VACUUM PRELOADING CONSOLIDATION METHOD, A CASE STUDY OF DINH VU POLYESTER PLANT

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ABSTRACT**:** This case study presents the design, operation, and results of a soil improvement project using the vacuum preloading method on the area of 12,0000m^2 for Dinh Vu Polyester Plant in Dinh Vu, Haiphong, Vietnam. The effects of soil improvement are demonstrated through the average consolidation settlement of 1.2 m and increases in undrained shear strengths by a factor of two to four or more. The study shows that the vacuum method is an effective tool for the consolidation of very soft, highly compressive clayey soils and loose sandy soils over a large area. This technique is especially feasible in cases where there is a lack of surcharge loading fills, short time schedule of project, extremely low shear strength, soft ground adjacent to critical slopes, feasibility to construction of clay/mixing wall to protect vacuum through sand layers and access to a power supply.

*Keywords***:** vacuum preloading, consolidation, soil improvement, soft clay, prefabricated vertical drains, clay/mixing wall.

INTRODUCTION

The vacuum consolidation method was firstly proposed by Kjellman (1952) for treatment of the soft soil strata. Since 1980, the first vacuum consolidation method of Kjellman has been improved by the combination with the surcharge and PVDs - abbreviated here as VCM. This improvement does not only speed up the soil consolidation process, reduces the construction time but also increases the soil stability [Masse (2001), Masse (2002), Chu (2005)]

Comparing to other methods of soil improvement, VCM has many advantages as well as disadvantages.

Advantages:

- The soil consolidation process is significantly speeded up;
- Soil instability hardly happens;
- VSPCM is an environmental friendly technology because of no toxic disposal.

Disadvantages:

- VSPCM costs relatively more than traditional methods such as surcharge combined with PVDs or sand drains;
- Quality control is highly required;
- It's quite hard to utilize this method for deep soft soil layers. To the best knowledge of the authors, until now, there is only one project in Kimhae, Pusan, Korea [after F. Masse (2002)] in which, the treated soft soil depth reached 45m.

Until now, VCM has been widely applied in various countries such as China, Japan, Korea, Thailand. Since 2006 the method was firstly executed in Vietnam and now has been successfully utilized in many projects, the most successful and recent projects of which is Dinh Vu Polyester Plant.

This paper presents the design, operation, and results of a soil improvement project using the vacuum preloading method in PVTex project as well as gives experiences for better application for future projects improved by VCM.

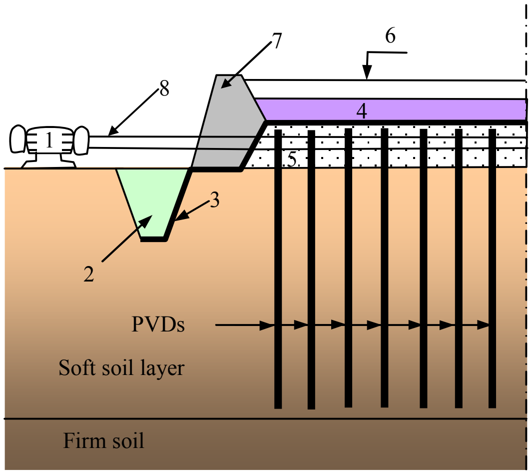

Figure 1 Scheme of vacuum consolidation method combined with surcharge and PVDs (modified from [after Masse (2001), F. Masse (2002), Serge Varaksin (2007)]). Where:, 1-vacuum pump, 2-clay mixing wall/trenches, 3- geomembrane, 4 –surcharge of sand, 5 –sand mat, 6 – surcharge of water, 7 –damp, 8 – drainage system.

MECHANISM OF VACUUM PRELOADING

The mechanism of preloading method is clearly presented in Fig 2 and 3. When placing the surcharge on soil, the total stress and the excess pore water pressure (PWP) will increase an amount corresponding the stress caused by the surcharge, After the consolidation time, the excess PWP diminishes, causing the effective stress to be added an amount equal to the excess PWP (Figure 2). Because the vertical stress (σ_1') is twice time of the horizontal ones (σ_2', σ_3'), the stress path follows the curve ABC and the outward lateral deformation ($\varepsilon_h < 0$) is produced. If the curve AB intersects with the failure line, there will happen the soil instability (Figure 3).

Inversely, vacuum pressure is negative stress in nature, which leads to no change in the total stress. When vacuum preloading is combined with surcharge, the total stress and the excess PWP principally increase an amount of stress by the surcharge. However, to the end of consolidation process, the excess PWP is lessened by an amount of the total stress caused by both surcharge and vacuum, which explains the reason why the excess PWP reaches negative value in this case as shown in Figure 2. As the results, the effective stress in soil increases an amount corresponding to the total stress by vacuum pressure and surcharge. Moreover, vacuum pressure when introduced into soil causes isotropic effect, meaning vertical stress is equal to horizontal ones, making the stress path follow the line AE. In additional, for the negative nature of vacuum pressure, AE lies in passive zone where there happens inward lateral deformation. Hence, the soil improved by vacuum pressure or even by VCM is hardly instable (Figure 3).

PROJECT BACKGROUND

Project brief description

Dinh Vu Polyester Plant (PVTex) locates in Dinh Vu Industrial Zone, Hai Phong city, in the northern of Vietnam (Figure 4). The total improved area of the project was 9.2h with the average thickness of the soft soil layer varying from 22 to 32m. For the high required service load (Table 1) and high compressible soil at the site, VCM was proposed to apply for soil improvement. It took 6 months to finish the soil improvement work, from August 2009 to January 2010.

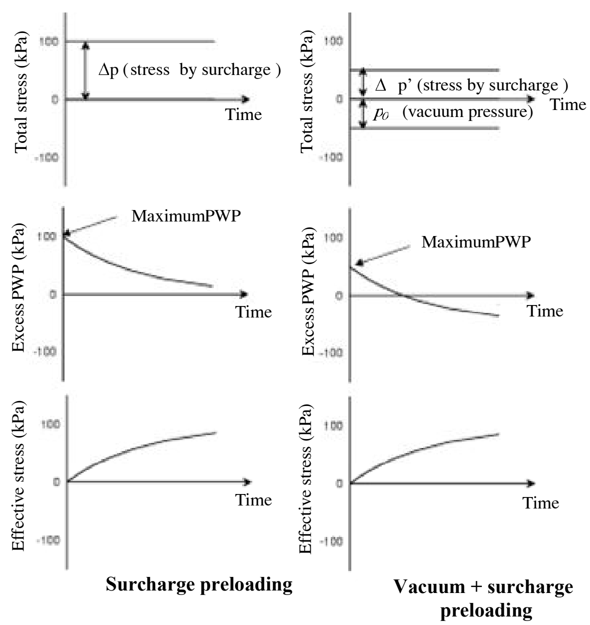

Figure 2 The mechanism of surcharge preloading and vacuum preloading combined with surcharge (after Masse (2002)).

Table 1 Service load of zones in PVTex project

Zone	Service load
1	50 kPa
2	30 kPa
3	30 kPa

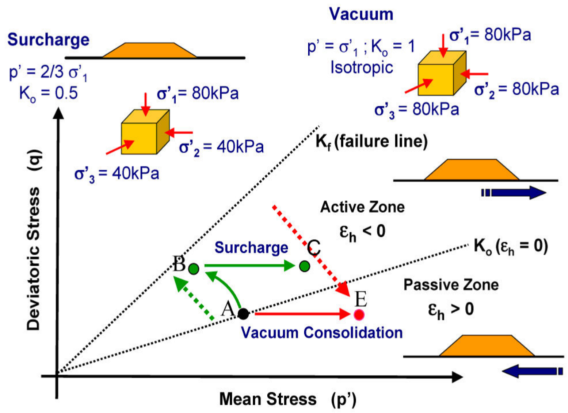

Figure 3 Vacuum pressure on stress path graphs (p', q'). AE: stress path of vacuum consolidation method; ABC: stress path of surcharging method (Modified from [after Masse (2001), Masse (2002), Serge (2007)]).

Figure 4 Location of PVTex project [after Google Earth]

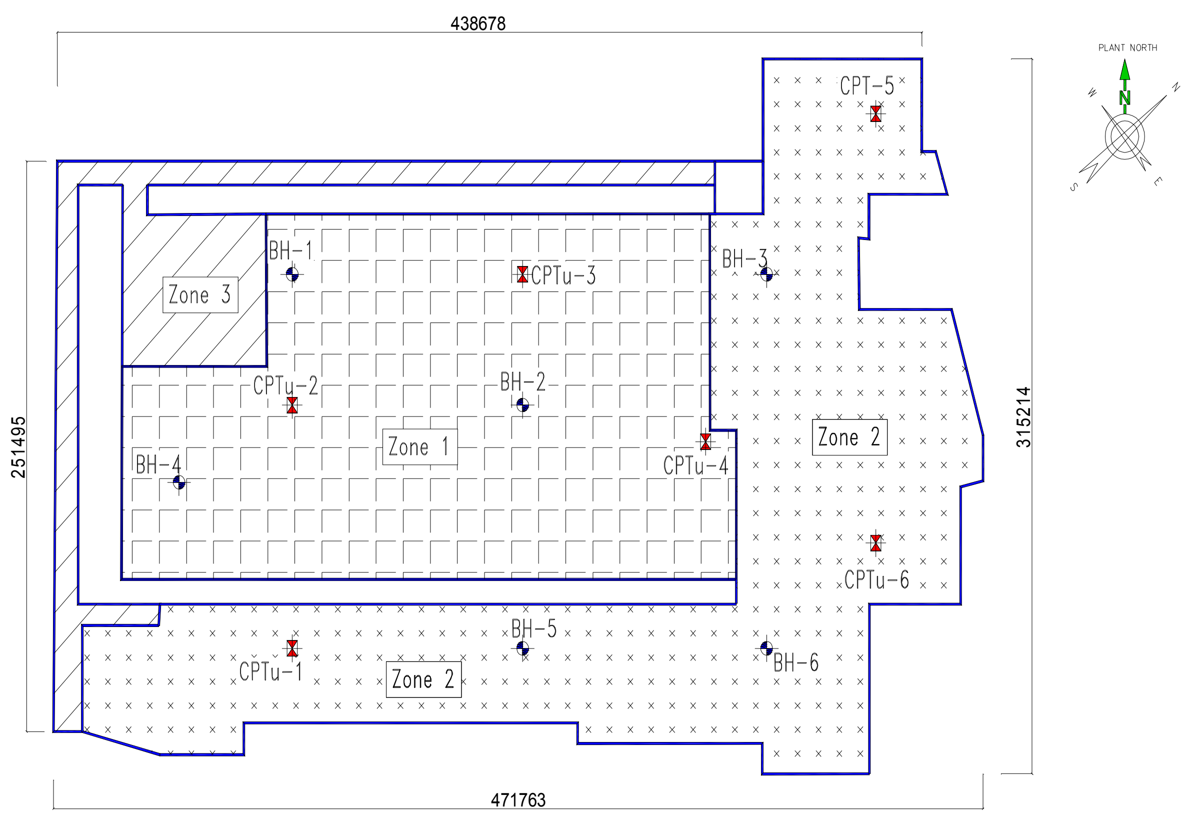

Figure 5 Plan layout of zones and field test locations (BH: boreholes, CPTu: cone penetration tests and vane shear tests are taken in BH-1, BH-3, BH-4, BH-5) before soil improvement in PVTex.

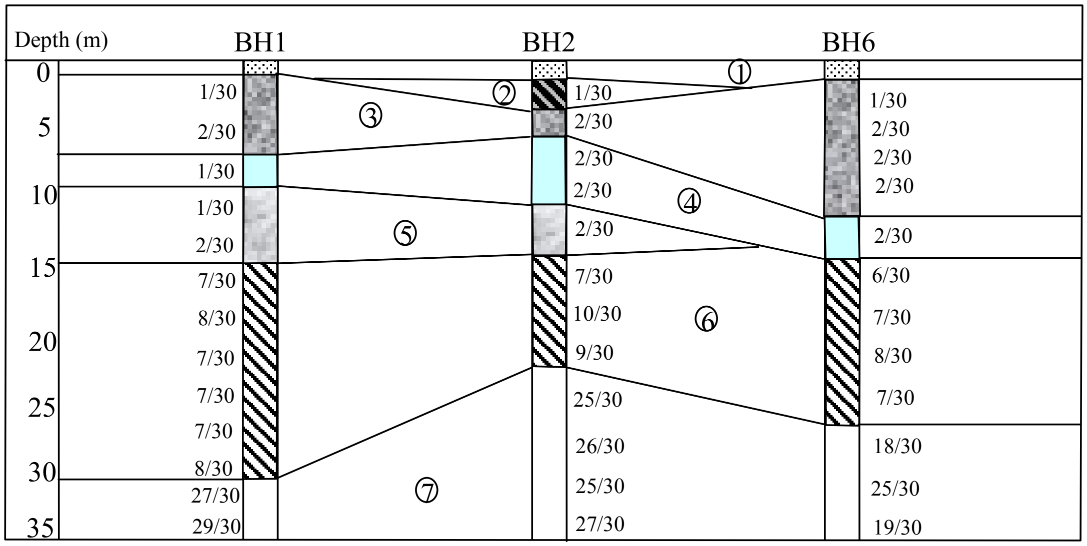

Figure 6 Typical geological profile of PVTex project [after Ngoc (2010)]

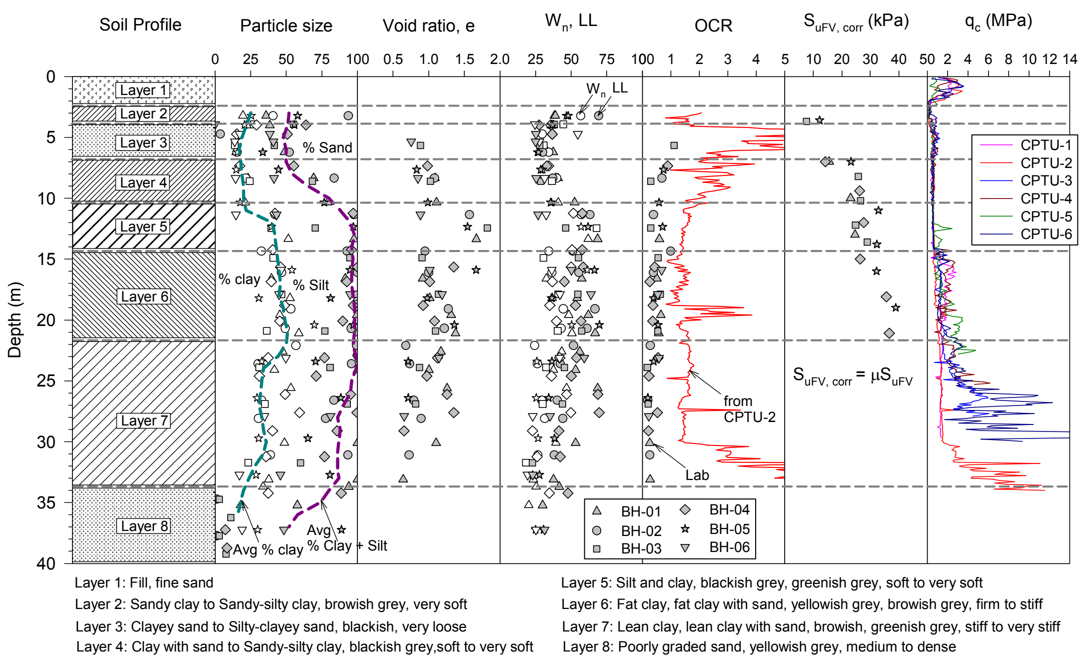

Figure 7 Typical geotechnical profile of PVTex project

Geological and geotechnical conditions

The average soft soil layers at the site varies strongly from 22 to 32m with very high compressibility. The typical geological and geotechnical profiles and soil properties of PVTex are clearly shown in Figure 5 and Figure 6.

DESIGN PRINCIPLES

Until now, the designing principle for VSPCM has not been completed. Therefore, the conventional consolidation theory is often practically applied for designing process of VSPCM together with the following assumptions and specifications [after Ngoc (2010)]:

- For primary consolidation settlement estimation, vacuum pressure is considered to be unchanged along the PVD length (Figure 3) and finished under PVD depth.
- The primary consolidation settlement in VSPCM method is initially calculated in accordance with the conventional consolidation theory. It will be then multiplied with an empirical coefficient of 0.8~0.9 [after Masse (2001), Masse (2002), Chinese standard JGJ79-2002].

- The effective space of PVDs is in range of 0.9~1.2m, which is corresponding to the drain-spacing ratio of n = 15~22 [after Loan (2006), Chinese standard JGJ79-2002].

For the project of PVTex, considering the geological and geotechnical conditions, the parameters chosen for design is shown as below:

- PVD depth: 22-32m @0.9m square grid;
- Vacuum pressure: 70kPa.
- Surcharge height: 1.5m for 3t/m2 zones and 2.0m for 5t/m2 zones (including sand mat).

SOIL IMPROVING PROCEDURE

Pretreatment

Before soil improvement, soil investigation have been taken at the site with 7 boreholes, in-situ tests such as SPT, CPTu and VST scatted all around the improved area (Fig 5) to get all necessary soil data for designing.

Installation of PVD

The site is leveled and filled with 0.5m sand mat prior to the PVD installation. PVDs were installed through the sand mat to the bottom depth of the soft soil layers. The drainage system was then enhanced by the drainage pipes in square pattern of 6m buried in the sand mat. Also, settlement plates, piezometers, inclinometers and vacuum gauges were installed to the site to monitor and control the soil improvement process.

Installation of geomembrane and cut-off wall

To strictly control the efficiency of the soil improvement the site area is divided into subzones with the area of about 3ha (Figure 8). The most distinction of vacuum preloading method is that the improving area must be completely air-tight, thus, the geomembrane then will be laid over the entire area and keyed into the cut-off wall at the periphery of each construction zones. For the appearance of sand lenses between soft soil layers, around the boundary of each sub-zones, clay mixing walls were constructed until the depth of 11~16m to prevent the site from vacuum leakage.

Vacuum operation

Vacuum system firstly operated in 10 day to check the working ability of the vacuum pumps and the air tightness of the geomembrane. Because of no occurrence of abnormal phenomena, the sand surcharge were filled to the site. For objective reasons, the schedule has been delayed of over a month, 0.5m water surcharge was added to the site as the recovering plan and remained until the consolidation reached the designed value (DOC of 90%).

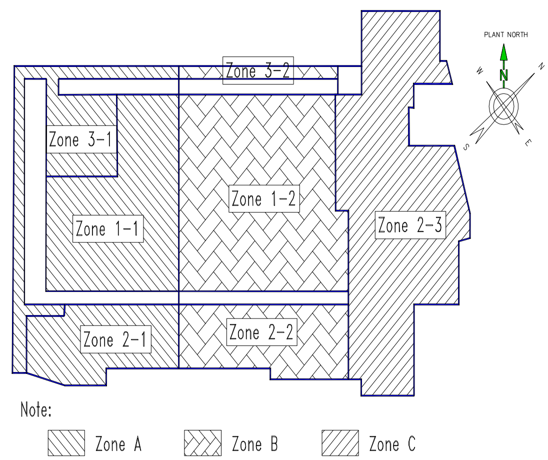

Figure 8 Layout of construction zones

1. PVD installation
2. Geomembrane installation
3. Clay mixing wall installation
4. Monitoring equipments installation
5. Vacuum + sand surcharge preloading
6. Water surcharge preloading

Figure 9 Construction procedures of VCM in PVTex project

POST-IMPROVED RESULTS

During and after soil improvement, the monitoring and post-soil investigation was taken placed strictly to control and manage the soil improvement results.

Opposing to the assumption of vacuum pressure (70kPa), at the site, the vacuum gauges recorded the pressure of 85-95kPa, which caused the designed load to be less than the actual one (Figure 10). And it can be noticed that the corresponding to vacuum increment, the settlement increased significantly at the first stage (Fig 9). At the end of the recorded settlement curves, the all points are merely aligned, which presents that the settlement is getting to reach the stable value in very short time.

Also, from Fig 9, the settlement calculated as the principles in above and the actual one of subzone 3-1 met each other quite well while the actual settlements in subzone 2-1 were parallel to the calculated one with the gap equal to the settlement that occurred during PVDs installation time. This could be explained by the strongly various thickness of the soft soil, causing the great settlement differences between sub-zones and the sample disturbance, leading to the inexact input soil parameters for consolidation modeling. Thus, the design principles generally could be practically applied for actual projects.

Figure 11 show the improvement of soil properties after soil improvement. In details, the water content (W) and the void ratio (e_0) reduced up to 30%, unit weight (γ) increased 10% while the cone resistance (q_C) (S_u) increased 20-40% and undrained shear strength increased 2-4 times, which proves the operation of VCM in PVTex project and that the soil has been much improved compared to the initial state. Actually, for the optimistic changes of soil properties, including the cone resistance (q_C), the piles installed to the site were decreased up to 50% comparing to the initial estimation.

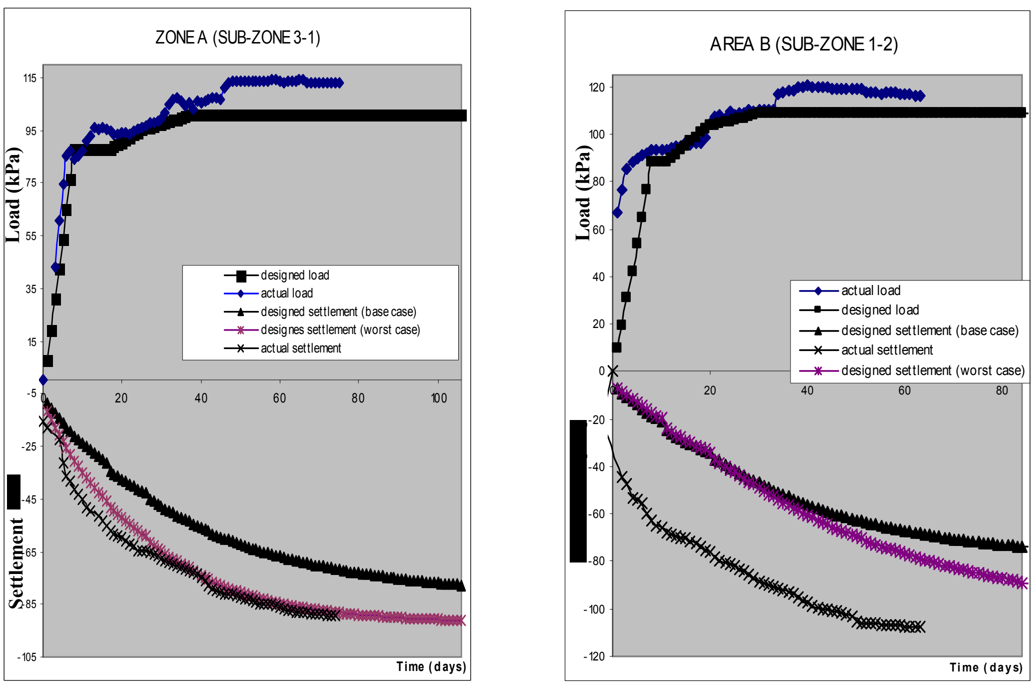

Figure 10 The designed and actual value of load and settlement in PVTex project

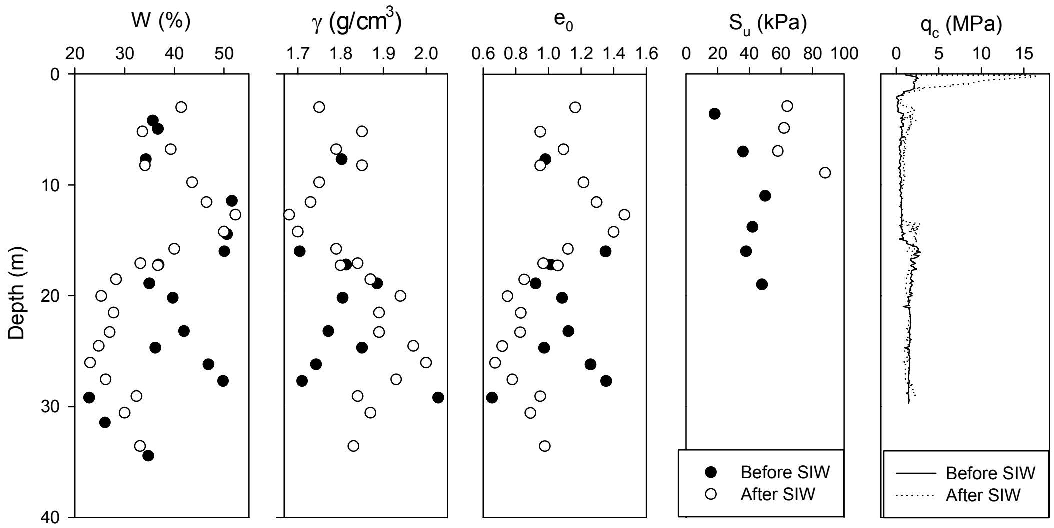

Figure 11 The soil properties before and after soil improvement in PVTex

CONCLUSIONS

PVTex is one of the most recent projects improved by VCM in Vietnam. The success of the project in very highly compressible soil with up to 32m in thickness of soft soil illustrated by post-soil impressive improvement results is the obvious evidence that VCM can be applied in very soft and thick ground area.

PVTex is also the first project where water surcharge was used. Water when used as surcharge presented the advantages of mobilization, availability, time and cost saving. Moreover, water automatically leveled at the site, thus the load by itself distributed onto the ground without leveling and controlling by machinery. In addition, water was installed to the site simply by the pumping gradually, by which, the load could be easily controlled, preventing soil instability. All of the advantages gives the feasibility for applying water surcharge in future projects.

As the designed settlement did not match well the actual value, and that the negative nature of the vacuum pressure is different from the conventional load by surcharge, the design principle such as the changes of vacuum pressure along the depth, the suitable modeling of vacuum in FEM should be further studied.

The detail soil investigation, monitoring during soil improvement and back-analysis are also recommended for accurately predicting the consolidation by vacuum preloading method as well as revealing and managing problems and further studying the mechanism of vacuum preloading method.

ACKNOWLEDGEMENTS

Authors would like to thank Fecon Foundation Engineering and Underground Construction JSC and Fecon-Shanghai Soft Soil Treatment Company Limited for enthusiasm supporting us the entire data of PVTex project.

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