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Dynamic Analysis to Study Soil-Pile Interaction Effects

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Abstract: *The prediction of the behaviour of the pile foundations is of paramount importance in the seismic design and assessment piles for the structural sustainability during earthquake. Generally pile provides a good agreeable performance in the complex soils conditions like soft soils having less bearing capacity. The nonlinear condition and dynamic condition are coupled with each other to produce the complex soil action to the pile motion which can be well captured by the soil structure interaction phenomenon stated as soil-pile interaction analysis. In this research paper numerical analysis of a single pile is carried out for a different soil conditions like, C-soils, Ø-Soils and C- Ø soils to understand the soil-pile interaction for the EL-Centro (1940) ground motion. The displacements profiles are studied for flexible long and rigid short pile for the different soil types as mentioned earlier and soil pile interaction analysis. The axi-symmetric numerical model is developed by using Finite Element Program Open-Sees PL[18] to understand the soil pile interaction under the dynamic loading condition. The study concludes that the maximum displacement is less for C- Ø soil as compared to other two types C-soil and Ø -soil. Under the dynamic loading conditions, long pile is more sustainable than the Short rigid pile.*

Keywords: *Soil-pile interaction, Rigid and flexible pile, Numerical analysis, Open-sees PL, Master slave analogy, Rigid interface*

1. Introduction

Piles are used in many soil conditions like soft, liquefiable soils and very soft rocks which have spread to the considerable depth. In such situations shallow foundation is not economical and always performs poor for the dynamic load cases and fails under bearing capacity of the boundary domain i.e. soil. Soil-Pile interaction can be an important consideration in evaluating the seismic performance of pile-group supported structures, particularly in soft clay or liquefying sand. Methods of analyzing seismic soil-pile-structure interaction have included 2D and 3D modelling of the pile and soil continuum using finite element or finite difference methods, dynamic beam on a nonlinear Winkler foundation methods [17] , and simplified two-step methods that uncouple the superstructure and foundation portions of the analysis. It is necessary to predict precisely the structure response considering soil-structure interaction for implementation of performance based design. Soil structure interaction during earthquake, however, is very complicated and is not always taken into account in seismic design of structure. Current study involves studying pile response for given ground motion.

Interaction between piles and soil was solved theoretically by Tajimi (1969) by using linear visco-elastic model of soil and by Penzein (1970) by developing a discrete nonlinear model [17]. In numerical analysis the pile soil interaction is achieved by representing boundary conditions of a pile with discrete non-linear springs with the stiffness of equal to the equivalent soil subgrade reaction.

2. Numerical Modelling

The numerical analysis is carried out with OpenSeesPL Developed by PEER, Berkely[18], is a graphical user interface (GUI) for three dimensional (3D) soil-pile interaction responses. The base shaking simulation is performed with a control boundary conditions and zero inclination mode. The pile is modelled with linear beam element and soil with non linear beam element. The Von Mises material model is adopted for simulating the non linear soil behaviour. The interface between pile

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and soil is simulated with zero-length elements .These elements connect the fixed node of pile with slave spring nodes of soil [18].

3. Soil Properties

The local soil considered for analysis is homogeneous of three basic different types viz purely cohesive (C-soils), purely non-cohesive (Ø-soils) and combination of both (C-Ø soil). Table 1, explains the different soil parameters of the soils considered for the analysis.

Table 1. *Soil data*

Soil Parameter	**C-soil**	**Ø-soils**	**C-Ø Soil**
Shear Modulus, G (kN /m^2)	6x10^4	10x10^4	10x10^4
Bulk Modulus , B (kN /m^2)	3x10^5	3x10^5	2.3x10^4
Cohesion , C (kN /m^2)	37	0	25
Permeability Co.eff (m/s)	1x10^{-9}	1x10^{-4}	1x10^{-4}
Unit Weight (kN /m^3)	15	20	19
Friction Angle (Degrees)	0	35	33.5

4. Pile Properties

Numerical analysis is carried out for circular rigid short and flexible long concrete pile with grade of concrete varies from M-30 to M-40 and length 4.5 m and 18 m respectively with diameter 0.5 m. The pile is considered to be fixed at the bottom and pinned at the top to find its response against the given dynamic load. The different combinations taken for analysis is shown in Table 2.

Table 2. *Different properties of soil and pile considered for present study*

Pile Type	Grade of Concrete	Soil Type		
Short pile L= 4.5 m, D=0.5 m	M-30	C-soils	Ø-soil	C-Ø soil
	M-35	C-soils	Ø-soil	C-Ø soil
	M-40	C-soils	Ø-soil	C-Ø soil
Long pile L= 18 m, D=0.5 m	M-30	C-soils	Ø-soil	C-Ø soil
	M-35	C-soils	Ø-soil	C-Ø soil
	M-40	C-soils	Ø-soil	C-Ø soil

The pile of 0.5 m is modelled with a semi-infinite soil medium of size 100 m x 100 m x 50m to simulate the soil structure interaction phenomenon [17] . Figure 1 shows basic soil-pile interactive model considered for dynamic analysis.

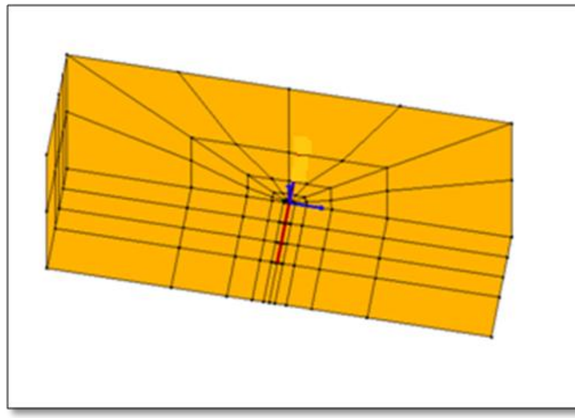

Figure 1. *Soil Pile Finite element model generated for study*

5. Dynamic analysis of the soil pile interaction model

A dynamic load in the form of El Centro ground motion (M= 6.9) with a peak ground acceleration 0.3g is applied at the rigid end of the pile to perform a Base Shaking analysis . The spectra of the given ground motion is shown in Figure 2. The tool offers the Newmark time integration procedure with two user defined coefficients β and γ [4] Computations at any time step are executed to a convergence tolerance of 0.0001.

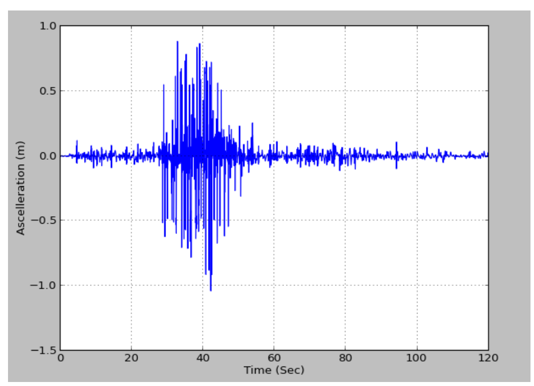

Figure 2. *Spectra for EL Centro ground motion (1940) with peak acceleration*

6. Results

For the given ground motions stresses and displacement are observed. The displacements are calculated in the direction of the lateral load applied. Figure 3 shows the initial stress condition for the given dynamic loading. The displacement is calculated along the length of pile for both short and long pile. Figure 4 and Figure 5 explains the displacement profile for the pile for all type of soil viz cohesive (c-soil), non-cohesive (Ø-soils) and combination of both (C-Ø soil) for short and long pile respectively.

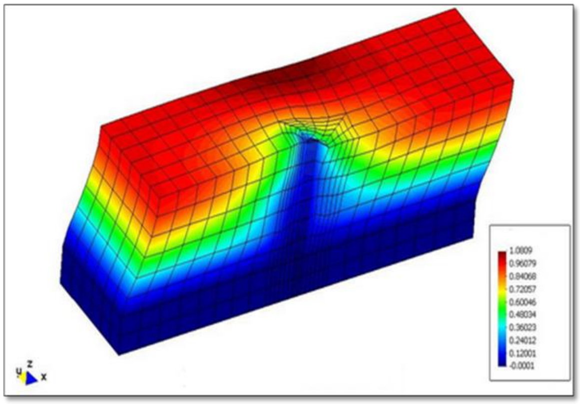

Figure 3. *Stress contours in the soil strata after application of the dynamic loads*

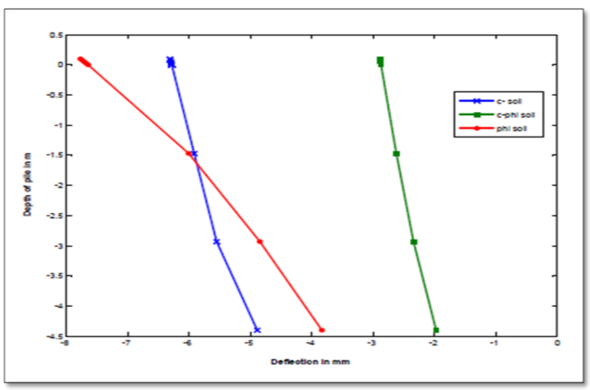

Figure 4. *Deflection profile for short pile (L= 4.5 m) for different soil types*

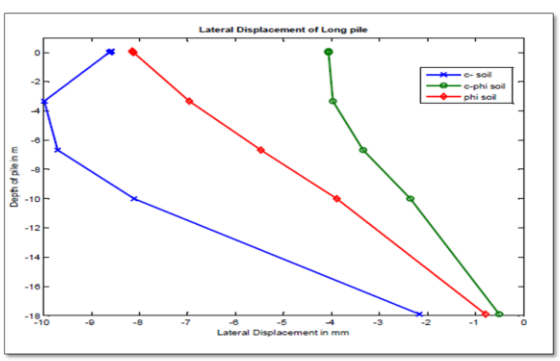

Figure 5. *Deflection profile for long pile (L= 18 m) for different soil types*

6. Summary and Conclusions

In order to carry out comparative study on soil pile interaction for long and short pile for different soil types like C-soil, Ø -soil and C- Ø soil the subjected to the earthquake loads a finite element analysis is carried out. Following are some observations drawn from the present study

- For short rigid short pile and flexible long pile the peak displacements at the top of the pile is found to be less for C-Ø soil as compared to c soil and Ø-soil.
- The values of peak displacements is more for long pile than the short pile, hence length of the pile is one of the important parameter for displacement controls.
- The grade of the concrete is not influencing the displacement characteristics of the pile. Change in displacements is negligible for the parametric grades considered for the present study.
- The type of surrounding soil of the pile plays a important role in the displacements at the top of the pile.
- The finite element tool is found to be easy to understand and operate for the interaction problem.
- The interface elements between soil and pile which simulates soil pile phenomenon is follows the theory of 'Master Slave analogy', reflects the rigid interface between soil and pile , hence can not achieve the actual soil-pile interaction phenomenon.

8. Notations

c- Cohesive soil
Ø -Cohisionless soil
c- ø combination soil having both the cohesive and cohisionless material
β and γ Newmarks Integration coefficient

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