SUSTAINABILITY ANALYSIS OF THE TALL ASYMMETRICAL BUILDING

by

Pallavi Ravishankar, Neelima Satyam

in

International Conference on Sustainable Civil Infrastructure

Hitex, Hyderabad, Telangana, India.

Report No: IIIT/TR/2014/-1

Centre for Earthquake Engineering
International Institute of Information Technology
Hyderabad - 500 032, INDIA
October 2014

SUSTAINABILITY ANALYSIS OF THE TALL ASYMMETRICAL BUILDING

B. Pallavi Ravishankar[1] and Neelima Satyam[2]

[1] Research Scholar, Geotechnical Engineering Laboratory, Earthquake Engineering Research Centre, IIIT Hyderabad, INDIA, Pallavi.ravishankar@research.iiit.ac.in
[2]Assistant Professor, Geotechnical Engineering Laboratory, Earthquake Engineering Research Centre, IIIT Hyderabad, INDIA, neelima.satyam@iiit.ac.in

ABSTRACT: In recent scenario to develop a sustainable infrastructure considering the earthquake as a devastating force has become increasingly challenging due to the complexity lies with design and analysis (Env**isi**on, 2012). The sustainability of the buildings can be achieved by considering the effect of soil structure interaction in the analysis as it captures the wave attenuation, soil vibration and inertial vibration of the superstructure. In these research paper tall asymmetric buildings is considered for sustainability analysis as tall structures experience more risk during the earthquakes due to the effect of attenuation of earthquake waves and local site response which get transferred to the structure and vice versa (Ming, 2010). This can be well explained by the Dynamic Soil Structure Interaction (DSSI) analysis. In the present study 150 m tall geometrically asymmetrical building with two different foundation systems including raft and pile supported on a homogeneous sandy soil strata is analyzed against the dynamic loading for Bhuj ground motion (2001, M= 7.7). The response of structure in terms of SSI parameters against dynamic loading for a given foundation systems has been studied and compared to understand the soil structure interaction for the tall structures. It has been clearly identified that the displacement at top is more than that at bottom of the building and stresses are more at immediate soil layer under foundation than the below layers .

INTRODUCTION

Most of the civil engineering structures involve some type of structural element which is in direct contact with soil. To ensure the sustainability of the superstructure it is required to analyze the system/ more practically. In general approach any structure is analyzed with fixed base approach where the superstructure is considered to be founded on the rocks. But practically this assumption leads to the improper estimation of the design forces like moments and base shear, as practically any structure is founded on the soil and soil has a less stiffness than the rock and shows a very different behavior than the rocks under the dynamic loading situation. Thus to obtain the sustainability of the superstructure it is required to include the soil structure interaction effect in analysis which based on the reality that the structure is founded on the soil and the foundation is always flexible (Winkler,1965). In general when the structure in subjected to the dynamic loading such as earthquakes, neither structure displacement nor soil displacement is independent but it is a combined effect of the superstructure and the foundation system. This effect is well captured in the Dynamic soil-structure interaction (DSSI) phenomenon. During Earthquake loading the waves travels always with kinetic energy from ground to the surrounding soil mass as well as the structural part in contact with it. A fraction of the kinetic energy released from earthquake waves is transferred into buildings through soil. The exact estimation of transfer of wave energy from soil to structure and again from structure to soil broadly can be divided into two phenomena like a) kinematic interaction and b) inertial interaction. Soil structure interaction parameters such as stresses and displacements in both structure and support systems including foundation and soil mass in contact are depends up on relative stiffness of superstructure, foundation system and supporting soil mass.Type of foundation system is one of the governing parameter on which interaction parameter depends. In this paper asymmetrical high rise building modelled along with the homogenous local sandy soil strata. The building is provided with two different types of foundation systems viz. raft foundation and pile foundation and interaction parameters like displacements and stresses are studied at different points under consideration.

MODELLING

A Finite element model for superstructure along with the supporting system is developed using finite element software Ansys-13 (ANSYS Inc). The material models are defined using material library in Ansys for a different linear, nonlinear and contact material for the soil and structure. In this paper soil and structure modelled integrally with introducing appropriate zero volume interface material as per meshing of foundation surface in contact with soil beneath and soil structure interaction parameters like displacements and stresses are studied.

Soil Properties

A local unbounded homogeneous deep sandy soil volume of 200m x 100m x50 m as shown in Fig.1 is considered with the following engineering properties is modelled with Ansys 13.

Table 1. Parameters of the non-linear soil model

Soil parameter		**Superstructure and foundation details**	
Soil Type	Sandy	Asymmetry Type	Loading
E_{ref} (kN/m^2)	19000	Height	150 m
Posson's ratio (η)	0.4	Asymmetrical Ht.	90 m
cohesion (C) kN/ m^2	23^0	Base Dimension	40x20 m
internal friction angle (Ø)	230	Raft Dimension	50x30x0.5 m
Mean shear velocity (Vs) m/s	290	Pile configuration	0.25 x 10 m 4 m c/c

The soil structure interaction is modelled with the concept of elastic half space theory (Wolf,1985). There are two ways to model the soil structure interaction problem viz. direct method and substructure method. In direct method superstructure, foundation system and unbounded soil mass is modelled together with a proper interface element. In substructure method superstructure and foundation system is modelled separately with proper consideration of load transfer from superstructure to the foundation system. In this paper superstructure and support system is modelled by direct method.

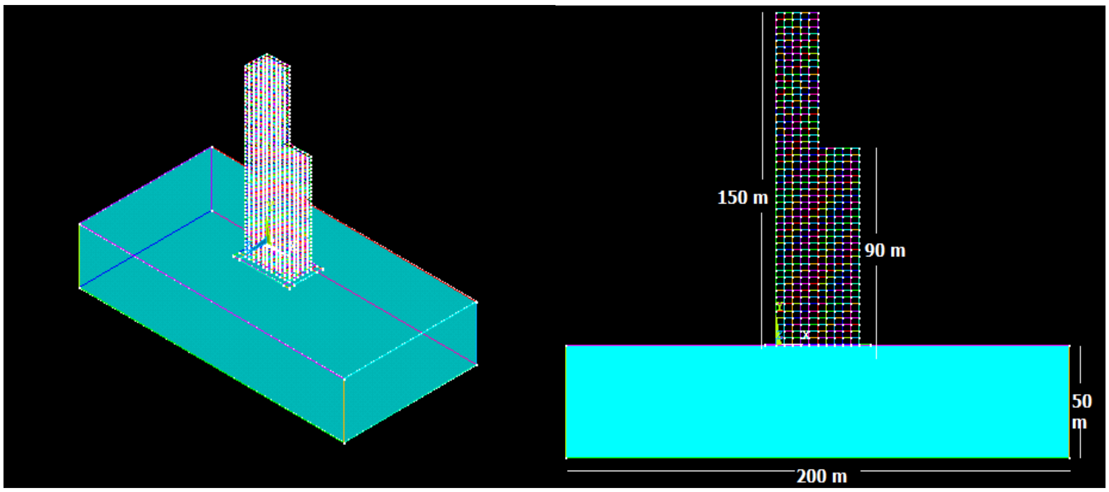

FIG. 1. Finite element model for asymmetrical building for sustainable analysis.

A 150 m tall superstructure as shown in Fig. 2 of base dimension 40mx20m is considered with a loading asymmetry in such a way, left half portion of building raised to 150 m(50 storeys) and right half raised to 90m (30 storeys). Initial framed structure is modelled in Finite element program Ansys-13.

Foundation System

Two type foundation systems is modelled including raft and pile foundation. Raft foundation system with a dimension 50m x 30m with design uniform thickness 0.5m and a concrete grade M-20 with rebar material Fe-415 is provided for the modelling. For pile foundation system pile cap of 0.2 m thickness is provided with 4m pile spacing in both directions. Pile of diameter 0.25 m and length 10m is modelled.

Elements selection in Ansys-13

In Ansys framed superstructure is modelled with 2D-Beam element BEAM188 and Piles with SOLID 185, interface element with CONTA175 and TARGE170. Soil is modelled with SOLID 65 and *Drucker–Prager* non linear material model is for soil behaviour.BEAM188 is suitable for analyzing slender to moderately thick beam structures. The element is based on Timoshenko beam theory which includes shear-deformation effects and element provides options for unrestrained warping and restrained warping of cross-sections.SOLID185 is eight noded 3-D element gives translations in 3-directions used for solid modeling.CONTA175 is ideal to use when there is sliding between two elements in contact (either node to node or line to line). Contact occurs when the element surface penetrates one of the target segment elements, TARGE170 on a specified target surface. Soil is modeled with SOLID 65 which is used for the 3-D modeling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression. Material model *Drucker–Prager* for soil describes the non linear plasticity behavior which depends on the engineering soil properties given as a input data of this model.

Dynamic analysis of the soil structure interaction model

The dynamic analysis carried out by considering Bhuj input ground motions (2001,M=7.7) at the bottom of the soil mass and stresses and displacement at different locations like A,B,C.D.E as shown in figure 2 of the building and the soil are studied. For the static analysis of structure the self weight, gravity weight is considered and initial stresses are observed which serves as initial stress conditions for dynamic analysis. The ground motion with PGA 0.31g is given to the model to find the displacements and stresses for the soil strata

RESULTS AND DISCUSSIONS

Displacements along X,Y and Z direction is calculated for the dynamic loading and at each point from bottom to top (Fig. 2) of model is been plotted. Figure 3 and 4 explains the displacements and stresses profiles developed along global X,Y and Z directions supported by raft foundation.

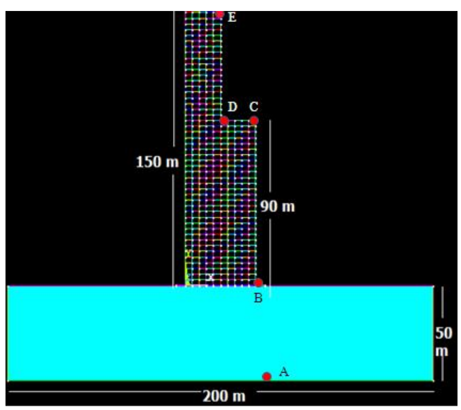

FIG. 2. Response Locations in the soil structure interaction system.

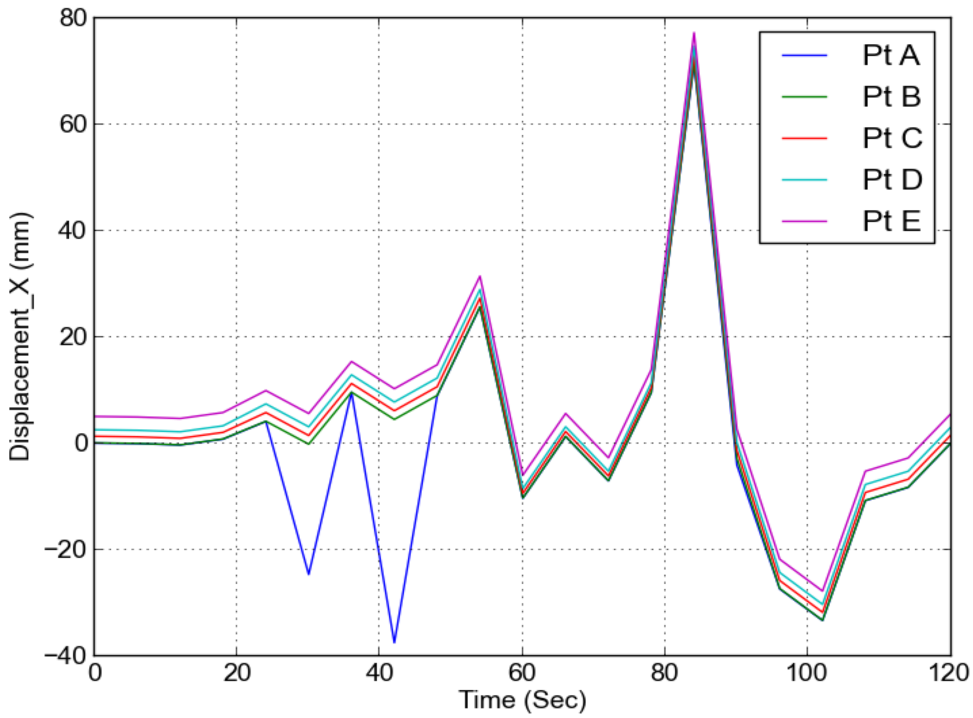

FIG. 3. Displacements in X directions at different locations for raft foundation system.

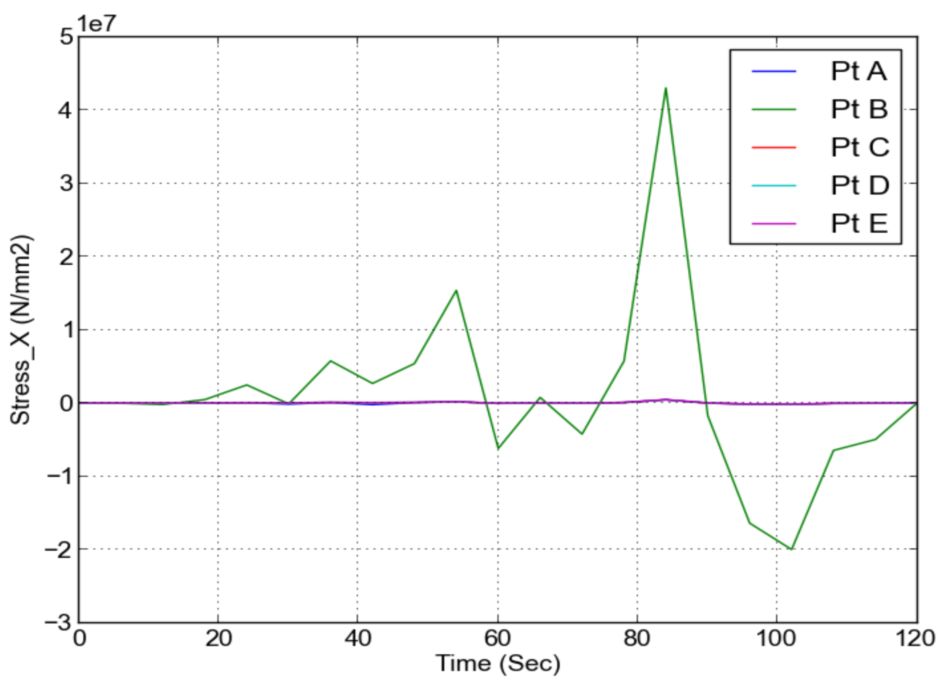

FIG. 4. Stresses in X directions at different locations for raft foundation system.

The change in the displacements and stresses are measured and estimated a transfer of these parameters from point A to E by estimating a percentage difference with respect to the point A. Table 2 and 3 gives the percentage deviation of the interaction parameters like stresses and displacement from the point A for the raft foundation respectively.

Table 2. Maximum displacements under dynamic load conditions for *Raft* foundation system

Points	Displacements (mm)		Deviation in displacements w.r.t point A (%)	
	X-Disp	Y-Disp	X-Disp	Y-Disp
A	71.398	37.100	0 %	0 %
B	71.698	37.100	0.42 %	0.34 %
C	73.195	38.734	2.51 %	4.39 %
D	74.694	40.369	4.61 %	8.43 %
E	77.198	42.869	8.12 %	14.29 %

Table 3. Maximum stresses under dynamic load conditions for *Raft* foundation system

Points	Stresses (kN/m2)		Deviation in stresses w.r.t point A (%)	
	X-Stress	Y- Stress	X-Stress	Y- Stress
A	428.3935	222.601	0 %	0 %
B	43019.30	22260.197	994 %	990 %
C	439.1935	232.4093	20.52 %	0.44 %
D	448.1935	242.216	14.61 %	8.43 %
E	463.1935	257.216	-8.11 %	8.29 %

When the soil mass and support system is subjected to the dynamic loading it undergoes the deformations which create the stresses. The stresses in x, y and z direction is calculated for each point. Stress plots at different locations under consideration along the elevation are shown in Figure 4 along X,Y and Z direction.

An interactive modelling is done for the same soil properties and same structural configuration and foundation system is altered by a pile type and again results are studied. Table 3 and 4 explains the displacements and stress respectively at different points under consideration for the pile foundation system with initial pile configuration mentioned in foundation system.

Table 3. Maximum displacements under dynamic load conditions for *Pile* foundation system

Locations	Displacements (mm)		Deviation in displacements w.r.t point A (%)	
	X-Disp	Y-Disp	X-Disp	Y-Disp
A	69.97036	35.91312	0 %	0 %
B	70.12156	35.98732	0.21 %	0.20 %
C	71.43905	37.37917	2.09 %	4.07 %
D	73.12633	39.36021	4.11 %	9.22 %
E	75.26856	41.92632	7.57 %	15.27 %

Table 4. Maximum displacements under dynamic load conditions for *Pile* foundation system

Locations	Stresses (kN/m2)		Deviation in stresses w.r.t point A (%)	
	X-Stress	Y- Stress	X-Stress	Y- Stress
A	427.9651	219.9298	0 %	0 %
B	42933.26	21970.81	763 %	812 %
C	433.0448	228.9232	1.18 %	0.24 %
D	438.7814	239.5516	2.52 %	8.55 %
E	456.2456	254.1294	6.61 %	11.29 %

The response in terms of displacements and stresses are compared in case of both raft and pile foundation system for same dynamic loading and local site condition. Figure 5 shows the response profile for both foundation systems.

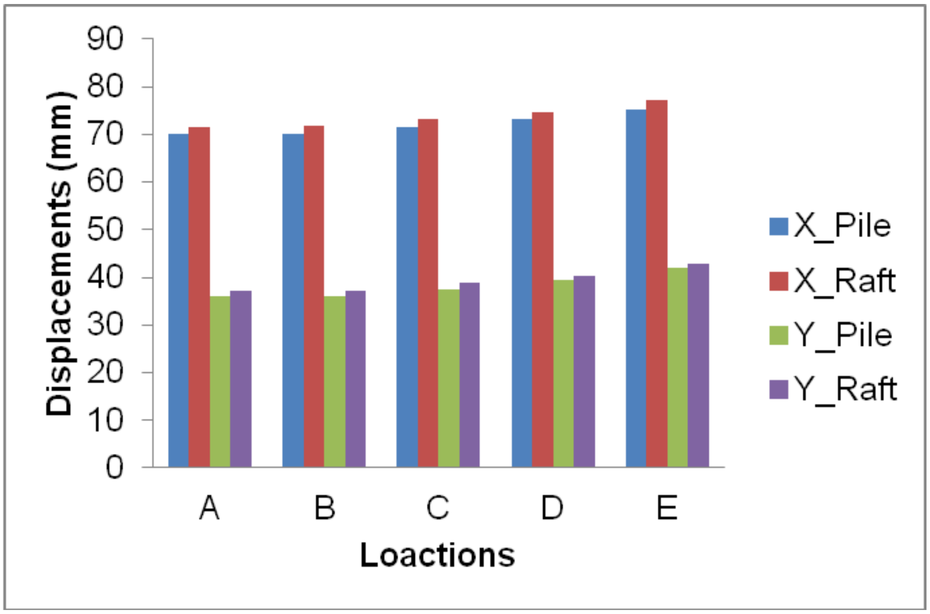

FIG. 5 Comparison of sustainability in case of Pile and raft foundation systems.

CONCLUSIONS

In order to check the sustainability of the super structure soil structure interaction analysis has been carried out for an asymmetrical building with respect to loading of 150 m height with base dimension 40 m x 20m by developing a finite element model for the integrated system including superstructure and foundation system which includes both raft and pile foundations separately. The nonlinear local soil behaviour is captured by modelling a semi-infinite soil mass with *Drucker–Prager* nonlinear material model in Ansys-13.The interactive response is studied for the input Bhuj ground motion with PGA 0.31g. The SSI response is observed for both pile and raft foundation systems and the response of building at different key location at different elevation are noted.

Displacements: It has been observed that for a given ground motion the displacements increases as from soil mass to superstructure top in both X and Y direction , but this change is very minute for the Vertical (Z) direction displacements. Thus the soil structure response is minimal along the axis which is transverse to the shaking area for both type of foundation system.

Stress: Stress concentration is found to be much more in immediate soil layer below the foundation and it decreases evenly in both directions as moving away down and up from foundation.

It is noted that for the same local soil condition displacements and stresses in case of pile foundation system is comparatively less than raft foundation system.

The study has been observed that the computation time to get the response for pile foundation is more than that of the raft foundation; this is due to the computation time consumed for the pile element which is 3-D in nature and the interfaces element modelled between soil element and pile element.

The computational time is increased with increasing the soil domain for 3-Dimentional analysis.
Pile foundation gives more sustainability to the superstructure than the shallow foundation like raft for the same dynamic loading.

REFERENCES

Azarbakht, A. and Ashtiany, M.Gh.(2008), "Influence of the Soil-Structure Interaction on the Design of Steel-Braced Building Foundation." *Seismic Engineering: Commemorating the 1908 Messina and Reggio Calabria Earthquake, Conference AIP Conference Proceedings* vol. 1020, pp. 595-601.

Borja, R.I., Wu, W.H., Amies, A.P. & Smith, H.A.(1994). "'Nonlinear Lateral, Rocking and Tortional Vibration of Rigid Foundations" *Journal of Geotechnical Engineering*, vol. 120, no. 3, pp. 491-513.

Bowles (1996) "Foundation Analysis and Design", *McGraw-Hill International Editions*, 5th edn, Civil Engineering Series.

B.K. Maheshwari, K.Z. Trumana, M.H. El Naggar, P.L. Goulda (2004) "Three-dimensional nonlinear analysis for seismic soil–pile-structure interaction" *Soil Dynamics and Earthquake Engineering* 24, 343–356.

Chau, K.T., Shen, C.Y. & Gou, X. (2009) "Nonlinear Seismic Soil-Pile-Structure Interactions: Shaking Table Tests and FEM Analyses" *Soil Dynamics and Earthquake Engineering*, vol. 29, no. 29, pp. 300-310.

Chopra, A.K. and Gutierres, J.A. (1973) "Earthquake Analysis of Multi storey Buildings Including Foundation Interaction" *ReportNo.EERC73-13*, University of California, Berkeley.

Han Yingcai (2002) "Seismic response of tall building considering soil-pile-structure interaction", *Earthquake Engineering and Engineering Vibration*, Article ID: 1671-3664(2002)01-0057-08, June.

H. Shakib,A. Fuladgar (2004) "Dynamic soil–structure interaction effects on the seismic response of asymmetric buildings", *Soil Dynamics and Earthquake Engineering*, 24 379–388.

J. L. Wegner, M. M. Yao and S. K. Bhullar (2009) "Dynamic wave soil structure interaction analysis of a two way asymmetric building system DSSIA-3D", *Journal of Engineering and Technology Research* Vol.1 (2), pp.026-038, May.

Jonathan P. Stewart, Gregory L. Fenves and Raymond B. Seed (1999) "Seismic Soil – Structure Interaction in buildings. I: Analytical Methods", *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, January, 125(1), 26-37.

Mao-guang Yue and Ya-yong Wang, 2009, "Soil-Structure Interaction of High-rise Building Resting on Soft Soil" , *EJGE*, Vol. 13.

R. R. Chaudhari and Dr K. N. Kadam (2013) "Effect Of Piled Raft Design On High – Rise Building Considering Soil Structure Interaction" *International Journal of*

Scientific & Technology ,volume 2,Issue 6, pp-72-79.

Wolf, J. P. (1985) "Dynamic soil structure interaction". *Prentice-Hall, Englewood Cliffs*.