4	0.333	647.25	0.019	0.63
		3	0.314	547.23	0.023	0.767
		2	0.291	289.31	0.018	0.6
		1	0.017	98.14	0.017	0.567
		0	0	0	0	0
DENSE SOIL	SSI, SW1	8	0.234	13318.62	0.014	0.467
		7	0.22	11424.63	0.019	0.63
		6	0.201	9647.87	0.021	0.7
		5	0.18	7846.51	0.02	0.67
		4	0.16	5423.69	0.02	0.67
		3	0.14	3654.12	0.017	0.567
		2	0.123	1836.12	0.022	0.73
		1	0.015	1245.36	0.015	0.5
		0	0	0	0	0
STIFF SOIL	FIXED BASE, BARE FRAME	8	0.296	2620.12	0.016	0.53
		7	0.28	2415.23	0.018	0.6
		6	0.262	2012.47	0.021	0.7
		5	0.241	1841.78	0.021	0.7
		4	0.22	1547.65	0.02	0.67
		3	0.2	1141.65	0.016	0.53
		2	0.184	845.96	0.018	0.93
		1	0.015	546.54	0.15	0.5
		0	0	0		0
		8	0.07	22123.64	0.017	0.567

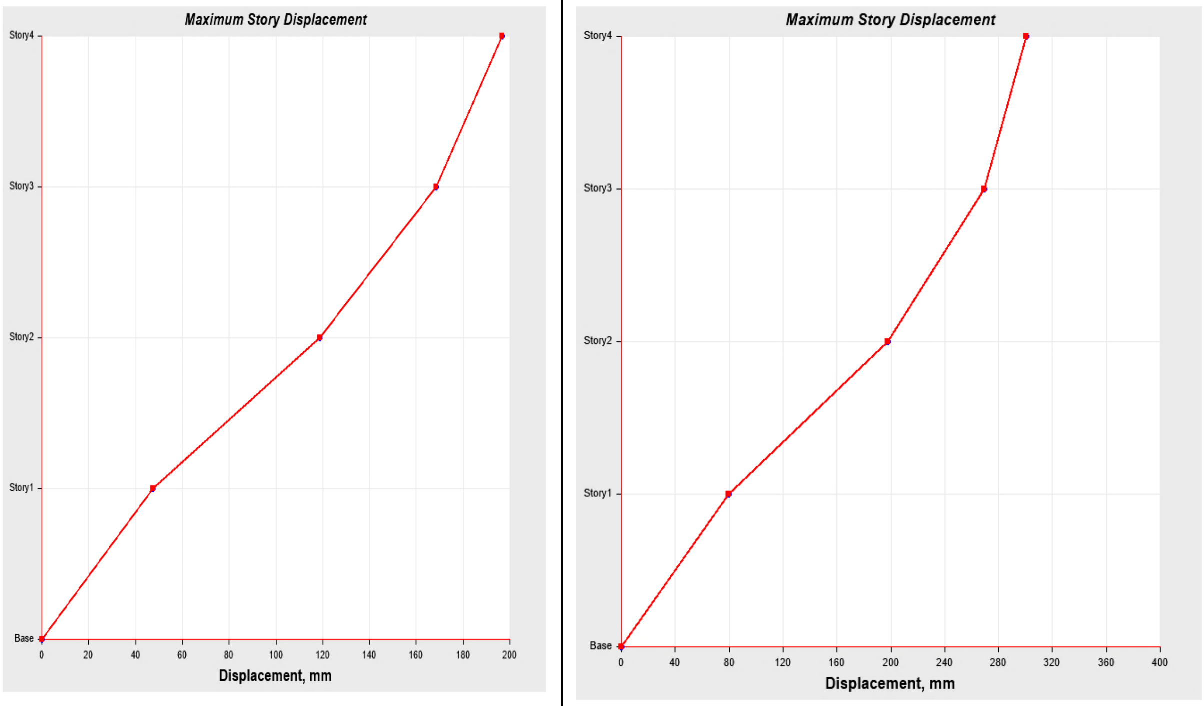
STIFF SOIL	FIXED BASE, SW1	7	0.053	20456.36	0.012	0.4
		6	0.041	18478.15	0.02	0.67
		5	0.021	15621.24	0.009	0.3
		4	0.021	12147.85	0.0029	0.9
		3	0.012	9763.35	0.009	0.3
		2	0.00032	6245.12	0.009	0.3
		1	0.000054	3475.12	0.000063	0.0036
		0	0	0	0	0
STIFF SOIL	SSI, BARE FRAME	8	0.458	1531.36	0.017	0.567
		7	0.441	1342.25	0.02	0.67
		6	0.421	1020.24	0.021	0.7
		5	0.4	824.36	0.019	0.63
		4	0.381	578.34	0.017	0.567
		3	0.364	320.14	0.015	0.5
		2	0.349	194.68	0.028	0.6
		1	0.017	102.47	0.017	0.567
		0	0	0	0	0
STIFF SOIL	SSI, SW1	8	0.3	12356.25	0.017	0.567
		7	0.283	10245.11	0.012	0.4
		6	0.271	8745.12	0.02	0.67
		5	0.251	6123.25	0.018	0.6
		4	0.233	4752.31	0.014	0.467
		3	0.219	2514.78	0.015	0.5
		2	0.204	1750.69	0.017	0.567
		1	0.016	1140.57	0.016	0.53
		0	0	0	0	0
SOFT SOIL	FIXED BASE, BARE FRAME	8	0.34	3455.12	0.02	0.67
		7	0.32	3311.25	0.02	0.67
		6	0.3	2945.25	0.03	1
		5	0.27	2547.12	0.02	0.67
		4	0.25	2145.69	0.07	0.567
		3	0.23	1845.21	0.02	0.67
		2	0.21	1425.12	0.06	0.53
		1	0.015	984.45	0.015	0.5
		0	0	0	0	0
SOFT SOIL	FIXED BASE, SW1	8	0.08	19395.2	0.015	0.5
		7	0.065	1796.32	0.016	0.53
		6	0.049	15421.74	0.018	0.6
		5	0.031	12489.87	0.009	0.3
		4	0.022	9745.63	0.01	0.33
		3	0.012	7421.54	0.002	0.06
		2	0.00000045	5342.68	0.000677	0.000223
		1	0.000000015	2431.26	0.00016	0.0053
		0	0	0	0	0

SOFT SOIL	SSI, BARE FRAME	8	0.531	1885.89	0.018	0.6
		7	0.513	1742.21	0.023	0.767
		6	0.49	1521.25	0.019	0.63
		5	0.471	1278.32	0.018	0.6
		4	0.453	935.23	0.019	0.63
		3	0.434	742.35	0.022	0.73
		2	0.412	423.69	0.022	0.73
		1	0.018	190.68	0.018	0.6
		0	0	0	0	0
SOFT SOIL	SSI, SW1	8	0.353	10643.53	0.015	0.5
		7	0.338	8741.56	0.015	0.5
		6	0.323	6541.25	0.013	0.43
		5	0.31	4123.52	0.016	0.53
		4	0.294	2541.63	0.016	0.53
		3	0.278	2236.62	0.016	0.53
		2	0.262	1978.65	0.017	0.567
		1	0.016	1512.32	0.016	0.53
		0	0	0	0	0

Table 28 shows that the total displacement observed in the SSI case are more than an average of 51% of the same soil. For both fixed base and SSI over varying soil sites the drift ratio capacity of the shear wall (estimated at 0.5% on average). All drift values of four story building are lesser than the permissible values of 0.048m and the story drift ratios are less than 0.5-1%. As story of structure increases, the story drift reaches critical limit value.

Fig. 4.5-4.14 indicates that the story drift increase based on the soil's flexibility. Therefore, the largest drifts are found in soft soil.

(a). FIXED BASE, BARE FRAME   (B). SSI, BARE FRAME



(.c). FIXED BASE, SW1   (d). SSI, SW1

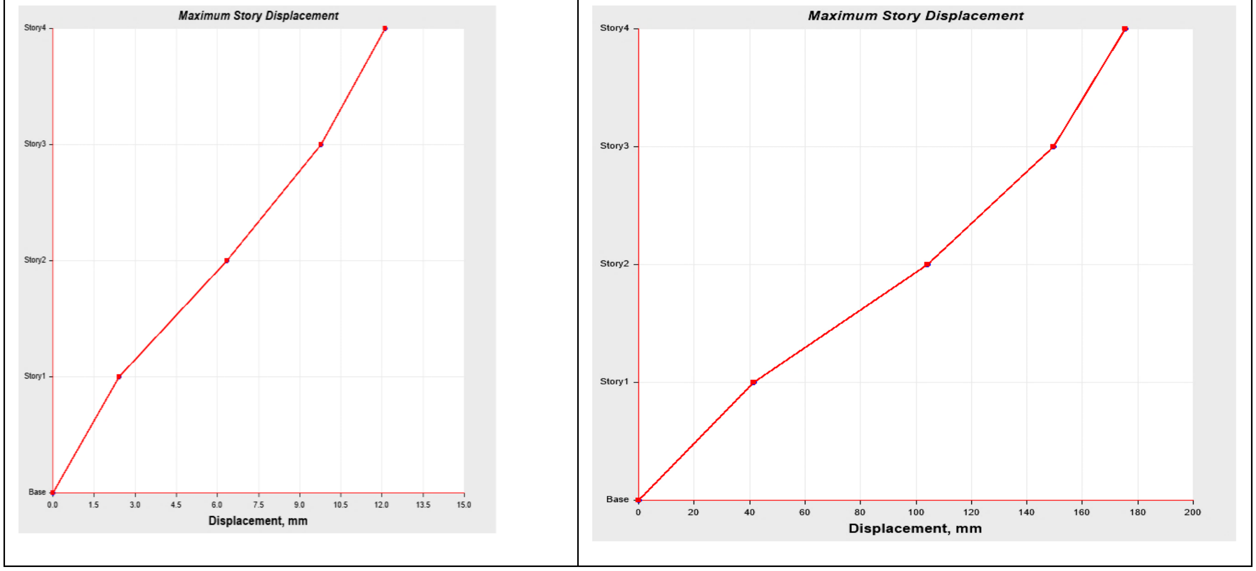
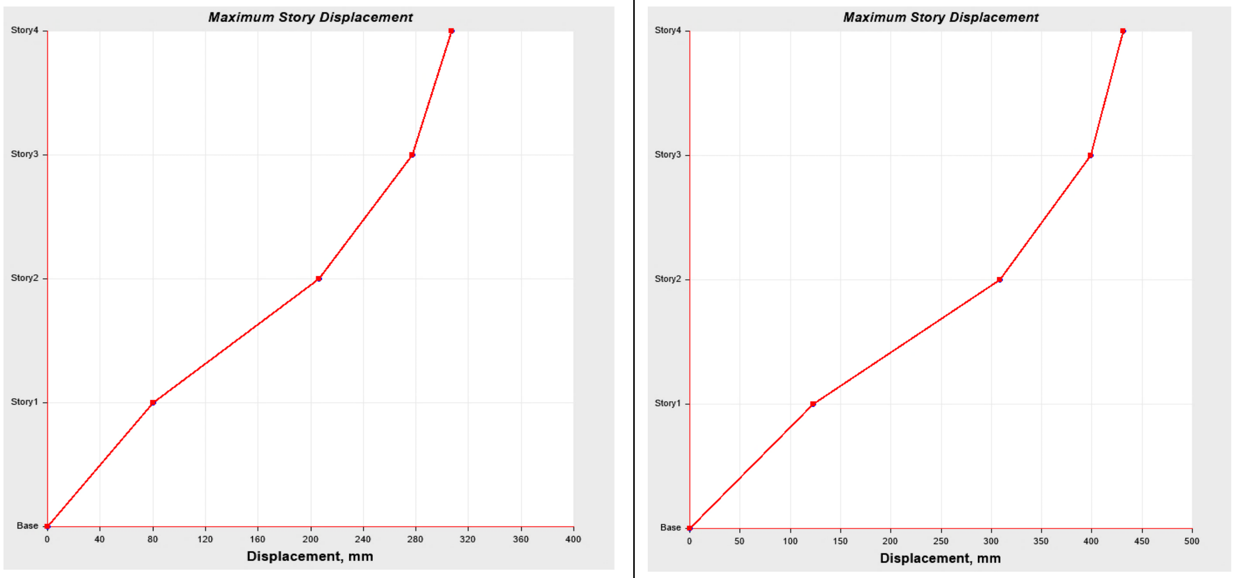


Figure 4.5: Story displacements of four-story buildings found on rock soil (a). Fixed Base, Bare Frame (b). SSI, Bare Frame (c). Fixed Base, SW1 (d). SSI, SW1.

(a). FIXED BASE, BARE FRAME

(b). SSI, BARE FRAME



(c.). FIXED BASE, SW1

(d). SSI, SW1

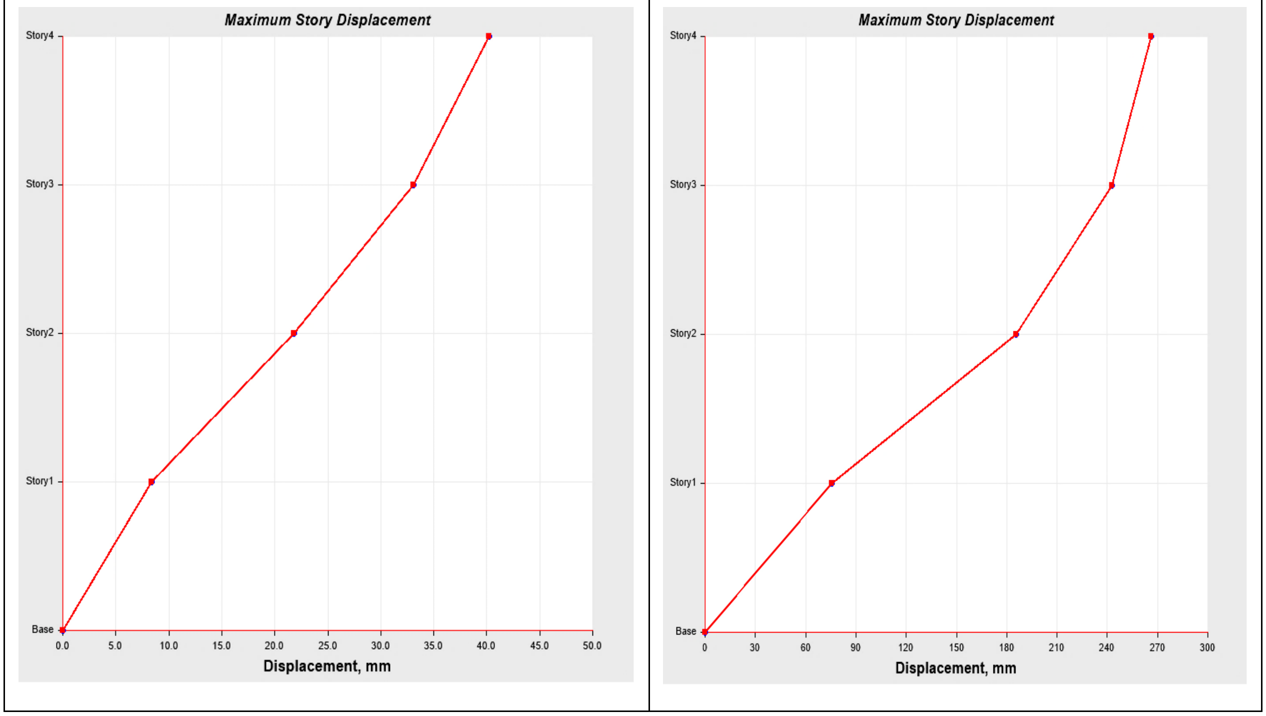
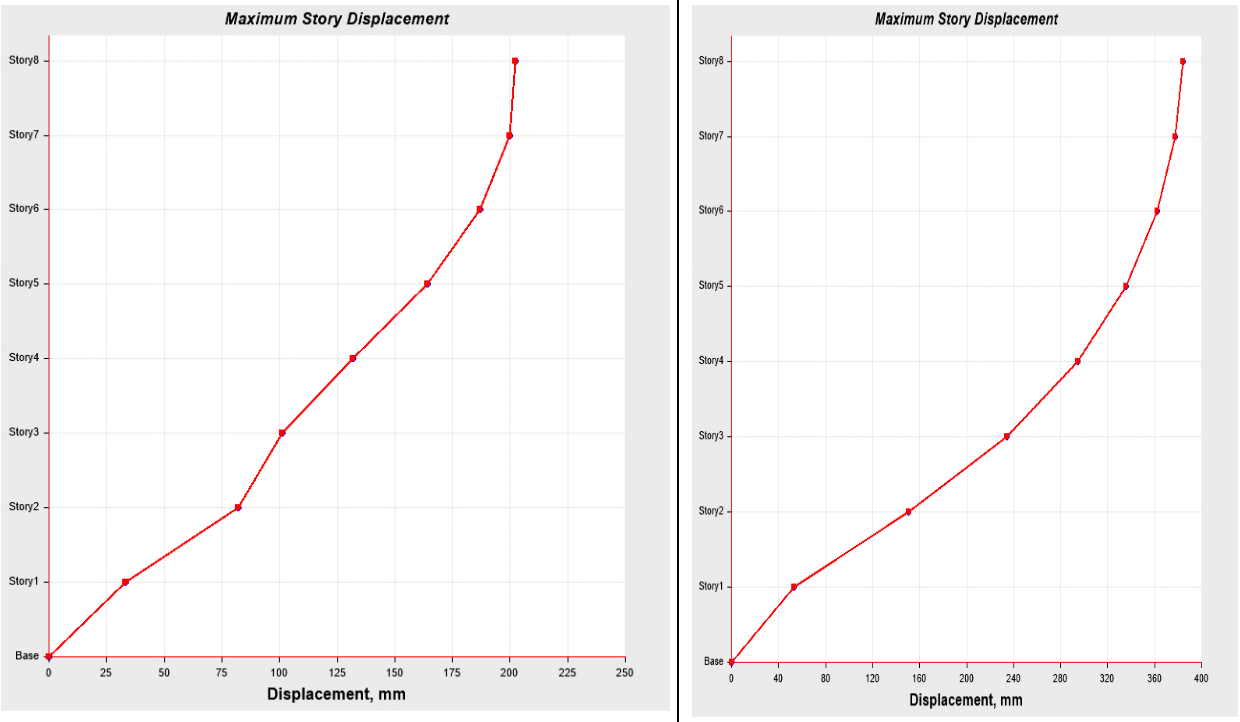


Figure 4.6: Story displacements of four-story buildings found on soft soil (a). Fixed Base, Bare Frame (b). SSI, Bare Frame (c). Fixed Base, SW1 (d). SSI, SW1

(a). FIXED BASE, BARE FRAME

(b). SSI, BARE FRAME



(c.). FIXED BASE, SW1

(d). SSI, SW1

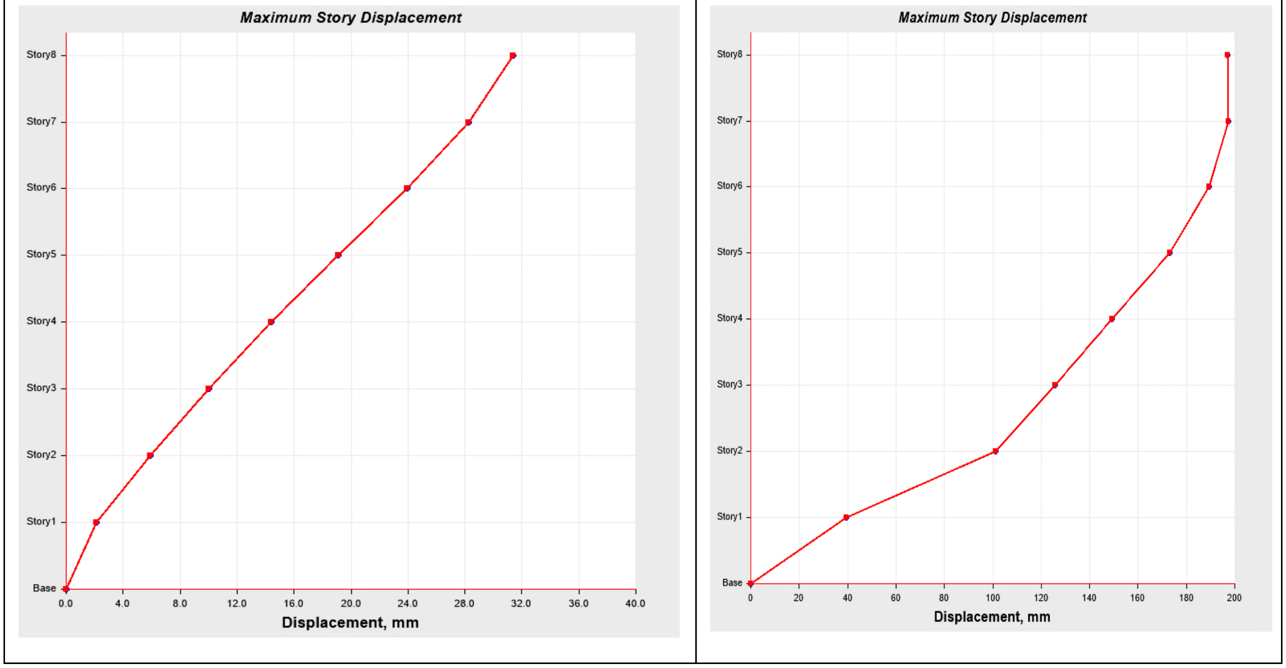
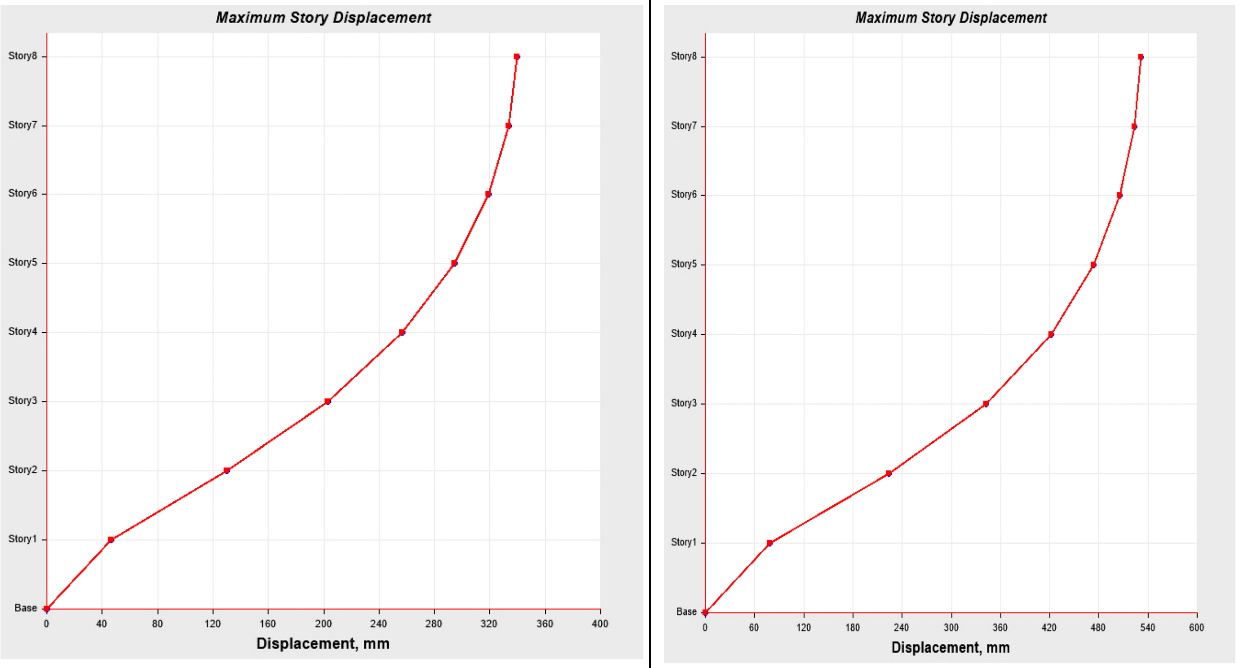


Figure 4.7: Story displacements of eight-story buildings found on rock soil (a). Fixed Base, Bare Frame (b). SSI, Bare Frame (c). Fixed Base, SW1 (d). SSI, SW1.

(a). FIXED BASE, BARE FRAME

(b). SSI, BARE FRAME



(c.). FIXED BASE, SW1

(d). SSI, SW1

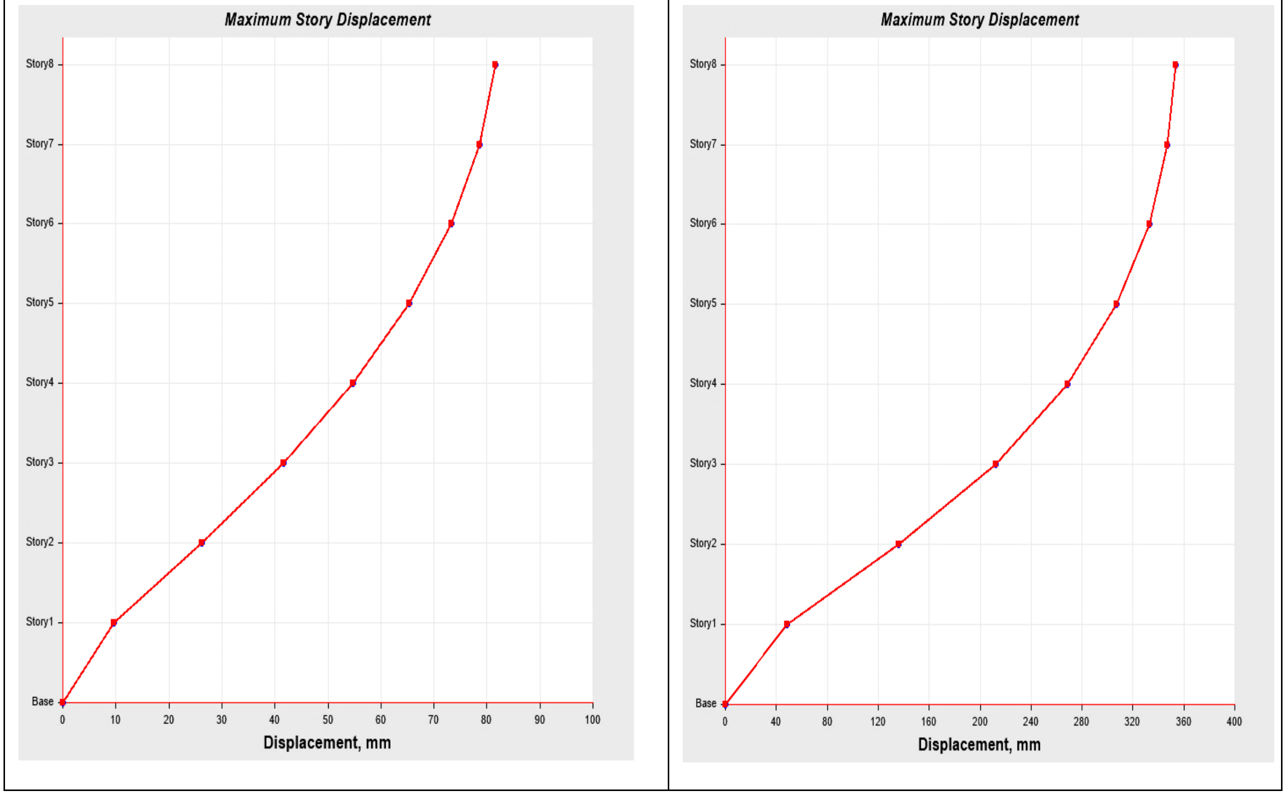
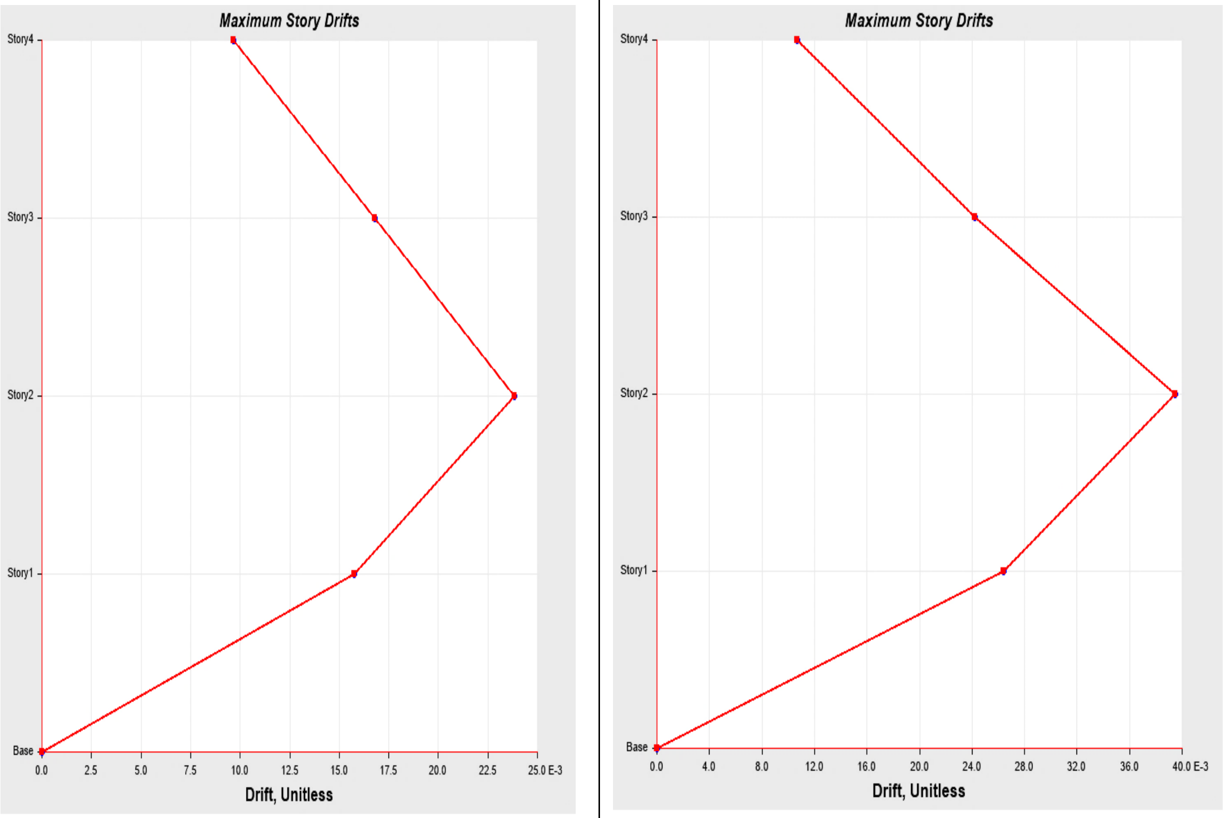


Figure 4.8: Story displacements of eight-story buildings found on soft soil (a). Fixed Base, Bare Frame (b). SSI, Bare Frame (c). Fixed Base, SW1 (d). SSI, SW1.

(a). FIXED BASE, BARE FRAME

(b). SSI, BARE FRAME



(c.). FIXED BASE, SW1

(d). SSI, SW1

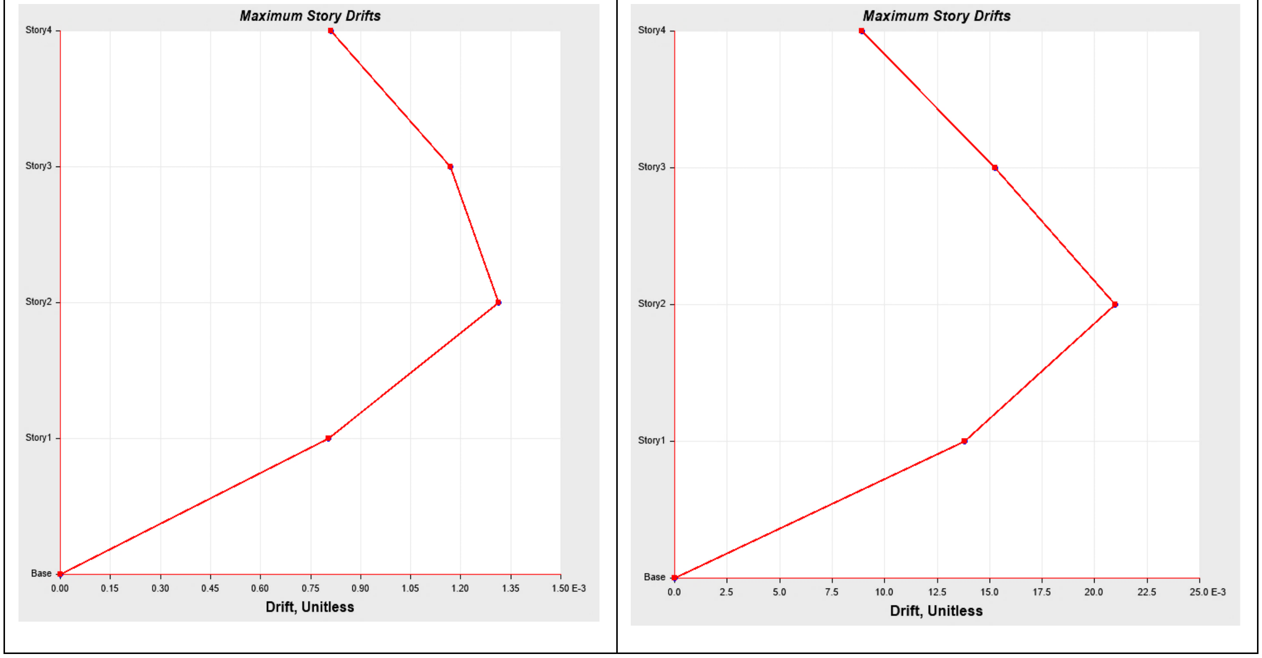
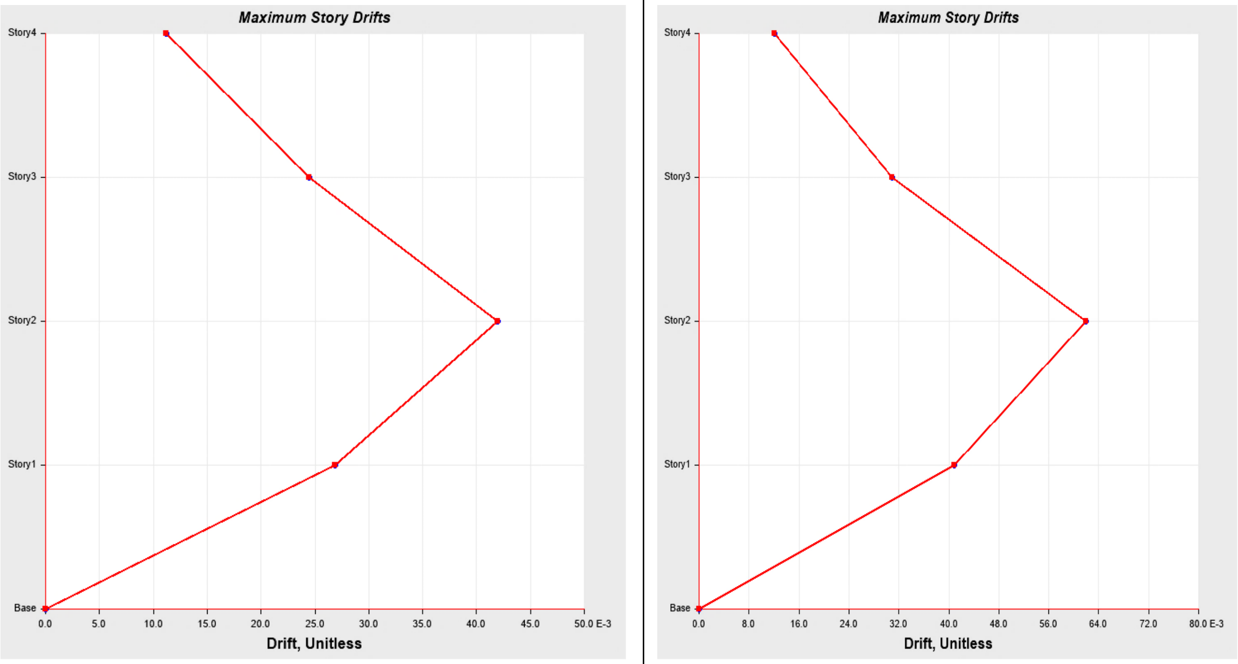


Figure 4.9: Story Drifts of four-story building resting on rock soil (a). Fixed Base, Bare Frame (b). SSI, Bare Frame (c). Fixed Base, SW1 (d). SSI, SW1.

(a). FIXED BASE, BARE FRAME

(b). SSI, BARE FRAME



(c.). FIXED BASE, SW1

(d). SSI, SW1

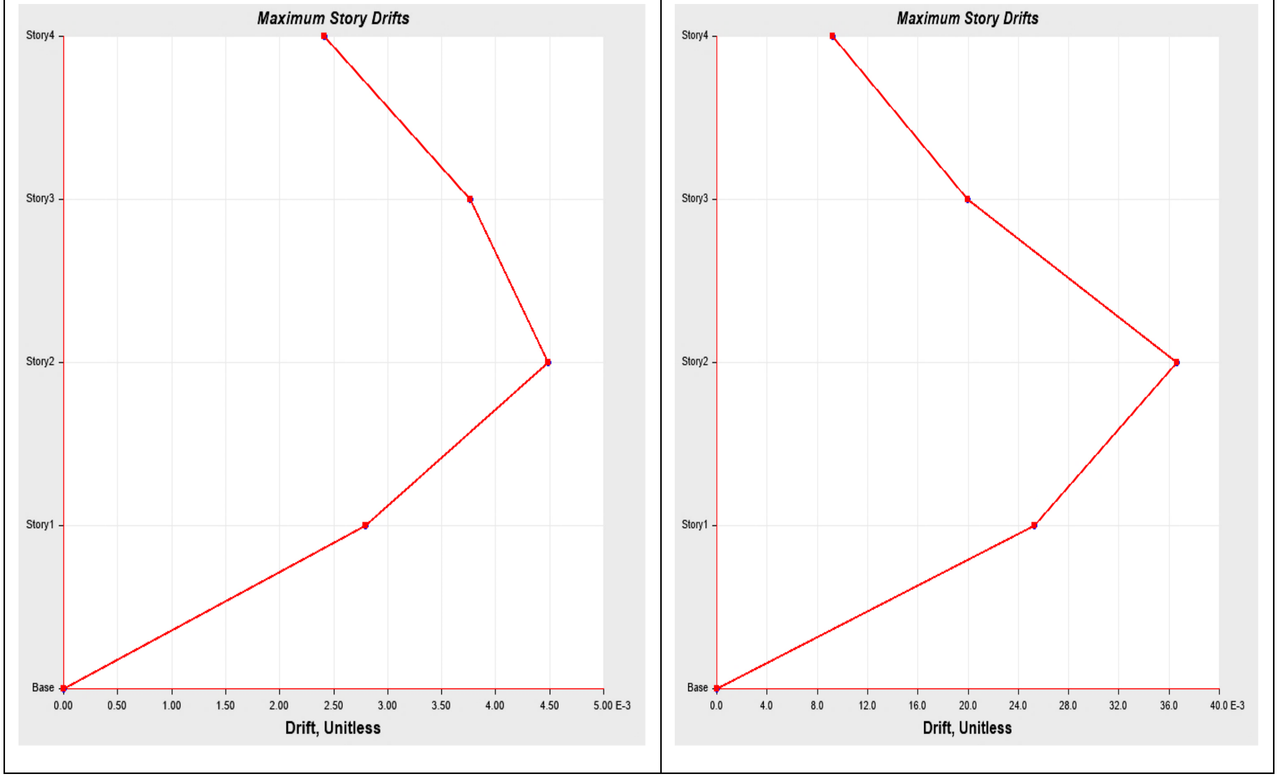
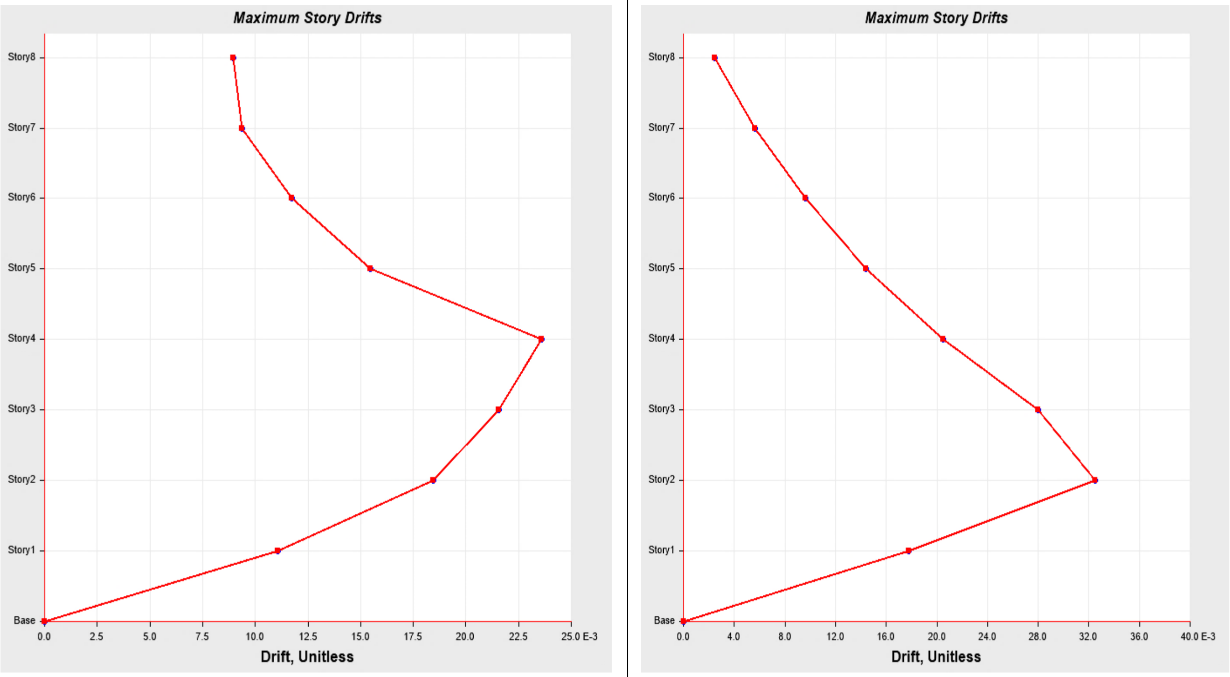
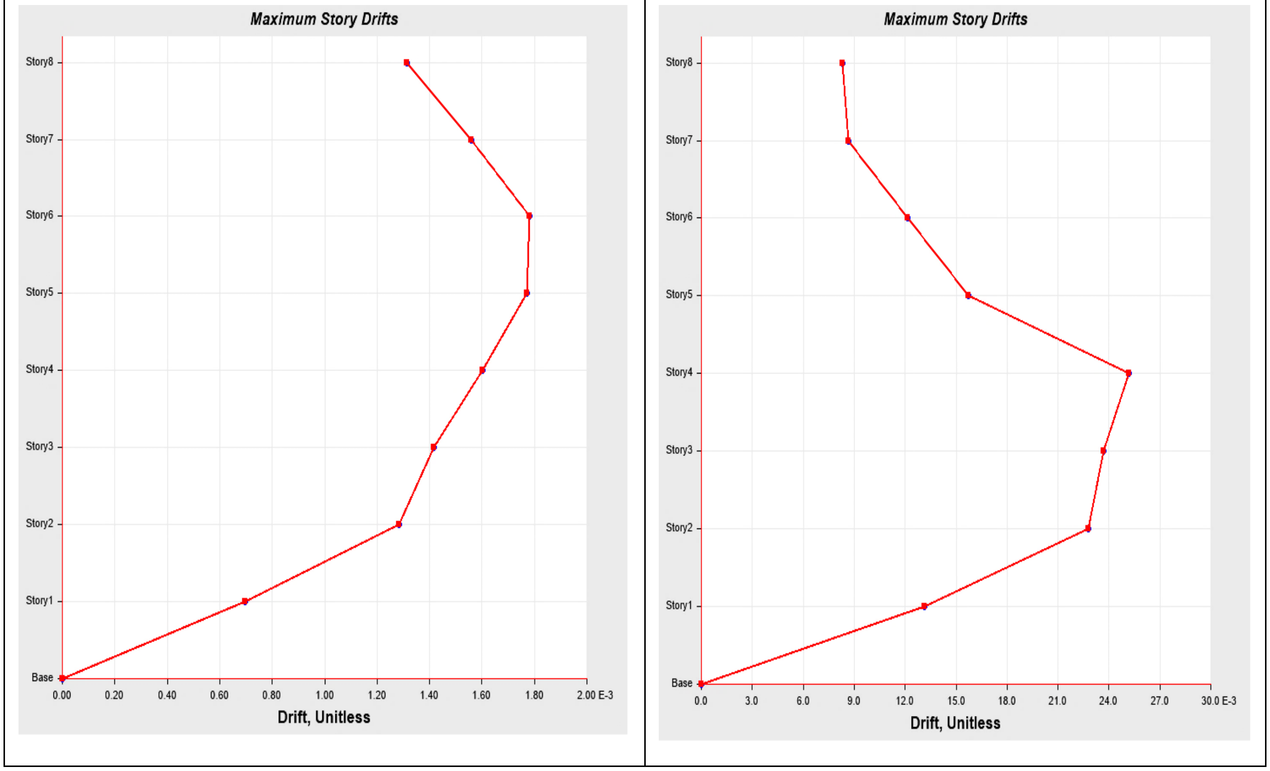


Figure 4.10: Story drifts of four-story building resting on soft soil (a). Fixed Base, Bare Frame (b). SSI, Bare Frame (c). Fixed Base, SW1 (d). SSI, SW1.



(a). FIXED BASE, BARE FRAME

(b). SSI, BARE FRAME

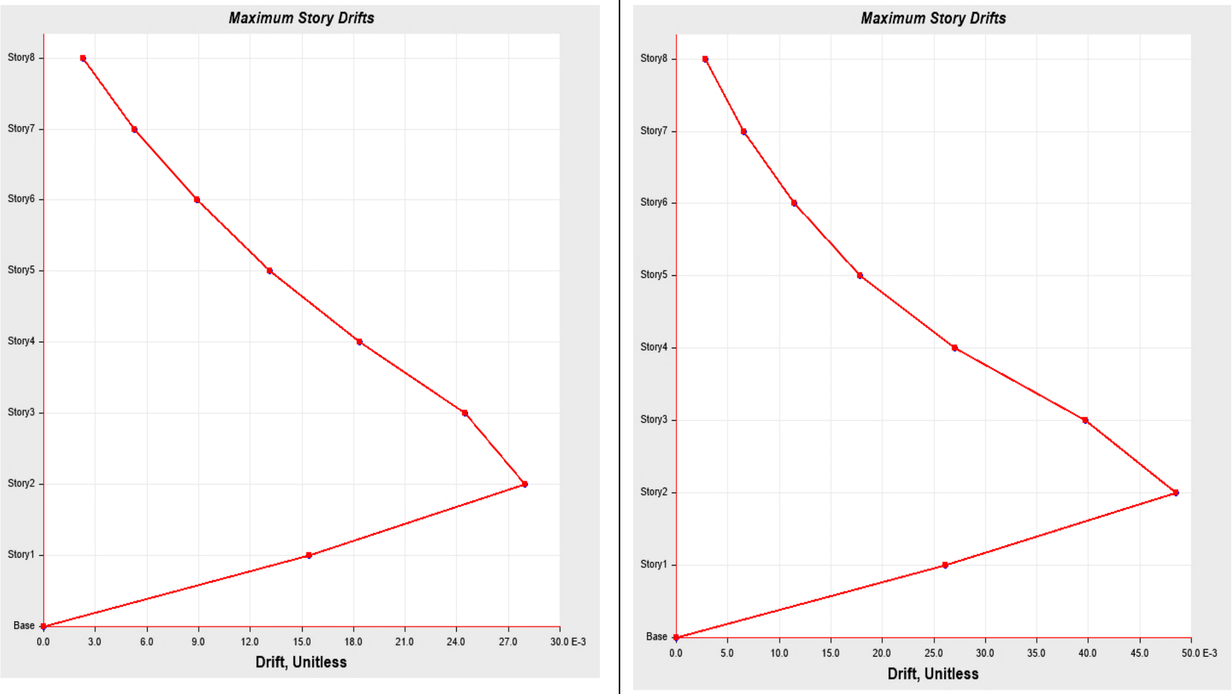


(c.). FIXED BASE, SW1

(d). SSI, SW1

Figure 4.11: Story drifts of eight-story building resting on rock soil (a). Fixed Base, Bare Frame (b). SSI, Bare Frame (c). Fixed Base, SW1 (d). SSI, SW1.

(a). FIXED BASE, BARE FRAME (b). SSI, BARE FRAME



(c.). FIXED BASE, SW1 (d). SSI, SW1

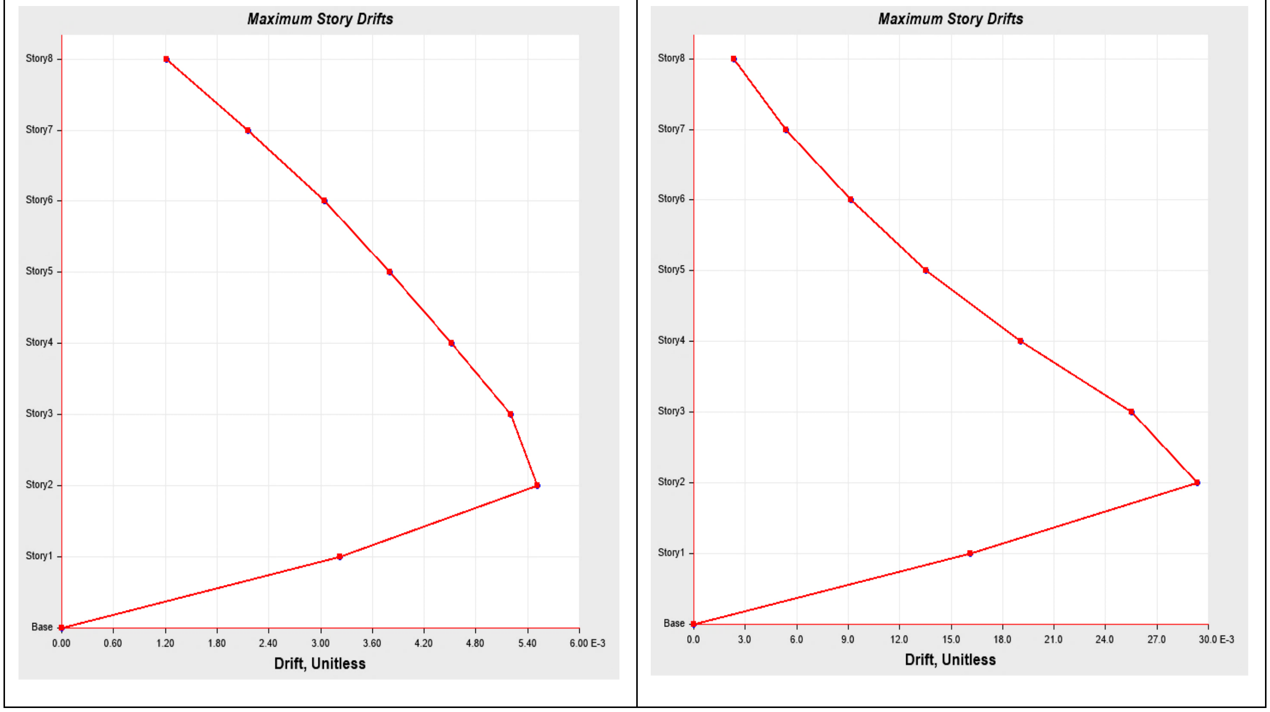
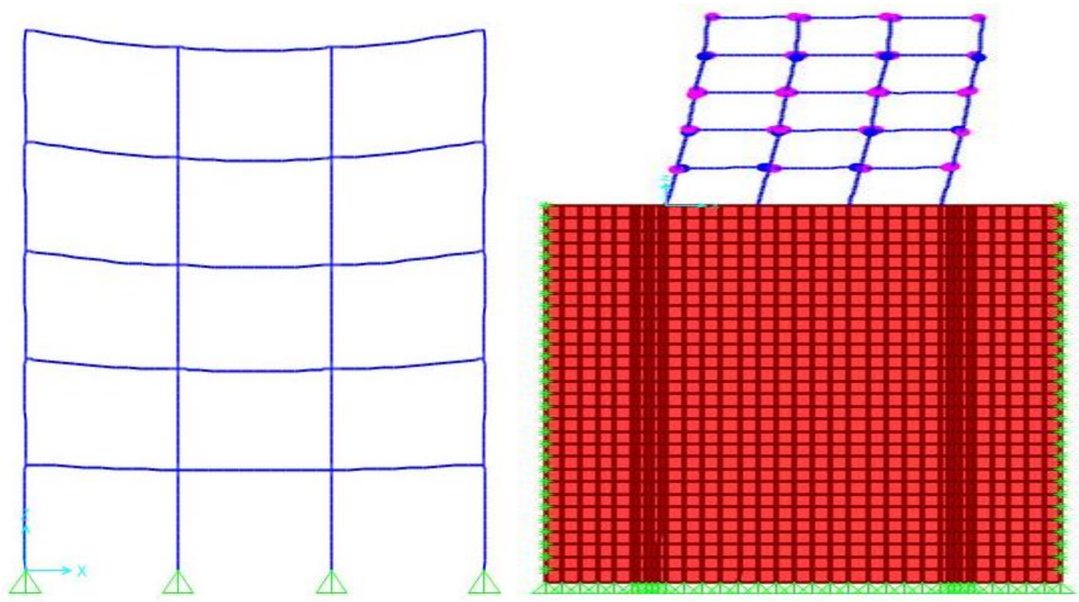


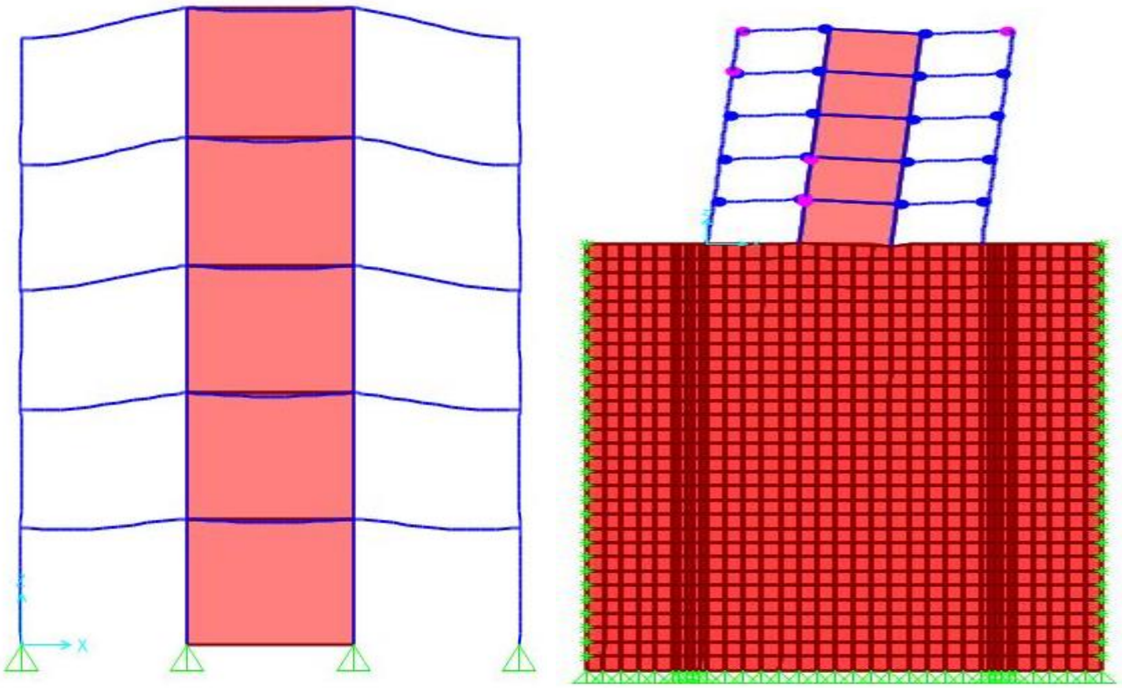
Figure 4.12: Story drifts of eight-story building resting on soft soil (a). Fixed Base, Bare Frame (b). SSI, Bare Frame (c). Fixed Base, SW1 (d). SSI, SW1.

4.2.4 Soil-Structure Interaction Effects on the Plastic Hinge Mechanism

A hinge property is a set of nonlinear properties that can be assigned to points along the length of one or more frame elements. Assigning Hinge properties of 5% and 95%. Hinge information: Beams- From Tables in ASCE 41-43, Table 10-7 (Concrete Beams-Flexure)- M3. And Columns- Auto Hinge Type- From Tables in ASCE 41-43, Table 10-8 (Concrete Columns)- P-M2-M3 in SAP 2000V21. Assign hinges to Model for observing the structural behavior of sequential loss of strength in different performance level of the structure due to seismic effect.

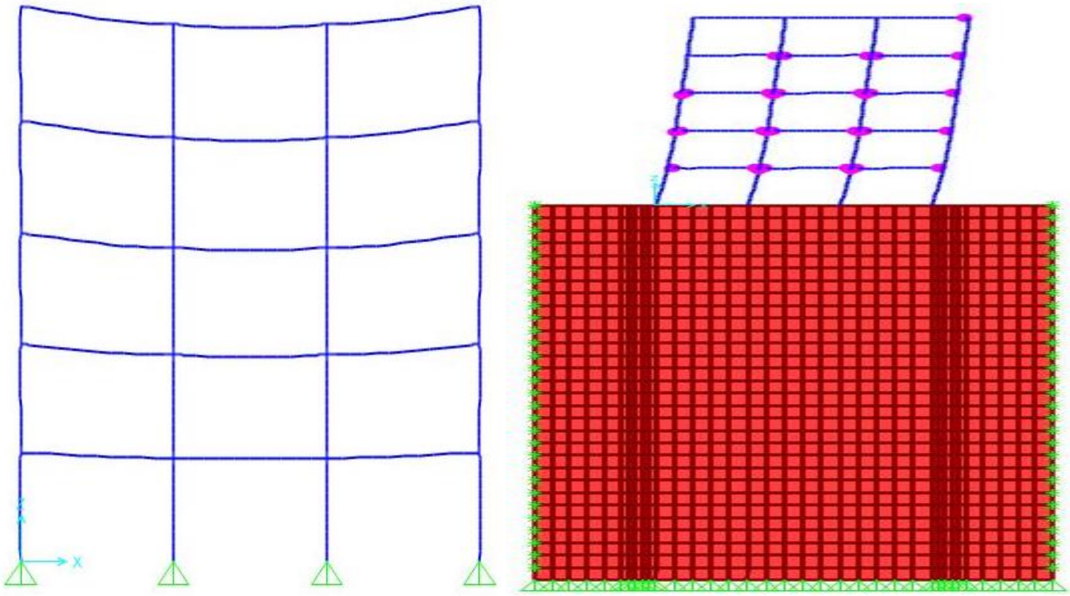


(a) (b)

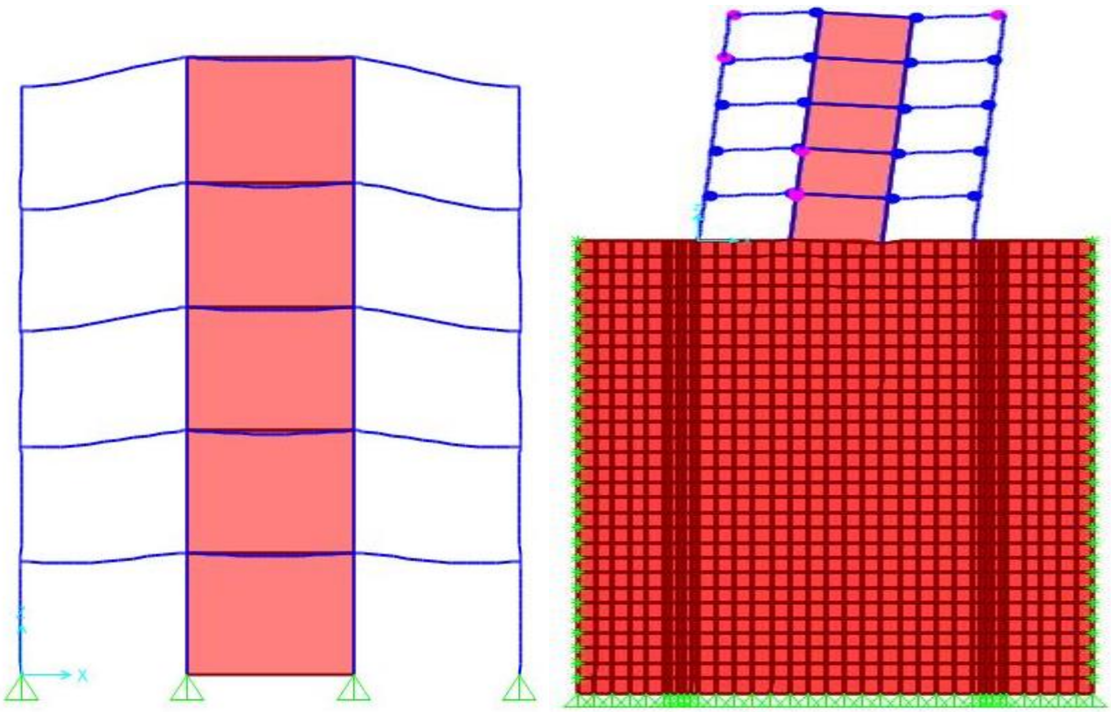


(c) (d)

Figure 4.13: Plastic hinge formation 4 story found on Rock soil (a) Fixed base, Bare frame (b) SSI, Bare frame (c) Fixed, SW1 (d) SSI, SW1



(a) (b)



(c.) (d.)

Figure 4.14: Plastic hinge formation 4 story found on Dense soil (a) Fixed base, Bare frame (b) SSI, Bare frame (c) Fixed, SW1 (d) SSI, SW1.

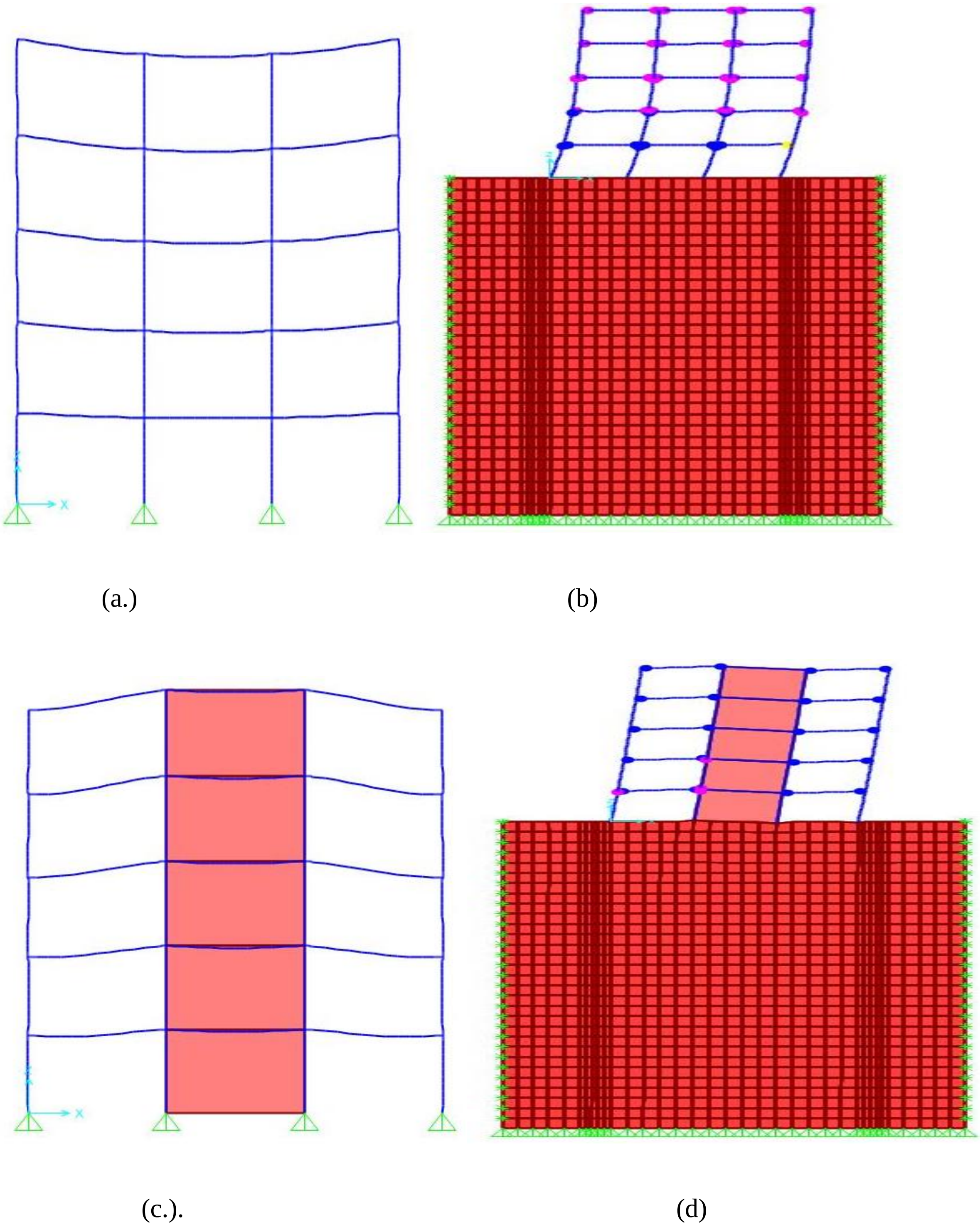
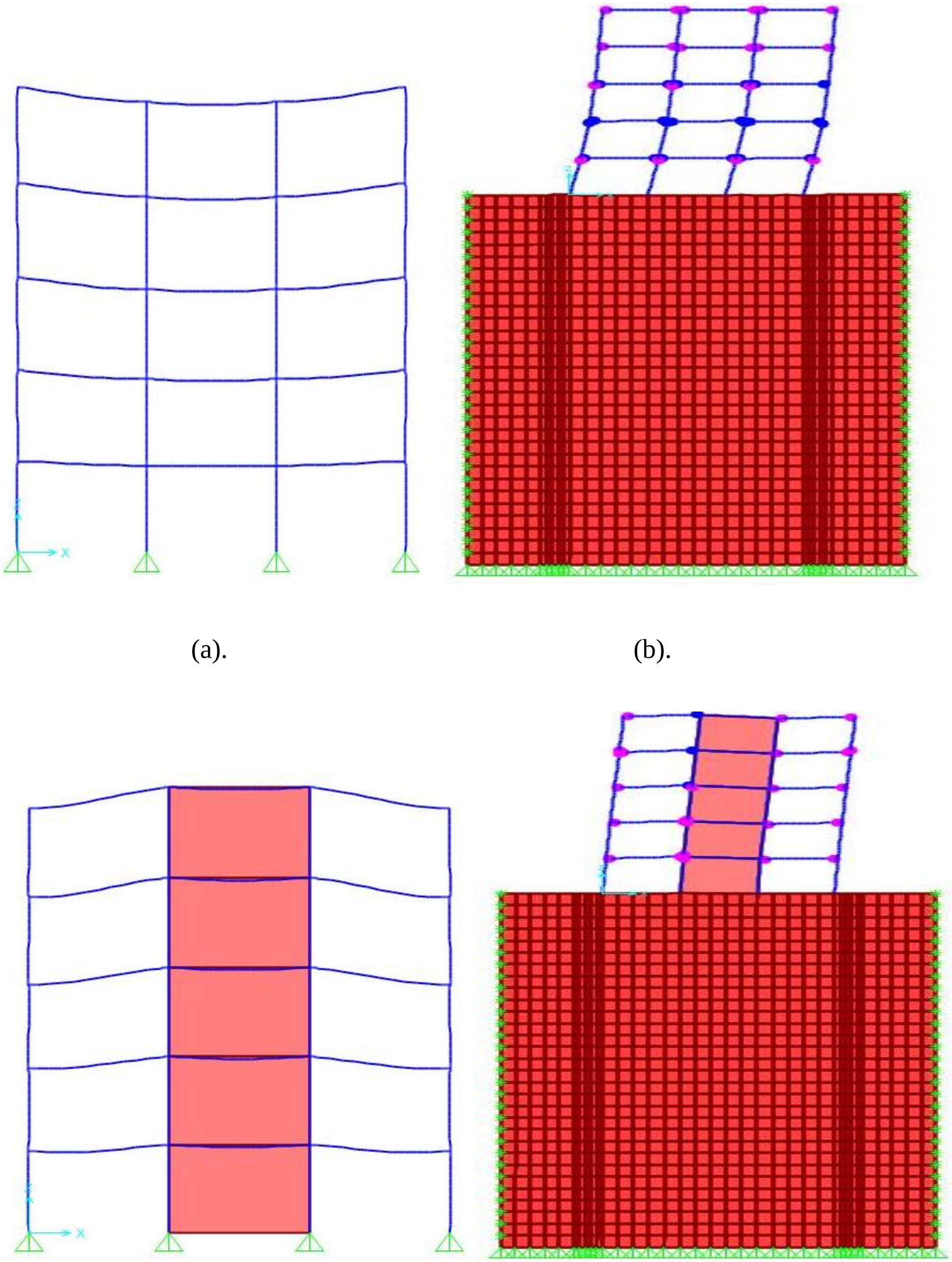


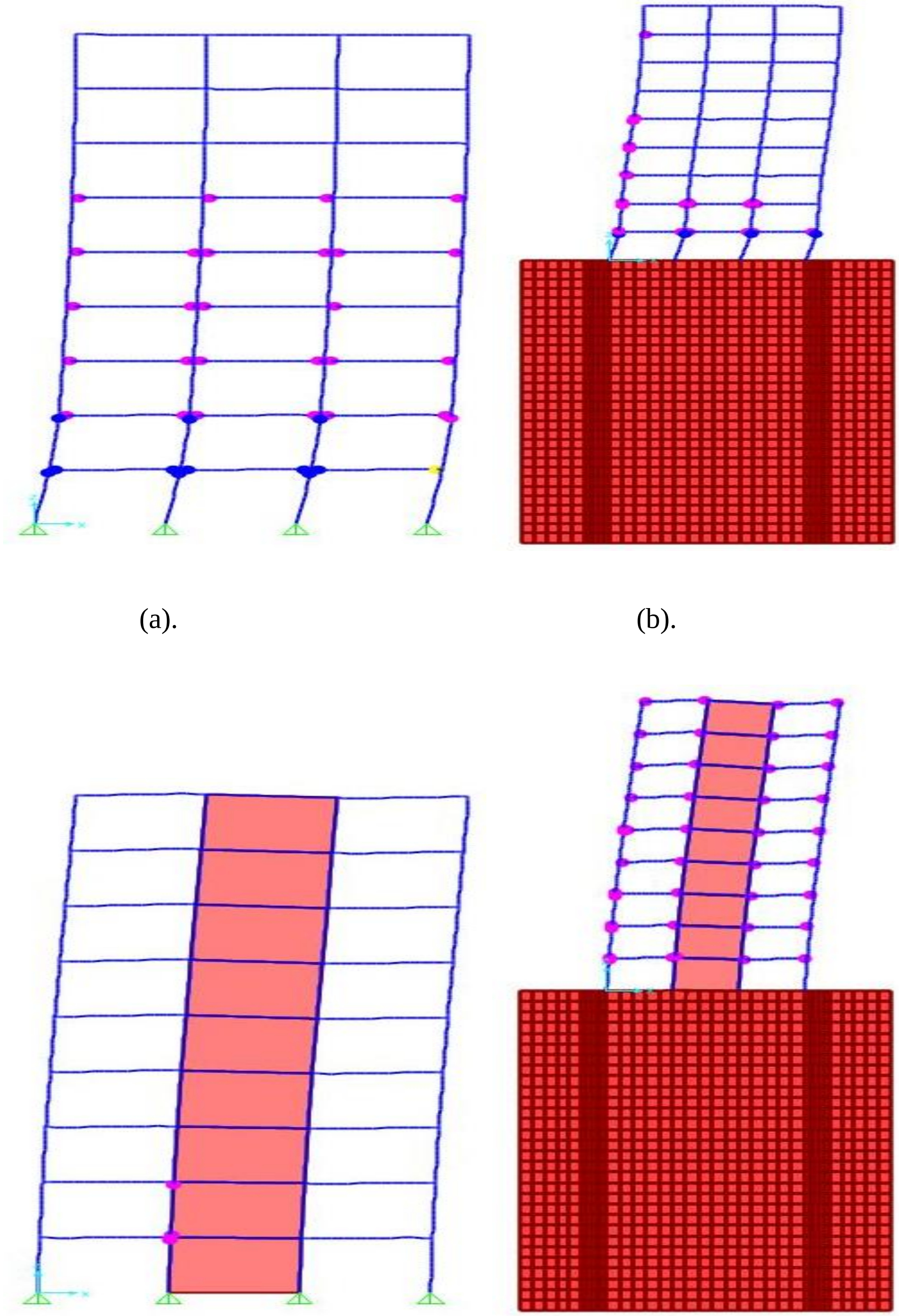
Figure 4.15: Plastic hinge formation 4 story found on Stiff soil (a) Fixed base, Bare frame (b) SSI, Bare frame (c) Fixed, SW1 (d) SSI, SW1.



(a). (b).

(c.). (d).

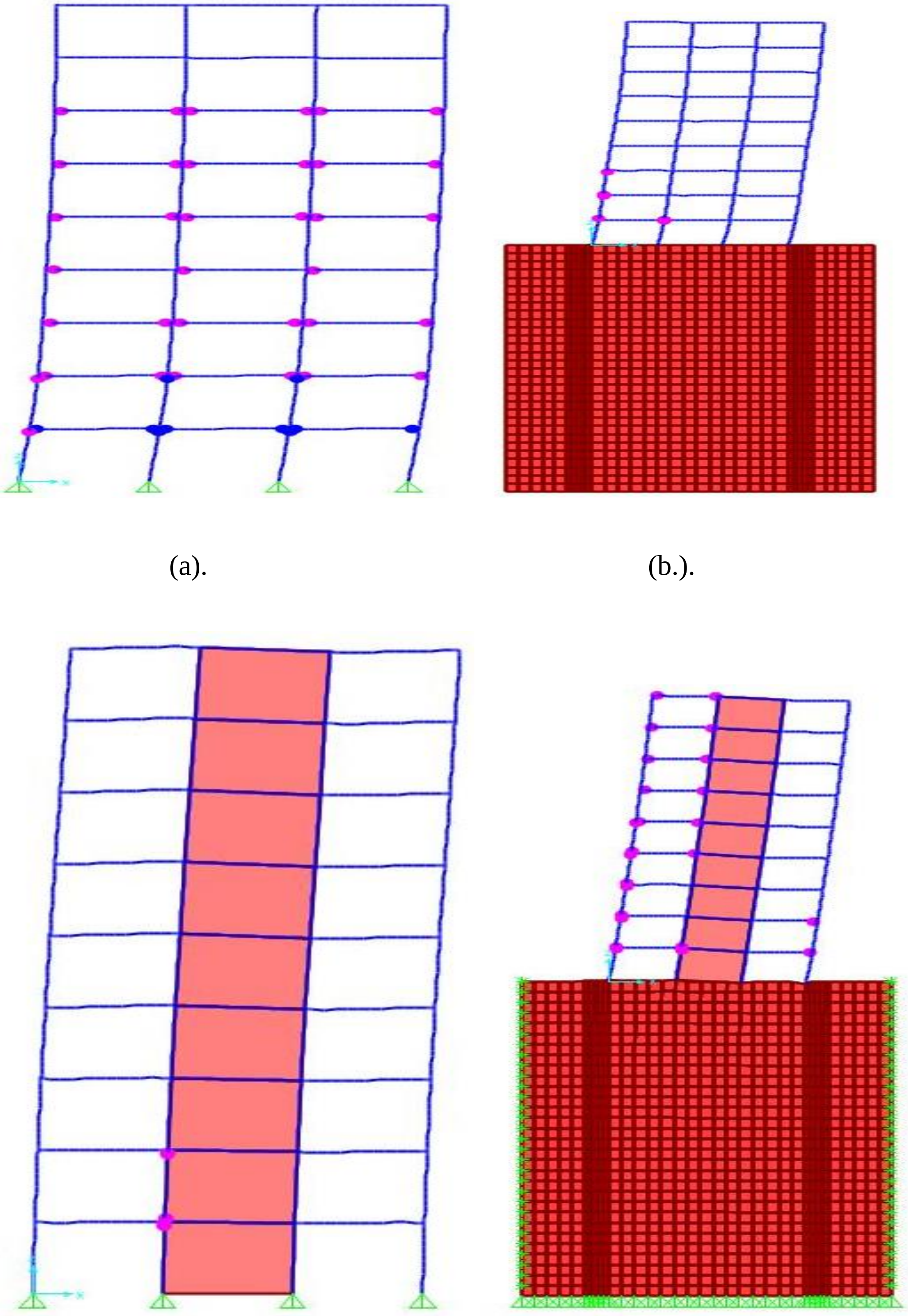
Figure 4.16: Plastic hinge formation 4 story found on Soft soil (a) Fixed base, Bare frame (b) SSI, Bare frame (c) Fixed, SW1 (d) SSI, SW1.



(a). (b).

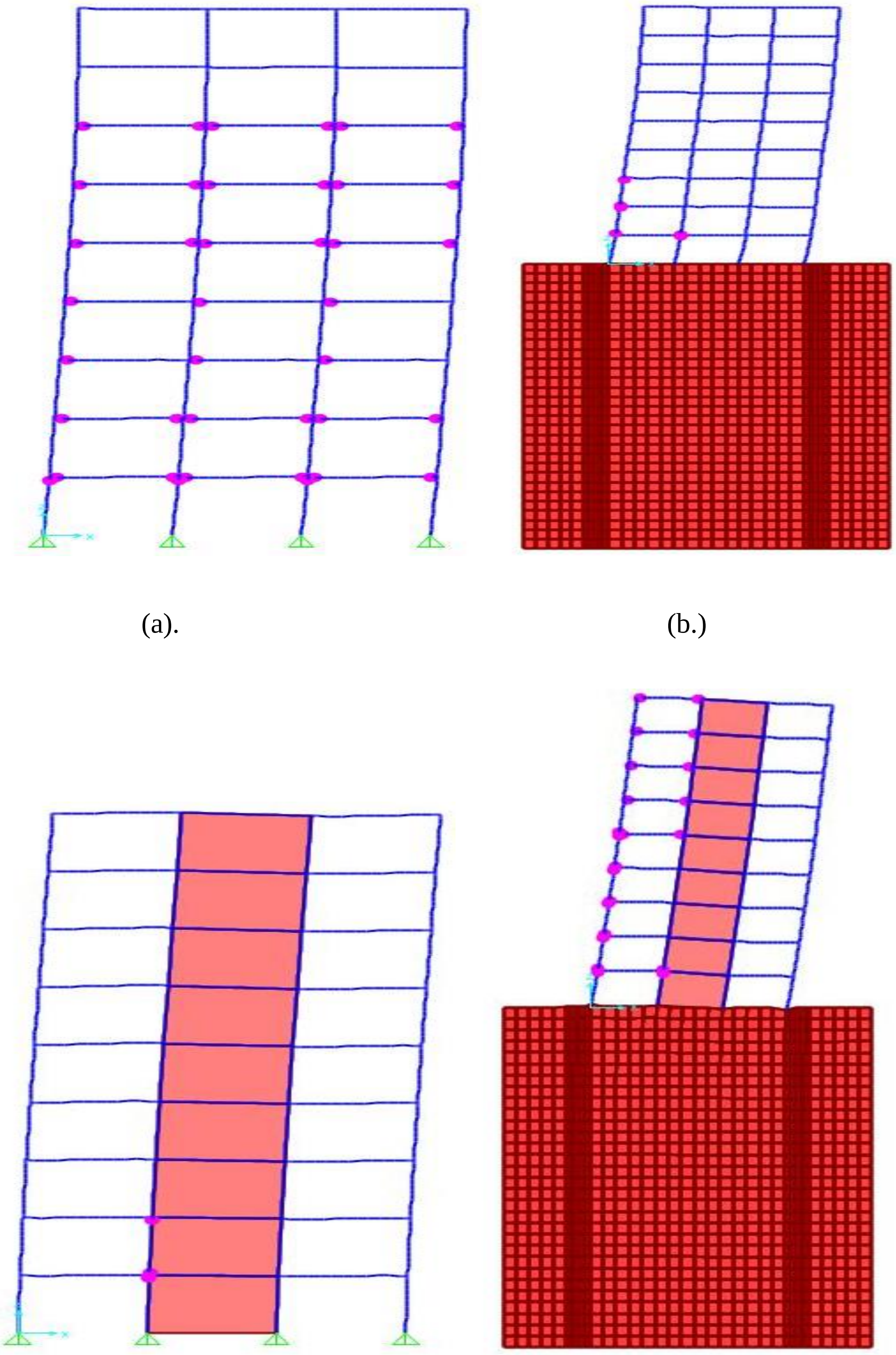
(c.). (d.).

Figure 4.17: Plastic hinge formation 8 story found on Rock soil (a) Fixed base, Bare frame (b) SSI, Bare frame (c) Fixed, SW1 (d) SSI, SW1.



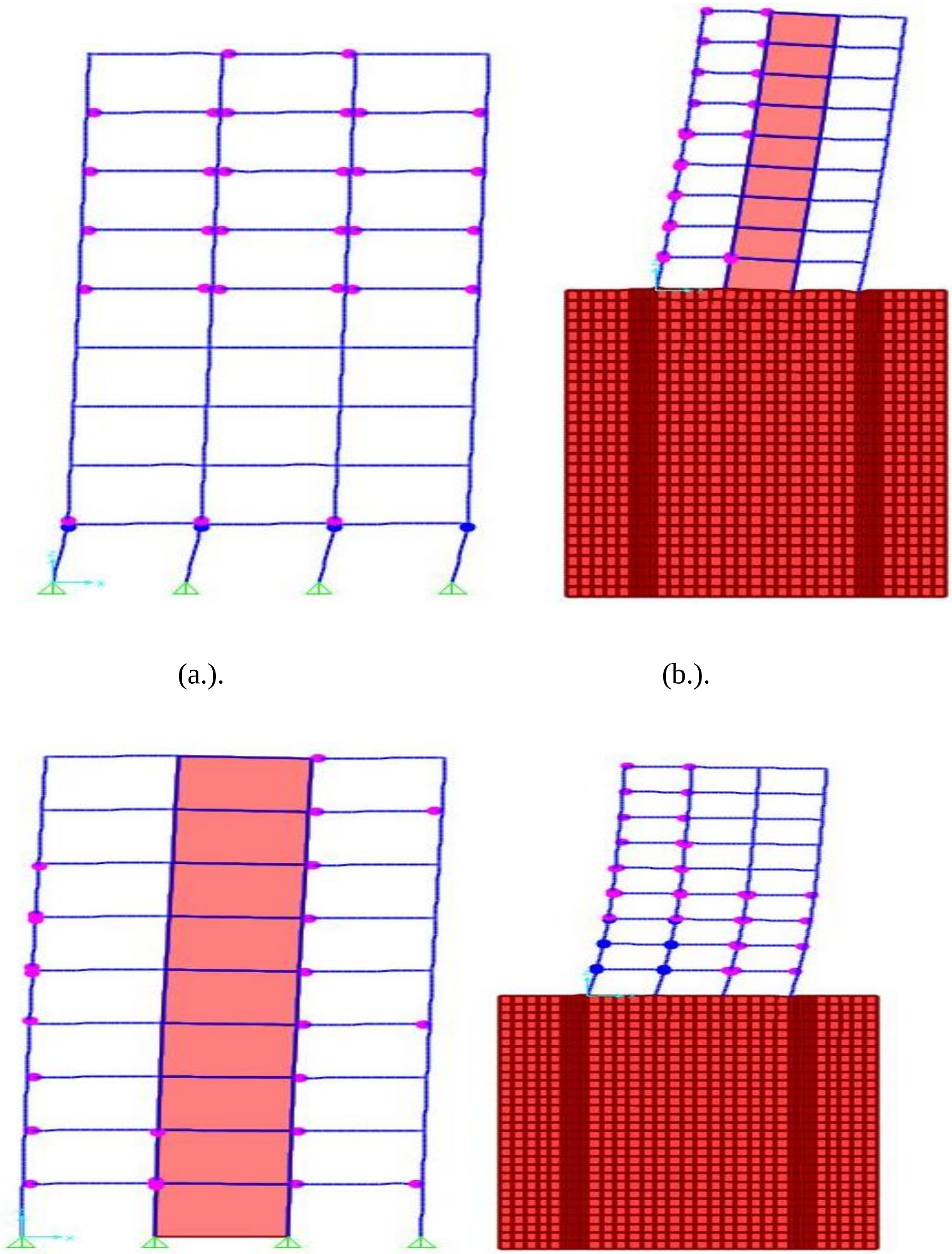
(a). (b).

Figure 4.18: Plastic hinge formation 8 story found on Dense soil (a) Fixed base, Bare frame (b) SSI, Bare frame (c) Fixed, SW1 (d) SSI, SW1.



(a). (b.)

Figure 4.19: Plastic hinge formation 8 story found on Stiff soil (a) Fixed base, Bare frame (b) SSI, Bare frame (c) Fixed, SW1 (d) SSI, SW1.



(a.). (b.).

(c.). (d.).

Figure 4.20: Plastic hinge formation 8 story found on Stiff soil (a) Fixed base, Bare frame (b) SSI, Bare frame (c) Fixed, SW1 (d) SSI, SW1.

Figure 4.13-4.20 shows considering for SSI results in increasing number of plastic hinges at different performance level. This means that soil-structure interaction increases the plastic deformation which leads to the seismic damage. Because, the base shear is smaller with soil-structure interaction and larger drifts.

CHAPTER 5

CONCLUSIONS

The seismic response of R.C. framed buildings with or without shear wall over raft foundation assessed with or without SSI effect through seismic analysis including response spectrum analysis and static nonlinear (pushover) analysis. The finite element model used to represent the soil-structure-interaction model. 4 and 8 story buildings with fixed base assumed to be found on rock soil, dense soil, stiff soil and soft soils and including soil-structure interaction effect are considered. The results of the study lead to the following conclusions.

(a) When a comparison is made between the Indian and Ethiopian building codes, substantial differences are seen between the design moment values calculated using both codes. The result shows that ESEN-2 moments exceed that of the IS 456:2000 by an average of about 15.61% at span and 15.35% at supports and the ESEN-2 exceeds IS 456: 2000 by an average of about 15.56% for beam area of tension reinforcement for span and 15.31% for support. So, Indian code provides a more economical design than Ethiopian code ESEN-2.

(b) The value of base shear in the absence/presence of soil-structure interaction is observed to be least in MRF and highest for building configuration with shear wall at core. Moreover, the magnitude of base shear becomes larger when an increase of soil flexibility and superstructure stiffness.

(c) As the SSI takes into account, the top horizontal displacement becomes increased. The story drift becomes larger based on the soil’s flexibility. Therefore, the largest drifts are found in soft soil. As story of structure increases, the story drift reaches critical limit value

(d) Considering for SSI results in increasing number of plastic hinges at various performance level. This means that soil-structure interaction increases the plastic deformation which leads to the seismic damage. Because, the base shear is smaller with soil-structure interaction and larger drifts.

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