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PARAMETRIC STUDY OF SOIL-STRUCTURE INTERACTION ON G+6 AND G+16 STOREY BUILDING FOR DIFFERENT SOIL CONDITION

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Abstract — *The paper presents the effect of Soil-Structure Interaction on a six and a sixteen storey building loaded as per IS 1893 and IS 456. Here the comparison of various forces, Storey Drift, Storey Displacement, Change in steel are compared for six storey building subjected to seismic force and supported on different types of soil condition. E.g. Fixed, Soft, Medium and Hard. Soil modeling is done by using stiffness of soil in 6 direction spring given by gazetas. (FEMA 356 The analysis of building is done using the analysis software STAAD Pro.*

Keywords- *Soil-Structure Interaction; Building Analysis; Support Condition; Staad Pro; Static Analysis; Dynamic analysis.*

I INTRODUCTION

Analysis of G+6 and G+16 storey building by varying different parameters are carried out in Staad Pro. The frame of model is rectangular in plan as well as in elevation. In this Staad model earthquake parameters like importance factor, response reduction factor and zone factor are kept constant and only soil type is changed. All the beams, slabs and column properties are kept same and geometry of building is also kept same. The structure is analyzed and designed as per IS 456. In this model the earthquake forces are automatically generated and results are matched with manual analysis and they are found satisfactory. The members which are found unsafe in different soil condition are identified as critical members. The properties of these critical members are changed and the structure is then reanalyzed. A comparison of forces, storey drift, storey displacement, quantity of steel and time period on different soil type are made.

In this paper, first of all, building is supported on fixed base. Then the soil mass is modeled using spring support using gazetas equation (FEMA 356) for multi-dimensional spring for different stiffness (eg. Soft, Medium and Hard) using different values of E and µ. Fixed but support is used to incorporate the spring stiffness in model. The G+6 building is analyzed with 4.0x4.0 and 5.0x5.0 using foundation plate. Then G+16 storey building is analyzed considering mat foundation. Results for G+6 storey building, (footing size 4.0x4.0), are directly taken for comparison with footing size (5.0x5.0). It has been earlier presented. Ref. No.6.

II. OBJECTIVE OF WORK

- To carry out parametric study to compare and study changes in storey displacement, storey drift, changes in steel, forces, moment and mode shape.
- To study the effect of stiffness on different parameters.

III. GEOMETRIC DEFINATION

3.1. Problem Statement

A G+6 storey building has been taken for a commercial complex. Design the building for seismic loads as per IS 1893 (Part 1): 2002.Table No.1.

Table 3.1: Design Data for Building

Live load	4.0 kN/m² at typical floor
	1.5 kN/m² on terrace
Floor finish	1.0 kN/m²
Water proofing	2.0 kN/m²
Terrace finish	1.0 kN/m²
Earthquake load	As per IS 1893 (Part 1): 2002.
Depth of foundation	2.5 m
Zone type	2
Storey height	Typical floor: 5 m, GF: 3.4 m
Floors	GF+ 5 upper floors.
Ground beams G.L.	To be provided at 100 mm below
Plinth level	0.6 m
Walls	230 mm thick brick wall masonry walls only at periphery.

3.2. Soil Modeling:

In present study, out of different methods of soil modeling study has been carried out by considering spring model using gazetas equation given in FEMA 356. The equations are given below.

In RC building with shallow foundation, the flexible foundation effect is incorporated with the help of six soil springs, whose stiffness's are calculated by Eq. 1.These soil springs represent the stiffness of soil in three translational directions and three rotational directions. Kx, Ky, Kz are translational soil stiffness's in kN/m in x,y and z directions respectively. K_{xx}, K_{yy}, K_{zz} are rotational spring stiffness's in kN-m/rad about x, y and z directions respectively.

$Ki = ki_{sur} \times \beta i$ (1)

Where, i = x, y, z, xx, yy and zz;

$Ki_{,sur}$ is stiffness of foundation at surface and β_i is correction factor for embedment, which can be calculated from the formulas given in Tables.

Table 3.2: Spring Constraints at Ground Surface for Rigid Footing

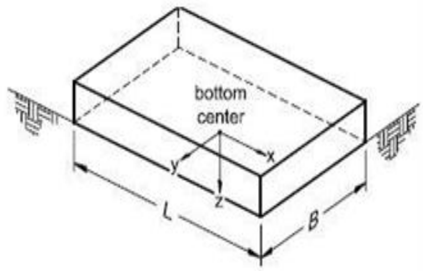
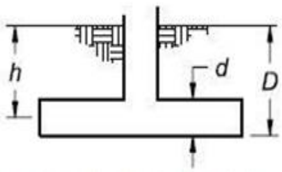
Degree of Freedom	Stiffness of Foundation at Surface	Note
Translation along x-axis	$K_{x,sur} = \frac{GB}{2-v}\left[3.4\left(\frac{L}{B}\right)^{0.65}+1.2\right]$	
Translation along y-axis	$K_{y,sur} = \frac{GB}{2-v}\left[3.4\left(\frac{L}{B}\right)^{0.65}+0.4\frac{L}{B}+0.8\right]$	
Translation along z-axis	$K_{z,sur} = \frac{GB}{1-v}\left[1.55\left(\frac{L}{B}\right)^{0.75}+0.8\right]$	
Rocking about x-axis	$K_{xx,sur} = \frac{GB^3}{1-v}\left[0.4\left(\frac{L}{B}\right)+0.1\right]$	
Rocking about y-axis	$K_{yy,sur} = \frac{GB^3}{1-v}\left[0.47\left(\frac{L}{B}\right)^{2.4}+0.034\right]$	Orient axes such that $L \geq B$
Torsion about z-axis	$K_{zz,sur} = GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45}+0.51\right]$	

Table 3.3: Correction Factor for Spring Constraints Due to Embedment Effect for Rigid Footing

Degree of Freedom	Correction Factor for Embedment	Note
Translation along x-axis	$\beta_x = \left(1+0.21\sqrt{\frac{D}{B}}\right)\cdot\left[1+1.6\left(\frac{hd(B+L)}{BL^2}\right)^{0.4}\right]$	
Translation along y-axis	$\beta_y = \beta_x$	
Translation along z-axis	$\beta_z = \left[1+\frac{1}{21}\frac{D}{B}\left(2+2.6\frac{B}{L}\right)\right]\cdot\left[1+0.32\left(\frac{d(B+L)}{BL}\right)^{2/3}\right]$	d = height of effective sidewall contact (may be less than total foundation height)
Rocking about x-axis	$\beta_{xx} = 1+2.5\frac{d}{B}\left[1+\frac{2d}{B}\left(\frac{d}{D}\right)^{-0.2}\sqrt{\frac{B}{L}}\right]$	h = depth to centroid of effective sidewall contact
Rocking about y-axis	$\beta_{yy} = 1+1.4\left(\frac{d}{L}\right)^{0.6}\left[1.5+3.7\left(\frac{d}{L}\right)^{1.9}\left(\frac{d}{D}\right)^{-0.6}\right]$	For each degree of freedom, calculate
Torsion about z-axis	$\beta_{zz} = 1+2.6\left(1+\frac{B}{L}\right)\left(\frac{d}{B}\right)^{0.9}$	$K_{emb} = \beta K_{sur}$

To compute the soil-spring stiffness, the effective shear modulus, Poisson's ratio and dimensions of Foundation are required. The foundations are designed as per code provisions by obtaining the design forces from Staad.

In present study to calculate stiffness for above formulae following data is used.

L=4, 5, 25.5m, B=4, 5, 25.5m, D = 1.5, d=0.75, h=1.125 and the shear modulus is calculated.

Table 3.4: Spring stiffness for various soils for (4.0x4.0), (5.0x5.0)and(25.5x25.5) foundation size

Spring Stiffness for (4.0x4.0) Size Footing											
Soil E (M.Pa.)	Soft 15	Med. 35	Hard 75	Soil E (M.Pa.)	Soft 15	Med. 35	Hard 75	Soil E (M.Pa.)	Soft 15	Med. 35	Hard 75
Kx,sur	6.39E+04	1.49E+05	3.19E+05	Bx	1.86	1.86	1.86	Kx,emb	1.19E+05	2.78E+05	5.95E+05
Ky	6.39E+04	1.49E+05	3.19E+05	By	1.86	1.86	1.86	Ky	1.19E+05	2.78E+05	5.95E+05
Kz	7.34E+04	1.71E+05	3.67E+05	Bz	1.26	1.26	1.26	Kz	9.27E+04	2.16E+05	4.63E+05
Kxx	2.50E+05	5.83E+05	1.25E+06	Bxx	1.67	1.67	1.67	Kxx	4.18E+05	9.75E+05	2.09E+06
Kyy	2.52E+05	5.88E+05	1.26E+06	Byy	1.89	1.89	1.89	Kyy	4.76E+05	1.11E+06	2.38E+06
Kzz	4.16E+05	9.71E+05	2.08E+06	Bzz	2.15	2.15	2.15	Kzz	8.96E+05	2.09E+06	4.48E+06
Spring Stiffness for (5.0x5.0) Size Footing											
Soil E (M.Pa.)	Soft 15	Med. 35	Hard 75	Soil E (M.Pa.)	Soft 15	Med. 35	Hard 75	Soil E (M.Pa.)	Soft 15	Med. 35	Hard 75
Kx,sur	7.99E+04	1.86E+05	3.99E+05	Bx	1.72	1.72	1.72	Kx,emb	1.38E+05	3.21E+05	6.88E+05
Ky	7.99E+04	1.86E+05	3.99E+05	By	1.72	1.72	1.72	Ky	1.38E+05	3.21E+05	6.88E+05
Kz	9.18E+04	2.14E+05	4.59E+05	Bz	1.22	1.22	1.22	Kz	1.12E+05	2.61E+05	5.59E+05
Kxx	4.88E+05	1.14E+06	2.44E+06	Bxx	1.50	1.50	1.50	Kxx	7.34E+05	1.71E+06	3.67E+06
Kyy	4.92E+05	1.15E+06	2.46E+06	Byy	1.74	1.74	1.74	Kyy	8.57E+05	2.00E+06	4.28E+06
Kzz	8.13E+05	1.90E+06	4.06E+06	Bzz	1.94	1.94	1.94	Kzz	1.58E+06	3.68E+06	7.89E+06
Spring Stiffness for (25.5x25.5) Size Mat Footing											
Soil E (M.Pa.)	Soft 15	Med. 35	Hard 75	Soil E (M.Pa.)	Soft 15	Med. 35	Hard 75	Soil E (M.Pa.)	Soft 15	Med. 35	Hard 75
Kx,sur	4.07E+05	9.50E+05	2.04E+06	Bx	1.21	1.21	1.21	Kx,emb	4.91E+05	1.15E+06	2.46E+06
Ky	4.07E+05	9.50E+05	2.04E+06	By	1.21	1.21	1.21	Ky	4.91E+05	1.15E+06	2.46E+06
Kz	4.68E+05	1.09E+06	2.34E+06	Bz	1.06	1.06	1.06	Kz	4.97E+05	1.16E+06	2.49E+06
Kxx	6.48E+07	1.51E+08	3.24E+08	Bxx	1.08	1.08	1.08	Kxx	6.99E+07	1.63E+08	3.49E+08
Kyy	6.53E+07	1.52E+08	3.26E+08	Byy	1.25	1.25	1.25	Kyy	8.19E+07	1.91E+08	4.09E+08
Kzz	1.08E+08	2.51E+08	5.39E+08	Bzz	1.22	1.22	1.22	Kzz	1.31E+08	3.06E+08	6.56E+08

IV. RESULTS AND DISCUSSIONS

4.1. Static Co-Efficient Method Analysis Results

4.1.1. Comparison of Displacement in Different Soil

Table 4.1: Comparison of Storey Displacement in Different soil (Static) (G+6)

Storey	Fixed Disp. (mm)	Soft Disp. (mm)	% Change in Disp.	Medium Disp. (mm)	% Change in Disp.	Hard Disp. (mm)	% Change in Disp.
6th	89.76	112.89	25.77	109.55	22.05	108.14	20.48
5th	81.55	102.14	25.24	99.35	21.82	98.17	20.37
4th	67.79	84.79	25.08	82.55	21.77	81.59	20.35
3rd	50.07	62.74	25.30	61.04	21.91	60.31	20.44
2nd	30.22	38.15	26.24	37.00	22.43	36.49	20.75
1st	10.60	13.85	30.68	13.23	24.81	12.94	22.12
G.F.	0.44	1.06	140.18	0.79	78.10	0.67	50.56

Table 4.2: Comparison of Storey Displacement in Different soil (Static) (G+16)

Storey	Fixed Disp. (mm)	Soft Disp. (mm)	% Change	Medium Disp. (mm)	% Change	Hard Disp. (mm)	% Change
16th	242.82	278.23	14.58	273.83	12.77	271.86	11.96
15th	237.05	271.50	14.53	267.20	12.72	265.27	11.91
14th	229.32	262.62	14.52	258.42	12.69	256.53	11.87
13th	219.28	251.21	14.56	247.11	12.69	245.26	11.85
12th	206.98	237.31	14.65	233.30	12.72	231.50	11.84
11th	192.61	221.13	14.81	217.22	12.78	215.46	11.86
10th	176.46	202.99	15.03	199.18	12.87	197.46	11.90
9th	158.80	183.20	15.36	179.48	13.02	177.81	11.97
8th	139.95	162.08	15.82	158.46	13.23	156.83	12.07
7th	120.16	139.95	16.46	136.43	13.54	134.84	12.21
6th	99.75	117.11	17.41	113.70	13.98	112.15	12.43
5th	79.01	93.92	18.87	90.60	14.67	89.11	12.78
4th	58.36	70.80	21.31	67.60	15.83	66.15	13.36
3rd	38.41	48.41	26.04	45.34	18.05	43.96	14.46
2nd	20.26	27.93	37.88	25.03	23.55	23.74	17.17
1st	6.05	11.62	92.23	8.96	48.22	7.81	29.20
GF	0.26	4.47	1633.33	2.12	722.09	1.16	350.00

4.1.2. Comparison of Drift in Different Soil

Table 4.3: Comparison of Storey Drift in Different soil (Static)(G+6)

Storey	Fixed Drift (mm)	Soft Drift (mm)	% Change in Drift	Medium Drift (mm)	% Change in Drift	Hard Drift (mm)	% Change in Drift
6th	8.20	10.75	31.04	10.20	24.34	9.97	21.56
5th	13.77	17.35	26.05	16.81	22.09	16.58	20.45
4th	17.72	22.05	24.45	21.50	21.37	21.28	20.10
3rd	19.85	24.59	23.87	24.04	21.12	23.82	19.98
2nd	19.62	24.30	23.84	23.77	21.14	23.55	20.01
1st	10.16	12.79	25.90	12.44	22.48	12.28	20.88
G.F.	0.44	1.06	140.18	0.79	78.10	0.67	50.56

Table 4.45: Comparison of Storey Drift in Different soil (Static) (G+16)

Storey	Fixed Drift (mm)	Soft Drift (mm)	% Change	Medium Drift (mm)	% Change	Hard Drift (mm)	% Change
16th	5.78	6.73	16.46	6.63	14.78	6.59	14.05
15th	7.73	8.88	14.84	8.78	13.57	8.74	13.03
14th	10.03	11.41	13.72	11.31	12.76	11.27	12.33
13th	12.30	13.91	13.02	13.81	12.23	13.77	11.89
12th	14.37	16.18	12.59	16.08	11.91	16.04	11.62
11th	16.16	18.14	12.30	18.05	11.70	18.00	11.43
10th	17.65	19.79	12.10	19.69	11.54	19.65	11.31
9th	18.86	21.12	11.98	21.02	11.46	20.98	11.23
8th	19.78	22.13	11.88	22.03	11.38	21.99	11.17
7th	20.42	22.84	11.85	22.73	11.35	22.69	11.14
6th	20.74	23.20	11.86	23.09	11.36	23.04	11.13
5th	20.65	23.12	11.95	23.01	11.40	22.96	11.15
4th	19.95	22.39	12.20	22.26	11.55	22.19	11.22
3rd	18.15	20.48	12.84	20.31	11.92	20.23	11.44
2nd	14.21	16.31	14.75	16.07	13.05	15.92	12.05
1st	5.79	7.15	23.54	6.84	18.19	6.65	14.91
G.F.	0.26	0.54	110.85	0.44	69.38	0.37	43.41

4.1.3. Comparison of Total Steel in Different Soil

Table 4.5: Comparison of Total Steel in Different soil (Static)

Footing (m2)	Fixed	Soft Soil	% Change	Medium Soil	% Change	Hard Soil	% Change
5.0x5.0	603.17	659.90	9.41	649.07	7.61	644.20	6.80
25.5x25.5	1866.00	1971.05	5.63	1971.46	5.65	1969.12	5.53

4.2. Dynamic (Response Spectrum Method) Analysis Results:

4.2.1. Comparison of Displacement in Different Soil

Table 4.6: Comparison of Storey Displacement in Different soil (Dynamic) (G+6)

Storey	Fixed Disp. (mm)	Soft Disp. (mm)	% Change in Disp.	Medium Disp. (mm)	% Change in Disp.	Hard Disp. (mm)	% Change in Disp.
6th	61.94	129.64	109.29	102.30	65.15	74.25	19.86
5th	56.87	118.59	108.55	93.77	64.90	68.12	19.78
4th	48.51	101.04	108.30	79.97	64.86	58.10	19.78
3rd	37.20	77.65	108.75	61.42	65.10	44.60	19.91
2nd	23.38	49.28	110.80	38.82	66.05	28.13	20.32
1st	8.69	19.12	119.89	14.79	70.08	10.61	22.06
G.F.	0.52	1.99	281.96	1.22	133.78	0.77	47.22

Table 4.7: Comparison of Storey Displacement in Different soil (Dynamic) (G+16)

Storey	Fixed Disp. (mm)	Soft Disp. (mm)	% Change	Medium Disp. (mm)	% Change	Hard Disp. (mm)	% Change
16th	193.82	378.59	95.34	245.10	26.46	198.59	2.46
15th	190.06	371.13	95.27	240.28	26.42	194.88	2.53
14th	185.01	361.25	95.26	233.85	26.40	189.92	2.65
13th	178.37	348.47	95.36	225.48	26.41	183.44	2.84
12th	170.12	332.72	95.58	215.14	26.46	174.44	2.54
11th	160.32	314.06	95.89	202.89	26.55	163.94	2.26
10th	149.05	292.65	96.34	188.81	26.67	153.03	2.67
9th	136.38	268.69	97.01	173.03	26.87	139.80	2.51
8th	122.44	242.35	97.93	155.69	27.15	125.35	2.38
7th	107.33	213.79	99.20	136.88	27.54	109.77	2.27
6th	91.11	183.22	101.10	116.73	28.12	93.13	2.22
5th	73.95	150.89	104.06	95.42	29.04	75.61	2.25
4th	56.12	117.31	109.03	73.28	30.57	57.43	2.33
3rd	38.09	83.39	118.90	50.89	33.61	39.06	2.55
2nd	20.79	50.90	144.88	29.40	41.45	21.40	2.94
1st	6.42	23.77	270.12	11.36	76.91	6.56	2.09
GF	0.28	11.57	4004.26	3.30	1069.50	0.29	2.84

4.2.2. Comparison of Drift in Different Soil:

Table 4.8: Comparison of Storey Drift in Different soil (Dynamic) (G+6)

Storey	Fixed Drift (mm)	Soft Drift (mm)	% Change in Drift	Medium Drift (mm)	% Change in Drift	Hard Drift (mm)	% Change in Drift
EQX	5.08	11.05	117.59	8.53	67.97	6.13	20.74
EQX	8.36	17.56	109.96	13.81	65.15	10.02	19.81
EQX	11.31	23.39	106.84	18.55	64.07	13.50	19.36
EQX	13.82	28.37	105.27	22.60	63.50	16.48	19.21
EQX	14.68	30.16	105.42	24.03	63.66	17.52	19.29
EQX	8.17	17.13	109.56	13.57	66.02	9.84	20.46
EQX	0.52	1.99	281.96	1.22	133.78	0.77	47.22

Table 4.9: Comparison of Storey Drift in Different soil (Dynamic) (G+16)

Storey	Fixed Drift (mm)	Soft Drift (mm)	% Change	Medium Drift (mm)	% Change	Hard Drift (mm)	% Change
16th	3.75	7.46	98.75	4.82	28.49	3.71	-1.20
15th	5.05	9.88	95.59	6.43	27.27	4.96	-1.78
14th	6.64	12.78	92.54	8.37	26.07	6.47	-2.47
13th	8.25	15.75	90.90	10.34	25.33	9.01	9.15
12th	9.80	18.66	90.47	12.26	25.10	10.49	7.10
11th	11.28	21.41	89.87	14.08	24.87	10.92	-3.20
10th	12.67	23.96	89.15	15.77	24.53	13.23	4.44
9th	13.94	26.34	89.00	17.34	24.44	14.45	3.65
8th	15.12	28.56	88.89	18.81	24.41	15.59	3.11
7th	16.22	30.58	88.51	20.15	24.24	16.63	2.54
6th	17.16	32.32	88.36	21.31	24.17	17.53	2.13
5th	17.83	33.59	88.41	22.15	24.23	18.18	1.99
4th	18.03	33.92	88.16	22.38	24.15	18.36	1.86
3rd	17.31	32.48	87.70	21.49	24.18	17.66	2.07
2nd	14.36	27.13	88.88	18.04	25.60	14.84	3.33
1st	6.14	12.20	98.65	8.07	31.33	6.27	2.05
GF	0.28	0.91	223.76	0.52	84.04	-0.69	-343.26

4.2.3. Comparison of Total Steel in Different Soil

Table 4.10: Comparison of Total Steel in Different soil (Dynamic)

Footing Size (m2)	Fixed	Soft Soil	% Change	Medium Soil	% Change	Hard Soil	% Change
5.0x5.0	504.78	862.64	70.89	749.58	48.50	570.99	13.12
25.5x25.5	1769.32	2470.99	39.66	1943.85	9.86	1777.96	0.49

4.2.4. Comparison of Axial Force in Different Soil

Table 4.11: Comparison of Axial Force (Fx) in Different soil (Dynamic) (G+6)

		Fixed Base	Soft Soil	% Change	Medium Soil	% Change	Hard Soil	% Change
Column	L/C	Fx (kN)	Fx (kN)		Fx (kN)		Fx (kN)	
6th	RX	19	38	95	31	59	23	17
5th	RX	55	108	96	88	59	65	18
4th	RX	104	202	95	165	59	122	18
3rd	RX	159	306	93	252	59	187	17
2nd	RX	217	416	92	344	58	255	17
1st	RX	270	514	91	426	58	316	17
G.F.	RX	290	549	90	457	58	340	17

Table 4.12: Comparison of Axial Force (Fx) in Different soil (Dynamic) (G+16)

		Fixed Base	Soft Soil	% Change	Medium Soil	% Change	Hard Soil	% Change
Column	L/C	Fx (kN)	Fx (kN)		Fx (kN)		Fx (kN)	
16 th	RX	24	52	114	32	32	24	0
15th	RX	56	120	113	74	32	56	0
14th	RX	96	202	110	125	30	95	-1
13th	RX	141	289	106	181	29	138	-2
12th	RX	190	381	100	241	27	185	-3
11th	RX	244	479	96	307	26	236	-3
10th	RX	304	586	93	379	25	292	-4
9th	RX	368	703	91	458	24	353	-4
8th	RX	437	829	90	542	24	419	-4
7th	RX	510	963	89	631	24	488	-4
6th	RX	586	1104	88	724	23	560	-4
5th	RX	665	1250	88	820	23	635	-5
4th	RX	745	1398	88	918	23	711	-5
3rd	RX	824	1543	87	1014	23	785	-5
2nd	RX	894	1673	87	1099	23	852	-5
1st	RX	942	1764	87	1159	23	898	-5
G.F.	RX	952	1789	88	1174	23	908	-5

4.2.5. Comparison of Time Period in Different Soil

Table 4.13: Comparison of Time Period in Different soil (Dynamic) (G+6)

Time Period (seconds)							
Mode	Fixed Base	Soft Soil	% Change	Medium Soil	% Change	Hard Soil	% Change
1.00	2.80	2.85	1.79	2.82	0.89	2.81	0.50
2.00	2.26	2.33	3.19	2.29	1.51	2.27	0.80
3.00	1.82	1.86	2.25	1.84	1.15	1.83	0.60
4.00	0.88	0.89	0.80	0.88	0.46	0.88	0.23
5.00	0.71	0.71	0.99	0.71	0.57	0.71	0.28
6.00	0.57	0.58	1.05	0.57	0.53	0.57	0.35

Table 4.14: Comparison of Time Period in Different soil (Dynamic) (G+16)

Time Period (seconds)							
Mode	Fixed Base	Soft Soil	% Change	Medium Soil	% Change	Hard Soil	% Change
1.00	6.82	6.97	2.26	6.90	1.19	6.87	0.70
2.00	5.75	5.89	2.45	5.83	1.39	5.80	0.90
3.00	4.49	4.60	2.29	4.55	1.22	4.53	0.73
4.00	2.16	2.21	2.31	2.19	1.11	2.18	0.55
5.00	1.81	1.85	2.10	1.83	0.99	1.82	0.50
6.00	1.43	1.46	2.38	1.44	1.12	1.43	0.56
7.00	1.19	1.23	3.10	1.21	1.42	1.20	0.67
8.00	0.99	1.07	8.31	1.00	1.32	0.99	0.61
9.00	0.79	1.02	29.10	0.80	1.78	0.79	0.89
10.00	0.77	0.82	6.49	0.78	1.69	0.78	0.78
11.00	0.63	0.80	26.54	0.72	13.90	0.64	0.79
12.00	0.54	0.66	22.74	0.65	19.22	0.55	1.29
13.00	0.51	0.58	15.42	0.56	10.08	0.52	3.16
14.00	0.44	0.54	22.50	0.52	17.50	0.51	16.14
15.00	0.40	0.48	20.55	0.45	13.28	0.45	11.53
16.00	0.35	0.45	27.12	0.42	17.80	0.41	14.69

4.3. Comparison of static and Dynamic Analysis Results

4.3.1. Comparison of Displacement in Different Soil

Table 4.15: Comparison of Storey Displacement in Different soil (Static-Dynamic) (G+6)

Storey	Fixed			Soft			Medium			Hard		
	Disp. (mm)		% Change	Disp. (mm)		% Change	Disp. (mm)		% Chan	Disp. (mm)		% Chang
	St.	Dy.		St.	Dy.		St.	Dy.		St.	Dy.	
6th	90	62	-31	113	130	13	110	102	-7	108	74	-31
5th	82	57	-30	102	119	14	99	94	-6	98	68	-31
4th	68	49	-28	85	101	16	83	80	-3	82	58	-29
3rd	50	37	-26	63	78	19	61	61	1	60	45	-26
2nd	30	23	-23	38	49	23	37	39	5	36	28	-23
1st	11	9	-18	14	19	28	13	15	12	13	11	-18
G.F.	0	1	18	1	2	47	1	1	54	1	1	15
Supp.	0	0	0	0	1	46	0	0	48	0	0	8

Table 4.16: Comparison of Storey Displacement in Different soil (Static-Dynamic) (G+16)

Storey	Fixed			Soft			Medium			Hard		
	Disp. (mm)	Disp. (mm)	% Change	Disp. (mm)	Disp. (mm)	% Change	Disp. (mm)	Disp. (mm)	% Change	Disp. (mm)	Disp. (mm)	% Change
	St.	Dy.		St.	Dy.		St.	Dy.		St.	Dy.	
16th	243	194	-20	278	379	27	274	245	-10	272	199	-27
15th	237	190	-20	271	371	27	267	240	-10	265	195	-27
14th	229	185	-19	263	361	27	258	234	-10	257	190	-26
13th	219	178	-19	251	348	28	247	225	-9	245	183	-25
12th	207	170	-18	237	333	29	233	215	-8	231	174	-25
11th	193	160	-17	221	314	30	217	203	-7	215	164	-24
10th	176	149	-16	203	293	31	199	189	-5	197	153	-23
9th	159	136	-14	183	269	32	179	173	-4	178	140	-21
8th	140	122	-13	162	242	33	158	156	-2	157	125	-20
7th	120	107	-11	140	214	35	136	137	0	135	110	-19
6th	100	91	-9	117	183	36	114	117	3	112	93	-17
5th	79	74	-6	94	151	38	91	95	5	89	76	-15
4th	58	56	-4	71	117	40	68	73	8	66	57	-13
3rd	38	38	-1	48	83	42	45	51	12	44	39	-11
2nd	20	21	3	28	51	45	25	29	17	24	21	-10
1st	6	6	6	12	24	51	9	11	27	8	7	-16
GF	0	0	9	4	12	61	2	3	55	1	0	-75
Supp.	0	0	-	4	11	63	2	3	65	1	1	23

4.3.2. Comparison of Drift in Different Soil

Table 4.17: Comparison of Storey Drift in Different soil (Static-Dynamic)(G+6)

Storey	Fixed			Soft			Medium			Hard		
	Drift (mm)		%	Drift (mm)		%	Drift (mm)		%	Drift (mm)		%
	St.	Dy.	Change	St.	Dy.	Change	St.	Dy.	Chan	St.	Dy.	Chang
6th	8	5	-38	11	11	3	10	9	-16	10	6	-39
5th	14	8	-39	17	18	1	17	14	-18	17	10	-40
4th	18	11	-36	22	23	6	22	19	-14	21	13	-37
3rd	20	14	-30	25	28	15	24	23	-6	24	16	-31
2nd	20	15	-25	24	30	24	24	24	1	24	18	-26
1st	10	8	-20	13	17	34	12	14	9	12	10	-20
G.F.	0	1	18	1	1	88	1	1	56	1	1	16

Table 4.18: Comparison of Storey Drift in Different soil (Static-Dynamic) (G+16)

Storey	Fixed			Soft			Medium			Hard		
	Drift (mm)	Drift (mm)	% Change	Drift (mm)	Drift (mm)	% Change	Drift (mm)	Drift (mm)	% Change	Drift (mm)	Drift (mm)	% Change
	St.	Dy.		St.	Dy.		St.	Dy.		St.	Dy.	
16th	6	4	-35	7	7	11	7	5	-27	7	4	-44
15th	8	5	-35	9	10	11	9	6	-27	9	5	-43
14th	10	7	-34	11	13	12	11	8	-26	11	6	-43
13th	12	8	-33	14	16	13	14	10	-25	14	9	-35
12th	14	10	-32	16	19	15	16	12	-24	16	10	-35
11th	16	11	-30	18	21	18	18	14	-22	18	11	-39
10th	18	13	-28	20	24	21	20	16	-20	20	13	-33
9th	19	14	-26	21	26	25	21	17	-17	21	14	-31
8th	20	15	-24	22	29	29	22	19	-15	22	16	-29
7th	20	16	-21	23	31	34	23	20	-11	23	17	-27
6th	21	17	-17	23	32	39	23	21	-8	23	18	-24
5th	21	18	-14	23	34	45	23	22	-4	23	18	-21
4th	20	18	-10	22	34	52	22	22	1	22	18	-17
3rd	18	17	-5	20	32	59	20	21	6	20	18	-13
2nd	14	14	1	16	27	66	16	18	12	16	15	-7
1st	6	6	6	7	12	71	7	8	18	7	6	-6
GF	0	0	9	1	1	68	0	1	19	0	-1	-285

4.3.3. Comparison of Total Steel in Different Soil

Table 4.19: Comparison of Total Steel in Different soil (Static-Dynamic)(G+6)

Footing (m2)	Fixed Support			Soft Soil			Medium Soil			Hard Soil		
	Steel (T)		% Change	Steel (T)		% Change	Steel (T)		% Change	Steel (T)		% Change
	St.	Dy.		St.	Dy.		St.	Dy.		St.	Dy.	
4x4	603	505	-16.31	647	839	29.73	636	713	12.00	632	547	-13.52
5x5	603	505	-16.31	660	863	30.72	649	750	15.48	644	571	-11.36
25.5x25.5	1866	1769	-5	1971	2471	25	1971	1944	-1	1969	1778	-10

4.4. Graphical Representation of Different results

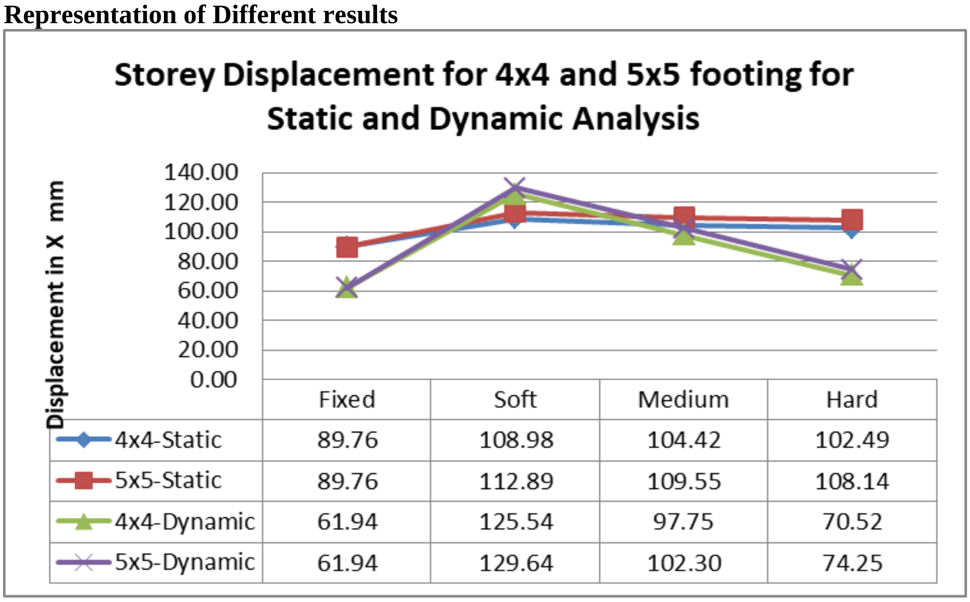
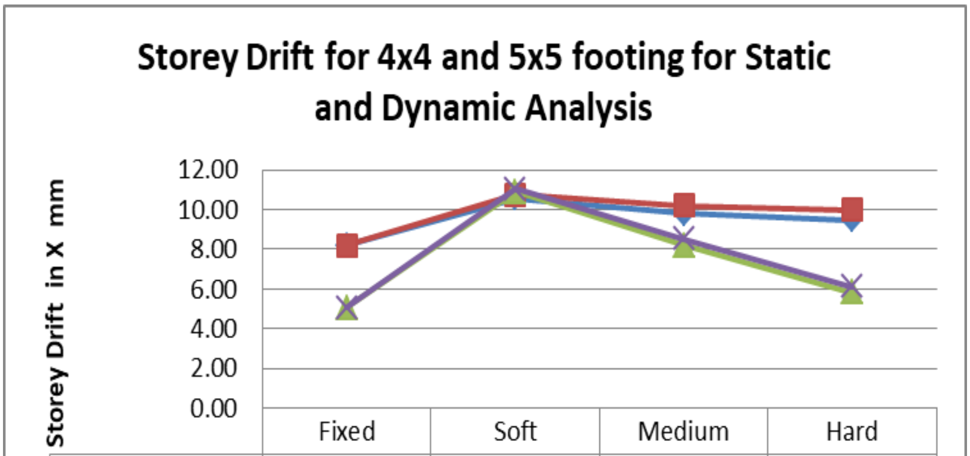
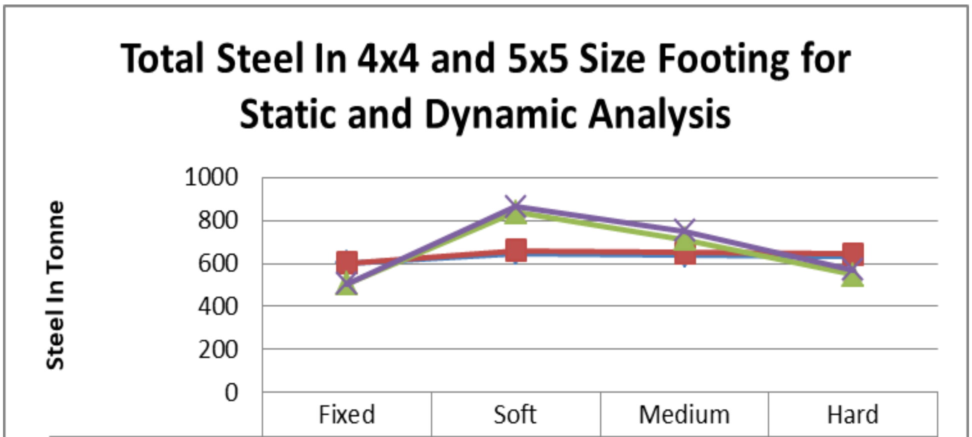


Fig. 4.1 Displacement in Static and Dynamic Analysis for Different Soil (G+6)



	Fixed	Soft	Medium	Hard
4x4-Static	8.20	10.56	9.81	9.49
5x5-Static	8.20	10.75	10.20	9.97
4x4-Dynamic	5.08	10.88	8.21	5.85
5x5-Dynamic	5.08	11.05	8.53	6.13

Fig. 4.2 Storey Drift in Static and Dynamic Analysis for Different Soil (G+6)



	Fixed	Soft	Medium	Hard
4x4-Static	603	647	636	632
5x5-Static	603	660	649	644
4x4-Dynamic	505	839	713	547
5x5-Dynamic	505	863	750	571

Fig. 4.3 Total Steel in Static and Dynamic Analysis for Different Soil (G+6)

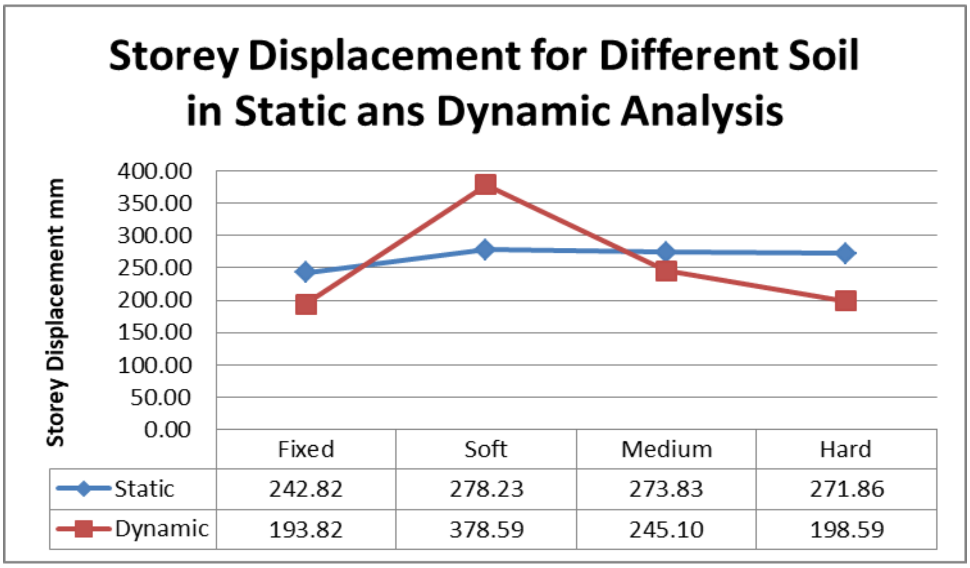


Fig. 4.4 Displacement in Static and Dynamic Analysis for Different Soil (G+6)

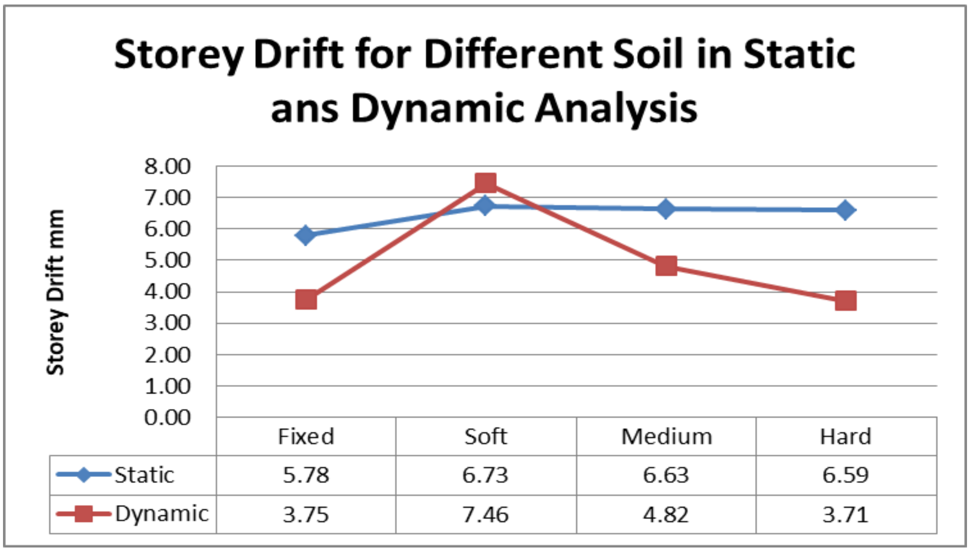


Fig. 4.5 Storey Drift in Static and Dynamic Analysis for Different Soil (G+16)

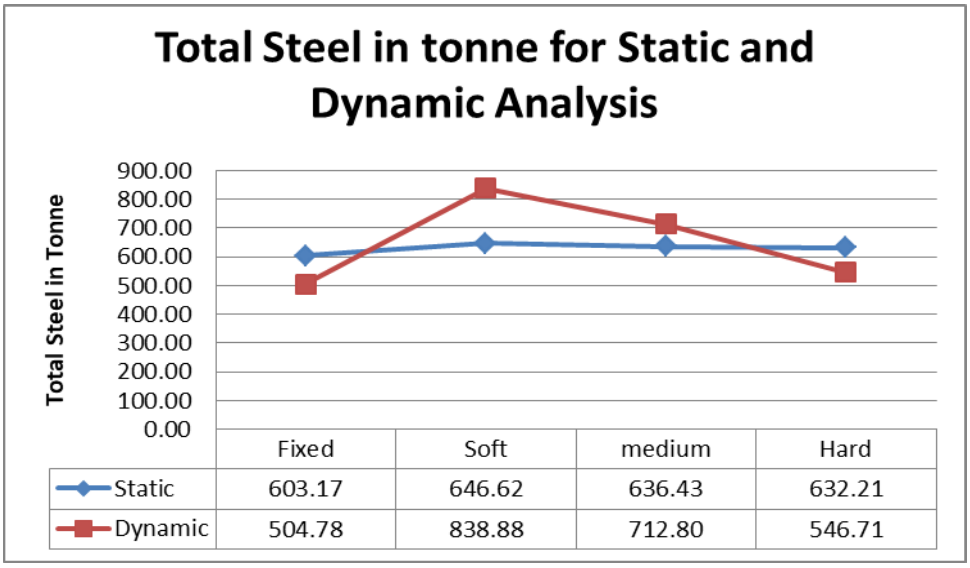


Fig. 4.6 Total Steel in Static and Dynamic Analysis for Different Soil (G+16)

V. CONCLUSIONS

5.1. Comparison of Different Results

5.1.1. Storey Displacement

Table 5.1: Variations of Storey Displacement for Different Size of Footing for Static and Dynamic Analysis in Different Soil (G+6)

% Variations in Storey Displacament at Top Storey					
Analysis Type	Footing Size (m2)	Fixed	Soft	Medium	Hard
Static	4.0x4.0	w.r.t	22	17	15
	5.0x5.0	w.r.t	26	22	20
Dynamic	4.0x4.0	w.r.t	103	58	14
	5.0x5.0	w.r.t	110	65	20
Static	4.0x4.0 and 5.0x5.0	w.r.t	3	5	6
Dynamic	4.0x4.0 and 5.0x5.0	w.r.t	3	5	6
Static and Dynamic	4.0x4.0	-30	13	-6	-31
Static and Dynamic	5.0x5.0	-30	13	7	-31

Table 5.2: Variations of Storey Displacement for Different Size of Footing for Static and Dynamic Analysis in Different Soil (G+16)

% Variations in Storey Displacament at Top Storey				
Analysis Type	Fixed	Soft	Medium	Hard
Static	w.r.t	15	13	12
Dynamic	w.r.t	95	27	3
Static and Dynamic	-20	26	-10	-26

5.1.1. Storey Drift

Table 5.3: Variations of Storey Drift for Different Size of Footing for Static and Dynamic Analysis in Different Soil (G+6)

% Variations in Storey Drift at Top Storey					
Analysis Type	Footing Size (m2)	Fixed	Soft	Medium	Hard
Static	4.0x4.0	w.r.t	30	10	10
	5.0x5.0	w.r.t	31	25	22
Dynamic	4.0x4.0	w.r.t	115	62	16
	5.0x5.0	w.r.t	118	68	21
Static	4.0x4.0 and 5.0x5.0	w.r.t	2	4	5
Dynamic	4.0x4.0 and 5.0x5.0	w.r.t	2	4	5
Static and Dynamic	4.0x4.0	-38	3	-16	-38
Static and Dynamic	5.0x5.0	-38	2	-16	-38

Table 5.4: Variations of Storey Drift for Different Size of Footing for Static and Dynamic Analysis in Different Soil (G+16)

% Variations in Storey Drift at Top Storey				
Analysis Type	Fixed	Soft	Medium	Hard
Static	w.r.t	16	15	14
Dynamic	w.r.t	99	30	1
Static and Dynamic	-35	11	-27	-45

5.1.1. Total Steel

Table 5.5: Variations of Storey Total Steel for Different Size of Footing for Static and Dynamic Analysis in Different Soil (G+6)

% Variations in Total Steel						
Analysis Type	Footing Size (m2)	Fixed	Soft	Medium	Hard
Static	4.0x4.0	w.r.t	7	5.5	4.8
	5.0x5.0	w.r.t	9.5	7.6	6.8
Dynamic	4.0x4.0	w.r.t	66	41	8.5
	5.0x5.0	w.r.t	71	49	13
Static	4.0x4.0 and 5.0x5.0	0	2	2	2
Dynamic	4.0x4.0 and 5.0x5.0	0	3	5	5
Static and Dynamic	4.0x4.0	-16	30	12	-13
Static and Dynamic	5.0x5.0	-16	30	16	-11

Table 5.6: Variations of Storey Total Steel for Different Size of Footing for Static and Dynamic Analysis in Different Soil (G+16)

% Variations in Total Steel				
Analysis Type	Fixed	Soft	Medium	Hard
Static	w.r.t	6	6	5
Dynamic	w.r.t	40	10	1
Static and Dynamic	-5	25	-1	-10

5.1.1. Forces and Moments

Table 5.7: **Variations of Forces and Moments for Different Size of Footing for Dynamic Analysis in Different Soil (G+6)**

% Variations in Forces and Moments in Dynamic(Response Spectrum) Analysis						
Footing Size		L/C	Fixed	Soft	Medium	Hard
4.0x4.0	Fx	RX	w.r.t	80	50	11
	Fx	DL+LL	w.r.t	8	4	2
5.0x5.0	Fx	RX	w.r.t	95	60	17
	Fx	DL+LL	w.r.t	7	3	2
4.0x4.0	Fy	RX	w.r.t	85	50	11
	Fy	DL+LL	w.r.t	35	20	9
5.0x5.0	Fy	RX	w.r.t	95	60	15
	Fy	DL+LL	w.r.t	25	15	5
4.0x4.0	Mx	RX	w.r.t	90	55	15
	Mx	DL+LL	w.r.t	0	0	0
5.0x5.0	Mx	RX	w.r.t	100	60	20
	Mx	DL+LL	w.r.t	0	0	0
4.0x4.0	Mz	RX	w.r.t	90	52	11
	Mz	DL+LL	w.r.t	30	18	9
5.0x5.0	Mz	RX	w.r.t	98	60	18
	Mz	DL+LL	w.r.t	25	12	7

Table 5.8: **Variations of Forces and Moments for Different Size of Footing for Dynamic Analysis in Different Soil (G+16)**

% Variations in Forces and Moments in Dynamic(Response Spectrum) Analysis					
	L/C	Fixed	Soft	Medium	Hard
Fx	RX	w.r.t	95	30	0
Fx	DL+LL	w.r.t	0	0	0
Fy	RX	w.r.t	95	30	2
Fy	DL+LL	w.r.t	0	0	0
Mx	RX	w.r.t	95	28	3
Mx	DL+LL	w.r.t	0	0	0
Mz	RX	w.r.t	95	30	2
Mz	DL+LL	w.r.t	0	0	0

5.1.1. Time Period

Table 5.9: Variations of Time Period in Different Soil (G+6)

Mode	% Variation in Time Period (s)		
	Soft	Medium	Hard
1.00	2.47	1.22	0.64
2.00	4.48	2.13	1.06
3.00	3.13	1.54	0.82
4.00	1.14	0.57	0.34
5.00	1.42	0.71	0.42
6.00	1.40	0.70	0.35

Table 5.10: Variations of Time Period in Different Soil (G+16)

Mode	% Variation in Time Period (s)		
	Soft	Medium	Hard
1.00	2.26	1.19	0.70
2.00	2.45	1.39	0.90
3.00	2.29	1.22	0.73
4.00	2.31	1.11	0.55
5.00	2.10	0.99	0.50
6.00	2.38	1.12	0.56
7.00	3.10	1.42	0.67
8.00	8.31	1.32	0.61
9.00	29.10	1.78	0.89
10.00	6.49	1.69	0.78
11.00	26.54	13.90	0.79
12.00	22.74	19.22	1.29
13.00	15.42	10.08	3.16
14.00	22.50	17.50	16.14
15.00	20.55	13.28	11.53
16.00	27.12	17.80	14.69

For G+6 storey building,

- Top storey displacement increases by 15 to 25 % as the soil varies from hard to soft when we use static co efficient method while it increases by 15 to 100% when response spectrum analysis is done.
- The response of the structure increases as the size of footing increases in both static and dynamic analysis.
- The response of the structure increases by @13% in soft soil when we consider response spectrum analysis as compared to static co efficient method where as it reduces for fixed base, hard and medium soil.
- Thus it is essential to carry out the response spectrum analysis when soft soil is encountered against static co efficient method.
- The storey drift is higher in structures founded on soft soil than on hard soils.
- The reinforcement requirement for soft soils is 7 to 10% higher than fixed base when static analysis is carried out and while it is 66-70% higher than fixed base when response spectrum analysis is carried out.
- The reinforcement required is about 30% higher in soft soil when response spectrum analysis is carried out as compared to static analysis.
- The axial force and moment increases by 60-80% in columns when softs soils are encountered.
- The time period of the structure increases as the soil changes from hard, medium to soft.

Soil structure interaction effect is severe in case of soft soil for both G+6 and G+16 storey building. It is important to analyse structure considering the effect of soil structure interaction. In case of very soft soil some other kinds of technique may be required (like use of pile-raft foundation or use of ground improvement techniques) to make structure safe.
In case of medium soil interaction effect gives most beneficial results. In the case of G+6 storey building supported on medium soil the results are more conservative. In the case of hard soil it can be concluded there is no need to do SSI analysis for hard soil.
By comparing the results of both G+6 and G+16 storey building it can be concluded that interaction effect will be more for high rise building. With increase in the height of the structure, weight of structure also increases and its behaviour also changes from building having low height.
It can be concluded that due to soil structure interaction in the structure time period increases.
For low rise buildings isolated footing is sufficient for medium and hard soil. For high rise building raft is required. In the case of isolated footing, because the contact area of footing and soil is less so SSI effect is also less. While, for raft foundation, contact area is more so SSI effect is also more.
So, by this whole study it can be concluded that consideration of SSI gives more realistic results.

REFERENCES

[1] Sekhar Chandra Dutta And Rana Roy”A Critical Review On Idealization Among Soil-Foundation-Structure System”, Computer and Structures, Bengal Engineering College, April 2002.
[2] Barnali Ghos And Zygmunt Lubkowski Modeling “Dynamic Soil Structure Interaction Under Seismic Loads”, Design of foundation in Seismic Areas:Principals and Applications, ISBN, 2004.
[3] Chandrashekhar.A,B.R. Jayalekshmi and Katta Venataramana “Dynamic Soil Structure Interaction Effects On multi storied RCC Frames”, Proceedings of the Internation Conference on Advances in Structural Dynamics and its Applica- tions, December, 2005.
[4] Daniel Thangaraj .D AND Ilamparuthi K, “Numerical Analysis Of Interaction Effects On Structure”, Raft and Soil System, IGEC, 2005.
[5] Daniel Thangaraj .D AND Ilamparuthi K, “Numerical Analysis Of Interaction Effects On Structure”, Raft and Soil System, IGEC, 2005.
[6] Nirav K Parmar AND Prof. Pareshkumar G Patel, “Parametric Study of Soil-Structure Interaction On G+6 and G+16 storey Building for different soil condition”, Volume 5, Issue 05, IJAERD, May -2018.
[7] IS: 1893-PartI-2002, Criteria for earthquake resistance design of structure, bureau of Indian Standards.
[8] IS: 456 (Part I)-2000 Code of Design Reinforcement, Bureau of Indian Standards.
[9] IITK-GSDMA-EQ-26 –V3.0.
[10] FEMA-256-NOV-2000-Prestandard and Complementary for the seismic rehabilitation of the building.

