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The effectiveness of vacuum preloading on eliminate secondary settlement; case study in summarecon city bandung area's development project

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Abstract. Summarecon City Bandung Area's Development Project is used to use embankment preloading with Prefabricated Vertical Drain (PVD) to improve the soil, but due to weather problems, used another alternative by replacing embankment preloading to vacuum preloading. Vacuum preloading with PVD is only intended for accelerate primary settlement, while secondary settlement still exists. Secondary settlement in this project needs to be paid attention because according to the reality in the field, secondary settlement happened quite large because the soil mix with organic soil. Secondary settlement could cause differential settlement which can damage the infrastructure and make the infrastructure drop until lower than flood water level. So far, there has not been a study about how to eliminate secondary settlement in order to complete that settlement before the infrastructure is built, so that differential settlement does not happen. Therefore, a study about eliminate secondary settlement in order to be completed before the infrastructure is built is needed with remove it along with primary settlement. In this case, secondary settlement is going to be eliminated by adding additional load in the form of embankment preloading. Overall, this study can be a suggestion and consideration for the decision-making of Summarecon on selecting the soil improvement; embankment preloading or vacuum preloading.

1. Introduction

About 20 million hectares or more than 10% of the land area in Indonesia are soft soil which consist of soft clay and peat soil. For the development of infrastructure in Indonesia, the possibility of infrastructure must be built in areas where the soil condition is soft clay. The main problems in soft clay are the soil has low bearing capacity, so that the load that able to borne by the soil is limited and the soil settlement is relatively large and also occurs for a long time. Therefore, it is necessary to improve the soil in order to prevent the failure of the infrastructure before its service age. The soil improvement which suitable for soft clay is preloading methods. Preloading methods include embankment preloading and vacuum preloading. Embankment preloading and vacuum preloading method's principle are the same, namely removing all or most of the soil settlement and increasing the bearing capacity of the soil by giving an initial load that greater or equal to the planned infrastructure load. In order to accelerate the time of soil settlement, both methods are usually combined with Prefabricated Vertical Drain (PVD).



Vacuum preloading was first introduced in Sweden by Kjellman (1942). Since then, this method has often been used as soil improvement to accelerate soil settlement in areas with soft soil in some countries. In Indonesia, vacuum preloading has been applied to Summarecon City Bandung Area's Development Project. The project is located in Gedebage, Bandung and built on soil that dominant of soft clay mix with organic soil. In the beginning, Summarecon City Bandung Area's Development Project used embankment preloading with PVD for the soil improvement. However, embankment preloading in this project has been obstructed due to weather problems which effected on project schedule. For this reason, another alternative is used to replace embankment preloading to vacuum preloading. As has been known that vacuum preloading does not require a lot of embankment materials, so that it is expected to still be able to run when facing weather problems again. Generally, vacuum preloading with PVD is only intended to accelerate primary settlement, while secondary settlement still exists. Both types of settlement take place at different times, starting with primary settlement and continues with secondary settlement. Under normal conditions, primary settlement occurred up to hundreds of years. With PVD, primary settlement's time becomes shorter which takes place monthly, so that secondary settlement occurs earlier. Most of the contractors pay little attention to secondary settlement because they consider this settlement is very small compared to primary settlement, even though the cases of bumpy roads and cracked buildings often happened due to differential settlement caused by secondary settlement which its magnitude is not the same. Secondary settlement is also feared causing the infrastructure drop until lower than flood water level if it is not eliminated. Secondary settlement in Summarecon Bandung City Area's Development Project needs to be considered because according to the reality on the field, secondary settlement occurred quite large because the soil mix with organic soil. Therefore, a study about how to eliminate secondary settlement is needed and will be discussed in this paper. Later on, this study can be a suggestion and consideration for the decision-making of Summarecon on selecting the soil improvement; embankment preloading or vacuum preloading.

2. Design of the project

Vacuum preloading is used in Dyanti cluster area which can be seen in figure 1. Later on, this cluster is going to be built for house. The cluster that has an area of 0.4 hectares has already been planned with vacuum pressure of 74 kPa which equivalent to 4.4 m of embankment, backfill of 2.8 m for levelling, triangular pattern of PVD with distance of 1.2 m and 20 m length, Prefabricated Horizontal Drain (PHD) as drainage, Non-Woven Geotextile for the protection layer, and also HDPE Geomembrane for impermeability layer. In order to observe the stability, the soil settlement, and pore water pressure as results of vacuum preloading, used geotechnical instrument devices. Geotechnical instrument devices consist of Vacuum Gauge to measure vacuum degree, Settlement Plates and Extensometers are used to monitor the soil settlement, Vibrating Wire Piezometer to monitor pore water pressure, Inclinator to monitor lateral displacement of soil, and Observation Wall to measure ground water level. This project has already run since 2017. For more detail, vacuum preloading method in this project is presented in figure 2.

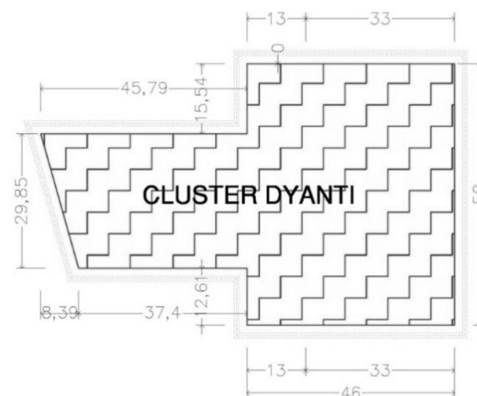


Figure 1. Dyanti cluster area.

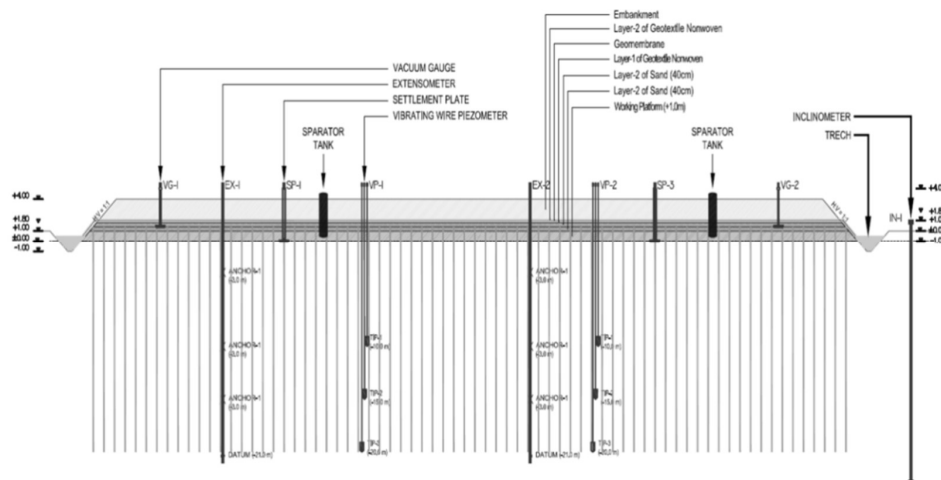


Figure 2. Vacuum preloading method in summarecon bandung city area's development project.

3. Experimental program

Study in this paper uses combination of vacuum preloading and embankment preloading that combination of both methods are expected to eliminate secondary settlement at the same time with primary settlement effectively. Vacuum preloading method is usually combined with embankment preloading method as backfill for levelling. The height of embankment preloading that must be added to eliminate secondary settlement using combination of vacuum preloading and embankment preloading will be compared to the height of embankment preloading when using only embankment preloading, where the parameters that needed to calculate primary settlement and secondary settlement is obtained from soil consolidation test.

This study was conducted based on field investigation tests include Cone Penetration Test (CPT) and Standard Penetration Test (SPT) to provide information on properties of soil where located around the vacuum area. The location of CPT named S-A and S-B and also SPT named BH-A can be seen in figure 3. This study was also conducted based on experimental study in a laboratory using undisturbed soil consisting of Volumetric and Gravimetric Test, Laboratory Vane Shear Test, and also Oedometer Test.

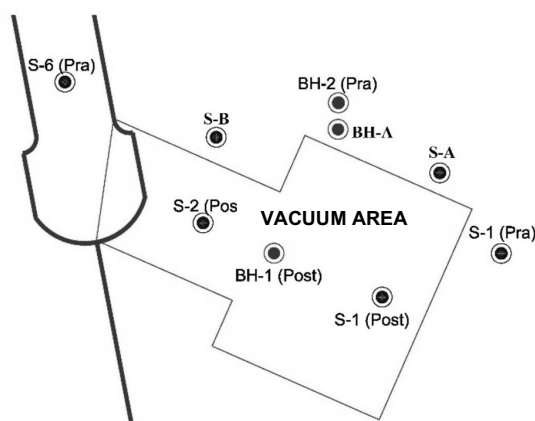


Figure 3. The location of soil investigation tests.

4. Results and discussion

4.1. Properties of soil based on field investigation tests

Both of CPT and SPT are done to 30 m depth. The result of CPT is the soil in Summarecon Bandung City Area's Development Project is dominant of clayey silt with thickness up to depth of 20 m. Above 22 m depth, the dominant soil is sand. As well as the result from SPT, the dominant soil is clayey silt with thickness up to depth of 26 m and sand with thickness from 26 m to 30 m. It can be concluded that the thickness of compressible layer is 20 m depth.

4.2. Properties of soil based on laboratory tests

The samples of soil for laboratory tests are obtained from undisturbed soil that has been taken from borehole in BH-A. Undisturbed soil has been gotten from 5 different depths. First, Laboratory Vane Shear Test is performed to determine the value of undrained shear strength (C_u). Then, Volumetric and Gravimetric Test to determine physical properties and also Oedometer Test to determine parameters of primary settlement and secondary settlement are performed. Oedometer Test was conducted in stages with load: 0.25; 0.5; 1; 2; 4 kg/cm² with loading time of 24 hours/loading. Properties of soil based on laboratory tests are listed on table 1. According to table 1, the soil in this project has larger value of water content (w_c) and void ratio (e_0) than common soft clay. It indicates that the soil mix with organic soil as said previously. Organic soil has high water content and void ratio. It is assumed that organic content in the soil only effect properties of soil, but the behaviour is still like mineral soils (organic silt and clay).

Table 1. Properties of soil based on laboratory tests.

	Depth (m)	Soil Consistencies	C_u (kPa)	w_c (%)	γ_{sat} (g/cm ³)	e_0	C_c	C_s	C_v (cm ² /s)	C_α
UDS 1	5-5.5 m	Very Soft	8.5	136.968	1.223	3.966	1.514	0.175	1.45×10^{-3}	0.087
UDS 2	9-9.55 m	Very Soft	10	210.239	1.259	5.313	2.282	0.170	5.05×10^{-4}	0.032
UDS 3	15-15.55 m	Very Soft	8	111.467	1.376	2.939	1.674	0.147	4.17×10^{-4}	0.031
UDS 4	19-19.55 m	Soft	22	184.164	1.215	4.992	3.016	0.348	4.80×10^{-4}	0.029
UDS 5	25-25.55 m	Soft	17	213.975	1.199	5.709	3.199	0.287	5.05×10^{-4}	0.048

4.3. Eliminate secondary settlement using embankment preloading

In this study, secondary settlement is eliminated at the same time with primary settlement by adding an additional load (Δq) that charged to primary settlement and causes more settlement with the magnitude which expected to equals secondary settlement. Then, Δq can be removed at the end of primary settlement. So that, after the soil improvement was completed and infrastructure has been built, there is no more settlement that caused by primary settlement and secondary settlement. To calculate primary settlement, determine some variations of specified constant of load embankment (q). q is load embankment after the soil was compressed. An embankment after undergoing the compression on the ground will undergo a weight change, because during the settlement some parts of embankment are under groundwater. After that, find out the magnitude of primary settlement (S_c), the initial height of embankment (H_i), and the final height of embankment (H_f) that caused by q .

Afterwards, calculate secondary settlement (S_s) with the reviewed time of occurrence is 20 years. Both of primary settlement and secondary settlement are calculated for compressible layer with thickness of 20 m. The calculation results of primary settlement, the initial height of embankment, the final height of embankment, and secondary settlement are listed on table 2. Then, from table 2, create a graph of the relationship between settlement (S) with load of embankment that shown in figure 4, a graph of the relationship between load of embankment with the initial height of embankment that shown

in figure 5, and also a graph of the relationship between the initial height of embankment and the final height of embankment that shown in figure 6 below.

Table 2. The results of S_c , H_i , H_f , and S_s .

q (t/m^2)	S_c (m)	H_i (m)	H_f (m)	S_s (m)	S_t (m)
3	0.616	2.127	1.511	0.344	0.960
5	1.423	3.778	2.355	0.361	1.784
7	2.069	5.335	3.266	0.376	2.445
9	2.611	6.380	4.219	0.389	3.000
11	3.077	8.281	5.203	0.400	3.478

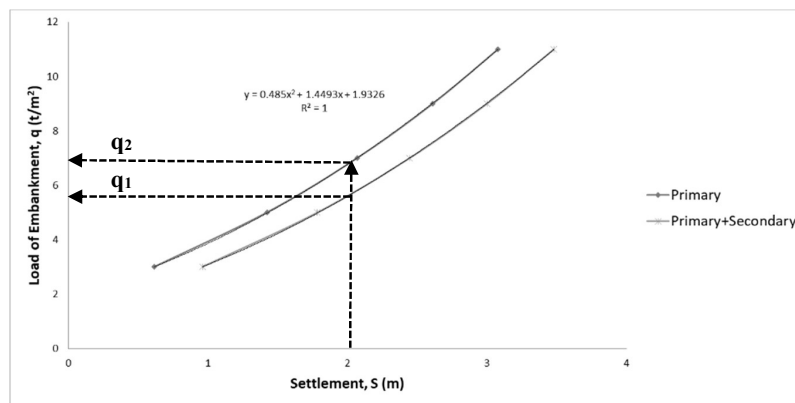


Figure 4. The relationship between S and q .

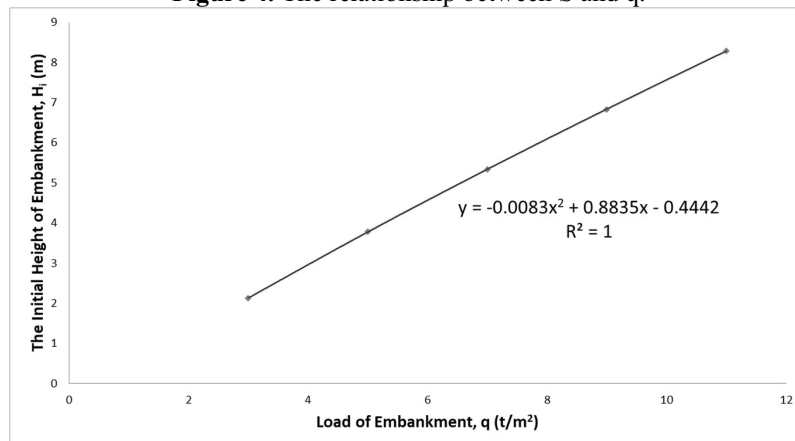


Figure 5. The relationship between q and H_i .

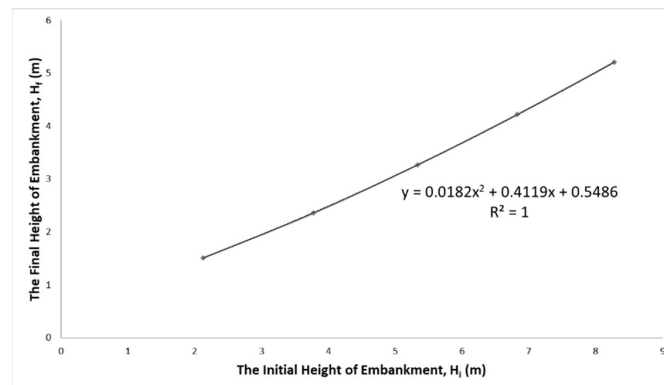


Figure 6. The relationship between H_i and H_f .

The following step is computing q_2 using the equation that shown in figure 4, so that the initial height of embankment and the final height of embankment have changed because there is Δq ($q_2 - q_1$) refers to additional load that equals secondary settlement. Δq is going to be removed along with preload at the end of primary settlement. The new initial height of embankment that includes secondary settlement ($H_{i(p+s)}$) can be calculated by using equation that shown in figure 5, while the new final height of embankment that also includes secondary settlement ($H_{f(p+s)}$) can be calculated by using equation that shown in figure 6. The last is calculating the final height of embankment after primary settlement and secondary settlement were completed ($H_{f(field)}$). The complete calculation can be seen in table 3. From the result of calculation in table 3, a graph of the relationship between the final height of embankment after primary settlement and secondary settlement were completed and the new initial height of embankment is obtained as presented in figure 7.

Table 3. The results of q_2 , Δq , $H_{i(p+s)}$, $H_{f(p+s)}$, and $H_{f(field)}$.

q_1 (t/m^2)	S_t (m)	q_2 (t/m^2)	Δq (t/m^2)	$H_{i(p+s)}$ (m)	$H_{f(p+s)}$ (m)	$H_{f(field)}$ (m)
3	0.960	3.77	0.77	2.769	1.829	0.787
5	1.784	6.06	1.06	4.606	2.832	1.619
7	2.445	8.38	1.38	6.374	3.913	2.516
9	3.000	10.64	1.64	8.019	5.022	3.467
11	3.478	12.84	1.84	9.531	6.128	4.458

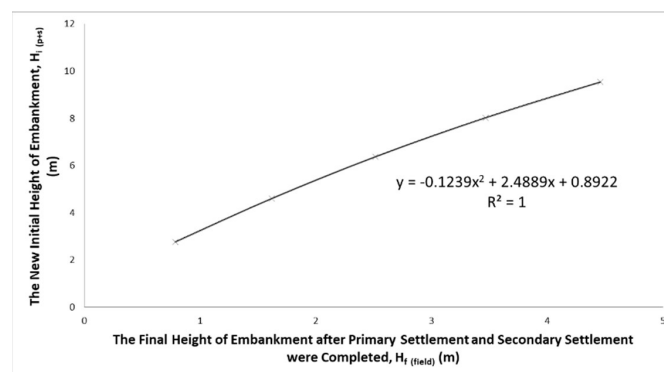


Figure 7. The relationship between $H_{f(field)}$ and $H_{i(p+s)}$.

A graph in figure 7 is later used as a guide for determining the initial height of embankment in embankment preloading method to eliminate secondary settlement at the same time with primary settlement. By inputting value of $H_{f(\text{field})}$ on the equation that shown in figure 7, $H_{i(p+s)}$ will be obtained. $H_{f(\text{field})}$ is also the height of embankment that designed on the planned elevation in the field. In Summarecon Bandung City Area's Development Project, the value of $H_{f(\text{field})}$ is 3 m. Hence, in order to eliminate secondary settlement along with primary settlement, the height of $H_{i(p+s)}$ must be 7.2 m.

4.4. Eliminate secondary settlement using combination of vacuum preloading and embankment preloading

Unlike embankment preloading, vacuum preloading does not need lots of embankment. Vacuum preloading utilizes atmospheric pressure as surcharge load to accelerate the soil settlement. Vacuum preloading method must apply the pressure at least reach 80% of atmospheric pressure for effectiveness, but atmospheric pressure depends on elevation of location. In order to measure elevation of location from sea level, used a device named Altimeter, so that atmospheric pressure is known. Bandung is located at +660 m and the maximum atmospheric pressure in the area is 92.5 kPa, so that this project is planned with vacuum pressure of 74 kPa which the value is 80% of 92.5 kPa.

As previously mentioned that this project is going to be built for house. A house is equal to 10 kPa which meant the vacuum pressure of 74 kPa is overload. The excess of 64 kPa as surcharge load is expected to add more settlement that includes secondary settlement. As a result of 74 kPa, the soil undergoes settlement in total amount of 3.4 m. The settlement that will happen is very large, so that the ground seems to be at below of 0.0 m. In order to backfill for levelling according to planned elevation which is 3 m height, additional embankment as height as 4.6 m is needed. It means that 4.6 m is higher than the vacuum pressure which equal to 4.4 m and feared that the soil will undergo further settlement.

In order to prevent the case above, the solution is doing some stages of loading and still compressing the soil up to 3.4 m. For more detail, the stages of loading are explained below as follows:

- First stage is placing the embankment as height as critical height of embankment. The critical height of embankment is 2.1 m. Then, seal the embankment with Geomembrane and apply vacuum pressure of 74 kPa. In this project, the vacuum degree takes a month or 4 weeks to reach the vacuum pressure of 74 kPa. Therefore, the loading must be waited for 4 weeks. Based on the calculation, the settlement that will happen in week 4 is 1.5 m and the rest of embankment is 0.65 m. Afterwards, turn off the vacuum pump and open the sealing. In the field, in order to know the settlement that has happened, used Settlement Plate.
- Second stage is placing the rest of embankment from first stage, then add more embankment as height as 2.1 m. The height of embankment is independent variable. The important thing is compressing the soil up to 3.4 m with anything height of load. Then, seal the embankment with Geomembrane and apply vacuum pressure of 74 kPa, and also wait for 4 weeks as done on the first stage. Based on the calculation, the settlement that will happen is 1.6 m and the rest of embankment is 1.2 m. Then, when the settlement has already reached 1.6 m or fit to the calculation, turn the vacuum pump off and open the sealing.
- In the way above, the soil undergo settlement in total amount of 3.1 m. Therefore, after the second stage, backfill for levelling is done. In order to levelling according to planned elevation which is 3 m height, additional embankment as height as 1.8 m is needed. Hence, in order to eliminate secondary settlement along with primary settlement, the total height of embankment preloading that must be added using combination of vacuum preloading and embankment preloading is 6 m.

5. Conclusion

Based on the explanation above, it can be concluded that the height of embankment preloading using embankment preloading to eliminate secondary settlement at the same time with primary settlement is 7.2 m, while the total height of embankment preloading using combination of vacuum preloading and embankment preloading is 6 m. Vacuum preloading which should use less embankment material, in fact

in this project, this method needs embankment preloading which is almost the same with embankment preloading. The height of embankment of both methods is only 1.2 m in difference. Actually, vacuum preloading is more effective on eliminate secondary settlement along with primary settlement than embankment preloading because vacuum preloading utilizes atmospheric pressure as surcharge load that expected to add more settlement that includes secondary settlement with require less embankment material. If viewed from the side of soil stability, eliminating secondary settlement using vacuum preloading method does not cause failure because this method applies atmospheric pressure that causes isotropic settlement which eliminates the risk of failure, while eliminating secondary settlement using embankment preloading method by placing 7.2 m of embankment material can cause failure because based on discussion previously, the critical height of embankment is only 2.1 m. Also if place some stages of 7.2 m of embankment material, it needs longer time. Hence, vacuum preloading should be an innovation on handling the problem of limited embankment material in infrastructure development in Indonesia and becomes an environmental friendly soil improvement because this method also applies no chemical admixtures.

In this project, vacuum preloading method is the only way in order to eliminate secondary settlement although this method is more expensive. However, it does not rule out the possibility, a further study about the effectiveness vacuum preloading on eliminate secondary settlement is done. A further study must be done in different area which dominant of pure soft clay. Therefore, the study is expected eliminate secondary settlement more effectively because pure soft clay is assumed undergo smaller settlement than organic soft clay and need less embankment material.

6. References

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