Numerical simulation analysis of the effect of Drainage Board length difference on vacuum pre-compression considering time factor

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Abstract. For the research of vacuum pre-compression is still lagging behind the engineering problems, based on the Shenzhen Marine Emerging Industry Base Soft Foundation Treatment Project, this paper adopts the finite element soft foundation to establish the vacuum pre-compression modeling method, and considers the effect of laying different lengths of drainage boards on the effect of vacuum pre-compression. The vacuum in the consolidation process with time and depth of the complex attenuation, carried out the laying of different lengths of drainage boards on the effect of vacuum pre-compression, the results show that: (1) vacuum pre-compression vertical settlement according to the three different conditions from large to small, in order of alternating lengths of short and long, long drainage boards and short drainage boards. (2) The size of the horizontal displacement is affected by the length of the drainage board, and the longer the drainage board, the larger the horizontal displacement; in addition, the different physical parameters of the soil layer have a significant effect on the horizontal displacement. (3) The consolidation effect of laying drainboards with alternating lengths is slightly better than that of laying all long drainboards, and it saves materials.

Keywords: drainage board length; vacuum pre-compression; Midas GTS NX; vacuum; soft base treatment.

1 Introduction

With the development of economic and human engineering activities, offshore countries and cities have become very eager for land demand, but most of the soils in offshore areas have high water content, large pore ratio, high compressibility, poor permeability, low natural strength, etc., which need to be consolidated, and the most common treatment methods are vacuum pre-compression method, pile loading method, etc., but if the consolidation method is incorrect, it may result in serious settlement and lateral displacement of foundation[1], so it is necessary to conduct a deeper study on the treatment method, vacuum soft foundation treatment technology as early as 1952, Swedish geologist Prof. Jermain. However, if the reinforcement method is not correct, it

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may lead to serious settlement and lateral displacement of the foundation , so it is necessary for us to carry out a deeper research on the treatment method, vacuum soft foundation treatment technology was proposed by Prof. W. Kjellman, a geological expert from Sweden, as early as 1952[2], and after nearly 70 years of development, the technology has been successfully applied to soft foundation treatment projects all over the world. Prof. W. Kjellman only put forward the basic theory that pumping vacuum reduces the water pressure and increases the effective stress in the soil.

At present, the research on vacuum combined pile load pre-compression method is still the theoretical research lagging behind the engineering practice, there are many problems, for example, the numerical simulation calculations of the groundwater level in the reinforced area, the change rule of the pore water pressure, the deformation characteristics of the soil in the reinforced area, the effect of reinforcement and the control of post-settlement after the work, etc., and the related theories of the vacuum attenuation with depth are obtained by the test as well as the actual engineering[3], of which, Zhou Q, et al.[4] proposed that the attenuation coefficient of vacuum with depth changes with time, and the analytical solution of consolidation under this condition was obtained, while Chen Junsheng et al[5] improved the vacuum attenuation process according to the depth into an upper exponential lower folded curve. In addition, the plastic drainage board is a vertical channel for soil water to be discharged outward during the consolidation process, and there are various problems in the actual engineering use, such as the drainage board in the working process there is a problem of bending too much[6] around the drainage board is prone to produce the soil column effect resulting in a decrease in its drainage capacity[7] and so on.

The rapid development of coastal areas in China in the last decade has accelerated the promotion of vacuum pre-compression technology in soft foundations such as silt soils and blowing fills with high water content soils[8]. In the recent development, the vacuum precompression method for reinforcing soft foundation tends to be put into practical application, however, there are still many problems in the research of reinforcement mechanism, such as the degree of suction decompression, pore water pressure and reinforcement effect, the estimation of geotechnical changes and ground settlement effect and the prediction of pressure density, the determination of unloading criterion, and the re-compression and deformation characteristic of the reinforced soil, etc., so the theory, although it has been developed rapidly, in general Theory lags behind practice, which limits the further development and engineering application of the method, so it is necessary to deeply study the mechanism of vacuum pre-compression method for reinforcing soft soil, in view of this.

2 Engineering characteristics of soils in the project area

2.1 Distribution of various soil layers in the study area

Project strata are: fluvial mud, silt, clay, coarse sand, silty clay, fully weathered gneiss, strongly weathered gneiss, stratigraphic composition of the weak permeability, high natural water content, large pore ratio, permeability, high compressibility and low shear strength and other properties of the properties of the characteristics, so the region of the state of the under-consolidation of the soil, the strength of the project can not meet the basic requirements of the project construction, if it is a conventional drainage Consolidation of the treatment, the consolidation process will be very long, and the effect of reinforcement is very likely to fail to meet the requirements of the project construction, neither to meet the requirements of the construction period can not meet the strength requirements, for this situation, we will use a more effective method of treatment.

2.2 Physical and mechanical indicators of soils in the study area

Based on the soil parameters obtained from outdoor soil tests, a table for analyzing the physical and mechanical parameters of different soil layers is listed in Table 1.

Table 1. Analysis table of physical and mechanical parameters of different soil layers.

	sand bedding	ooze	loam	silty chalky clay	medium-hard sand
Soil thickness(m)	0.5	9.08	6.02	4.7	3.2
modulus of elasticity(kPa)	18000	2900	3000	2950	20000
Poisson's ratio	0.32	0.38	0.35	0.37	0.3
cohesive force (kN/m^2)	0.1	9	34	16	0.1
angle of internal friction (°)	34	6	10	6	18
severe(kN/m^3)	18	14.6	18.1	16.5	18.8
compression factor(MPa^{-1})		0.75	0.6	0.7	0.3
Horizontal permeability coefficient(cm/s)	9.1×10^{-3}	4.5×10^{-7}	4.9×10^{-6}	1.5×10^{-6}	9.3×10^{-3}
vertical permeability coefficient(cm/s)	9.1×10^{-3}	4.3×10^{-7}	1.2×10^{-6}	1.9×10^{-6}	9.3×10^{-3}

3 MIDAS finite element model

3.1 Modeling

MIDAS finite element numerical simulation software for modeling, the original three-dimensional space into a two-dimensional plane strain problem to discuss and analyze, with the vacuum pre-pressure method for the analysis of soft foundation in the project, the model reinforced area width of 60m, the depth of 23m, the width of the impact area of 30m. model symmetric left and right, so the size of the model b*h = 120*23m, the reinforced area is located in the model The model is symmetrical, so the model size is b*h=120*23m, the reinforced zone is located in the center of the model, and the two sides are 30m of the impact area.

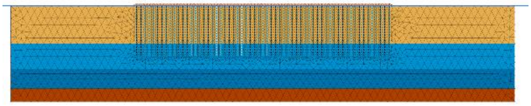
In order to study the difference in the length of the drainage board on the effect of vacuum soft foundation treatment, this paper will be the long drainage board for 14m; short drainage board depth of 12m. according to the different laying of the drainage board is divided into the following three working conditions:

Condition 1: In the reinforced area, only the short drainage board with a length of 12m is laid.

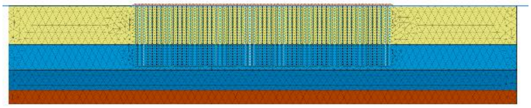
Condition 2: Only short drainage boards with a length of 14m are laid in the reinforced area.

Condition 3: Alternating long and short drainage boards in the reinforced area

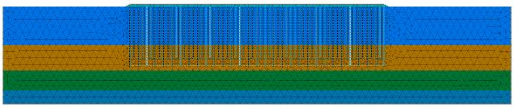
As shown in Figure 1:



(1)short drainage board



(2)long drainage board



(3) alternating between long and short term

Fig. 1. Vacuum pre-compression finite element software model.

3.2 Drainage board related parameters and diameter equivalent calculation

The project uses c-type plastic drainage board, the size of 100mm*4mm, in the finite element software need to drain the board for planar simulation, the first will be converted to sand wells, so that two-dimensional modeling calculations can be made, and the basic idea is to make the equivalent after the cylindrical sand wells with the plastic drainage board with the same drainage capacity, the cross-sectional dimensions of the drainage board is converted into the equivalent diameter of the sand wells, that is, the drainage board of the equivalent diameter of the d_w[9].

$$d_w = \alpha \frac{2(a+b)}{\pi} \tag{1}$$

Where a and b are the width and thickness of the drainage board section; a is the conversion coefficient, generally 0.75 ~ 1.

Then in order to convert the three-dimensional sand well problem into a two-dimensional planar problem, the sand well is equivalent to a sand wall, the key to the equivalent conversion of sand well foundations on the adjustment of the permeability coefficient, the conversion of the equivalent formula for sand wall is as follows:

$$k_{xp} = D_x k_{ra} \tag{2}$$

$$k_{zp} = D_z k_{za} \tag{3}$$

Where, and k_{xp} and k_{zp} are the horizontal and vertical permeability coefficients of the sand wall respectively; k_{ra} and k_{za} are the horizontal and vertical permeability coefficients of the manhole respectively; D_x and D_Z are the horizontal and vertical permeability coefficients adjustment coefficients respectively. According to the above formula, the equivalent diameter of the drainage board and the equivalent permeability coefficient can be obtained, and the equivalent parameters of the drainage board are shown in Table 2, and then the parameters of the drainage board are listed as follows:

Table 2. Drainage board parameter table.

parameters	retrieve value
Equivalent Diameter of Drainage Plate(d_w)	0.06m
Spacing(s)	1.0m
Poisson's ratio(v)	0.25
modulus of elasticity(E_a)	15000
permeability coefficient(k)	5.8×10^{-6}k/m·s^{-}
Adjustment factor for horizontal permeability coefficient	1.05
Adjustment factor for vertical permeability factor	0.83
Adjusted horizontal permeability coefficient(k_x)	6.1×10^{-6} k/m·s
Adjusted vertical permeability coefficient(k_z)	4.8×10^{-6} k/m·s

3.3 Vacuum calculation formula

In this paper, the upper exponential lower folded curve improved by Chen Junsheng et al. as mentioned before is used for the vacuum of the drainage board, and the vacuum curve under the touch is categorized into two types according to the different positions of the drainage board:

$$-[1-(1-e^{-T_h})(1-e^{-\sqrt{\frac{a_1 z}{H}}})]p_v \qquad (0<\frac{z}{H}\le 0.5) \tag{4}$$

$$-[1-(1-e^{-T_h})(1-e^{-\sqrt{\frac{a_1}{H}}})]p_v + a_2(z-0.5H)\cdot(1-e^{-T_h}) \quad (0.5<\frac{z}{H}\le 1) \tag{5}$$

$$T_h = \frac{C_h t}{4r_e^2} \tag{6}$$

Where: P_V is the applied vacuum, e is the initial pore space of the soil, a_1 is a dimensionless correction coefficient, ranging from 0 to 1, in this paper we take 1. a_2 is the vacuum per unit length of this coefficient, which is usually taken as 2kPa/m[10]. z is the depth of the drainage board, H is the total length of the drainage board, and Th is the time factor, in which C_h is the degree of radial consolidation, t is the time, and re is the radius of the effective drainage influence area.

3.4 Construction Phase Definitions

In MIDAS software it is possible to control the construction conditions by passivating and activating different construction processes. Vacuum pre-compaction can be defined in the following five construction stages:

(1) Initial consolidation stage: activate the original soil and its own drainage conditions, constraint boundaries, and self-weight.

(2) Drainage board construction: activate the properties of the drainage board and passivate the properties of the soil layer corresponding to the location of the drainage board.

(3) Sand bedding construction: activate the sand bedding grid, and keep other settings unchanged.

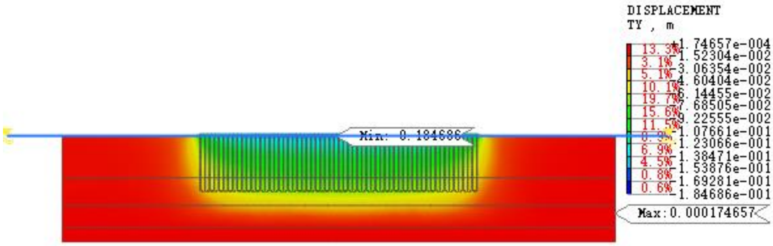
(4) Vacuum pre-pressurization: calculate according to the vacuum formula mentioned above, and set the vacuum degree of the drainage board at the same depth in relation to the time function, apply the length of 90d, and start the consolidationand other settings remain unchanged.

(5) Resting: keep the other options unchanged and end the phase after a resting duration of 30d.

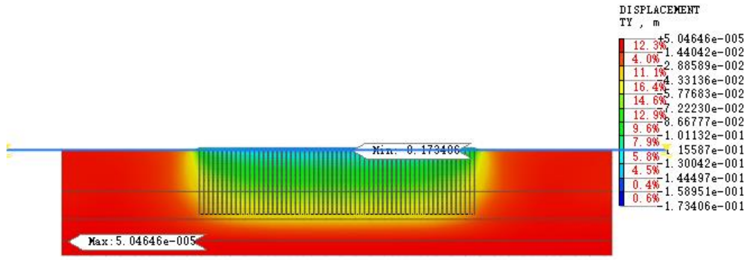
4 Analysis of results

4.1 Calculation and analysis of vertical settlement

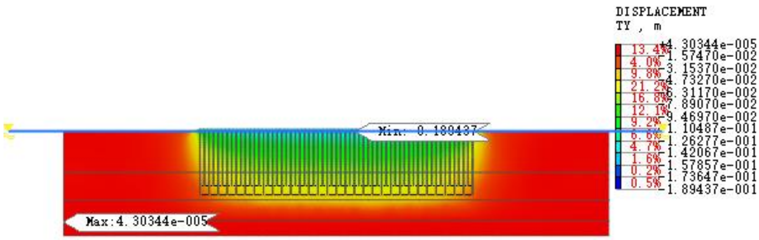
Figure 2 shows the final settlement cloud obtained under three different working conditions, in which it is found that the final settlement cloud obtained by the three schemes is more or less the same, the maximum value of which is at thecenter of the reinforced area at the surface, and the settlement in the reinforced area decreases gradually from the surfacedownward, which can be seen that the final settlement in the reinforced area is larger than that in other areas.



(1)short drainage board



(2) long drainage board



(3)alternating between long and short term

Fig. 2. Vertical Settlement Cloud Map.

Figure 3 shows three different working conditions, data collection on the centerline of the surface of the reinforced area, the depth and the final settlement of the relationship between the surface of the vertical settlement is the largest, the final settlement from large to small for the length of the drainboard 143.5125mm, long drainboard 142.3092mm and short drainboard 141.3092mm, but the trend of the settlement with the depth change is close to the depth is gradually reduced when the depth reaches about 23m, the three settlement is very close to 7.8591mm, 7.8409mm and 7.7809mm. Increase and gradually reduce, when the depth reaches about 23m, the three settlement is very close, respectively 7.8591mm, 7.8409mm and 7.7809mm.In addition, because the drainage board elastic modulus is larger than the underlayment of soil layer, and the geotextile fabrics are mainly through the friction with the soil to play an effect, so to a certain extent, the long drainage boards play the role of reinforcing, which leads to its

The final settlement of the surface center is smaller than that of the alternating long and short drainage board condition[11].

Figure 4 shows the surface center settlement versus time for the three different conditions. As seen in Figure 4, three different conditions are under the action of vacuum pre-pressure settlement increased rapidly, the change rule is nearly linear, and when the consolidation process nearly 20d, three conditions curve are beginning to become flat, after another 15 days of consolidation time, the amount of its settlement did not change significantly. Due to the beginning of consolidation vacuum, the initial pore space in the soil is large, the pore water pressure is quickly converted into effective stress, which leads to accelerated consolidation.

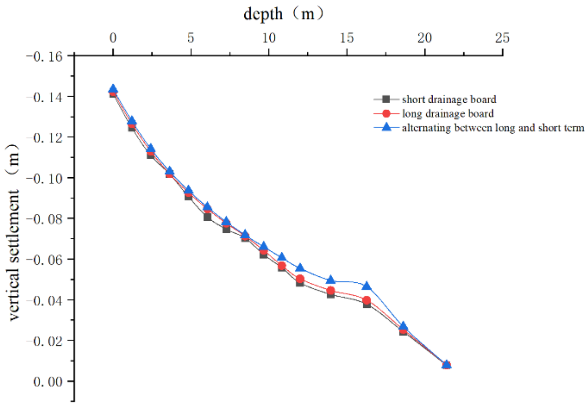


Fig. 3. Depth versus final settlement plot.

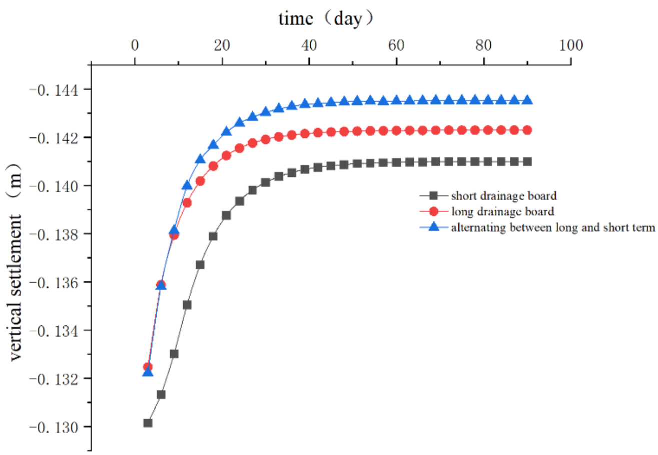


Fig. 4. Plot of surface center settlement versus time.

4.2 Calculation and analysis of horizontal displacement

Figure 5 shows the relationship between depth and horizontal displacement obtained from data collection on the surface centerline of the reinforced area under three different working conditions. From the figure can be seen in the depth of 9m and the depth of 15m or so, the horizontal displacement curve has obvious changes, that is, in the soil layer interface changes significantly, indicating that the different physical properties of the soil layer has a greater impact on the horizontal displacement.

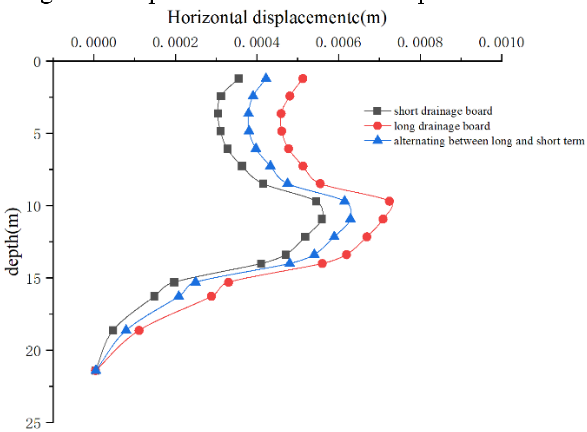


Fig. 5. Depth versus horizontal displacement graph.

5 Conclusion

This study focuses on the effect of differences in the length of the drainage boards and the variation of the vacuum according to the non-linear equivalence treatment taking into account the time factor and obtains the following results:

(1)The final settlement is in a decreasing trend, according to the three different working conditions from large to small in the order of alternating long and short, long drainage plate and short drainage plate.

(2)The maximum value of horizontal displacement under three different working conditions appeared at the boundary between the reinforced area and the affected area, and the numerical size of horizontal displacement was affected by the length of the drainage board, and the longer the drainage board, the larger the horizontal displacement.

(3) The consolidation effect of alternating long and short drainage boards is slightly better than that of all long drainage boards, and it saves materials.

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