Experimental application of optimal depth of PVDs determination under vacuum loading condition

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ABSTRACT

Viet Nam is one of the country that has a very soft and complicated geological feature. Therefore, how to economize cost but satisfy the standard and technical requirements in designing by selecting an appropriate method in building especially projects constructed on soft ground is always needed to consider and research continuouslly. In this paper, a method how to determine the optimal depth of PVDs under vacuum loading condition for soft ground improvement is presented and applied to specific case in 861 provincial street, Ward Cai Be, Tien Giang District. The soft soil includes two layers with total 12m thick and is allowed to drain on the top and bottom faces (double drainage). The result shows that the optimal depth of PVDs is about 10,5m with the small error of 0,7%

Keywords: *optimal depth, PVDs, vacuum loading*

1. INTRODUCTION

In the 30 recent years, method used PVDs has been developing due to its prominent advantages [3-9]. In case of big and important projects such as highway, plant, port or airport, PVDs are combined with vacuum loading in soft ground improvement. Many researches have been implemented to study on soft ground improvement by using vacuum loading [3,4,6,9].

In Viet Nam, many highway projects have been invested and constructed to solve traffic problem as well as for the development of the country such as Ho Chi Minh – Trung Luong, East – West, Long Thanh – Dau Giay, Ben Luc – Long Thanh, Cao Lanh – Vam Cong and so on. These projects spend a lot of money especially in improving soft soil problem. Therefore, the problem needed to consider is how to decrease the the cost, and in this situation, how to determine the optimal depth of PVDs is very important and necessary. Chai et al have introduced the method how to determine the optimum installation depth of PVD under vacuum consolidation [5,6]. However, this is just applied to one soft soil layer.

There are some standards which guide how to design and calculate in soft ground improvement [1,2,7]. However, in these standards, the method how to design PVDs for soft soil improvement under vacuum consolidation has not been considered clearly yet and especially in case of determining the optimal depth of PVDs. This paper applies the method introduced by Chai et al to a provincial street project in Mekong Delta region in order to validate its exactness and applicability as well as to contribute an article to standard for designing.

2. SCOPE OF WORK

In this paper, the experimental work is executed for the specific circumstance in the scope as follows:

- Determine the optimal depth of PVDs
- The applied load is just only vacuum loading
- The soft soil with PVDs includes two different layers
- The researched area is 861 provincial street, Ward Cai Be, Tien Giang District
- The spacing between PVDs is 1 m
- The soft soil is allowed to drain on the top and bottom faces (double drainage)

3. METHODOLOGY

It is assumed that the ground water level locates at the soil surface and hydraulic conductance is a constant in the whole soft soil area, at stable state, vacuum pressure distribution in the soil can be illustrated as shown in Figure 1. With double drainage condition, the optimal depth of PVDs, noted as H_1, proposed by Chai et al can be calculated as follows:

$$H_1 = \frac{k_{v1} - \sqrt{k_{v1}k_{v2}}}{k_{v1} - k_{v2}} H \qquad \text{(Eq.1)}$$

$$k_{v1} = \left(1 + \frac{2,5 l^2}{\mu D_e^2} \frac{k_h}{k_v}\right) k_v \qquad \text{(Eq.2)}$$

$$\mu = \ln\left(\frac{n}{s}\right) + \frac{k_h}{k_s}\ln(s) - \frac{3}{4} + \pi \frac{2l^2 k_h}{3q_w} \qquad \text{(Eq.3)}$$

In which

$$s = \frac{d_s}{d_w} \qquad \text{(Eq.4)}$$

$$d_w = \frac{a+b}{2} \qquad \text{(Eq.5)}$$

$$d_s = 2d_m \qquad \text{(Eq.6)}$$

$$n = \frac{D_e}{d_w} \qquad \text{(Eq.7)}$$

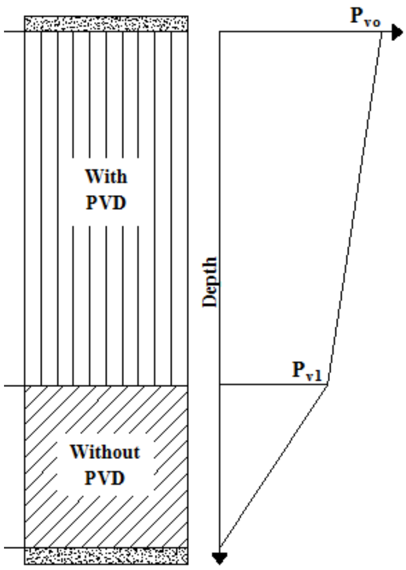

Figure 1. Diagram of vacuum pressure distribution [5,6]

where

d_s - Diameter of smear zone

d_w - Equivalent diameter of PVD

d_m - Equivalent diameter of steel pipe

P_{v0} - Vacuum pressure

P_{v1} - Pressure at end point of PVD

H_1 - Optimal depth of PVD

H - Soft soil thickness

k_{v1} - Vertical hydraulic conductivity in soft soil zone with PVD

k_{v2} - Vertical hydraulic conductivity in soft soil zone without PVD

k_h - Horizontal hydraulic conductivity in unsmear zone

k_s - Horizontal hydraulic conductivity in smear zone

l- Drainage length of PVD (= H_1)

q_w - Volume rate of flow corresponding to the hydraulic gradient of 1

D_e - Effective diameter of PVD

Albakri et al (1990) implemented experimental tests to determine the ratio of the hydraulic conductivities from piezocone instrument and the results are given in Table 1 [9]:

Table 1. Ratio of the hydraulic conductivities resulted by Albakri et al (1990)

Properties of clay	k_h/k_v
Without or less coarse-grained structure, homogeneous ground	1÷1,5
With coarse-grained structure, sedimentary clays with incoherent lens and large hydraulic conductivity	2÷4
Sedimentary clay from lake and pond, sediments with continuously permeable layers	3÷15

In fact, according to standard [1], it is allowed to use

$$\frac{k_h}{k_s} = \frac{k_h}{k_v} = \frac{C_h}{C_v} = 2 \div 5$$

According to Bergado et al (1993) [9]:

$$\frac{d_s}{d_m} = 2 \div 3$$

In case of PVDs installed in soil with two or many layers, the equivalent hydraulic conductivity can be calculated by:

$$k_{eq} = \frac{h_1 + h_2 + h_3 + \ldots}{\frac{h_1}{k_1} + \frac{h_2}{k_2} + \frac{h_3}{k_3} + \ldots} \qquad \text{(Eq.8)}$$

The optimal depth of PVDs can be obtained by substituting the above given parameters into Eqs 1 and 2 and then implementing the iterations continuously until H_1 and *l* have the same value. The results can be adopted approximately when the error is small significantly.

4. SOIL PROPERTIES

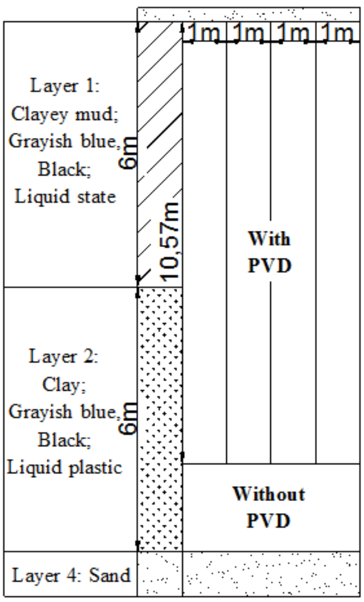

Figure 2. Soil profile of the researched area

Table 2. Soil properties of researched area

Depth	Unit weight	Void ratio	Consolidation coefficient	Hydraulic conductivity	Compression index	Soil type
z, (m)	γ_{sat} , (kN/m^3)	e_0	$C_v\ (m^2/s)$	$k_v\ (10^{-7}\ cm/s)$	C_c	-
0,0 ÷ 6,0	15,8	1,902	0,85	0,25	0,777	Mud
6,0 ÷ 12,0	15,9	1,806	0,78	0,23	0,927	Clay
>12,0	20,0	-	-	-	-	Sand

Table 3. The designed and calculated parameters selected

No.	Parameters	Unit	Value
1	Spacing of PVDs	m	1
2	$s = d_s/d_w$	-	4
3	K_h/k_s	-	5
4	K_h/k_v	-	3
5	$n = D_e/d_w$	-	20,92
6	D_e	m	1,13
7	q_w	$10^{-6}\,m^3/s$	300
8	F_s	-	5,545
9	d_w	m	0,054

The researched area is 861 provincial street, Ward Cai Be, Tien Giang District. In order to match studied condition, the selected soil properties and designed parameters are given in Tables 2 and 3 respectively and the soil profile is presented in Figure 2. The soil profile includes two layers of soft soil with 6m thick for one layer above sand layer. This allows water drains both sides, from top and bottom.The designed parameters, as shown in Table 3, are selected appropriately based on standards, experiences from researches and papers.

5. EXPERIMENTAL RESULTS

In order to achieve the exact enough results, the two soft soil layers are divided into 12 sub-layers with thickness of 1m.

We vary value of drainage length of PVDs increasingly with an increment of 1m. In each stage, we implement the iterations until we get the same value of l and H_1. The calculated results are summarized in Table 4. As shown in Table 4, as drainage length of PVDs increases continuously, the value of H_1 also increases. However, the rate of an increase is decreased gradually. Finally, in a range of 10m and 11m deep, the values of l and H_1 are approximately same. By implementing the detail calculation step, the result shows that the optimal depth of PVDs achieved is about 10,5m with very small error of 0,7%.

Table 4. The experimentally calculated results

l	k_{v1}^{tb}	k_{h1}^{tb}	k_{v1}	k_{v2}	H_1	μ	**Error**
(m)	(10^{-6} cm/s)	(10^{-6} cm/s)	(10^{-6} cm/s)	(10^{-6} cm/s)	(m)		(%)
1	0,0250	0,0750	0,044	0,0238	6,90	7,84	590,2
2	0,0250	0,0750	0,098	0,0237	8,04	7,84	302,2
3	0,0250	0,0750	0,184	0,0236	8,84	7,84	194,5
4	0,0250	0,0750	0,296	0,0235	9,36	7,84	134,0
5	0,0250	0,0750	0,426	0,0233	9,73	7,84	94,5
6	0,0250	0,0750	0,569	0,0230	9,99	7,84	66,5
7	0,0245	0,0735	0,706	0,0230	10,16	7,84	45,2
8	0,0245	0,0735	0,853	0,0230	10,31	7,84	28,8
9	0,0242	0,0726	0,988	0,0230	10,41	7,84	15,7
10	0,0241	0,0723	1,123	0,0230	10,50	7,84	5,0
11	0,0240	0,0720	1,250	0,0230	10,57	7,84	-3,9
12	0,0239	0,0717	1,368	0,0230	10,62	7,84	-11,5
>12	Sand						

6. CONCLUSIONS

In this paper, the method how to determine the optimal depth of PVDs introduced by Chai et al (2006) is applied to a project in Viet Nam for soft ground improvement under vacuum loading condition. The soil profile consists of two soft soil layers with a total 12m thick. The distance between PVDs is assumed to be 1m and the considered vacuum pressure is usually 75 kPa.

The experimentally calculated results show that the optimal depth of PVDs is about 10,5m, smaller than the thickness of soft soil. This proves that it is not necessary to install PVDs along the whole thickness of soft soil.

7. DISCUSSION

The scope of research in this paper is just only in case of vacuum loading condition. The next step is to propose a method using PVDs combined with preloading in order to determine the optimal depth of PVDs and compare these two methods.

The result implies that the mentioned method is valid. Until now, this problem has not been guided in Viet Nam standard. Therefore, it is suggested that this method can be added to standard to perfect it.

Ứng dụng phương pháp xác định chiều sâu tối ưu của bấc thấm dưới tác dụng của tải trọng bơm hút chân không

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TÓM TẮT

Việt Nam là một trong những nước có nền địa chất yếu và phức tạp. Do đó, làm thế nào để tiết kiệm chi phí nhưng vẫn đáp ứng tiêu chuẩn và yêu cầu kỹ thuật trong thiết kế bằng cách lựa chọn phương pháp hợp lý trong xây dựng đặc biệt là các công trình xây dựng trên nền đất yếu luôn luôn cần được quan tâm và nghiên cứu liên tục. Bài báo giới thiệu phương pháp xác định chiều sâu tối ưu của bấc thấm dưới tác dụng của tải trọng bơm hút chân không trong cải tạo nền đất yếu và ứng dụng vào công trình Tỉnh lộ 861, Huyện Cái Bè, Tỉnh Tiền Giang. Đất yếu gồm 2 lớp với bề dày tổng cộng 12m và thấm 2 chiều. Kết quả cho thấy là chiều dài tối ưu của bấc thấm khoảng 10,5m với sai số thấp 0,7%.

Từ khóa: *chiều sâu tối ưu, PVDs, bơm hút chân không*

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