EFFECT OF SOIL STRUCTURE INTERACTION ON G+5 STOREYED BUILDING WITH RAFT FOUNDATION

P VIJAYA BHASKAR 1*, Dr. DUMPA VENKATESWARLU 2*

1. *Student, Dept of CIVIL, GODAVARI INSTITUTE OF ENGINEERING AND TECHNOLOGY, RAJAHMUNDRY.*
2. *Head - Dept of CIVIL, GODAVARI INSTITUTE OF ENGINEERING AND TECHNOLOGY, RAJAHMUNDRY.*

Abstract— This Paper addresses the behavior of multi storey structure considering soil structure interaction i.e. interaction between substructure of the building and soil. For this purpose a sample of 5 storey RC frames is analyzed in conventional method with incremental static analysis for various load combinations and determines the parameters displacement, shear force and bending moment. Then a same 5 storey RC frame is analyzed in numerical analysis using Finite Element Method (FEM) with raft foundation by assigning the soil properties to substructure and determines the parameters displacement, shear force and bending moment. According to the analysis results the parameters displacements, shear force and bending moment varies from conventional analysis to numerical analysis. Displacements of the structure increases, shear forces of structure decreases and bending moment of the structure decreases at some points and increases at some points from conventional method of analysis to numerical method of analysis.

Keywords: Soil Structure interaction, Conventional Method of Analysis, Numerical Method of Analysis, Displacement, Shear Force, Bending Moment.

1. INTRODUCTION

Most of the civil engineering structures may involve some type of structural element with direct contact with ground surface. When the external forces, such as seismic or earthquakes, act on these systems, neither the structural displacements nor the ground surface displacements, are independent of each other. The process in which the response of soil influences the motion of the structure and motion of the structure influences the response of soil is termed as soil-structure interaction (SSI).

Generally, Conventional structural design methods neglect the SSI effects. Neglecting SSI is reasonable for light structures in relatively stiff soils such as low rise buildings and simple rigid retaining walls. The effect of SSI, however, becomes prominent for high structures resting on relatively soft soils for example nuclear power plants, high-rise buildings and elevated-highways on soft soils.

Investigations of soil structure interaction have shown that, the dynamic response of a structure supported on a flexible soil may differ significantly from response of the same structure when supported on rigid base. One of the important reasons for this difference is that part of the vibration energy of flexible mounted structure is dissipated by radiation of stress waves in the supporting medium and by hysteretic action in medium itself.

Analytical method to calculate the dynamic soil structure interaction effects are well established. When there is more than a single structure in the medium, because of interference of the structural responses through the soil, the soil structure responses through the soil, soil structure problem evolves to a cross interaction problem between multiple structures.

All those discussions have laid a solid theoretical and practical foundation for the subsequent research on Soil Structure Interaction (SSI). However, most of those studies are based on the elastic half space theory; which may analyzing the structure with shallow foundation attached to a homogeneous and thick soil layer simple and practical for engineers. Due to the difficulty of the solution for the analysis method and excessive simplifications of model for soil and structures, it was far from the real solution for problems of SSI.

When superstructures, foundations, topographic and geological conditions become complicated, producing a mathematical solution can be difficult.

1.1 Methods used to solve SSI problems:

1.1.1 Numerical Methods:

The numerical method was greatly developed because of the rapid progress of computers. This method of calculations is considered one of the most effective tools for the study of SSI. Thus, some seismologists have used it, and a great deal of publications based on it having spring up from 1980 up to present.

1.1.2 Finite Element Method:

Finite element method, an efficient common computing method widely used in civil engineering, discrete a continuum into a series of element with limited sizes to compute for the mechanics of the continuum. FEM can stimulate the mechanics of the soil and structures better than other methods, deal with the complicated geometry and applied loaded and determined non linear phenomenon. Up to date, there are many general purpose programs developed by a commercial corporations for research in the study of Soil structure interaction, and produced some notable achievements in the field of SSI

1.1.3 Experiment:

Experiment is an important mean for scientist and engineers to improve human knowledge about the nature law.

1.1.4 Prototype Observation:

Studies of recorded responses of instrumental structures constitute an integral part of seismic hazard-reduction programs, leading to improved designing or analyzing procedures are done by modeling a prototype structure and those are results are compared with conventional design methods so as to ensure the safety of structure.

1.2 Effect of soil structure interaction on structural response:

It has conventionally been considered that SSI has a beneficial effect on seismic response of a structure. Many design codes had been suggested that the effect of SSI can reasonably be neglected for the earthquake analysis of structures. This myth about SSI apparently stems from the false perception that soil structure interaction reduces the overall seismic response of a structure, hence, leads to improved safety margins. Most of the Indian design codes use oversimplified design spectra, which can attain constant acceleration up to a certain period of time , and there after decreases monotonically with period. Considering SSI makes a structure high flexible and thus, increasing the natural period of structure compared to corresponding rigidly supported structure. Moreover, considering the soil structure interaction effect increases effective damping ratio of the system. The smooth idealizations of design spectrum suggest smaller earthquake response with the increased natural periods and effective damping ratio due to soil structure interaction. With this assumption, it was traditionally been considered that the SSI can conveniently be neglected for conservative design. In addition, neglecting soil structure interaction tremendously reduces the complications in analysis of the structures which have tempted designers to neglect the effect of soil structure interaction in the analysis.

This conservative simplification is valid for certain class of structure and soil conditions, such as light structures in relatively stiff soil. Unfortunately, the assumptions does not always hold true. In fact, the soil structure interaction can have a detrimental effect on the structural response, and neglecting SSI in the analysis may lead to unsafe of design for both the superstructure and the foundation.

1.3 Objectives

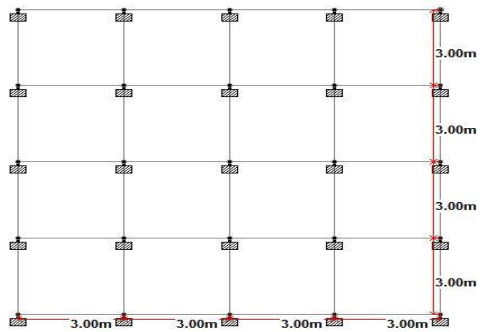
In this paper a 5 storey reinforced concrete frame is analyzed and designed as per IS 456:2000 in conventional method with different load combinations and determine the parameters displacements, shear force and bending moment by keeping the base as fixed. From the reactions obtained in conventional methods for the RC frame, raft foundation is designed.

Similarly a same 5 storey reinforced concrete frame is analyzed in Numerical method based on finite element method with raft foundation at the base by assigning soil properties to the substructure and determines the parameters displacements, shear forces, bending moment. Comparison of parameters displacements, shear forces and bending moments for both models is done i.e. with soil structure interaction and without soil structure interaction.

2. CONVENTIONAL METHOD OF ANALYSIS

A symmetrical 5 storey building is modeled using STAAD Pro software package with 4 no of bays in X direction and 4 no of bays in Z direction. The span of the columns is 3m in X direction and 3m in Z direction. The plinth area of the building is 12m x 12m. The total height of the 5 storey building is considered as 15m. The height of each storey is taken as 3m respectively.

Fig 1: Plan view of the structure



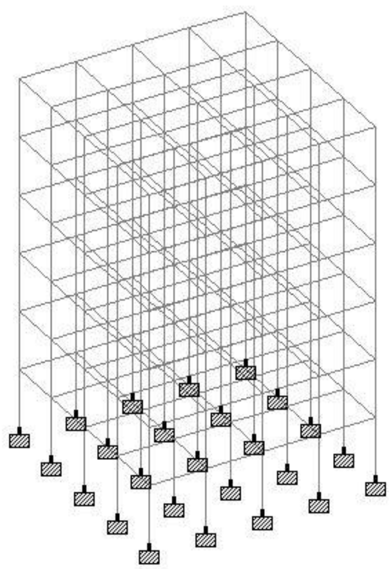


Fig 2: Isometric view of the structure

Table 1: Data required for modeling:

Structural Properties	
Structure	OMRF
No of Storey's	5
Storey Height	3.00 m
Type of building used	Residential
Foundation Type	Raft Foundation
Seismic Zone	III
Material Properties	
Grade of concrete used	M 30
Grade of steel used	415 MPA
Young's Modulus of Concrete	27.38 x 106 KN/m2
Density of Reinforcement Concrete	25 KN/m3
Modulus of Elasticity of brick masonry	3.50 x 106 KN/m3
Density of brick masonry	19.2 KN/m3
Member Properties	
Thickness of Slab	0.125 m
Beam size	0.45 x 0.23 m
Column size	0.45 x 0.45 m
Thickness of outer wall	0.230 m
Thickness of inner wall	0.115 m
Seismic Parameters	
City	Vijayawada
Zone	III
Response Reduction Factor	3
Structure type	RC Framed building
Damping Ratio	5%
Soil Properties	
Type of soil	Loose Sand
Soil Bearing Capacity	215 KN/m2
Codes	
RCC Design	IS 456:2000
Seismic Design	IS 1893 Part 4

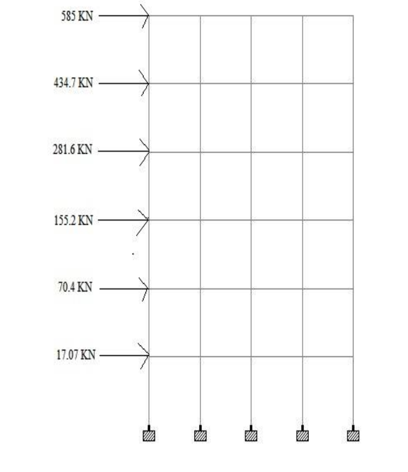
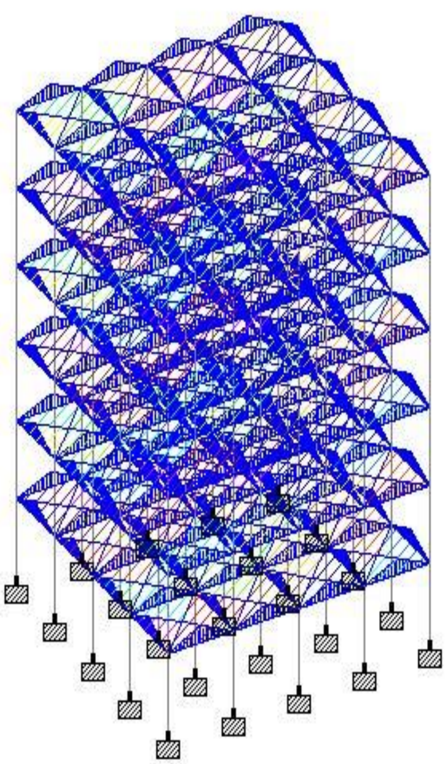


Fig3: Equivalent static lateral load (sway to right) On frame in KN

Fig 4: Live load Diagram



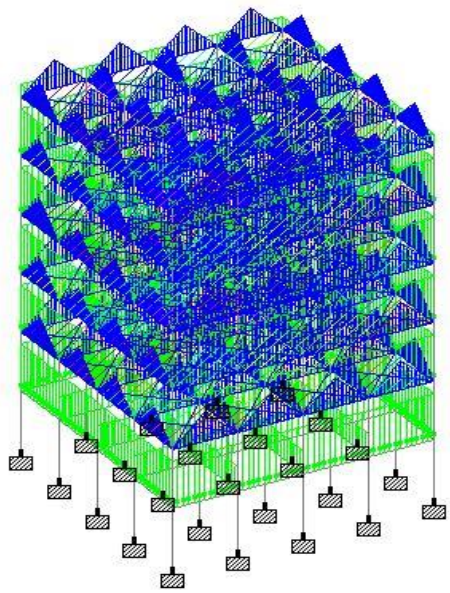


Fig 5: Dead Load Diagram

2.1 NUMERICAL ANALYSIS USING FINITE ELEMENT METHOD

Finite element method (FEM) is a numerical technique for the extraction of approximate solutions to boundary valued problems for partial differential equations (PDE). It uses subdivision of a whole problem domain into a simpler part, called finite elements, and variation methods from the calculus of variations to solve the problem by minimizing an associated error functions. Analogous to the idea that connecting many tiny straight lines can approximate a larger circle; finite element modeling encompasses methods for connecting many simple element equations over many small sub domains; named finite element, to approximate a high complex equation over a larger domain.

Various number of software based on finite element methods which are widely used in construction industry

In this paper numerical analysis using ANSYS software package is done

2.2 ANSYS:

ANSYS is a general purpose of finite element modeling package for numerically solving a wide variety of mechanical problems. It include: static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problem, acoustic and electro-magnetic problems.

Generally, a finite element (FEM) solution may be broken into the following stages. It is a general guideline that can be used for setting up any FEA.

1. Pre-processing: The main steps in pre-processing are given below:

Define key points /lines/area/volumes
Define element type and material type/geometric Property
Mesh lines/areas/volume as required.

The amount of detail required will depend on the dimensionality of the analysis (i.e., 1D, 2D, ax symmetric, 3D).

2. Solution: Assigning loads, constraints and solving, here we specify loads (Point/Pressure), constraints (Translation and Rotation) and finally solve the resulting set of equations.

3. Post processing- Further processing and checking of the results

Lists of nodal displacements
Element forces and moments
Deflection plots
Stress contour diagrams

A similar symmetrical 5 storey building is taken with 4 no of bays in X direction and 4 no of bays in Z direction. The span of the columns is 3m in X direction and 3m in Z direction. The plinth area of the building is 12m x 12m. The total height of the 5 storey building is considered as 15m. The height of each storey is taken as 3m respectively.

Raft foundation is designed for this 5 storey building from the axial loads obtained from conventional method of analysis for worst cases.

2.3 Structural Design of Raft Foundation:

This foundation will be done for a 5 storey building. The raft will be economical consideration.

The raft foundation is a kind of combined footing that covers the entire area under the structure supported by several columns in one rigid body. In this project, the soil profile shows that the bearing stress is around 215 KN/m2. The raft foundation is usually used with this kind of soil. The columns have high axial loads. In this big spread footing condition, the raft foundation could be much practical and economical.

In this project, the raft will be design as flat plate, which has uniform thickness and without any beams or pedestals.

Objective:

This report shows the structural design of raft foundation. All analysis and design are based on Indian code (IS 456:2000). Raft foundation can be designed using several methods. In this project the method used in the design called 'Conventional Rigid Method' and all the design steps will be shown below.

Table 2: Design parameters

Parameters	Value
Yield strength of steel	415 MPA
Strength of concrete	30 MPA
Young modules of elasticity	2000000
Soil unit weight	17.5 KN/m3
Allowable bearing stress	215 KN/m3

Raft Modeling and Analysis:

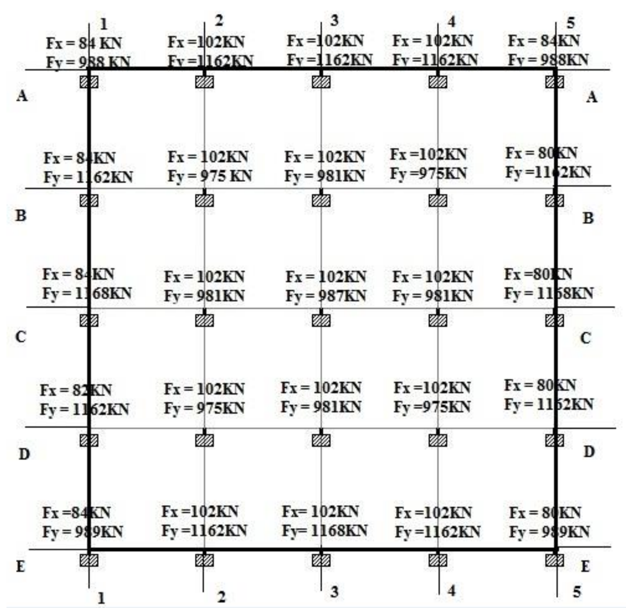


Fig 6: Raft layout

Total area of the raft = 12m x 12m = 144 m2

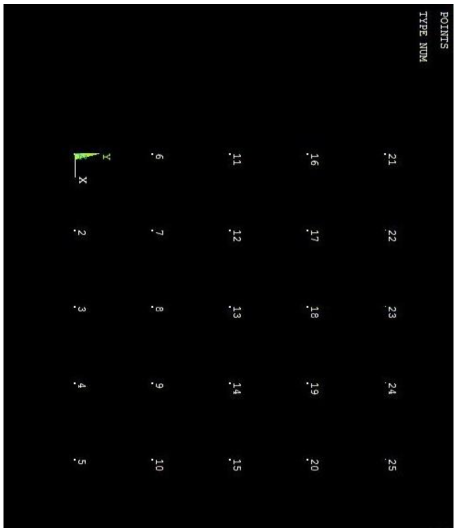


Fig 7: Columns layout in ANSYS

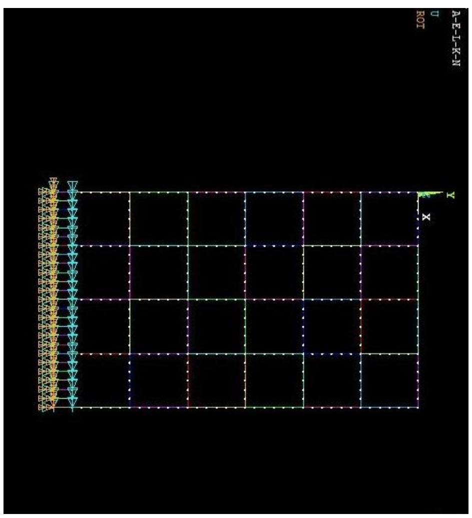


Fig.8: Elevation of the Structure

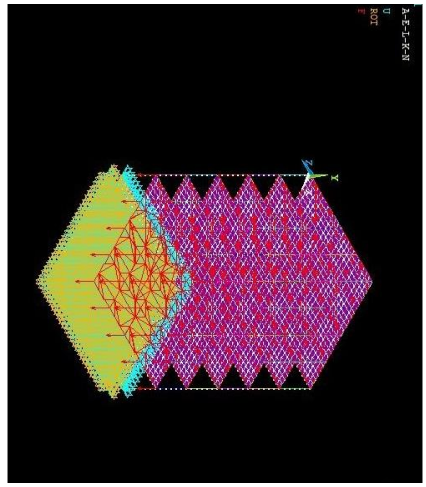


Fig 9: Loads acting on the Structure

3. RESULTS AND DISCUSSIONS

3.1 Maximum displacements:

Table 3: Maximum Displacements in 5th Storey in mm

Column Number	Displacement without SSI	Displacement with SSI
C 1	2.59	2.80
C 2	2.63	2.82
C 3	2.59	2.79

Table 4: Maximum Displacements in 4th Storey in mm

Column Number	Displacement without SSI	Displacement with SSI
C 1	2.439	2.655
C 2	2.504	2.730
C 3	2.439	2.655

Table 5: Maximum Displacements in 3rd Storey in mm

Column Number	Displacement without SSI	Displacement with SSI
C 1	2.249	2.541
C 2	2.270	2.610
C 3	2.249	2.540

Table 6: Maximum Displacements in 2nd Storey in mm

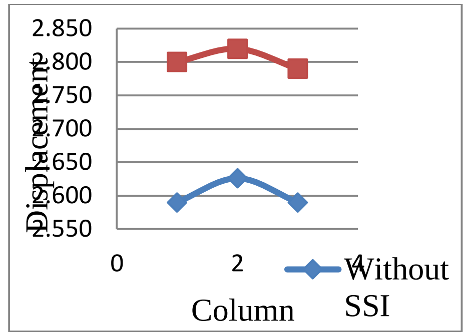
Column Number	Displacement without SSI	Displacement with SSI
C 1	1.843	2.341
C 2	1.870	2.461
C 3	1.820	2.341

Table 7: Maximum Displacements in 1st Storey in mm

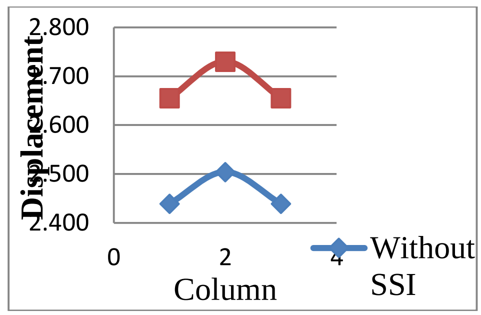
Column Number	Displacement without SSI	Displacement with SSI
C 1	1.353	2.004
C 2	1.380	2.177
C 3	1.321	1.972

Table 8: Maximum Displacements in G.L in mm

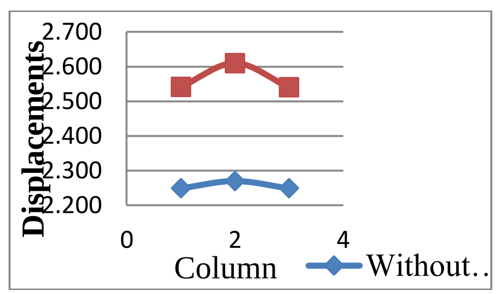
Column Number	Displacement without SSI	Displacement with SSI
C 1	0.709	1.355
C 2	0.771	1.451
C 3	0.699	1.354



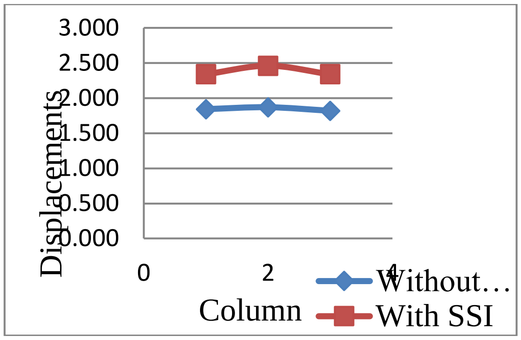
Graph 1: Maximum displacements in 5th storey with and without soil structure interaction



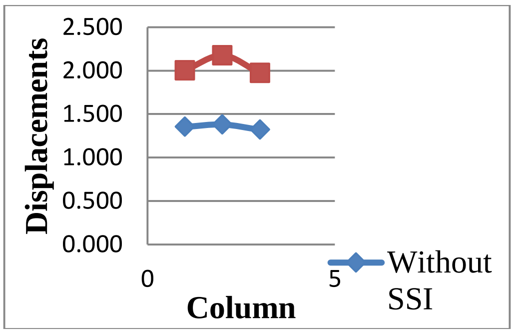
Graph 2: Maximum displacements in 4th storey with and without soil structure interaction



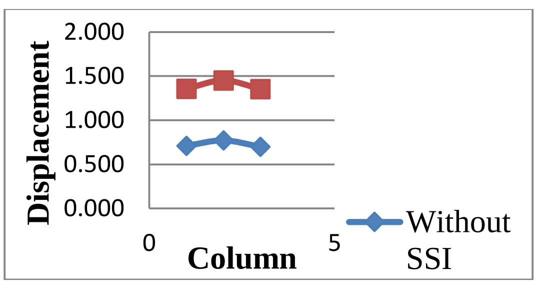
Graph 3: Maximum displacements in 3rd storey with and without soil structure interaction



Graph 4: Maximum displacements in 2nd storey with and without soil structure interaction



Graph 5: Maximum displacements in 1st storey with and without soil structure interaction



Graph 6: Maximum displacements in G.L with and without soil structure interaction

3.2 Maximum Shear Forces:

The maximum shear forces of 5 storied building for the cases of dead load, live load multiplied with safety factor with soil structure interaction and without soil structure interaction for each storey is presented in table below. The results are taken only for extreme loading conditions and static loading condition i.e. only dead loads and live loads are considered.

Maximum Shear Forces in Structure

Table 9: Maximum Shear Forces in 5th Storey KN

Column Number	SF without SSI	SF with SSI
C 1	12.948	10.122
C 2	14.074	11.496
C 3	12.867	10.289

Table 10: Maximum Shear Forces in 4th Storey in KN

Column Number	SF without SSI	SF with SSI
C 1	8.903	7.144
C 2	9.033	6.998
C 3	8.953	7.064

Table 11: Maximum Shear Forces in 3rd Storey in KN

Column Number	SF without SSI	SF with SSI
C 1	9.054	6.434
C 2	9.180	7.142
C 3	9.017	6.982

Table 12: Maximum Shear Forces in 2th Storey in KN

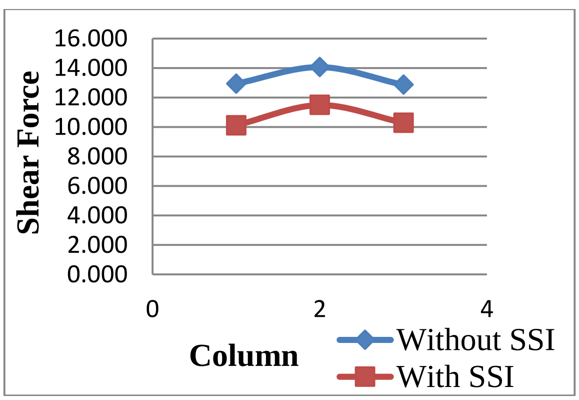
Column Number	SF without SSI	SF with SSI
C 1	8.866	6.721
C 2	8.756	6.356
C 3	8.844	6.809

Table 13: Maximum Shear Forces in 1st Storey in KN

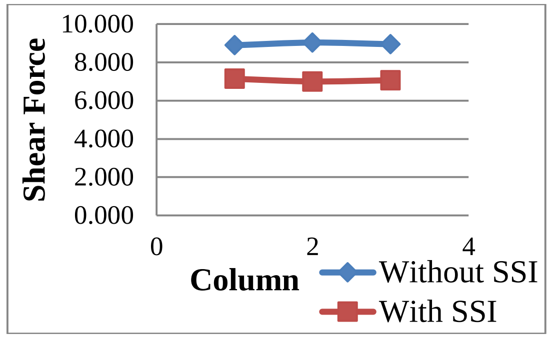
Column Number	SF without SSI	SF with SSI
C 1	5.971	4.591
C 2	7.080	3.653
C 3	5.942	4.467

Table 14: Maximum Shear Forces in G.L in KN

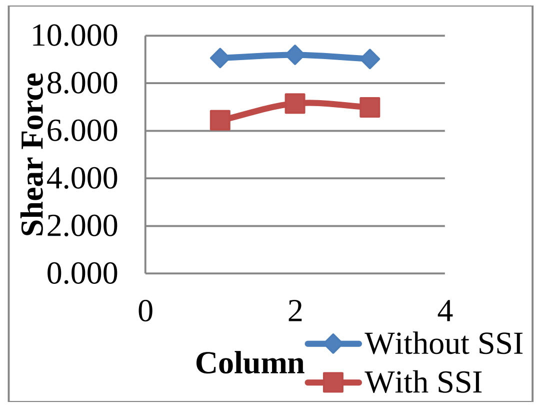
Column Number	SF without SSI	SF with SSI
C 1	1.716	1.617
C 2	3.157	2.902
C 3	1.686	1.431



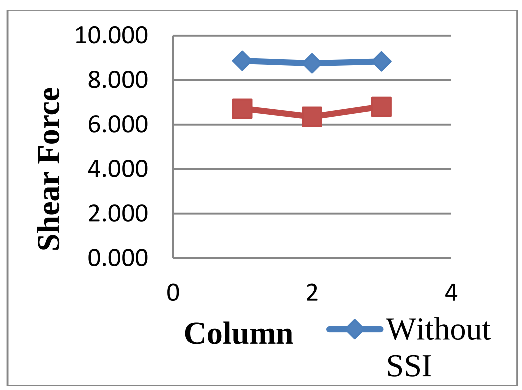
Graph 7: Maximum SF in 5th storey with and without soil structure interaction



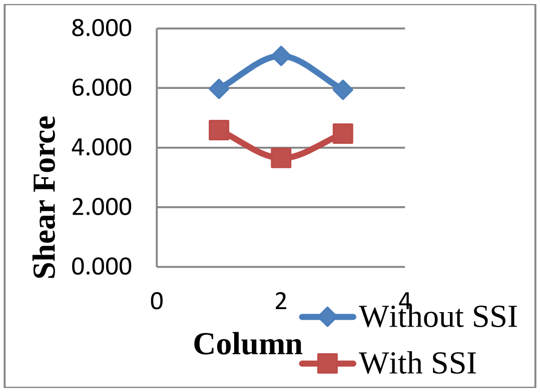
Graph 8: Maximum SF in 4th storey with and without soil structure interaction



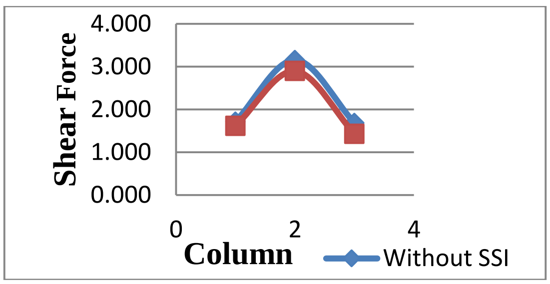
Graph 9: Maximum SF in 3rd storey with and without soil structure interaction



Graph 10: Maximum SF in 2nd storey with and without soil structure interaction



Graph 11: Maximum SF in 1st storey with and without soil structure interaction



Graph 12: Maximum SF in G.L with and without soil structure interaction

3.3 Maximum Bending Moments:

The maximum Bending Moment of 5 storied building for the cases of dead load, live load multiplied with safety factor with soil structure interaction and without soil structure interaction for each storey is presented in table below. The results are taken only for extreme loading conditions and static loading condition i.e. only dead loads and live loads are considered.

Maximum Bending Moment in Structure

Table 15: Maximum Bending Moments in 5th Storey in KN/m

Column Number	BM without SSI	BM with SSI
C 1	22.842	20.534
C 2	25.364	21.783
C 3	22.681	20.851

Table 16: Maximum Bending Moments in 4th Storey in KN/m

Column Number	BM without SSI	BM with SSI
C 1	13.866	12.980
C 2	14.040	13.467
C 3	13.805	12.988

Table 17: Maximum Bending Moments in 3rd Storey in KN/m

Column Number	BM without SSI	BM with SSI
C 1	13.699	11.789
C 2	13.958	12.772
C 3	13.702	11.533

Table 18: Maximum Bending Moments in 2nd Storey in KN/m

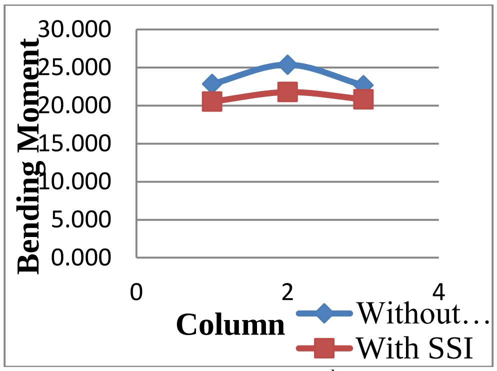
Column Number	BM without SSI	BM with SSI
C 1	13.485	11.868
C 2	13.125	11.204
C 3	13.485	11.868

Table 18: Maximum Bending Moments in 1st Storey in KN/m

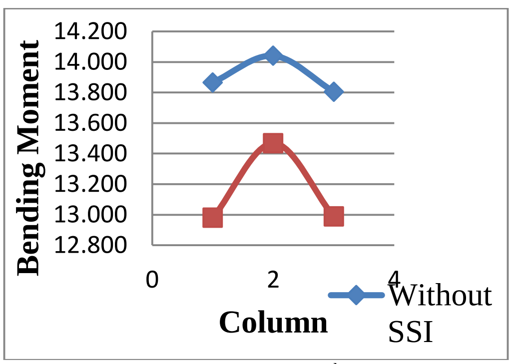
Column Number	BM without SSI	BM with SSI
C 1	10.713	9.747
C 2	11.476	10.333
C 3	10.713	9.984

Table 19: Maximum Bending Moments in G.L in KN/m

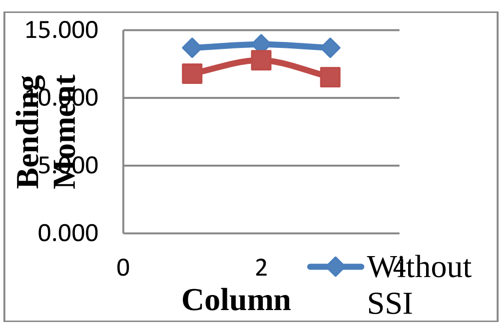
Column Number	BM without SSI	BM with SSI
C 1	3.294	1.404
C 2	6.232	4.262
C 3	3.233	1.283



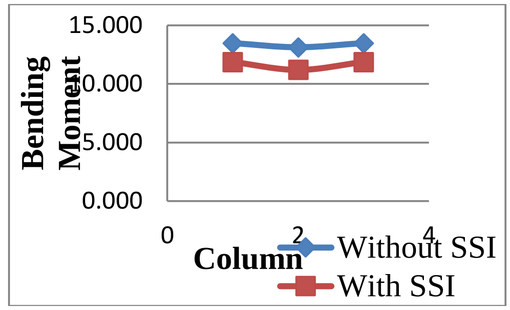
Graph 13: Maximum BM in 5th storey with and without soil structure interaction



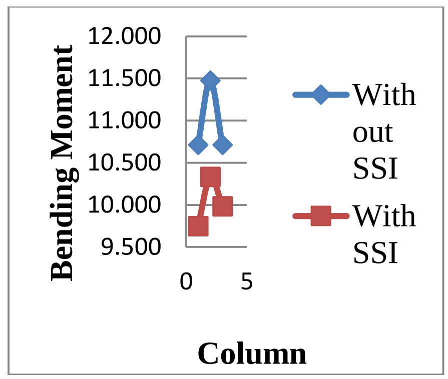
Graph 14: Maximum BM in 4th storey with and without soil structure interaction



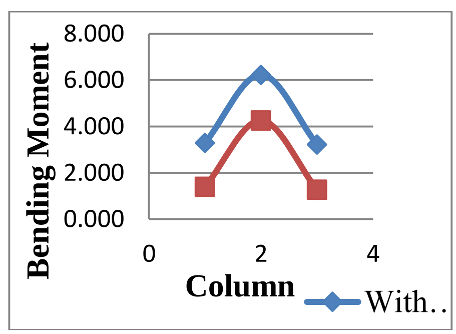
Graph15: Maximum BM in 3rd storey with and without soil structure interaction



Graph 16: Maximum BM in 2nd storey with and without soil structure interaction



Graph 17: Maximum BM in 1st storey with and without soil structure interaction



Graph 18: Maximum BM in G.L with and without soil structure interaction

4. CONCLUSION

The displacements, shear forces and bending moments are estimated from conventional design method and numerical analysis method using finite element method in columns i.e. without soil structure interaction and with soil structure interaction. The displacements, Shear forces and bending moments are compared with soil structure interaction and without soil structure interaction. The value of sub grade modulus reaction K_s have been assumed 12000 KN/m^3.

The following conclusions have been drawn from above results:

1. Analysis of structure with soil structure interaction shows more displacement than the analysis of structure without soil structure interaction.
2. Analysis of structure with soil structure interaction shows more or less Bending moments as compared with analysis of structure without soil structure interaction.
3. Analysis of structure with soil structure interaction shows average of 23.3% increase in displacements compared with analysis of structure without soil structure interaction.
4 Analysis of structure with soil structure interaction shows average of 30.1% decrease in shear forces compared with analysis of structure without soil structure interaction.
5. Design performed by conventional method is high safe as we are designing the structure for higher shear forces and higher bending moments.
6. Conventional method of design is somewhat uneconomical as the structure is design for higher shear forces and higher bending moments, so we can go for a structure designed by considering soil structure interaction.

5. REFERENCES

1. Dr. C. Ravi Kumar Reddy and T.D Gunneswara Rao 2011: Experimental study of a modeled building frame supported by pile groups embedded in cohesion less soil.
2. K. Natarajan and B. Vidivelli 2009: Effect of column spacing on the behavior of frame raft and soil systems.
3. Haytham Adnan Sadeq, Mohammed saleem Taha 2009: Structural design of raft foundationwith soil structure intraction.
4. H.S Chore, V.A Sawant and R.K Ingle 2012: Non-linear analysis of pile groups subjected to lateral loads.
5. Sushma Pulikanti and Pradeep Kumar Ramancharla 2013: SSI Analysis of framed structures supported on pile foundations
6. Vivek Garg and M.S Hora 2012: A review on interaction behavior of structure foundation soil system.
7. R. R. Chaudhari, Dr K. N. Kadam 2013: Effect Of Piled Raft Design On High-Rise Building Considering Soil Structure Interaction.
8. Gaikwad M.V, Ghogare R.B, Vagessha S. Mathada 2015: Finite element analysis of frame with soil structure interaction.
9. Lou Menglin, Wang Huaifeng, and Chen Xi Zhai Yongmei 2011: Structure soil Structure interaction: literature review.
10. Dr. M. Reza Emami Azadi, Ali Akbar Soltani 2010: Effect of soil structure interaction on dynamic response of Delijan cement storage soil under earthquake loading.
11. D. Daniel Thangaraj and L Ilampathi 2012: Numerical analysis of soil raft foundation and space frame system.
12. Eduardo Kausel 2010: Early history of soil structure interaction.
13. IS 875 (Part-3)-1987 Indian Standard Code of Practice for "Design of Wind Loads for Buildings and Structures".
14. IS 456:2000 Indian Standard Code of Practice for "Plain and Reinforced concrete design".
15. IS 1893 (Part-4)-2002 Indian Standard "Criteria for Earthquake Resistant Design of Structures".