ISSN No:-2456-2165

Long Term Effect Study on Soft Clay Kendal Treated by Prefabricated Vertical Drain with Vacuum

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Abstract:- Structures constructed above soft clay could face problems due to its characteristics, where soft clay has high compressibility, low permeability, and low shear strength. One of the soil treatments for soft clay is using prefabricated vertical drain (PVD) with vacuum, where this combined method shortens drainage path and increases consolidation rate. A finite element method (FEM) study was conducted to see the long-term effect of this method. Analysis was carried out on soil settlement, lateral displacement and pore pressure changes during construction and long after. The final result shows that a rebound happened after the vacuum stopped, and was continued by secondary settlement. Soil moved laterally inward to the vacuumed area during treatment, and moving outward slowly after the treatment is done. The longer duration of vacuum affecting settlement and lateral displacement increase.

Keywords:- *Soft Clay; Prefabricated Vertical Drain, Vacuum Consolidation Method, Long Term Effect.*

I. INTRODUCTION

Soft soil is spread all around the world [14]. Soft soil has low shear strength, low permeability, low bearing capacity, high compressibility [4, 11]. Structures constructed on soft soils could face lots of problems due to its characteristics mentioned above, such as large settlement and differential settlement after construction, instability during excavation and embankment [10]. Ground improvement is needed to eliminate the risk of problems that could occur, which aims to increase soil shear strength and density, controling settlement, and speeding up consolidation [1]. Primary and secondary consolidation could happen in soft soil, where secondary settlement has already observated in a lot of cases, for example in Nansha soft clay [9].

One of the popular ground improvement method is embankment combined with prefabricated vertical drain (PVD) [2, 6]. PVD decreases drainage path, resulting in increase of consolidation rate. Vacuum consolidation, a method combined of vacuum and PVD, replacing embankment by suction pressure to improve soft soil. In this paper, a study is conducted to learn about long term effect on soft soil treated by vacuum consolidation method, using FEM Software Midas GTS NX.

II. LITERATURE STUDY

A. Consolidation

Primary consolidation is a result of change in volume in saturated cohesive soil with low permeability, due to pore water drainage, where this process would continue until excess pore water pressure dissipated completely. Once primary consolidation is done, the following settlement is secondary compression or creep, where the volume change in soil is caused by change in soil internal structure. Due to high compressibility in soft soil, secondary settlement could not be overlooked.

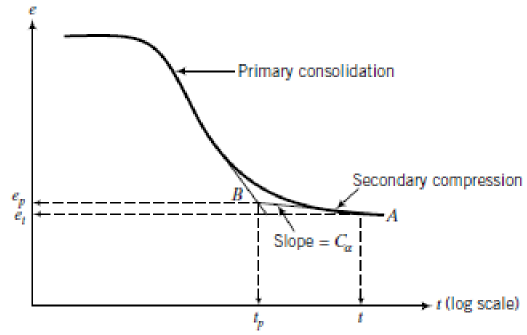


Fig. 1 Consolidation in soil
Source: [3]

B. Prefabricated Vertical Drain and Vacuum Consolidation Method

Prefabricated vertical drain is a drainage path consist of plastic core covered with non-woven polypropylene geotextile [3]. PVD increases consolidation settlement of saturated clay by shorten soil's drainage path. PVD installation is relatively simple, it's penetrated into soil by mandrel, with the help of shoe plate. This method causes disturbance on the soil around, especially the area that mandrel intersects with [7]. In the disturbed area, horizontal permeability and compressibility decreases, affecting consolidation [7], this is shown by two study cases in Naval Dockyard, Bangkok and Muar Clay, Malaysia.

Aside from preloading, PVD can be combined with vacuum. Vacuum consolidation method (VCM) introduced by Kjellman in 1952. VCM is a mechanical ground improvement, where water and air inside the isolated soil suctioned by vacuum pressure. In this method, PVD is installed until the bottom end of soft soil layer. VCM can be done both with and without airtight membrane. In VCM membraneless, direct tubing on vertical and horizontal drain is used [13].

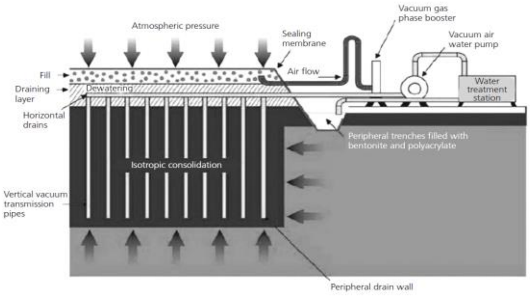


Fig. 2 Schematic Diagram of Vacuum Consolidation Method with Airtight Membrane
Source: (Masse, Spaulding, Wong, & Varakin, 2001)

III. RESEARCH METHODOLOGY

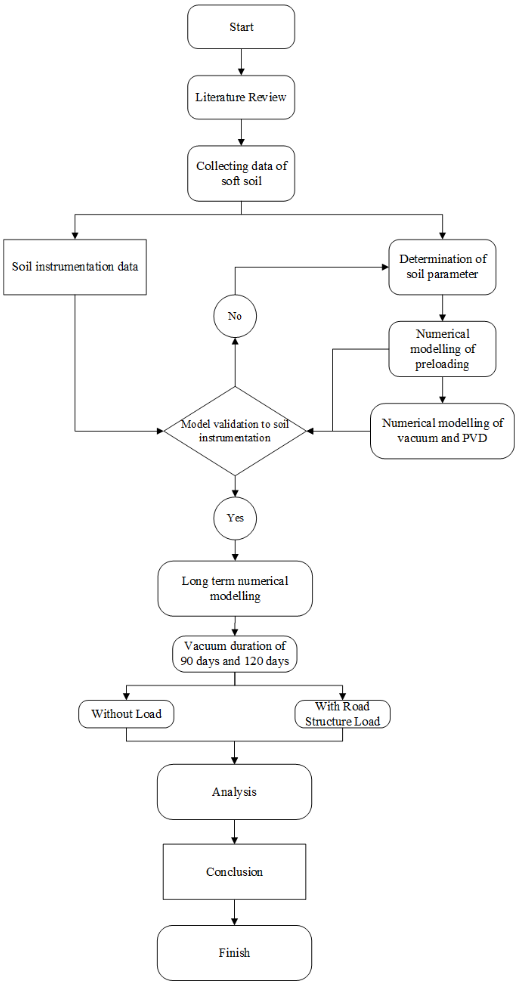


Fig. 3 Research Flow Chart

A. *Site Location and Condition*

In this research, VCM trial is conducted in Kendal, where the area was used for fish pond. Embankment must be made with 1.5 m thickness due to softness of the soil. Soil layering is done by analyzing SPT and CPT data, shown in Fig. 4 and Table 1. PVD is installed until 20 meter depth with 16.5 meter of PVD and 3.5 meter of connecting tube. Vacuum pressure used in this field trial is 90 kPa.

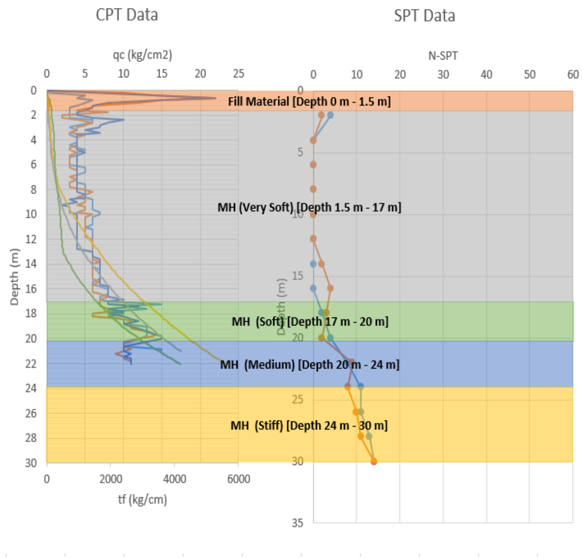


Fig. 4 Soil layering used in model

Table 1. Soil Parameter Input

Soil Name	Fill Material (CH)	MH			
		Very Soft	Soft	Medium	Medium
Material Model	Modified Cam Clay	Soft Soil Creep			
Elastic Modulus (kPa)	10000	10000	12000	15000	20000
Poisson's Ratio (v)	0.3	0.32	0.33	0.34	0.3
k0	0.691	0.807	0.733	0.657	0.604
Unit Weight (KN/m3)	15	14.26	14.16	16.69	16.11
Wet Unit Weight (KN/m3)	17	14.83	14.8	17	16.5
Initial Void	0.75	2.26	2.33	3.06	1.5
Permeability (cm/s)	4.483E-07	4.483E-07	3.430E-07	2.420E-07	2.420E-07
λ	0.522	0.522	0.565	0.691	0.361
k	0.075	0.075	0.113	0.138	0.072
e	1.000	2.290	2.330	3.060	1.460
Ca	-	0.046	0.067	0.044	0.033
c (kPa)	10	7.51	12.72	13.97	21.91
φ (°)	15	7.12	10.25	11.37	18.79

B. *Stage Construction*

Construction stage is modelled based on construction work on VCM trial, where the details is written below.

- Initial condition
- Embankment on treatment area, with 1.5 meter thickness for 10 weeks long.
- Leaving time due pandemic for 45 weeks, where VCM installation could not be done.
- PVD and Vacuum installation, where vacuum is modelled both 90 days and 120 days long.

- Long term model without load and with road structure load after vacuum stopped.

C. Geometry Modelling and Analysis Condition

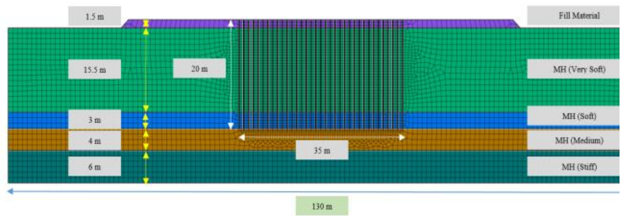


Fig. 5 Geometry Model

Geometry measurement and material in model, shown in Fig.5, was made by information provided on Fig. 4 and table 1. Vacuum pressure 90 kPa was modelled by suction in Midas GTS NX. Smear effects is included in model, where the smear zone is twice of mandrel equivalent radius. Mandrel dimension used is 140 mm and 65 mm [12], thus the smear zone radius used is 120 mm. Soil permeability in smear zone used is 1/3 soil's horizontal permeability. Long term modelling is conducted for 52 years after vacuum stopped.

D. Model Validation

Model validation is conducted to discover the accuracy of analysis produced. Model is validated to settlement plate (SP) and inclinometer data (IC), where the floor plan is shown below. Settlement plate 1 and 2 (SP1 & SP2) is located inside the vacuumed area and settlement plate 3 (SP3) is placed outside treatment area.

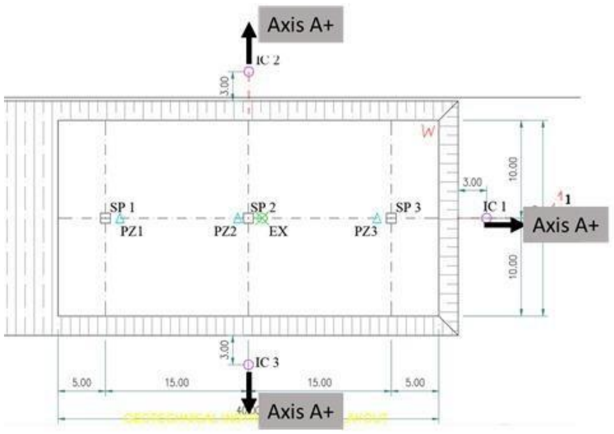


Fig. 6 Instrumentation Floor Plan
Source: PT. Geoforce Indonesia, 2020

Vacuum process is conducted until soil reach the end primary consolidation, where soil settlement estimated by Asaoka and Hyperbolic method. Final settlement analysis from both methods on SP1 are shown in following figures and table. Vacuum is stopped after 90 days, where settlement reading on VCM trial site had passed both method's estimation, especially inside the treatment area.

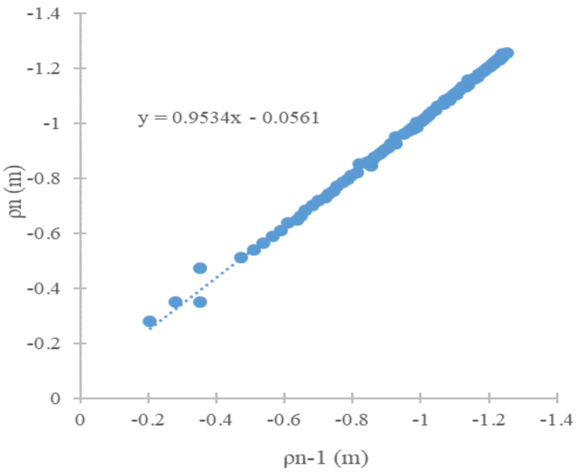


Fig. 7 Final settlement by Asaoka Method for SP1

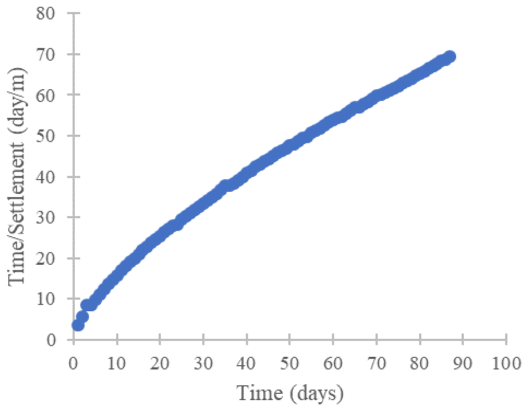


Fig. 8 Final settlement by Hyperbolic Method for SP1

Table 2. Comparison of final settlement reading and prediction

	Settlement plate reading (m)	Asaoka Method Estimation (m)	Hyperbolic Method Estimation (m)
SP1	1.255	1.204	1.137
SP2	1.092	1.051	1.079
SP3	0.434	0.462	0.420

Model validation to each of settlement plate (SP1, SP2, and SP3) and inclinometer (IC 1) is shown below, where the analysis result approaching instrumentations reading.

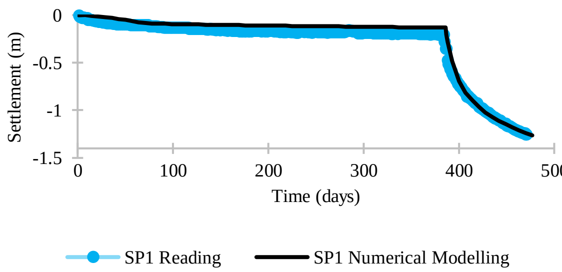


Fig. 9 Settlement validation on SP1

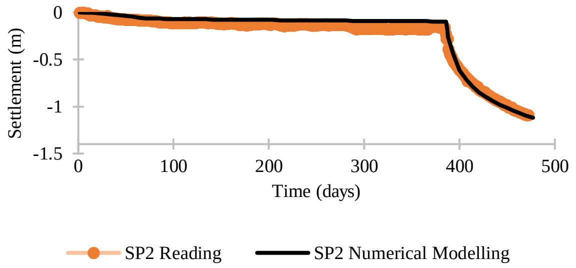


Fig. 10 Settlement validation on SP2

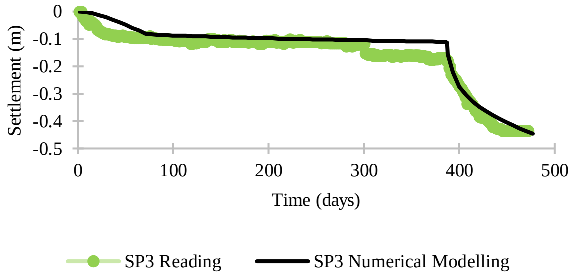


Fig. 11 Settlement validation on SP3

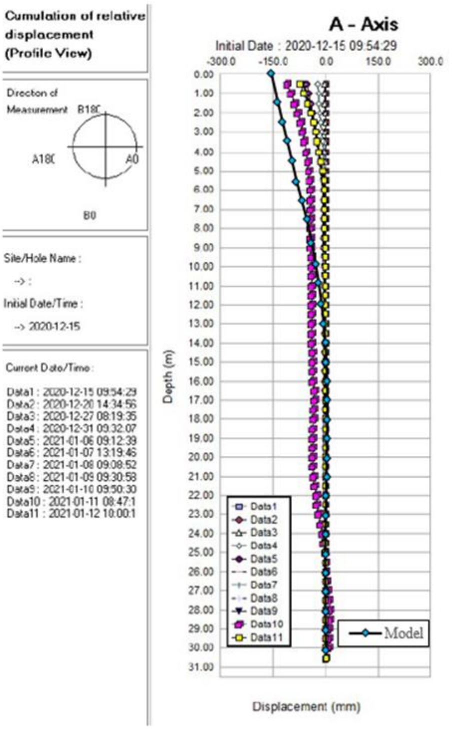
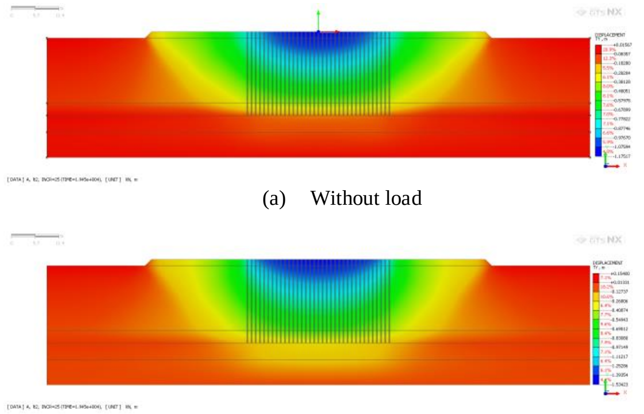


Fig. 12 Lateral displacement validation

IV. RESULT AND DISCUSSION

A. Secondary Compression

In the end of vacuum treatment, right after the vacuum stopped, the model analysis shows that the largest settlement happened in the center treated area. Two models, 90 days vacuum without load and with road structure load are compared, where the settlement area of model with road structure is more focused nearby the load placement with larger settlement than model without load, right above the treated area. This phenomenon can be seen on these two figures. From these figures, we can also see that the further distance from treated area, impact of the vacuum is decreasing, which results on smaller settlement.



(a) Without load

(b) With road structure load

Fig. 13 Settlement analysis result after 90 days vacuum

From analysis result of these two models, it’s also found that there’s a difference in settlement behavior through time (Fig. 14). After vacuum stopped, both of the models shows that rebound happened due to sudden increase of pore water pressure, with road structure road model has it smaller. Rebound after vacuum stopped also happened in VCM project conducted in Thailand [8]. In model with no load, swelling is still happening with decreasing rate over time. Different behaviour is shown in model with road structure, where secondary settlement happened after rebound is finished.

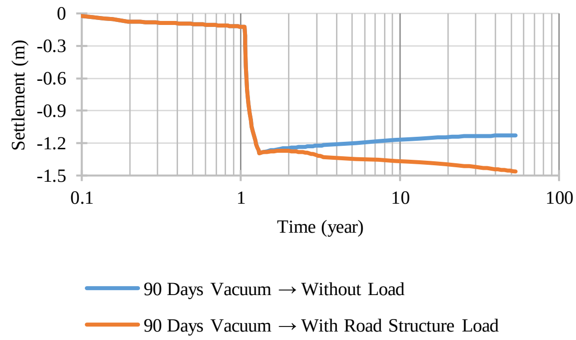


Fig. 14 Settlement comparison inside vacuum area (90 Days)

Longer duration of vacuum is also modelled in this study, where it shows the same behavior with larger settlement. 30 days difference on vacuum results in settlement difference of 9.03 centimeters.

B. Lateral Displacement

Analysis result of lateral displacement shows that it moves inward to treated area. The same behavior is also shown in lateral displacement analysis, where vacuum impact is decreased the further distance analyzed (Fig. 15). In the end of both models, lateral displacement difference is not large, where model without load has larger lateral displacement.

ISSN No:-2456-2165

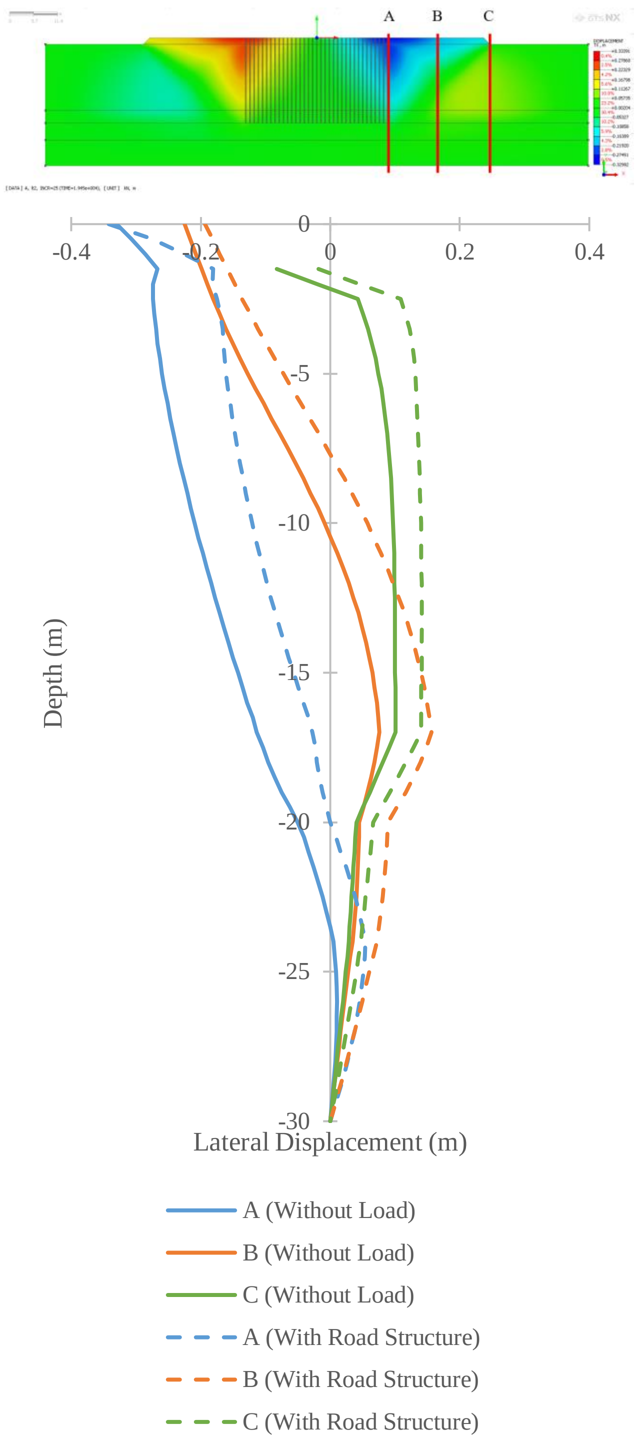


Fig. 15 Analysis result of lateral displacement (90 Days Vacuum)

Analysis on point A is also conducted over time in several conditions; the time on vacuum started, vacuum stopped, soil rebound, and in a long term. In the end of vacuum, maximum lateral displacement happened, before moving outward after. This behavior is shown in both of the models (Fig. 16 and Fig. 17). Additional time of vacuum also results in larger lateral displacement, where the behavior is not different.

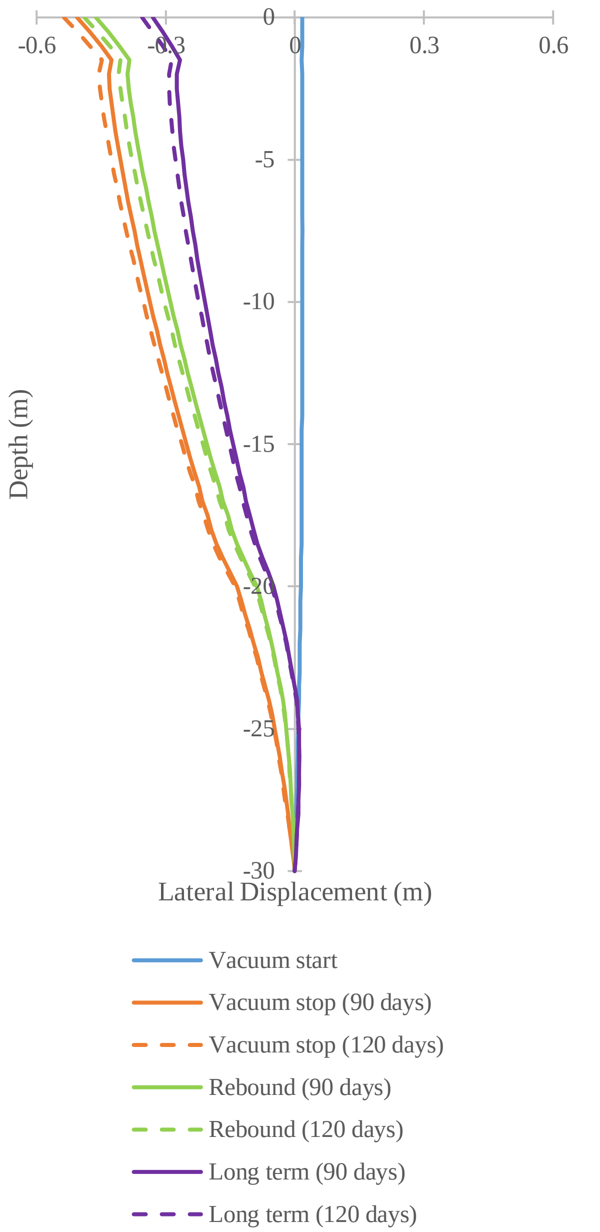


Fig. 16 Lateral displacement on point A based on time in model without load

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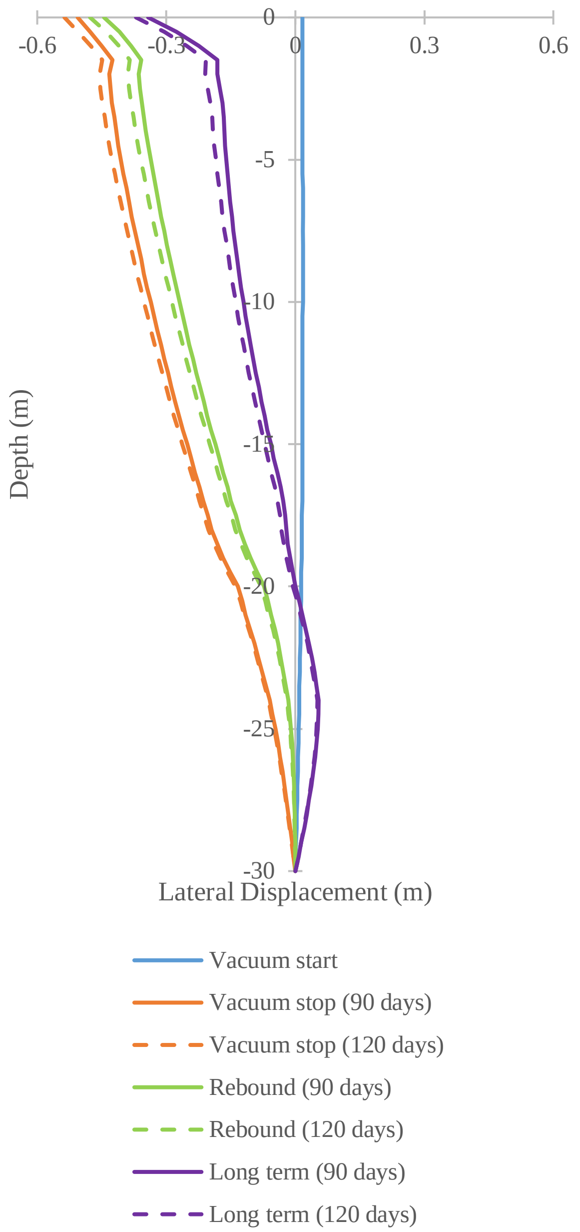


Fig. 17 Lateral displacement on point A based on time in model with road load

C. Pore Water Pressure

Pore water pressure change throughout consolidation process is viewed in 10 meter depth below soil surface, in the middle of vacuumed area, in which can be seen on Fig. 18 and Fig. 19. When ground improvement with vacuum is conducted, pore water pressure drops to -89.97 kPa, which this value is not far from vacuum pressure. After vacuum stopped, there's a sudden rise in pore water pressure for 40 weeks in model without load. This sudden pore pressure rise happened for two years in model with road structure. For the long term, there's a slight difference in model with different vacuum duration, where 120-days vacuum has smaller pore water pressure. In the end of modelling time (52 years after vacuum stopped), difference in pore water pressure in model without load is 0.326 kPa and model with road load is 0.842 kPa.

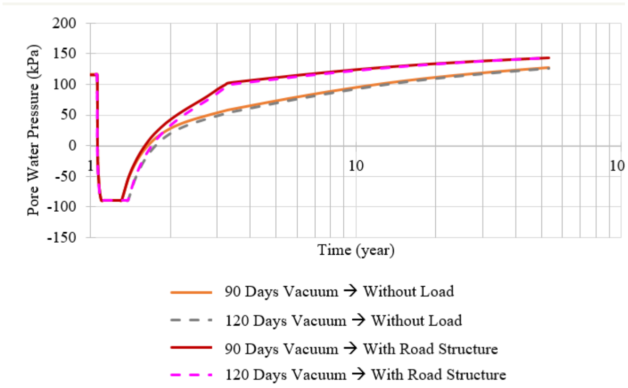
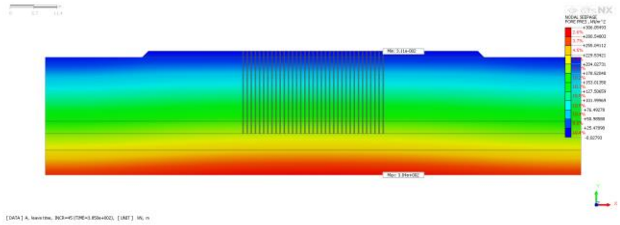
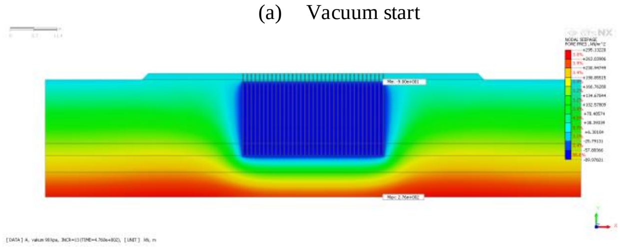


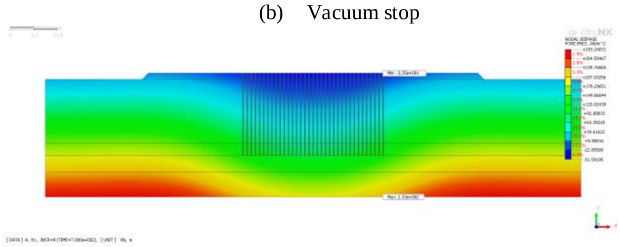
Fig. 18 Pore water pressure changes through time



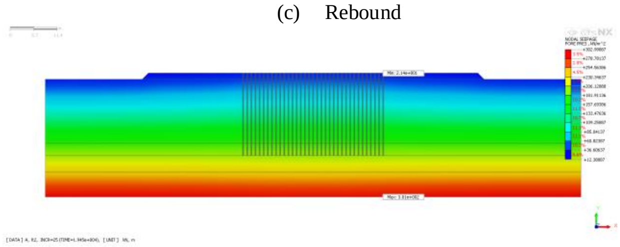
(a) Vacuum start



(b) Vacuum stop



(c) Rebound



(d) Long Term

Fig. 19 Pore water pressure change illustration

V. CONCLUSION

From this research about long term effect of soft clay treatment by PVD and vacuum, the analysis results shows that:

- The further distance from treated area, it can be concluded that vacuum effects decreases. This is shown by smaller ground settlement and lateral displacement.
- After vacuum stopped, soft soil experienced a rebound due to loss of vacuum load pressure in soil. A different characteristic is seen, where swelling would still happen over time if load is not given on top of soil. Secondary

settlement will still happen but with much smaller rate after rebound finished.

- Lateral displacement due to vacuum pressure results in inward movement, before moving outward after the vacuum stopped.
- Road structure load affects pore water pressure, where sudden increase of pore water pressure happens longer.
- Vacuum duration affects ground settlement, lateral displacement and pore water pressure. Longer vacuum duration results in larger ground settlement and lateral displacement. A slight lower pore water pressure also can be seen in longer vacuum duration model.

ACKNOWLEDGMENT

This paper and research would not be possible without the help of PT. Geoforce Indonesia, for providing soil and ground improvement data. We sincerely express our gratitude for the contribution mentioned and countless experience sharing regarding soil improvement.

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