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Effect of Soil Structural Interaction on Multi-Storey Building with Raft Foundation

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ABSTRACT:
Most of the foundations of an any structure is contact with soil. i.e. interaction between substructure of the building and soil. In this paper addresses the behavior of multi-storey structure considering soil structure interaction Forth is purpose a sample of 4 storey RC frame is analyzed in conventional method with incremental static analysis for various load combinations and determine the parameters displacement, shear force and bending moment. Then a same 4 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 from conventional method of analysis to numerical method of analysis.

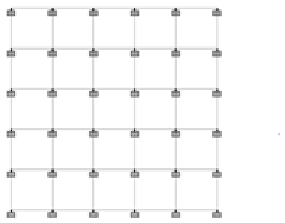
Keywords:
Soil Structure interaction, Conventional Method of Analysis, Numerical Method of Analysis, Displacement, Shear Force, Bending Moment.

Introduction:
Most of the civil engineering structures involve some type of structural element with direct contact with ground.

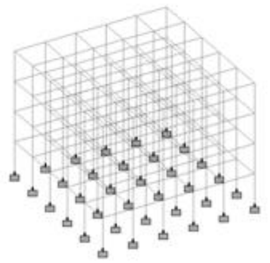
When the external forces, such as earthquakes, act on these systems, neither the structural displacements nor the ground displacements, are independent of each other. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as soil-structure interaction (SSI) 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.

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 modeling a prototype structure and those are results are compared with conventional design methods so as to ensure the safety of structure.

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



Plan view of the structure



Isometric view of the structure

Model data of the Structure:

Structural Properties	
Structure	OMRF
No of Storeys	4
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	27.38×10^6 KN/m^2
Density of Reinforcement Concrete	25 KN/m^3
Modulus of Elasticity of brick masonry	3.50×10^6 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	Kadapa
Zone	III
Response Reduction Factor	3
Structure type	RC Framed building
Damping Ratio	5%
Soil Properties	
Type of soil	Medium dense sand
Soil Bearing Capacity	150 KN/m^2
Stiffness	4800-16000 Kg/m^2
Codes	
RCC Design	IS 456:2000
Seismic Design	IS 1893 Part 4

Calculations of loads:

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.

Type of Section	No	Length (m)	Breadth (m)	Height (m)	Density KN/m^3	Load	Weight KN
Slab	1	15	15	0.125	25	1	705
Beam							
1) P Beams in X direction	5	15	0.45	0.23	25	1	195
2) P Beams in Y direction	5	15	0.45	0.23	25	1	195
Columns	36	0.45	0.45	2.55	25	1	464.73
External wall	1	60	0.23	2.55	20	1	703.8
Internal wall	1	120	0.115	2.55	20	1	704
Parapet wall	1	60	0.23	1	20	1	276
Live Load	1	15	15	1	1	2	450
Floor Finishes	1	15	15	1	1	1.5	338

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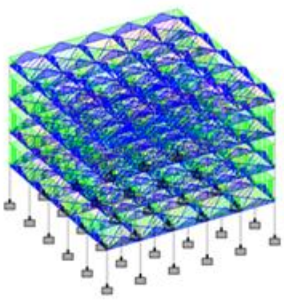
Design lateral loads at each floor:

Level	W_i (KN)	h_i (m)	$(W_i h_i^2/\Sigma W_i h_i^2)$	Lateral Force (KN)
4th Floor	1210	15	0.422	508.00
3rd Floor	1210	12	0.307	371.41
2nd Floor	1210	9	0.173	209.33
1st Floor	1210	6	0.076	91.00
Ground Level	1210	3	0.0192	23.00

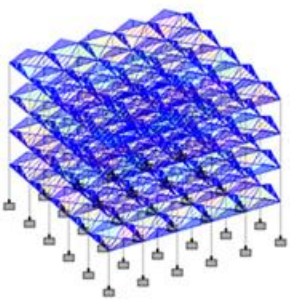
Load Combinations:

The load combinations given in the analysis according to relevant IS codes of practice (IS 1893-2002 and IS 875 Part III-1987)

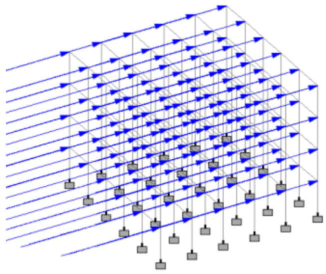
1.5(DL ± LL)	1.5(DL ± ELx)
1.5(DL ± WLx)	1.5(DL ± ELz)
1.5(DL ± WLz)	0.9 DL ± 1.5 ELx
0.9 DL ± 1.5 WLx	0.9 DL ± 1.5ELz
0.9 DL ± 1.5WLz	1.2 (DL+LL± ELx)
1.2 (DL+LL± WLx)	1.2 (DL+LL± ELZ)
1.2 (DL+LL± WLZ)	



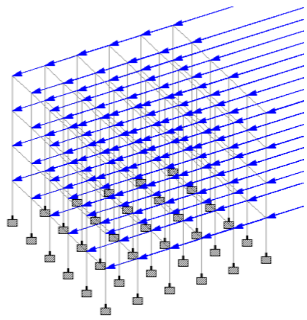
Dead Load Diagram



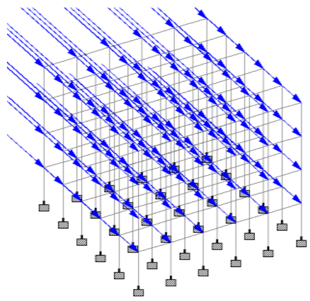
Live load Diagram



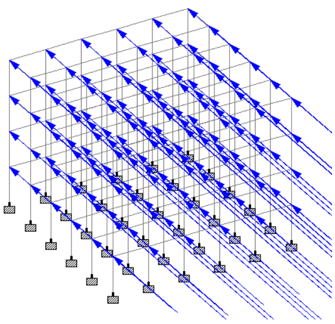
Earthquake Load in X Direction



Earthquake Load in -X Direction



Earthquake Load in Z Direction



Earthquake Load in -Z Direction

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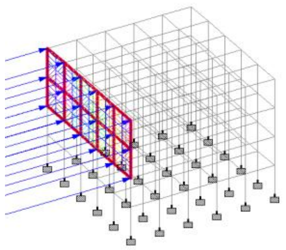
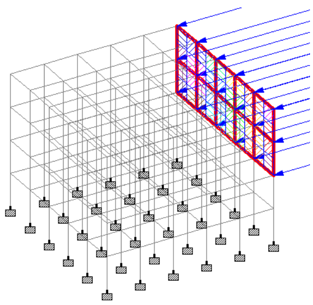
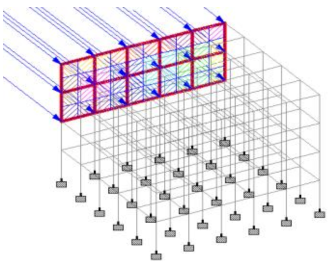


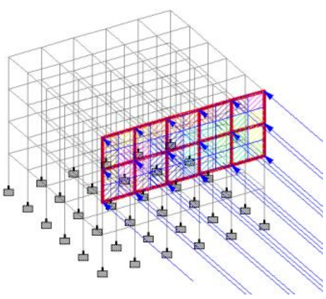
Wind Load in X Direction



Wind Load in -X Direction



Wind Load in Z Direction



Wind Load in -Z Direction

NUMERICAL ANALYSIS USING FINITE ELEMENT METHOD:

The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations.

It uses subdivision of a whole problem domain into simpler parts, called finite elements, and variation methods.

Structural Design of Raft Foundation:

This foundation will be done for storage of 4 storey building. The raft will be used for economical consideration.

The raft foundation is a kind of combined footing that covers the entire area under the structure supporting several columns in one rigid body. The soil bearing capacity is 150kN/m^2

Objective:

The design of raft foundation is based on Indian code. There are different methods used to design raft foundation. But the method used in this project is “Conventional Rigid Method”.

Design parameters:

Yield strength of steel (f_y)=415N/mm^2

Grade of concrete (f_{ck})=M_{30}

Young’s modulus of concrete (E) =2x10^{16}N/mm^2

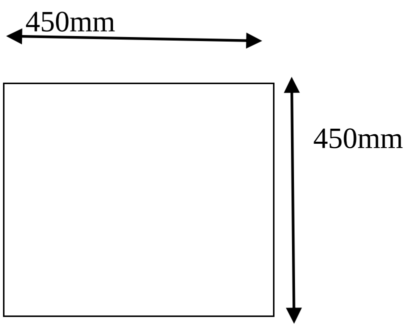
Raft dimensions:

The raft has X side spacing of 3 meters and Y side spacing of 3 meters edge is round the edges of columns.

Area of raft = 15m x 15m = 225m^2

Column dimensions and Reinforcement

All columns have dimensions of 450mm x 450mm with 16mm Ø



Why raft should be used:

Raft foundation is designed only where there is loose soil or soft soil.

Soil type = Medium dense sand

SBC (q) = 150kN/m^2

Maximum service load = 670kN

Area of single square footing = (1.5 x 670)/150 = 6.7 Sqmts.

This area is considered to be very big to be excavated under one column. So the raft foundation will be much efficient and more economical for this building.

Thickness of raft foundation:

Maximum shear stress in concrete

J_c = 1.36 N/mm^2

For corner C1 column

Perimeter b = 2(d/2 + 450)

B = d+900

Designed shear stress $J_c = V_u$ / bd = 1.5 x 510 x 510 / (d+900)d

1.36 = 390150 / d^2 +900d

1.36d^2 + 1224d – 390150 = 0

d = 250mm

For column C9

Perimeter b = 2(d / 2 +450)

B = d + 900

$J_c = V_u$ / bd = 1.5 x 670 x 670 / (d + 900)d

1.36 = 673350 / (d^2 +900d)

1.36d^2 + 1224d – 673350 = 0

d = 385mm

Adopt thickness of raft = 400mm

Soil pressure check:

Eccentrically at Y direction obtained taking moments of column loads about grid 1-1.

Y=

$$\frac{3(510+620+625+625+620+510)+6(620+670+670+670+670+620)+9(620+670+670+670+670+625)+12(625+670+670+670+670+625)+15(510+620+625+625+620+510)}{Total\ column\ load\ 22720}$$

Y = 7.4313

$$?? = \frac{3(620+670+670+670+670+620)+6(625+620+670+670+670+625)+9(625+670+670+670+670+625)+12(620+670+670+670+670+625)+15(510+620+625+625+620+510)}{22720}$$

X = 7.4894

Eccentricity X = e_x = 7.48,Y = e_y=7.43

Soil pressure check:

Q1 = P/A ± $M_Y / I_Y \pm M_X / I_X$

I_X = 15 x 15^3 / 2 = 4218.75mm^4

I_Y = 15 x 15^3 / 2 = 4218.75mm^4

Q = 22720 / 225

Q = 100.9kN/m^2< 150kN/m^2 safe

Modeling in ANSYS:

Elements used in Modeling of structure:

BEAM4 Element:

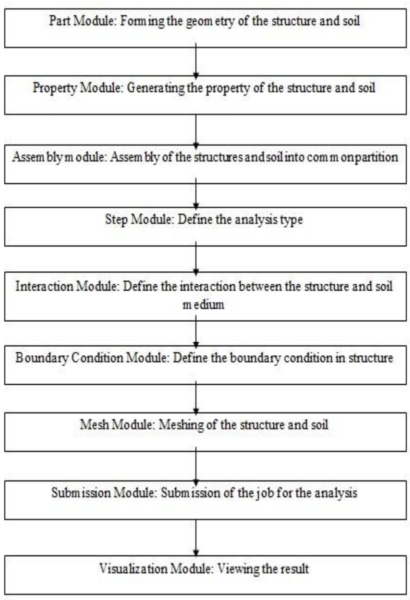
BEAM4 Real constants:

SHELL63 Element:

SHELL63 Real constants:

COMBIN14 Element:

Step by step procedure for modeling structure in ANSYS:



Columns layout in ANSYS

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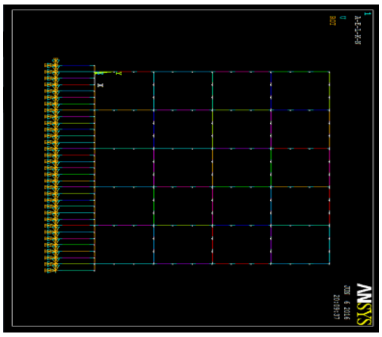
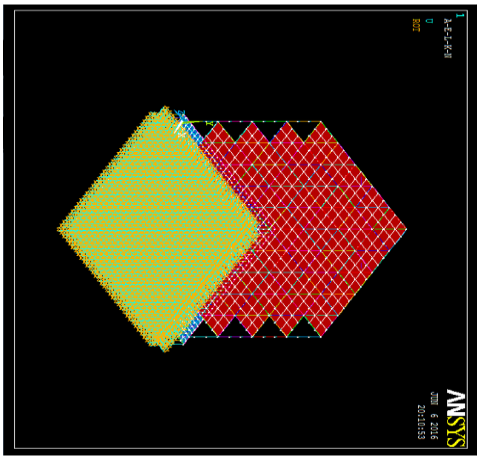
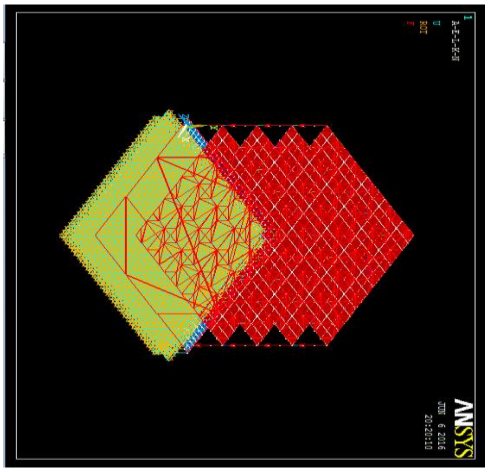


Elevation of the Structure



Isometric view of Structure



Loads acting on the Structure

RESULTS AND DISCUSSIONS:

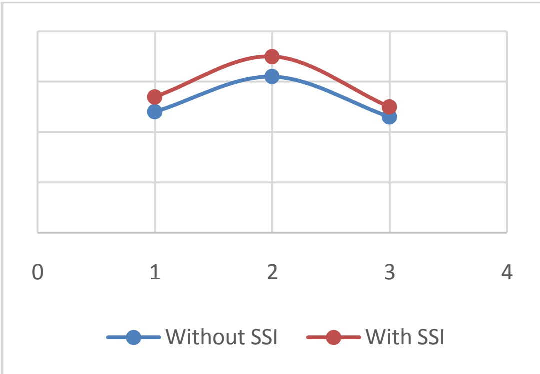
Graphs for Column Results:

Graphs are plotted between the results of with soil structure interaction and without soil structure interaction for displacements, shear force and bending moment in columns for ground floor, first floor, second floor, third floor.

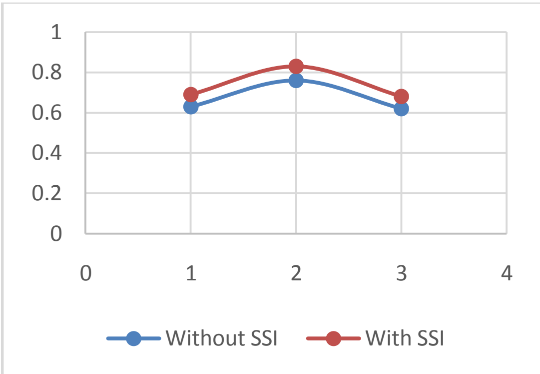
X axis: Column numbers

Y axis: obtained results for displacements, shear force and bending moment respectively

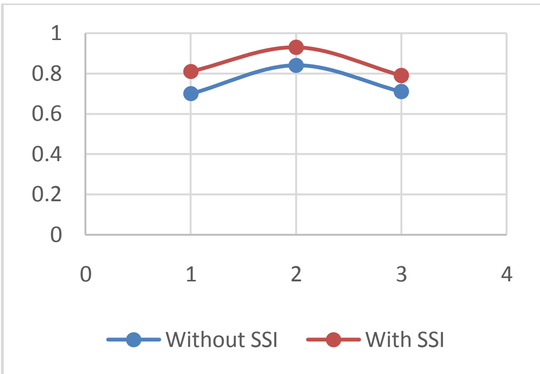
Graphs for Displacements in Columns



Max displacements in 1st floor



Max displacements in 2nd floor



Max displacements in 3rd floor

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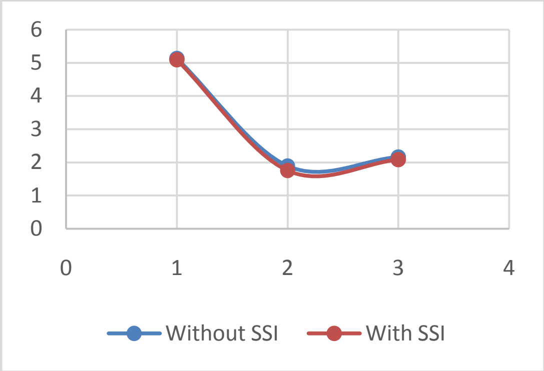
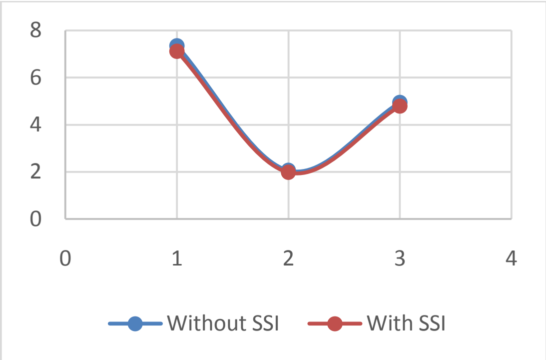
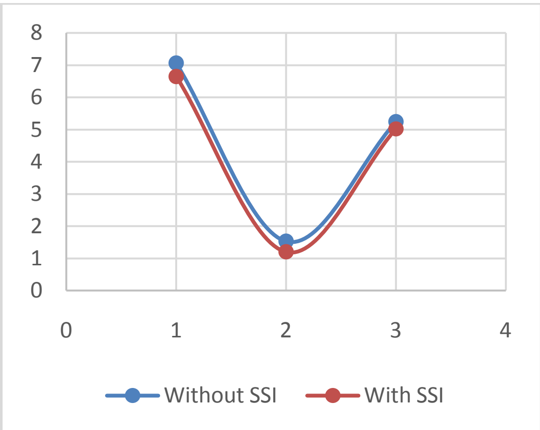
Graphs for Shear Force in Columns



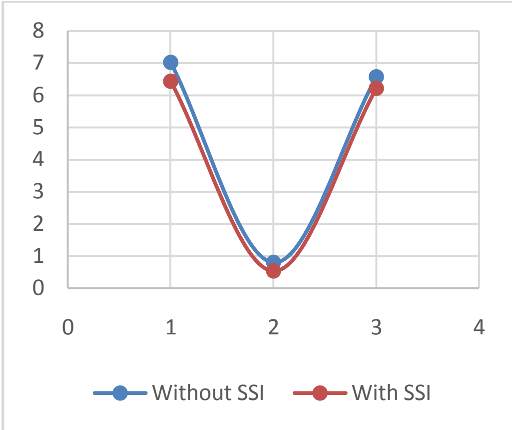
Max S.F in G.F



Max S.F in 1st floor

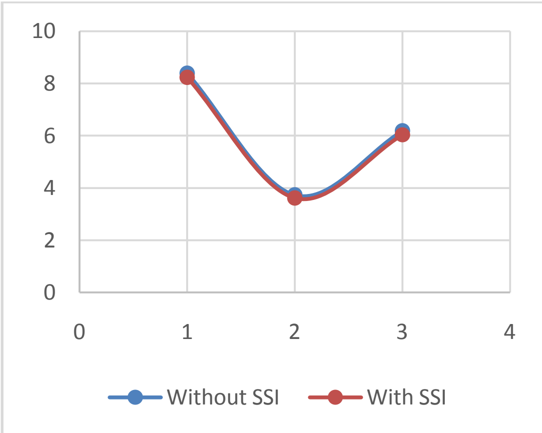


Max S.F in 2nd floor

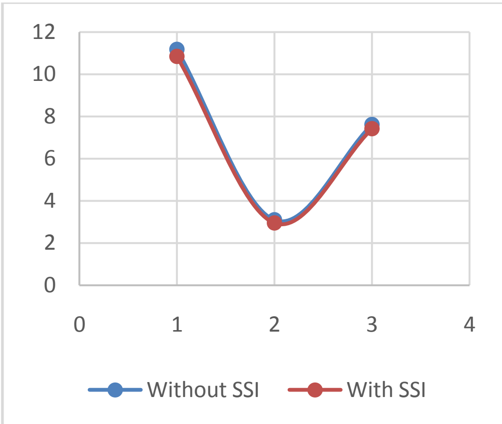


Max S.F in 3rd floor

Graphs for Bending Moment in Columns



Max B.M in G.F



Max B.M in 1st floor

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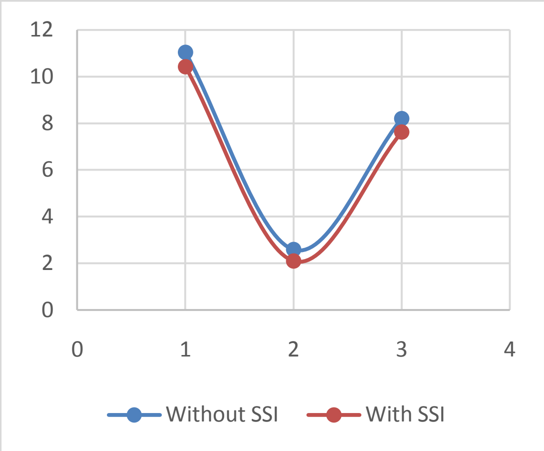
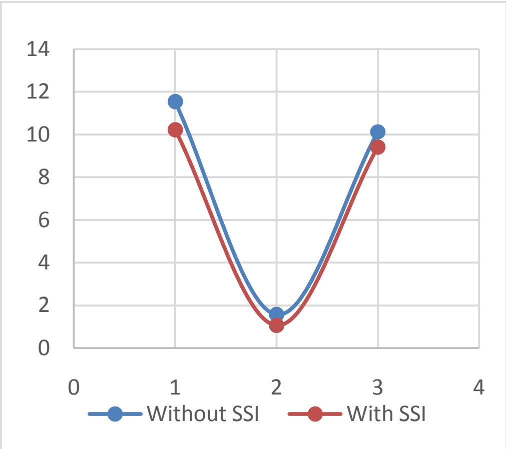


Max B.M in 2nd floor



Max B.M in 3rd floor

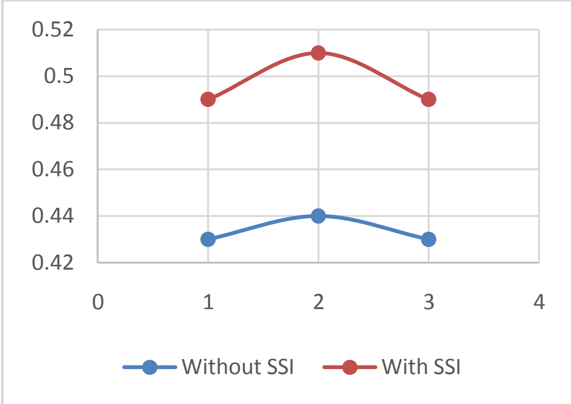
Graphs for Beam Results:

Graphs are plotted between the results of with soil structure interaction and without soil structure interaction for displacements, shear force and bending moment in beams for ground floor, first floor, second floor, third floor.

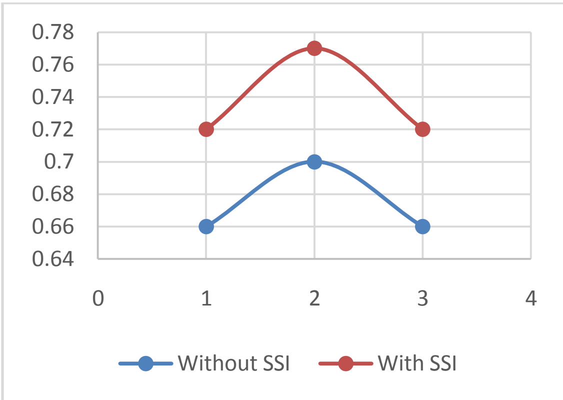
X axis: Beam numbers

Y axis: obtained results for displacements, shear force and bending moment respectively

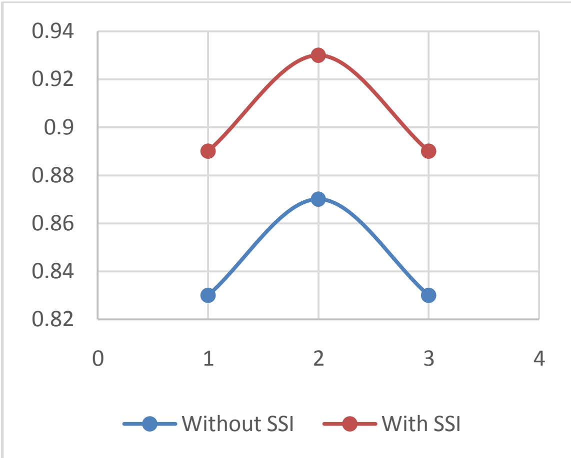
Graphs for Displacements in Beams



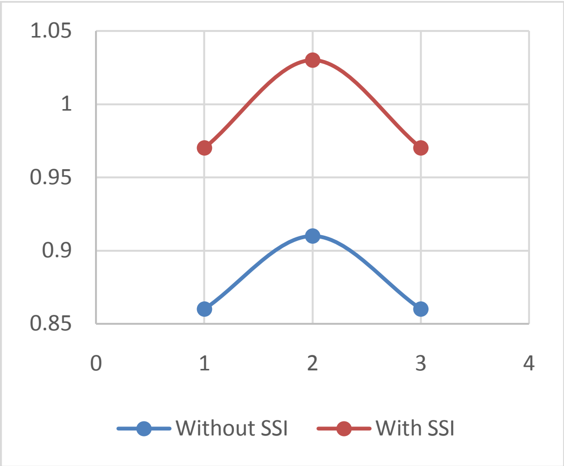
Max displacements in G.F



Max displacements in 1st floor



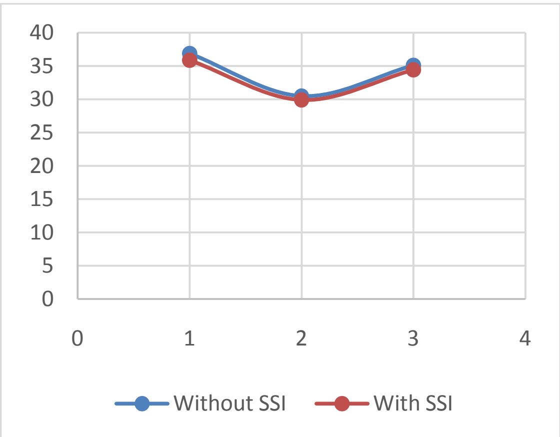
Max displacements in 2nd floor



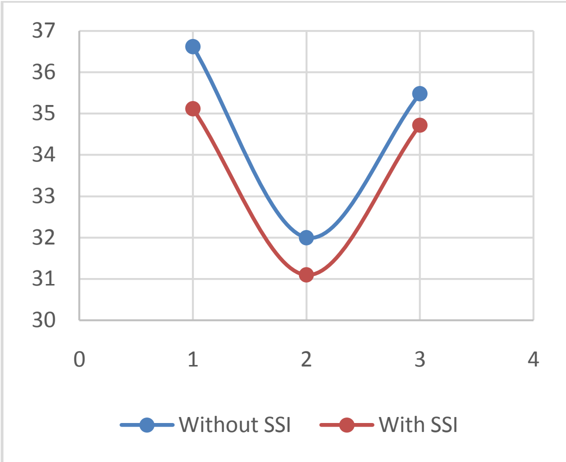
Max displacements in 3rd floor

Graphs for Shear Force in Beams:

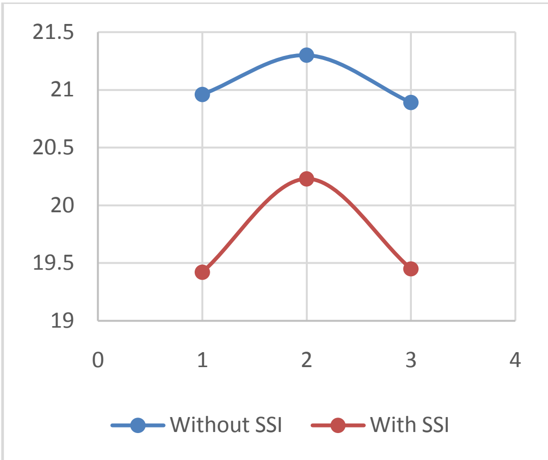
Max S.F in G.F



Max S.F in 1st floor

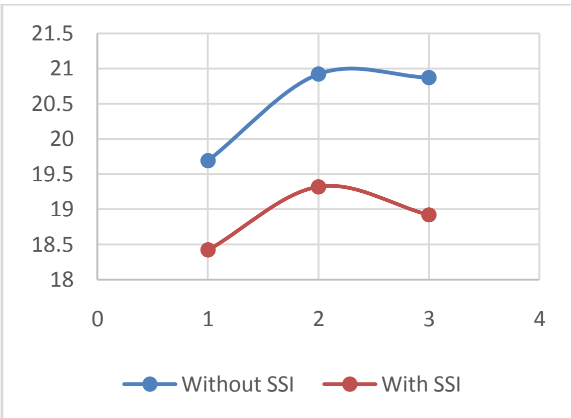


Max S.F in 2nd floor



Max S.F in 3rd floor

Graphs for Bending Moment in Beams



Max B.M in G.F

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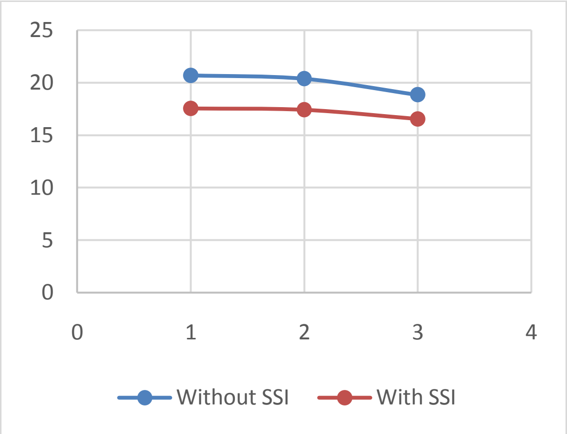
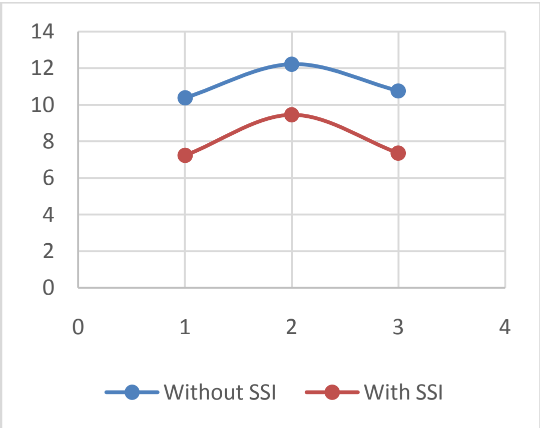
Max B.M in 1st floor



Max B.M in 2nd floor



Max B.M in 3rd floor

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 less Bending moments as compared with analysis of structure without soil structure interaction.
4. Analysis of structure with soil structure interaction shows avg of 32% increase in displacements compared with analysis of structure without soil structure interaction.

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