International Journal of Civil Engineering Research.
ISSN 2278-3652 Volume 5, Number 3 (2014), pp. 261-268

http://www.ripublication.com/ijcer.htm

Influence of Orientation of Piles on Seismic Response of Pile Groups

K. Salinitha[1] and Asha Joseph[2]

[1]Civil Engineering Department, IES College of Engineering, Chittilappilly, Thrissur City, Kerala, INDIA.
[2]Civil Engineering Department, IES College of Engineering, Chittilappilly, Thrissur City, Kerala, INDIA.

Abstract

The impact of earthquakes on foundations has been a matter of concern since the occurrence of some heavy earthquakes. Pile foundations are the widely used type of deep foundations for supporting heavily loaded structures like nuclear power plants, oil tanks, bridges etc. SSI problem involving pile foundation is one of the most complex problems in geotechnical engineering. The pile foundation responses during earthquakes are strongly affected by nonlinear soil-pile interaction. The soil profile as well as the configuration of pile foundations has effects on the seismic response of the soil-pile-structure systems.

The influence of orientation of piles in a group on the seismic response of pile group was examined by conducting transient dynamic analyses on 1x2 and 1x3 pile groups in series and parallel configurations. The effect of soil condition on the seismic response was investigated by doing the dynamic analysis of the pile groups embedded in homogeneous stiff cohesive soil and actual layered soil mediums. Nonlinear 3-D finite element analyses were carried out using MSC Softwares. MSC.Patran and MSC.Marc Mentat were used as pre-processor and post-processor respectively and MSC.Marc as the solver. In the analyses, behaviour of soil was idealized using Drucker-Prager constitutive model and that of rock by Mohr Coulomb constitutive model. Pile group and pile cap was treated as linear elastic material. Time history method of dynamic analyses was conducted using acceleration time history of Bhuj earthquake, 2001.

From the analyses, it was found that the pile groups subjected to seismic load in parallel configuration deflected more than that in series configuration irrespective of group size and soil condition. Maximum displacement in parallel configuration indicates that soil offers little resistance to displacement and the only factor offering the resistance to displacement is the flexural rigidity of pile.

Keywords: End bearing Pile foundation; Pile Groups; Orientation of piles; Seismic Response of Piles; Non-linear dynamic analysis.

1. Introduction

A review on the history of earthquakes shows that earthquakes have disastrous impact not only on superstructures but on the structures embedded in soil also. This makes the seismic designing of foundations very important and hence the evaluation of dynamic interaction between the structure and the surrounding soil too. The seismic response of pile foundations depends on the soil-pile-structure interaction. In most of the numerical studies conducted, soil profile is idealized as homogeneous stratum. But actual soil is neither purely cohesive nor cohesionless. It is usually layered soil profile with varying properties. The response of piles in layered soils is different from that embedded in homogeneous soil because of the difference in the possible failure mechanisms. The soil profile as well as the configuration of pile foundations has effects on the seismic response of soil-pile-structures systems.

Sawant et.al, 2009, conducted studies on pile groups in series and parallel configuration subjected to lateral load. They found that under static lateral load, pile groups in series configuration were displaced more than that in parallel configuration. Narasimha Rao et.al conducted studies on pile groups embedded in marine clay subjected to lateral load in both series and parallel configurations. Several studies on the orientation of pile groups with respect to the direction of static lateral loading have been carried out earlier by Chandrasekaran et. al, 2010, Chore et. al, 2012 etc. But the studies on the influence of orientation on seismic response of pile groups need to be conducted.

2. Dynamic Analyses

Nonlinear three dimensional finite element analyses were conducted using MSC Softwares (2008). MSC.Patran and MSC.Marc were used as pre processor and post processor respectively and MSC.Marc Mentat as solver. Transient dynamic analyses were conducted using the acceleration time history of Bhuj earthquake, 2001 as input motion.

2.1 Description of Soil and Pile

End bearing pile groups, 1 x 2 and 1 x 3, in two types of soil mediums were considered in this study - pile groups in homogeneous stiff clayey soil and layered soil. Layered soil profile considered for the study was collected from Paravattani, Thrissur, Kerala. In homogeneous soil profile, cohesive stiff soil upto 10m depth from ground level was considered. Beyond 10m depth from ground level, the rock stratum of 2.1m depth was considered. The properties of the homogeneous stiff clay are Young's Modulus, E = 40 x 10^3 kN/m^2, Poisson's Ratio, ν = 0.3, Cohesion, c = 70 kN/m^2, Mass Density, γ = 1800 kg/m^3. The details of layered soil profile are shown in Table 1 given below.

Table 1: Description of Layered Soil Profile.

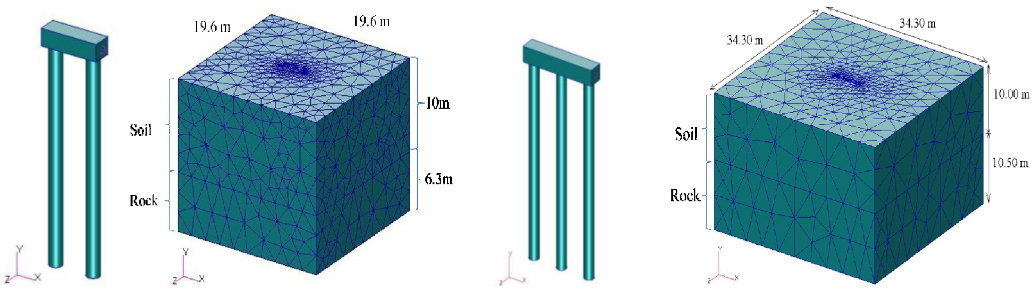
Depth from GL (m)	Description	Modulus of Elasticity (kN/m2)	Poisson's ratio	Cohesion (kN/m2)	Angle of internal friction (Degree)	Mass Density (kg/m3)
0 - 1.6	Clayey Sand	10 x 103	0.3	58	17	1850
1.6 – 2.8	Silty Clay	25 x 103	0.3	80	13	1900
2.8 – 9.1	Sandy Silt	20 x 103	0.3	70	26	1750
9.1 – 10.0	Silty Sand	20 x 103	0.3	15	27	1800
>10.0	Rock	50 x 106	0.24	-	-	2650

Concrete circular piles of diameter 0.7m are socketed within rock. Length of pile in soil was taken as 9.2m. Plan dimensions of pile cap of 1x2 pile group and 1x3 pile group were 3.1 x 3.1m and 5.2 x 5.2m respectively. Depth of pile cap considered for both pile groups were 0.8m. The properties of pile group and pile cap are E = 25 x 10^6 kN/m^2, ν = 0.15 and γ = 2500 kg/m^3.

Soil behaviour was modelled using Drucker-Prager constitutive model to incorporate nonlinear material behaviour. Behaviour of rock stratum was incorporated using Mohr Coulomb constitutive model. To model the behaviour of RCC pile, isotropic linear elastic model was chosen.

2.2 Finite Element Modelling

The finite element used for discretisation of the soil, rock and pile were Tet10 elements as it can model complex curved solids more accurately with fewer elements. The finite element models of 1 x 2 and 1 x 3 pile groups in homogeneous soil condition are shown in the Fig. 1.



(a) **(b)** **(c)** **(d)**

Figure 1: Finite element model of (a) 1 x 2 pile group, (b) 1 x 2 pile group embedded in homogeneous stiff cohesive soil,(c) 1x 3 pile group, (d) 1 x 3 pile group embedded in homogeneous stiff cohesive soil.

2.3 Seismic Loading and Boundary Conditions

The selection of the acceleration time history of earthquake was done based on the seismicity of the area from which the soil profile was taken for the study. As per Indian Standard Code IS 1893 (Part 1) – 2002, Kerala state is in the seismic zone III. The state comes in the area with Richter magnitude of earthquake of 6.5 to 6.9. One of the major disastrous earthquakes that occurred in India in the past was Bhuj earthquake, 2001 which had a Richter magnitude of 6.9. So the acceleration time history of Bhuj earthquake was considered for the study. The peak ground acceleration of Bhuj earthquake was 1.038 m/sec^2 at 46.94 sec. The acceleration time history for 25 sec, ie between 30sec and 55sec of Bhuj earthquake time history that include the peak acceleration, was considered as the input motion. The acceleration time history of Bhuj earthquake considered for the study is shown in the Fig. 2 given below:

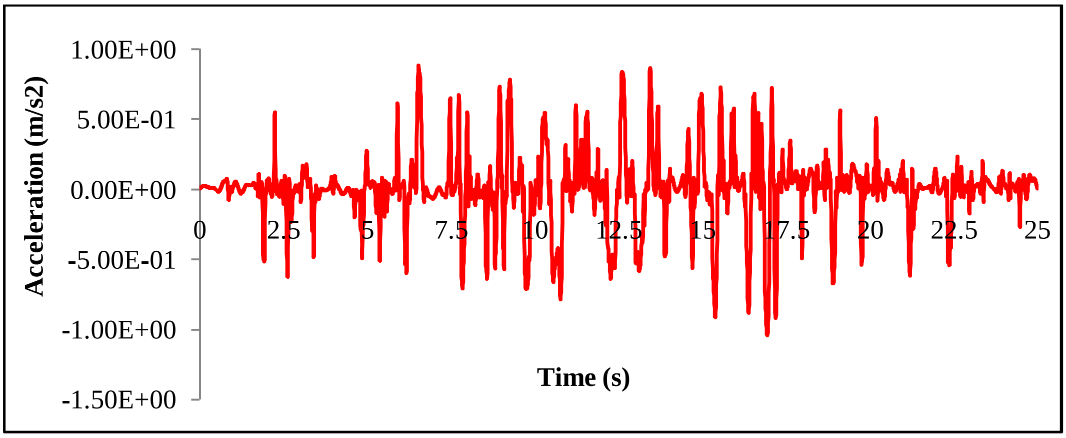


Figure 2: Acceleration Time History of Bhuj earthquake considered for the study

Piles in the group are spaced at a distance of 3D (D – diameter of pile) and are socketed into rock for a depth of 1D. The plan view of the pile groups and the direction of loading in series and parallel orientations are shown in the Fig. 3.

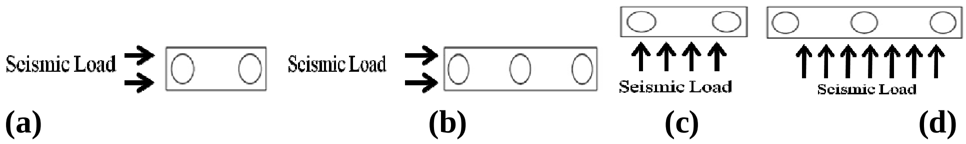


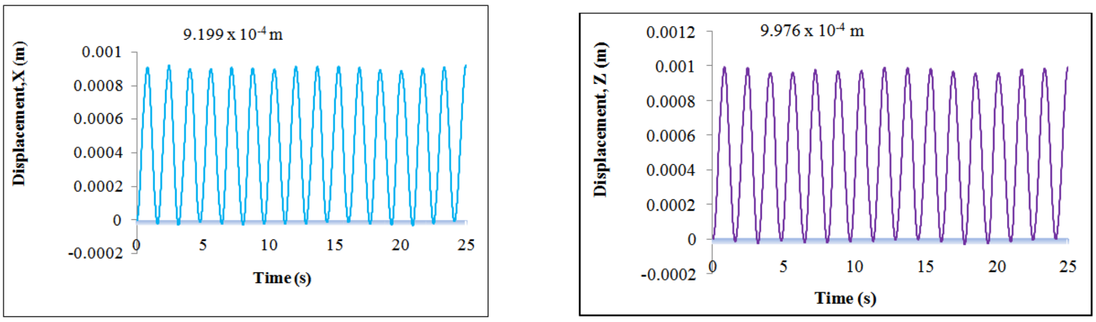
Figure 3: Seismic loading on pile group in series configuration (a) 1 x 2 pile group (b) 1 x 3 pile group and in parallel configuration (c) 1 x 2 pile group (d) 1 x 3 pile group.

3. Results and Discussions

Study on the seismic response of pile groups was conducted by carrying out dynamic analyses on 1 x 2 and 1 x 3 pile groups in series and parallel configurations in homogeneous stiff clayey soil and layered soil. A control point was selected at the centre of the pile cap at free surface and the response displacement of control point was plotted.

3.1 Pile Groups embedded in Homogeneous Stiff clay

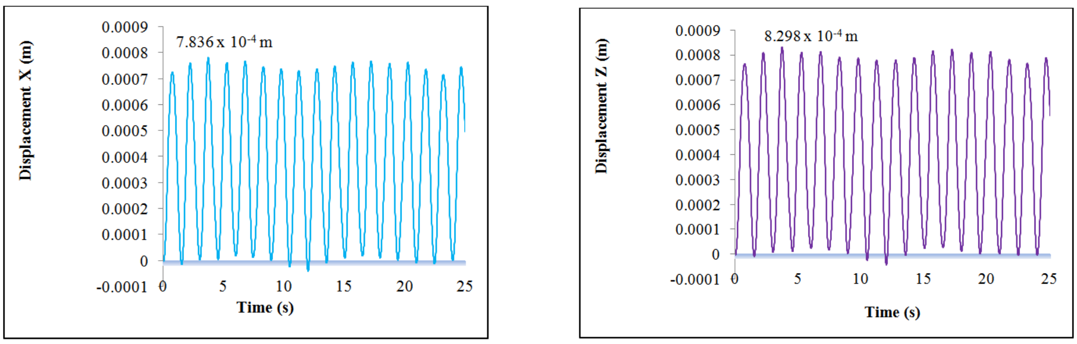
The response displacement vs. time plot of control point for 1 x 2 pile group embedded in homogeneous stiff clay subjected to seismic loading in series and parallel configuration is plotted. Fig. 4 (a) shows displacement in X direction, i.e., in the direction of loading in series configuration and Fig. 4 (b) shows displacement in Z direction, i.e., in the direction of loading in parallel configuration.



(a) **(b)**

Figure 4: Displacement Vs. Time Plot for 1 x 2 Pile Group in (a) Series Configuration and (b) Parallel Configuration.

From the Fig. 4 it can be seen that the maximum lateral displacement of 1 x 2 pile group subjected to seismic loading of 25sec duration in series configuration is 9.199×10^{-4} m and that in parallel configuration is 9.976×10^{-4} m. The response displacement vs. time plot of control point for 1 x 3 pile group embedded in homogeneous stiff clay subjected to seismic loading in series and parallel configuration is plotted. The displacement vs. time plot of control point for 1 x 3 pile group along the direction of loading in series configuration and in parallel configuration is shown in Fig. 5 (a) and 5 (b) respectively.



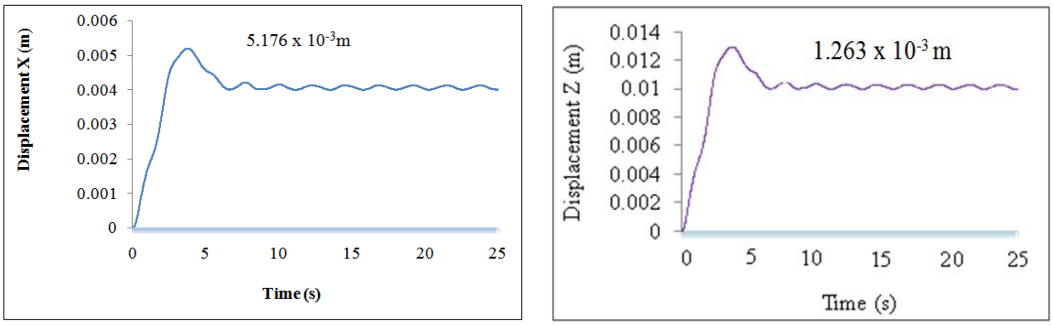
(a) **(b)**

Figure 5: Displacement Vs. Time Plot for 1 x 2 Pile Group in (a) Series Configuration and (b) Parallel Configuration.

From the Fig 5, it can be observed that the maximum lateral displacement of 1 x 3 pile group subjected to seismic loading of 25sec duration in series configuration is 7.836 x 10^{-4} m and that in parallel configuration is 8.298 x 10^{-4} m.

3.2 Pile Groups embedded in Layered Soil Medium

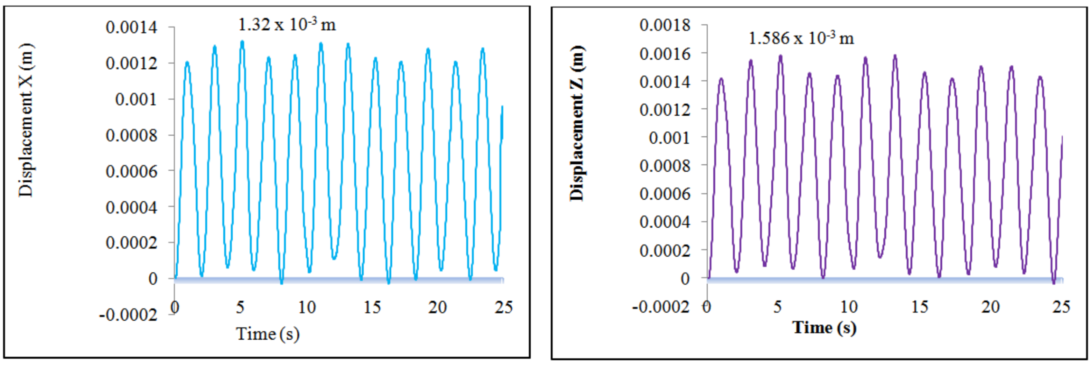
The response displacement vs. time plot of control point for 1 x 2 pile group in embedded in layered soil subjected to seismic loading in series and parallel configuration is plotted. Fig. 5 (a) shows displacement vs. time plot along the direction of loading in series configuration and Fig. 5 (b) shows that along the direction of loading in parallel configuration.



(a) **(b)**

Figure 6: Displacement Vs. Time Plot for 1 x 3 Pile Group in (a) Series Configuration and (b) Parallel Configuration.

From the Fig. 6, it can be seen that the maximum displacement of 1 x 2 pile group embedded in layered soil in series and parallel configurations are 5.176 x 10^{-3}m and 1.263 x 10^{-2} m respectively. The displacement vs. time plot of control point for 1 x 3 pile group subjected to seismic loading in series and parallel configuration are given in the Fig. 7 (a) and Fig. 7 (b) respectively.



(a) **(b)**

Figure 7: Displacement Vs. Time Plot for 1 x 3 Pile Group in (a) Series Configuration and (b) Parallel Configuration.

The maximum displacement of 1x3 pile groups embedded in layered soil in series and parallel configurations are 1.32 x 10^{-3} m and 1.586 x 10^{-3} m respectively.

From the results obtained, it can be understood that irrespective of the soil condition and pile group size, the maximum lateral pile head displacement occurred in pile groups in parallel configuration. Maximum displacement in parallel configuration is due to the fact that soil offers little resistance to displacement and the only factor offering the resistance to displacement is flexural rigidity of pile. The maximum lateral displacement in layered soil is more than that in homogeneous soil.

4. Conclusions

From the dynamic analyses conducted the following observations were made.

1. The maximum lateral pile head displacement occurred in pile groups in parallel configuration irrespective of the size and soil condition.
2. Maximum displacement in parallel configuration occurs since the soil offers little resistance to displacement and the only factor offering the resistance to displacement is flexural rigidity of pile.
3. The maximum lateral displacement in layered soil is more than that in homogeneous soil.

References

[1] H S Chore, V A Sawant and R K Ingle (2012), Parametric Study of laterally loaded pile groups using simplified F.E. models, *Coupled Systems Mechanics*, **1**, *1*, pp. 1-7.

[2] IS 1893 (Part 1) (2002), Criteria for earthquake resistant design of structures.

[3] R Narasimha, V G S T Ramakrishna and B M Roa (1998), Influence of rigidity on laterally loaded pile groups in marine clays, *J. Geotech. Geoenviron. Eng.*, **124**, *6*, pp. 542-549.

[4] S S Chandrasekaran, A Boominathan and G R Dodagoudar (2010), Group interaction effects on laterally loaded piles in clay, *J. Geotech. Geoenviron. Eng.*, **136**, *4*, pp. 573-582.

[5] Theory and User Information Marc (2010), **A.**

[6] V A Sawant and H S Chore (2009), Parametric Study of Pile group subjected to lateral load using ‘P-Y’ analysis, *Proc. Indian Geotech. Conference*, Guntur, pp. 723-726.