PARAMETRIC STUDY OF LATERAL DISPLACEMENT DUE TO PILE GROUP INSTALLATION

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ABSTRACT: Pile installation generates lateral ground movement and excess pore pressure surrounding it. Both are causing problem to the existing adjacent earth structures. The objective of this paper is to do sensitive analysis of lateral ground movement due to pile group installation. Pile numbers, diameter, and spacing are the parameters to be considered. Plaxis is utilized to do numerical analysis and pile installation is modeled using displacement controlled cavity expansion. The lateral displacement – pile group correlation charts are proposed based on the simulation results. The charts are useful to predict the lateral displacement on pile group design.

Keywords: *Pile Group, Lateral Ground Movement, Pile Installation, Numerical Analysis.*

INTRODUCTION

Pile installation generates lateral ground movement and excess pore water pressure surrounding it. Both are causing problem to the existing adjacent earth structures. Poulos (1994) describes the displacement of soil while installation of the following: (i) horizontal movement relatively uniform at a depth of about $0.8L$, where L is the depth of penetration of the time of pile installation, (ii) The movement of the soil under the pile tip decreases rapidly according to its depth, and (iii) the maximum displacement does not depend on the depth of penetration and decreases with distance from the pile.

Prediction radial displacement of soil caused by the installation of a single pile can be approximated by cavity expansion theory given by Carter et al (1979), Vesic (1972), and also Chai et al (2005, 2007). Francescon (1983) and Pestana et al (2002) conducted experiments on soil movement due to the installation of the pile into the clay soil is saturated, the results are also consistent with the theory of cavity expansion.

Broere and Van (2006), as well as Pham (2009) has conducted a simulation jacked pile. The simulation using Plaxis 2D with axisymmetry model and the wall along the cavity which represents the pile applied displacement (prescribed displacement). The numerical results give void ratio and stress values around the pile that is acceptable when compared with the results of centrifuge tests. Stress-controlled methods cavity expansion and displacement - controlled cavity expansion into appropriate methods for the numerical simulation of displacement pile installation (Satibi et.al, 2007). For pile installation, the result will be more thorough if approached with cavity expansion method and theory of displacement (Maryono, 2014).

In the previous paper has explained the numerical simulation for analysis of lateral displacement and excess pore water pressure due to the installation of single pile. Numerical simulations using the displacement method - controlled cavity expansion results lateral displacement and excess pore water pressure when compared to the corresponding cavity expansion theory given by Carter et al (1979) and Randolph et al (1979).

Generally lateral displacement issues involving more than one pile, so it takes prediction lateral displacement due to the installation of a pile group. In this paper will be presented graphs / charts in order to facilitate the prediction lateral displacement due to the installation of pile groups.

SOIL PARAMETERS AND GEOMETRY

In this numerical analysis, pile parameter considered as linear elastic with parameters as in Table 1. As for soil behavior to be considered as an elastic-plastic model of Mohr Column using the parameters in Table 2, where the soil layer is considered as a homogeneous soil with undrained condition.

Table 1. Pile Parameter (Linier-Elastis)

Parameters	Unit	Values
Unit weight ( )	kN/m^3	24
Poisson's Ratio (ν)	-	0,2

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Young's Modulus (E□)	MPa	23500

Table 2. Soil Parameter (Mohr-Column)

Parameters	Unit	Values
□Unit weight (□□)	kN/m^3	15,66
Poisson's Ratio (v□)	-	0,35
Young's Modulus (E□)	kPa	3300
Cohession (c_u)	kPa	11
Friction Angle (□□)	^{0}	0,8

(References: Soil investigation reports of Project X)

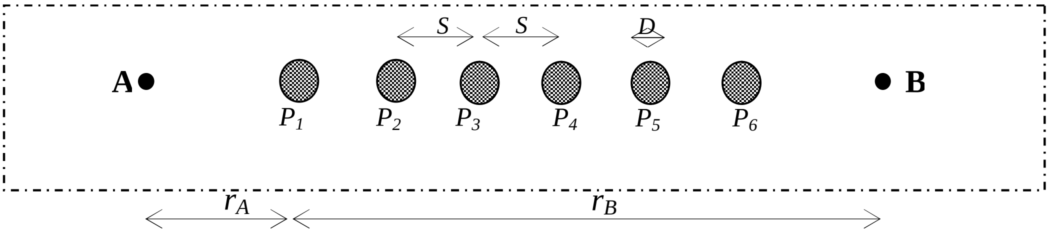


Figure 1. Plan - Pile Group Model

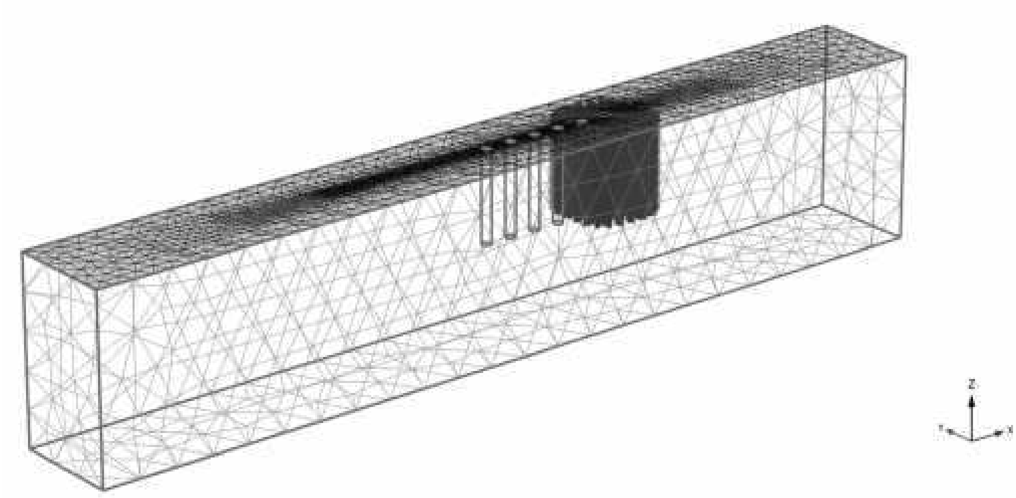


Figure 2. Geometry Model in Plaxis 3D

Pile group modeled extending in rows direction as shown in Figure 1. The diameter D of the pile is 30 cm and 50 cm of length L pile is 5 m, space of piles S taken as 2,5D and 3D, Total n piles is determined to 6 piles, point A and B are points to be reviewed when the lateral displacement simulation pile installation that begins from P1 to P6. Radial distances r_A and r_B taken from 5D to 30D. The geometry modeled on the Plaxis 3D as shown in Figure 2. Meshing elements are determined in such a way to get results when compared with the theory according to single pile given by Carter et al.

SIMULATIONS

Simulations performed using the displacement method - controlled cavity expansion. The process begins by setting the initial conditions. There after, the pile element is removed to create a cavity along the center line, then apply the priscribed displacement horizontal direction uniformly on the walls of the cavity. In addition, the vertical stress ($\sigma'_v = \gamma \cdot L$) is also applied in the bottom of the cavity, where L is the length of the pile is embedded. Stages of numerical simulation pile group for P1 to P6 are presented in Table 3, where the direction of installation begins from the point P1 to leave point A and point to point B. For Phase-1 (P1), simulation results compared with the cavity expansion theory given by Carter et al (1979), namely:

$$□ = (r^2 + r_0^{\,2})^{0,5} - r \tag{1}$$

where □□ is lateral displacement of soil. The symbols r and r_0 denote the horizontal distance between the point reviewed and the center of pile and the outer radius of pile. The numerical simulation conducted consists of 4 types of simulations with variations in diameter D of pile and spacing of pile S as shown in Table 4.

Table 3. Numerical Simulation Stages

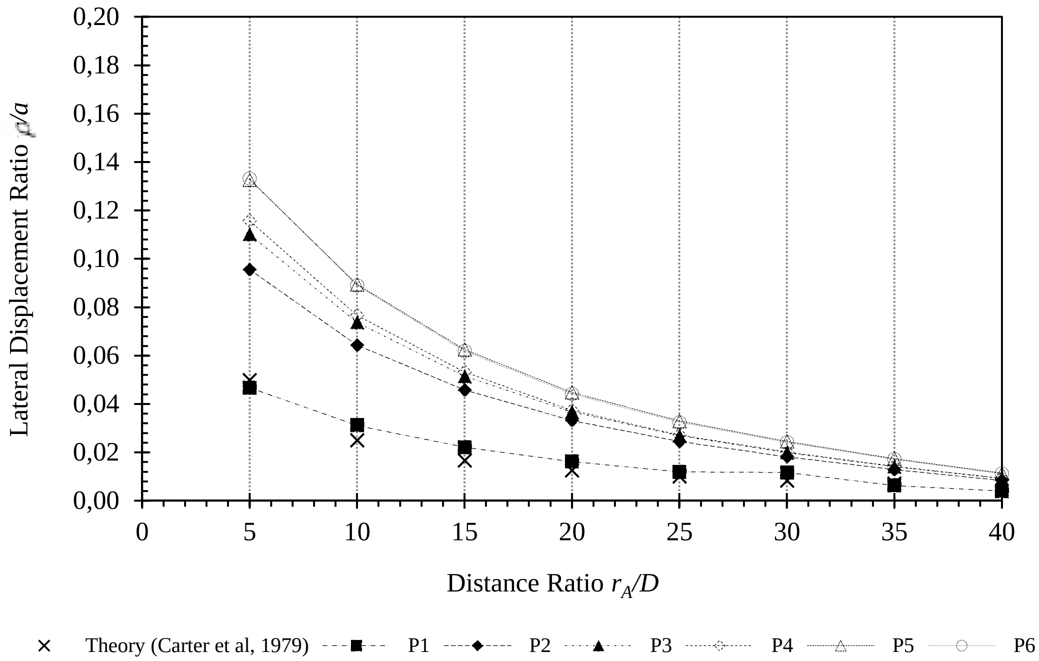
Phase	Construction Phase
Initial	Initial Stress
Phase-1 (P1)	Created cavity and prescribed displacement/stress for P1.
Phase-2 (P2)	Apply pile material and removed prescribed displacement/stress for P1. Created cavity and prescribed displacement/stress for P2.
Phase-3 (P3)	Apply pile material and removed prescribed displacement/stress for P2. Created cavity and prescribed displacement/stress for P3.
Phase- 4 (P4)	Apply pile material and removed prescribed displacement/stress for P3. Created cavity and prescribed displacement/stress for P4.
Phase-5 (P5)	Apply pile material and removed prescribed displacement/stress for P4. Created cavity and prescribed displacement/stress for P5.
Phase-6 (P6)	Apply pile material and removed prescribed displacement/stress for P5. Created cavity and prescribed displacement/stress for P6.

Table 4. Simulation Type

Type	Diameter D, cm	Space S, m
Simulation - 1	50	3 D
Simulation - 2	50	2,5 D
Simulation - 3	30	3 D
Simulation - 4	30	2,5 D

RESULT & ANALISYS

Figure 3a and 3b show the correlation between the ratio of the lateral displacement of pile radius □ / a from Simulation-1, where the pile diameter D in this simulation is 50 cm and the spacing of pile S is 3D. Notation r_A is the distance between point A to pile P1, while r_B is the distance between point B to the pile P1. For Phase-1 (P1), The lateral displacement □□□ from Simulation-1 is similar when compared with the results of calculations based on the theory of cavity expansion given by Carter et al , this is because the simulation of Phase-1 (P1) is single pile simulation.



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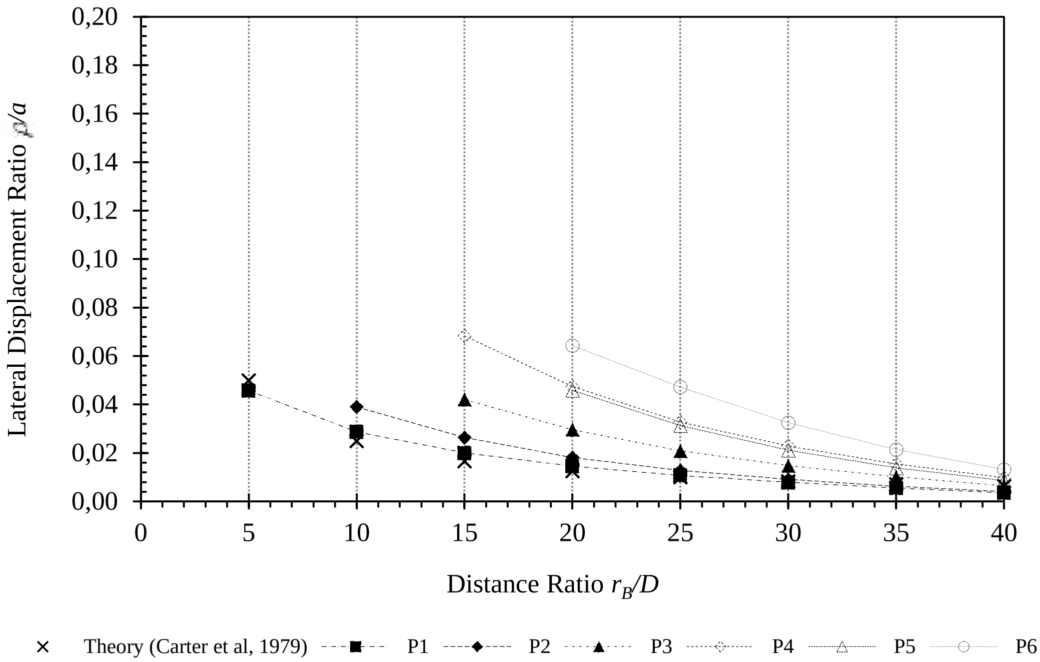

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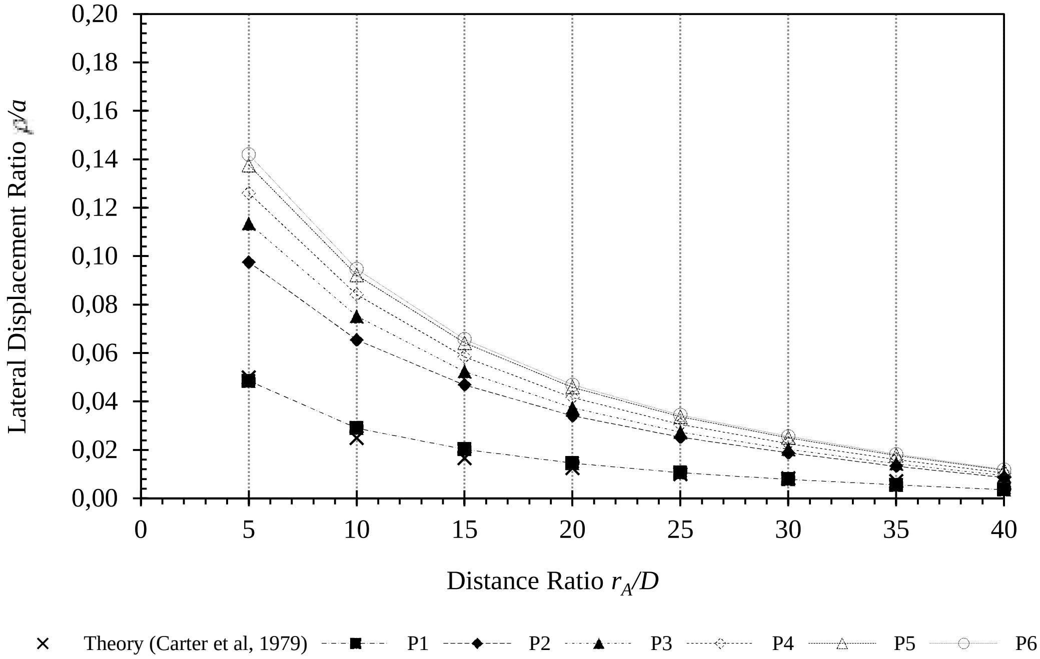
Figure 3. Lateral Displacement of Numerical Simulation Results Plaxis 3D, Diameter D = 50 cm and Space of Pile S = 3D: (a) Point A, (b) Point B.



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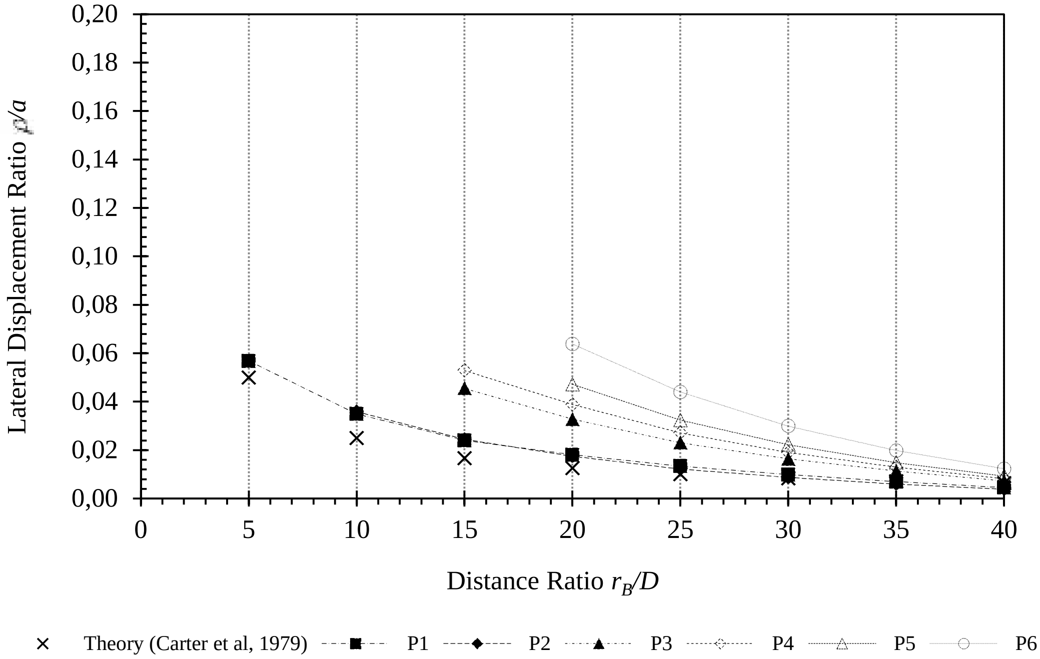


(b)

Figure 4. Lateral Displacement of Numerical Simulation Results Plaxis 3D, Diameter D = 50 cm and Space of Pile S = 2,5D: (a) Point A, (b) Point B.

The results of Simulation-1 at point A (Figure 3a) shows the direction of pile instalation is getting away from a point (Point A). For Phase-1 to Phase 6 (Pile pile P1 to P6) showed that the displacement lateral □ is increased as the number of piles n. For Phase-6, the value of the displacement ratio □□/ a at point A with distance r_A = 5D is 13.31% and then decreased to 1.12% at a distance r_A = 40D, this show that when the distance r_A (point P1 to point A) increasingly, the lateral displacement ratio is decreases. At a distance r_A = 20D □x lateral displacement changes from Phase-5 to Phase 6 is 0.2 mm smaller than the lateral displacement changes □x from Phase-1 to Phase-2 is equal to 4.2 mm, this shows the lateral displacement changes □x tends to shrink as the numbers of piles n.

The results of Simulation-1 at point B (Figure 3b) show the direction of pile instalation that closer to a point (Point B). The results of simulation show that the direction of installation may affect the value of lateral displacement □.

When the spacing distance r_B (point P1 to point B) is increasing, then the lateral displacement ratio decreases. For Phase-6, the value of the displacement ratio □□/ a at point B with the distance r_B = 40D is 1.32%, where as for the distance r_B = 20D is 6.44%, this value is greater than the value of the displacement ratio □□/ a in A point with a distance r_A = 20D is 4.41%. However, in Phase-2, the ratio of lateral displacement □□/ a at point B looks smaller than the lateral displacement ratio □□/ a at point A at the same distance ratio.

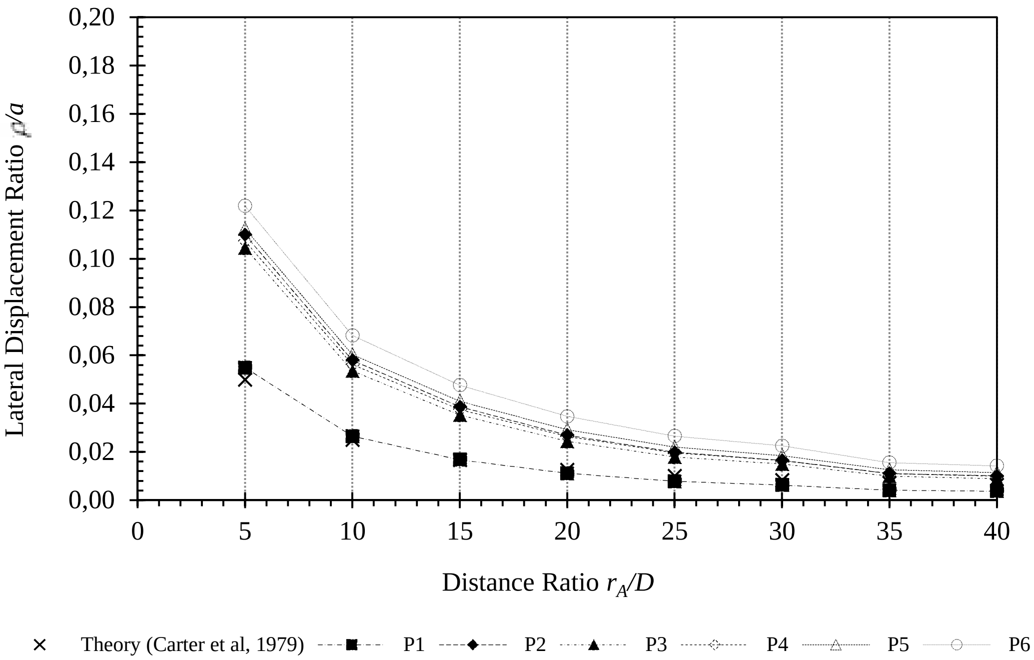
Figure 4a and 4b show the correlation between the lateral displacement ratio of radius □□/ a from simulation-2. The result of Simulation -2 at point A (Figure 4a) for Phase-1 to Phase-6 (P1 to P6) provides trends displacement ratio □□/ a is similar as the results of Simulation-1 at point A (Figure 4a), which in Phase-6 displacement ratio value □□/ a at point A with distance r_A = 5D is 9.47% and then decreased to 1.19% at a distance r_A = 40D. The result of Simulation-2 at point B (Figure 4b) also provides trends displacement ratio □□/ a is equal to the Simulation-1 at point B, which in Phase-6 displacement ratio value □□/ a at point B with the distance r_B = 40D is 1,23%, where as for the distance r_B = 20D is 6.38%, this value is greater than the value of the displacement ratio □□/ a at point A with distance r_A = 20D is 4.69%.

Figure 5a and 5b shows the correlation between the lateral displacement ratio of radius □□/ a from Simulation-3, As Simulation-1 and Simulations-2, The results of Simulation-3 for Phase-1 (Single pile) provide sufficient appropriate lateral displacement □□□current compared with the results of calculations based on the theory of cavity expansion given by Carter et al. The result of Simulation-2 in point A (Figure 5a) for Phase-1 to Phase-6 (P1 to P6) provides trends displacement ratio □□/ a is similar as the results of Simulation-1 and Simulation-2 in point A (figure 5a), where in the ratio of the value of the displacement Phase-6 □□/ a at point A with distance r_A = 5D is 7.65% and then decreased to 1.63% at a distance r_A = 40D. The result of Simulation-2 at point B (Figure 4b) also provides trends displacement ratio □□/ a similar with results of Simulation-1 and Simulation-2 at point B. For Phase-6, displacement ratio value □□/ a at point B with the distance r_B = 40D is 1.13%.

Figure 6a and 6b show the correlation between the lateral displacement ratio of radius □□/ a from simulation-4. The result of simulation-4 at point A (Figure 6a) for Phase-1 to Phase-6 (P1 to P6) provides trends displacement ratio □□/ a is similar as the results of previous simulation at point A (Figure 6a), where as in Phase-6 displacement ratio value □□/ a at point A with distance r_A = 5D is 8.41% and then decreased to 1.58% at a distance r_A = 40D. The results of Simulation -2 at point B (Figure 6b) also provides trends displacement ratio □□/ a is equal to the previous simulation at point B, which in Phase-6 displacement ratio value □□/ a at point B with the distance r_B = 40D is 0 , 98%.

Of the four aforementioned simulation can be seen that the simulation gives the similar trend that this shows that when the distance r_A (P1 to point A) and the distance r_B (P1 to point B) is increasing, then the lateral displacement ratio decreases, whereas in distance 40D, the value of lateral displacement ratio is very small, this is less than 2%.

There is little difference between the results of simulation-1 to simulation-4 for Phase-1 (single-pile) with the theory given by Carter et al is due to the determination of element mesh, where the finer the mesh arrangement of the elements then the result will be better.



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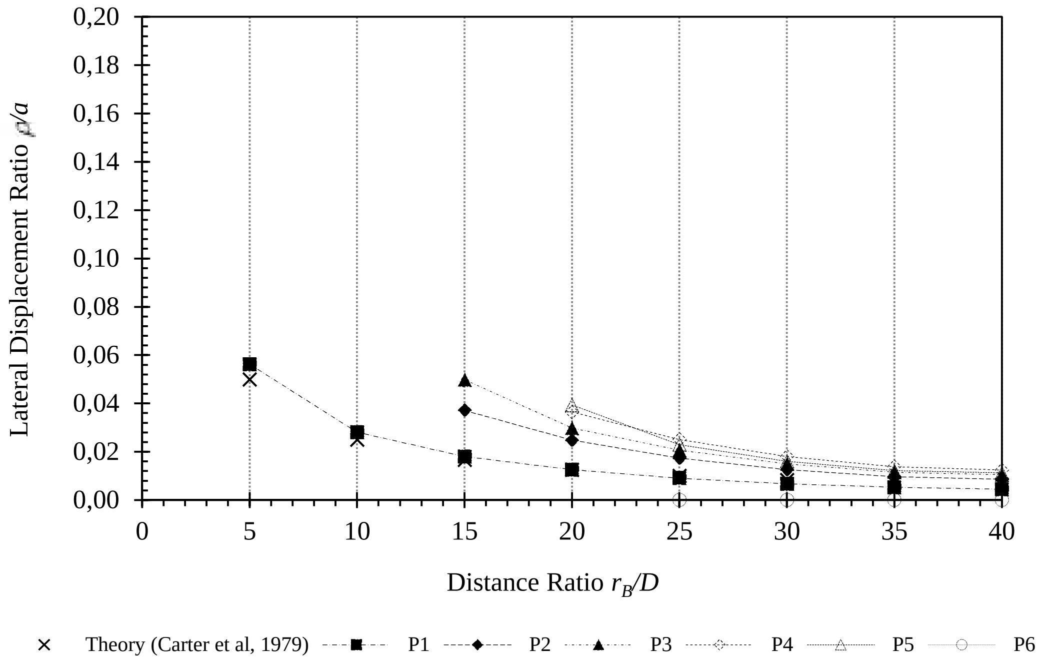

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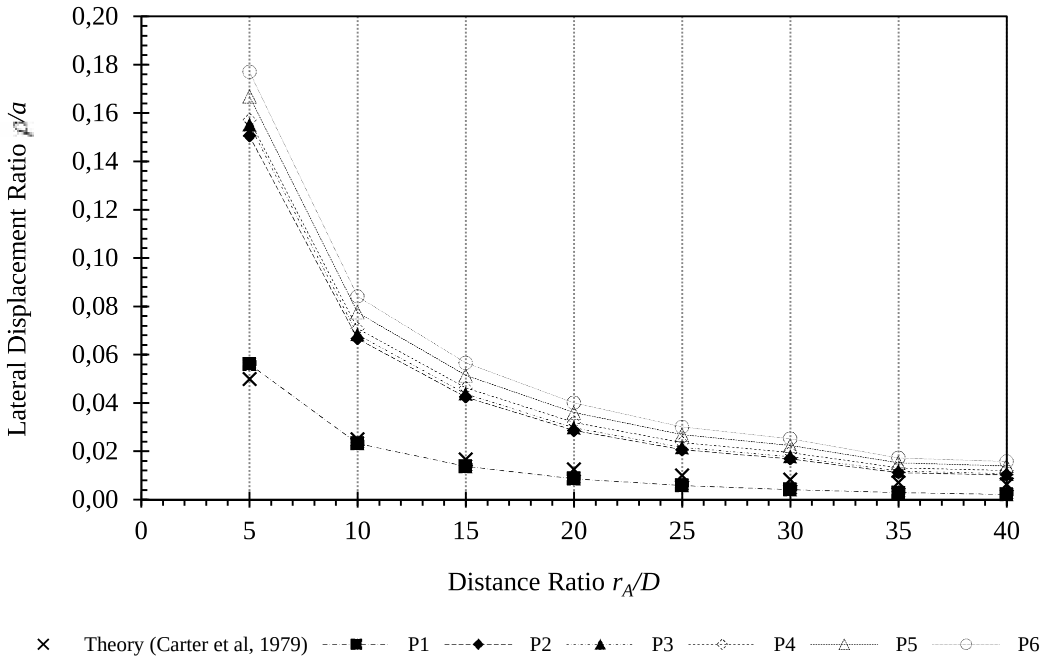
Figure 5. Lateral Displacement of Numerical Simulation Results Plaxis 3D, Diameter D = 30 cm and Space of Pile S = 3D: (a) Point A, (b) Point B



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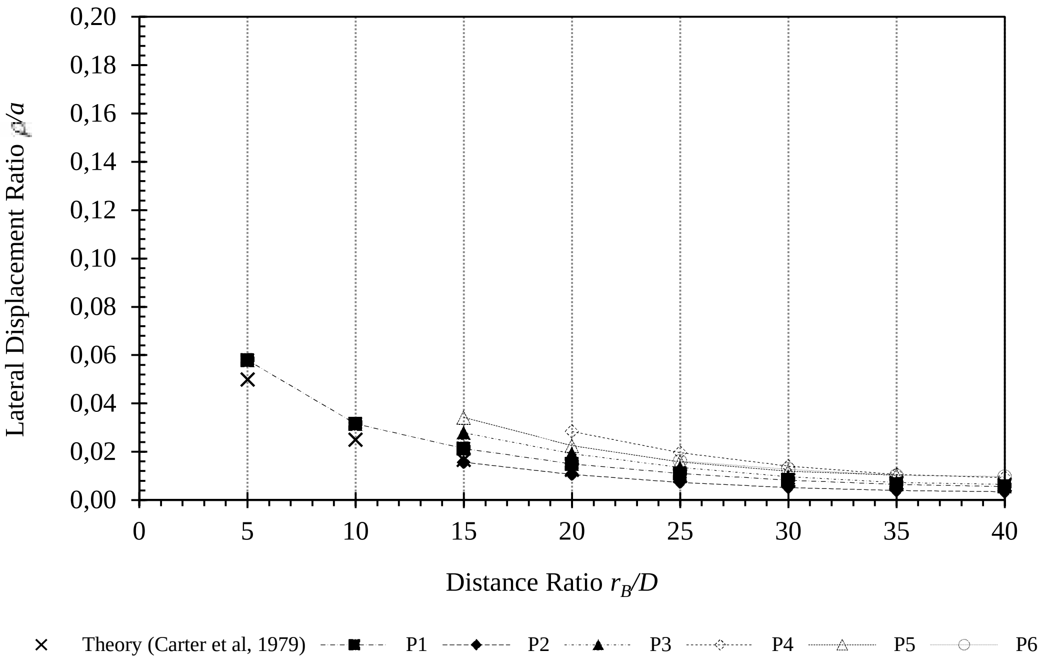

(b)

Figure 6. Lateral Displacement of Numerical Simulation Results Plaxis 3D, Diameter D = 30 cm and Space of Pile S = 2,5D: (a) Point A, (b) Point B

CONCLUSION

From the analysis and the discussion above, we can conclude several things:

- When the radial distance *r* farther from the pile, the value of lateral displacement has narrowed.
- The Simulation result for Phase-P1 provides sufficient lateral displacement according when compared with the results of calculations based on the theory of cavity expansion given by Carter et al
- Lateral displacement increases as the number of pile.
- The sequence of pile installation genereted affects of lateral displacement

REFERENCES

Broere, W and A. F. van Tol. (2006). Modelling The Bearing Capacity of Displacement Piles in Sand. Proceeding of the institution of Civil Engineers - Delft University of Technology –Meshingherlands.

Chai, J.-C., Miura, N., and Koga, H. (2005). Lateral displacement of ground caused by soil-cement column installation. J. Geotech. Geoenviron. Eng., 131(5), 623–632.

Chai, J.-C., Miura, N., and Koga, H. (2007). Closure to “Lateral displacement of ground caused by soil-cement column installation. J. Geotech. Geoenviron. Eng., 133(1), 124–126. Co

Francescon, M. (1983). Model Pile Tests In Clay: Stresses And Displacements Due To Installation And Axial Loading. Ph.D. thesis, Cambridge University, Cambridge, U.K.

Jun-wei Liu, Zhong-miao Zhang, Feng Yu, dan Zhi-zhuan Xie. (2012). Case History of Installing Instrumented Jacked Open-Ended Piles . American Society of Civil Engineers.

Maryono. (2014). *Analisis Deformasi Tanah Dan Sheet Pile Akibat Pemancangan Tiang Pada Tanah Lunak. Tesis.* Universitas Katolik Parahyangan. Bandung.

Pham Huy Dung. (2009). Modelling of Installation Effect of Driven Piles by Hypoplasticity. MSc Thesis of Faculty of Civil Engineering & Geosciences Delft University of Technology – Meshingherlands.

Poulos, H.G (1994), Effect Of Pile Driving On Adjacent Piles In Clay. Can. Geot. Jnl, Vol. 31, No. 6,856-867

Randolph, M. F., Carter, J. P., and Wroth, C. P. (1979). Driven piles in clay - the effects of installation and subsequent consolidation. Geotechnique, 29(4), 361–393.

Satibi Syawal, Ayman Abed., Chuang Yu., Martino Leoni., Pieter A. Vermeer. (2007). FE Simulation of Installation and Loading of Tube-Installed Pile. Universitat Stuttgart.

Vesic, A. S. (1972). Expansion of cavities in infinite soil mass. J. Soil Mech. And Found. Div., 98(SM3), 265–290.

EXCAVATION ADJACENT TO THE EXISTING BUILDING: A STUDY CASE

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ABSTRACT: A 17 stories building is planned to be erected at the crowded area. A 4 floors office and 2 floors house are its right and left neighbors. 2 floors surgery building of the hospital is right behind the project area. Of 3.2m depth will be excavated at the area for basement in which the ground water table is at 2m depth. The excavation could trigger instability for the surrounding buildings, especially when the dewatering process takes place. This paper intends to describe the analysis of the excavation process and the inferred ground stability. The model simulation by means of Plaxis 2D 2011 recommends the modification of construction stages drastically. Local excavation at the pile cap area is the best method to generate the smallest deformation on the nearby area.

Keywords: *excavation, ground stability, construction stage, dewatering*

INTRODUCTION

The high rise building has been planned to be built in the middle crowded building. A 4 floors office and 2 floors house are its right and left neighbors. 2 floors surgery building of the hospital is right behind the project area. Of 3.2 m depth excavation will be conducted at the area for pile caps in which 4.5 m depth has to be dug at lift area. The water table exists at 2 m depth. The excavation work is susceptible to affect the surrounding building. Careful planning of excavation should be carried out to minimize those effects.

The excavation next to existing building is one of the most problems in geotechnical practices. Research and investigation in this area had been conducted till recent time. Ramadan et al. (2013) revealed that contiguous pile succeeded to reduce lateral movement but not below the piles and the bottom of excavation. Sanjay et al. (2005) proposed grouting method combined with bore foundations to stabilize the slope of deep excavation. Meanwhile, a careful investigation was conducted by Hui (2014). He did numerical simulation on three different condition of deep excavation: slope excavation, cantilever sheet pile wall and retaining pile combined with bracing support. He recommended the retaining pile combined with bracing support among other methods. However, he revealed also that the stabilization method fully depend on the field and soil condition. Moreover, Koff (2009) did scrutiny work to access the excavation effects in the soft soil area. He proposed damage criteria to classify the building condition affected by the excavation stages. He demonstrated that the excavation induced displacement to cause the building damage depended on the stiffness of the building in axial and bending modes and the interface between soil and foundation and between foundation and building.

This paper intends to discuss about excavation case in a commercial high rise building project in Surabaya. The paper emphasizes on the excavation construction stage sequence.

PROJECT DESCRIPTION

The project was construction of 17 stories building. It had 42 columns. The number of piles to support column are vary from 3 to 12 piles. The piles had 21 m long. The piles were jacked to 24 m depth. The 3 m space above the piles to the ground surface was prepared for the pile caps and the basement. The basement was planned at 1.5 m depth supported by 50 m thick plate floor and pile caps with 1 m thickness. To stabilize the excavated soil, 6 m soldier piles was installed with 50 cm spacing. Meanwhile, the dead man piles were set 1 m from the soldier piles with 1 m spacing. The detail actual piles installed in the area can be checked in Fig. 1.

In the beginning, the contractor planned to do 3.2 m depth excavation at all the building area. However, the experience on the excavation project at the neighborhood location led the contractor to do careful examination on the excavation stage planning.

Standard Penetration Test (SPT) results shown in Fig. 2 show that the soils were soft to medium types. The upper layers to 8 m depth were loose and medium sand. About 3 m thick of very soft soil layer was found at 10 m depth. Meanwhile, the deeper soil layers were medium soil. Such soil conditions had high possibility to have lateral displacement due to excavation work.

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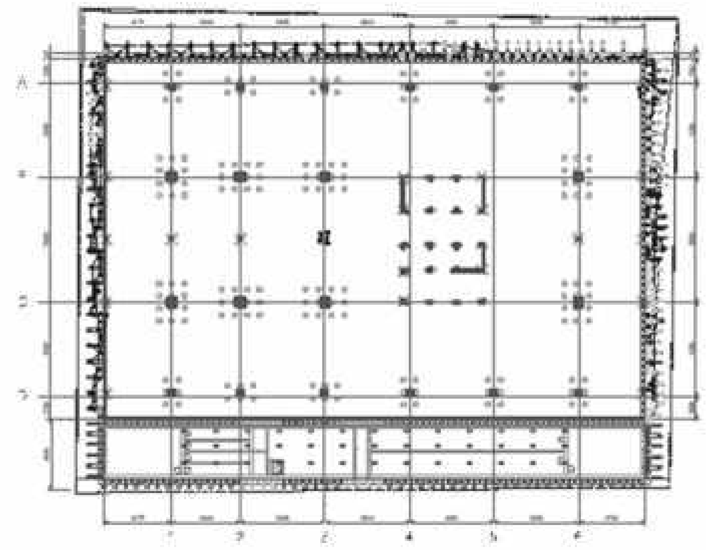

Fig. 1 The actual lay out of installed piles

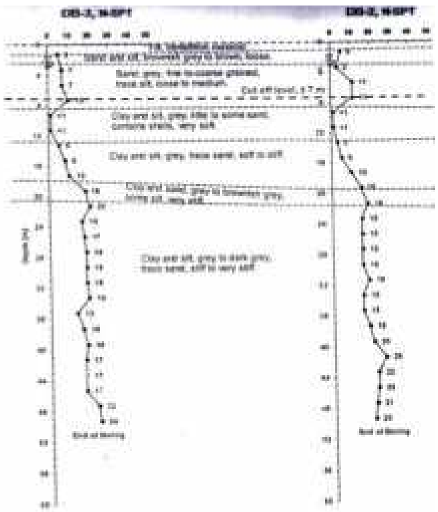

Fig. 2 SPT results

SOIL PARAMETER AND GEOMETRY

3.2 m excavation of the whole area would induce very large lateral displacement that causes serious problems to the neighborhood existing buildings. The excavation stages then turned from the whole area to local excavation. At the first stage, 1 m depth excavation was conducted to the whole area. It was followed by 0.5 m excavation in the middle with average distance of 7 m from the soldier pile wall. The rest of excavation to 3.2 m depth was carried locally for each pile cap sequentially. The next pile cap excavation had been conducted after the previous pile cap casting finished. To be noticed, the sheet pile wall was installed prior the excavation process. The detail layout of the excavation is demonstrated at Fig. 3. Since the analysis was in 2D condition, 5 cross sections were chosen in which 3 of them were in vertical direction and the rest were in horizontal direction. This paper presents only a cross section of each direction (P1 and L2).

Table 1 Soil parameters.

Parameter	Fill soil	Silty clay 1	Sand	Clay 1	Clay 2	Silty clay 2
γ_{unsat} (kN/m^3)	17	16.3	18.5	15.1	16.8	17.5
γ_{sat} (kN/m^3)	18	17	19	16	18	19
E' (kN/m^2)	10E3	15E3	15E3	2500	20E3	25E3
ν	0.3	0.2	0.3	0.2	0.2	0.2
c' (kN/m^2)	5	20	7	17	47	30
φ (^{o})	30	15	33	1	9	10

The simulation of the excavation was utilized commercial finite element software named PLAXIS 2D 2011. The model geometry developed for the simulation can be seen in Fig. 4. It had 6 soil layers. Each soil layer parameters can be checked in Table 1. The model utilized in this simulation was Mohr-Coulomb. The model was chosen due to the soil data availability. Meanwhile, for dewatering and consolidation analysis, the soil permeability was chosen based on the grain size distribution classification available in PLAXIS.

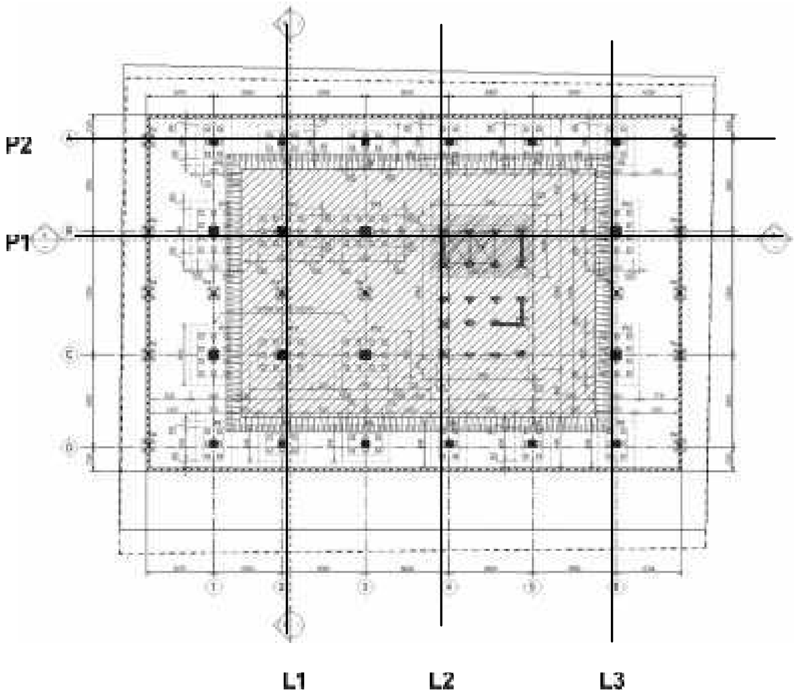

Fig. 3 Excavation layout and the cross section lines

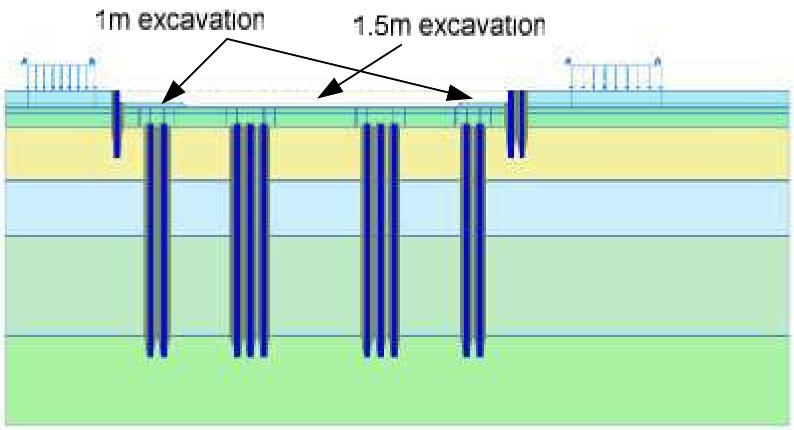

Fig. 4 Illustration of the excavation stages

SIMULATION RESULTS

Cross section P1

The cross section P1 passed 4 pile caps and the lift (Fig. 5). The lift was excavated to 4.65 m depth. Braced supports were installed at soldier piles, the edge cap and lift excavation. The critical exaction was the lift one. 2 braced supports were required to stabilize the excavation. The maximum displacement induced was 6.7 mm occurred on the top of the lift excavation (Fig. 7). The safety factor during excavation was 2.7 (Fig. 6). Interesting result is shown in Fig. 8. It shows that displacement occurred both in the excavation wall and floor. The sheet pile wall should be long enough to reduce the displacement below the bottom of the excavation. The main result associated to the building near the excavation was the deformation of the building. It was about 3.5 mm for the 3 stories building.

Fig. 5 The geometry model of cross section P1

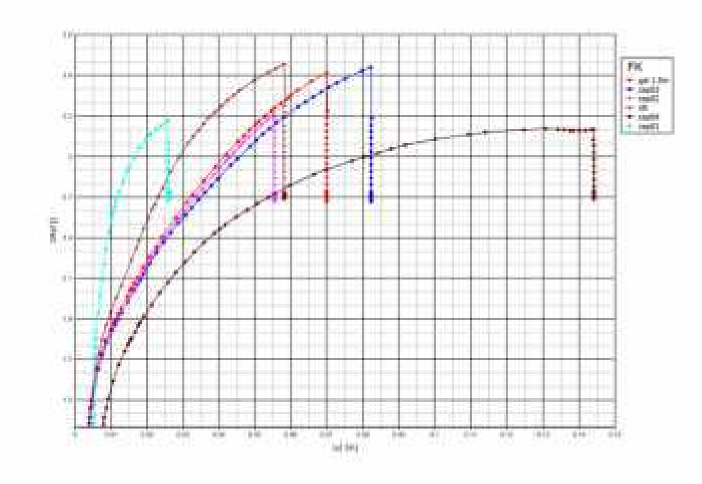

Fig. 6 Safety factor for each excavation stage

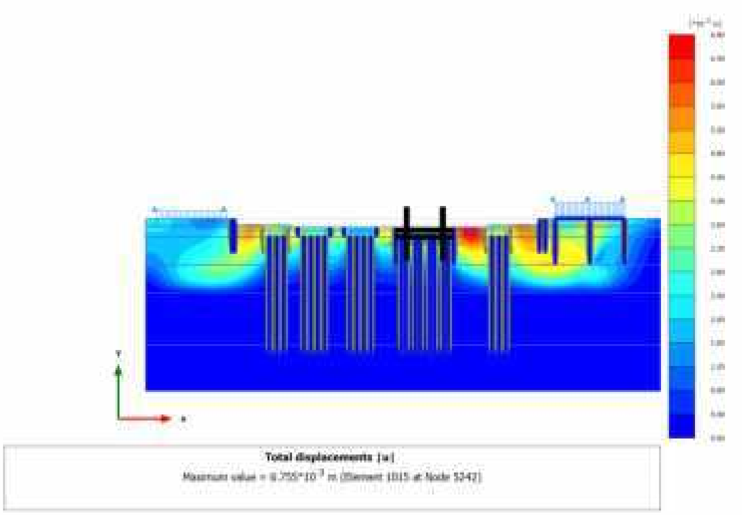

Fig. 7 Displacement distribution for lift excavation

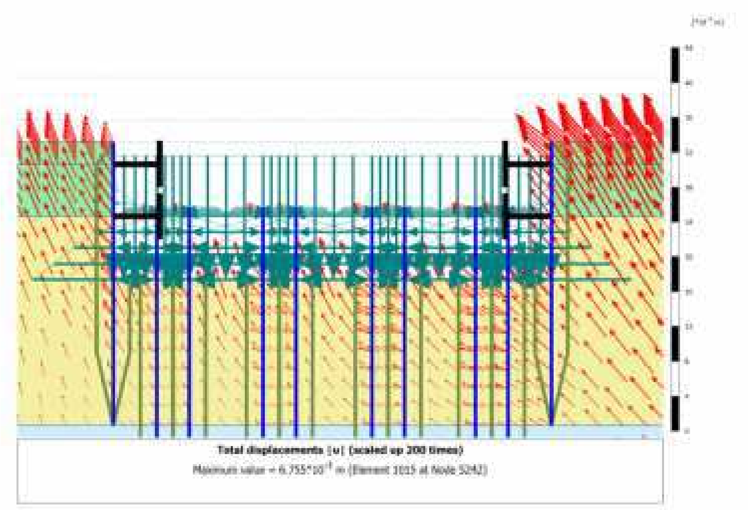

Fig. 8 displacement direction around the lift excation

Cross Section P2

Cross section P2 was important since it was a 2 stories surgery room of the hospital next to the project. Small deformation only should be tolerated during the excavation. The safety factor reached during excavation was 2.4 (Fig. 10). Meanwhile the maximum deformation occurred at the hospital was 2.4 mm (Fig. 9). The results were tolerable to keep the hospital building stable.

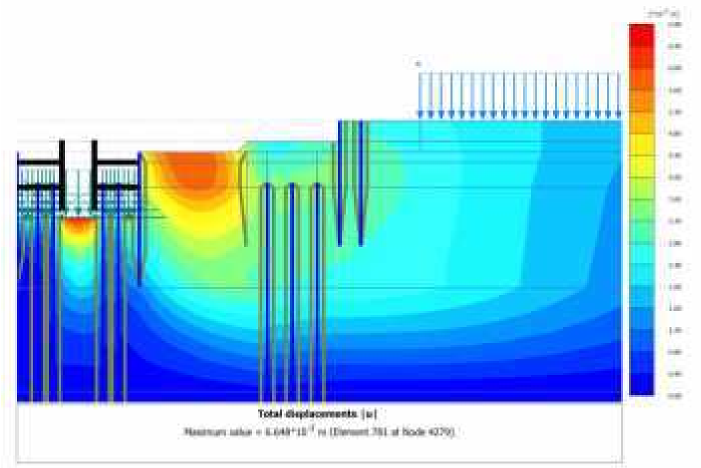

Fig. 9 Geometry model of cross section L2

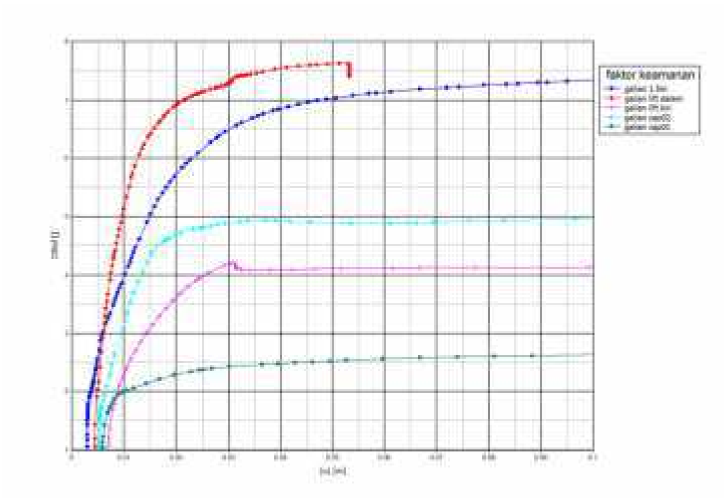

Fig. 10 Safety factors for each excavation stage of P2

CONCLUSION

An evaluation of excavation next to the existing building was conducted. The numerical simulation showed that local excavation stage yield small deformation to the neighborhood building. The deformation occurred at adjacent building was less than 5 mm.

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REFERENCES

Hui, L. (2013). Effect on Existing Building by Foundation Pit Excavation, Electronic Journal of Geotechnical Engineering, vol 19.

Koff, M. (2009). Deformations and damage to buildings adjacent to deep excavations in soft soils, External research report, TU. Delft.

Ramadan, E.H., Ramadan, M., Khashila, M.M., and Kenawi, M.A.(2013). Analysis of Piles Supporting Excavation Adjacent to Existing Buildings, Proc. of the 18th International Conference on Soil Mechanics and Geotechnical Engineering "Challenges and Inovations in Geotechnics", Paris, France.

Sanjay, G., Ravi, S., and Pushpendra, S. (2005). Deep Excavation Adjacent to Multi-storeyed Building Lateral Support, Proc. of IGC-2015, 17 – 19 December 2005, Ahmedabad, India.