Theoretical study on effective reinforced depth of vacuum preloading

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Abstract. A new idea about analysis of reinforced depth is proposed. The consolidation degree of soil at any point is calculated base on the conventional consolidation equation for sand-drained ground, and the reinforced depth is deduced through the consolidation degree. The variation of reinforced depth is analyzed. The results show: Within a certain period of consolidation (90days), the effective reinforced depth is uneven. The effective reinforced depth of the soil near the PVD reach the bottom of the PVD, and the soil between the PVDs do not. The reinforced depth will improve with increasing consolidation time.

1. Introduction

Vacuum preloading has been widely applied to soft ground treatment in the past 20 years. Currently, studies on reinforcement mechanism, construction technology design theory, etc. get a larger development, but study on effective reinforcement depth of vacuum preloading is still hot. Many scholars do research in this area. Yan yun etc. [1] thought the soil within 18m has good reinforcement effect when the length of plastic vertical drain between 26~33m. Peng jie [2]believed that the effective improving depth of vacuum preloading is about 18m under the surface. Li Shi-liang[3] considered that the effective reinforcement depth of vacuum preloading can reach the bottom of the plastic vertical drain by field test results. Yan Shu-wang[4] explained the mechanism of vacuum preloading method by using a spring system model, the analyses on variations of subsidence and pore water pressure indicate that effective depth of vacuum preloading is independent of the magnitude of vacuum and relate to the transmission of vacuum pressure only. Therefore, the reinforcement depth consensus has not formed, and theoretical study is still relatively small.

The effective reinforced depth of vacuum preloading is defined as the range that the consolidation degree of the soil reaches 80%. In order to analyze on the effective range of vacuum preloading, the consolidation degree of the soil is calculated based on the analytical theory of sand drain foundation, and the effective reinforced depth is deduced according to the degree of soil consolidation. Thus the variation of the effective reinforced depth is analyzed.

2. Consolidation theories for drain wells

Xie Kang-he etc. [5] put forward a new solution for the consolidation of soils with penetrating drain wells under the condition of equal vertical strain bases on Hansbo's classical theory[6]. the analytical solution of sand drain consolidation equation is:

$$\bar{u}_r = \sum_{m=0}^{\infty} \frac{2}{M} \sin\left(\frac{M}{H} Z\right) \cdot e^{-B_r t} \cdot u_0 \qquad (1)$$

$$u_r = \sum_{m=0}^{\infty} \frac{2}{M} \sin\left(\frac{M}{H} Z\right) \cdot e^{-B_R t} \cdot u_0 \left[\frac{k_h B_r}{k_s F_a \lambda} \left(\ln\frac{r}{r_w} - \frac{r^2 - r_w^2}{2r_e^2} \right) + \frac{\lambda - B_r}{\lambda} \right]$$

$$r_w \leq r \leq r_s \qquad (2a)$$

$$u_r = \sum_{m=0}^{\infty}\frac{2}{M}\sin(\frac{M}{H}Z)\cdot e^{-B_r t}\cdot u_0\left\{\frac{B_r}{F_a\lambda}\left[\left(\ln\frac{r}{r_s}-\frac{r^2-r_s^2}{2r_e^2}\right)+\frac{k_h}{k_s}\left(\ln\frac{r_s}{r_w}-\frac{r_s^2-r_w^2}{2}\right)\right]+\frac{\lambda-B_r}{\lambda}\right\} \quad r_s\leqslant r\leqslant r_e \qquad (2b)$$

Formula (1) is the average of excess pore water pressure at any depth in foundation. Formula (2a), (2b) is expression of excess pore water pressure at any point in foundation.

Where Z is the length of PVD; H is the soil thickness(single drainage); r_e is radius of influence of PVD; r_w is equivalent radius of PVD; r_s is radius of the smear zone; k_h is the horizontal soil permeability in the undisturbed zone; k_s is the soil permeability in the smear zone; k_w is permeability coefficient of PVD; r is radial coordinate; z is vertical coordinate.

The calculation of degree of consolidation as follows:

$$U_r = 1-\frac{u_r}{u_0}$$

$$U_r = 1-\sum_{m=0}^{\infty}\frac{2}{M}\sin(\frac{M}{H}Z)\cdot e^{-Brt}\left[\frac{k_h B_r}{k_s F_a\lambda}\left(\ln\frac{r}{r_w}-\frac{r^2-r_w^2}{2r_e^2}\right)+\frac{\lambda-B_r}{\lambda}\right]$$

$r_w\leq r\leq r_s$ （3a）

$$U_r = 1-\sum_{m=0}^{\infty}\frac{2}{M}\sin(\frac{M}{H}Z)\cdot e^{-B_r t}\cdot\left\{\frac{B_r}{F_a\lambda}\left[\left(\ln\frac{r}{r_s}-\frac{r^2-r_s^2}{2r_e^2}\right)+\frac{k_h}{k_s}\left(\ln\frac{r_s}{r_w}-\frac{r_s^2-r_w^2}{2}\right)\right]+\frac{\lambda-B_r}{\lambda}\right\}$$

$r_s\leq r\leq r_e$ （3b）

Formula (3a) and (3b) are the consolidation degree at any point in foundation.

$$\overline{U}_r = 1-\sum_{m=0}^{\infty}\frac{2}{M}\sin(\frac{M}{H}Z)\cdot e^{-Brt} \qquad (4)$$

Formula (4) is the average of the consolidation degree at any depth in foundation.

$$\overline{U}_{r总} = 1-\sum_{m=0}^{\infty}\frac{2}{M^2}\cdot e^{-Brt} \qquad (5)$$

Formula (5) is average consolidation degree of the whole foundation.

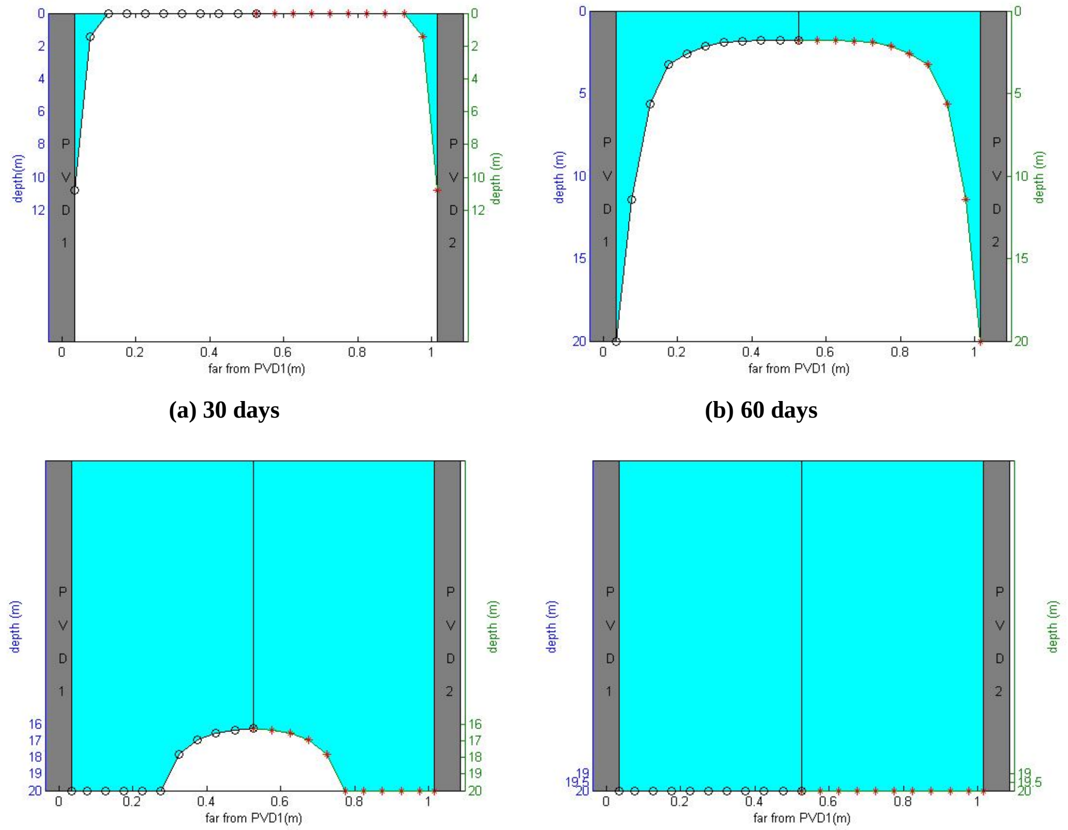
3. Calculation method

1) The consolidation degree of soil at any point calculates by formula (3a) and (3b);
2) Calculates the depth that consolidation degree is 80%;
3) Draws the map of effective reinforced depth..

4. Analysis on the effective reinforced depth

In this paper, the calculation parameters of dredger fill is selected from the dredger fill port headquarters experimental plot project in miaoling district of lianyungang, this project uses negative pressure PVD to strengthen hydraulic mud fill foundation. The value of the parameters of dredger fill is as follows: k_h=6.91e-4m/d, k_z=3.46e-4m/d, k_h/k_z=2, k_w=86.4m/d, H=20m, c_h=1.59e-2m/d. The parameters of PVD are as follow: r_e=0.525m, r_s=0.175m, r_w=0.035m, $n=r_e/r_w$=15, $s=r_s/r_w$=5.

Fig.1 is the schematic diagram of the effective reinforced depth with consolidation time. The shaded is the soil consolidation degree of greater than 80%. The curves represent the depth of the consolidation degree of 80%.



(a) 30 days **(b) 60 days**

(a) 90 days **(b) 120 days**

Fig.1 Changes of the effective reinforced depth with consolidation time

As shown in Fig.1, the shaded appears near the PVD at first, and then gradually spreads to the surface soil and the depth of soil near the PVD, finally extends to other locations soil.

When the consolidation time is 90days, the average consolidation degree throughout the soil is 86%, but the soil consolidation degree has not reached 80% in some soil between the PVD. Therefore, the effective reinforced depth of the soil near the PVD reach the bottom of the PVD, and the soil between the PVDs do not.

When the consolidation time is 120days, the average consolidation degree throughout the soil is 93%, and the soil consolidation degree has reached 80% in the soil between the PVD. Therefore, the effective reinforced depth of the soil would reach the bottom of PVD when the time is enough.

5. Summary

This paper analyzes the variation of the effective reinforced depth of vacuum preloading by the theoretical study. The following conclusions:

1) Within a specific period of time (90days), the effective reinforced depth of the soil between the PVDs is not same .A part of the soil reinforced depth does not reach the bottom of the PVD.

2)In the vacuum preloading, the effective reinforced depth will be increased by extending the consolidation time.

3)In fact, the parameters of the soil and the PVD are not constant in the vacuum preloading. This does not take into account, and it is necessary to further research.

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