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EVALUATION OF DISPLACEMENT ON UNSATURATED SOILS IN BANGKOK PLAIN

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ABSTRACT: Chao Phraya River basin is located in the central area of Thailand which has a lot of ground displacement issues due to groundwater pumping. Following the Department of Groundwater Resources (DGR) in Thailand recording data, the groundwater level changed due to water pumping from 1960 until now. In 1997, DGR issued a law regulating the use of groundwater effect to the characteristic of changing groundwater levels. Therefore, the characteristic of groundwater level change was separated into two periods. In the first period, the high groundwater pumping rate led to a rapid decrease in groundwater level at about 27 meters from the ground surface. After DGR issued the law, the pumping ratio decreased and the groundwater level was increased or recovered close to the ground surface. The groundwater level recovery still affected ground displacement. This study focuses on evaluating and predicting ground displacement during groundwater level recovery in the future based on Terzaghi's theory. The study area considers only zone D (10 to 14 m of soft clay thickness) in the Bangkok clay area. The soil profile and the soil boring log were gathered from the Department of Public Works and Town & Country Planning in Thailand. This study research the ground displacement behavior of the clay layer during groundwater recovery. All data will be used to make a 3D soil profile and calculate to predict ground displacement in the future of the soil layer. The results found that the ground displacement has rebound to the ground surface of every bored hole during the groundwater recovery.

Keywords: Ground displacement, Unsaturated soil, Suction, Bangkok plain

1. INTRODUCTION

Before 1997, the groundwater level decreases continuously due to groundwater pumping in the central part of Thailand. The high demand for groundwater pumping has affected ground displacement, especially in the soft soil area or center part of Thailand. After the Department of groundwater resources in Thailand issued the law to control the amount of groundwater pumping for industry, the groundwater level tends to increase or recovered to nearly the ground surface. This is an interesting point to evaluate ground displacement refer to the instrument data of some areas that still occur ground displacement and some areas that occur rebound of ground displacement. The ground displacement during groundwater level recovery has been affected in terms of civil engineering structure issues such as road cracks and building damage especially the old building design at lowest the groundwater level.

Ground displacement is a global problem including in Thailand. Many researchers try to analyze and explain the ground displacement behavior in soft soil areas. ground displacement occurs around the world in soft soil areas. The reason depends on the usage of that area such as groundwater pumping, [1] and [2]. Jakarta city in Indonesia is located on the lowest sea water level. The groundwater rapidly decreases during groundwater pumping. The ground displacement continuously increased during that period. Thailand also occurs due to groundwater pumping same as Jakarta. [3] showed the evaluation of ground displacement after groundwater pumping was controlled. Previous researcher predicted that the ground displacement has rebound approximately 0.26 to 0.32 cm/yr by using ABAQUS software. [4] studied ground displacement during groundwater recovery from 1997 to 2037 also, the ground displacement has rebound around 35 percent of the maximum ground displacement of groundwater decreasing period.

This study tries to evaluate ground displacement during groundwater recovery or the behavior after 1997 in Thailand. The Bangkok clay has a wide area along the Chao Phraya River basin, the central area of Thailand. The previous study summarized the soft soil area followed by the soft clay thickness in each zone. So, this study chooses only zone D of soft soil thickness to consider the ground displacement in soft clay and stiff clay layer based on Terzaghi’s theory of consolidation in both saturated and unsaturated soil.

2. RESEARCH SIGNIFICANCE

Evaluation of ground displacement is very important in terms of groundwater recovery. Because the main effect of ground displacement depends on the quality of groundwater pumping. Many buildings and infrastructures have the effect of groundwater level change such as cracking on the walls of buildings or underground structures. ground displacement has not occurred only in Bangkok, Thailand but also in many countries. This study simplifies the theoretical calculation to evaluate ground displacement during groundwater recovery. And, the results of ground displacement are related to the results of the finite element method which uses the case study of Bangkok plain, Thailand. The study has proved that theoretical calculation needs to consider unsaturated conditions.

3. BANGKOK SUBSOIL PROFILE

Bangkok's soft soil layer is covered along the Chao Phraya River basin covering many provinces in Bangkok and urban areas. In the past, this area has been the sea. The soil was deposited to be a clay layer alternated with a sand layer. The subsoil layer consists of very soft clay to soft clay, very stiff to stiff clay, first sand, hard clay, and second sand respectively. Department of Groundwater Resource (DGR) in Thailand, the Department of Public Works and Town & Country Planning in Thailand and many researchers have studied the characteristics of the subsoil layer in the Chao Phraya River basin area and found that the subsoil layer has a variance. It also includes the soil parameters. However, the overall soil layer still the clay layer alternates with the sand layer.

4. GROUNDWATER LEVEL SITUATION

Characteristics of the groundwater level situation in the Bangkok area depend on the behavior of groundwater pumping. After 1997, the groundwater level in the Bangkok area tend to recover to the ground surface after groundwater pumping was controlled. Figure 1 showed the relationship between groundwater level and ground displacement during groundwater consumption changing each year [5]. The graph represented the groundwater level has increased since 1997 and tends to reach the ground surface in the future. In contrast, ground displacement still occurs and is gradually stable after 2008.

At present, DGR measures the groundwater level by using piezometer measurements. The situation of groundwater level showed the rate of increasing groundwater level in each province in Table 1. All of the provinces located along the Chao Phraya River basin have a groundwater level increasing. The minimum ground displacement rate that occurred in the Nonthaburi province is about 0.57 m/yr. The maximum ground displacement rate that occurred in Bangkok is about 2.74 m/yr. Figure 2 also, Bangkok and urban areas show the ground displacement by the observation data from DGR. In some areas still occurs ground displacement while in some areas are not occurring ground displacement. On the opposite, in some places, ground displacement seems to rebound such as Bangkok. Figure 2 represents still occurrences of the different ground displacements at groundwater drawdown and recovery. Because each province

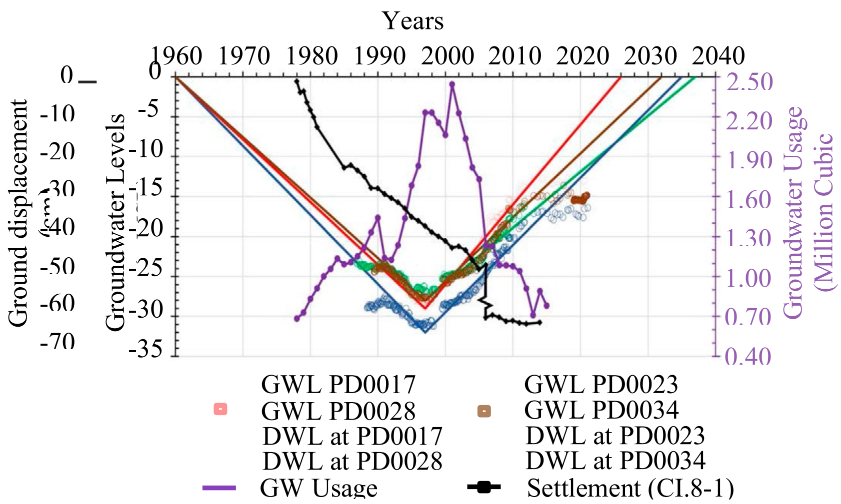

Fig. 1 Groundwater level and ground displacement

shows the characteristic of ground displacement seems similar but there have different ground displacement rates. It means that the evaluation of ground displacement has to concern especially during groundwater recovery. This is important evidence to consider what factors affect ground displacement value.

Table 1 Groundwater level situation of each hole

Province	Elevation (m)	Minimum Rate (m/yr)	Maximum Rate (m/yr)
Bangkok	32.86	0.57	2.74
Samutprakan	29.47	1.07	2.45
Pathumthani	19.3	0.48	2.41
Nonthaburi	12.7	0.27	1.06
Ayutthaya	16.3	0.61	1.23
Nakhonpathom	19.18	0.60	1.59
Samutsakhon	32.75	1.94	2.34

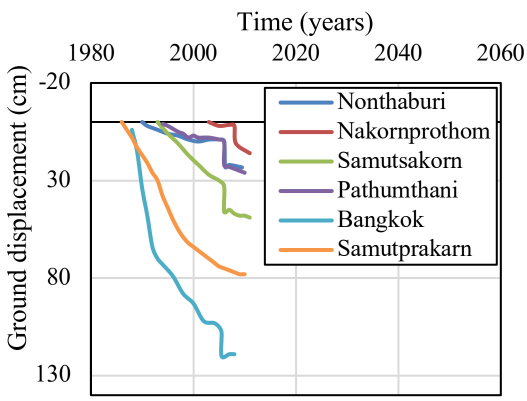

Fig. 2 Characteristics of ground displacement in Bangkok and urban areas

5. METHODOLOGY

This study focuses to collect the data from the soil boring log from the Department of Public Works and Town & Country Planning in Thailand to evaluate the ground displacement from each subsoil layer. The subsoil layer characteristic was compared and verified by the groundwater level data from the Department of Groundwater Resource in Thailand. All data was drawn and presented subsoil layers in a 2D and 3D layout, respectively. The soil parameters from the 3D layout were used to calculate the ground displacement during groundwater level change.

5.1 Subsoil profile of Zone D

Following the soft clay thickness in the Bangkok plain in Fig. 3, the area of the soft Bangkok clay was separated into 6 zones with different colors [6]. Each zone was divided by the soft clay thickness**.** The dark red (F) area has a soft clay layer thicker than 18 m. The red (E) area has a soft clay thickness from 14 m to 18 m. The yellow (D) area has a soft clay thickness from 10 m to 14 m. The blue (C) area has a soft clay thickness from 6 m to 10 m. The green (B) area has soft clay thicknesses from 3 m to 6 m and the grey (A) area has a soft clay thickness of less than 3 m. The markers name NP, SS, BK-1, BK-2, NB, SP, PT-1, and PT-2 shows the data from the boring log by the Department of Public Works and Town & Country Planning in Thailand. The markers name BH-1, BH-2, BH-3, BH-4, BH-5, and BH-6 show the investigated holes by DGR. The name of each hole is shown in Table 2. This study considers only zone D because this area is a developed area and has data to evaluate the behavior of ground displacement by using Terzaghi's theory of consolidation. There are conducted data from DGR and the Department of Public Works and Town & Country Planning [7].

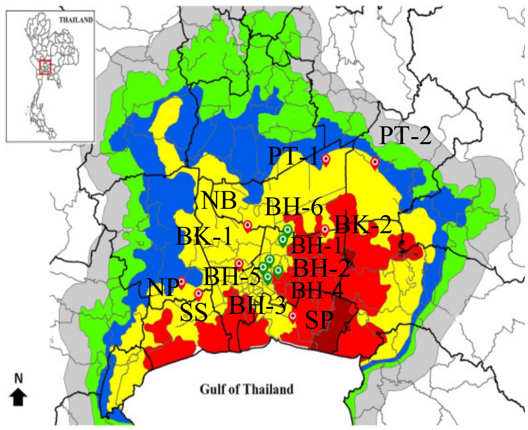

Fig. 3 Location of the studied hole (Modified [1])

Table 2 Location of the marks on the map

Name	Description
NP	NahonPathom
SS	SamutSakhon
BK-1	Bangkok (Taling Chan)
BK-2	Bangkok (Khlong Sam Wa)
NB	Nonthaburi
SP	SamutPrakon
PT-1	PathumThani (KhlongLuang)
PT-2	PathumThani(Thanya)
BH-1	Chatuchak Park
BH-2	Lumphini Park
BH-3	Suea Pa Park
BH-4	Rommaninath Park
BH-5	Rajamangala University
BH-6	Kasetsart University

5.2 Soil parameters

The soil parameters in this study were adopted from the boring log data of 8 boreholes located in zone D. Soil parameters such as water content, liquid limit, plastic limit, total density, undrained shear strength and standard penetration test (SPT) were gathered from each borehole. The initial void ratio was calculated by using the phase relationship equation from borehole parameters. The soil parameters and thickness of the soil layer were calibrated with the data from DGR. This study chooses 8 boreholes to evaluate the ground displacement. The soil parameters of each soil layer are shown in Table 3. Some parameters cannot be interpreted by using only boring log data. So, some soil parameters were adopted from previous studies such as the specific gravity equal to 2.7 for both soft clay and stiff clay [6]. The Over Consolidation Ratio (OCR) is equal to 1.3 for soft clay. And 1.5 for stiff clay [8] and the effective stress parameter as matric of suction coefficient (χ) is equal to 0.71 at the isotropic line for normally consolidated soil while the effective degree of saturation is kept constant. It is considered for both soft clay and stiff clay. An effective stress parameter was conducted using the results of the oedometer compression tests (undrained) of unsaturated silty soil [9]. Terms of suction values were adopted from the previous research about the Soil-Water Characteristic Curve (SWCC) of unsaturated soil. This study considers suction values by using the degree of saturation value of each soil layer. The degree of saturation values was referenced from the Bangkok clay parameters in the Sukhumvit site by the Oedometer test and Triaxial test [10]. This study considers the degree of saturation equal to 96% for soft clay and 94% for stiff clay. Soil-Water Characteristic Curve (SWCC) shows the relationship between suction and degree of saturation was fit using the Van Genuchten model [11]-[12]. This study uses a suction value equal to 10 kPa as Fig. 4. Table 3 shows Stiff clay has a sand content of 66% and a clay content of 34%. Suction value was determined as the soil sample of S70C30 is 70% fine sand and 30% Ariake clay in Fig. 5 [13]. It shows the degree of saturation of Stiff clay is equal to 94%, and the suction value is 180 kPa.

Table 3 Properties of Bangkok clay

Properties	Soft clay	Stiff clay
Natural water content (%)	122-130	20-24
Natural void ratio	3.11-3.64	1.10-1.30
Grain size distribution		
Sand (%)	4.0	23
Silt (%)	31.7	43
Clay (%)	64.3	34
Specific Gravity	2.75	2.74
Liquid limit (%)	118±1	46±2
Plastic Limit (%)	43±0.5	19±2
Dry unit weight (kN/m^3)	16.5	15.5-16.5
Degree of saturation (%)	98±2	94-100

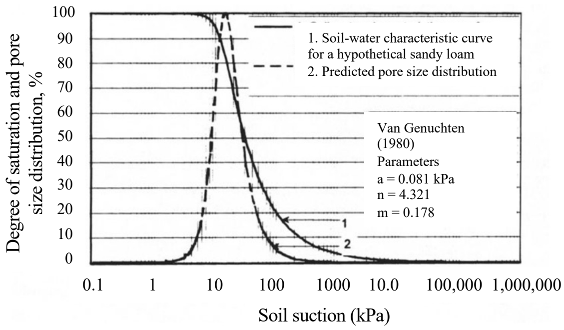

Fig. 4 SWCC curve for soft clay [11]

Table 3 Soil parameters for the theoretical calculation

Soil layers	Soil parameters	Description	Bored holes							
			NP	SS	NB	BK-1	BK-2	SP	PT-1	PT-2
Very soft to Medium Clay (2 to 13 m.)	Wn (%)	Water content	52	38	88	69	72	62	78	65
	LL (%)	Liquid Limit	41	43	87	64	48	46	50	38
	PL (%)	Plastic Limit	23	25	67	27	25	37	25	20
	γ_t (t/m^3)	Total density	1.70	1.84	1.50	1.59	1.58	1.64	1.55	1.62
	e_o	Initial void ratio	1.40	1.03	2.37	1.86	1.94	1.67	2.10	1.75
Stiff to Very stiff clay (13 to 25 m.)	Wn (%)	Water content	19	17	-	22	37	34	25	25
	LL (%)	Liquid Limit	31	35	-	51	50	51	60	40
	PL (%)	Plastic Limit	18	17	-	2.06	1.85	1.88	2.01	2.01
	γ_t (t/m^3)	Total density	2.12	2.16	-	2.06	1.85	1.88	2.01	2.01
	e_o	Initial void ratio	0.51	0.46	-	0.59	0.99	0.92	0.68	0.68

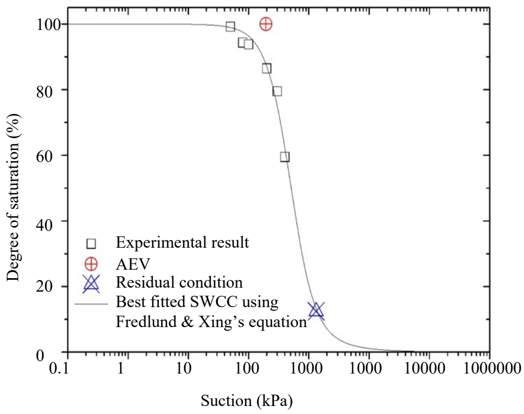

Fig. 5 SWCC curve for stiff clay [13]

5.3 Theoretical calculation

The ground displacement calculation is very important to evaluate the stability of the building in each period. This study tries to simplify the equation to evaluate the ground displacement during groundwater level change based on the timing of DGR during groundwater level increase. The DGR report represents the changing groundwater level in the 8 locations around Bangkok, Thailand. All of the locations show the groundwater level change has a similar trend of groundwater level recovery from 1997. Moreover, DGR forecast that the groundwater level will reach the ground surface around 2032 to 2034 [6]. The characteristic of groundwater level recovery is almost the same in every location. Therefore, this study follows the name location BH-1 as Chatuchak Park. The BH-1 shows the groundwater level will reach the ground surface in 2032. This study simplifies by evaluating of groundwater level from 2001 to 2032, in the period of groundwater recovery.

The consolidation settlement equation calculates in the case of over-consolidation clay because the maximum vertical effective stress is more than the final vertical effective stress, as in Eq. (1). The theoretical calculation model is mentioned in Fig. 6. The soil layers above groundwater level are considered by using the unsaturated equation. While the soil layers below the groundwater level are considered by using the saturated equation. Many parameters were calculated such as the recompression index (C_r), the initial void ratio (e_o), the maximum vertical effective stress (σ'_{vm}), the final vertical effective stress (σ'_{vf}) and the thickness of soil or drainage path. High groundwater level was considered as saturated soil refer to Eq. (2) based on Terzaghi theory [14] and low groundwater level was considered as unsaturated soil refer to Eq. (3) following the expression of Bishop equation [15]. The total vertical effective stress (σ), an effective stress parameter (s), pore-air pressure (u_a), pore water pressure (u_w) and suction (S) as in Eq. (4).

$$\Delta H = \frac{C_r}{1+e_o}\log\frac{\sigma'_{vf}}{\sigma'_{vm}}H_o \quad (1)$$

$$\sigma' = \sigma - u_w \quad (2)$$

$$\sigma' = [(\sigma - u_a) + \chi(u_a - u_w)]\ ;\ 1 > \chi > 0 \quad (3)$$

$$S = u_a - u_w \quad (4)$$

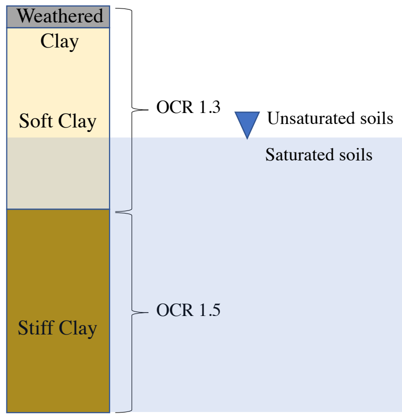

Fig. 6 Schematic of the theoretical calculation

6. RESULTS AND DISCUSSIONS

This part shows the results of ground displacement after estimation and interpretation of the soil parameters, soil profile and groundwater level recovery.

6.1 THE 3D SOIL PROFILE

The 8 bored holes were located in zone D, the yellow area of Bangkok plain. All bored holes are distributed around the yellow area. It is evaluated the soil parameters and soil profiles. The soil layers were specified from soil parameters in boring log data. The data in the boring log is not enough to determine the characteristic of the soil layers. So, some parameters were adopted from the previous research and DGR data. Such as C_c and C_r are accessed by calculation and verification from Bangkok clay of other researchers [16]-[20]. The Cc (compression index) and Cr (recompression index) in this research adopted only the value which has an R square value of more than 0.9 by the relationship between the compression index and recompression index with the water content (w_n%). Then, this study drew the 2D soil profile using the AutoCAD software as Fig. 7 and drew the 3D layout with the 3ds Max software from Fig. 8 to Fig. 10.

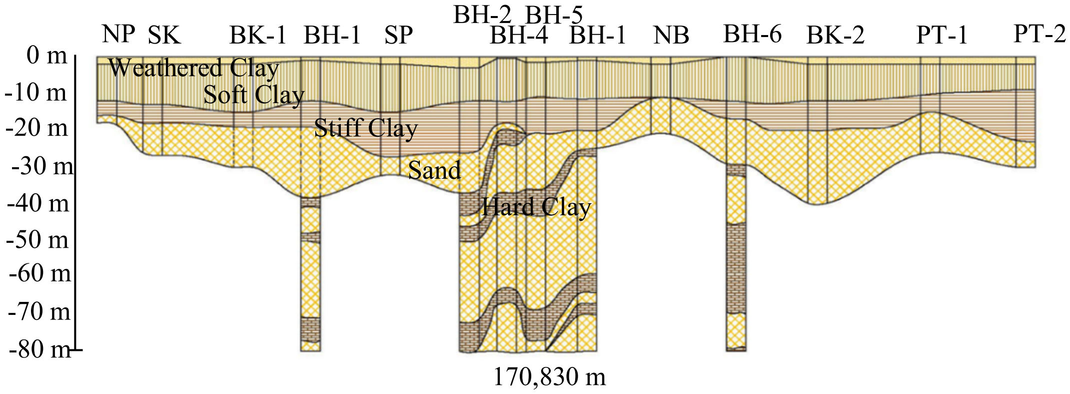

Fig. 7 Soil profile layout of zone D

The variation of each soil layer in the 3D soil profile was interpreted from a soil boring log that was verified by DGR. (BH-1 to BH-6). This study has considered only the upper 3 subsoil layers that have affected groundwater level change covering an area of 1,334 square meters. All the soil profiles found that each layer has a different soil thickness. So, this is the gap to evaluate ground displacement in the future.

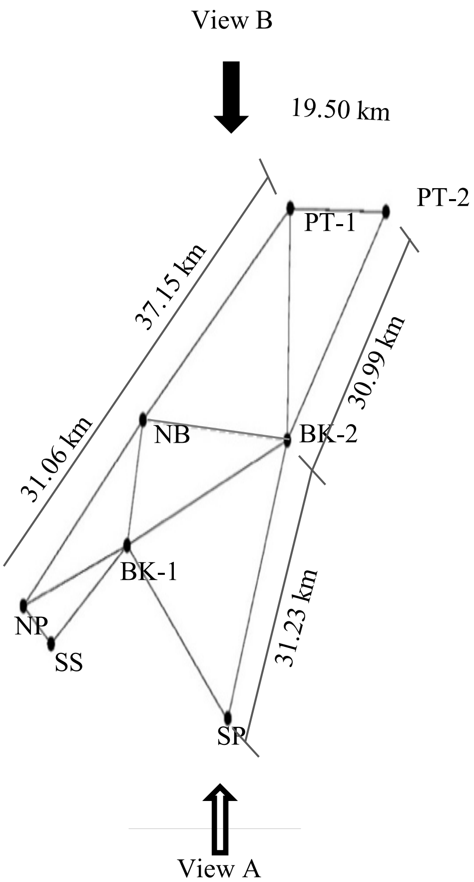

Fig. 8 Top view of the evaluating area

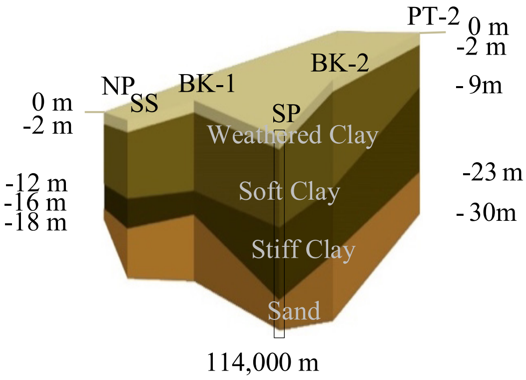

Fig. 9 The 3D of view A

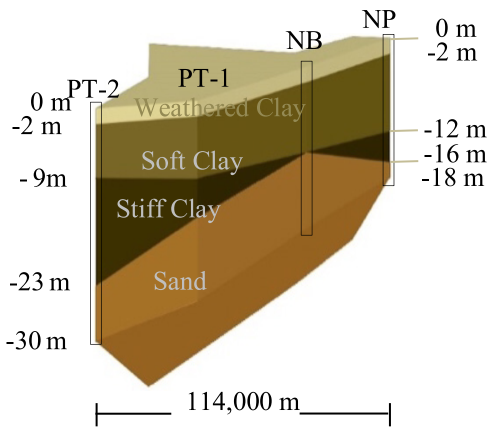

Fig. 10 The 3D of view B

6.2 GROUND DISPLACEMENT

This study focuses on the evaluated ground displacement of the soft Bangkok clay and stiff to very stiff clay by using theoretical calculation. This result shows the total ground displacement and ground displacement rate during groundwater increase or recovery to the ground surface. The methodology of theoretical calculation was considered by following the period prediction of DGR.

So, this study estimates the total ground displacement every 5 m of groundwater level recovery. It represents the groundwater level equal to -25 m in 2001 then the groundwater level increased to the ground surface in 2032. The 8 bored holes have similar total ground displacement trends and ground displacement rates from 2001 to 2032 as in Table 4. Figure 11 shows the relationship between the total ground displacement and the time of all bored holes in zone D. There is a rebound trend of ground displacement due to groundwater recovery. In the same study area, the results have the characteristic of ground displacement similar to other results such as the ground displacement equal to 0.25 cm/yr by the measurement of DGR, the results of the ABAQUS software have the rebound rate from 1997 to 2016 equal to 0.26 to 0.32 cm/yr. And the result of PLAXIS2D evaluated the ground displacement rate equal to 0.35 cm/yr from 1997 to 2037. By the way, the result of this study was evaluated by using the prediction of groundwater level from previous studies. At present, no one knows when the groundwater level will increase to the ground surface and how about ground displacement during groundwater recovery. So, this study tries to simplify the calculation method. Therefore, the results from simplified theoretical calculation can be conducted to evaluate or predict ground displacement due to groundwater recovery in the future.

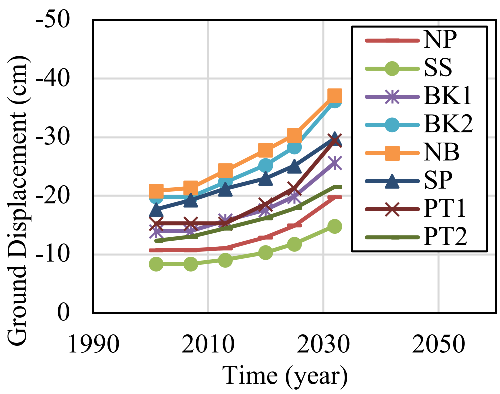

Fig. 11 The evaluation ground displacement of each bored hole

Table 4 The results of ground displacement

Bored hole	Total ground displacement (cm)		ground displacement Rate (cm/yr)
	At 2001	At 2032	
NP	-9.07	-17.68	-0.28
SS	-7.29	-13.64	-0.20
BK1	-12.30	-23.50	-0.36
BK2	-17.41	-33.31	-0.51
NB	-18.92	-35.03	-0.52
SP	-17.05	-28.52	-0.37
PT1	-12.63	-25.90	-0.43
PT2	-11.48	-20.44	-0.29

7. CONCLUSION

This study summarizes the subsoil layer characteristics and soil properties to evaluate the ground displacement during groundwater recovery. The results of this study were separated into two parts. The first part is simplified the subsoil layers of zone D. The soil schematics are verified by the subsoil data of DGR. The second part is the evaluation of the ground displacement during groundwater recovery by theoretical calculation. All of the results can summarize as;

1. The soil layer of each borehole has a similar depth and continuity of the soil layer. The soil layer's variability depends on the clay layer's thickness. There are represented in 2D and 3D illustrations.
2. Affecting factors of ground displacement rate are a percentage of water content (w_n%), borehole location, the thickness of both the clay layers and groundwater level.
3. The theoretical calculation was one of the methods used to evaluate or predict the ground displacement during groundwater recovery. The ground displacement has rebound every bored hole. The calculation is based on Terzaghi's and Bishop's equations, which have the same results as previous research by ABAQUS software and PLAXIS2D software. It shows that the unsaturated parameters need to consider.

Finally, the results of this study can guide for calculation of the value of ground displacement during groundwater recovery in each site. Not only Zone D in Bangkok plain, Thailand but can also apply this methodology to other sites or other countries. This methodology can help to protect the building from damage.

8. ACKNOWLEDGMENTS

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9. REFERENCES

[1] Intachai K., Assessment on pile capacity given effects of groundwater drawdown and rebound Associated with deep well pumping in Bangkok, Asian Institute of Technology, 2018.

[2] Phien-Wej N., Giao P.H., and Nutalaya P., Land Subsidence in Bangkok, Thailand., Geology, Vol. 82(4), 2006, pp. 187–201.

[3] Saowiang K., and Giao P. H., Numerical analysis of subsurface deformation induced by groundwater level changes in the Bangkok aquifer system, Acta Geotechnica, 2021, pp. 1265–1279.

[4] Phoban H., Seeboonruang U., and Lueprasert P., Numerical Modeling of Single Pile Behaviors Due to Groundwater Level Rising, Appl. Sci., 2021, 11, 5782.

[5] Amornkul C., Engineering Subsoil Database of Lower Central Plain, Thailand, Master of Engineering, 2010, pp. 3-161.

[6] Department of Groundwater Resources., The study of the effect of underground structures due to the recovery of water pressure in the groundwater layer in Bangkok and its vicinity, Ministry of Natural Resources and Environment, 2012, pp. 17-62.

[7] Department of Public Works and Town & Country Planning, Soil GIS DPT, [online], Available from: http://soilgis.dpt.go.th/login.php, 2020, April.

[8] Giao P. H., Paveechana T., and Saowiang K., Consolidation Settlement Analysis with Reference to Groundwater Recovery in The Bangkok Multi-Aquifer System, Advances in Geotechnical Infrastructure, 2013, pp. 567-573.

[9] Zhou A.N., Sheng D., Scott W. Sloan., and Gens A., Interpretation of unsaturated soil behavior in the stress – Saturation space, I: Volume change and water retention behavior, Computers and Geotechnics 43, 2012, pp. 178-187.

[10] 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, The Japanese Geotechnical Society, 2012.

[11] Siller W., The mathematical representation of the soil-water characteristic curve, M.SC. thesis University of Saskatchewan, Saskatoon, Canada, 1997.

[12] Van Gebuchten M. Th., A closed from equation predicting the hydraulic conductivity of unsaturated soils, Soil Science Society of America Journal, 44, 1980, pp. 892-898.

[13] Khaimook P., Predicting soil-water characteristic curve from soil basic properties and its application for ground improvement, Department of Science and Advanced Technology Graduate School of Science and Engineering Saga University, Japan, 2019.

[14] Terzaghi K., The shearing resistance of saturated soils and the angle between the planes of shear, in The First International Conference on Soil Mechanics and Foundation Engineering, A. Casagrande, P. C. Rutledge, and J. D. Watson, Eds., 1936, pp. 54–56.

[15] Bishop A. W., The principle of effective stress. Teknisk Ukeblad 106(39), 1959, pp. 859–863.

[16] Adikari, G.S.N., Statistical Evaluations of Strength and Deformation Characteristics of Bangkok Clays, MSc Thesis, Asian Institute of Technology, Bangkok, Thailand, 1977.

[17] Suthamnatpong S., Engineering Properties and Behaviour of Bangkok Clay Soils, M.Eng. Thesis Chulalongkorn University, 1977.

[18] Tsai, C.Y., A Monograph on the Engineering Properties of Bangkok Subsoils. M.Eng. Thesis, Asian Institute of Technology, Bangkok,1982.

[19] Kusuwan K., Statistical Evaluation of Engineering Properties of Bangkok Subsoil, Chulalongkorn University, 1988.

[20] Chuenwattana R., Evaluation of engineering properties of soft Bangkok clay, M.Thesis, Kasetsart university, 2002.