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# EFFECT OF SUB STRUCTURE COLLABORATION ON MULTI-STOREYED BUILDING WITH RAFT FOUNDATION

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**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 determine 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 the 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, Displacement, Shear Force, Bending Moment.

## 1. INTRODUCTION

**1.1 General:** Conventional structural design methods neglect the SSI effects. 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. Investigations of soil structure interaction have shown that the dynamic response of a structure supported on 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 vibrational energy of flexible mounted structure is dissipated by radiation of stress waves in the supporting medium and by hysteretic action in the medium itself. Analytical methods to calculate the dynamic soil-structure interaction effects are well established. When there is more than one 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 make analysing 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 the excessive simplification of the model for soil and structures, it was far from the real solution for problems of SSI. When superstructures, foundations, and topographic and geological conditions become complicated, producing a mathematical solution can be difficult.

**1.2 Methods used to solve SSI problems:**

**1.2.1 Numerical Methods:**The numerical method 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.

**1.2.2 Finite Element Method**:Finite element method, an efficient common computing method widely used in civil engineering, discretizes a continuum into a series of elements 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 complicated geometry and applied loaded, and determine non linear phenomena. To date, there are many general purpose programs developed by

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commercial corporations for research in the study of SSI, and has produced some notable achievements in the field of SSI

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

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

**1.3 Effect of soil structure interaction on structural response:**

It has conventionally been considered that soil-structure interaction has a beneficial effect on the seismic response of a structure. Many design codes have suggested that the effect of SSI can reasonably be neglected for the seismic analysis of structures. This myth about SSI apparently stems from the false perception that SSI reduces the overall seismic response of a structure, and hence, leads to improved safety margins. 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. Moreover, considering the SSI effect increases the effective damping ratio of the system. The smooth idealization of design spectrum suggests smaller seismic response with the increased natural periods and effective damping ratio due to SSI. With this assumption, it was traditionally been considered that SSI can conveniently be neglected for conservative design. In addition, neglecting SSI tremendously reduces the complication in the analysis of the structures which has tempted designers to neglect the effect of SSI in the analysis.This conservative simplification is valid for certain class of structures and soil conditions, such as light structures in relatively stiff soil. Unfortunately, the assumption does not always hold true. In fact, the SSI can have a detrimental effect on the structural response, and neglecting SSI in the analysis may lead to unsafe design for both the superstructure and the foundation.In this paper a 5 storey reinforced concrete frame is analysed 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 analysed in Numerical method based on finite element method with raft foundation at the base by assigning soil properties to the substructure and determine 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.LITERATURE REVIEW

**M.V Gaikwad** analysed a frame with soil structure interaction using FEM. It states the behaviour of bare frame having soil beneath. The results shows bare frame with soil structure interaction shows more displacements than the analysis of structure without soil structure interaction. Also analysis of bare frame with soil structure interaction shows less shear force and bending moment as compared with analysis of bare frame without soil structure interaction.

**Rama Rao et al** analysed a structure to study the effect of soil-structure interaction on horizontal and vertical displacements at the supports for various heights providing sub grade modulus of soil as a defining soil medium by springs for some defined wind loads. From the results it states that the displacement increases with the increase in the value of sub grade modulus reaction and the displacement increases with the increase in the storey level of the building.

## 3. CONVENTIONAL METHOD OF ANALYSIS

**3.1 Introduction:**A symmetrical 5 storey building is modelled 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.

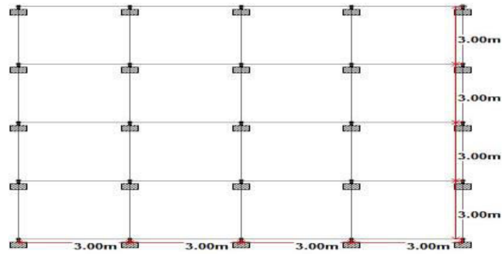


**Fig 3.1** Plan view of the structure

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### 3.2 Model data of the Structure:

| | |
|---|---|
| Structural Properties | |
| Structure | OMRF |
| No of Storeys | 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 $10^6$ KN/m$^2$ |
| Density of Reinforcement Concrete | 25 KN/m$^3$ |
| Modulus of Elasticity of brick masonry | 3.50 x $10^6$ KN/m$^3$ |
| Density of brick masonry | 19.2 KN/m$^3$ |
| 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 | Vishakapatnam |
| 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/m$^2$ |
| Codes | |
| RCC Design | IS 456:2000 |
| Seismic Design | IS 1893 Part 4 |

### 3.3 Calculations of loads:

**3.3.1 Dead loads and Live loads of the building:** The dead load of the building includes the self weight, wall load (outer walls and inner walls), floor load and parapet wall load are calculated as for codes

**3.3.2 Wind load:**
From IS 875 (Part III)

Design Wind Pressure ($P_z$) = 0.6 $V_z^2$

Where $P_z$ = design wind pressure in N/ms at height z, and

$V_z$ = design wind velocity in m/s at height z.

Design Wind Speed ($V_z$) = $V_b$ x $k_1$ x $k_2$ x $k_3$

Where $V_b$ = basic wind speed

[$V_b$ = 55m/s, $V_b$ = 50m/s,$V_b$ = 47m/s and $V_b$ =39m/s]

$k_1$= probability factor (Table 1 clause5.3.1)

$k_2$ = height and structure size factor (Table 2 clause 5.3.2)

$k_3$ = topography factor (Table 2 clause 5.3.3)

For 5 storey building

$V_z$ = 55 x 1 x 1.1 x 1 = 60.5 m/s; $P_z$ = 0.6 $V_z^2$ = 2.196 KN/m$^2$

$V_z$ = 50 x 1 x 1.1 x 1 = 55.0 m/s; $P_z$ = 0.6 $V_z^2$ = 1.815 KN/m$^2$

$V_z$ = 47 x 1 x 1.1 x 1 = 51.7 m/s; $P_z$ = 0.6 $V_z^2$ = 1.603 KN/m$^2$

$V_z$ = 39 x 1 x 1.1 x 1 = 42.9 m/s; $P_z$ = 0.6 $V_z^2$ = 1.104 KN/m$^2$

**3.3.3 Earthquake load parameters:**

For Zone III
Structure type = RC framed building
Response reduction factor (RF) = 3
Importance Factor (I) = 1
Zone Factor = 0.16
Damping ratio (DM) = 5%

### 3.4 Base Shear Calculation:

Zone factor for zone III = 0.16
Importance factor = 1.5
Response factor = 3
Intensity of dead load = 16.8 KN/m$^3$
Imposed load:
Floor load = slab thickness x density of concrete
= 0.125 x 25
= 3.125 KN/m$^3$
Liveload = 2 KN/m$^3$
Dust load = 0.5 KN/m$^3$
Imposed load = Floor load + live load +Dust Load
= 3.125 + 2+ 0.5
= 5.625 KN/m$^3$
Total floor area = 12m x 12m = 144 m$^2$
Load on one floor = 144 (16.8 + 0.25 x 5.625) = 2621.7 KN
Load on roof = 144 x 16.8 = 2419.2 KN
Total load on structure (W) = 5 x 2621.7 + 2419.2 = 15527.7 KN

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Base shear ($V_b$) = $A_h W$

$A_h = (ZIS/2RG) = (0.16 \times 1.5 \times 2.5)/(2 \times 3) = 0.1$

Base shear ($V_b$) = 0.1 x 15527.7 = 1552.7 KN

Vertical distribution of base shear:

$Q_5 = (W_1 h_1^2 / \Sigma W_i h_i^2)$

## 4. NUMERICAL ANALYSIS USING FINITE ELEMENT METHOD

Various softwares based on finite element methods which are widely used in construction industry are:

1. ABACUS
2. ANSYS
3. SAP 2000
4. SAFE
5. ETABS

In this paper numerical analysis using ANSYS software package is done.

### 4.3 ANSYS:

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

In general, a finite element solution may be broken into the following three stages. This is a general guideline that can be used for setting up any finite element analysis.

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

   1. Define key points /lines/areas/volumes
   2. Define element type and material/geometric properties
   3. Mesh lines/areas/volumes as required

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

2. Solution: assigning loads, constraints and solving; here we specify the loads (point or pressure), constraints (translational and rotational) and finally solve the resulting set of equations.

3. Post processing: Further processing and viewing of the results, in this stage one may wish to see:

   4. Lists of nodal displacements
   5. Element forces and moments
   6. Deflection plots
   7. 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.

### 4.4 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 may cover the entire area under the structure supporting several columns in one rigid body. In this project, the soil profile shows that the bearing stress is around 215 KN/$m^2$. 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.

#### 4.4.1 Objective:

This report shows the structural design of the raft foundation. All analysis and design are based on Indian code. Raft foundation can be design using several methods. In this project the method used in the design called "The Conventional Rigid Method" and all design steps will be shown below.

All design parameters are shown in table below

| Parameters | Value |
|---|---|
| Yield strength of steel | 415 MPA |
| Strength of concrete | 30 MPA |
| Young modules of elasticity | 2000000 |
| Soil unit weight | 17.5 KN/$m^3$ |
| Allowable bearing stress | 215 KN/$m^3$ |

#### 4.4.2 Raft Modelling and Analysis:

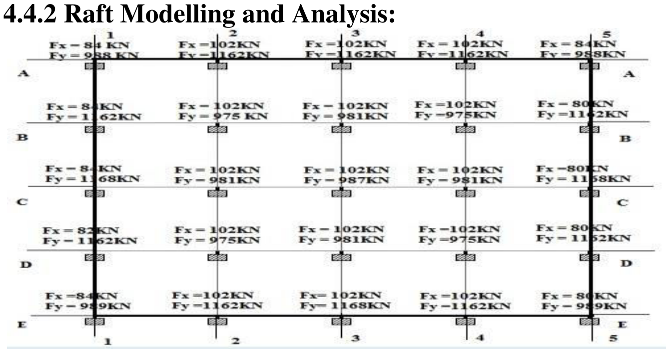


**Fig 4.1** Raft layout

**Modelling in ANSYS:**

A symmetrical 5 storey building with raft foundation is taken with 4 no of bays in X direction and 4 no of

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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.

**4.5.1 Elements used in Modelling of structure:**

**BEAM4 Element:**BEAM4 is a uniaxial element with tension, compression, torsion, and bending capabilities. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection (finite rotation) analyses. See BEAM4 in the Theory Reference for the Mechanical APDL and Mechanical Applications for more details about this element. A tapered unsymmetrical elastic beam is described in BEAM44 and a 3-D plastic beam in BEAM24.In this structure beams and columns are taken as beam elements. The geometry, node locations, and coordinate systems for this element are shown in figure below.

BEAM4 Real constants:

**SHELL63 Element:**SHELL63 has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection (finite rotation) analyses. See SHELL63 in the Theory Reference for the Mechanical APDL and Mechanical Applications for more details about this element. Similar elements are SHELL181 (plastic capability) and SHELL281 (mid side node capability). The ETCHG command converts SHELL57 and SHELL157 elements to SHELL63.

In this structure slabs and raft foundation are taken as shell elements. The geometry, node locations, and coordinate systems for this element are shown in figure below.

SHELL63 Real constants:

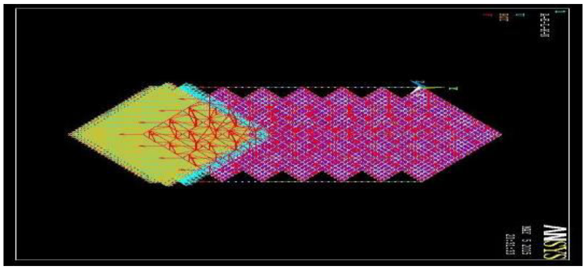
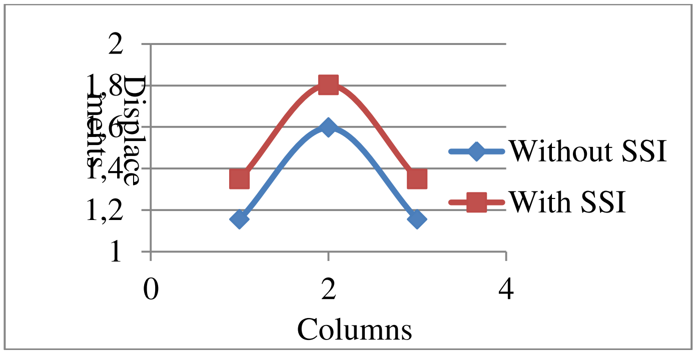


**Fig 4.9** Loads acting on the Structure

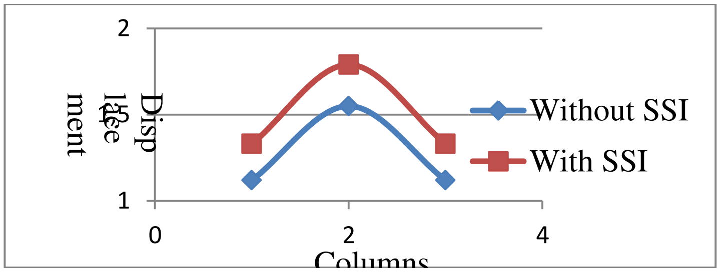
## 5 RESULTS AND DISCUSSIONS

**Maximum Displacements:**

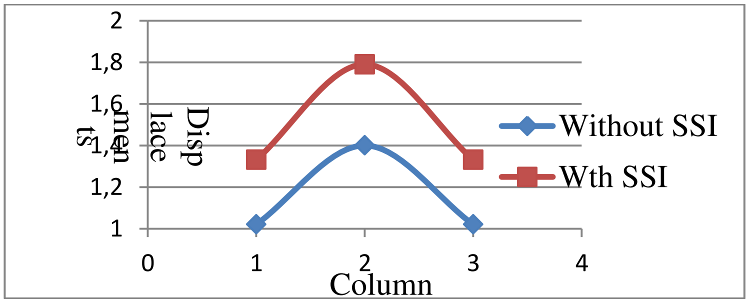
The maximum displacements of 5 storeyed building for the cases of dead load, live load multiplied with safety factor with soil structure interaction and without soil structure interaction for each storey is presented in table below. The results are taken only for extreme loading conditions and static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




**Graph 5.1** Maximum displacements in 5th storey with and without soil structure interaction




**Graph 5.2** Maximum displacements in 4th storey with and without soil structure interaction




**Graph 5.3** Maximum displacements in 3rd storey with and without soil structure interaction

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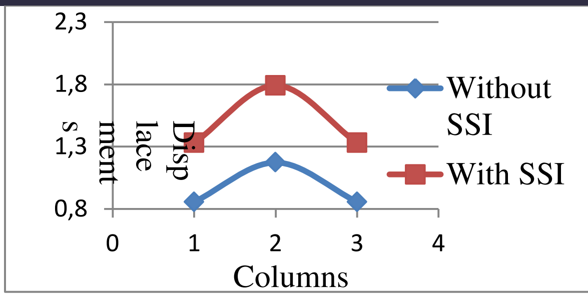
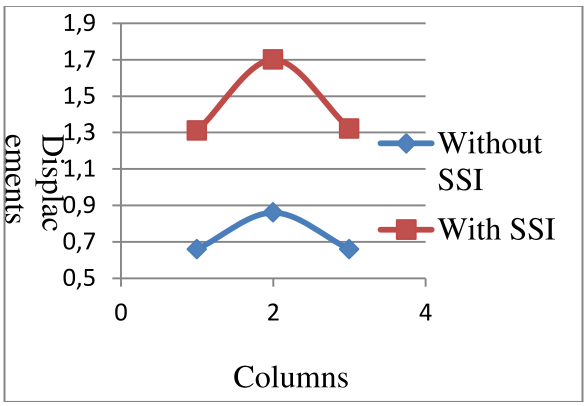
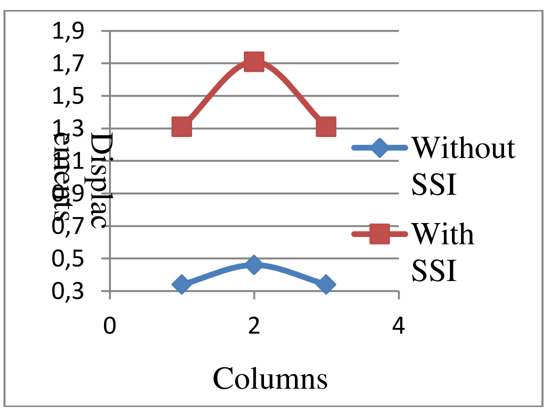



**Graph 5.4** Maximum displacements in 2nd storey with and without soil structure interaction



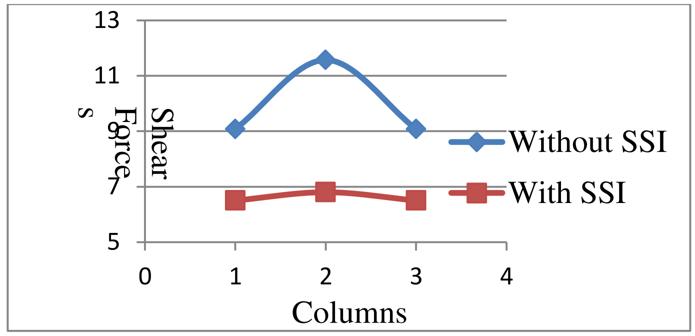

**Graph 5.5** Maximum displacements in 1st storey with and without soil structure interaction



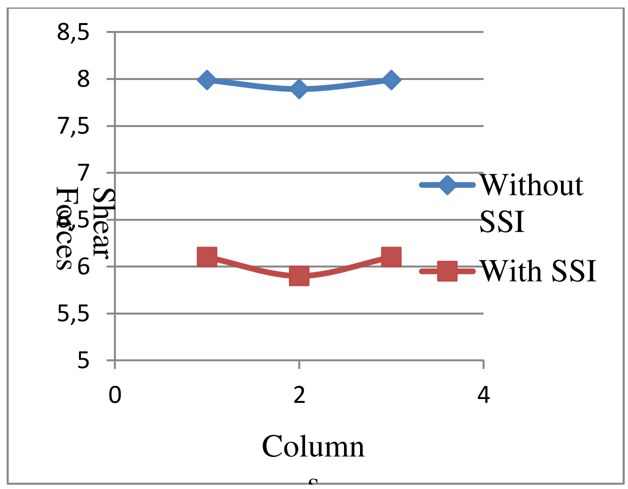

**Graph 5.6** Maximum displacements in G.L with and without soil structure interaction

**Maximum Shear Forces:**

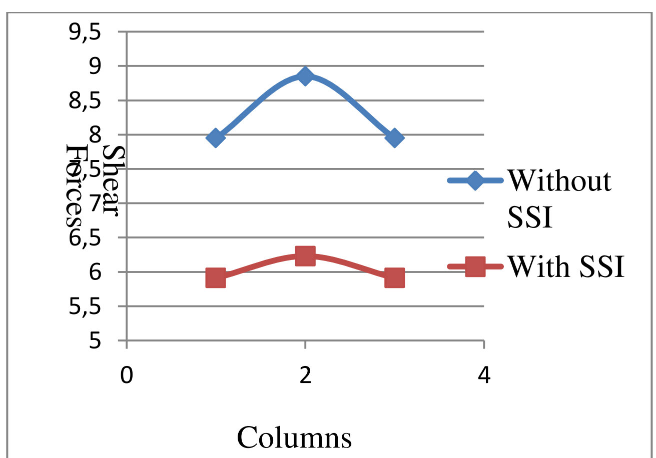
The maximum shear forces of 5 storeyed building for the cases of dead load, live load multiplied with safety factor with soil structure interaction and without soil structure interaction for each storey is presented in table below. The results are taken only for extreme loading conditions and static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




**Graph 5.7** Maximum SF in 5th storey with and without soil structure interaction




**Graph 5.8** Maximum SF in 4th storey with and without soil structure interaction




**Graph 5.9** Maximum SF in 3rd storey with and without soil structure interaction

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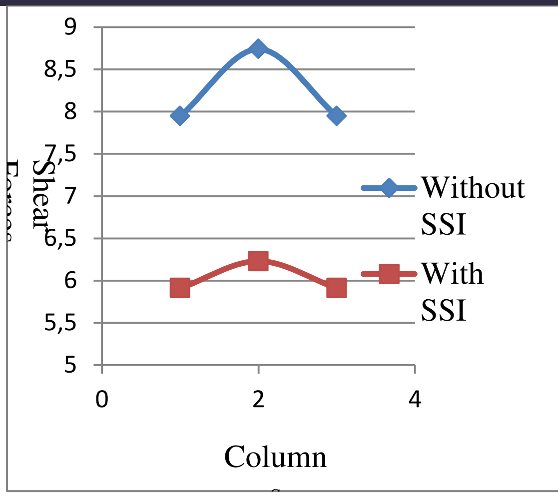
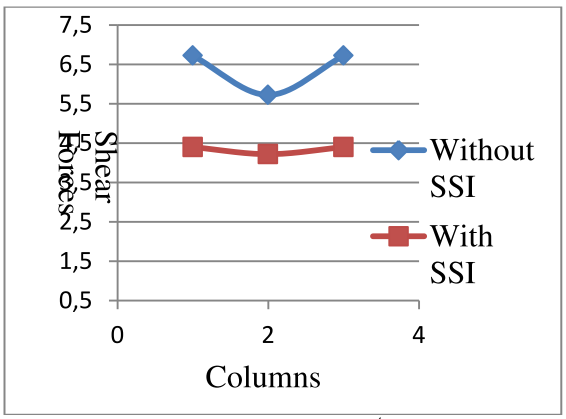
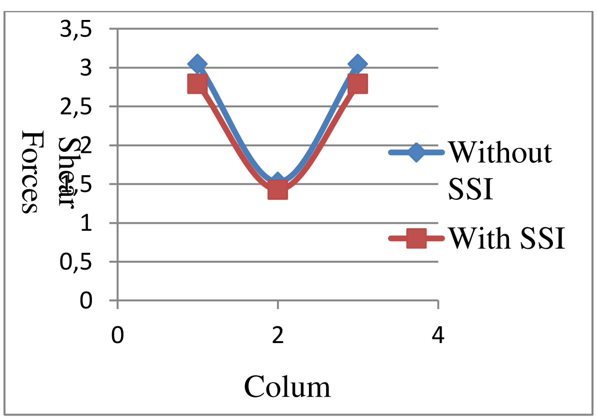



**Graph 5.10** Maximum SF in 2nd storey with and without soil structure interaction



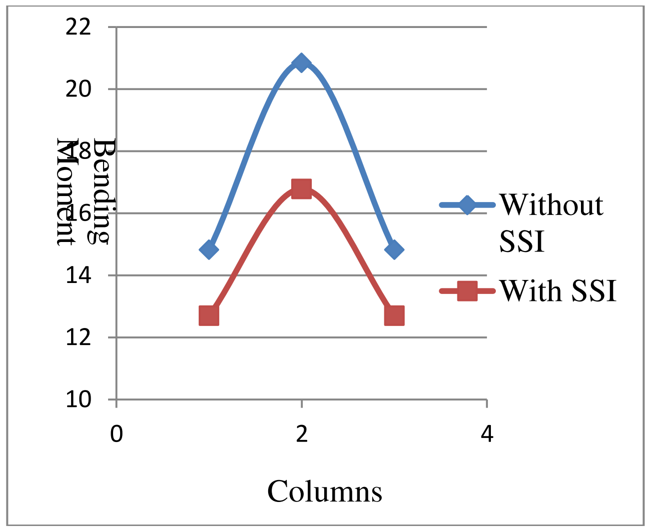

**Graph 5.11** Maximum SF in 1st storey with and without soil structure interaction



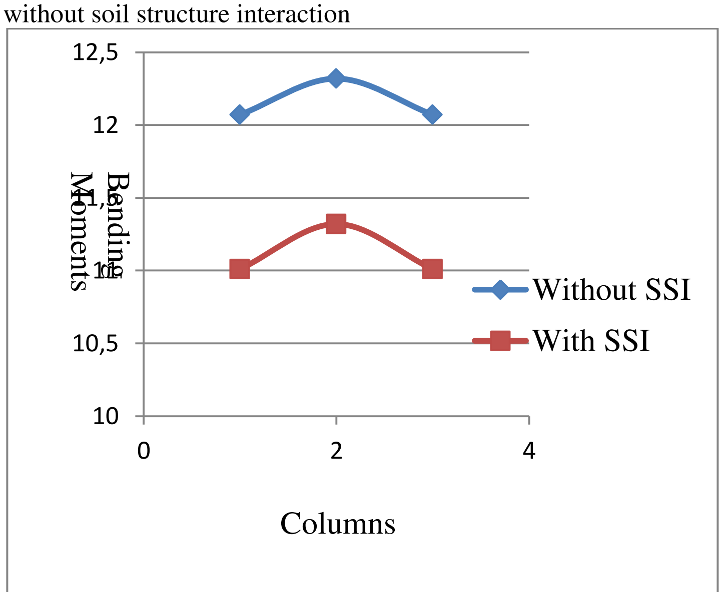

**Graph 5.12** Maximum SF in G.L with and without soil structure interaction

**Maximum Bending Moments:**

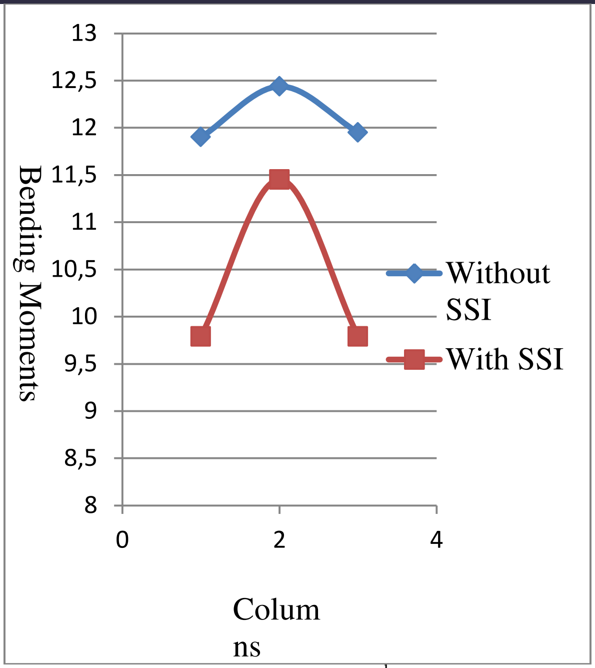
The maximum Bending Moment of 5 storeyed building for the cases of dead load, live load multiplied with safety factor with soil structure interaction and without soil structure interaction for each storey is presented in table below. The results are taken only for extreme loading conditions and static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



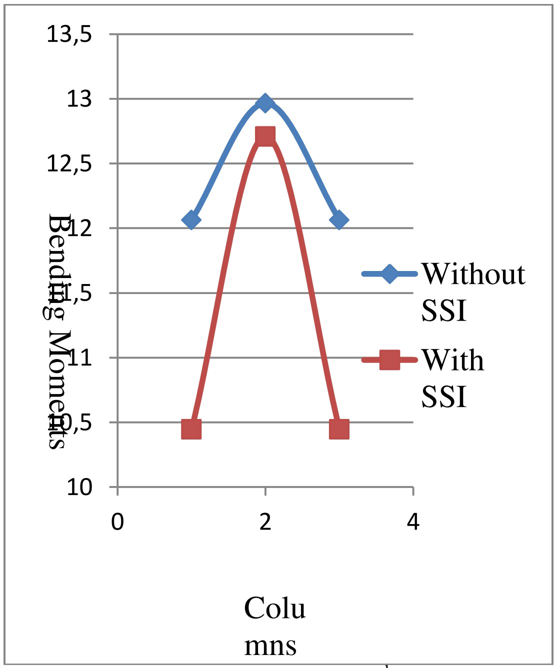

Graph 5.13 Maximum BM in 5th storey with and without soil structure interaction



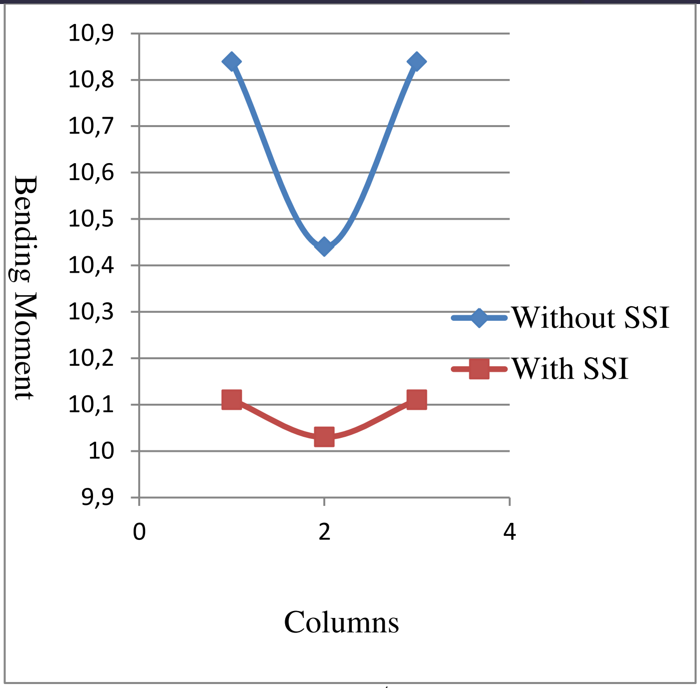

Graph 5.14 Maximum BM in 4th storey with and without soil structure interaction



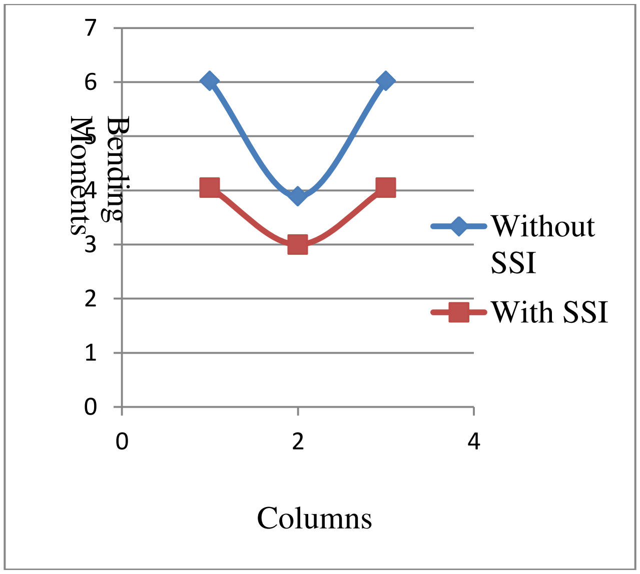

**Graph 5.15** Maximum BM in 3rd storey with and without soil structure interaction




**Graph 5.16** Maximum BM in 2nd storey with and without soil structure interaction




**Graph 5.17** Maximum BM in 1st storey with and without soil structure interaction




**Graph 5.18** Maximum BM in G.L with and without soil structure interaction

## 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 less shear forces as compared with analysis of structure without soil structure interaction.
3. Analysis of structure with soil structure interaction shows more or less Bending moments as compared with analysis of structure without soil structure interaction.
4. Analysis of structure with soil structure interaction shows avg of 38% increase in displacements compared with analysis of structure without soil structure interaction.
5. Analysis of structure with soil structure interaction shows avg of 29.6% decrease in shear forces compared with analysis of structure without soil structure interaction.

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