Civil Engineering Dimension, Vol. 14, No. 1, March 2012, 51-56
ISSN 1410-9530 print / ISSN 1979-570X online

Technical Note:

Application of Prefabricated Vertical Drain in Soil Improvement

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Note from the Editor: Although the use of Prefabricated Vertical Drain (PVD) in soil improvement is not new, this paper is interesting since it gives the full spectrum from preliminary design stage; trial embankment and pilot test to final soil improvement. The final installation of the PVD was based on the soil investigation report and the results of instrumentation monitoring. Finally, using back analysis, vertical and horizontal coefficients of consolidation and compression index can be determined, which can be applied to predict a more accurate prediction of settlement.

Keywords: PVD, preloading, settlement, marine clay.

Introduction

Surabaya is a metropolitan city which is continuously expanding to its surrounding area, as a result of economic growth in Indonesia. The economic growth can be observed from increasing traffic flow of goods in the form of containers through Port of Surabaya, Tanjung Perak. The increase of container flows consequently requires large area as container yard. The development of this container yard is situated on western part of the harbor, formerly fish pond and sedimentary bay area. Soil type in this coastal area is very soft silty clay or marine clay layered with a thin layer of silt or fine sand. Soil layer from the surface up to 2 m depth consists of very loose silty sand, followed by 8 m thick of very soft silty clay layer. A 30-60 cm thick of sand layer was observed in this layer. In some places, sand lenses were found between 13 m and 15 m depth of soft silty clay layer. This layer is underlain by soft to firm clay layer. Sand layer with some gravel was found in 26-30 m depth.

In this project, ground improvement using Prefabricated Vertical Drains (PVD) with preloading was performed. Theoritically, the relationship between loading increment and settlement can be shown in Figure 1.

Initial settlement, ρ_i, occurred immediately after loading p is applied, followed by consolidation ρ. Settlement ρ_c at the time t is given as:

$$\rho_c = U \rho_{cf} \quad (1)$$

Where:
U = degree of consolidation
ρ_{cf} = final settlement.

Figure 2 shows the preloading process and its related settlement.

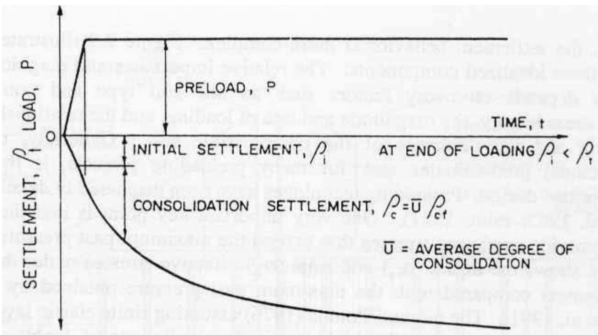

Figure 1. Relation between Loading and Settlement [1]

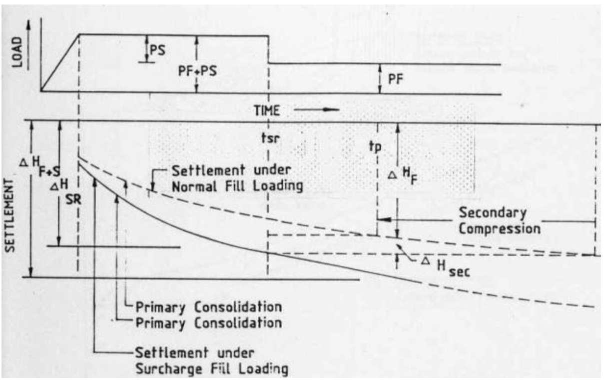

Figure 2. Relation between Preloading and Settlement [2]

Temporary surcharge loading is added in order to accelerate the settlement. The total given loading is a combination of final design loading, PF and surcharge loading, PS. The surcharge loading is then

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Note: Discussion is expected before June, 1st 2012, and will be published in the "Civil Engineering Dimension" volume 14, number 2, September 2012.

Received 07 December 2011; revised 25 January 2012; accepted 04 February 2012.

reduced when settlement reaches the predicted settlement due to design loading time, t_{SR}.

The installation of vertical drains will shorten the distance of drainage path, since water will flow horizontally to the vertical drain and upwards, which in turn will shorten the consolidation time. Therefore, two-dimentional consolidation theory is applied.

The relationship between degree of consolidation, U, horizontal,U_h, and vertical degree of consolidations, U_v, can be obtained from Carillo equation [3]:

$$U = 1 - (1 - U_h)(1 - U_v) \tag{2}$$

Vertical consolidation coefficient c_v, can be obtained from the consolidation test, while horizontal consoledation coefficient c_h, is calculated using Barron equation [4], which had been simplified by Hansbo and Torstensson [5]:

$$c_h = \frac{D^2}{8t}\left[\ln\left(\frac{D}{d}\right) - \frac{3}{4}\right]\ln\frac{1}{1-U_h} \tag{3}$$

In which:
D = vertical drain distance
d = vertical drain diameter
t = consolidation time

Analysis of settlement is obtained using corrected result of consolidation test as proposed by Schmertman [6] and the settlement effect during backfilling is analyzed using Schiffman method [7]. When settlement reaches design consolidation settlement, the surcharge load can be removed. Method proposed by Asaoka [8] was used to determine whether the backfill shall be added or removed.

Secondary compression settlement occurred when primary consolidation process was almost done, where excess pore pressure at that time was assumed to be zero.

To calculate secondary compression δ_s, Taylor formulae [9] can be used:

$$\delta s = C_a H_t \log\frac{t_{sec}}{t_p} \tag{4}$$

In which,
C_α = coefficient of secondary compression
H_t = Total height of soft clay
t_{sec} = time used for secondary compression process
t_p = time used for primary consolidation process

To study the effectiveness of vertical drains, a trial embankment using vertical sand drain was constructed. Folowing the trial embankment, the additional trial called Pilot Test using PVD was built to ensure the performance.

Trial Embankment

Trial embankment was built in the same area where the soil improvement would be conducted. The trial embankments was carried out to observe the settlement of embankment with and without vertical drains. In this trial embankment, sand drain, which is an early application of vertical drain to accelerate consolidation of soft, is used.

In the trial embankment area, 8–10 m thick of sandy silt or silty sand layers was found, then 10 m thick of soft clay layer having undrained shear strength of 0.165 kg/cm² contains thin soft sand layer, followed by 2–4 m thick of stiff clay with undrained shear strength of 0.5 kg/cm², and finally sand layer with gravel was found in 28.3 m deep

Pilot Test

Pilot test was constructed to ensure that soil improvement using PVD able to accelerate the consolidation process. Dimension of pilot test was 20x20 sqm with 3 m height of embankment.

PVD's were driven every 1 m in rectangular pattern up to 30 m deep. To measure settlement development, settlement plates and extensometers were installed in various depths. To measure pore water pressure development, pneumatic piezometers and hydraulic piezometers were installed. Pneumatic Piezometer (PP), Settlement Plate (SP), Extensometer (S), and Hydraulic Piezometer (HP) installation can be seen in Figure 3.

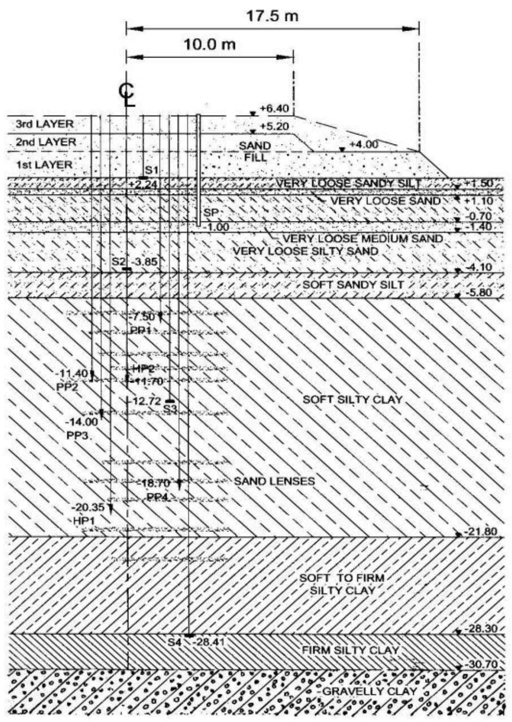


Figure 3. Soil Profile and Instrument Location in Pilot Test

Consolidation Analysis of Trial Embankment

Construction and planning for former fish pond area was conducted based on the result in Trial Embankment with maximum slope of 1:5. The settlement of Trial embankment is shown in Figure 4.

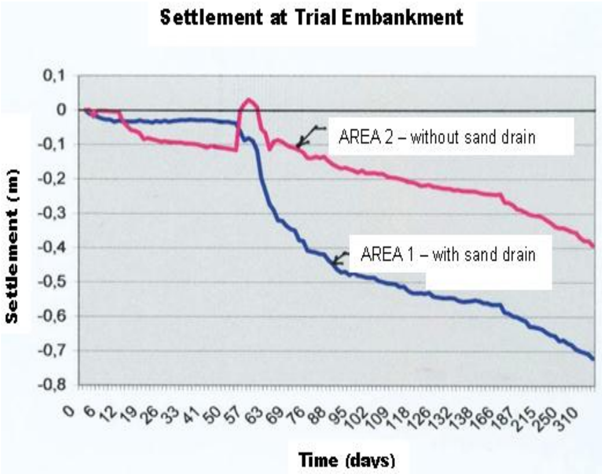


Figure 4. Settlement in Area 1 and Area 2

Settlement in Area 1 (using sand drains) is 3 times the settlement in Area 2 (without sand drains) in 90 days, 2 times in 280 days, and 1.85 times in 310 days.

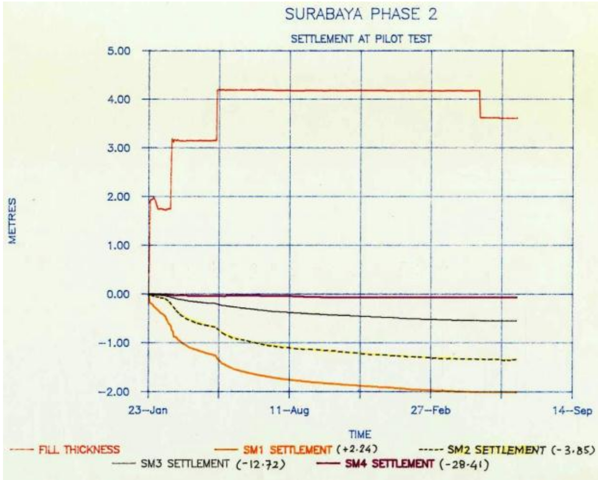
Moeljadi and Setiawan [10], based on back calculation, state that the vertical consolidation coefficient c_v, and horizontal consolidation coefficient c_h, are about 0.0022 m^2/day and 0.0069 m^2/day, respectivelly. While the secondary compression coefficient, c_α, is 0.286.

Pilot Test

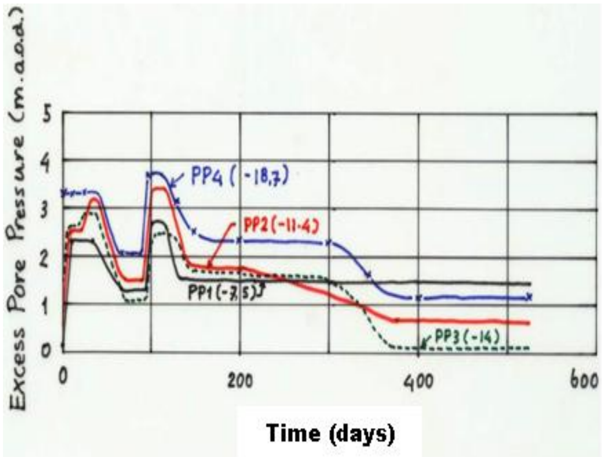
It was found that the observed settlement of embankment, obtained from settlement plate records as depicted in Figure 5.a, is in a good aggrement with settlement calculated using c_v of 25.9 cm^2/day, as shown in Figure 6.a. With average c_v of 25.9 cm^2/day, the total settlement would take approximately 85 years.

Degree of consolidation at 435 days observation of Pneumatic piezometer was about 79.7%. However, the record shows that pore pressure at the depth of 14 m significantly lower than those at the depth of 11m and 17m as shown in Figure 6.b. It is assumed that the piezometer experienced some error.

The amount by which the pressure in the pore water exceeds the stable ground water situation is termed the excess pore water pressure. The excess pore water pressure generation during load increment process in Pilot Test is presented in Figure 5.b.



(a) Extensometer Observation Result



(b) Excess Pore Water Pressure

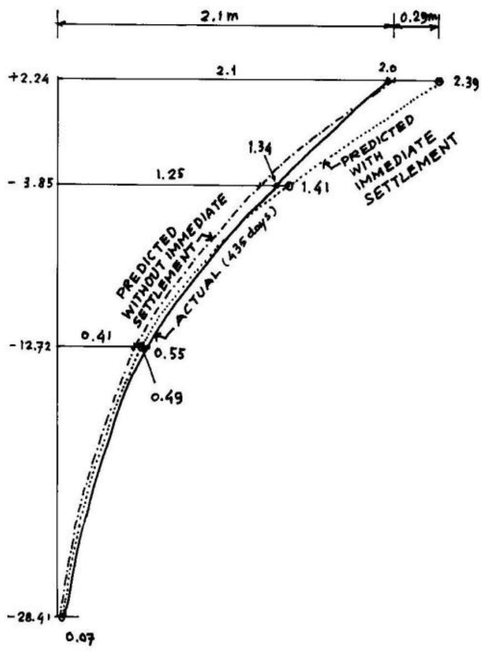
Figure 5. Extensometer and Excess Pore Water Pressure observation in Pilot Test location

Container Yard

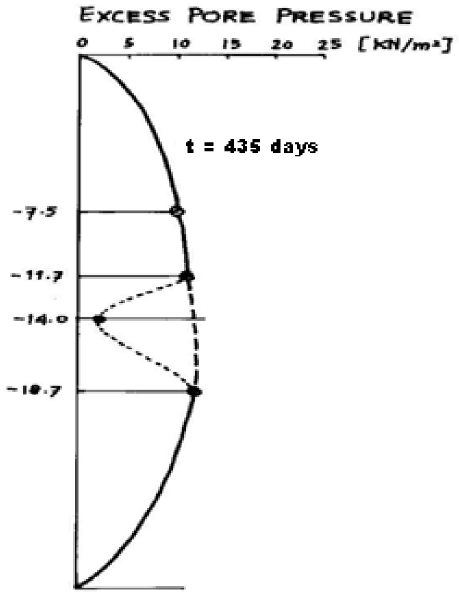
In general, the top layer in container yard consists of 5.5 m thick of very loose sandy silt to soft sandy clay, followed by 0.4 m thick of sand layer, and 15.2 m thick of soft clay layer. Below the 18.50 m depth, 8 meter thick of soft to firm silty clay and firm silty clay layer was found. Very dense fine sand is found at the depth of 26 meter.

The PVD with spacing of 1.5 x 1.5 sqm pattern were installed up to the depth of 26 m. To monitor the settlement of each layer, 5 Magnet Spiders (SM) were installed as sketched in Figure 7.

Based on consolidation tests of 11 undisturbed samples, the average c_v is 25.7 cm^2/day. For preloading, final 5 m height of surcharge soil was used. The relationship between loading increment and its settlement, and pore pressure generation with time are presented in Figure 8.a and 8.b, respectively.



(a) Extensometer Record



(b) Excess Pore Water Pressure Record

Figure 6. Monitoring Extensometer and Piezometer Monitoring in Pilot Test Compared with Prediction

Settlement plate measurement for 406 days sank for 2.46 m. Based on each magnet spider and extensometer, it were found that smaller settlement occurred with lower depth, as shown in Figure 9.a. Total settlement at 10 and 20 m deep from the surface was about 50% and 25%, respectively, compared to the settlement at the surface.

Degree of consolidation based on settlement plates monitoring was found 68.7%, while based on pneumatic piezometers reading was 56.5%.

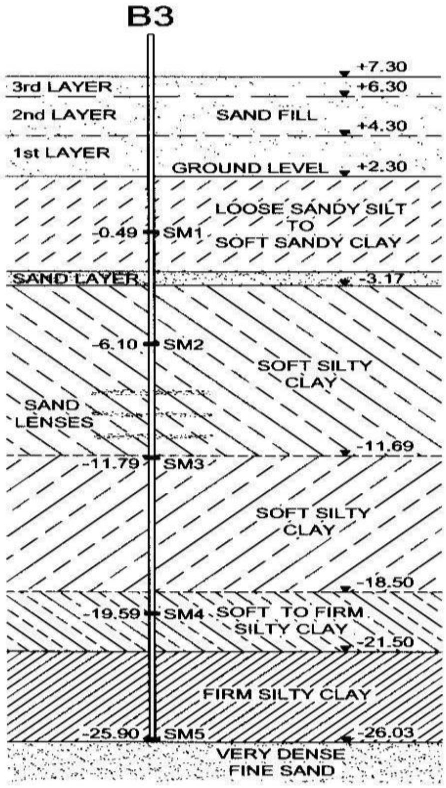
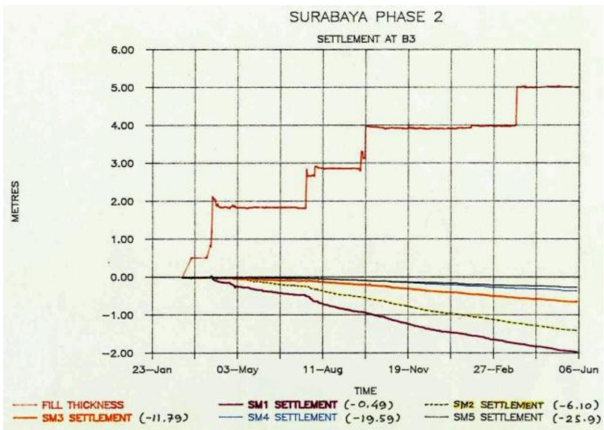
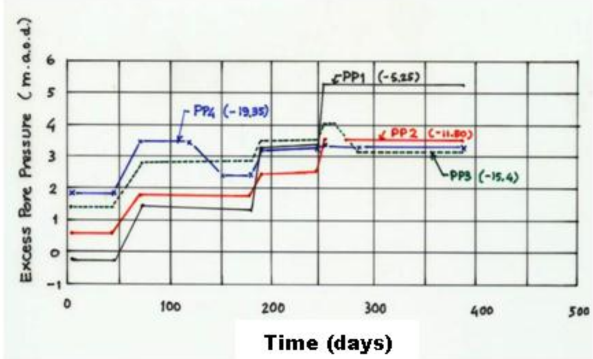


Figure 7. Soil Profile and instrumentation in B3

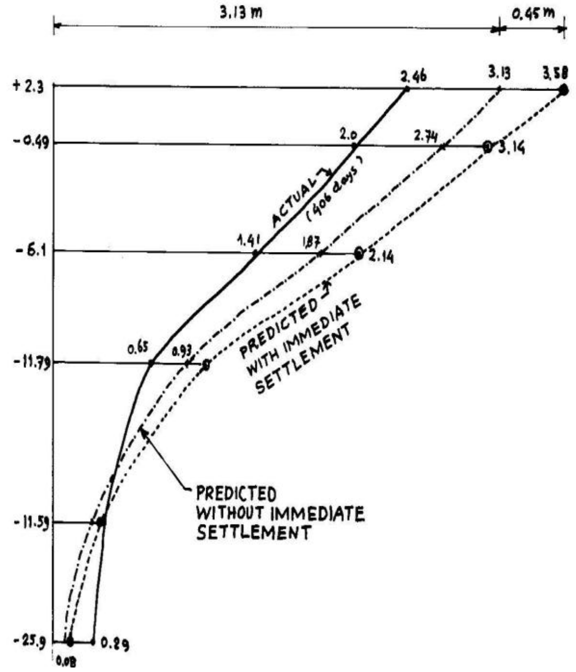


(a) Extensometer Observation Result

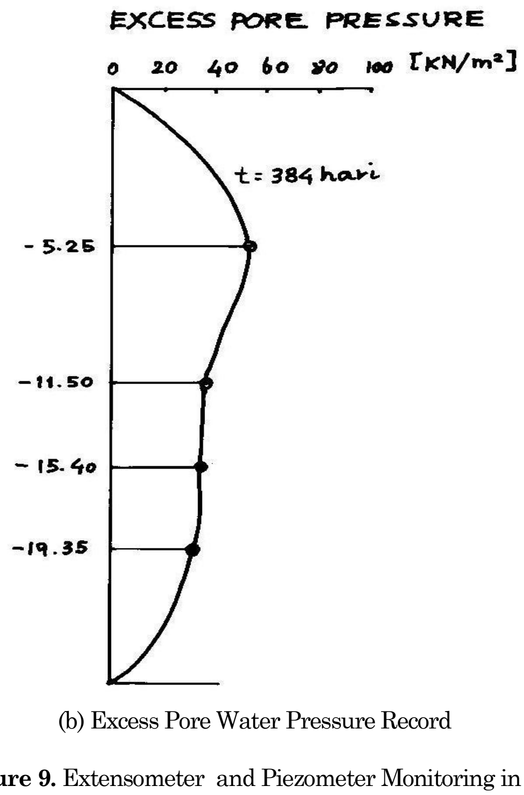


(b) Excess Pore Water Pressure Monitoring

Figure 8. Extensometer and Excess Pore Water Pressure Monitoring in B3



(a) Extensometer Record



(b) Excess Pore Water Pressure Record

Figure 9. Extensometer and Piezometer Monitoring in B3 Compared with Prediction

Evaluation

Asaoka method [8] is used to determine the time the surcharge load shall be removed. By plotting settlement δ_i and settlement $\delta_{(i-1)}$ on the 45 degree line, it can be determined the time to remove the surcharge load, that is when the plot-settlement coincide with the 45 degree line, as shown in Figure 10.

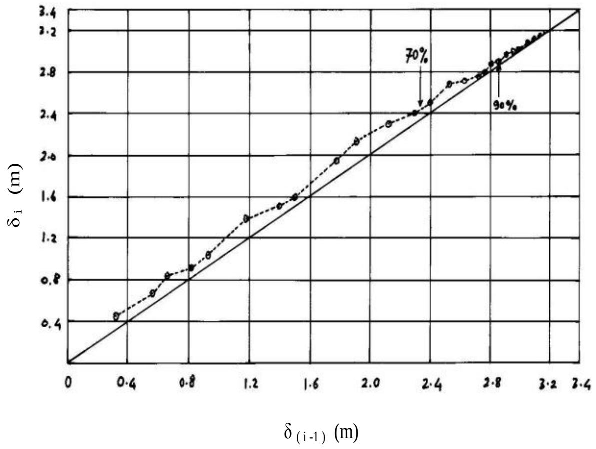


Figure 10. Evaluation using Asaoka Method in B3

Degree of consolidation about 70% and 90% were reached within 406 and 621 days, respectively.

Based on nomogram provided by Colbond [9], it was found that c_h was 35.6 cm²/day, while the average c_v was 23.8 cm²/day. So, c_h was about 1.5 times of c_v. This large value of c_h might be caused by the presense of several sand lenses. Using the aforementioned coeficient of consolidations, the calculated and observed settlement of embankment in container yard is presented in Figure 11.

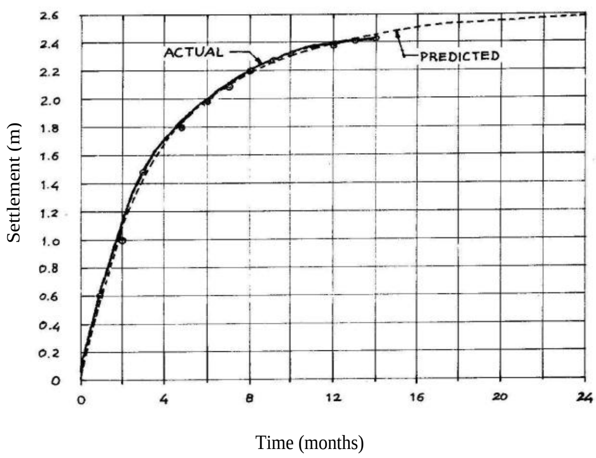


Figure 11. Actual and Predicted Settlement Occurred in A5

Conclusions

Based on this study, it can be concluded that:

1. The ground improvement using Preloading and PVD on marine clay located on North of Surabaya area is very effective. At 280 days, the rate of settlement of clay using PVD and preloading is twice as much as embankment without PVD.
2. Sand lenses between clay layers might affect the rate of settlement.
3. Settlement occurred in the deeper soil layer will be smaller than in the upper layer. In comparison to the settlement on the surface, settlement in 10

m deep, decreased to 50%, and in 2 m deep, the settlement decreased about 25-20%.

4. Determination of the degree of consolidation based on settlement plates reading data is more reliable than the pneumatic piezometers readings.
5. From the back analysis, it is concluded that horizontal and vertical consolidation coefficients for marine clay northern of Surabaya is 1.5.
6. Pneumatic piezometer instrument can be limited to each local soil type and it shall not be installed on sand lenses layer.

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