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Consolidation Theory Selection of Dredger Fill

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ABSTRACT

The theoretical study of blow fill is of great significance for the increasing land reclamation projects year by year. Through reading the online literature, combining the physical properties of the blown fill and the existing consolidation theory, the consolidation theory suitable for most scenarios of the blown fill is selected, and the advantages and disadvantages of the existing methods are introduced.

KEYWORDS

Bearing capacity of foundation; Terzaghi formula; Empirical formula

1. INTRODUCTION

The blown fill formed by the reclamation of the sea is in the state of flowing mud before consolidation, and becomes solid soil after vacuum precompression. Therefore, in the process of reinforcement, the blown fill experienced a change from the flow state with relatively large pores to the solid state with relatively small pores, and the pore ratio changed greatly in this process. The permeability and compressibility of soil are related to the porosity ratio of soil, so compared with the consolidation characteristics of soft soil, the permeability of soil with high water content changes greatly during the process of vacuum precompression consolidation [1].

This paper introduces the Terzaghi consolidation theory, Biol consolidation theory and unified consolidation theory, and compares the advantages and disadvantages of several theories to select the consolidation theory which is most suitable for blow fill.

2. CONSOLIDATION THEORY

2.1. Terzaghi s Consolidation Theory

The process of soil consolidation is the process of pore water pressure dissipation. In order to quantitatively analyze the consolidation process, it is necessary to put forward the calculation theory of pore pressure changes with time and space. In 1925, Terzaki put forward the one-dimensional consolidation theory [5].

The consolidation theory includes the following assumptions:

I.The soil layer only has vertical compression deformation, but there is no lateral expansion, and the seepage is only vertical. That makes it a one-dimensional problem.

II.The soil is saturated, only the soil skeleton and water two phases.

III.The soil is uniform, the compression of the soil under load is only the reduction of the pore volume, the compression of the soil particle itself and the water can be ignored, and the compression coefficient a is assumed to be constant.

IV.The permeability flow of pore water conforms to Darcy's law, and the permeability coefficient K is constant.

V.The external load is a uniformly distributed continuous load, and is applied to the soil layer at one time.

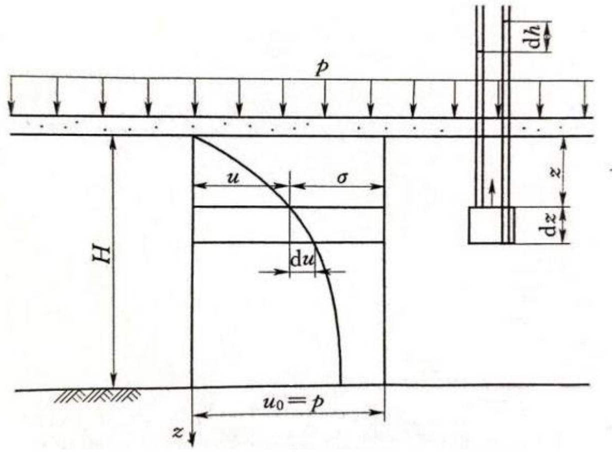

Figure 1. Pore pressure variation of saturated clay layer

Figure 1 shows a clay layer, the bottom is impervious to water, the top surface can be drained, the ground action has a uniform load *p*, widely distributed, so the additional stress is constant along the depth, its value is $\sigma=p$. In order to establish the equation, the zero point of coordinate *z* is placed on the permeable surface of the clay layer, and the direction is from permeable to impervious surface, that is, the downward direction in the figure.

The variation of water volume and pore volume compression in a unit with thickness dz and area 1×1 at *z* depth below the clay layer are investigated. Before surface loading, the water level at the top and bottom of the unit is flush with the water table. At the moment of loading, that is, when t=0, the water level will rise p/γ_w, where γ_w is the bulk density of water. At a certain time, t during the consolidation process, the water level on the top surface of the unit is higher than the groundwater level $h=u/\gamma_w$, while the water level on the bottom surface is higher than the water level on the top surface dh=($\partial h/\partial z$) dz= ($\partial u/\gamma_w\partial z$) dz, as shown in Figure 1. Due to the water head difference d*h* between the top surface and the bottom surface of the unit body, seepage will occur in the unit body and cause the change of water volume and pore volume.

Through a series of derivations, the unidirectional consolidation differential equation is obtained:

$$\frac{\partial u}{\partial t}=C_v\frac{\partial^2 u}{\partial z^2} \tag{1}$$

$$C_v=\frac{K}{m_v\gamma_w}=\frac{K\left(1+e_1\right)}{a\gamma_w} \tag{2}$$

As can be seen from equation 1, it is directly proportional to the permeability coefficient *K* and inversely proportional to the compression coefficient *a*. The higher the permeability coefficient of soil, the faster the drainage, the faster the natural pore pressure dissipation; The high compression coefficient means that the compressed volume under the same load is large, and the compressed soil volume is equal to the discharged water, which means that the amount of water needs to be discharged to achieve the same pore pressure dissipation effect, so the consolidation coefficient is small when the compression coefficient is large.

Tersharky and Lendulic later extended the one-dimensional consolidation theory to three dimensions and established the three-dimensional consolidation equation. The assumptions used in one-dimensional consolidation theory also apply to three-dimensional theory. It is deduced that:

$$\frac{\partial u}{\partial t} = C_{v3} \nabla^2 u \tag{3}$$

$$C_{v3} = \frac{KE}{3(1-2\nu)\gamma_m} \tag{4}$$

Equation 3 is a three-dimensional consolidated differential equation. The one-dimensional consolidation differential equation 1 is the form of one-dimensional heat conduction equation. Here the three-dimensional consolidation differential equation is also in the form of the three-dimensional heat conduction equation. Due to the assumption that the sum of total stresses does not change with time, which is not completely consistent with the actual situation, the three-dimensional consolidation theory is often called quasi-three-dimensional consolidation theory.

2.2. Biot's Consolidation Theory

Biao derived a three-dimensional consolidation theory that accurately reflects the relationship between pore pressure dissipation and soil skeleton deformation from a strict consolidation mechanism, which is generally called the true three-dimensional consolidation theory, and the Terzaghi three-dimensional equation is called the pseudo-three-dimensional consolidation theory.

Biot considers the equilibrium condition of isotropic saturated soil under external force, the linear deformation of soil skeleton and the continuity condition of pore water seepage. The advantage of this method is that not only the change of pore water pressure with time, but also the corresponding soil deformation can be calculated. Due to the complexity of its exact solution, analytical solutions can only be obtained in a few cases. At present, due to the development of electronic computers and finite element method, Biot theory has been widely used.

Biot's consolidation equation is:

$$\begin{cases} -[\partial]^{\mathrm{T}}[D][\partial]\{w\} + [\partial]^{\mathrm{T}}\{M\}u = f_r \\ \dfrac{\partial}{\partial t}\{M\}^{\mathrm{T}}[\partial]\{w\} - \dfrac{K}{\gamma_w}\nabla^2 u = 0 \end{cases} \tag{5}$$

The equation contains four differential equations of partial differential equations and four unknown variables *u*, w_x, w_y, w_z, which are functions of coordinates *x*, *y*, *z*, and *t*. Under certain initial conditions and boundary conditions, these four variables can be solved. The above equation is a simultaneous equation, reflecting the coupling of deformation and seepage, and also becomes the fluid-structure coupling. In it, the first term of the equilibrium equation represents the force corresponding to the displacement that occurs, and the second term represents the force corresponding to the current pore pressure. Their sum is balanced with the external load. The first term of the continuity equation represents the volume deformation corresponding to the change of displacement per unit time, and the second term represents the amount of seepage caused by the change of pore pressure. The balance of force has the contribution of pore pressure, and the balance of water has the contribution of deformation, which are coupled with each other.

2.3. Unified Consolidation Theory

For saturated soft clay such as blow fill soil, due to its large amount of consolidation deformation, secondary consolidation accounts for a large proportion, and the consolidation parameters of soil will also change greatly during the consolidation process. The consolidation problem of such soil can usually be calculated by using the finite strain consolidation theory, also known as the large deformation consolidation theory. However, it also fails to take into account the deformation of the secondary consolidation process. In order to take into account both the primary and secondary consolidation processes of soil mass, Hailetou et al. put forward the unified consolidation theory. The theory is based on six basic equations and focuses on studying the change law of stress-strain relationship with time

As a unified consolidation process, the study of the consolidation process is applicable to large deformation consolidation problems, which has universal significance.

The unified consolidation theory consists of the following six basic equations:

I. Volume continuity equation

In saturated soil, the soil compression per unit time is equal to the net seepage rate of pore water in the soil.

$$\frac{\partial e}{(1+e)\partial t} = -\frac{\partial v}{\partial x} \tag{6}$$

$$v = n(v_w - v_s) \tag{7}$$

II. Darcy's law of penetration

$$v = n(v_w - v_s) = -\frac{k}{\gamma_m}\frac{\partial u}{\partial x} \tag{8}$$

III. Principle of effective stress

$$\sigma = \sigma' + u \tag{9}$$

IV. Stress balance equation

$$\frac{\partial \sigma}{\partial x} = \frac{(\gamma_e + e\gamma_w)}{(1+e)} \tag{10}$$

V. The relationship between permeability and porosity ratio

$$e = A + B\lg k \tag{11}$$

VI. Stress-strain relationship of soil

In the previous consolidation theory, it is believed that the stress-strain relationship in the main consolidation stage is unique, and there is a one-to-one correspondence between the pore ratio and the effective stress. In fact, more and more experimental data show that the stress-strain relationship of clay is a function of loading rate or strain rate.

The unified consolidation theory does not attempt to establish a unified consolidation equation, but holds that the above six basic relations should be satisfied at any point in the soil at any time whether it is in the so-called main consolidation stage or the secondary consolidation stage.

3. CONSOLIDATION THEORY SELECTION OF BLOW FILL

The blown fill formed by the reclamation of the sea is in the state of flowing mud before consolidation, and becomes solid soil after vacuum precompression. Therefore, in the process of reinforcement, the blown fill experienced a change from the flow state with relatively large pores to the solid state with relatively small pores, and the pore ratio changed greatly in this process. The permeability and compressibility of soil are related to the porosity ratio of soil, so compared with the consolidation characteristics of soft soil, the permeability of soil with high water content changes greatly during the process of vacuum precompression consolidation. However, in engineering design, Terzaghi consolidation theory or Barron consolidation theory is generally used to calculate the foundation consolidation under vacuum load, and the consolidation coefficient, permeability coefficient and compressibility parameters are assumed to be constant in the calculation process. Therefore, the classical consolidation theory has poor adaptability to the consolidation of filled soil under vacuum load. The results of model test and field test also show that the traditional consolidation theory is used to calculate the consolidation degree of the blown fill reinforced with high water content by vacuum precompression, and the calculated result is much higher than the actual consolidation degree of the soil.

In the initial stage of consolidation, due to the large porosity of the soil, the permeability coefficient and compression coefficient of the soil are relatively large, and the consolidation coefficient of the soil is large, so the consolidation rate of the soil is very fast. With the progress of consolidation, the porosity of soil decreases, the permeability coefficient and compression coefficient of soil decrease, and the consolidation coefficient also decreases, so the consolidation speed gradually slows down. During the consolidation process, the permeability coefficient of soil increases gradually with the increase of the radial distance from the drainage plate. At the position very close to the drainage plate, the permeability decreases very quickly, which is equivalent to forming a less permeable soil layer near the drainage plate. The pore ratio changes greatly in the process of vacuum precompression consolidation, so there is a great deviation in the consolidation calculation by using the constant permeability coefficient, which is not consistent with the consolidation calculation of the initial water content and the relatively large voidage.

Many experimental and research data show that the concepts of primary consolidation and secondary consolidation and the classification criteria will be inaccurate and not strict with the increase of soil thickness and the decrease of load rate. There are also some large deviations between the consolidation process calculated by Terzagyi consolidation theory and the measured results, and these deviations are more obvious for saturated soft clay.

According to the study of some research, the actual consolidation process of saturated soft clay is faster than the theoretical value of Terzagyi, and the result of unifying the consolidation theory is more reasonable. During the initial consolidation period, the pore pressure dissipation rate of the unified consolidation theoretical value is faster, but the dissipation rate of the later period is slower than that of the Terzaki theoretical value.

The unified consolidation theory considers the main consolidation process and secondary consolidation process of clay in a unified way, and can also analyze the consolidation problem of large deformation. In the consolidation theory, the stress-strain relationship of soft clay is not the only one, but a function of strain rate. The unified consolidation theory is based on the spatial surface model and takes into account the change of consolidation parameters. Some deviations between Tersharky's theory and the measured results are eliminated, so it is more reasonable.

Barone's consolidation theory assumes that the permeability coefficient is constant, but the initial moisture content of the blown mud in the reclamation area is high and the initial void ratio is large, so the pore ratio changes greatly during the process of strengthening from the blown mud to the blown soil. In this process, the calculated results assuming that the permeability coefficient is constant are significantly different from the actual measured values. Therefore, the traditional consolidation theory can no longer be well adapted to the consolidation analysis of filled soil. Some research improved Baron's consolidation theory by establishing the relationship between permeability coefficient and vacuum consolidation stress. The improved consolidation theory is used to calculate the consolidation of the blow-filled mud with large initial water content and pores, which is in good agreement with the measured values, indicating that the improved consolidation theory is suitable for the vacuum prepressure consolidation calculation of blow-filled mud.

4. CONCLUSION

With the development of coastal cities, landfilling has become an important way to solve the shortage of urban land resources. Because of its special engineering properties such as high porosity, high water content, low permeability and low strength, especially the complex physical and chemical interaction between soil particles and water, the treatment of landfilling has become one of the important problems in the field of geotechnical engineering. In this paper, based on the analysis of the engineering characteristics of the blown fill, based on the dynamic compaction method, vacuum precompression method and high vacuum compaction method three typical physical treatment methods, to make the blown fill drainage consolidation, reduce the water star of the soil, improve the strength of the soil, in order to meet the requirements of the engineering site. In the engineering application, the appropriate foundation treatment method should be selected according to the bearing capacity and deformation requirements of the building to the foundation, considering the technology, economy and construction period.

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