Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 52(5) (2020) 269-272
DOI: 10.22060/ceej.2018.15184.5848

3-Dimensional Numerical Modelling of Pile Group Response to Liquefaction-induced Lateral Spreading

A. Kavand* , A. Sadeghi Meibodi
School of Civil Engineering, College of Engineering, University of Tehran

ABSTRACT: In this paper, a 3D coupled soil-water finite element analysis is undertaken to simulate the behavior of a pile group subjected to liquefaction-induced lateral spreading. The results demonstrate that the numerical model can satisfactorily simulate the response of soil, including its accelerations, excess pore water pressures, and displacements as well as that of the piles including displacements and bending moments. Time histories of excess pore water pressure show that liquefaction in free field soil begins at the initial stages of shaking, and upon liquefaction, the amplitude of soil acceleration decreases. The maximum lateral displacement of the ground is observed in the regions far from the piles. On contrary, the extent of ground displacement decreases in areas close to the piles. The numerical model was able to predict the bending moment profiles in piles and particularly their maximum values. The maximum negative bending moments occur nearby the pile cap, while their maximum positive values are observed at the base of the piles. Moreover, the maximum bending moment in downslope piles of the group is about 70% greater than that in upslope one. The results of the parametric study show that with increasing either the flexural stiffness of piles or the relative density of the sand, the displacement of piles decreases while the bending moment in them increases. Also, it is revealed that the amplitude of input acceleration is the most influencing factor affecting the pile response as increasing it by a factor of 3.5 induces 3.6 times greater bending moments in piles.

Review History:

Received: 2018-10-26
Revised: 2018-12-07
Accepted: 2018-12-05
Available Online: 2018-12-17

Keywords:

Liquefaction
Lateral Spreading
Pile Group
Numerical Modelling
OpenSees

1. INTRODUCTION

Pile-supported structures in seismic prone coastal areas are exposed to liquefaction and its associated ground failures, including lateral spreading. Liquefaction-induced lateral spreading has been recognized as one of the most destructive causes of significant damage to pile foundations during past earthquakes (e.g., the 1964 Niigata, Japan, the 1989 Loma Prieta, USA, the 1995 Kobe, Japan, the 2010 Haiti and 2011 Tohuku, Japan). These observations have motivated researchers to scrutinize the mechanisms involved in pile damage during lateral spreading using analytical, experimental [1-3] and numerical [4-6] approaches. For numerical modeling of the problem, generally, two different approaches have been employed, including one-dimensional Winkler models (or p-y springs) and two or three-dimensional finite element analyses. The most prominent advantage of finite element modeling over Winkler models is its capability for precise consideration of the mechanisms affecting liquefaction of the soil as well as the soil-pile dynamic interaction.

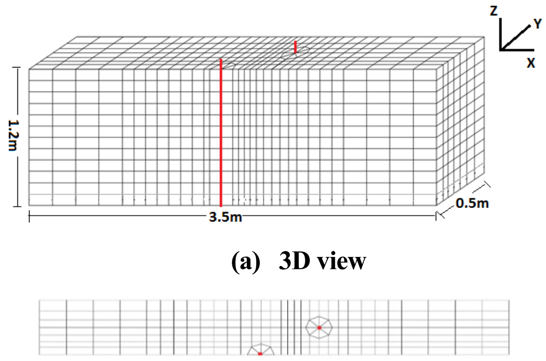
In the present paper, a soil-water coupled three-dimensional finite element model in OpenSees is developed to predict the seismic behavior of a pile group subjected to liquefaction-induced lateral spreading. The results of a large scale physical model test conducted on a marine dolphin supported on a group of piles with triangular pattern [7] are used for validation of the numerical simulation. Finally, a parametric study is undertaken to investigate the effects of various mechanical parameters of the soil and the pile on the model response.

*Corresponding author's email: akavand@ut.ac.ir

2. NUMERICAL MODELING

In this paper, OpenSees (Ver. 2.5.0) was used for three-dimensional finite element simulations based on dynamic effective stress soil-water analyses of porous media implementing u-p formulation. The numerical model was verified against a 1g large scale shake table test on a group of piles in laterally spreading ground made of Firoozkuh no.161 sand. A constitutive soil model based on the multi-yield plasticity framework named Pressure Depend Multi Yield (PDMY) model [8] was used to simulate the behavior of liquefied soil during lateral spreading. This model is capable of simulating the cyclic response of sands under undrained loading conditions. The constitutive parameters of this model were determined according to the index geotechnical properties of the model sand, or the general behavior of the model observed during the shake table test.

The modeled soil domain was 3.5 m long, 0.5 m wide (only half of the physical model width was included due to symmetry) and 1.2 m high (Figure 1), which was discretized by 2604 3D cubic elements termed as Brick-UP. Also, the piles were modeled using 178 elastic beam-column elements. The



(a) 3D view

(b) Plan view

Fig. 1. Finite element model used for numerical analysis

boundary conditions of the physical model in a rigid container were accurately imposed on the developed numerical model. The piles were fixed at their bottoms and were connected to the cap at their top points. Drainage was only allowed at ground surface nodes, and to model the ground slope, a portion of gravity corresponding to a 7% slope was applied to all soil elements in the slope direction. The numerical model was analyzed in two different stages including gravity and dynamic analyses. The well-known Newmark algorithm was used to integrate the dynamic equations of motion and in addition to hysteretic damping of the soil, a low viscous damping (Rayleigh type damping) of 2% was considered in the analysis. To check the convergence of solution during dynamic analysis, an energy increment test with a tolerance of 0.0001 was utilized.

3. RESULTS OF NUMERICAL ANALYSIS

Comparison between different parameters of the numerical and experimental models behavior including time histories of acceleration, excess pore water pressure, and displacement in free field soil as well as pile cap displacement and bending moment in piles shows that the two series of results are in acceptable agreement. Time histories of excess pore water pressure show that liquefaction in free field soil begins at the initial stages of shaking and upon liquefaction, the amplitude of soil acceleration decreases. The maximum lateral displacement of the ground is observed in the regions far from the piles. The maximum negative bending moments occur nearby the pile cap, while their maximum positive values are observed at the base of the piles. The maximum values of numerical and experimental bending moments in the piles are compared in Table 1. As seen, the numerical values are comparable to their corresponding experimental values. An interesting result is that the maximum positive bending moment in downslope pile of the group (P3) is about 70% larger than that obtained in the upslope pile (P1).

4. PARAMETRIC STUDY

After verification of the numerical model, a series of parametric analyses were conducted to investigate the effects of various parameters such as pile stiffness, soil density and the amplitude of input motion on the pile group response during lateral spreading. The results demonstrate that with increasing either the flexural stiffness of the piles or the relative density of the sand, the displacement of piles decreases while the bending moment in them increases. Also, it is revealed that the amplitude of input acceleration is the most influencing factor affecting the pile response as increasing it by a factor of 3.5 induces 3.6 times greater bending moments in piles.

Table 1. Maximum bending moments in model piles

Pile no.	Max. positive bending moment (kN.m)		Max. negative bending moment (kN.m)	
	Numerical	Experimental	Numerical	Experimental
P1	0.186	0.154	0.057	0.075
P3	0.318	0.269	0.069	0.064

5. CONCLUSIONS

Main conclusions of this research can be highlighted as below:

1- The numerical model acceptably simulated the development of excess pore water pressure in the free field and its variation with depth.

2- Comparison between simulated and experimental accelerations in free field soil shows a good agreement as the amplitude of acceleration decreases and its frequency content considerablely changes after liquefaction.

3- The employed numerical model satisfactorily predicted time histories of pile cap displacement as well as the variation of bending moments in piles with depth.

4- The numerical results illustrate that for a group of piles with a triangular pattern, the maximum bending moment in downslope pile is about 70% larger than that obtained for the upslope pile.

5- With reducing the flexural stiffness of pile to 0.2 of its initial value, the pile cap displacement increases about 9% and the induced bending moment decreases about 10% while increasing it by a factor of 5, reduces the pile cap displacement about 15% and increases the induced bending moments about 10%.

6- As the density of sand increases form an extremely loose state to loose and medium dense states, the pile cap displacement reduces about 60% and 82%, respectively, while the induced bending moments increase about 50% and 79%, respectively.

7- the amplitude of input acceleration is the most influencing factor affecting the pile response as increasing it by a factor of 3.5 induces 3.6 times greater bending moments in piles.

REFERENCES

[1] Haeri, S. M., Kavand, A., Rahmani, I., Torabi, H., 2012. "Response of a group of piles to liquefaction-induced lateral spreading by large scale shake table testing," *Soil Dynamics and Earthquake Engineering*, vol. 38, pp. 25-45.

[2] Kavand, A., Haeri, S. M., Rahmani, I., Ghalandarzadeh, A., Bakhshi, A., 2014. "Study of the behavior of pile groups during lateral spreading in medium dense sands by large scale shake table test," *International Journal of Civil Engineering*,

12(3-B), pp. 186-203.

[3] Brandenberg, S., Boulanger, R., Kutter, B., Chang, D., 2005. "Behaviour of pile foundations in laterally spreading ground during centrifuge test," *Journal of Geotechnical and Geoenvironmental Engineering*, 131(11), p.p 1378-1391.

[4] Uzouka, R., Cubrinovski, M., Sugita, H., Sato, M., 2008. " Prediction of pile response to lateral spreading by 3-D soil-water coupled dynamic analysis: Shaking in the direction perpendicular to ground flow," *Soil Dynamics and Earthquake Engineering*, 28(6), pp. 436-452.

[5] Cheng, Z., Jeremic, B., 2009. "Numerical Modeling and simulation of pile in liquefiable soil," *Soil Dynamics and Earthquake Engineering*, vol. 29, pp. 1405-1416.

[6] Rahmani, A., Pak, A., 2012. "Dynamic behavior of pile foundations under cyclic loading in liquefiable soils," *Computers and Geotechnics*, vol. 40, pp. 114-126.

[7] Haeri, S. M., Kavand, A., Raisianzade, J., Padash, H., Rahmani, I., Bakhshi, A., 2014. "Observations from a large scale shake table test on a model of existing pile-supported marine structure subjected to liquefaction induced lateral spreading," in *Second European Conference on Earthquake Engineering and Seismology*, Istanbul, Turkey.

[8] Elgamal, A., Yang, Z., Parra, E., 2002. "Computational modeling of cyclic mobility and post-liquefaction site response," *Soil Dynamics and Earthquake Engineering*, vol. 22, pp. 259-271.

HOW TO CITE THIS ARTICLE

A. Kavand, A. Sadeghi Meibodi, 3-Dimensional Numerical Modelling of Pile Group Response to Liquefaction-induced Lateral Spreading, Amirkabir J. Civil Eng., 52(5) (2020) 269-272.

DOI: 10.22060/ceej.2018.15184.5848