

NUMERICAL INVESTIGATION ON PILE BEHAVIOR DUE TO THE RISING GROUNDWATER EFFECT

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ABSTRACT: Since the late 1990s, the changing of groundwater level in the aquifer beneath Bangkok has been realized because the enforcement of groundwater laws and improvement of water supply have been adopted. Then, the groundwater with piezometric drawdown has risen to almost hydrostatic equilibrium. In the principle of soil mechanics, when the porewater pressure in soil mass increases, the effective stress decreases. This can affect underground structures. Under the soft ground condition such as Bangkok, Thailand, pile foundations are commonly constructed to support structures. With decreased effective stresses, the loss of ultimate load-carrying capacity of existing piles can occur, and the structures can be damaged. This research investigates the effects of the groundwater rising on the pile foundation in the Bangkok subsoil. An advanced numerical model with the fully coupled flow deformation analysis, both groundwater flow and soil deformation behaviors with time-dependent conditions are modeled, is conducted by using PLAXIS 2D. The results found that the calculation type of fully coupled flow deformation can express the pile-soil movement behavior. The pile-soil heave and the pile load capacity be significantly reduced during the groundwater rising event. Despite the reduction of pile load capacity with groundwater changed not enough to failure (Factor of safety <1.0), the pile stability should be concerned, and the optimum groundwater level must be controlled.

Keywords: Groundwater rising, Pile capacity, Numerical modeling, Bangkok subsoil, Fully coupled flow deformation analysis

1. INTRODUCTION

In the past, Bangkok has been mainly taken the water resource from deep well pumping from aquifers underneath the city. That is caused by the increased groundwater demand for urban expansion and industrialization. Specifically, the groundwater level was declined to 31 m below the ground surface (m bgs) in 1997 in the central city area (Rommaninat Park) [1]. After that, the groundwater level was slightly increased, the Thailand Department of Groundwater Resources prompted the policy, which included a pricing policy on groundwater and expansion of tap water supply from surface sources in the needy industrial suburban areas.

Groundwater levels are rising in many urban areas because of reduced pumping from the underlying aquifers for industrial processes. That is a problem common to many cities founded and effect underground structures (i.e., metro tunnels, deep foundations, etc.). Recent many studies research, an increasing trend in groundwater level due to the deindustrialization process was observed in urban aquifers all around the world: Aswan (Egypt), London (England), Paris (France), Naples (Italy), Milan (Italy), Tokyo (Japan) and Bangkok (Thailand). The groundwater level rising in the urban areas was the result of a decrease in groundwater pumping, which was not appropriately managed. That thus caused damages to

underground structures and infrastructures.

The piled foundations are the part of a structure used to carry and transfer the load of the structure to the bearing ground located at some depth below ground surface. The pile capacity was generally considered with skin friction and end bearing. The increasing of porewater pressure leads to a decrease of the effective stresses, a loss in the ultimate load-carrying capacity of existing piles has occurred. Recently research investigated the impact of the groundwater level rising in Bangkok, for example, [2, 3] to study the effects of groundwater level drawdown and rebound from deep well pumping in Bangkok on the piled foundation of buildings. They reported that for a short pile of length in the order of 30 m, the bearing capacity might be reduced by 40% in the future when the groundwater level is allowed to rebound close to the ground surface for the pile installed during the period of maximum ground drawdown in 1997. However, they considered only the analytical method on pile capacity. In this research, the numerical model was carried out to investigate the pile behavior due to the rising groundwater level. A Fully coupled flow deformation analysis is conducted to analyze the simultaneous development of deformations and pore pressures in saturated and partially saturated soils as a result of time-dependent changes in the hydraulic boundary conditions [4, 5]. The pile-soil movement, load distribution along with the pile, and the reduction of pile capacity were observed.

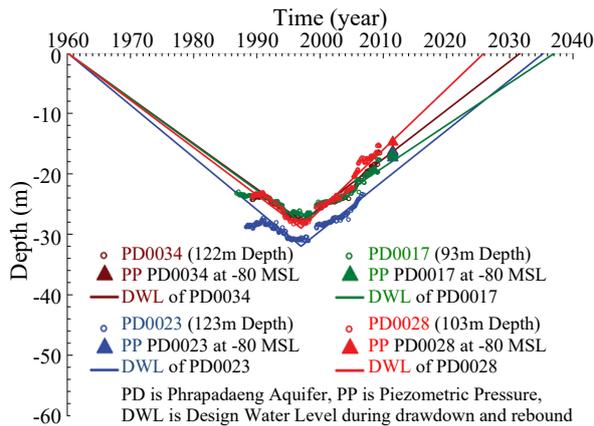


Fig.1 Groundwater levels changed with time in Bangkok [1]

2. GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The data obtained from the central plain area of Thailand are used for this study. During the past 50 years, the study area has been rapidly developed with urbanization, especially Bangkok, the capital of Thailand. The geology and hydrogeology beneath the study area are significantly changed. Thus, the geological and hydrological changes in this area have been studied by many researchers. However, there are well-documented reports in the literature [1, 6].

The geology conditions of the study area were covered by the marine and alluvial deposits. At the shallow depth of the entire area, the subsoils were almost uniform with consisting of soft clay, stiff clay, and sand. At the greater depth, the stiff to hard clay and dense sand layers were found. The first dense sand layer with a thickness ranging about 5-10 m is generally located below the stiff clay layer (the depth about 20-25 m bgs). The hard clay layer was found underneath the first dense sand layer. The second dense sand layer locating at the depth about 45-60 m bgs is below the hard clay layer.

Bangkok aquifer system is identified as 8 aquifers by JICA [6] with continuous relatively impermeable aquitards (clay layers). Each layer with a thickness of 30-70 m, from ground surface consisting of the Bangkok (BK), Phra Pradeang (PD), Nakorn Luang (NL), Nonthaburi (NB), Sam Khok (SK), Phayathai (PT), Thonburi (TB) and Pak Nam (PN) aquifers, respectively. Groundwater is mainly pumped from the PD, NL, and NB aquifers at depths about 100 m to 200 m.

In the past decade, the groundwater demand for utility and industrial systems was very high as

shown in Fig.1. [1, 7]. With serious controlling the amount of water pumping and utilizing the tap water supply, the groundwater pumping decreased while the trend of piezometer rise up to the hydrostatic after 1997. This current research focuses on PD aquifer (about 100 m bgs) due to the rising trend of the piezometer that may impact the pile.

3. NUMERICAL MODELING OF PILE FOUNDATION ANALYSIS

3.1 Reference case

The geological condition and static pile load test pile data of the Silom-Sathon located in the inner-city zone of Bangkok are used to model in this research. The construction of this building was completed in 1999, having 20 floors. The pile foundation of this building was installed during the period of maximum groundwater level drawdown (1997-1999). The bored pile diameter of 1m with a pile tip of -55 m bgs was constructed by using the wet process.

The change of groundwater levels with time at Phrapadaeng aquifer for modeling was acquired from observation data at the monitoring groundwater station PD0023(Fig.1), where was located at Metropolitan Electricity Authority Substation Thung Maha Mek (about 1 kilometer from the building reference). The rate of groundwater level rising was approximated of +0.75 m/year from the years 1997(GWL -30 m bgs) to 2037(GWL -0 m bgs).

3.2 Modelling and Boundary Condition

3.2.1 Soil Model and Parameters

The finite element method (FEM) using software PLAXIS 2D was used to investigate the mechanical behavior of single piles foundation under axial load and groundwater level rising load on Bangkok soft clay. The Linear Elastic Perfectly Plastic Mohr-Coulomb model and hardening soil with small strain stiffness (HS Small) model, which can simulate stiffness dependent on stress, strain, and paths were applied. Parameters were adopted and modified from [1, 8-10], who studied and calibrated the model parameters for Bangkok soils. All parameters are summarized in Table 1.

The numerical result of the pile load test was compared with monitoring data in the field test as shown in Fig.2. The failure load of 1600 tons was evaluated by Mazurkiewicz's (1972) method. The working load of 640 tons was applied on the pile head that was considered with a factor of safety (F.S.) of 2.5.

Table 1 Model parameters used in analyses

Parameters	Unit	Weathered clay	Soft clay	Medium stiff clay	Stiff to very stiff clay	1 st Sand	2 nd sand	Hard clay	Pile
<i>Model</i>	-	MC	HS Small	HS Small	HS Small	MC	MC	HS Small	LE
<i>Material type</i>	-	Undrained	Drained	Drained	Drained	Drained	Drained	Drained	Non-porous
γ_{sat}	kN/m ³	17	16.5	18	20	20	20	20	24(Unsat)
E_{50}^{ref}	kN/m ²	E'=6000	800	1650	8500	E'=85800	E'=85800	30000	E =2.70E7
E_{oed}^{ref}	kN/m ²	-	850	1650	9000	-	-	30000	-
E_{ur}^{ref}	kN/m ²	-	8000	5400	30000	-	-	120000	-
<i>power (m)</i>	-	-	1.00	1.00	1.00	-	-	1.00	-
C'_{ref}	kN/m ²	Su=40	1.00	10.00	25.00	0.1	0.1	40.00	-
ϕ'	degree	0	23	25	26	36	37	24	-
ψ	degree	0	0	0	0	5	5	0	-
$\gamma_{0.7}$	-	-	0.05000	0.00100	0.00100	-	-	0.00150	-
G_0^{ref}	kN/m ²	-	10000	16000	50000	-	-	124000	-
v'_{ur}	-	0.30	0.20	0.20	0.20	0.30	0.30	0.20	$v(nu)=0.15$
P_{ref}	kN/m ²	-	100	100	100	-	-	100	-
K_0^{nc}	-	-	0.74	0.65	0.50	0.5	0.5	0.50	-
R_f	-	-	0.90	0.90	0.90	-	-	0.90	-
R_{inter}	-	-	0.75	0.75	0.75	0.75	0.75	0.75	1
OCR	-	-	1.2	2	2	-	-	1.1	-
k_x	m/day	8.640E-7	8.640E-5	8.640E-4	8.640E-4	1.600	0.800	8.640E-5	-
k_y	m/day	8.640E-7	8.640E-5	8.640E-4	8.640E-4	1.600	0.800	8.640E-5	-

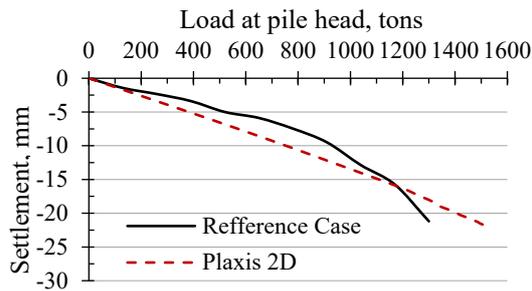


Fig.2 Measured load settlement curve compared with field test and numerical analysis

3.2.2 Geometry Model and Boundary Conditions

The 2D FE mesh indicating the single bored pile, soil profile, and element discretization is depicted in Fig.3. The bored pile with a diameter of 1.0 m and a depth of 55.0 m bgs is considered. For the displacement boundary conditions, all vertical sides were restrained against lateral movement but permitted for vertical movements. The bottom of the mesh was fixed (no movement in all directions). For the groundwater condition, groundwater flow on the bottom mesh is set to be no flow condition (no vertical flow) while the horizontal flow is set in all vertical sides of the mesh. The groundwater level was controlled by flow functions, the groundwater level change with time-dependent was defined in this step. The size of the model is 80 m for width and 100 m for depth. The size of the model is greatly larger than the required distance of six times the pile diameter at the side and the pile base.

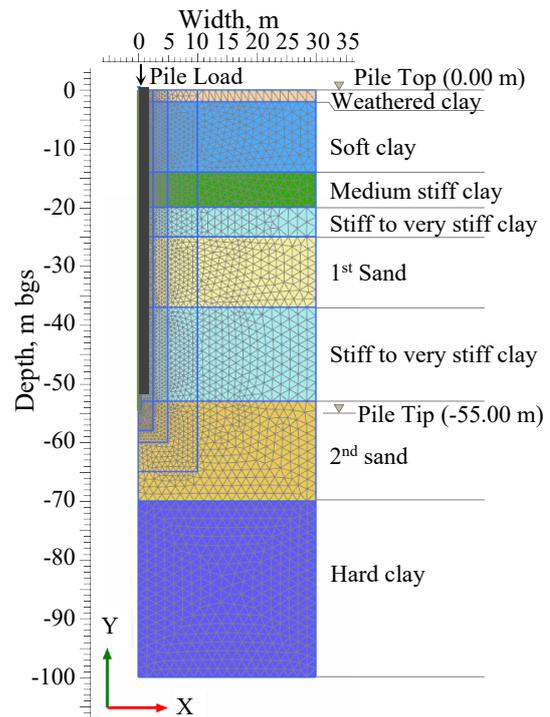


Fig.3 Geometry of the problem and 2D Finite element mesh used in this analysis

3.2.3 The Analysis Steps

This analysis focus on the pile-soil movement, load distribution along with the pile, and the reduction of pile capacity during the groundwater level rising event. The soil without piled in the initial stage, the groundwater level starts from the

ground surface (Hydrostatic pressure) was controlled by flow function to decrease of -0.75 m/year in 40 years. Then, the pile foundation of this building was installed during the period of maximum ground drawdown (1997). The load at the top of the pile was maintained to constant by working load for 40 years that had been rising of groundwater level rate of +0.75 m/year.

In the first step, the stress in soils was initialized according to K0, NC. After that, a bored pile was constructed, R_{inter} between the pile and soil was active. This model was assumed that the soil displacement has not occurred during the bored pile was installing. For pile loading, the surface load is applied to the cross-section area of the pile by 8,120 kN/m² or 640 tons (working load). In the groundwater level rising step, the groundwater level changing with time-dependent was defined. The calculation type to Fully coupled flow deformation analysis is a condition in this step. The time interval is 14,600 days (approximately 40 years from 1997 to 2037). The groundwater level rising was defined rate of +0.75 m/year. The groundwater level with a time of this model was presented in Fig.4, that related to piezometric levels changed with time in Bangkok at PD0023 in Fig.1. The summaries of stage modeling and pile-soil movements during the groundwater level changing were demonstrated in Fig.4, the soil surface movements depend on groundwater level changing, the similar behavior was presented in a full-field test by Armishaw and Cox [11], and the pile foundation shows less heave than the surrounding soil surface during the groundwater level rising event as a result of centrifuge tested by Morrison [12, 13].

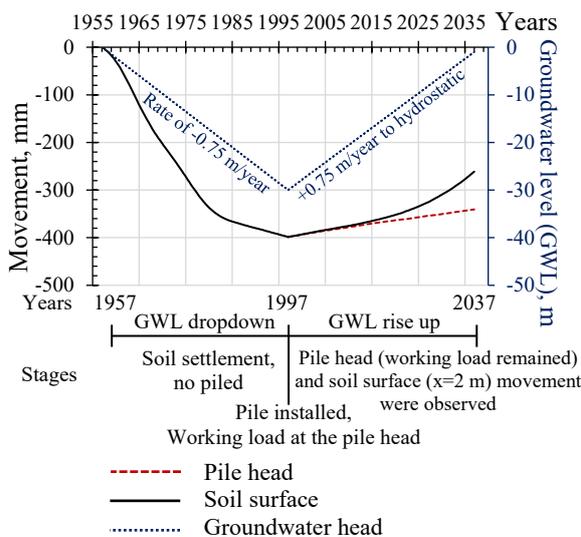


Fig.4 Pile head and soil surface movements with groundwater level changing in the model

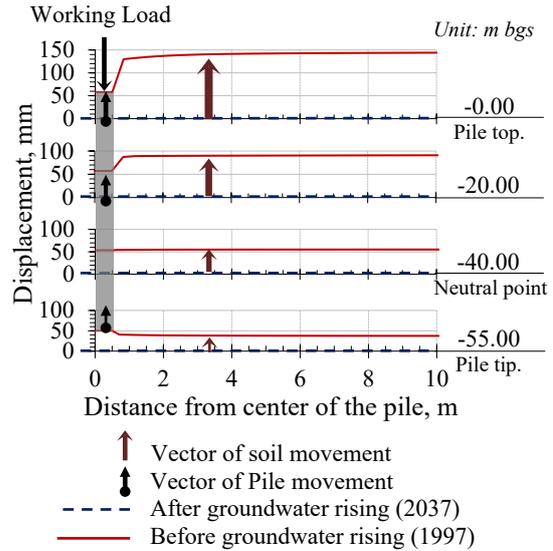


Fig.5 Soil displacement at various depth after groundwater level rising

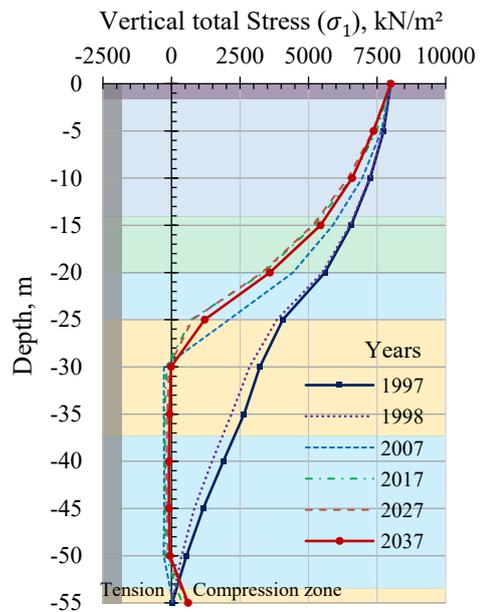


Fig.6 Stress distribution along with the pile during groundwater level rising

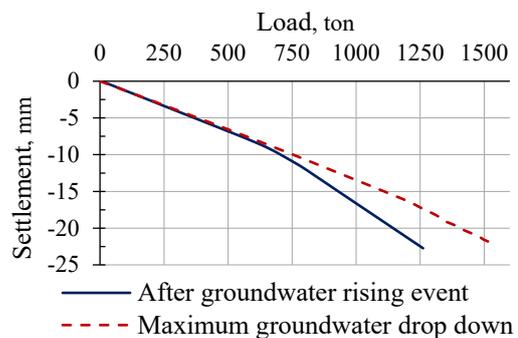


Fig.7 Reduction of pile capacity

4. RESULTS AND DISCUSSIONS

4.1 Pile-Soil Movement

The pile-soil movements before and after the groundwater level rising event were showed in Fig.5, the pile foundation, and the soil heave. The large soil heave was found near the soil surface. However, the pile foundation shows less heave than the surrounding soil above the neutral point (level of zero pile-soil displacements), which represents a decrease of friction force between soil and pile because the effective stress was reduced by the rising groundwater level. The behaviors were seen to affect pile settlement relative to the soil surface during the rising of groundwater level.

4.2 Stress Distribution along the Pile

Fig.6 shows the vertical stress distribution along with the depth under the friction pile. Which represents the stress profile each year. The neutral point demonstrating the depth of soil causing pile settlement relative to the surface of the pile. According to groundwater level raising, the soil surrounds the pile surface was forced by uplift, cause the pile was heave. The load distribution was transferred from the compression zone to the tension zone. For after rising groundwater level, the end bearing was expressed at the end of the pile.

4.3 Pile Capacity

The reduction of pile capacity was represented in Fig.7. The magnitude of pile settlement was decided at -20 mm, comparable to that of the pile capacity reduce by 20%, that relative to the loss of the ultimate load for the increased pore water pressure. Despite the pile will not reach up to fail, but some of the pile that has less of a factor of safety (F.S.) must reconsider the stability of the pile.

5. CONCLUSIONS

The fully coupled flow deformation analysis, both groundwater flow, and soil deformation behaviors with time-dependent conditions in Plaxis program can express the pile-soil movement behavior, that corresponds to the previous study in a full field test and centrifuged test by Armishaw and Cox [11] and Morrison [12, 13] respectively. The results of the numerical modeling found that:

The pile foundation shows less heave than the surrounding soil surface during the groundwater level rising.

The load distribution along the pile was transferred from the compression zone to the tension zone at the lower part near the neutral point of the pile.

The pile load capacity is significantly reduced by the increase in the groundwater level.

Despite the reduction of pile load capacity with groundwater level changed not enough to failure (Factor of safety <1.0), the pile stability should be concerned, and the optimum groundwater level must be controlled.

6. ACKNOWLEDGMENTS

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7. REFERENCES

- [1] DGR, Groundwater and Land Subsidence Investigation Project, Department of Groundwater Resources, 2013.
- [2] Kanthima I., Analytical Assessment on Pile Capacity in View of Effects of Groundwater Drawdown and Rebound Associated with Deep Well Pumping in Bangkok, Master thesis, AIT, 2016.
- [3] Department of Groundwater Resources and Seven associated consultants Co., Ltd., The Effect to Underground Structure cause by the Groundwater Rising in Bangkok Aquifer around Bangkok Metropolitan Region, Final report, 2011.
- [4] Galavi V., Brinkgreve R., Bonnier P. and Gonzalez N., Fully coupled hydro-mechanical analysis of unsaturated soils, Computational Geomechanics I (ComGeo I), At Juan-les-Pins, France, 2009, pp.486-495.
- [5] Galavi V., Groundwater Flow Fully Coupled Flow Deformation and Undrained Analyses in PLAXIS 2D and 3D, Internal report, Plaxis BV 2010, research department, 2009.
- [6] JICA, DMR and PWD, The Study on Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and Its Vicinity, Interim report, 3, Kokusai Kogyo Co. Ltd, Tokyo, Japan, 1995.
- [7] Tussanee N., Situation of Groundwater in Bangkok Metropolitan Area, Available at <http://www.gwcr.org>, Accessed June 10, 2015.
- [8] Thayanan B., Zaw Z. A., Nutthapon T., Sahapap S. and Sereyroath C., Settlement Prediction of Large Diameter Bored Pile in Bangkok Soils, Sixth International Conference

- on Geotechnique, Construction Materials and Environment, 2016.
- [9] Surarak C., Likitlersuang S., Wanatowski D., Balasubramaniam A., Oh E. and Guan H., Stiffness and Strength Parameters for Hardening Soil Model of Soft and Stiff Bangkok Clays, *Soils and Foundations* 52 (4), 2012, pp.682–697.
- [10] Likitlersuang S., Teachavorasinskun S., Surarak C., Oh E. and Balasubramaniam A., Small Strain Stiffness and Stiffness Degradation Curve of Bangkok Clays, *Soils and Foundations*, 53(4), 2013, pp.498–509.
- [11] Armishaw J. W. and Cox D. W., The Effects of Changes in Pore Water Pressures on the Carrying Capacities and Settlements of Driven Piles End Bearing in Sand and Gravel Stratum, *Proc. Conf. on Recent developments in the design and construction of piles*. I.C.E., London, 1979, pp.227-236.
- [12] Morrison P. R. J. and Taylor R. N., Foundations in a Rising Groundwater Environment, *Proc. Int. Conf. on Groundwater Problems in Urban Areas*, ICE, London, 1994a, pp.342-354.
- [13] Morrison P. R. J. and Taylor R. N., Modelling of Foundations in a Rising Groundwater Environment, *Proc. Int. Conf. Soil Mechanics and Foundation Engineering*. New Delhi, 1994b, Vol. 2 pp.655-658.

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