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

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Abstract — *The paper presents the effect of Soil-Structure Interaction on a six 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- *Building analysis; support condition; parametric study; staad; seismic analysis*

I INTRODUCTION

Analysis of G+6 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 and quantity of steel 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.

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.

The design data is as follows:

Live load	: 4.0 kN/m^2 at typical floor
	: 1.5 kN/m^2 on terrace
Floor finish	: 1.0 kN/m^2
Water proofing	: 2.0 kN/m^2
Terrace finish	: 1.0 kN/m^2
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 1: Spring Constraints at Ground Surface for Rigid Footing

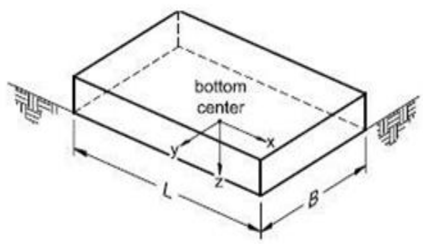
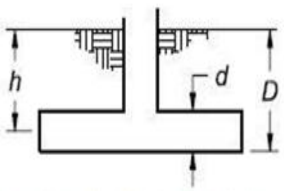
Degree of Freedom	Stiffness of Foundation at Surface	Note
Translation along x-axis	$K_{x,\,sur} = \frac{GB}{2-v}\left[3.4\left(\frac{L}{B}\right)^{0.65}+1.2\right]$	
Translation along y-axis	$K_{y,\,sur} = \frac{GB}{2-v}\left[3.4\left(\frac{L}{B}\right)^{0.65}+0.4\frac{L}{B}+0.8\right]$	
Translation 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 2: 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=4m, B=4m, D = 1.5, d=0.75, h=1.125 and the shear modulus is calculated.

Table 3: Spring stiffness for various soil

SOIL	SOFT	MEDIUM	HARD	SOIL	SOFT	MEDIUM	HARD	SOIL	SOFT	MEDIUM	HARD
E	15000.00	35000.00	75000.00	E	15000.00	35000.00	75000.00	E	15000.00	35000.00	75000.00
Kx,sur	63888.89	149074.07	319444.44	Bx	1.86	1.86	1.86	Kx,emb	119022.31	277718.73	595111.57
Ky	63888.89	149074.07	319444.44	By	1.86	1.86	1.86	Ky	119022.31	277718.73	595111.57
Kz	73437.50	171354.17	367187.50	Bz	1.26	1.26	1.26	Kz	92694.18	216286.43	463470.92
Kxx	250000.00	583333.33	1250000.00	Bxx	1.67	1.67	1.67	Kxx	417667.41	974557.29	2088337.04
Kyy	252000.00	588000.00	1260000.00	Byy	1.89	1.89	1.89	Kyy	475949.58	1110549.02	2379747.90
Kzz	416000.00	970666.67	2080000.00	Bzz	2.15	2.15	2.15	Kzz	895510.17	2089523.72	4477550.83

IV. RESULTS AND DISCUSSIONS

4.1. Static Co-Efficient Method Analysis Results
4.1.1. Comparison of Displacement in Different Soil

Table 4: Comparison of Storey Displacement in Different soil(Static)

	Fixed	Soft		Medium		Hard	
Storey	Disp. (mm)	Disp. (mm)	% Change In Disp.	Disp. (mm)	% Change In Disp.	Disp. (mm)	% Change In Disp.
6th	89.76	108.98	21.42	104.42	16.34	102.49	14.19
EQX							
5th	81.55	98.42	20.68	94.62	16.02	93.00	14.04
EQX							
4th	67.79	81.64	20.43	78.58	15.92	77.28	14.00
EQX							
3rd	50.07	60.43	20.68	58.12	16.07	57.13	14.10
EQX							
2nd	30.22	36.83	21.85	35.26	16.68	34.59	14.44
EQX							
1st	10.60	13.51	27.44	12.67	19.52	12.29	16.00
EQX							
G.F.	0.44	1.21	173.14	0.83	87.81	0.67	51.02
EQX							

4.1.2. Comparison of Drift in Different Soil

Table 5: Comparison of Storey Drift in Different soil(Static)

	Fixed	Soft	% Change In Drift	Medium	% Change In Drift	Hard	% Change In Drift
Storey	Drift (mm)	Drift (mm)		Drift (mm)		Drift (mm)	
6th							
EQX	8.20	10.56	28.74	9.81	19.54	9.49	15.72
5th							
EQX	13.77	16.78	21.92	16.04	16.48	15.72	14.22
4th							
EQX	17.72	21.21	19.72	20.46	15.51	20.15	13.74
3rd							
EQX	19.85	23.61	18.91	22.86	15.15	22.55	13.58
2nd							
EQX	19.62	23.32	18.83	22.60	15.14	22.29	13.59
1st							
EQX	10.16	12.30	21.08	11.84	16.54	11.63	14.48
G.F.							
EQX	0.44	1.21	173.14	0.83	87.81	0.67	51.02

4.1.3. Comparison of Total Steel in Different Soil

Table 7: Comparison of Total Steel in Different soil (Static)

Fixed	Soft Soil	% Change In Steel	Medium Soil	% Change In Steel	Hard Soil	% Change In Steel
603174.00	646623.00	7.20	636428.00	5.51	632208.00	4.81

4.2. Dynamic (Response Spectrum Method) Analysis Results:

4.2.1. Comparison of Displacement in Different Soil

Table 8: Comparison of Storey Displacement in Different soil(Dynamic)

	Fixed	Soft	% Change In Disp.	Medium	% Change In Disp.	Hard	% Change In Disp.
Storey	Disp. (mm)	Disp. (mm)		Disp. (mm)		Disp. (mm)	
6th	61.94	125.54	102.67	97.75	57.81	70.52	13.84
EQX							
5th	56.87	114.66	101.63	89.54	57.45	64.67	13.72
EQX							
4th	48.51	97.60	101.22	76.32	57.34	55.15	13.69
EQX							
3rd	37.20	75.02	101.68	58.62	57.59	42.34	13.82
EQX							
2nd	23.38	47.72	104.14	37.09	58.65	26.71	14.26
EQX							
1st	8.69	18.74	115.53	14.21	63.41	10.11	16.24
EQX							
G.F.	0.52	2.26	333.01	1.28	145.30	0.77	47.22
EQX							

4.2.2. Comparison of Drift In Different Soil:

Table 9: Comparison of Storey Drift in Different soil(Dynamic)

	Fixed	Soft		Medium		Hard	
Storey	Drift (mm)	Drift (mm)	% Change In Drift	Drift (mm)	% Change In Drift	Drift (mm)	% Change In Drift
6th							
EQX	5.08	10.88	114.34	8.21	61.82	5.85	15.15
5th							
EQX	8.36	17.05	103.97	13.22	58.09	9.52	13.90
4th							
EQX	11.31	22.58	99.73	17.70	56.54	12.81	13.27
3rd							
EQX	13.82	27.30	97.52	21.53	55.78	15.63	13.07
2nd							
EQX	14.68	28.99	97.40	22.88	55.84	16.61	13.09
1st							
EQX	8.17	16.48	101.66	12.93	58.19	9.34	14.27
G.F.							
EQX	0.52	2.26	333.01	1.28	145.30	0.77	47.22

4.2.3. Comparison of Total Steel in Different Soil

Table 10: Comparison of Total Steel in Different soil(Dynamic)

Fixed	Soft Soil	% Change In Steel	Medium Soil	% Change In Steel	Hard Soil	% Change In Steel
504784.00	838877.00	66.19	712803.00	41.21	546708.00	8.31

4.3. Comparison of static and Dynamic Analysis Results

4.3.1. Comparison of Displacement in Different Soil

Table 11: Comparison of Storey Displacement in Different soil (Static-Dynamic)

	Fixed			Soft			Medium			Hard		
Storey	Displacement (mm)	Displacement (mm)	% Change In Disp.	Displacement (mm)	Displacement (mm)	% Change In Disp.	Displacement (mm)	Displacement (mm)	% Change In Disp.	Displacement (mm)	Displacement (mm)	% Change In Disp.
	Static	Dynamic		Static	Dynamic		Static	Dynamic		Static	Dynamic	
6th	89.76	61.94	-30.99	108.98	125.54	13.19	104.42	97.75	-6.39	102.49	70.52	-31.20
EQX												
5th	81.55	56.87	-30.27	98.42	114.66	14.16	94.62	89.54	-5.37	93.00	64.67	-30.46
EQX												
4th	67.79	48.51	-28.45	81.64	97.60	16.36	78.58	76.32	-2.88	77.28	55.15	-28.64
EQX												
3rd	50.07	37.20	-25.71	60.43	75.02	19.45	58.12	58.62	0.86	57.13	42.34	-25.89
EQX												
2nd	30.22	23.38	-22.65	36.83	47.72	22.83	35.26	37.09	5.18	34.59	26.71	-22.77
EQX												
1st	10.60	8.69	-17.98	13.51	18.74	27.91	12.67	14.21	12.14	12.29	10.11	-17.81
EQX												
G.F.	0.44	0.52	17.61	1.21	2.26	46.37	0.83	1.28	53.61	0.67	0.77	14.65
EQX												

4.3.2. Comparison of Drift in Different Soil

Table 12: Comparison of Storey Drift in Different soil (Static-Dynamic)

	Fixed			Soft			Medium			Hard		
Storey	Drift (mm)	Drift (mm)	% Change In Drift	Drift (mm)	Drift (mm)	% Change In Drift	Drift (mm)	Drift (mm)	% Change In Drift	Drift (mm)	Drift (mm)	% Change In Drift
	Static	Dynamic		Static	Dynamic		Static	Dynamic		Static	Dynamic	
6th												
EQX	8.20	5.08	-38.11	10.56	10.88	3.04	9.81	8.21	-16.23	9.49	5.85	-38.42
5th												
EQX	13.77	8.36	-39.26	16.78	17.05	1.61	16.04	13.22	-17.57	15.72	9.52	-39.43
4th												
EQX	17.72	11.31	-36.17	21.21	22.58	6.48	20.46	17.70	-13.50	20.15	12.81	-36.43
3rd												
EQX	19.85	13.82	-30.38	23.61	27.30	15.65	22.86	21.53	-5.81	22.55	15.63	-30.68
2nd												
EQX	19.62	14.68	-25.17	23.32	28.99	24.30	22.60	22.88	1.27	22.29	16.61	-25.50
1st												
EQX	10.16	8.17	-19.53	12.30	16.48	34.03	11.84	12.93	9.23	11.63	9.34	-19.67
G.F.												
EQX	0.44	0.52	17.61	0.68	1.27	86.07	0.61	0.95	55.07	0.57	0.66	15.70

4.3.3. Comparison of Total Steel in Different Soil

Table 13: Comparison of Total Steel in Different soil(Static-Dynamic)

Steel kg	Steel kg	% Increase In Steel	Steel kg	Steel kg	% Increase In Steel	Steel kg	Steel kg	% Increase In Steel	Steel kg	Steel kg	% Increase In Steel
Static	Dynamic		Static	Dynamic		Static	Dynamic		Static	Dynamic	
603174.00	504784.00	-16.31	646623.00	838877.00	29.73	636428.00	712803.00	12.00	632208.00	546708.00	-13.52

4.4. Graphical Representation of Different results

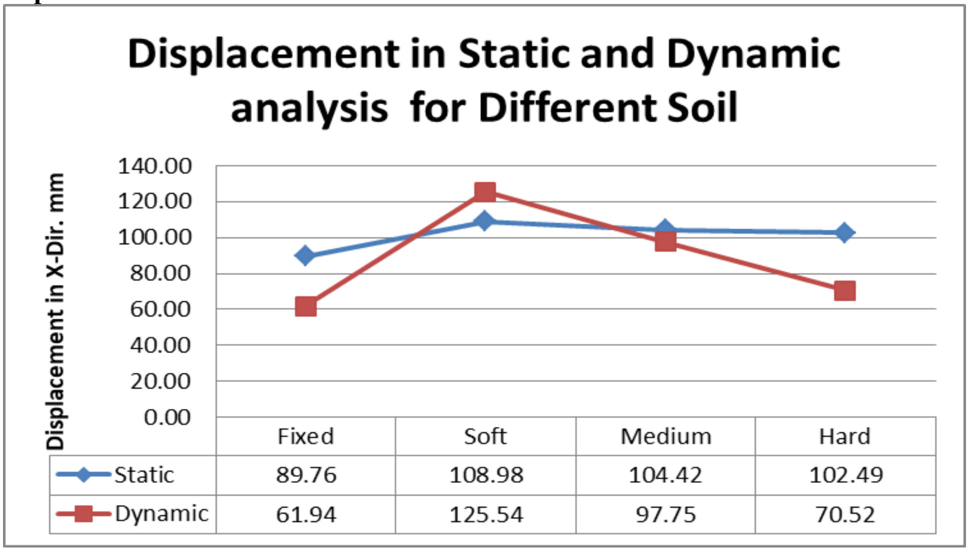


Fig. 1 Displacement in Static and Dynamic Analysis for Different Soil

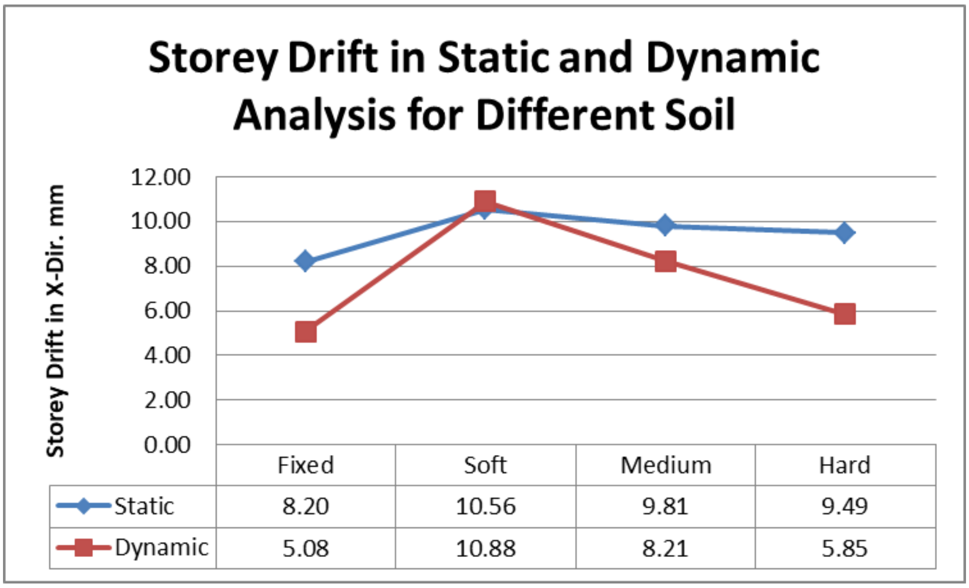


Fig. 2 Storey Drift in Static and Dynamic Analysis for Different Soil

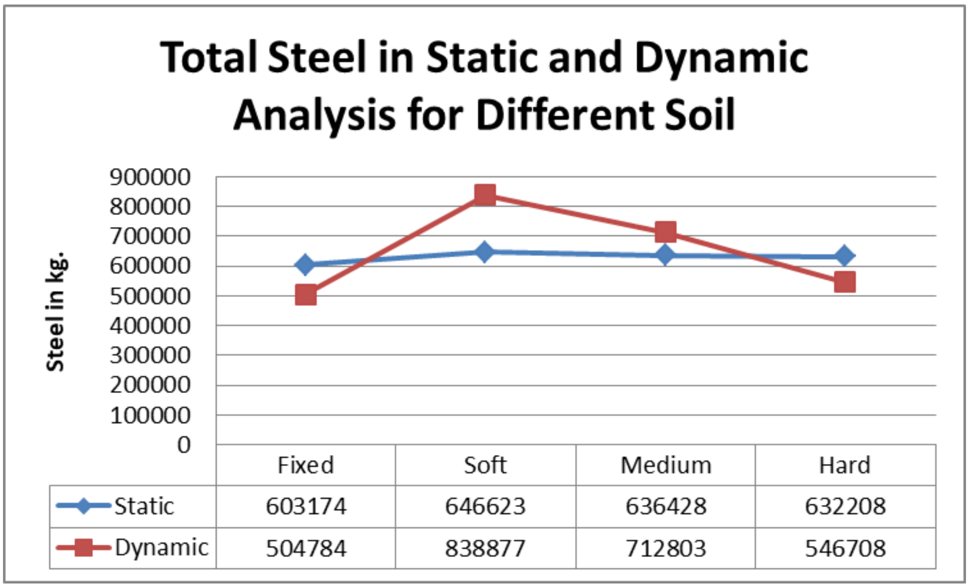


Fig. 3 Total Steel in Static and Dynamic Analysis for Different Soil

V. CONCLUSIONS

- The top storey displacement is about 21% higher in soft soil and gradually decreases to 16% and 14% in medium and hard soil when static co-efficient method is used.
- The top storey displacement is about 105% higher in soft soil and gradually decreases to 60% and 20% in medium and hard soil when response spectrum method is used.
- Similar pattern is also observed in the storey drift.
- When the size of the footing is increased the response of the structure also increases in both type of analysis.
- The response in soft soil is about 13% higher in dynamic analysis than static analysis.
- The fixed base response and hard soil response are almost same in dynamic analysis.
- When static co-efficient method is used the reinforcement requirement is @ 7-10% higher in soft soil as compared to fixed base
- In response spectrum method the reinforcement required is @70% higher in soft soil as compared to fixed base.
- Response spectrum analysis yield conservative results when the soil is medium or hard and can be avoided for such soils but for soft soil the response is high and so we need to use response spectrum analysis over static co-efficient method for soft soil.

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