Effect of Embedment of Foundation in Seismic Analysis of RC Building

Amit Shiuly
Assistant Professor
Department of Civil Engineering
Meghnad Saha Institute of Technology, Kolkata, West Bengal, India

Abstract: In this study an attempt has been made to compare the variation of time period and base shear of building analyzed dynamically considering base of the structure hinge, fixed and stiffness of soil as spring for Kolkata region. Push over analysis also has been carried out for all the three cases. Variation of shear modulus in Kolkata is determined for 144 locations and contour was plotted for accurate analysis of building considering stiffness of soil in the city.

Keywords: Spring Constants, Fixed Based, Spring Based, Hinge Based, Dynamic Analysis, Pushover Analysis.

I. INTRODUCTION

In general practice during design and analysis of structure, it is assumed that base of structure is fixed. Here it is considered that soil don't allow the foundation in translation in X, Y and Z direction and rotation about X, Y and Z axis. However that is not fully true in practical case. But if it is considered that the base of the structure is hinged i.e. the soil don't allow the foundation in translation in X, Y and Z direction and but allow rotation about X, Y and Z axis. This is also not the true behavior of the soil. The soil acts as spring (([3] & [6]) with specific stiffness. If a structure is analyzed dynamically considering base of the structure fixed or hinge, it will give erroneous result. To get rid of here it is considered the soil as spring with specific stiffness. A comparison have been made with respect to time period and base shear by analyzing a building dynamically considering the above mention three condition of support. Push over analysis also has been carried out and performance point is obtained for above three base conditions. Variations of shear modulus in Kolkata were computed for 144 locations in the city and contour was plotted for accurate analysis of building considering stiffness of soil in the city.

II. STIFFNESS OF SOIL

Spring constants for shallow rectangular footings have been obtained by modifying the solution for circular footing bonded the surface of elastic half space, i.e. $\boldsymbol{K = \alpha\beta K_0}$ ([3] & [6])**.** In which K_0 =stiffness coefficient of equivalent circular footing, α =foundation shape correction factor, β =embedment factor. Foundation correction factor and embedment factor values are shown in figure (1-a) and figure (1-b) respectively. The equations of radius of equivalent circular footing (figure-2) considering degree of freedom is tabulated in table (1).From the equivalent radius K_0 can be computed using table (2). Here G and ν are the shear modulus and poisson's ratio respectively.

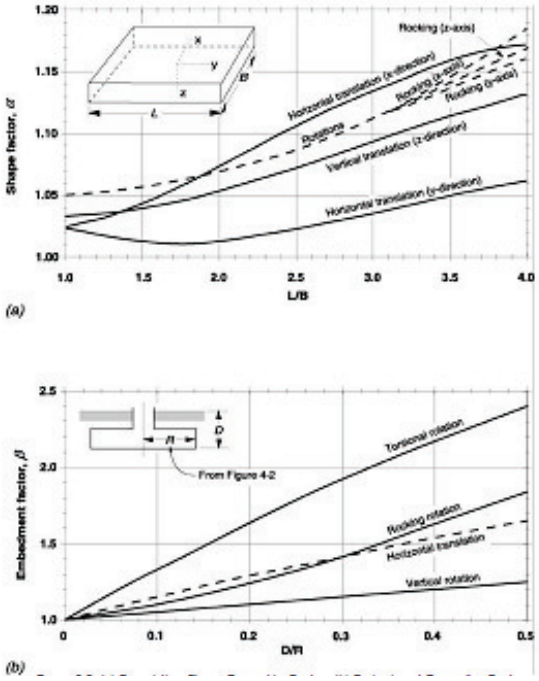


Figure 1. (a) Foundation correction factor (b) Embedment factor after, [3] & [6].

.

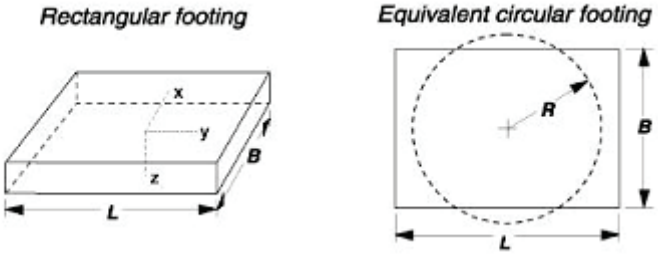


Figure 2. Radius of equivalent circular footing, after [3] & [6].

Table 1 Radius of equivalent circular footing after [3] & [6].

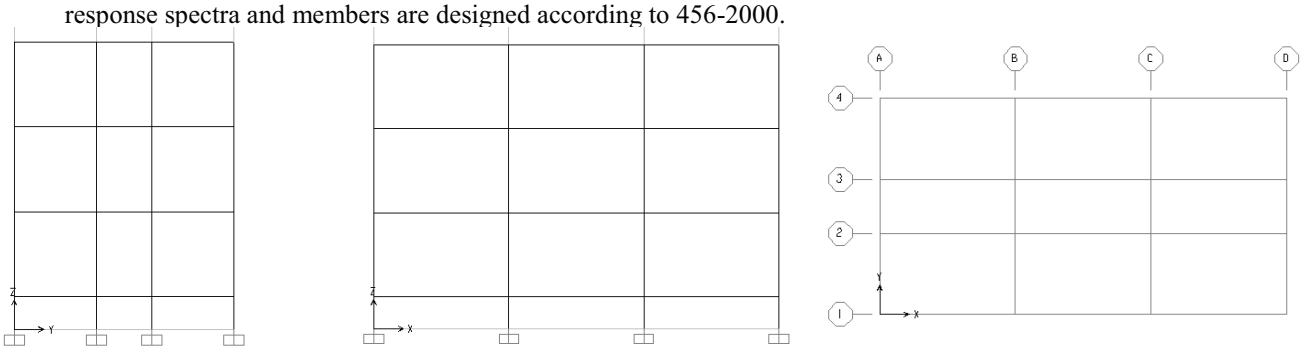
	Degree of freedom			
	Translation	**Rocking**		**Torsion**
		About X axis	**About Y axis**	**About Z axis**
Equivalent radius, R	$\left(\frac{BL}{\pi}\right)^{\frac{1}{2}}$	$\left(\frac{BL^3}{3\pi}\right)^{\frac{1}{4}}$	$\left(\frac{B^3L}{3\pi}\right)^{\frac{1}{4}}$	$\left(\frac{BL(B^2+LB^2)}{6\pi}\right)^{\frac{1}{4}}$

Table 2 Equivalent radius K_0 after [3] & [6].

Displacement degree of freedom	K_0
Vertical translation	$\frac{4GR}{1-\nu}$
Horizontal translation	$\frac{8GR}{2-\nu}$
Torsonal rotation	$\frac{16GR^3}{3}$
Rocking rotation	$\frac{8GR^3}{3(1-\nu)}$

III. STUDY

Using SAP-2000 numerical modeling is done of a G+3 storey building. Figure 2-a, 2-b and 2-c the elevation in X, Y direction and plan respectively. The details of the buildings are described in table (3). The location of the building is 91, Park Street, Kolkata (22.5413N, 88.3679E). The building is analyzed by these data and using IS-1893 (zone-III) response spectra and members are designed according to 456-2000.



(a) (b) (C)

Figure 2 (a) Elevation in X direction (b) Elevation in Y direction (c) Plan of building.

Table 3 Details of the building.

1	Grade of concrete	M-20	9	Size of column and beams	300X400mm
2	Floor to floor height	3.1m	10	Floor finish	1 KN/m^2
3	Plinth height above GL	0.55m	11	Roof treatment	1.5 KN/m^2
4	Depth of foundation below GL	0.65	12	Site located in IS1893 zone	III
5	Slab thickness	150ml	13	Building is resting on	Soft soil
6	Parapet height	1.5m	14	Building frame type	OMRF
7	External wall thickness	230mm	15	Density of concrete	25 KN/m^2
8	Internal wall thickness	150mm	16	Density of masonry	20 KN/m^2

A. Considering building base as fixed

We have analyzed the building in SAP-2000 considering the base of foundation is fixed. That means we have considered that the soil does not allow translation and rotation in any direction. By analyzing the building dynamically we have obtained base reaction 127.47 KN and 126.42 KN in X and Y direction respectively. The time period of 1st and 2nd mode obtained are tabulated in table - 4.

B. Considering the building base as hinged

Dynamic analysis has been carried out for the same building situated in same location but considering support condition as hinged. That means we have restricts the translation in all direction but allow rotation in X, Y and Z direction.

C. Considering support condition as spring

We have collected bore-hole soil data from C. E. Testing of 91, Park Street, Kolkata (22.5413N, 88.3679E). This soil data consist of N value, bulk density, water content finer content, plasticity etc. Correction of N value have been carried out for over burden pressure, bore hole diameter, sampling method, finer content, hammer effect (Youd et al, 2000). From empirical relation proposed by Krammer, $G = 15.56N^{0.68}$ MPa, (Krammer, 2003) is applied for the location to obtained modulus of rigidity value up to 2m depth. By the above mention procedure we have computed the K_x, K_y, K_z, $K_{\theta x}$, $K_{\theta y}$ and $K_{\theta z}$ as transitional stiffness in X, Y, Z direction and rotational stiffness about X,Y, Z direction respectively for the same location. These values were obtained 1064595540 N/m, 843490178.3 N/m, 843490178.3 N/m, 2008181462 N/m, 1233093880 N/m and 1035317002N/m respectively.

Again we have analyzed the same building dynamically considering the stiffness of soil. By analyzing the building time period obtained as 0.5413 second 0.477 sec respectively. The value reveals that if we consider stiffness of soil the time period of buildings lies between support fixed and support hinged condition. Naturally in this case the base shear lies between the fixed and hinged support condition. We have obtained base shear as 128.026 KN and 126.474 KN respectively.

Figure 3 shows the mode vs. time period of building. It clearly reveals that time period of modes no is gradually decreasing for fixed based, spring based and hinged based respectively. For all this three cases only time period of 1st two modes fell in velocity control range of response spectra. For hinge based condition the time period rapidly decreases and in response spectra corresponding spectral acceleration value decreases. For this reason we are obtained base shear so less.

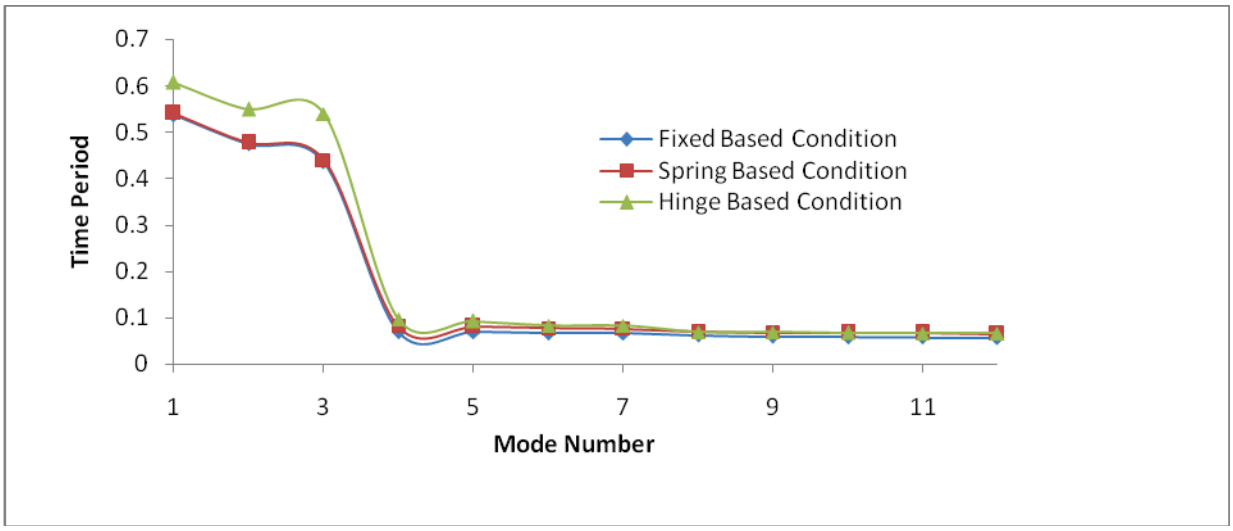


Figure 3.The mode vs. time period of building for three base conditions.

IV. PUSH OVER ANALYSIS

Push over analysis (Nonlinear static) has been carried out for the three support condition of same building and performance point is obtained according to ATC-40. Table 4 depicts that performance point of hinged based building is much lower than other two cases. In this analysis also based supported as spring lies between fixed based and hinged based condition. The figure 4 clearly depicts that capacity of building of spring based condition is slightly lower than fixed based condition, whereas capacity of hinge based building is very less.

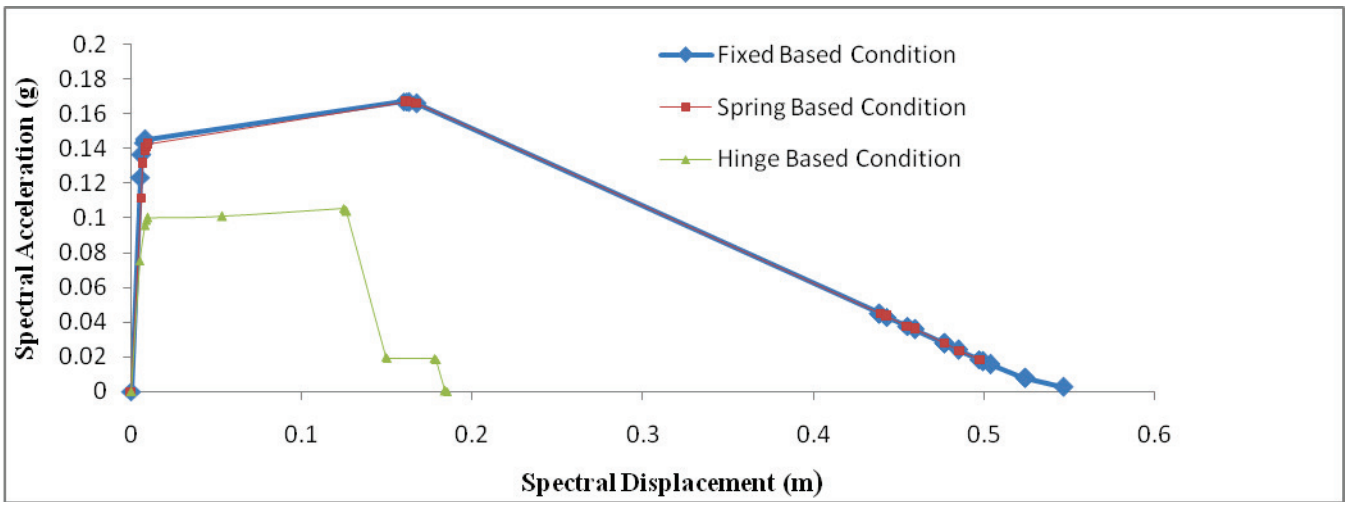
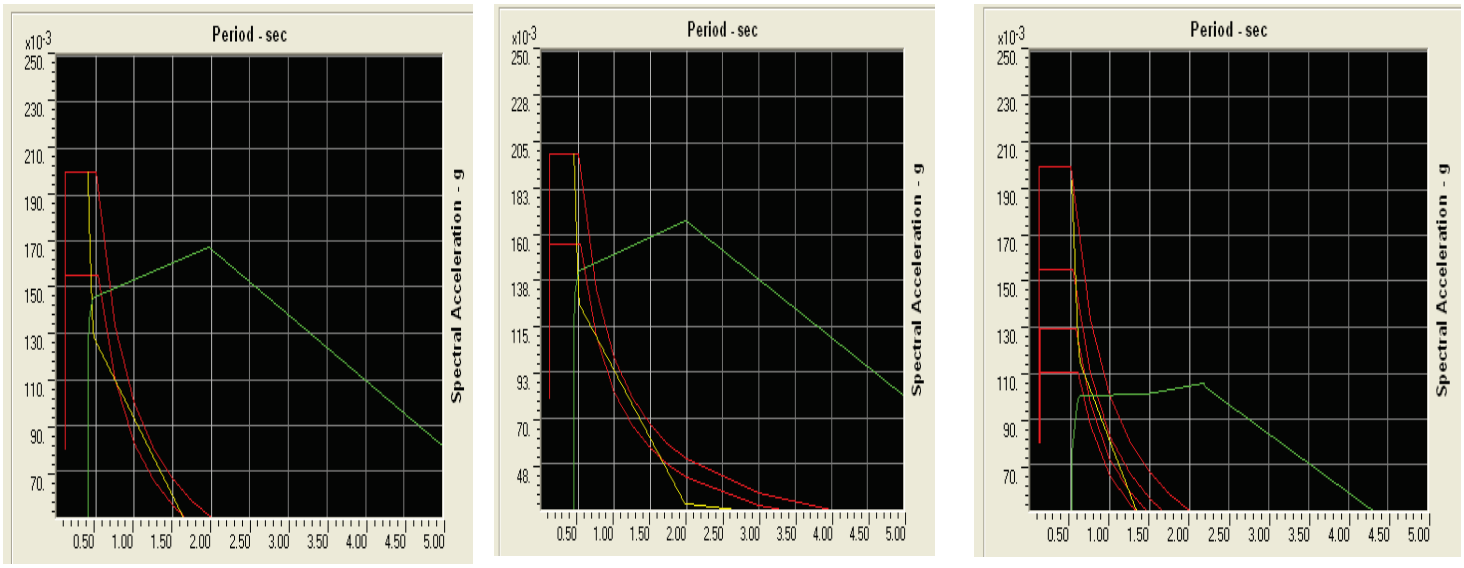


Figure 4. Comparison of Pushover curve of the building.

Table 4 Study result of the building

		Fixed	**Spring**	**Hinge**
Base Shear (X)		127.47KN	128.1 KN	134.28 KN
Base Shear (Y)		126.42 KN	126.5 KN	122.70 KN
1st mode time period		0.536822 s	0.56034 s	0.607562 s
2nd mode time period		0.473804 s	0.496983 s	0.549519 s
Performance point	Base shear, Displacement	1054 KN, 0.0074 m	1008.6 KN, 0.0087 m	789.2KN, 0.012 m
	Spectral Acceleration, Spectral Displacement	0.143 m/s^2 0.00718 m	0.14m/s^2 0.0084 m	0.1m/s^2 0.011 m



(a) (b) (c)

Figure 5. Performance point obtained from Demand-Capacity curve [1] of (a) Fixed based Condition (b) Spring Based Condition (c) Hinge Based Condition.

V. VARIATION IN SHEAR MODULUS IN KOLKATA

144 borehole data were collected from unpublished report of several soil agency like C.E.Testing, S.Ghosh, Associate, ITD Cementation and Shear modulus were computed for each of these location by the above mention procedure at 1.5m from the ground surface level. Figure 6 shows the variation of shear modulus in the city. The shear modulus varies from 55MPa to 113MPa.

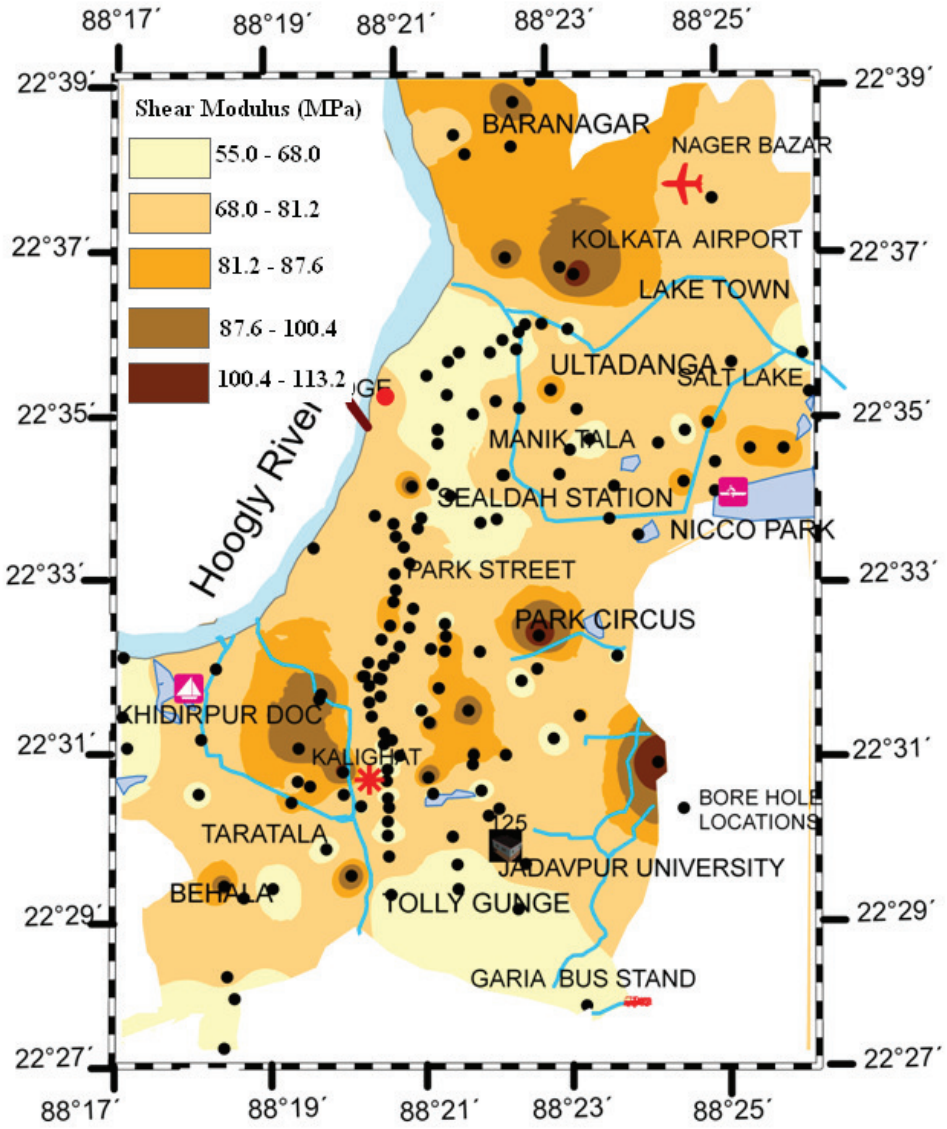


Figure 6. Variation of shear modulus in the Kolkata city.

VI. CONCLUSION

In this study a building has analyzed linear dynamic and nonlinear static (Push-over) method considering base of the structure fixed, hinge and spring. The study reveals that base shear in fixed based condition coming much more than the analyzed when the base is hinged or spring. In actual during earthquake the soil acts as spring with specific stiffness. So during usual design practice the structure will be safe if it is analyzed and designed considering base as spring rather than fixed. On the other hand if the building is analyzed and designed considering base as spring rather than fixed hinge, it will be economical. But the stiffness is determined from the shear modulus of soil. For 144

locations shear modulus at 1.5m below from the ground surface level were computed and contour have been plotted in Kolkata city area. This will help for constructing safe and economic building in Kolkata city.

REFERENCES

[1] Applied Technology Council (ATC), "Seismic Evaluation and Retrofit of Concrete Buildings", *Rep. No. SSC 96-01: ATC-40, 1, Redwood City, Calif,* (1996).

[2] C. E. Testing Pvt. Ltd., *124 A, N.S.C. Bose Road, Kolkata - 700 092*.

[3] Gazetas G, "Foundation Vibration," *Foundation Engineering Handbook, edited by Fang, H. Y., Van Nostrand Reinhold, New York, NY*, pp. 553-593, (1991)

[4] IS – 1893 (Part 1), "Criteria for earthquake resistant design of structures – Part 1: General provision and buildings", *Bureau of Indian Standards*, (2002).

[5] Kramer S.L., "Geotechnical Earthquake Engineering", *Prentice Hall*, (1996).

[6] Lam I.P., Martin, G.R. and Imbsen, R. "Modeling Bridge Foundations for Seismic Design and Retrofitting", *Transportation Research Record No. 1290, Transportation Research Board - National Research Council, Washington, D.C.*, pp. 113-126, (1991).

[7] Youd, T.L., Idriss, I.M., Andrus, R.D., Arango, I., Castro, G., Christian, J.T., Dobry, R., Liam Finn, W.D., Harder Jr., L.H., Hynes, M.E., Ishihara, K., Koester, J.P., Liao, S.S.C, Marcuson, W.F., Marting, G.R., Mitchell, J.K., Moriwaki, Y., Power, M.S., Robertson, P.K., Seed, R.B, And Stokoe, K.H., 2001, "Liquefaction Resistance of Soils: Summary from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils", *Journal of Geotechnical and Geoenvironmental Engineering* , pp.817–833, (2001).