The effect of rapid conventional preloading on PVD works under compressible soil based on geotechnical monitoring data

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ABSTRACT: Prefabricated Vertical Drain (PVD) is a solution to increase the bearing capacity of a compressible soil by accelerating settlement process and release of excess pore pressure of the compressible soil. The PVD work is usually controlled by geotechnical instrumentations such as settlement plate to measure the settlement, piezometer to measure the pore pressure, and inclinometer to measure the movement of the soil. These instrumentations are used to determine the success of PVD works. Correlation between the preload to the geotechnical instrumentations is when the preload height is increased, the settlement and the pore water pressure that occur will also increase. Then, the PVD will facilitate the excess of pore water pressure to dissipate rapidly. From the case study, the designed depth of PVD is 20 m with 1 m spacing and the preload height is 4 m. The expected settlement should be 2.8 m at 90% of consolidation in 6 months period. Actual result of measured settlement was lower than expected settlement. The results of geotechnical instrumentation shows that a slower phase of preload embankment process shows a smaller increase in pore pressure compared to a quicker phase. It was due to a quicker phase of embankment construction with less waiting time caused the accumulation of excess pore pressure.

Keywords: PVD, Preloading, Ground Improvements, Geotechnical Monitoring, Geotechnical Instrumentation, Settlement, Porewater pressure, Compressible Soil

1 INTRODUCTION

Compressible soil always provides a problematic challenges for engineers to build structures. It is due to its consolidation properties and settlement. Indonesia has a large area of compressible soil, especially on the northern area of Java. There are several methods that can be done to improve compressible soil, one of which is preloading with prefabricated vertical drains (PVDs). PVDs will fasten consolidation and increase bearing capacity of soil during the process.

In order to know whether PVDs are working properly, geotechnical instrumentation needs to be installed. The main purpose was to know settlement, condition of the soil, and soil movement during preloading process. Sometimes, preloading process is not implemented as written in the design, therefore to monitor soil movement during preloading process is indispensable. The purpose of this paper is to know the effect of rapid conventional preloading process by comparing geotechnical instrumentation monitoring results during the time of construction.

2 PRINCIPLES OF PREFABRICATED VERTICAL DRAINS (PVDS)

The main purpose of prefabricated vertical drain (PVDs) installation are to help fasten consolidation process by accelerating the dissipation of pore pressure. To achieve that purpose, all PVDs material should have a higher discharge capacity compared to actual soil. Discharge capacity cannot be less than 100 m^3 per year (Mesri and Lo, 1991). Besides that, all PVDs material should also have a high tensile strength.

PVDs should be able to withstand at least 0.5 kN without deformation more than 10% (Kremer et al., 1983).

The analysis of radial consolidation due to vertical drain had already been done. Time to achieve radial consolidation can be calculated using equation below (Baron, 1948):

$$t = \frac{D^2}{8\,c_h} F(n) ln\left(\frac{1}{(1-\overline{Uh})}\right) \quad (1)$$

where: t = time required to reach Uh, Uh = degree of horizontal consolidation, D= cylindrical diameter of soil affected by PVDs installation, c_h = horizontal consolidation coefficient, and F(n) is a factor of drainage space.

The equivalent diameter of vertical drain (d_w) can be calculated using equations below:

$$d_w = \frac{2(a+b)}{\pi} \quad (2)$$

where: a = width of PVDs and b = thickness of PVDs.

PVDs are normally installed using square pattern or triangular pattern. Most people prefer to use a triangular pattern due to its effectivity that is more than square patterned PVDs.

3 CASE DESCRIPTION

The major problem in the expansion of Ahmad Yani International Airport in Semarang was large settlements due to a very soft soil layer in the area. Soil improvement method was needed to fasten consolidation process and increase bearing capacity of the soil before the construction of terminal building, parking area, and airport utilities. Soil improvement method chosen for this area was preloading with PVDs. Figure 1 shows the area that will be improved using PVDs. Total area was about 1.2 hectares.

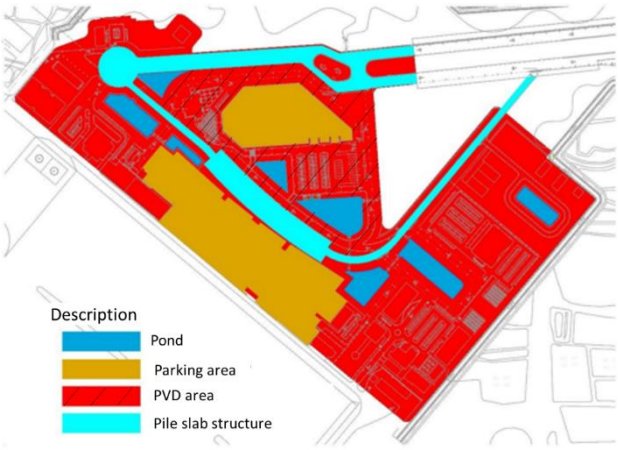


Figure 1. Study case area layout

3.1 *Soil description*

Soil investigation was conducted in the area to find out the property of soil in the area. There were 16 bore holes data. Based on boring log, the water level was in the current elevation or even higher during high tide. So basically, soil layer in this area was always fully saturated with water.

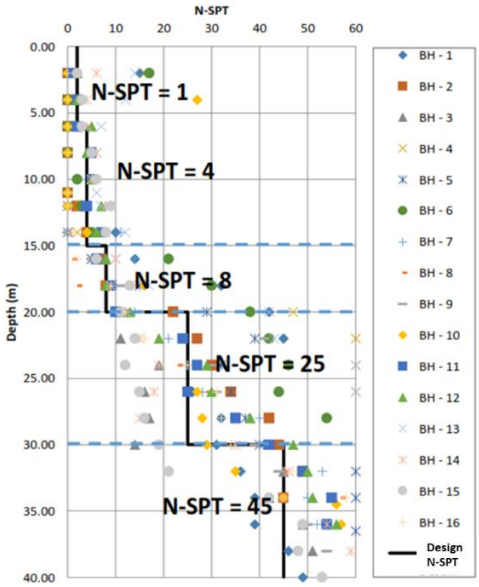


Figure 2. Simplified result of N-SPT

The simplified result of N-SPT can be seen in Figure 2. The overall soil layer in the area can be divided into 5 layers of soil. The first layer of soil (depth 0-6 m) is a very soft soil layer with average N-SPT value 1. The second layer (depth 6-15 m) is a very soft soil layer with average N-SPT value of 4. The third layer (depth 15-20 m) is medium stiff clay with average N-SPT value of 8. The fourth layer (depth 20-30 m) is a stiff clay with average N-SPT value of 25. The fifth layer (depth 30-40 m) is a hard clay with average N-SPT value of 45.

Most of the soil layer from 0-18 m depth is a slightly over consolidated soil. The void ratio of the soil ranged from 1.5 to 2.7 and the Cc ranged from 0.55-0.95.

3.2 *Geotechnical instrumentation layout*

This soil improvement method using PVDs and conventional preloading process will be conducted in about 6-12 months. It is advisable to install geotechnical instrumentation to know the condition and movement of soil during preloading process. In this case study area had been installed 12 points of settlement plates, 12 points of piezometers, and 8 points of inclinometers. Layouts of geotechnical instrumentation is as shown on the picture below:

Figure 3. Geotechnical instrumentation layout

Until this paper was made, the location is still undergoing preloading phase. This paper would only use data up to March 5th 2017, which was 6 months period after installation of PVDs and geotechnical instrumentation.

4 SOIL IMPROVEMENT DESIGN

The predicted settlement of the area based on soil investigation data and a 4 m preload was ± 3.1 m. With double drainage assumption, time needed to achieve 90% of consolidation is about 19 years with calculated 90% settlement about 2.8 m. The construction process of the expansion of Ahmad Yani International Airport should be completed in about 2 years, so to wait 19 years for soil to be 90% consolidated is very unlikely. Therefore, some soil improvement methods should be implemented to fasten consolidation.

Preloading with PVDs was chosen as soil improvement method in this area. PVDs will be installed to a 20 m depth to help fasten the consolidation process. The chosen PVDs configuration was triangular with 1 m space of each PVDs. With this method and assumption of preloading to a 4 m height resulted in 6 months to achieve 2.8 m of settlement.

To know whether soil had already achieve 90% of consolidation, geotechnical instrumentation need to be installed. The main function of geotechnical instrumentation is to know current settlement, condition of the soil, and movement of the soil. Monitoring instrumentation result then will be evaluated and compared to the design.

5 GEOTECHNICAL INSTRUMENTATION RESULT

There were three types of geotechnical instrumentation which were installed in the area: settlement plates, vibrating wire piezometers, and inclinometers. Each instrumentation was monitored on a daily basis to know the movement of soil. The data provided was a 6 months monitoring data prior to geotechnical instrumentation installation. Below were the result of geotechnical instrumentation:

5.1 *Settlement plates*

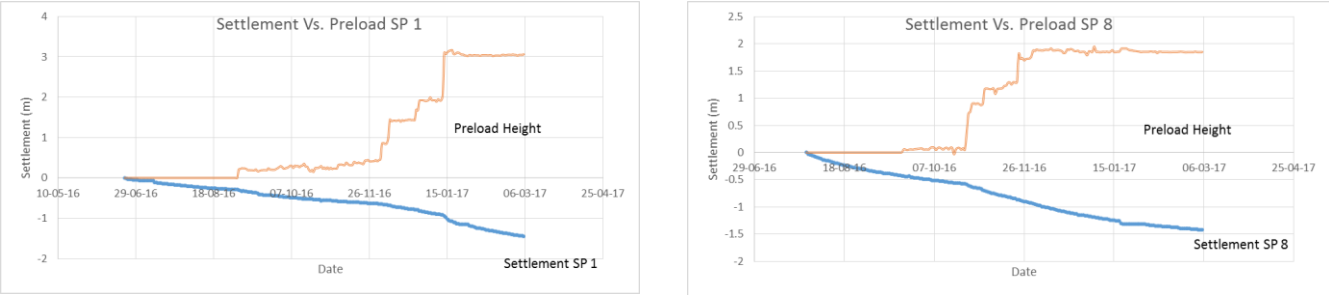
There were 12 settlement plates installed in the area (see Figure 1). Settlement plates were placed 0.5-0.75 m below sand blanket and before preloading. The main purpose is to know the actual movement of the soil. Settlement plates should actually be placed on the original ground elevation to actually measure settlement of soil, but since replacement soil and sand drain had already been placed, settlement plates were placed in sand blanket elevation. The cumulative settlement data of each settlement plates is as shown in Table 2 below:

Table 1. Settlement plates monitoring result

Number of SP	Cumulative settlement (m)	Designed settlement (m)	Percentage of consolidation (%)	Preload Height (m)
SP1	-1.44	-2.8	51.46	3.06
SP2	-1.07	-2.8	38.11	3.06
SP3	-1.09	-2.8	39.04	3.06
SP4	-0.68	-2.8	24.29	3.06
SP5	-1.09	-2.8	38.93	2.29
SP6	-1.25	-2.8	44.55	2.29
SP7	-1.03	-2.8	36.80	2.29
SP8	-1.42	-2.8	50.82	1.85
SP9	-0.82	-2.8	29.25	1.71
SP10	-0.98	-2.8	35.09	2.46
SP11	-1.17	-2.8	41.80	2.46
SP12	-0.89	-2.8	31.64	2.46

Data above indicated that despite of difference in preload height applied, there were differential settlement occurred. It was a right decision to use PVDs and preloading to help fasten consolidation process and minimize impact of differential settlement later. The actual settlement data compared to designed settlement was not reach 60% of expected consolidation yet. That was happened because at the time of construction, conventional preloading was not conducted as it was supposed to be in the design. It was due to lack of embankment source on location. At this time of construction (6 months) the supply of embankment should reach 3.5 m already, but as seen on Table 1, all area had not already reach 3.5 m and not all

the location had the same embankment height. The other factor was because elevation of settlement plate installation was not in the original ground elevation, so actual settlement will be lower than expected designed settlement.



(a) (b)

Figure 4. Comparation of settlement plate data: a. settlement vs preload for SP 1; b. settlement vs preload for SP 2

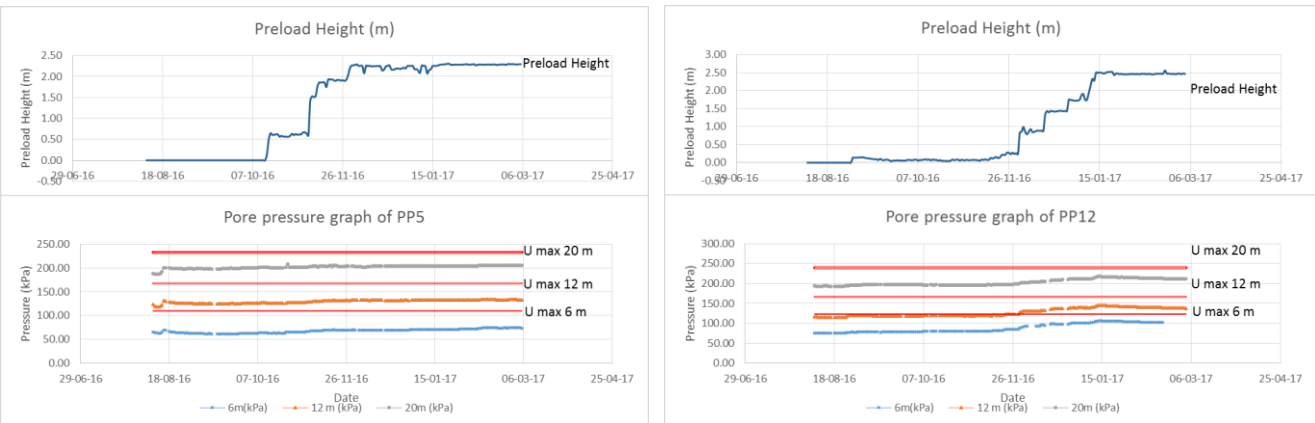
Above (Figure 4) was two sample data of 12 settlement plates. Both data located in the center of embankment. SP 1 data (Figure 4a.) had 3.06 m of embankment and 1.44 m settlement. As seen from the graph, this point had not already finish its 90% of consolidation. The same thing happened in SP 8 (Figure 4b.) which had 1.85 m of embankment and 1.42 m of settlement.

Both settlement plate point (SP 1 and SP 8) had settlement about 1.40 m with different height of embankment shows that the rate of consolidation at SP 8 point is relatively higher compared to SP 1. This was due to different soil properties and effectiveness of PVDs worked under preloading on both location. Due to failure to reach 90% of consolidation at this point, the construction time should be extended until all the points showed 90% of consolidation achieved.

5.2 *Piezometers*

The main purpose of piezometers installation was to monitor pore pressure during preloading process. The value of pore pressure generated from piezometers will be data to monitor whether preloading process should be stopped or not. This instrumentation played an important role to keep stability of embankment and existing soil. All measured pore pressure data should not reach allowable maximum pore pressure to avoid decrease value of bearing capacity of the soil.

There were 12 points of piezometers as shown in Figure 1. The measured pore pressure of all piezometers point at this time of construction were still below allowed maximum pore pressure. Some points might already be exceeded 80% of allowable maximum pore pressure (PP1, PP2, PP3, PP4, and PP 12). Below are samples of piezometer graph of two piezometer points:



(a) (b)

Figure 5. Comparation of piezometer data: a. piezometer graph for PP 5; b. piezometer graph for PP 12

Figure 5 compares the measurement of pore pressure on piezometer point on which different phase of embankment applied with almost same height of embankment. In figure 5a., preload height applied at a periodic time and there was a relatively long waiting time on each stage of preload, whereas in Figure 5b., preload height applied at a quicker phase of construction. Both piezometers shows a different trend of pore pressure increment.

At PP 5, in which preload process was done in a slower phase, measured pore pressure on this site is relatively steady and way below allowed maximum pore pressure. At PP 12 in which almost the same

embankment height applied as in PP5, but in much quicker phase, measured pore pressure increased dramatically and reach above 80% of allowed maximum pore pressure. It was due to a quicker phase of embankment construction with less waiting time caused the accumulation of excess pore pressure. The quicker phase of embankment didn't allow excess pore pressure to dissipate, so it was accumulated in the soil. This could be dangerous if the embankment process were still going without a waiting time. Bearing capacity of the soil in the area might dropped down and stability of embankment might be disturbed if measured pore pressure exceeded the allowed number. Therefore, in point PP12, the embankment process should be stopped and will be continued when excess pore pressure already dissipated.

5.3 *Inclinometers*

There were 8 points of inclinometers installed as shown in Figure 1. The main purpose of inclinometer installation was to know the lateral movement of soil due to preloading process. Lateral movement of soil due to embankment is biggest at the toe of the embankment, so all inclinometers were installed in the edge of the embankment. The main concern of this inclinometer data result is to monitor the impact of soil movement to pile slab structure that has already built before all the PVDs and preloading process.

Table 2. Inclinometer monitoring result

Number of Inclinometer	Max. cumulative displacement (mm)
In 1	185.15
In 2	38.37
In 3	85.52
In 4	165.96
In 5	166.02
In 6	87.54
In 7	101.67
In 8	11.82

As shown on the table above that maximum cumulative displacement of the soil has reached above 150 mm in several locations. It was a main concern of the contractors as the displacement was feared to endangered pile slab that has already constructed. Some movement were already visible as shown in figure 6 below

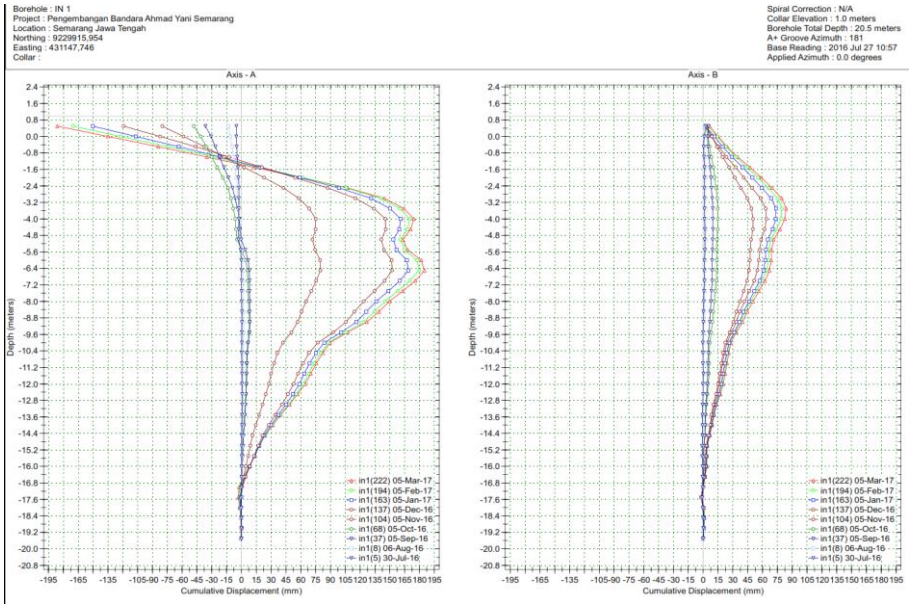


Figure 6. Soil movement in one of the pile and its inclinometer monitoring result

The cumulative displacement at In 1 area had already reached 185.15 mm. Movement of piles had already visible at this point. This was due to the construction sequence in which pile slabs were constructed before preloading process. Therefore all pile slabs would be affected with soil movement from preloading embankment. The effect was already irreversible, but pile slab structures were still able to withstand soil movement.

6 CONCLUSIONS

At the site of expansion of Ahmad Yani International Airport, Semarang, soil improvement has been done for 6 months and still undergo preloading process until October 2017. The method of soil improvement was designed by using PVDs with triangular pattern spacing of 1 m to a 20 m depth and preloading of 4 m. The expected settlement should be 2.8 m at 90% of consolidation. Based on geotechnical instrumentation data and analysis in the expansion of Ahmad Yani International Airport Project, the following conclusions can be made:

1. All soil in the area had not reached the expected settlement, in fact many areas were still under 50% consolidated according to expected settlement. This was because the preloading process that was not conducted as calculated in the engineering design due to lack of embankment source on site. The other factor was because settlement plates were not installed in the original ground elevation while the designed settlement was in the original ground elevation. Therefore, the actual measured elevation was slightly lower than design.
2. The rate of consolidation in the area varies. For example, both settlement plate point (SP 1 and SP 8) had settlement about 1.40 m with different height of embankment shows that the rate of consolidation at SP 8 point is relatively higher compared to SP 1. This was due to different soil properties and effectiveness of PVDs worked under preloading on both location.
3. Based on piezometer monitoring data in the area, the effect of rapid preloading process will affect the measured pore pressure. With the same height of preload embankment, but different phase of construction resulted on a different pore pressure readings. A slower phase of preload embankment process shows a smaller increase in pore pressure compared to a quicker phase. It was due to a quicker phase of embankment construction with less waiting time caused the accumulation of excess pore pressure. The quicker phase of embankment didn't allow excess pore pressure to dissipate, so it was accumulated in the soil. This could be dangerous if the embankment process were still going without a waiting time.
4. Lateral displacement of soil in the area were monitored using inclinometer shows that the maximum cumulative displacement of the soil has reached above 150 mm in several locations. The construction of pile slab structures had done before preloading process caused a noticeable movement of the piles. However the pile slab structures still able to withstand soil movement. It would be better in the future that preloading process should be done before any structural construction to minimize the effect of soil movement to the stability of the structures.

ACKNOWLEDGEMENTS

Heartfelt thanks are given to PT. Geoforce Indonesia for supporting this research. Author would also thank all instrumentation engineering team for their endless effort, hard works, and dedication to the work.

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