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Soil Structure Interaction Analysis on a RC Building with Raft foundation under Clayey Soil Condition

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***Abstract*— During seismic activity, the response of structures is influenced by Soil Structure Interaction (SSI) which is the process where the response of soil particles to earthquake ground motion affects the motion of structure and the response of structure affects the motion of soil mass. In design offices the base of multi-storey buildings are taken as fixed and analyzed for earthquake response using provisions of IS 1893-2002 with the aid of response spectrum given for soft, medium and hard soils in foundation. But in reality, the type of soil present in and around the foundation structure also participates in the seismic response and the assumption of fixed base becomes conservative. Soil structure interaction usually carried out for soft, medium and hard soil. This study is mainly concentrated on in situ clayey soil conditions. The RC building considered to analyse SSI is an apartment of G+12Storey with an elevation of 40.15m and with the plan shape of 28.2mX16.1m proposed at Mambakkam, South Chennai, Tamil Nadu state, India. The study has used the finite element tools ETABS 9.7.4 for modeling and SAP2000 ver17 for SSI analysis.**

Keywords— ***Clayey soil; ETABS; RC building; Soil Structure Interaction, SAP2000***

I. INTRODUCTION

Indian population is estimated at 1,282,390,303 as of 2015 and India has become second most populous country in the world. Vertical growth of built environment is unavoidable for providing shelter and workspace for them. Dynamic analysis of tall buildings with all considered safety factors has become a challenge for Civil Engineers. Earthquake resistant tall buildings behaving well in all type of soil conditions, especially in soft soils are necessary to be constructed. Wind analysis is also important in case of tall buildings. Earthquakes are frequent and of larger magnitude in the Himalayan and sub Himalayan region, Gujarat, Cutch, Assam, Bihar and other regions in the Northern India. Peninsular India is also not free from earthquakes although the magnitude and frequency is low.

Referring to the Cutch Earthquake of 1819 in India, which killed around 20,000 people, Kramer made a statement Mac Murdo that "*Buildings situated on rock soil were not by any means so much affected as those whose foundations did not reach the bottom of the soil*".

Halkude et al (2014) [9] Studied that SSI is more dominant in soft soil, as the natural period of structure increases SSI. Natural time period is main parameter which affects the seismic response of structures. If soil flexibility increases, the base shear also increases. So it is faster in rate for soft soil conditions.

Xilin Lu et al (2003) [11] showed that increase in dynamic shear modulus of soil causes increase in Natural frequency of SSI. SSI is a very complicated for varying shear modulus of soil, hence shear modulus to be constant and below the critical level.

The investigations have been carried out by many researchers on the structural behaviour of tall buildings with SSI by considering many parameters like foundation type, soil conditions, lateral forces, ratio of flexural stiffness of beam and column etc. Very few investigations have been carried out on soil-structure interaction of tall buildings under clayey soil conditions, particularly in Indian seismic zones. Therefore, the present study has proposed on a tall building with raft foundation on clayey soil to study the behavior and response for a given Earthquake ground motion and compared with fixed base conditions for Drift, Storey displacement, Base shear and Natural time period.

II. DETAILS OF THE PROPOSED BUILDING

Chennai falls under Seismic Zone-III of IS 1893-2002 is located in a coastal region and structures are exposed to coastal environment and surfaces of buildings are protected by plastering and painting coats. As per IS 456-2000 (Table 3), moderate exposure condition shall be considered in design. Basic wind speed for Chennai, V_b is 50 m/sec. When the earthquake forces are considered along with other normal loads, in the elastic method of design, the permissible stresses in the materials are increased by 33%. Also when Earthquake forces are included, the allowable bearing pressure in soils shall be increased as per Table 1 of IS 1893 (part 1):2002, depending upon type of foundation of the structure and type of soil.

A. Description of the Building

A G+12 Storey R.C. building, a real structure which is under construction near Mambakkam, Chennai is considered for the present study to investigate SSI effects on tall buildings. The plan dimension of the building is 28.20 m by 16.10 m and the height of the building is 40.15 m from the ground level. Elevation and storey details are shown in TABLE I. The stilt and first storey height is 4 m and 3.15 m respectively from the base level and all other stories are 3 m and replicas of the first storey.

TABLE I. HEIGHT AND ELEVATIONS OF STOREYS

Level	Height (in m)	Elevation (in m)	Similar to
Storey 12	3.00	40.15	Storey 1
Storey 11	3.00	37.15	
Storey 10	3.00	34.15	
Storey 09	3.00	31.15	
Storey 08	3.00	28.15	
Storey 07	3.00	25.15	
Storey 06	3.00	22.15	
Storey 05	3.00	19.15	
Storey 04	3.00	16.15	
Storey 03	3.00	13.15	
Storey 02	3.00	10.15	
Storey 01	3.15	7.15	Master Storey
Stilt floor	4.00	4.00	
Base	0	0	

B. In Situ Soil conditions at Mambakkam

In situ soil conditions are very important to be considered for the analysis of structures for Earthquake ground motions. The Soil profile and its depth or thickness affects the structural behaviour. The soil properties taken are purely based on Geotechnical investigation report and some standard studies on seismic hazards of Chennai. Geotechnical investigation has been carried out by M/s Geotechnical Solutions, Chennai. Fourteen exploratory boreholes have been dug for geotechnical exploration. Four types of clayey soils are present in the building. First layer at GL to 0.6 m of sandy clayey, second layer 0.6 m to 1.4 m of Yellowish grey clayey cementitious sand, third layer 1.4 m to 2.4 m of dark Yellowish grey clayey silty fines and the fourth layer 2.4 m to 4m of very dense clayey sand. The present study considered the Yellowish Grey clayey soil of unit weight 18 kN/m^3 to facilitate SSI effect.

III. MODELING AND ANALYSIS

The 12 story building modeled using ETABS 9.7.4 software for ease of modeling. The whole building is modeled as 3 dimensional R.C frame model. The beams and columns are modeled using R.C 3-D beam elements with six degrees of freedom at each node. The slab is modeled as membrane infinitely rigid in its own plane to offer diaphragm action for transferring horizontal loads to columns and shear walls. Shear walls are modeled using R.C 3-D Shell elements.

TABLE II. MATERIAL GRADES USED IN MODELING

Structural Member	Grade of Concrete
Slabs	M25
Beams	M25
Columns	M40
Retaining walls	M25
Reinforcement Steel	Fe 500 for all elements except floor slabs
Floor slabs	Fe 415

3-Dimensional R.C beam elements are used for modeling the frame of the structure. Steel is modeled as a bar element and concrete as a beam element and perfect bond is assumed between the two materials. Frame sections in modeling process include beams and columns. Different columns sections used in modeling, all columns are made of M40 grade concrete and of Fe 500 grade steel. Details of beam and column sections used in modeling are shown in TABLE III.

TABLE III. BEAM AND COLUMN SECTIONS

Beam	Column
B-100x100	C-300x900
B-125x125	C-300x2750
B-150x200	C-200x1250X1800
B-200x215	C-300x1800
B-200x265	C-900x300
B-200x450	C-300x1200
B-200x600	C-300x2700
B-200x750	C-200x450X1800
B-300x1050	C-300x900

Slabs and Shear walls are modeled with R.C Shell elements. Shell element is a stack of single layer membranes with different thickness and eccentricities. Shell elements can withstand bending, shear and membrane forces. The floor slabs are assumed as rigid diaphragms and hence are modeled using membrane elements. The Shear walls are modeled using 3-D quadrilateral Shell elements and M25 grade material is assigned to every shell elements.

A. Load Combinations

Safety and Serviceability are two important factors in the design and construction of any tall building. Limit state method of Design, adopts safety and serviceability criteria in the design of structures. Limit state of collapse is the critical state of the structural element, in which ultimate or yield stress levels are reached. In seismic response of tall buildings the limiting the inter-storey drift levels constitutes the serviceability criteria.

The following load combinations shall be accounted for as per IS 1893 (Part 1),

- 1.5(DL+LL)
- 1.2(DL+LL±EL)
- 1.5(DL ± EL)
- 0.9DL±1.5EL

Where, DL-Dead load, LL- Live load and EL- Earthquake load.

The different load combinations taken for the analysis, design and investigations are to be considered as per IS 1893, are shown in Table-4 and the parameter that have been taken in the seismic analysis of the tall building in the present study as per IS1893-2002 (Part I) are shown in TABLE IV. When the earthquake forces are considered along with other normal forces, the permissible stresses in the material, in the elastic method of design, may be increased by 33%. Also, when earthquake forces are included, the allowable bearing pressure in soils shall be increased as per Table 1 of IS 1893 (part 1):2002, depending upon type of foundation.

TABLE IV. LOAD COMBINATIONS

Sl. No.	Load Combination	Load Factors		
		DL	LL	EL
1	LC1	1.5	1.5	-
2	LC2	1.2	1.2	1.2 (X)
3	LC3	1.2	1.2	-1.2 (X)
4	LC4	1.2	1.2	1.2 (Y)
5	LC5	1.2	1.2	-1.2 (Y)
6	LC6	1.5	-	1.5 (X)
7	LC7	1.5	-	-1.5 (X)
8	LC8	1.5	-	1.5 (Y)
9	LC9	1.5	-	-1.5 (Y)
10	LC10	0.9	-	+1.5 (X)
11	LC11	0.9	-	-1.5 (X)
12	LC12	0.9	-	+1.5 (Y)
13	LC13	0.9	-	-1.5 (Y)

TABLE V. SOIL TYPES AND SEISMIC DETAILS

Soil Type	Hard soil, medium soil and soft soil for fixed base & Yellowish grey clayey for flexible base.
Response Reduction Factor	5
Fundamental Natural Period in Seconds	$0.075(h)^{0.75}$ [h= height of the building]
Zone Factor	0.16
Importance Factor	1.00
Damping	5%

B. Building with Fixed Base

The co-ordinate points are the placements of columns according to the base plan layout of the structure. All the points will be constrained with ux, uy, uz, rx, ry and rz co-ordinates for fixed base condition, which means no linear and rotational displacements are allowed.

Storey 1 being a Master storey, remaining stories modeled according to it. The complete building has been modeled using appropriate elements of beams, columns, slabs and shear walls in each storey. The 3-Dimensional view of the tall building is as shown in *Fig. 1.*

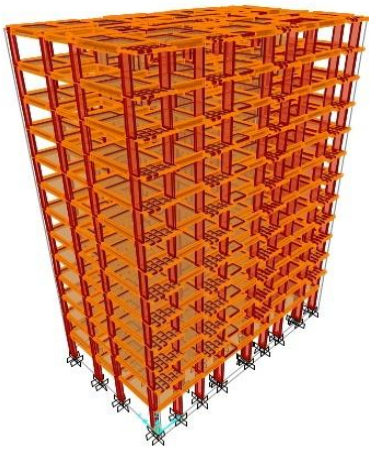

Fig. 1. 3-Dimensional View of the Building with Fixed base

C. Building on Raft foundation

Raft foundation of 29.8x17.7x0.5m has been modeled using thick R.C. Shell elements, to facilitate simulation of Soil Structure Interaction effects for the clayey soil. The building with raft foundation model is as shown in the *Fig. 2.* The properties of clayey soil have adopted and calculated, are shown in Table-6. The spring stiffness values for vertical, horizontal, rocking and twisting motions are calculated as per Richart and Lysmer model. The whole area is meshed with quad shell elements and soil springs are applied.

TABLE VI. SOIL SPRING VALUES AS PER RICHART AND LYSMER

Direction	Spring Values	Equivalent Radius
Vertical	$K_z = \frac{4Gr_z}{(1-\vartheta)}$	$r_z = \sqrt{\frac{LB}{\pi}}$
Horizontal	$K_x=K_y= \frac{32(1-\vartheta)Gr_x}{(7-8\vartheta)}$	$r_x = \sqrt{\frac{LB}{\pi}}$
Rocking	$K\phi x = \frac{8Gr_{\phi x}^3}{3(1-\vartheta)}$	$r_{\phi x}= \sqrt[4]{\frac{LB^3}{3\pi}}$
	$K\phi y = \frac{8Gr_{\phi y}^3}{3(1-\vartheta)}$	$r_{\phi y} = \sqrt[4]{\frac{LB^3}{3\pi}}$
Twisting	$K\phi z = \frac{16Gr_{\phi z}^3}{3}$	$r_{\phi z}= \sqrt[4]{\frac{LB^3+BL^3}{6\pi}}$

K=spring stiffness, r = equivalent radius, L= Length of Raft B= Width of Raft

The present study is mainly deals with clayey soil. The important parameters for the yellowish grey clayey soil is listed and shown in TABLE VII. According to the formulae tabulated in TABLE VI, the spring values for yellowish grey clayey soil have been calculated and tabulated in TABLE VIII. The clayey soil spring values are applied to the raft foundation to facilitate Soil Structure Interaction. This method of applying soil springs to the raft foundation is also known as Winkler approach.

TABLE VII. YELLOWISH GREY CLAYEY SOIL PROPERTIES

Clayey soil parameters			Calculated values
SPT No.	N	6	
Shear wave Velocity	*Vs*	$100xN^{1/3}$	181.71 m/s
Unit weight	γ	By soil test	$1800\ Kg/m^3$
Mass density	ρ	$\frac{\gamma}{g}$	$183.48\ N/m^3$
Shear modulus	G	ρV_s^2	$6058.23\ KN/m^2$
Poisson's Ratio	μ	0.4-0.5	0.4

TABLE VIII. YELLOWISH GREY CLAYEY SOIL SPRING VALUES

Direction	Notation	Spring Values (kN/m)
Vertical	K_z	523027.19
Horizontal	$K_x= K_y$	396399.55
Rocking	KØx= KØy	40950269.12
Twisting	KØz	80204821.80

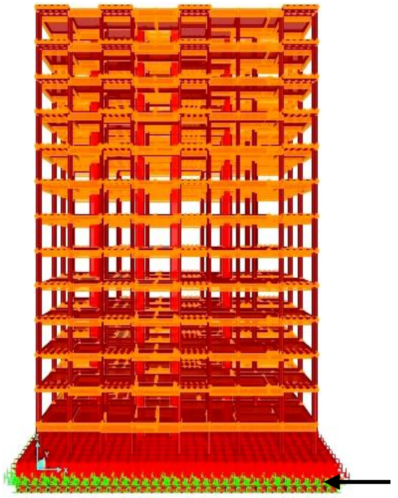

Fig. 2. 3-Dimensional Finite element model of the building with raft foundation and applied soil springs

IV. RESULTS AND COMPARISON

Seismic response has been studied with respect to storey drift, base shear and Natural time period of the building with fixed base for Hard, Medium and Soft soils and building with raft foundation (flexible base) for Yellowish grey clayey soil of Mambakkam. And the results obtained are compared by using graphs. The storey names have been changed to Numbers for the convenience and to plot the graphs, storey names as storey wise numbers are shown in TABLE IX

TABLE IX. STORY NAMES AS NUMBERS

Storey Names	Storey No
Storey 12	13
Storey 11	12
Storey 10	11
Storey 9	10
Storey 8	9
Storey 7	8
Storey 6	7
Storey 5	6
Storey 4	5
Storey 3	4
Storey 2	3
Storey 1	2
Stilt	1
Base	0

A. Story Drift

Storey Drift is the relative displacement of one storey with respect to the other, immediately above or below. The drift of the building on fixed base and flexible base (raft foundation) conditions are tabulated in TABLE X.

B. Base Shear

The Maximum lateral force occur at the base of the structure due to an earthquake is called as base shear. The base shear of the structure can be affected by the ground motions with respect to different soil conditions. Base shear results of the proposed building with fixed base and flexible base are shown in TABLE XI.

TABLE X. STORY DRIFT RESULTS FOR FIXED AND FLEXIBLE BASE

Storey Name	Fixed Base (without SSI)			Flexible Base (with SSI)
	Hard soil	Medium soil	Soft soil	Yellowish grey clayey soil
Storey 12	1.7	2.2	2.8	5.2
Storey 11	2.2	2.9	3.6	6.8
Storey 10	2.7	3.7	4.5	8.6
Storey 9	3.2	4.4	5.4	10.3
Storey 8	3.7	5.0	6.1	11.6
Storey 7	4.0	5.4	6.7	12.7
Storey 6	4.2	5.7	7.0	13.5
Storey 5	4.3	5.9	7.2	13.7
Storey 4	4.3	5.8	7.1	13.6
Storey 3	4.2	5.7	7.0	13.3
Storey 2	3.8	5.2	6.4	12.2
Storey 1	3.2	4.3	5.3	10.2
Stilt	1.8	2.5	3.1	5.8

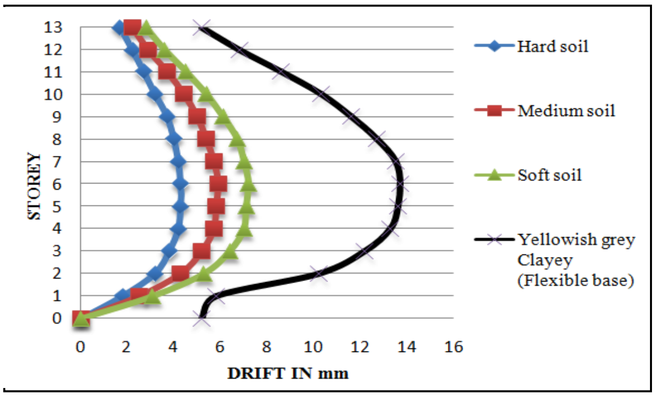

Fig. 3. Storey drifts comparison for fixed and flexible base conditions

TABLE XI. BASE SHEAR FOR FIXED AND FLEXIBLE BASE

Soil Type		Base Shear kN
Fixed Base	Hard	1105.23
	Medium	1503.12
	Soft	1845.74
Yellowish grey clayey soil (Flexible base)		3475.9

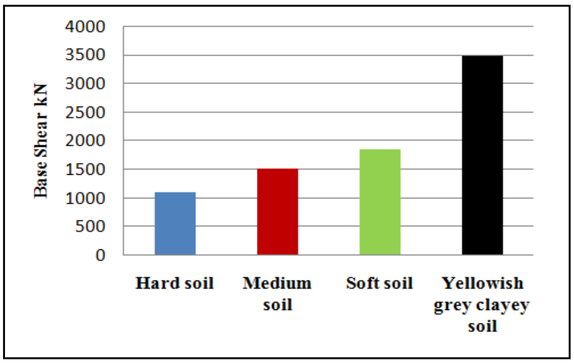

Fig. 4. Base shear comparison of building for fixed and flexible base conditions

C. *Natural Time Period*

In Modal analysis the building is analyzed as a continuous model with infinite number degrees of freedom and natural frequencies. The Natural time periods are the important factors, which affect the seismic behaviour of the structure. Natural time periods obtained from the analysis for fixed base flexible base are shown in TABLE XII.

TABLE XII. MODAL BEHAVIOUR OF BUILDING

Mode No.	Time Period (sec)	
	Fixed Base	Flexible Base
1	2.551	3.505
2	1.744	2.399
3	1.602	2.205
4	0.819	1.125
5	0.523	0.72
6	0.462	0.635
7	0.452	0.621
8	0.297	0.408
9	0.274	0.377
10	0.226	0.311

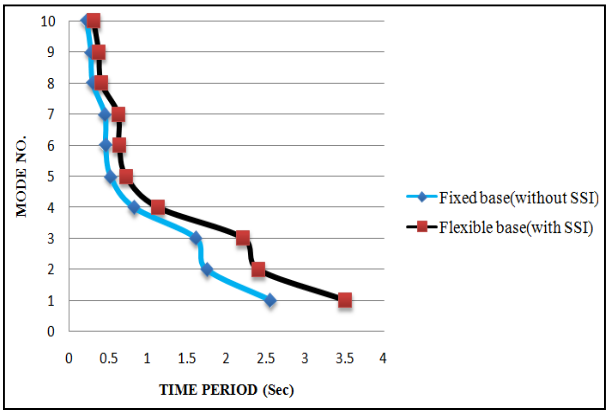

Fig. 5. Natural time period comparison with respect to mode numbers for fixed and flexible base conditions

V. CONCLUSIONS

Tall building of G+ 12 storeys with fixed base has analyzed for hard, medium and soft soil conditions. Same building is also analyzed for flexible base simulating clayey soil conditions. SSI has been incorporated by using soil springs taking into consideration the in situ clayey soil properties of Mambakkam, while Raft foundation has been modeled as a thick slab. Analysis is made with the help of response spectrum of IS 1893 (Part-I) 2002. Seismic response results of flexible base in terms of storey drift, base shear and modal behavior are compared with those of fixed base building founded on soft soil in foundation.

The following conclusions are drawn after comparing the responses of fixed base and flexible base buildings for earthquake ground motion.

- Variation of storey drift in both the cases is parabolic with middle storeys showing maximum drift. When SSI is considered there is a magnification of storey drift in the middle storeys.
- The base shear for flexible base condition maximum compared to fixed base condition. It is found to have almost doubled when SSI effects are considered, from 1845.74 KN to 3475.90 KN.
- The natural time period in case of building with fixed base on soft soil in first mode is 2.551 sec and increases to 3.505 sec in case of flexible base on clayey soil which is an increase of 37.39%. Similar amount of increase in the natural time period is found in all 10 modes.
- The response of the tall building founded on clayey soil has shown significant increase compared to conventional approach of assuming fixed base and founded on soft soil.
- Significant increase in response of tall building when SSI is considered is because of flexibility induced to the base by the softness of clayey soil.

REFERENCES

[1] Anand N. and Mightraj C. “Seismic behavior of RCC shear wall under different soil conditions” *GEO trendz, Indian Geotechnical Conference, IGC-2010, IIT Bombay*, December 16-18, 2010.

[2] A. Boominathan, G. R. Dodagoudar, A. Suganthi and R. Uma Maheswari “Seismic Hazard Assessment Considering Local Site Effects for Microzonation Studies of Chennai city” *A Workshop on Microzonation ©Interline Publishing, Bangalore*

[3] A.D. Pandey, Prabhat Kumar and Sharad Sharma “Seismic soil-structure interaction of buildings on hill slopes” *Journal of Civil and Structural Engineering*, 2011.

[4] A.D. Shirhatti and Dr. S.S. Quadri “Seismic response analysis of RC frames considering soil structure interaction” *Proceedings of Indian Geotechnical Conference December 22-24, 2013, Roorkee.*

[5] Bhattacharya, K., Dutta, S.C., and Dasgupta, S. (2004). “Effect of soil-flexibility on dynamic behaviour of building frames on raft foundation” *Journal of Sound and Vibration*, 274, pp. 111–135.

[6] Dutta, S.C., Maiti, A., Moitra, D. (1999). “Effect of soil-structure interaction on column moment of building frames” *Journal of Institution of Engineers (India).*

[7] Jenifer Priyanka, R.M. and Anand, N. (2012). “Effect of lateral force on tall buildings with different type of irregularities” *Proceedings of the INCACMA Conference on Advances in Construction, Manufacturing and Automation Research.*

[8] Jinu Mary Mathew, Cinitha A, Umesha P K, Nagesh R Iyer and Eapen Sakaria (2014). “Seismic response of RC Building by considering Soil Structure Interaction” *ISSN 2319 – 6009 Vol. 3, No. 1, February 2014.*

[9] Halkude S. A, Kalyanshetti M.G and Barelikar S.M (2014) “Seismic Response of R.C. Frames with Raft Footing Considering Soil Structure Interaction” *International Journal of Current Engineering and Technology E-ISSN 2277 – 4106, P-ISSN 2347-5161*

[10] Hamid Reza Tabatabaiefar, Bijan Samali, and Behzad Fatahi, “Effects of Dynamic Soil-Structure Interaction on Inelastic Behaviour of Mid-Rise Moment Resisting Buildings on Soft Soils” *Australian Earthquake Engineering Society 2010 Conference, Perth, Western Australia.*

[11] Xilin Lu, Bo Chen, Peizhen Li, Yueqing Chen (2003). “Numerical Analysis of Tall Buildings considering Dynamic Soil-Structure Interaction” *Journal of Asian Architecture and Building Engineering*