Numerical Study: Effects of New Piles' Installation on Adjacent Existing Piles

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ABSTRACT

The deep foundation technologies that are most applied in Vietnam and other countries are pile driving, static jack-in and press-in works. Among them, the press-in installation method seems to be the most promising method because of its mobility and rapid pile installation process with less noise and ground vibration. Piles installed by the press-in method may cause relatively large displacement of the ground surrounding a pile being pressed-in. Consequently, existing piles, foundations, underground walls and so on nearby may be significantly influenced. In Mekong River Delta, there were many cases showing that the existing riverside walls were collapsed when installing new piles next to the old ones. These effects are not considered in construction design. In this paper, the discrete element method (DEM) is proposed to study the effects of new piles' installation on adjacent existing piles in granular media. Piles are constructed by using a group of small particles bonded each other which allow lateral movement at many locations of piles, then it is allowed to move into the soil media, during this process, the behaviour of ground and existing piles will be observed.

Key words: *Pile Installation, Existing Piles, Ground Displacement, Discrete Element Method*

1. Introduction

In Vietnam, the deep foundation technologies that are most applied are pile driving and static jacking works (Pierre *et al*., 1989). The installation impact of these technologies to other buildings around the construction site, especially in narrow area of Hanoi, Ho Chi Minh City where houses and buildings are built closely or in soft soil area, is a big problem because it makes structures cracked, rutted or creates even landslide. In South of Vietnam, there were many cases where the existing riverside walls were collapsed when installing new piles next to the old ones. For instance in 2014, there was a harbor on Vam Co Dong river (Long An province) whose width and length are 2.1m and 7.4m, respectively; and the harbor was supported by concrete piles which length were about 30m, but all structures of harbor were damaged and moved away from land when installing new piles by diesel hammer. This is a reason for not using the press-in method in pile driving or not considering of new pile installation next to existing piles. Besides, there is not any method in Vietnam for calculation of these problems except for studies of modeling around the world at small-scale laboratories.

Pile installation has been conducted and modeled around the world for investigation of ultimate capacity, soil-pile interaction and also its effect. There are several methods in evaluating the ultimate uplift capacity of piles according to the load–displacement curve such as Hanna and Afram (1986), Rao and Nasr (2010). Hanna and Afram investigated the pull-out capacity of single rigid vertical and batter piles in sand and subjected to axial loading; they found that the pull-out capacity of batter piles decreases slightly when the pile inclination increased. Rao and Nasr conducted small-scale model tests to investigate the behavior of vertical single piles embedded in reinforced and non-reinforced cohesionless soil; they found that the behavior of piles under uplift loads within geogrid reinforcement involves a complex interaction between the surrounding soil, the pile surface and the geogrid layers. Besides, the tangent intersection method has been used by Hirany and Kulhawy (1989) for the asymptotic load–displacement curve with a rapid transition from elastic behavior to failure. Then, in order to make it simpler, especially in modeling, Fang *et al.* (2014) defined the uplift load corresponding to the axial displacement of the pile equal to 10% of the pile diameter or they used the 32.5kN of ultimate uplift capacity in view of serviceability based on the idea of Nasr (2013). This 32.5kN of ultimate uplift capacity will be used in this paper. Furthermore, the installation process of a jacked displacement pile, and the influence on the soil during installation, is still a subject of research such as Lobo-Guerero *et al.*. (2005, 2007), Jiang *et al.*. (2006), Yetginer *et al.* (2006), Tran *et al.* (2012), and Lee *et al.* (2012) who used the Discrete Element Method (DEM) for their researches instead of the Finite Element Method. After Fang *et al.* (2014), 2D DEM is still useful from the geotechnical engineering viewpoint due to its ability in featuring the strength properties, failure and instability of geo-materials with carefully-calibrated contact models. 2D DEM is an advantageous choice using a current conventional computer to investigate large boundary-value problems with an extremely large number of particles.

The main objective of this paper is to construct a 2D DEM framework for simulating pile installation with a particular emphasis on selecting an appropriate contact model and parameter of soil and pile particles, and then to examine the penetration mechanism. Afterwards, the simulation results reveal the effects when a new pile was installed close to an old pile, including vertical and horizontal displacement. In the two survey cases of distances between the new pile and the existing pile are three and five times the diameter of the pile.

2. Simulation from discrete element method

The DEM software, Particle Flow Code in Two Dimensions (PFC2D version 5.0, Itasca Company, USA) was used in this study. In the following sessions, the simulation setup and procedures are described in detail.

The geometry of the problem being considered in two dimensions (plane-strain conditions) in which the height and width are the same and are 22m. The out-of-plane thickness of the DEM model is 1 m. A pile with a diameter of 0.4m and an embedded length of 7.1m is used. In this study, two cases of distances between 2 piles are used for evaluation: 3D and 5D with D is the pile diameter. The chosen distance from existing pile to the closest boundary is 9m which is bigger than 20 times of the pile radius. 20 times of pile radius comes from Bolton *et al.* (1999) who conducted centrifuge experiments and concluded that the additional stresses on the side boundary induced by penetration is too small to have any effect on the tip resistance when the hard boundary is sufficiently far from the penetrometer, farther than 20 times of the pile radius.

In this study, the problem was scaled down to 1/20 in size of the prototype discrete element method model. Accordingly, the gravity acceleration used in the simulation was scaled up in such a way that the scaled model provided the same gravity-induced stress field as the prototype. Water was not physically modeled in the simulation and the gravity acceleration was justified to account for the reduction of effective stresses due submergence. As a result, the scaling factor of gravity acceleration (n_g) was computed as follows:

$$n_g = \rho' n_d / \rho \qquad (1)$$

where n_d is the scaling factor of geometric dimensions and n_d=20 used in this study; ρ is the density of the particles, and ρ' is the buoyant density of the particles, ρ=2.6g/cm^3 and ρ'=1.6g/cm^3 is used. Then, the gravity acceleration is 12.31g.

The parameters of soil and pile particles are showed in **Table 1** and **Table 2**.

The simulation procedure of the pile – soil interaction includes three steps: (1) ground generation; (2) pile installation; and (3) pile loading. Firstly, a homogenous ground was applied based on the expansion method which is used widely (Tran and Lee, 2012) as follows: ground generated by creating wall, then generating particle; then running to get balance and applying friction, as well as gravity acceleration of 12.31g; then running until the force equilibrium was reached; then removing the top wall and running to get balance. Secondly, pile installation based on Fang *et al.* (2014) was initiated by removing the particles where the pile was intended, forming a 20mm wide and 400mm high space in the model. This space was then filled with a pile which was assembled by a total of 320 disks with a diameter of 5mm. This pile is regarded as a non-displacement pile, since it was virtually installed in the space left by soils previously removed without disturbing the surrounding soils or changing the stress state at any point of the surrounding soils. Then, the pile was formed by regularly arranging identical circular particles in the loosest packing with a theoretical planar void ratio of 0.27. The particle density was chosen in such a way that the pile is comparable to a concrete pile with the bulk unit weight equal to 23.5kN/m^3. The parallel bond contact model was used here for the contact behavior of the pile particles with model parameters given in **Table 2**. Extremely large values were assigned to the strength parameters of the parallel bonds in order to avoid failure in the pile itself. The inter-particle friction coefficient of pile particles was set to be 5 to eliminate unwanted particle slippage. However, a smaller inter-particle friction coefficient equal to 0.75 was used at pile–soil contacts to render the reasonable friction characteristics on the pile–soil interface. The parameters associated with particle stiffness and parallel bond stiffness were selected in such a way that the pile resembled a concrete pile made of concrete with the Young's modulus of 30GPa according to the Vietnamese standard. In order to reach this point, a vertical cantilever pile with a fixed base was simulated in response to a horizontal load at the pile head, and the parameters associated with stiffnesses were justified on a trial-and-error basis until the pile deflection matched the theoretical value based on the Timoshenko beam theory. Finally, pile loading was simulated by applying 0.5mm/s of velocity on particles on the top of the pile and running until getting desired settlement which is measured by tracking location of particles on the top of the pile. Force is measured by summing the vertical component of the contacts between soil particles and pile particles.

Table 1. Summary of soil parameters

Parameter	*Value*
Particle size (mm)	6-9
Initial planar void ratio	0.21
Particle density (g/cm^3)	2.6
Particle-wall normal stiffness (N/m)	$6x10^8$
Particle-wall tangential stiffness (N/m)	$4x10^8$
Local damping coefficient	0.7
Viscous damping coefficient	0.0
Particle normal stiffness (N/m)	$6x10^8$
Particle tangential stiffness (N/m)	$4x10^8$
Inter-particle frictional coefficient	0.75

Table 2. Summary of parameters of pile particles

Parameter	*Value*
Particle number	320
Particle diameter (mm)	5
Initial planar void ratio	0.27
Particle density (g/cm3)	3.06
Inter-particle frictional coefficient	0.75
Parallel bond normal tensile strength (Pa)	$1.0x10^{100}$
Parallel bond tangential shear strength (Pa)	$1.0x10^{100}$
Particle normal stiffness (N/m)	$6x10^8$
Particle tangential stiffness (N/m)	$2.4x10^8$
Parallel bond normal stiffness (Pa/m)	$5.66x10^{12}$
Parallel bond tangential stiffness (Pa/m)	$2.26x10^{12}$
Parallel bond radius ratio r	1

The procedure of installing new piles next to the old ones is: Adding the existing pile; using walls to create a new pile with the same diameter of the existing pile, the distance between the new pile and the existing pile is 3D and 5D; applying 30kN of designed load on the existing pile by applying load on particles on the top of the pile and the force is 32.35kN as 2.35kN contributes from the weight of pile. All model setups, including penetration process of the new pile by applying velocity of 10cm/s on the walls or the new pile, could be seen on **Fig. 1**.

Effects of new installed piles next to the existing pile are presented from **Fig. 2** to **Fig. 5** for two types of piles distances.

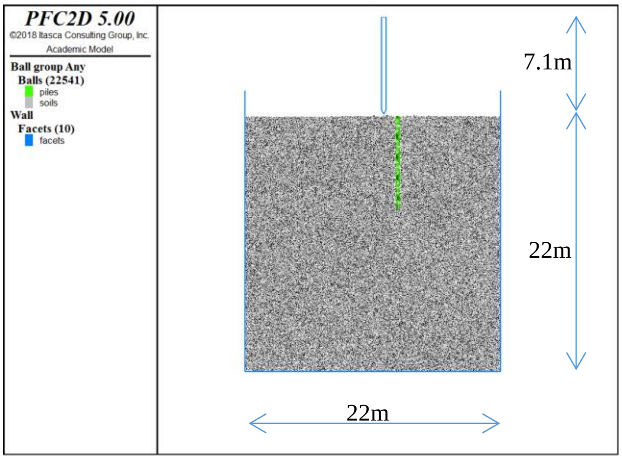

Fig. 1 Model setup

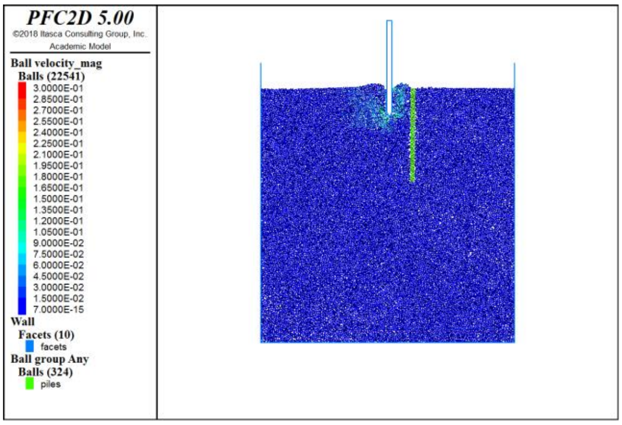

Fig. 2 Field velocity when the penetration depth of the new pile below 2.1m (distance of piles is 5D)

3. Effects of new pile installation on existing pile

Force was measured by summing the vertical component of the contacts between soil particles and pile particles; the vertical and horizontal displacements of the existing pile were also measured.

The changes of load and vertical displacement on the existing pile during the penetration of a new pile are in **Fig. 6** and **Fig. 7**. **Fig. 6** shows the force or load in the existing pile when a new pile was installed. It indicates that the 30kN applied load is rather good and there are some scatters for the case of 3D of distance of piles. **Fig. 7** shows that when the penetrated depth of a new pile is about half of existing pile length, two cases of distances are the same in normalized vertical displacement of the existing pile. When the penetrated depth of the new pile is over half of the existing pile length, the trend of displacement of two cases are different because of the effect of distances between old and new pile.

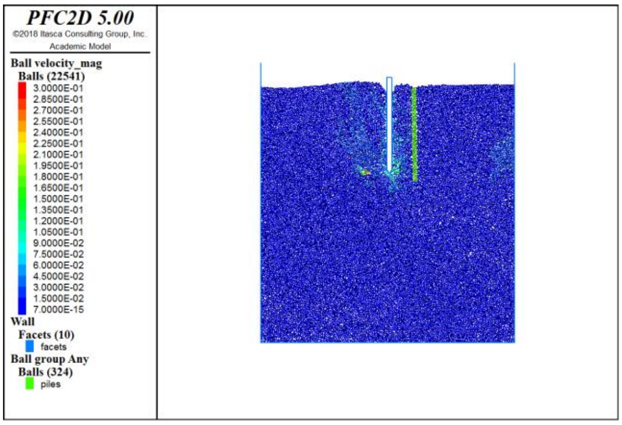

Fig. 3 Field velocity when the penetration depth of the new pile below 7.1m (distance of piles is 5D)

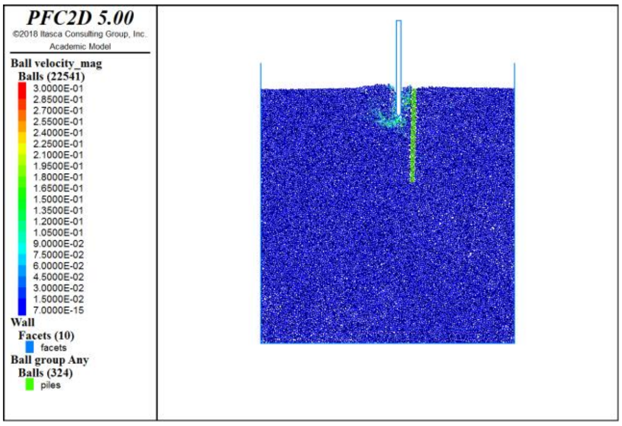

Fig. 4 Field velocity when the penetration depth of the new pile below 2.1m (distance of piles is 3D)

Besides, the effect of a new pile installation on an existing pile can be seen through the horizontal displacement of the existing pile during the penetration of new pile. These effects are in **Fig. 8** and **Fig. 9**. As a result, the tendency of cures between normalized of the existing pile and normalized of horizontal displacement are based on the penetrated depth of installing a new pile.

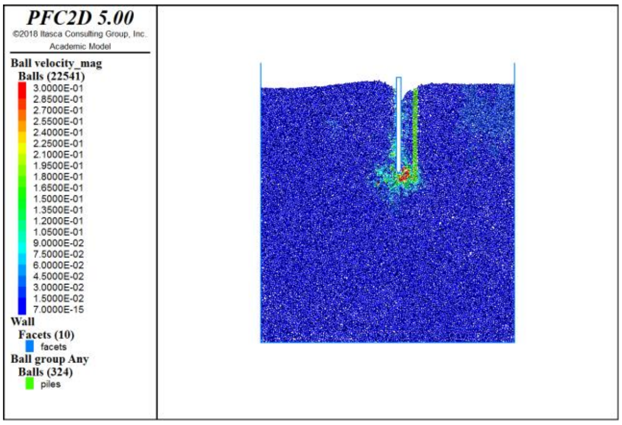

Fig. 5 Field velocity when the penetration depth of the new pile below 7.1m (distance of piles is 3D)

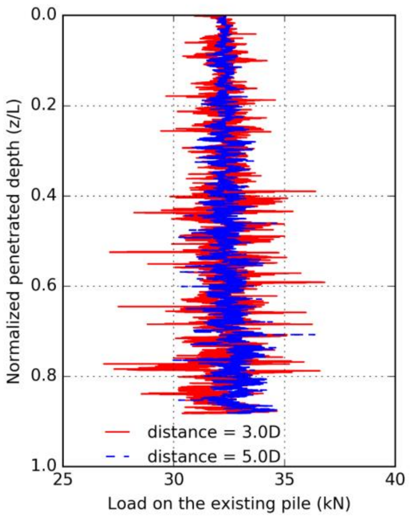

Fig. 6 Changes of load on existing pile during the penetration of a new pile

4. Concluding remarks

The paper presents the first stage in consideration of the effect of a new pile driving on an existing pile by using the discrete element method in two dimensions. Two piles with 0.4m of diameter and 7.1m of embedded length was used. Two cases of distances between 2 piles are used for evaluation: 3 and 5 diameter called the first and the second case, respectively. The main conclusions are as follows:

- The present new pile affects to horizontal and vertical displacement of the existing pile;
- When the new pile was installed at the middle of the existing pile, vertical displacements of two cases have same trend and vice versa;
- The horizontal displacements of the existing pile increased when a new pile was embedded at the lowest level.

In the future, the experiment of two piles should be conducted for checking the agreement between the analytical and test results.

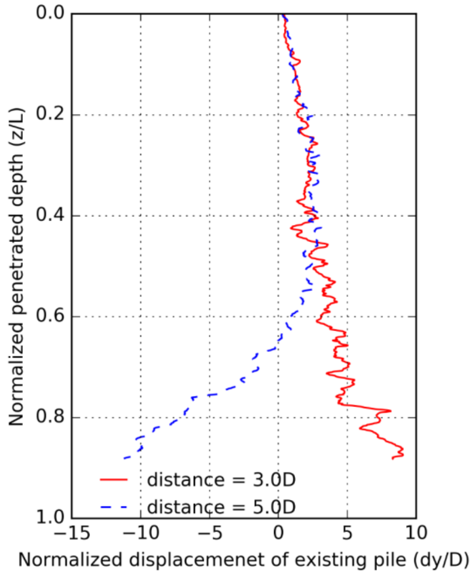

Fig. 7 Vertical displacement of the existing pile during the penetration of a new pile

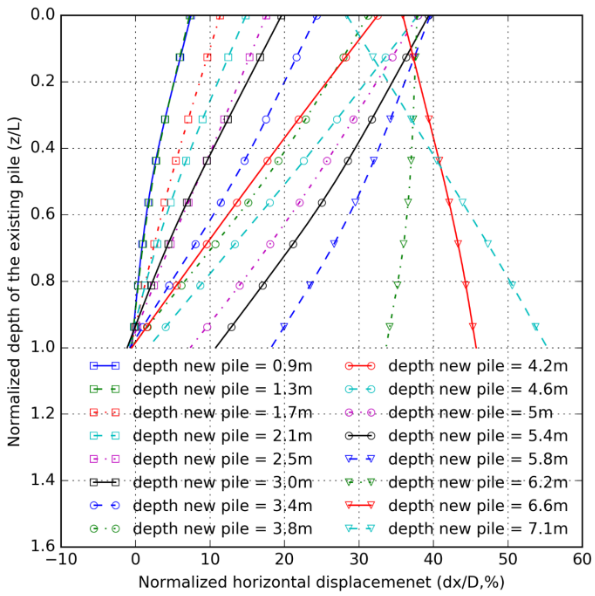

Fig. 8 Horizontal displacement of the existing pile during the penetration of a new pile (distance of piles is 5D)

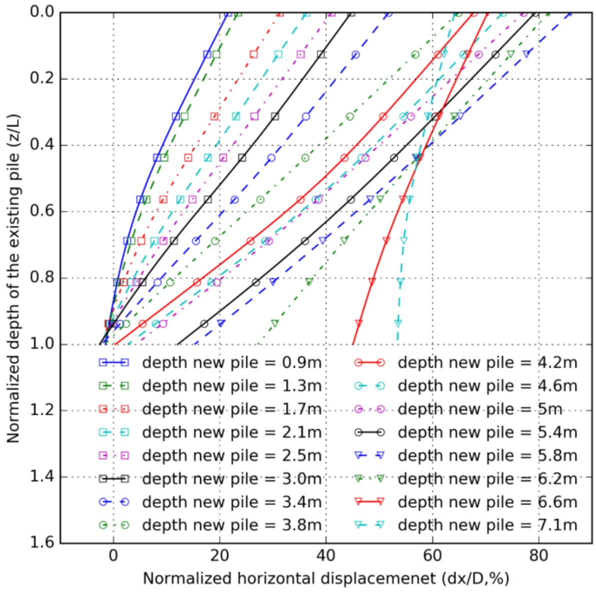

Fig. 9 Horizontal displacement of the existing pile during the penetration of a new pile (distance of piles is 3D)

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