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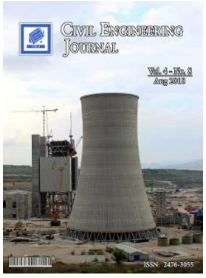

Physical Model Test for Soft Soil With or Without Prefabricated Vertical Drain with Loading

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Abstract

The paper builds a physical model of testing in the laboratory with the parametric tempered glass box 0.5 × 0.5 ×1.2 m (length × width × depth) containing saturated clay to study the settlement and consolidation when loading increased gradually over time. The research covers herein to present the monitoring of settlement and pore water pressure, settlement calculation, numerical simulation using PLAXIS software V8.2 based on the results of soil physical and mechanical tests before and after loading in case of having or not prefabricated vertical drain (PVD). In case of no PVD, the calculation and numerical simulation using the soil parameters before loading have the differential settlement from the monitoring data, approximately 3.86 mm (10.45%), 0.41 mm (1.11%) respectively. Meanwhile, the deviation in the case using data after loading is about 2.29 mm (6.20%), 0.21 mm (0.56%) respectively. In case of PVD, the calculation and numerical simulation with the testing result of before loading deviation from the settlement monitoring by subsidence meter is 2.91 mm (7.88%), 44.42 mm (120.28%), calculation and simulation with the testing result of after loading deviation is 0.80 mm (2.17%), 1.26 mm (3.41%). In the case of having PVD, the difference in calculation, subsidence observation, and numerical simulation between the mechanical properties before and after loading is significant, when using the mechanical data after loading then the results are quite close to the subsidence of observation and simulation rather than before loading.

Keywords: Physical Model; Settlement; Soft Soil; Prefabricated Vertical Drain; Numerical Model.

1. Introduction

The method of soft soil treatment by PVD with loading is widely used around the world and Vietnam because of its advantages such as stable material supply sources, cost-saving, effectiveness and low environment impact, etc. Many scientists have concentrated on studying PVD with the laboratory models, field observations and numerical simulation.

Hansbo (1979) [1], Atkinson and Eldred (1981), Rixner et al., (1986), Long and Covo (1994) [2] gave the equation of converting the equivalent diameter of PVD. The deformation impact and limited water drainage capability of PVD were published by Chai and Miura (1999, 2000), Chai et al., (2004) [3]. The most recent results, for example, belonged to Bo (2004) [4], (2010) [5] indicated the effect of laboratory test results on water drainage capability of PVD. Since the material filter might get some working faults during and after construction, the finer or clayey soils are able to get into the filter. Furthermore, the vast majority settlement of soil foundation causes PVD does not work well because of large deformation. These reasons have said much effect on PVD performance either in short-term or long-term uses such a reduction of drainage ability.

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Kremer (1983), Rixner et al., (1986), Holtz at al., (1991), Chai et al., (2004) [5] studied the effect of horizontal pressure on water drainage capability of soft soil. The research groups came into conclusion that the water drainage capability of PVD reduces when horizontal pressure increases. Le, et al., [6] analyzed and evaluated the stability of embankment on the soft soil with the provision of PVD based on the displacement data of the embankment according to two methods: Matsuo – Kawamura method and Tominaga - Hashimoto method corresponding to the conditions in Vietnam.

Nguyen, et al. (2013) [7] evaluated observation results during treatment process of the sub-grade construction on the soft soil belonging to the tendering package of EX-9 at Km91+300-KM96+300, Ha Noi - Hai Phong Expressway Project to recommend construction sequences and the time of waiting for consolidation, which shall contribute to give solutions to different settlements of the transition sections between embankments, bridges, and culverts. Ho and Tran (2012) [8] showed that the theoretical and practical operation of PVD is not consistent. Therefore, a wide range of works after completion encountered residual settlement, which caused a negative impact on the quality of the works. Where the work has loading completion time settlement of S <0.6 m, it is recommended to use equivalence partitioning method (FEM-2); where S>0.6 m, it is recommended to use the method of considering PVD as an elastic material which has vertical permeability factor (FEM-1) because it obtains higher reliability.

The calculation of settlement and consolidation of the weak ground base much depends on mechanical and physical characteristics especially the coefficient of consolidation in vertical and horizontal direction Cv and Ch. Since engineers make calculations based on the data of the geological engineering survey before installing PVD and loading, the obtained calculation results are much different from the actual observation results. A quite wide range of research groups around the world and Vietnam built physical models and experimental simulation for soft soil treatment by PVD such as Saowapakpiboon et al., 2011 [9], Rujikiatkmajorn, 2012 [10], Pham 2015 [11]. Although there exist some drawback of physical models among their study such as affected by boundary conditions and still have tiny gap between simulation and model, these authors are able to present the general process of soil - structure behavior. In fact, using physical model in laboratory allow to carefully observe the mechanism of soil – structure, authors thus easily predict and correct the results based on the performance of physical model.

In addition, other researchers of selecting appropriate techniques, measurements, analysis and numeric simulation conducted by Vietnamese and the groups around the world showed that the treatment of soft soil with PVD has been paid much attention and studied widely as Luu, et al., [12], Le, et al., [13], J. Saowapakpiboon et al., [14] and S.G. Chung et al., [15]. However, the results of study present the narrowing subjects among range of physical model and numerical modelling, longer time observation and investigation of research should be paid much attention in order to apply these results in the actual projects.

In order to develop the study in soft soil treatment using PVD in consideration to soil characteristics testing before and after loading, a laboratory test model containing saturated clay is used to measure settlement and consolidation where loading increases gradually by time. The soil samples are taken from various depths to identify mechanical and physical properties before and after loading. The calculation of settlement results from mechanical and physical properties is made for two cases before and after loading; at the same time the settlement observation is conducted by displacement meter and pore water pressure observation and numeric simulation are done by PLAXIS V8.2 software. As a consequence, the results of the settlement are compared each other based on the soil parameters before and after loading.

2. Building of Model and Calculation Theory

2.1. Building of Model

The physical model has dimension of $0.5 \times 05 \times 1.2$ m and volume of 0.3 m^3, which is built of steel frame and the lateral tempered glass surface of 1 cm thickness and one layer of soft soil is put inside as shown in Figure 1. Model testing equipment includes: piezometers and data logger determine pore water pressure, displacement gauges, prefabrication vertical drains, geotextile.

- Case 1: Without PVD, loading with 1.25, 2.5, 3.75, 5 kN corresponding to 5, 10, 15, 20 kPa respectively.

- Case 2: With PVD, loading with 1.25, 2.5, 3.75, 5 kN corresponding to 5, 10, 15, 20 kPa respectively.

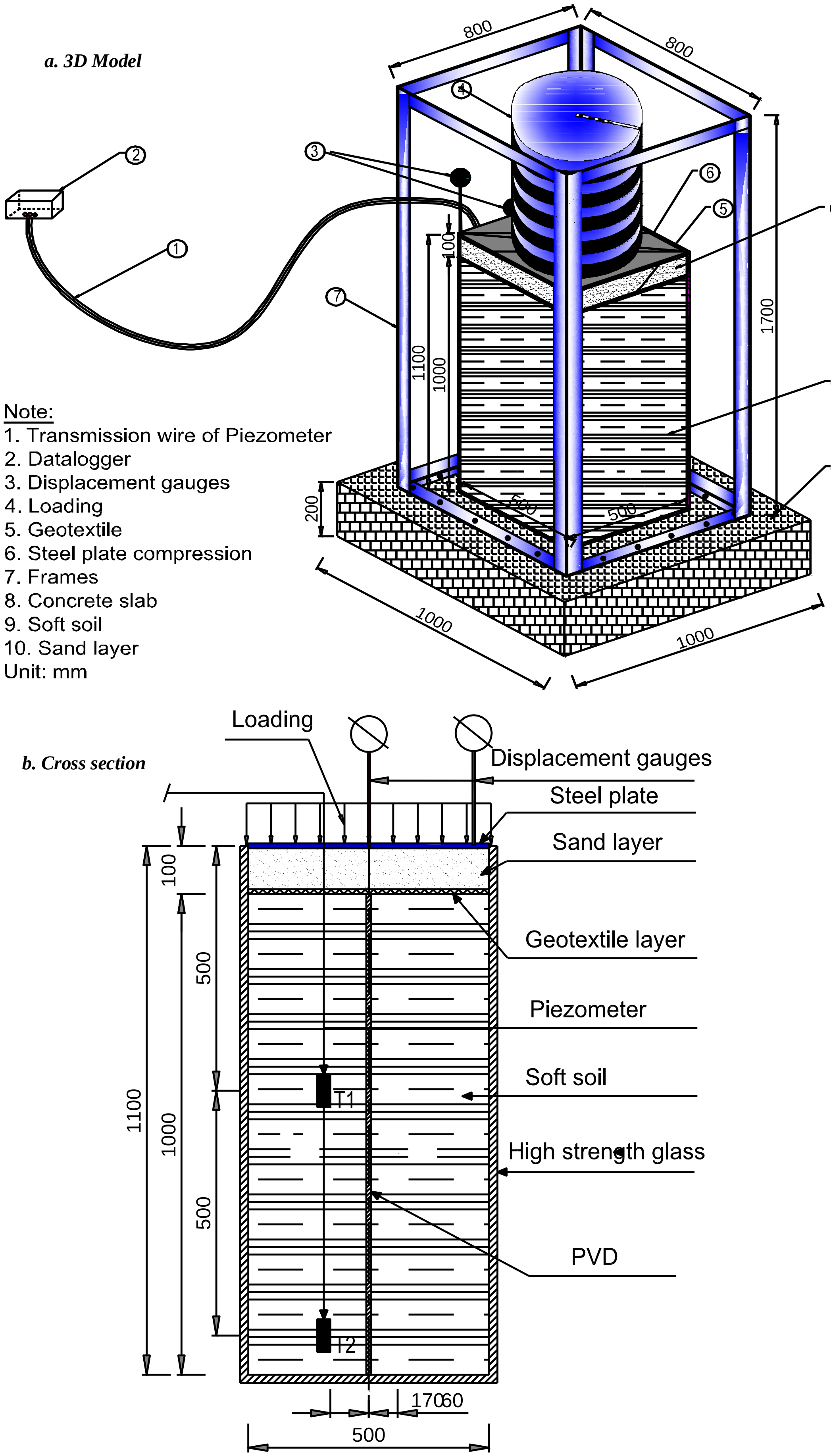

Figure 1. Design physical model

Figure 2. Model building

The construction sequences the physical model as follows:

a) Moisturize soil samples, mix it uniformly, then put it in the Styrofoam box for continuous moisturizing, continue to mix many times, check moisturize at various points of the block to make sure that the soil samples have been mixed uniformly.

b) Put the soil in the sample container, use the plastic pipe ϕ60 to take undisturbed sample at various points, test the mechanical and physical characteristics before loading.

c) Install two ends of measuring pore water pressure at the depths of 0.5 m and 1.0 m.

d) Install PVD with dimension of 3mm*100mm*1200mm in the middle of soil sample container.

e) Place geotextile and grade coarse sand.

f) Place steel plate with dimension of 0.49 × 0.49 × 0.05 m.

g) Install settlement gauges.

h) Conduct loading and check settlement meter data and Geokon 403 reading data for piezometer.

The pictures for steps a through h in Figure 3.

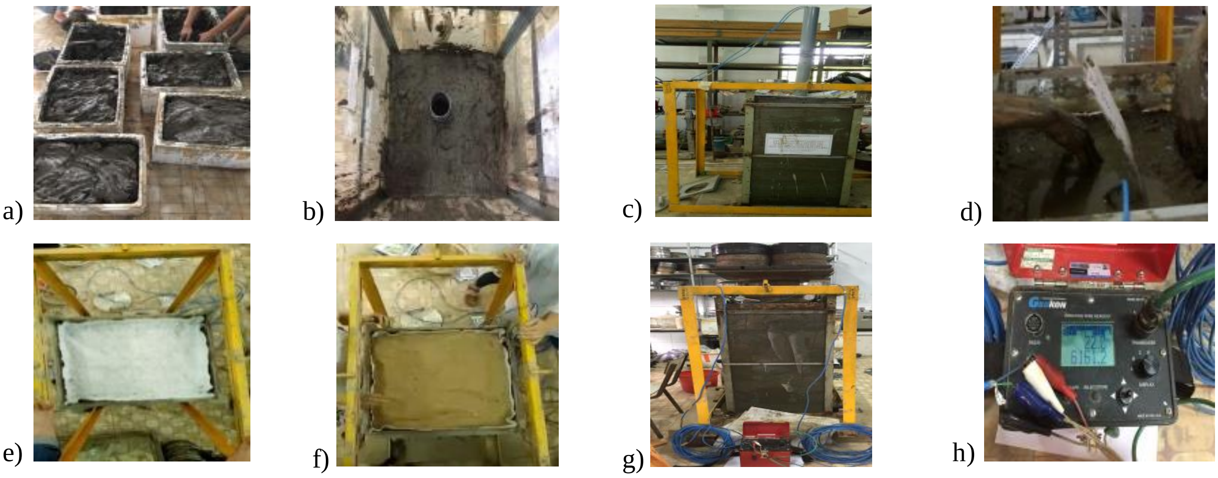

Figure 3. Process model

2.2. Calculation Theory

The design for soft soil treatment with PVD for the works of plan preparation, dam, and transportation with embankment shall comply with the 22TCN 262-2000 [16] Survey and design procedures for motorway sub-grade on soft soil and TCVN 9355-2012 [17] Ground improvement by the prefabricated vertical drain (PVD).

2.2.1. Consolidation

- The consolidation U obtained after time t upon the completion of backfill:

$$U = 1 - (1 - U_v)(1 - U_h) \quad (1)$$

- Vertical consolidation U_v depends on time:

$$T_v = \frac{C_v^{tb}}{H^2} t \quad (2)$$

- The average vertical coefficient of consolidation of the soft soil layer:

$$C_v^{tb} = \frac{H_a^2}{\left(\Sigma \frac{h_i}{\sqrt{C_{vi}}}\right)^2} \quad (3)$$

- Horizontal consolidation (Hansbo, 1981) [17]:

$$U_h = 1 - \exp\left\{\frac{-8T_h}{F(n)+F_s+F_\gamma}\right\} \quad (4)$$

Where: The definition of legends as per TCVN9355:2012 [17] and Duong Ngoc Hai (2011) [18].

T_h: Time factor in horizontal;

F(n): Factor considering the effect of PVD distance;

F_s: Factor considering the impact of ground disturbance when plug PVD;

F_γ: Factor determining the resistance of PVD.

2.2.2. Pore Water Pressure from Piezometer Data

The daily measured and read data is the square number of frequency and temperature. Data logger is used to read and record all data in memory when connecting to pore water pressure probe. Data logger comes from Geokon, USA with model of GK-403. The reader shall receive current data then convert it into frequency.

$$f_0 = \frac{1}{2}\sqrt{\frac{F}{ml}} = \frac{1}{2}\sqrt{\frac{\sigma}{\rho}} = \frac{1}{2}\sqrt{\frac{E\Delta l}{\rho l^3}} \quad (5)$$

- Pressure is determined by the following Equation:

$$P = (R_1 - R_o).G + (T_1 - T_0).K \quad (6)$$

Where:

R_1, T_1: read number at cycle;

R_0, T_0: initial read number;

G, K: regression coefficient; G=0.31487, K=0.00000 (PIE 1) and G=0.31674, K=0.00000 (PIE 2)

2.2.3. Evaluation of Consolidation According to the Pore Water Pressure Observation Results [19]

- Initial pore water pressure u_0:

$$u_0 = u_1 - \Delta u_0 \quad (7)$$

$$\Delta u_o = \gamma_w.g\,(H_{w1} - H_0 + S_1) + \gamma_k\,.g.(H_1 - H_{w1}) \quad (8)$$

Where:

u_1: Pore water pressure for the first measurement;

Δu_0: Pore water pressure difference;

γ_k: the dry unit weight of sand;

γ_w: the unit weight of sand;

H_{w1}: the underground level at the first measurement;

H_o: base elevation before backfilling;

H_1: base elevation at the first measurement of pressure;

S_1: Base settlement at the first measurement of pressure.

- Initial effective stress:

$$\sigma_o' = \gamma_s.g.(H_o - H_p) + g.(H_{wo} - H_o) - u_0 \quad (9)$$

Where:

γ_s: the saturated unit weight of clay;

H_P: elevation of the probe;

H_{WO}: initial underground level before backfilling.

- Effective stress at the time of consideration:

$$\sigma_t' = \sigma_{kt} + \gamma_s.g.(H_o - H_p) + \gamma_w.g.(H_{wt} - H_0 + S_t) + \gamma_k .g.(H_t - H_{wt}) + g.S_{pt} - u_t \quad (10)$$

Where:

σ_{kt}: Service load;

H_t: Base elevation at the time of consideration;

H_{wt}: water level at the time of consideration;

u_t: Pore water pressure at the time of consideration;

S_t: Surface settlement at the time of consideration;

S_{pt}: Settlement of pore water pressure probe.

Consolidation at the time of consideration: $U_t = (\sigma_t' - \sigma_o')/ \sigma_{kt}$ (11)

3. Test Result

3.1. Test Results of Mechanical and Physical Characteristics of Soil

The soil samples are taken at various depths before and after loading in two cases with and without PVD. The soil samples are determined in the laboratory for some mechanical and physical characteristics as listed in Table 1. In which, Nguyen and Nguyen (2017) [20] showed that the horizontal consolidation coefficient C_h and horizontal permeability coefficient K_h are tested in accordance with horizontal sample method based on the consolidation properties of ASTM2435: 1996 [21] and TCVN4200: 2012 [22]. As shown in Table 1, in case of no PVD, mechanical and physical characteristics have changed but not considerably; in case of PVD, mechanical and physical characteristics have changed considerably, in particular, after loading, density and friction angle have increased.

Table 1. Results of phy-mechanical properties for testing case

Parameter	Sym bol	Unit	Without PVD				With PVD			
			Before loading		After loading		Before loading		After loading	
			Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand
Dry density	γ_k	kN/m^3	11.18	16.50	11.47	16.50	11.29	16.50	12.33	16.50
Wet density	γ_{wet}	kN/m^3	16.97	19.00	17.15	19.00	17.08	19.00	17.69	19.00
Horizontal coefficient of permeability	k_x	m/day	8.346e-5	1	1.920e-4	1	1.521e-4	1	6.109e-5	1
Vertical coefficient of permeability	k_y	m/day	5.461e-5	1	1.337e-4	1	7.171e-5	1	5.348e-5	1

Cohesive	c_{ref}	kN/m^2	8.826	1.000	12.749	1.000	9.709	1.000	12.454	1.000
Friction angle	φ	degree	3.730	32.000	6.033	32.000	4.167	32.000	8.767	32.000

3.2. Settlement Results by Time

3.2.1. Settlement Calculation Results by Time

Without PVD, at the loading level of 20 kPa, the settlement is 40.79 mm and consolidation reaches 55.26% after 22 days compared with the data before loading. In addition, U reaches U=90% after 78 days and 100% after 249 days. Compared with the data after loading at the loading level of 20 kPa, the settlement is 39.22 and consolidation reaches about 49.36% when U reaches 90%, it shall take up to 100 days and when U reaches 100%, it shall take up to 322 days.

With PVD, it is clearly seen that the settlement reduction appears sharp. The time for consolidation becomes shorter, particularly 60 days before loading and 65 days after loading. Therefore, with PVD, water drainage speed shall be faster, so consolidation time is shortened, the number of days for consolidation to reach 90% shall be less than that of the case without PVD.

Table 2. Calculation data of the settlement by the phy-mechanical properties of soil before and after loading

Calculations based on testing results	Para-meter	Results											
		Without PVD						With PVD					
		5 kPa	10 kPa	15 kPa	20 kPa	U=90 %	U=100 %	5 kPa	10 kPa	15 kPa	20 kPa	U=90 %	U=100 %
Before loading	t_i(day)	3	3	4	22	78	249	7	7	6	23	-	60
	U (%)	30.09	25.25	27.24	55.26	90	100	68.78	61.29	55.90	92.14	-	100
	S_t(mm)	3.92	23.22	26.57	40.79	50.05	52.66	16.42	28.66	29.69	48.88	-	50.26
After loading	t_i(day)	3	3	4	22	100	322	7	7	6	23	35	65
	U (%)	27.90	23.98	25.59	49.36	90	100	56.77	48.41	43.83	80.13	90	100
	S_t(mm)	3.87	22.71	26.14	39.22	50.13	52.66	15.83	26.07	28.57	46.77	48.59	50.18

3.2.2. Settlement Observation Result by Time

Table 3 and Figure 4 indicate that the settlement measured by the meter at the various levels of loadings for two cases with and without PVD. In case of PVD, the settlement is higher than that of the case without PVD. As visual inspection, without PVD the amount of water drained at the level of 20 kPa is 485 ml and the settlement at the final loading level of 20 kPa is 36.93 m. With PVD, the amount of water drained at the level of 15, 20 kPa is 567, 1661 ml respectively; and the observed settlement at the level of 20 kPa is 45.97 mm. With PVD, water is drained earlier and more than that of the case without PVD because horizontal permeability has occurred.

Table 3. Settlement by time of monitoring by displacement meter

Loading level	Without PVD					With PVD				
P (kPa)	S_1 (mm)	S_2 (mm)	S_3 (mm)	S_4 (mm)	S_{tb} (mm)	S_1 (mm)	S_2 (mm)	S_3 (mm)	S_4 (mm)	S_{tb} (mm)
5	4.30	4.33	4.31	4.33	4.32	17.35	17.50	17.50	17.75	17.53
10	12.80	13.02	13.15	12.98	12.99	28.18	28.00	27.80	28.00	28.00
15	26.32	26.60	26.45	26.45	26.46	35.47	35.45	35.20	35.10	35.31
20	37.08	36.65	37.12	36.86	36.93	45.80	45.60	45.78	46.70	45.97

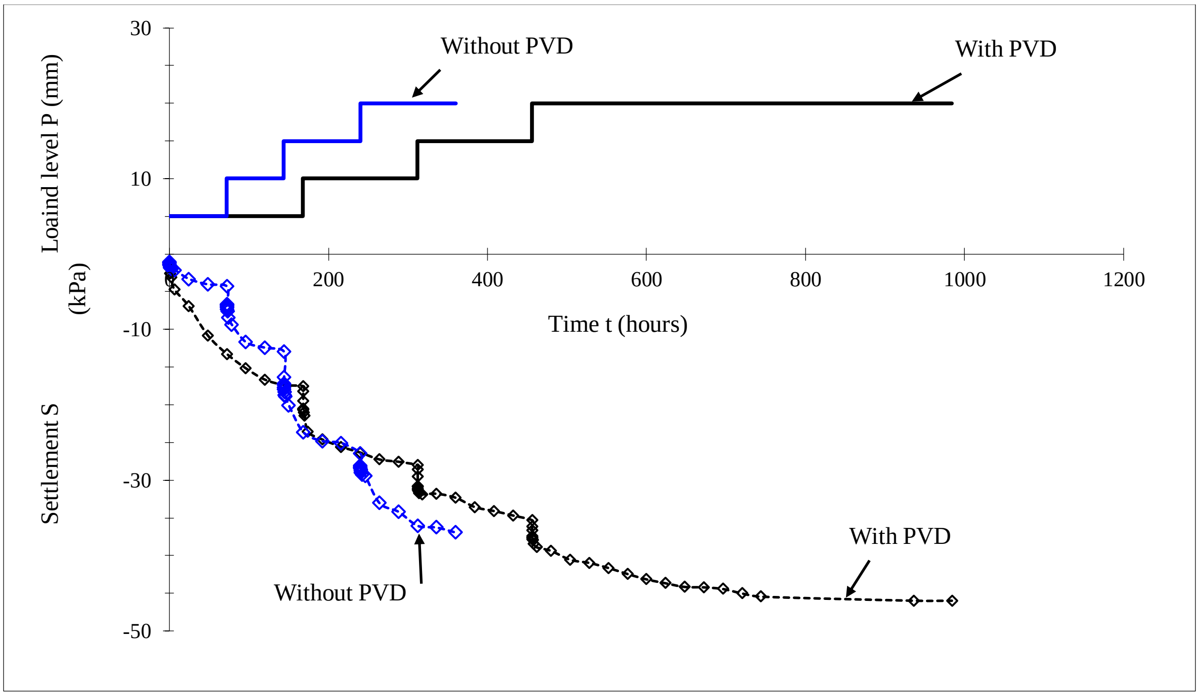

Figure 4. Settlement-time monitoring for each loading level by the displacement meter

3.3. Observation Results of Pore Water Pressure

3.3.1. Observation Results

The pore water pressure of two piezometers at the depths of 0.5 and 1.0 m for two cases with and without PVD is stipulated in the Figures 5 and 6. Then, it is possible to determine the consolidation of the soil based on the progress of pore water pressure as the Table 4.

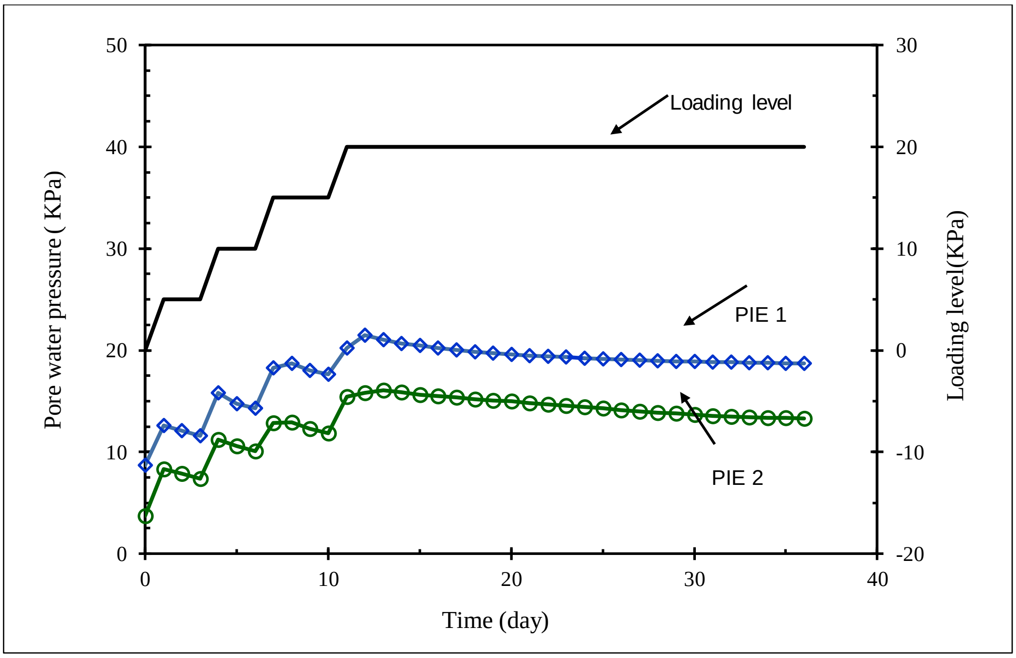

Figure 5. Pore water pressure by time graph when loading (without PVD)

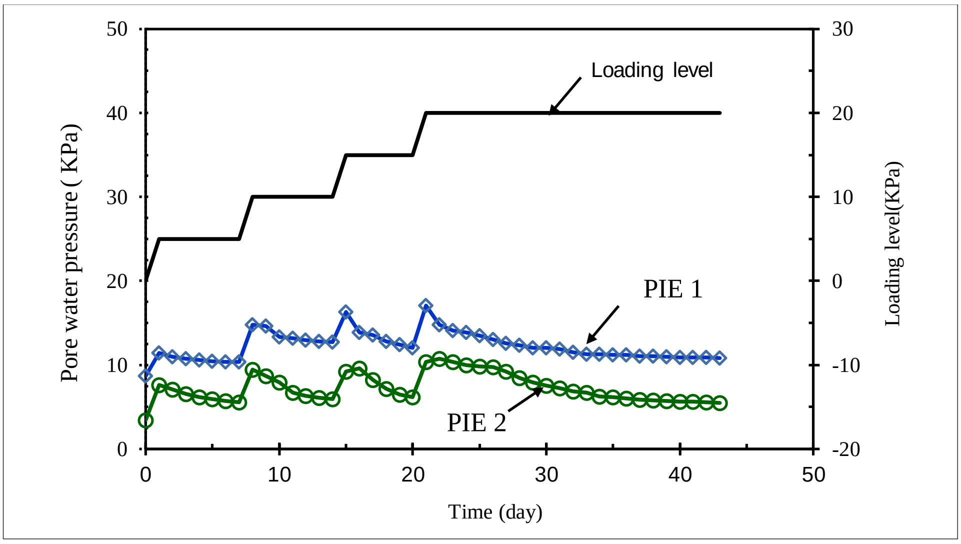

Figure 6. Pore water pressure by time graph when loading (with PVD)

It is clearly seen that the changes in distribution of pore water pressure in both case with or without PVD have the same tendency to significantly fluctuate at the initial and slightly decrease at the final of time-loading period. In terms of the pore water pressure value, there are significant decreases at the end of time-loading period after using PVD. For instance, the value of pore water pressure reduce by approximately 42% and 58.3% for the PIE1 located at 50 cm and PIE2 located at 100 cm below the ground surface, respectively.

3.3.2. Calculation Results

In 2 cases with or without PVD, set up piezometer at depth 0.5 and 1.0 m, record data and calculate by formula in the section 2.2.2 and 2.2.3. According to the observation results of pore water pressure in Table 4 and Figures 5 and 6, the evaluation of consolidation after 32 days for the case without PVD is U=50.90%÷54.08% and for the case with PVD is U=90.10%÷91.43%. Consolidation is higher at a deeper depth and in case with PVD water drainage faster, so the fast consolidation reached 90%.

Table 4. Cohesion based on pore water pressure monitoring data by time

Case		Without PVD		With PVD	
Symbol	**Unit**	**Piezo 1 (1.0m)**	**Piezo 2 (0.5m)**	**Piezo 1 (1.0m)**	**Piezo 2 (0.5m)**
H_p*	m	1.000	0.500	1.000	0.500
H_1	m	-0.100	-0.100	-0.100	-0.100
H_p	m	-1.000	-0.500	-1.000	-0.500
H_o	m	-0.100	-0.100	-0.100	-0.100
H_{wo}	m	-0.100	-0.100	-0.100	-0.100
H_{w1}	m	-0.100	-0.100	-0.100	-0.100
γ_k	g/cm^3	1.700	1.700	1.700	1.700
γ_w	g/cm^3	1.900	1.900	1.900	1.900
γ_s	g/cm^3	1.708	1.708	1.708	1.708
S_1	m	0.000	0.000	0.000	0.000
u_1	kPa	8.690	3.710	8.660	3.390
u_0	kPa	8.690	3.710	8.660	3.390
Δu	kPa	0.000	0.000	0.000	0.000
σ'_o	kPa	6.393	2.994	6.423	3.314
σ_{kt}	kPa	20.000	20.000	20.000	20.000
H_t	m	-0.046	-0.046	-0.046	-0.046
H_{wt}	m	-0.038	-0.038	-0.038	-0.038
u_t	kPa	18.700	13.300	10.830	5.510
S_t	m	0.046	0.046	0.046	0.046
S_{pt}	m	0.000	0.020	0.000	0.020
σ't	kPa	16.573	13.809	24.443	21.599

Case		Without PVD		With PVD	
Symbol	**Unit**	**Piezo 1 (1.0m)**	**Piezo 2 (0.5m)**	**Piezo 1 (1.0m)**	**Piezo 2 (0.5m)**
Ut	%	50.90	54.08	90.10	91.43

4. Simulation for Test Model

4.1. Input Data

The software PLAXIS 2D is used to analyze and compare settlement for the cases without and with PVD. The marginal conditions and dimensions of calculation model are described in Figure 7. For the lean sand layer, Mohr-Coulomb (M-C) is specified for drained behaviour (drained). For clay layer, Soft Soil model is used for simulating saturated clay layer with un-drained behaviour (undrained).

The soft soil model is the Modified Cam-Clay type model especially suitable for primary compression of normally consolidated soils. According manual PLAXIS 2D version 8.2, some features of this model are as following: (1) stress dependent stiffness, (2) distinction between primary loading and unloading-reloading, (3) memory for pre-consolidation stress, and (4) failure behaviour according to the Mohr – Coulomb criterion. The model requires the following material constants containing 5 basic and 3 advanced input parameters: λ^* - the modified compression index, $\lambda^* = \lambda/(1+e_0)$; κ^* modified swelling index, $\kappa^* = \kappa/(1+e_0)$; c'- cohesive; φ - friction angle; ψ - dilatancy angle; M – slope of critical state line; ν_{ur} – Poisson's ratio for unloading/reloading; and K_o^{nc} – coefficient of lateral stress in normal consolidation.

The data for model are taken from Table 1 and 5. For the case without PVD, the mechanical and physical data of soil before loading is called D_1 and after loading is called D_2. For the case with PVD, the mechanical and physical data of soil before loading is called $D_{1'}$ and after loading is called $D_{2'}$. As for simulating, the calculation stages shall include the steps corresponding to the loading levels of 5, 10, 15 and 20 kPa.

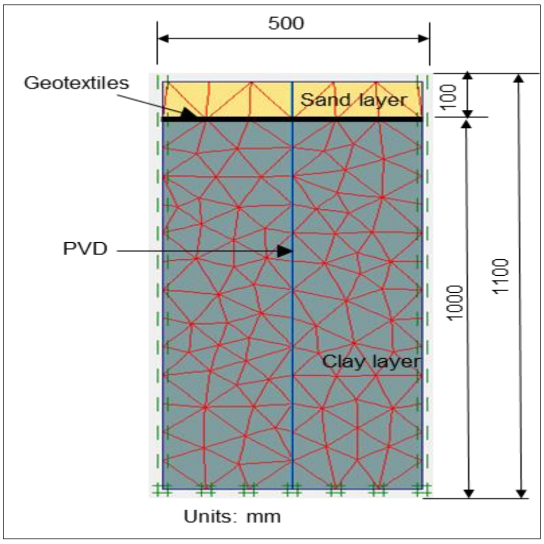

Figure 7. Boundary conditions and model size

Table 5. Input data for numerical

Parameter	Symbol	Unit	Without PVD				With PVD			
			Before loading		After loading		Before loading		After loading	
			Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand
Model calculation	Model	[-]	Soft soil	M-C	Soft soil	M-C	Soft soil	M-C	Soft soil	M-C
Behavior	Type	[-]	Undrain	Drain	Undrain	Drain	Undrain	Drain	Undrain	Drain
Young's modulus	E_{ref}	kN/m²	-	4e+4	-	4e+4	-	4e+4	-	4e+4
Poisson ratio	ν	[-]	-	0.30	-	0.30	-	0.30	-	0.30
Dilatancy angle	ψ	°	0.00	2.00	0.00	2.00	0.00	2.00	0.00	2.00
Modified compression index	λ*	[-]	0.112	-	0.094	-	0.104	-	0.081	-
Modified sweeling index	κ*	[-]	0.027	-	0.028	-	0.021	-	0.017	-

4.2. Simulation

According to the simulation result in Table 6 and Figures 8 and 9, it reveals that with PVD, the settlement with chemical and physical characteristics after loading has closer results to the actual observation result than that with chemical and physical characteristics before loading. At levels of 5, 10, 15 and 20 kPa with mechanical and physical characteristics before loading, the simulated settlement much different from the actual observed settlement with 25.63, 31.80mm, 37.32 and 44.42 mm corresponding to 146.2%, 113.6%, 105.7% and 96.6%; with the mechanical and physical after loading, the simulated settlement is quite little from the actual observed settlement with 1.39, 0.31, 0.98 and 1.26 mm corresponding to 7.9%, 1.1%, 2.8% and 2.7% respectively.

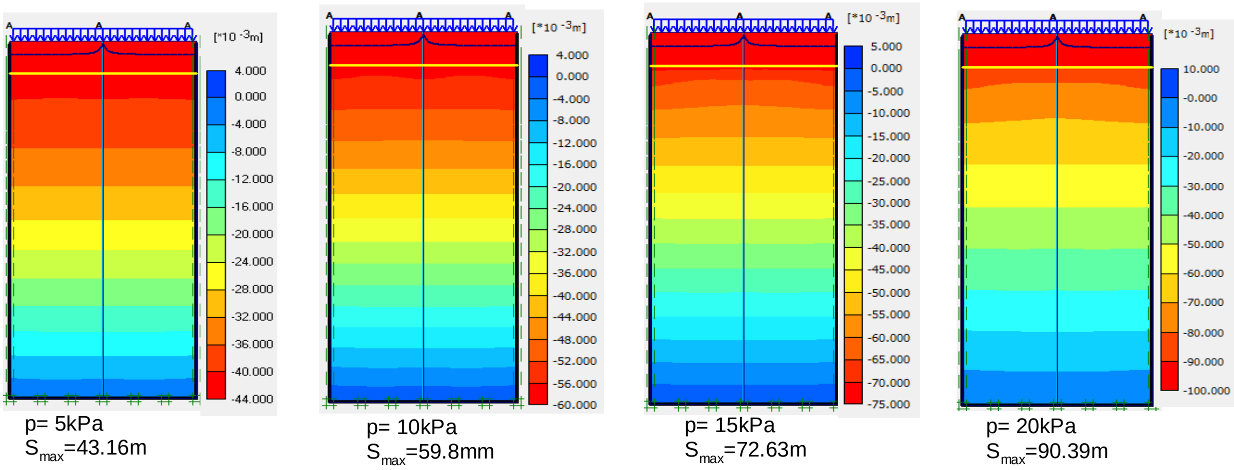

Figure 8. Numerical settlement results for the case of PVD with testing data before loading

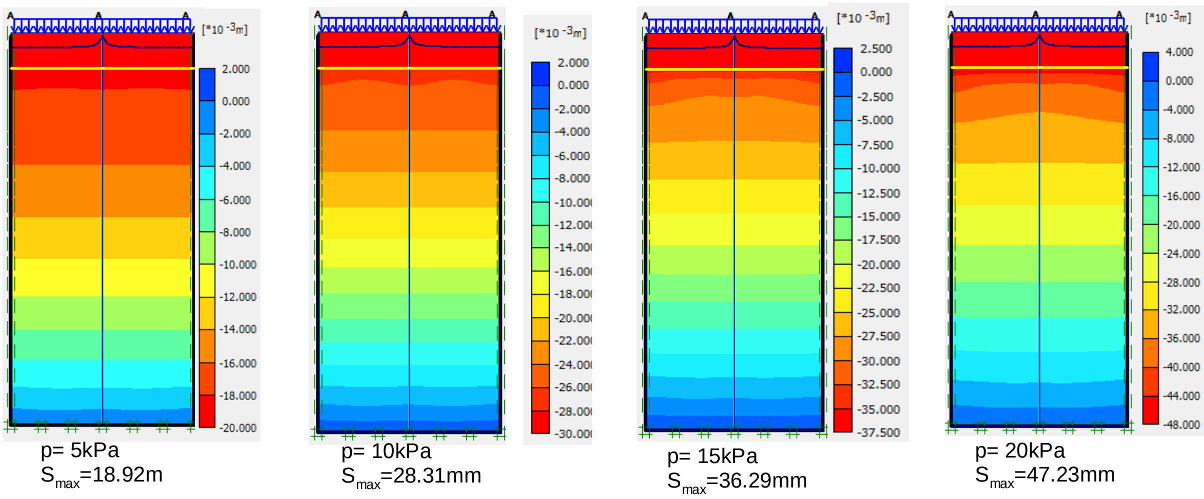

Figure 9. Numerical settlement results for the case of PVD with testing data after loading

Table 6. Settlement by time when numerical with before and after loading data in case without or with PVD

Case	Without PVD		With PVD	
	Before loading	After loading	Before loading	After loading
Settlement at 5 kPa	4.09	4.41	43.16	18.92
Settlement at 10 kPa	13.29	11.83	59.80	28.31
Settlement at 15 kPa	26.23	26.38	72.63	36.29
Settlement at 20 kPa	36.52	37.14	90.39	47.23

4.3. Evaluation of Results

Figure 10 shows the results of the case without PVD, the calculation and simulation of settlement based on the mechanical and physical characteristics of soil after loading against the observed settlement give more equivalent results than that with the mechanical and physical characteristics before loading as listed in Table 7. The calculation of settlement with the mechanical and physical after loading is only 6.2% different from the observation but up to 10.45% for the mechanical and physical characteristics before loading. Similarly, the simulation of settlement with the mechanical and physical characteristics after loading is only 0.56% different from the observation data but up to 1.11% for the mechanical and physical characteristics before loading.

As for the case having PVD shown in Figure 11, the calculation and simulation of settlement based on the mechanical and physical characteristics of soil after loading against the observation that gives more equivalent results than that of using the soil data before loading. The calculation of settlement with the mechanical and physical after loading is only 2.17% different from the observed results but up to 7.88 % for the mechanical and physical characteristics before loading. Similarly, the simulation of settlement with the mechanical and physical characteristics after loading is only 0.92% different from the observation but up to 165.15% for the mechanical and physical characteristics before loading. The simulation of settlement at various levels of loading gives results which are very different from the observation. This reveals that the selection of input data for simulation is quite important. This huge difference is the result of a sharp change of soil properties.

During treating the weak ground base with PVD, the speed of consolidation is much faster because of more drainage, consequently, the calculation and simulation based on the mechanical and physical characteristics after loading shall be sharply different from the ones before loading.

Table 7. Comparison of settlement between calculation, numerical before and after loading with actual monitoring

Settlement differences compared with actual monitoring	Case	Calculation		Numerical	
		Before loading	After loading	Before loading	After loading
mm	Without PVD	3.86	2.29	0.41	0.21
%		10.45	6.20	1.11	0.56
mm	With PVD	2.91	0.80	60.98	0.34
%		7.88	2.17	165.12	0.92

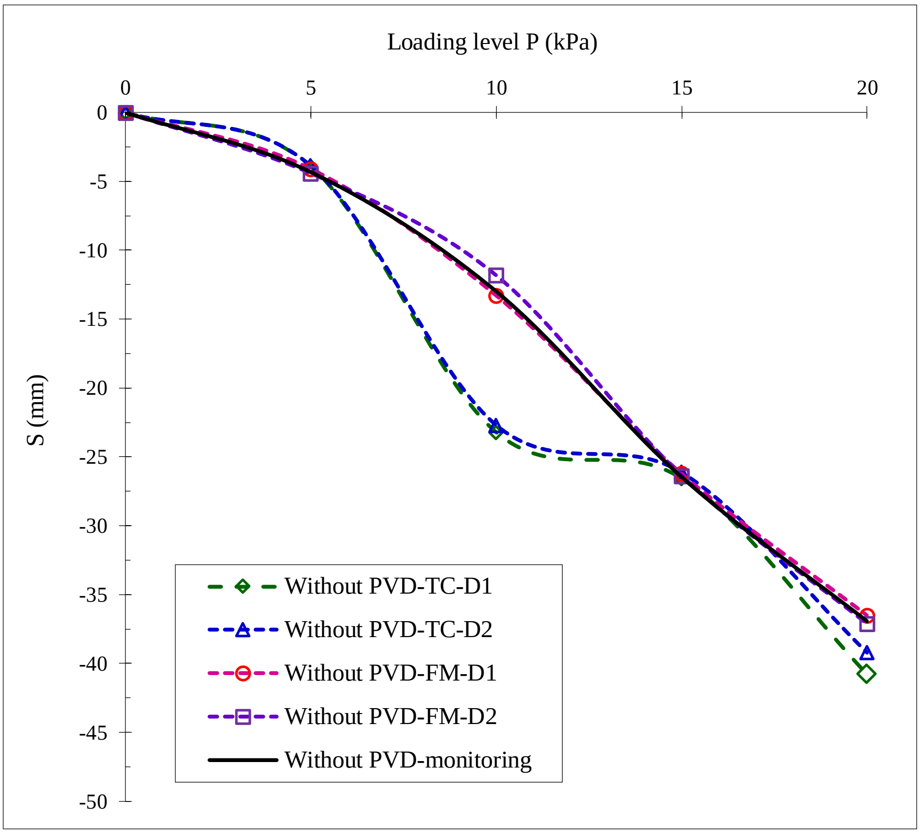

Figure 10. Settlement by time chart at S-P (Without PVD)

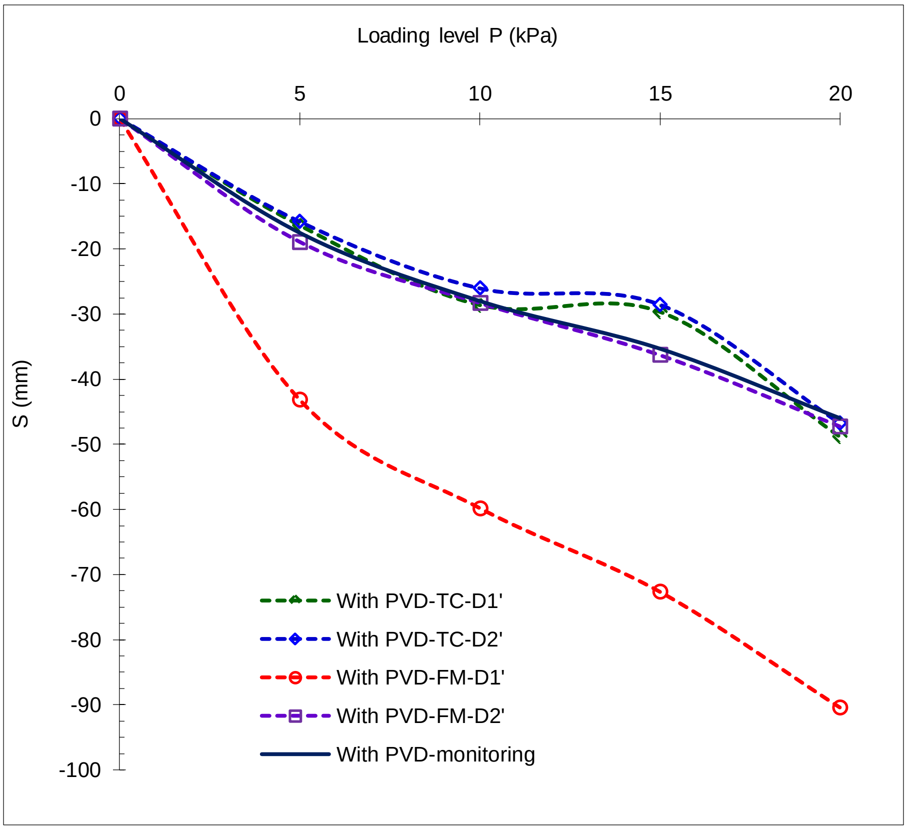

Figure 11. Settlement by time chart at S-P (With PVD)

5. Conclusions

- The mechanical and physical characteristics of soil have been changed after loading. Through the test and calculation, the settlement of soft soil is sharply different with the input data of mechanical and physical characteristics of soils before and after loading. Especially with the case of PVD, the mechanical and physical characteristics of soils encounter more critical change and the results of settlement calculation vary accordingly.
- The results of calculation settlement with the mechanical and physical characteristics after loading are a minor difference from the observation than that with the mechanical and physical characteristics before loading.
- Without PVD, the calculation and simulation with the mechanical and physical characteristics before loading are 3.86 mm (10.45%) and 0.41mm (1.11%) different from the observation data respectively; the calculation and simulation with the mechanical and physical characteristics after loading are 2.29 mm (6.20%) and 0.21 mm (0.56%) different from the observation data respectively.
- With PVD, the calculation and simulation with the mechanical and physical characteristics before loading are 2.91 mm (7.88%) and 44.42 mm (120.28%) different from the observation data respectively; the calculation and simulation with the mechanical and physical characteristics after loading are 0.80 mm (2.17%) and 1.26 mm (3.41%) different from the observation data respectively.
- Via the observation of pore water pressure by time for evaluating if the consolidation is similar to the ones at various stages; it reveals that physical model has a progress in accordance with working environment behaviour.
- The study may be oriented for bigger levels of loading with 50, 100, 200 and 400 kPa in naturally saturated clay; this shall give more apparent results.

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