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Seismic Response of Diagrid system Building with Soil-Structure Interaction

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ABSTRACT: During earthquake, civil structures are subjected to damaging forces. Tall buildings if damaged would threaten the life safety of inhabitants or at least would cease to offer the same level of function. For this reason, tall buildings should be designed in accordance with the seismic provisions that ensure suitable performance during and aftermath. Also, recently diagrid structural system is adopted in tall buildings due to its structural efficiency and flexibility in architectural planning. The diagonal members in diagrid structural systems can carry gravity loads as well as lateral forces due to their triangulated configuration and diagrid system Building save approximately 20 percent of the structural steel weight when compared to a conventional moment-frame structure. One of the factors that dominate Diagrid buildings design is the dynamic soil-structure interaction (SSI) that differs significantly with the variation of several aspects.

In this research have considered with SSI effect and without SSI effect on diagrid building using the Winker's method, studied the effect on Soft soil, Medium Soil, Hard Soil of the Diagrid building under consideration. Seismic load may cause collapse during the life of building. Therefore, it must have been studied then building's seismic performance with soil effect. That's why we see the term SSI refers to the actual performance with considering the effect of soil. The building was taken to be G+10, symmetrical space frame of 4 bay in both x and y direction, 11 storey, 3.2m storey height (4 X 4 X 11), which is resting on raft foundation with fixed base and flexible base. Three types of soil i.e. Hard, Medium Hard and Soft Soil are used for the SSI study. Dynamic analysis is carried out using the Time-History of El-Centro. The soil flexibility is incorporated in the analysis using Winkler approach (spring model). SAP-2000 is used for developing these models. The effect of SSI on various structural parameters i.e. natural time period, base shear, Story displacement, Story Drift are studied and discussed. The comparison is made between the approaches of SSI modeling i.e. Winkler approach (spring model) and Fixed base. The study reveals that the SSI significantly affects the response of the structure. The seismic load input was El-Centro acceleration time-history record. Results of analysis showed the displacements and base shear values time period. Then compared the result of diagrid building without SSI and with SSI effect in various type of Soil.

KEYWORDS*:* Diagrid system, High-rise buildings, Seismic Response, Raft Footing, Finite Element Method, Winkler Method, SAP2000, structure soil structure interaction (SSI), Time History.

1 INTRODUCTION

1.1 Diagrid Building system

The growth of high-rise buildings is contributed by the evolution of efficient structural system, advances in construction technology, scarcity of urban land and advanced computational techniques. High rise buildings are increasing in major cities of world since last decades. Lateral loading due to wind or earthquake are governing in design of high-rise buildings along with gravitational loading. For tall structures, interior structural systems and exterior structural systems are provided to resist the lateral loads. The widely used internal lateral load resisting systems are: rigid frame, braced frame, shear wall and outrigger structure. The exterior systems are: tubular structure and diagrid structure. Recently, the diagrid system has been applied to several tall steel buildings because of its structural efficiency. Diagrid is particular form of space truss, which does not have any conventional column on the exterior periphery of the structure. Diagrid is formed by intersecting the diagonal columns and horizontal beams and is made up of the series of triangulated truss system as show in fig. 1.1. Diagrid structural system provides more flexibility in planning interior space and facade of the building.

Diagrid has good appearance and it is easily recognized. The configuration and efficiency of a diagrid system reduce the number of structural elements required on the facade of the buildings, therefore less obstruction to the outside view. The structural efficiency of diagrid system also helps in avoiding interior and corner columns, therefore allowing significant flexibility with the floor plan. Perimeter "diagrid" system save approximately 20 percent of the structural steel weight when compared to a conventional moment-frame structure.[3]

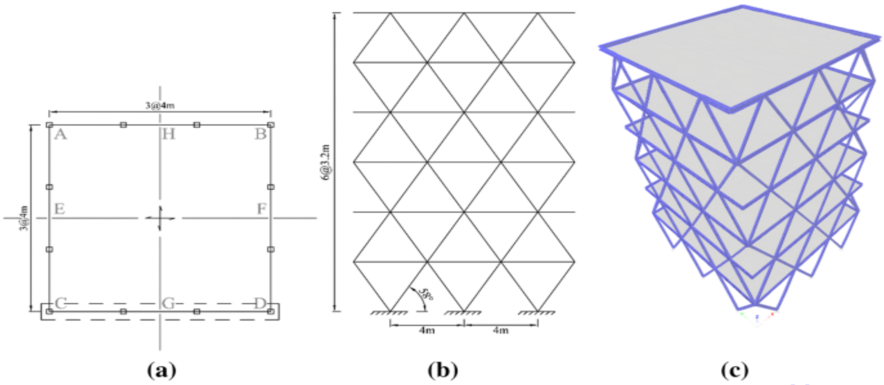


Fig. 1.1: Typical plan, elevation and 3D view of Diagrid Building. [3]

1.1.1 History

Diagrid is formed by intersecting the diagonal and horizontal components. The famous examples of diagrid structure all around the world are the Swiss Re in London, Hearst Tower in New York, Cyclone Tower in Asan (Korea), Capital Gate Tower in Abu Dhabi and Jinling Tower in China.

1.1.2 Importance of Diagrid Structural System

The rapid growths of urban population and consequent pressure on limited space have considerably influenced the residential development of city. The high cost of land, the desire to avoid a continuous urban sprawl, and the need to preserve important agricultural production have all contributed to drive residential buildings upward. As the height of building increase, the lateral load resisting system becomes more important than the structural system that resists the gravitational loads. The lateral load resisting systems that are widely used are: rigid frame, shear wall, wall-frame, braced tube system, outrigger system and tubular system. Recently, the diagrid–Diagonal Grid–structural system is widely used. for tall steel buildings due to its structural efficiency and aesthetic potential provided by the unique geometric configuration of the system Diagrid is a particular form of space truss. It consists of perimeter grid made up of a series of triangulated truss system.

The advantages of the diagrid in the construction of the structure majorly improves the aesthetic view of the building. The use of diagrid reduces the steel up to 20% compared to brace frame structure. It doesn't need technical labour as the construction technology is simple. A diagrid (a portmanteau of diagonal grid) is a framework of diagonally intersecting metal, concrete, or wooden beams that is used in the construction of buildings and roofs. It requires less structural steel than a conventional steel frame.[3]

1.1.3 Types of Diagrid Structures

- Concrete diagrids
- Steel diagrids
- CFST diagrids **(**Concrete Filled Steel Tubular)

1.2 Introduction of Soil Structure Interaction.

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)**. Ground structure interaction (SSI) consists of the interaction between soil (ground) and a structure built upon it. It is primarily an exchange of mutual stress, whereby the movement of the ground-structure system is influenced by both the type of ground and the type of structure. This is especially applicable to areas of seismic activity. Various combinations of soil and structure can either amplify or diminish movement and subsequent damage. A building on stiff ground rather than deformable ground will tend to suffer greater damage. A second interaction effect, tied to mechanical properties of soil, is the sinking of foundations, worsened by a seismic event.

The structural engineers and geotechnical engineers in the field of Soil-structure interaction (SSI), which is a phenomenon that connects between structural engineering and geotechnical engineering. Moreover, seismic load may cause collapse during the life of building. Therefore, it must have been studied the building's seismic performance with soil effect. The term (SSI) refers to the actual performance with considering the effect of soil. SSI problem has become an interdisciplinary approach that is connecting between structural and geotechnical engineering. Especially in sites where a soft soil and seismic activity are. However, with hard soil, the response of high-rise building is the same case like fixed base due to high stiffness.[9]

1.2.1 Soil-structure interaction (SSI) provisions of seismic design codes on structural responses.

- It is conventionally believed that SSI is a purely beneficial effect, and it can conveniently be neglected for conservative design.
- Neglecting SSI is reasonable for light structures in relatively stiff soil such as low-rise buildings and simple rigid retaining walls.
- The effect of SSI, however, becomes prominent for heavy structures resting on relatively soft soils for example nuclear power plants, high-rise buildings and elevated-highways on soft soil.
- SSI provisions of seismic design codes are optional and allow designers to reduce the design base shear of buildings by considering soil-structure interaction (SSI) as a beneficial effect.
- Not required for structure founded on rock/hard soil at shallow depths. {IS 1893-2016 (Part I), cl. 6.1.5}[21]
- As per Indian standard codes SSI effected on different type of Soil and height of Building is given in table 1.1.

Table 1.1: SSI effected on different type of Soil.[21]

	Rock / Hard Soil	Medium Soil	Soft Soil
Low-rise			
Mid-rise		✓	✓
High-rise	✓	✓	✓

- The main idea behind the provisions is that the soil-structure system can be replaced with an equivalent fixed-base model with a longer period and usually a larger damping ratio.
- The soil interaction refers to effect of the flexibility of supporting system soil-foundation system on the response of structure. {IS 1893-2016 (Part I), cl. 6.1.5}
- Most of the design codes use oversimplified design spectra, which attain constant acceleration up to a certain period, and thereafter decreases monotonically with period.
- Considering soil-structure interaction makes a structure more flexible and thus, increasing the natural period of the structure compared to the corresponding rigidly supported structure.

1.2.2 What are the effects or Soil Structure Interaction?

The effects of the SSI are more focused on its detrimental effects, As mentioned, even if studies have told that the design based on soil structure interaction increases the time period, increase in time period is not always a beneficial factor. There is elongation of seismic waves when it is on a site of soft soil sediments. This results in the increase of the natural period hence leading to resonance. This happens with a long period vibration. Il' the natural period increases, the demand for ductility also increases. This may result in permanent deformation and soil failure that will 'further worsen the structural seismic response. A structure under the action of seismic force (seismic excitation), there is interaction between the soil and foundation which brings changes in the ground motion. The soil structure interaction can have some types of phenomena or effects (As per FEMA P-750, NEI-IRP).[9]

1. Kinematic Interaction.
2. Inertial Interaction.

1.2.3 Analysis in Soil Structure Interaction

The above-mentioned interactions can be measured by two methods of analysis. They are the: -

1. Direct Analysis
2. Substructure Approach

1) Direct Analysis in Soil Structure Interaction

In this type of analysis, the soil and the structure are used in the same model for analysis. They are analyzed as a complete system. As shown in figure no.1.2, the soil system is represented as a continuum. One such example is by the representation of finite elements. The foundation, structural elements, the load transmitting boundaries, the elements at the interface located on the edges of foundation are also included. [9]

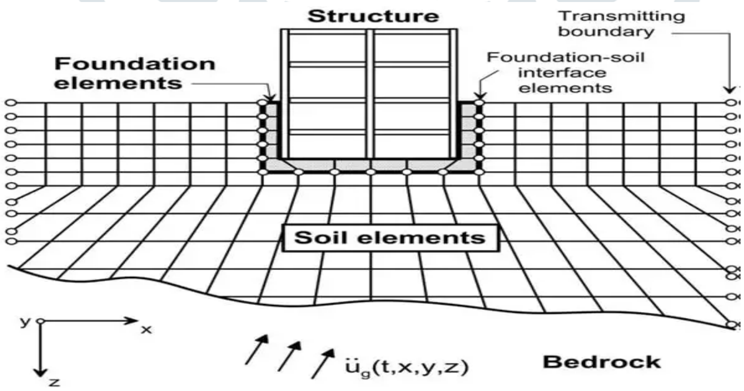


Figure 1.2: Illustration of direct analysis of soil structure interaction with the help of finite elements.[9]

2) Substructure Approach in Soil Structure Interaction

The soil structure interaction activity is divided into two parts. These are later combined to form a complete solution for the problem. In this approach, a model is generated with certain requirements:

- Free -field motions and the corresponding soil properties is evaluated
- The transfer functions are evaluated to convert the free -field motion to the foundation input motion
- Springs and the dashpots are incorporated. The springs represent the stiffness and the dashpots represent damping at the soil and foundation interface
- Response analysis of the combined structure

The figure 1.3 shows the how a general problem A is evaluated. It is divided into two problems A1 and A2 such a way that A= A1 + A2. This is done based on the principle of superposition. Each problem is evaluated separately and the combination of the results will give the final solution.

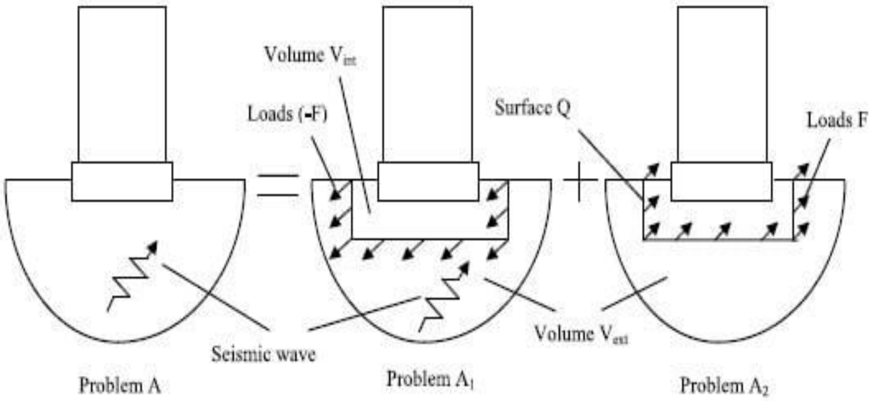


Figure 1.3: Splitting of a problem a by superposition substructure approach.[9]

1.3 Need for study

Soil–Structure Interaction (SSI) has progressed rapidly in the of 21th century stimulated mainly by requirements of the nuclear power, off-shore industries, high rise building to improve the seismic safety. Soil structure interaction affect the response of the structure, so for more assessing realistic behavior of structure the flexibility of soil should be taken into account.

- The Scope of work is to study of R.C High-Rice building under seismic loads in the case of fixed-base and the case of Soil Structure Interaction including the effects on displacement, shear base, and seismic time history.
- Along with these benefits, one of the issues that has always been a concern for engineers is the preventing of the Soil Structure Interaction Effect.
- This will help in the design of Diagrid System Building with better strengths and prevention of Soil Structure Interaction failures. This analysis is carried out by Winkler's Spring Method using SAP2000 software.

1.4 Objective of Study

The main Objective of work is to determine the seismic behavior of structure with Diagrid System Building on different type of soil (hard, medium, soft). The behavior of such structure under seismic excitation will be studied by using SAP2000 software.

1. To Prepare the Diagrid building model in Fixed Base and Flexible base.
2. To find the Time History data.
3. To understand nonlinear dynamic analysis (time history analysis) of building with effect of SSI.
4. To Compare the Result of Diagrid building in Fixed Base condition and Flexible base Condition.
5. To Study the Soil-Structure Interaction Effect in Difference type of soil.
6. To study the parameters such as displacement, storey shear and storey drift of building with soft soil, Medium Soil, Hard Soil and effect of SSI.

2 LITERATURE REVIEW

2.1 General

The present review concerned with Studies or development and application of Soil Structure Interaction and who reduce the response of structure to earthquake induce excitation. The review also about the parametric study and effectiveness of Diagrid Building.

2.2 Parametric study of Diagrid Building

This study summarizes the results of a parametric study performed to enhance the understanding of some important characteristics of Diagrid Building. The literature for this study is as follow:

Neha Tirkey, G.B. Ramesh Kumar, [2019][1]: In this paper the case study on diagonal perimeter often known as the diagrid structure using software ETABS (Extended Three-Dimensional Analysis of Building System). The diagrid structure has emerged into an innovative method in the recent construction field and has led to the advancement of tall buildings and high-rise structures not only in the engineering field but also in the architectural field. It has also made the structure stiffer and lighter when compared to the normal conventional buildings. The diagrid structure is designed, analyzed and is compared with the conventional building using ETABS software mainly focusing on seismic and wind analysis parameters. As per IS 456:2000 and the Linear Static Method all the structural members of the diagrid model are designed and IS 1893 (PART 1): 2002 is considered for load combination of seismic analysis. The comparative study has been executed for different diagrid structures using ETABS software to find the stiffness and flexibility of the high raised structures and also for an asymmetrical structure through simple framework. The lateral load resisting system is better in resisting the gravity loads than the structural system when the structure height gets increased. The configuration and efficiency of the diagrid system has reduced the number of structural elements. The ETABS software is used to design and analyse the results such as axial, shear and bending moment. The possibility of failure is much lesser for diagrid structure when compared to the conventional structure by heavy vibration during an earthquake.[1]

Kai Hua,b, Yimeng Yang a, Suifeng Mua, Ge Qua, [2011][2]: In this paper, response spectrum, time history and linking slab in-plan stresses analysis were execute combine with a practical project by these programs. Also, the facing a large number of new-type complex structural system and progressively consummate earthquake-resistant theories, the conventional software can no longer meet the needs of calculation and analysis. Meanwhile, some international finite element programs, such as ETABS, SAP2000, MIDAS/gen and SATWE, were updating themselves but remain respective limitations. The response spectrum, time history and linking slab in-plan stresses analysis were execute combine with a practical project with inclined columns by several programs such as ETABS, SAP2000, MIDAS/gen and SATWE, and the main study are as follows:

1. All the results of response spectrum analysis calculated by different programs are basically similar, while ETABS may miss the statistic of oblique columns, which need to be paid attention to in future designs.
2. The results of time history analysis by SAP2000 and ETABS are roughly similar. However, SAP2000 does not have the concept of "storey", which made the post-processing much more complicated. Therefore, to the regular structure, ETABS is recommended; and to those gymnasium or space truss structures, SAP2000 has its irreplaceable advantages.
3. As for the slab stress analysis, ETABS and MIDAS/Gen have their respective advantages: ETABS/s good at pre-processing with automatically line constraint and area division; and MIDAS/Gen does well in the post-processing such as the stresses combinations.
4. Slab, as the important lateral force resistant component, should not be ignored in design works. Especially to those complex structures, the slabs stress analysis at weaken positions is really essential.[2]

Khushbu D. Jani and Paresh V. Patel, [2013][3]: In this paper, analysis and design of 36 storey diagrid steel building is presented in detail. A regular floor plan of 36 m×36 m size is considered. ETABS software is used for modeling and analysis of structure. All structural members are designed using IS 800:2007 considering all load combinations. Load distribution in diagrid system is also studied for 36 storey building and Dynamic along wind and across wind are considered for analysis and design of the structure Also, the analysis and design results of 50, 60, 70 and 80 storey diagrid structures is carried out. Comparison of analysis results in terms of time period, top storey displacement and inter-storey drift is presented in this study. In this paper is observed that most of the lateral load is resisted by diagrid columns on the periphery, while gravity load is resisted by both the internal columns and peripherial diagonal columns. So, internal columns need to be designed for vertical load only. Due to increase in lever arm of peripherial diagonal columns, diagrid structural system is more effective in lateral load resistance. Lateral and gravity load are resisted by axial force in diagonal members on periphery of structure, which make system more effective. Diagrid structural system provides more flexibility in planning interior space and facade of the building.[3]

Faisal Mehraj Wani, Jayaprakash Vemuri, Chenna Rajaram, Dushyanth V. Babu R, [2022][6]: The main objective of this paper is to study the effect of SSI on a multi-story (G + 10) building resting on a mat foundation. The building is modeled using Finite Element Method (FEM) software and SSI is incorporated using Winkler's (un-coupled) and pseudo-coupled approaches. In this paper study the dynamic response of the structure is affected not only by the behavior of the superstructure but also by the nature and behavior of the soil present in and around the substructure. The conventional structural design process usually assumes the base of the foundation to be completely restrained, in a fixed condition. However, this assumption is inaccurate as it neglects the effect of flexibility offered by the interaction of the soil with the structure. There is no clear consensus on either the beneficial or detrimental effects of soil-structure interaction (SSI) on the seismic response of structures. A case study is done to understand the non-linear dynamic response of building with different soil bearing capacities. The results are represented in terms of fundamental period, base shear, and story drift. Seismic evaluation of reinforced concrete structures typically considers only the superstructure and neglects the flexibility of foundations. However, the dynamic characteristics of structural response are affected by soil-structure interaction. This paper presented results from a nonlinear time history analysis of a G+10 reinforced concrete building considering the effects of soil-structure interaction. The soil-structure interaction is modeled using Winkler's approach. From the research paper results, is observed that using Winkler's hypothesis with a constant coefficient of subgrade reaction does not produce accurate estimates of settlements. It is also observed that the period of the building increases with an increase in the stiffness of springs. The period of the building is maximum in the case of soft soil as compared to the fixed base condition. The base shear or the case of a flexible base decreases by 10% when compared to the case of a fixed base. The story drifts due to medium and soft soil increases in the higher stories. The maximum drift was observed in the middle stories. These results were also compared with those obtained from the alternate pseudo-coupled approach. Overall, the observations indicate that the effect of SSI should be incorporated in the case of soft soil, otherwise, it could lead to reduced accuracy in our assessment of the overall structural safety under severe earthquakes. Further, the use of a single modulus of subgrade could be discontinued. It is further observed that a proper assessment of the modulus of subgrade reaction is important in Winkler's spring approach. The best way to estimate the modulus of subgrade reaction is by performing studies on determining SSI using geotechnical field investigations and geotechnical software and then performing the inverse analysis. Further, the parametric analysis by varying the height and shape of structure, with and without SSI, revealed that high-rise structures on soft soil are more affected by SSI than low-rise structures.[6]

Wesam Al Agha, Waleed Alozzo Almorad , Nambiappan Umamaheswari , Amjad Alhelwani, [2021][7]: In this research authors have considered SSI using the direct method (FEM soil medium) and studied the effect of changing soil type (soft soils and hard soils) on the performance of the tall building under consideration. The building was taken to be 16 stories, wall-framed dual system for seismic loading resistance. Semi-infinite elements from Abaqus (similia's Abaqus 6.14) solid element library were used to model the boundaries of soil media. The seismic loading input was El-Centro acceleration time-history record. Results of analysis showed differences between soft soil and hard soil types, especially on the displacements and base shear values. The factors that dominate tall buildings design is the dynamic soil-structure interaction (SSI) that differs significantly with the variation of several aspects. Soil type that incorporate the building's foundations, the height of the building, the type of lateral load resisting system, and many other factors. This paper presents analytical study of R.C High-Rice building under seismic loads in the case of fixed-base and the case of Soil Structure Interaction including the effects on displacement, shear base, and fundamental period values, the results showed: Increasing of displacement values in the case of Soil Structure Interaction. By comparing between soft and hard soil, the displacement values in hard one almost equal to the values from the case of Fixed-base. Decreasing of base shear values in the case of Soil Structure Interaction with soft soil comparing to hard one whereas the values in hard soil almost equal to the values from the case of Fixed-base. Increasing of time periods in the case of Soil Structure Interaction, especially with soft soil. The peripheral RC shear walls at the corners presented the smallest displacement and base shear comparing to the other position with hard soil. However, with soft soil the core RC shear wall was the best due to the smallest displacement and base shear value.[7]

2.3 Concluding Remark

From the literature review study, it is observed that most of the lateral load is resisted by diagrid columns on the periphery, while gravity load is resisted by both the internal columns and peripherial diagonal columns. So, internal columns need to be designed for vertical load only. Due to increase in lever arm of peripherial diagonal columns, diagrid structural system is more effective in lateral load resistance. Lateral and gravity load are resisted by axial force in diagonal members on periphery of structure, which make system more effective. Diagrid structural system provides more flexibility in planning interior space and facade of the building.

This literature's deal with numerous numbers of papers that have been found helpful for carrying out work. An extensive literature review is done and interface noted down. Lots of literature are available on effect of SSI on only RC or conventional building. But No literatures papers are available in effect of SSI on Diagrid building and their effect with Various type of Soil. So, aim of this study is to find parameter such as displacement, storey shear, storey drift with effect of SSI on Diagrid building with Various type of Soil.

3 METHODOLOGY

1) **MODELLING OF DIAGRID BUILDING WITH DIFFERENT PARAMETERS CONSIDERED.**
2) **FIXING SOIL PROPERTIES.**
3) **COLLECTION OF DETAILED INFORMATION ABOUT EARTHQUAKE GROUND MOTION.**
4) **SOIL STRUCTURE INTERACTION IS INCORPORATED AT THE BASE OF BUILDING.**
5) **ANALYSIS IS CARRIED OUT BY USING NON-LINEAR DYNAMIC PROCEDURE.**

3.1 Non-linear Dynamic History Analysis

Nonlinear time-history analysis is by the mast comprehensive method for seismic analysis. The earthquake record in the form acceleration time history is input at the base of the structure. The response of the structure is computed at each second for the entire duration of an earthquake. This method differs from response spectrum analysis because the effect "time" is Considered. That is, stresses and deformations in the structure instant considered as an initial boundary condition for computation of stresses in the next step Furthermore, nonlinearities that commonly occur during an earthquake can be included in the time-history analysis. The result is realistic and not conservative. In this work all the seven selected ground motion records data were taken from NGA SIRONG MOTION RECORD database of pacific Earthquake Engineering Research (PEER) center, (PEER, 2010).

3.2 Soil Structure Interaction

In this present paper, substructure methodology is employed for the implementation of SSI into analysis. The movement regarding 3 axes has been thought-about. Shallow isolated footing resting on varied soil varieties, 3 translational stiffness springs has been applied in 2 horizontal directions and one vertical direction i.e. X-Y-Z direction severally and equally 3 rotational Stiffness springs has been applied in X-Y-Z direction to feature SSI into the analysis, soil spring stiffness equations are taken from FEMA356 (George Gazetas 1991). Orientation of rooting w.r.t axes as per George Gazetas is shown in fig 3.1.[14]

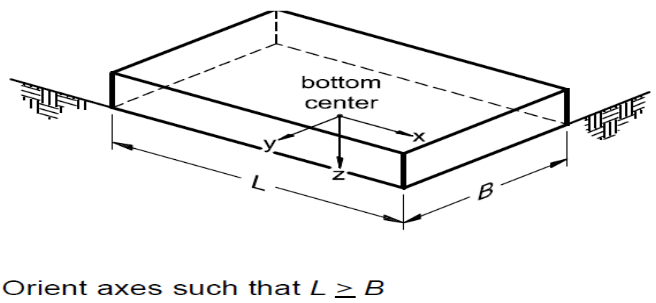


Figure 3.1: Orientation of rooting w.r.t axes.[14]

Table 3.1 Equations give stiffness of soil when the footing is at surface level.

Table 3. l: Stiffness equations at surface given by Gazetas.[14]

Degree of Freedom	Stiffness of Foundation at Surface
Translation along x-axis	$K_x = \frac{GB}{2-\mu}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 1.2\right]$
Translation along y-axis	$K_y = \frac{GB}{2-\mu}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 0.4\frac{L}{B} + 0.8\right]$
Translation along z-axis	$K_z = \frac{GB}{1-\mu}\left[1.55\left(\frac{L}{B}\right)^{0.75} + 0.8\right]$
Rocking about x-axis	$K_{xx} = \frac{GB^3}{1-\mu}\left[0.4\left(\frac{L}{B}\right) + 0.1\right]$

Rocking about y-axis	$K_{yy} = \frac{GB^3}{1-\mu}\left[0.47\left(\frac{L}{B}\right)^{2.4} + 0.034\right]$
Torsion about z-axis	$K_{zz} = GB^3\left[0.53\left(\frac{L}{B}\right)^{0.2.45} + 0.51\right]$

4 VALIDATION

G+10 Conventical Building RC, rectangular shaped buildings take for the investigation in this paper. Non-linear time history analysis carried out by considering El-Cento earthquakes. Comparison between without and with Flexible base of building is to be carried out. Floor to floor height = 3.2m, Grid Spacing X-Direction =4m, Grid Spacing Y -Direction=4m.[6]

4.1 Validation case result

From table 4.1 shows the value for SAP2000 Software, model period of G+10 symmetrical building frame in Soft Soil condition with SSI and without SSI. The value of model period is found to be nearly same with reference paper.

Table 4.1: Model period from SAP2000 Software.

Model	Period (sec)
With SSI (Fixed base)	1.46849
Without SSI (flexible base)	1.69603

Table 4.2: Results of model period from research paper reference paper.[6]

Model	Period (sec)
With SSI (Fixed base)	2.21
Without SSI (flexible base)	2.41

From the table 4.2 is taken from the research paper shows value for the model period of building frame in Soft Soil condition with SSI (Fixed base) and without SSI (flexible base). The values table 4.1 obtained from the analysis result from SAP2000 i.e. table are compared with model period values form research paper i.e. table and found to be nearly same. View of SAP2000 for model period are shown in fig 4.1.

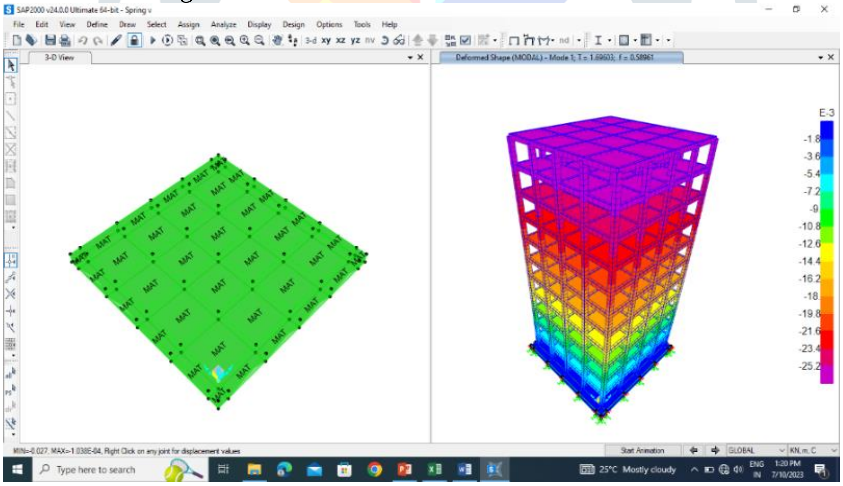


Figure 4.1: view of SAP2000 for model period

4.2 Comparison of calculated results with results of research paper

Time period

From the below figure 4.2 it is compared that chart graph of time period of with and without SSI effect for Soft Soil. It is observed from graph period is reduce by using 20 to 30% effectively.[6]

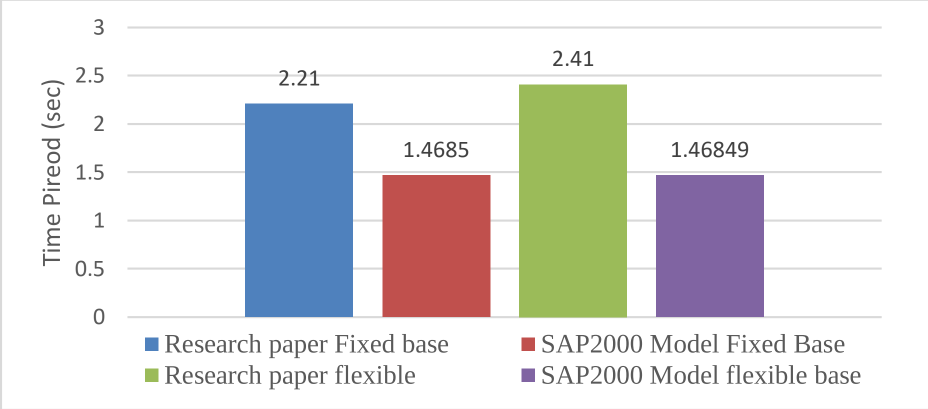


Figure 4.2: Chart graph of time period

Base Shear

From the figure 4.3 it is compared that chart graph of Base Shear of with and without SSI effect for Soft Soil. It is observed from graph Base Shear is reduce by using 10% effectively.[6]

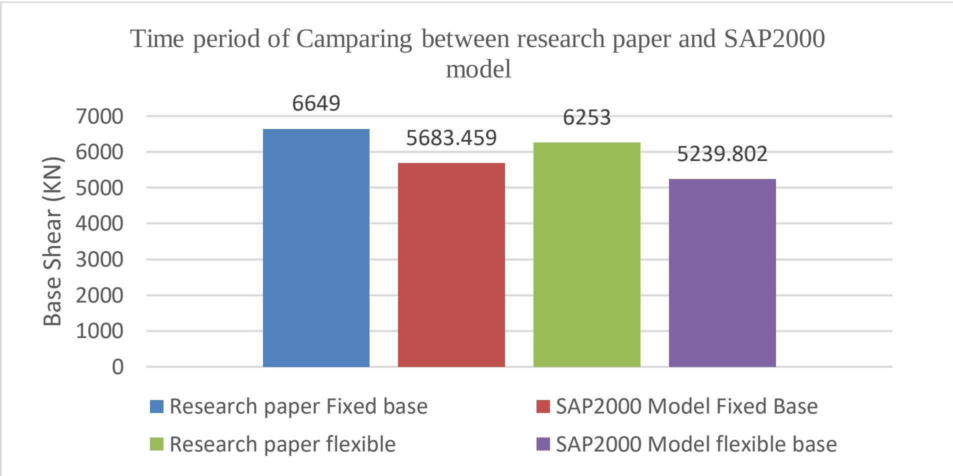


Figure 4.3: Chart graph of base shear

4.3 Conclusion Validation case result:

From the Validation case study table 4.1 and table 4.2, for analysis results is compared with research paper result it is found that the 20 to 30% variation in period as shown in fig.4.2 and 10 to 15% variation in base shear as shown in fig.4.3, with and without SSI for soft soil.

5 Model Introduction

Description of Building for Modelling of G+10 Storey

The model of building is G+10 storey RCC structure considered for the analysis. The building is symmetric in plan as shown in figure 5.1. The building has bay width of 4m in X and Y direction with 3.2m storey height. Slab is 150mm thick. Diagrid system Building of structure. Non-linear time history analysis is carried out in SAP2000 software using EL Centro.

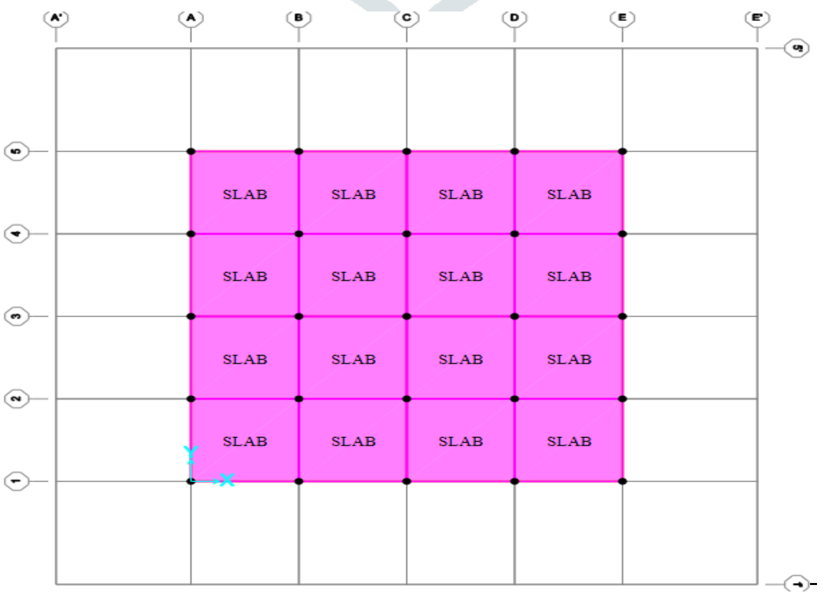


Figure 5.1: Plan view of symmetrical building

5.1 Building Description of the model

The SAP2000 model description and data of diagrid building is given in table 5.1, table 5.2, table 5.3. and table 5.4.

Table 5.1: Building Dimension.[6]

Description	Data
Length _ Width	16 m X 16 m
No. of storeys	11
Height of similar storey	3.2m
Thickness of slab	0.15m
Beam dimension	300mm X 500mm
Column dimension	450mm X 600mm

Table 5.2: Material specification. [6]

Properties Data	Data
Grade of concrete, M30	F_{ck} = 30N/mm^2
Grade of steel	f_y = 500N/mm^2
Density of concrete	ϒ concrete = 25 kN/m^3

Table 5.3: Safe bearing capacity of soil in KN/m^2. [6]

Hard Soil	Medium Soil	Soft Soil
300	200	100

Table 5.4: Detail of Soil parameter consider. [6]

Soil type	Shear modulus G (KN/m^2)	Elastic modulus (KN/m^2)	Poisson ratio (μ)	Mass Density (KN/m^3)
Hard soil	30000	72000	0.2	20
Medium soil	20000	50000	0.25	18
Soft soil	10000	26000	0.3	16

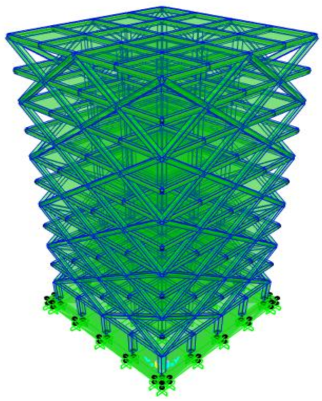
5.2 Loading Considered

1. Dead Load
   Weight of F.F = 1 KN/m^2
2. Live Load
   Live Load at all floor levels —3 KN/m^2
   Live load on all roof is taken as 1.5 KN/m^2

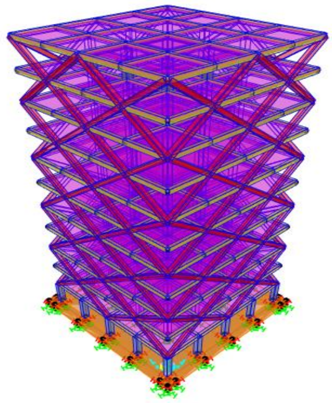
5.3 Seismic Properties

Zone factor = 0.36
Response reduction Factor = 5
Damping ratio =5%
Importance factor = 1
Time History = EL Centro, May 18, 1940.[24]

As per above properties of diagrid building with and without SSI drawn in SAP2000 is shown in fig. 5.2 (a)&(b). and the spring constants calculations are mentioned in table 5.5



(a)



(b)

Figure 5.2: (a) Diagrid Building without SSI and (b) Diagrid Building with SSI.

Table 5.5: Spring constant for different soil used in foundation for G+10 Building. [14]

Soil Stiffens	Hard Soil	Medium Soil	Soft Soil
$K_x(KN/M)$	1380000	946285.714	487058.823
$K_Y(KN/M)$	1380000	946285.714	487058.823
$K_Z(KN/M)$	1586250	1128000	6042285.714
$K_{xx}(KN-M/rad)$	63281250	77760000	41657142.8571
$K_{yy}(KN-M/rad)$	110224800	78382080	41990400
$K_{zz}(KN-M/rad)$	181958400	121305600	606582800

5.4 Result and Discussion

Computational Analysis for project Work

Result of G+10 building with fixed base and flexible base storey resting on different soil.

Result obtained from nonlinear dynamic analysis for G+10 diagrid building without and with soil structure interaction storey resting on Fixed Base, hard soil medium soil, soft soil is presented comparison value shown in table no.5.6 and also maximum storey displacement. G+10 diagrid building without and with soil structure interaction on hard soil, medium soil and soft soil for time history EL-centro. Maximum displacement in X-direction for G+10 Diagrid building is given in table 5.7.

Table 5.6: Displacement for diagrid building without and with soil structure interaction rest on different soil for time history El-centro.

Storey level	Displacement (mm)			
	Without SSI	With SSI		
	Fixed base	Soft Soil	Medium Soil	Hard Soil
11	153.5	127.5	152.3	144.7
10	139.7	116.4	138.4	131.5
9	125.6	105.2	124.1	118
8	111.1	93.8	109.5	104.1
7	95.5	83.3	95.7	91.1
6	83.3	72.9	81.4	77.5
5	71.9	64.4	70.5	66.8
4	60.8	56	61.5	58.1
3	54.4	50.4	55.2	52.5
2	47.4	44.5	48.2	45.5
1	43.9	41.4	44.4	42.1
0	0	0	0	0

Table 5.7: Maximum displacement for G+10 Diagrid building

Max. Displacement (mm)	Fixed Base	Soft Soil	Medium soil	Hard Soil
X Direction	61	128	71	67

From result it has been observed that the displacement is maximum for G+10 diagrid building fixed base and soft soil which is more than diagrid building on hard soil and medium soil. After considering soil structure interaction (SSI) as energy absorbing storey on diagrid building, it is observed that the great reduction in displacement of G+10 diagrid building for different type of soil show in figure 5.3. Maximum displacement in X-direction for G+10 Diagrid building is given in figure 5.4.

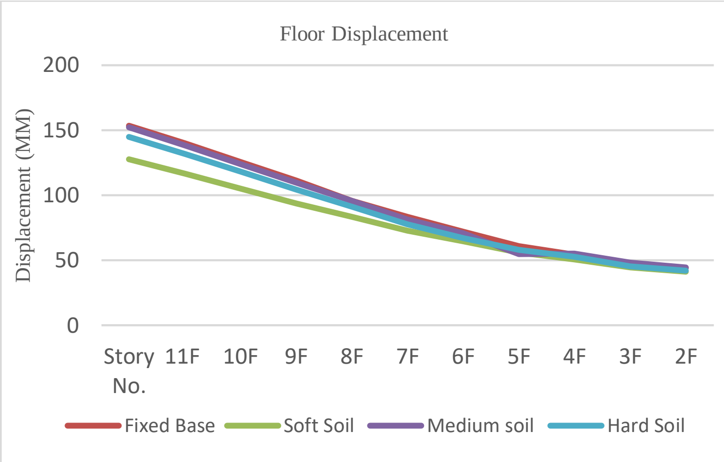


Figure 5.3: Displacement for diagrid building without and with soil building structure interaction rest on different soil for time history El-centro.

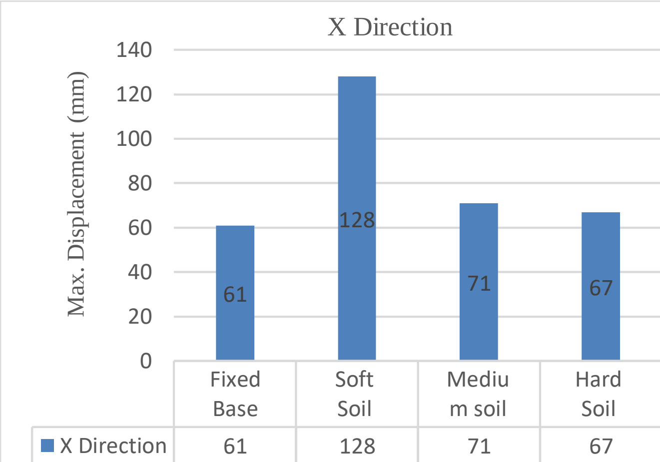


Figure 5.4: Maximum displacement for G+10 Diagrid

Time period

From table 5.8 shows the value for model period of G+10 Diagrid building frame with SSI and without SSI condition.

Table 5.8: Maximum Time period for G+10 Diagrid building

Time period (sec)			
Without SSI	With SSI		
Fixed base	Soft soil	Medium soil	Soft soil
1.00223	1.35452	1.02072	1.0166

From result it has been observed that the time period is maximum for G+10 diagrid building fixed base and soft soil which is more than diagrid building on hard soil and medium soil as show in figure 5.5. After considering soil structure interaction (SSI) as energy absorbing storey on diagrid building, it is observed that the great reduction in time period of G+10 diagrid building for different type of soil as show in figure 5.5.

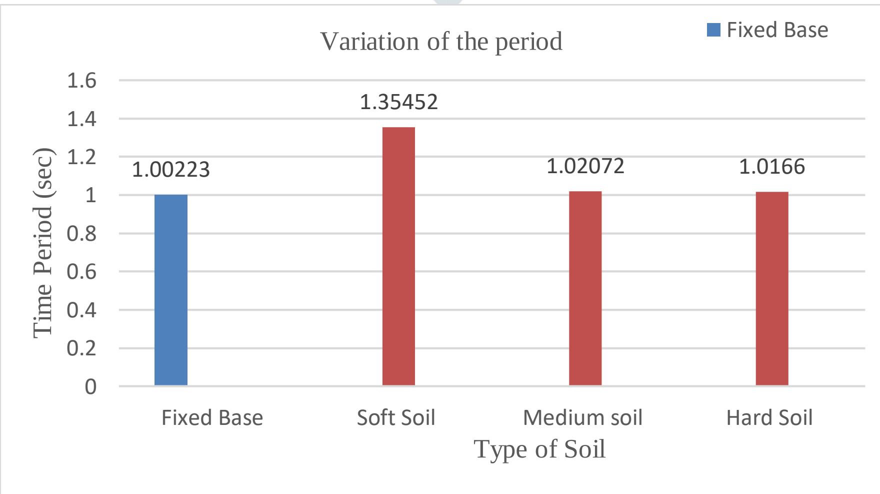


Figure 5.5: Time period of Without and with SSI

Storey drift

From result it has been observed that the storey drift is maximum for G+10 diagrid building fixed base is more than diagrid building on hard soil, medium soil, Soft Soil shown in table no.5.9. After considering soil structure interaction (SSI) as energy absorbing storey on diagrid building, it is observed that the great reduction in Story Drift of G+10 diagrid building for different type of soil show in figure 5.6.

Table 5.9: Storey drift for diagrid building without and with soil structure interaction rest on different soil for time history El-centro.

Storey level	Storey drift (mm)			
	Without SSI	With SSI		
	Fixed base	Soft Soil	Medium Soil	Hard Soil
11	13.8	11.1	13.9	13.2
10	14.1	11.2	14.3	13.5
9	14.5	11.4	14.6	13.9
8	12.2	10.5	14	13
7	11.4	10.4	10.9	13.6
6	11.1	8.5	15.7	10.7
5	6.4	8.4	9	8.1
4	7	5.6	6.3	5.6
3	3.5	5.9	7	7
2	3.2	3.1	2.8	3.4
1	0	0	0	0

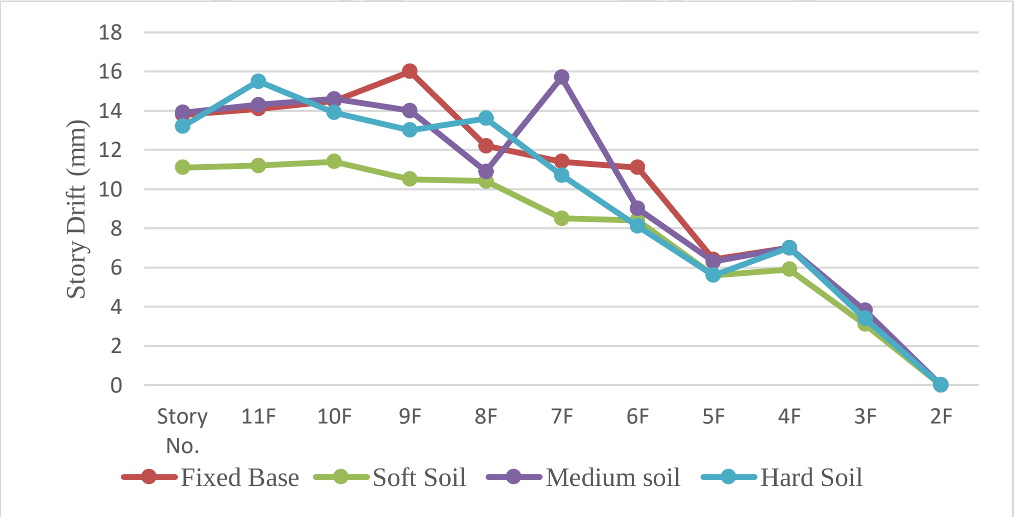


Figure 5.6: Storey drift of Without and with SSI

Base Shear

Result obtained from nonlinear dynamic analysis for G+10 diagrid building without and with soil structure interaction. storey resting on fixed base and hard soil, medium soil, soft soil is presented in table 5.10 also, comparison is shown in figure 5.7 for base share of time history EL-centro.

Table 5.10: base shear for diagrid building without and with soil structure interaction rest on fixed base and different soil for time history El-centro.

Base shear (KN)			
Without SSI	With SSI		
Fixed base	Soft Soil	Medium Soil	Hard Soil
10616.622	10246.33	9832.65	9488.418

From result it has been observed that the Base shear is maximum for G+10 diagrid building fixed base and Soft Soil is more than diagrid building on hard soil, medium soil. After considering soil structure interaction (SSI) as energy absorbing storey on diagrid building, it is observed that the great reduction in Base shear of G+10 diagrid building for different type of soil show in figure 5.7.

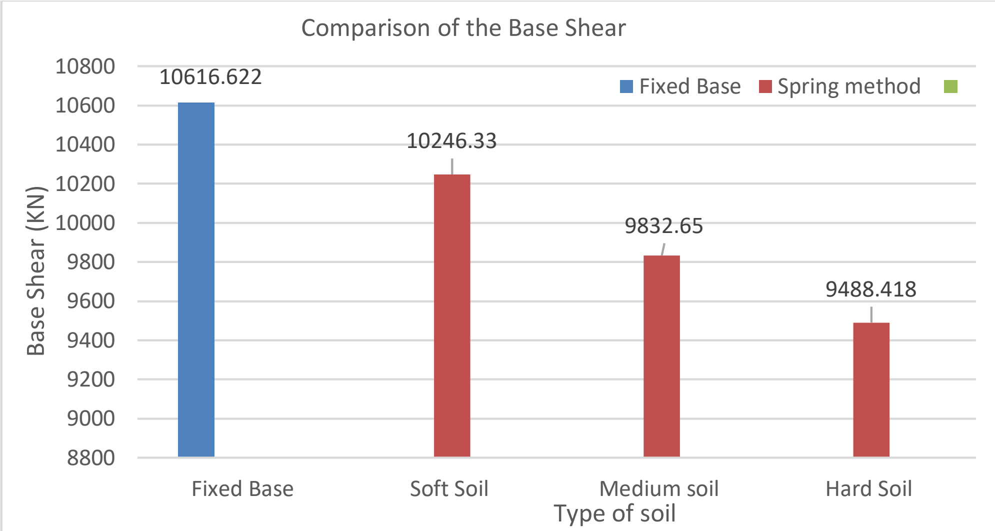


Figure 5.7: Base shear of Without and with SSI

6 CONCLUSIONS

This study for effect of soil structure interaction on Diagrid RC building without (Fixed base) and with (flexible base) soil structure interaction (SSI) as a storey on different soil conditions. For that G+10 is analyzed by using time history analysis in SAP2000 software. Comparison results are made for storey displacement, storey drift, storey shear for the effectiveness of soil structure interaction on different soil. On the basis of the results following conclusions can be drawn:

6.1 General Conclusions

1. The application of Winkler's method in the form of soft storey at the Bottom of high-rise building is the simplest and feasible method for structural response of the building.
2. It can be seen that it is necessary to properly implement and construct Winkler's spring any high-rise building situated in earthquake prone areas.

6.2 Specific Conclusions

1) Natural time period is a primary parameter which regulates the seismic lateral response of the structural frames. The natural period of structure increases due to SSI effect. For soft soil the effect is more prominent. Thus, evaluation of this parameter without considering SSI may cause serious failure in seismic design.
2) The period of the building is maximum in the case of soft soil as compared to the fixed base condition.
3) Increase in soil flexibility causes increase in the base shear. For soft soil base shear increases with higher rate. Base Shear shows a remarkable increment with increase in soil softness and storey height.
4) The base shear for the case of a flexible base decreases by up to 10-20% when compared to the case of a fixed base.
5) By Considering SSI, displacement of G+10 building can be increase in Soft, Medium Soil. laterally it decreased other soil condition and fixed base.
6) The story drifts due to medium and soft soil increases in the higher stories. The maximum drift was observed in the middle stories.
7) Roof displacement is also observed to be increasing due to incorporation of SSI. For soft soil the roof displacement is higher and in Fixed base the increment is more than in flexible base.
8) Winkler's Spring method has proved to be more useful method for studying the effect of SSI.
9) Using Winkler's hypothesis is also observed that the period of the building increases with an increase in the stiffness of springs.
10) Storey drift of the building with SSI as a soft storey can reduce up to 20-30% on hard soil, medium soil.
11) Therefore, Soil Structure Interaction in form of soft storey at bottom of the building is found to be effective effect on seismic response of a high-rise building on hard soil. medium soil and soft soil.
12) The best way to estimate the modulus of subgrade reaction is by performing studies on determining SSI using geotechnical field investigations and geotechnical software and then performing the inverse analysis.
13) Further, the parametric analysis by (G+10) high-rise structure, with and without SSI, revealed that high-rise structures on soft soil are more affected by SSI than low-rise structures.

6.3 Future Scope of Work

- The present work done on diagrid building by considering effect of soil structure interaction, further study can be done on conventional building.
- The present study has been done on soil structure interaction with substructure method. Further study can be on direct method.
- In this study non-linear time history analysis is performed.

- In present case, the RC columns are used, further study can be done for steel columns and CSFT (concrete filled steel tube) can be changed.
- As per Reacher paper, Elastic continuum approach (FEM model) is more effective than Winkler approach (Spring Model), so further study can be done for Direct Approach (pseudo-coupled) SSI Method.

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