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Measures to decrease the environmental influence of vacuum preloading dredging project

Jun YAN\textsuperscript{a*}, Qisong WANG\textsuperscript{a}, Xianbo YANG\textsuperscript{b}, Xiaolei ZHANG\textsuperscript{a}

\textsuperscript{a}North China University of Water Conservancy and Electric Power, Zhengzhou 450011, Henan
\textsuperscript{b}Changjiang Wuhan waterway Engineering Bureau, 140 Yanjiang Road, Wuhan, China, 430014

Abstract

Vacuum preloading is one of the effective technologies for consolidating soft foundation. The definition of vacuum preloading is presented and the consolidation mechanism of vacuum preloading is explained either. The main environmental problems of the vacuum preloading have been further investigated. In addition, on the basis of analyzing the characteristics of vacuum preloading, application prospect of vacuum preloading is predicated. Finally the reasonable advices on decreasing the environmental influence and improving the vacuum preloading work craft, equipments and finding the substitute materials, are provided

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1. Introduction

The limp clay layer is widely distributed in the south-east coast and inland of China. This clay is characterized by containing large amount of water, high compressibility, low intensity, poor penetrability and low loading. Therefore, it can’t meet the requirements of construction. The distortion of concretion needs to be accurately estimated during the port construction in Tianjin, Shenzhen, Lianyungang, Shantou, as well as the disposal of groundwork for oil tank in Shanghai, and Zhejiang. At present, the prevalent approaches are vacuum preloading, vacuum surcharge preloading, vacuum combination surcharge preloading, etc. This disquisition mainly focuses on the vacuum preloading mechanism and related engineering problems.

* Corresponding author. Tel.: +86371-69127630
E-mail address: yanjun@ncwu.edu.cn
2. Vacuum Preloading Mechanism

In vacuum preloading the airtight membrane is utilized usually, the jet pump and the pipeline are embedded in the cushion layer to drawing out air in the soil body and form vacuum, so the negative pressure is produced to eject groundwater within the soft foundation upright to earth's surface through the sand well or drain panel and to enhance the compactness of the foundation \cite{1}. If we assume before the pressure of inside and outside of the membrane is the atmosphere pressure \( P_a \), after evacuation the pressure outside the is still \( P_a \), pressure inside the membrane is \( P_v \), and assume the difference between the two is \( P_0 \), so \( P_0 = P_a - P_v \). The difference of pressure makes the membrane clung to the sand layer tightly setting on the surface of the foundation. As the jet pump begins working, water inside the groundwork will be ejected from the soil body of the foundation and makes the difference of pressure and hydraulic gradient between the water inside the vertical drainage equipment. If the water inside the foundation soil seeps, the pore water pressure will be reduced, the effective stress will rise, so the soil body will be consolidated. The essential of this method is that almost with the same total stress, the pore water stress will be reduced; the effective stress will be increased. The shadow parts are the changes of effective stress at different depth \cite{2}.

3. The Environmental Problems

3.1. The Ground Water Level during Vacuum Preloading Project

To research the water change situation in the soil body during vacuum preloading process, especially the ground water level change situation, is helpful to the further understanding of the vacuum preloading consolidation mechanism, so as to appraising and analyzing the consolidation effect of vacuum preloading \cite{3}. There are three kinds of possibilities of ground water level change situation in vacuum preloading process: drop, rise or invariable, and every viewpoint has its supporters. The ground water level is different because of the different vacuum preloading project. But existing vacuum preloading ground water level research results are different not only at ration, but also at quality. The main reason is that most analysis on the ground water level change of reinforcement area is only from the point of vacuum preloading project measured data and not from the vacuum preloading mechanism.

There are methods by using open piezometric tube or closed piezometric tube to measure the vacuum preloading ground water level \cite{3}. The closed piezometric tube measurement is to install the head of the piezometric tube gauge in the measuring point, while the other end will be left in the membrane too. Because the piezometric tube is buried in the membrane and has to be gauged with the electrode, this measurement is rarely applied. Usually in the actual project the open piezometric tube measurement (or water level tube measurement) are adopted. The pore water pressure water value of measuring point is under the normal atmospheric pressure. Supposing the vacuum degree of measuring point is \( P \), the vacuum pressure is \( P_v \), pore water pressure \( u = P_v + r_w h + \Delta \), and piezometric head \( u' = P_a + r_w h' + \Delta \), then due to \( u = u' \) we have:

\[
P_v + r_w h + \Delta = P_a + r_w h' + \Delta
\]

(1)

So, \( h' = (P_v - P_a + r_w h)/ r_w = h + \Delta P/r_w \). Thus, the relative press head \( h' \) measured by measuring pipe is less than the real press head \( h \) of reposed water, and the difference of the two is \( \Delta P/r_w \). But in actual project, the test engineering condition and the test equipments themselves will affect the press head of the hole-water. If the groundwater level is measured by the open measuring pipe, we will have a misunderstanding that the groundwater level has dropped by \( \Delta P/r_w \), and in the groundwork reinforced by vacuum pre-pressing technique, the changes of groundwater level in reinforced zone is related with the condition of flow and
border the soil permeability of reinforced zone. The water level may be different in the reinforced zone because of the impact of water gasification. So a measurement without using the measurement pipe may be designed to measure the groundwater level, that is to lay a electrode every certain distance in the soil along the vertical direction, and a series of electrodes can be obtained, each electrode is lead out of the membrane by a insulation wire, according to the electric characteristic of the water in soil, the changes of water table can be got by measuring the electric character between each electrode while reinforcing.

3.2. The boundary Impact

It is significant important for the research of influence of vacuum pressure to the boundary and this research has more important meaning for understanding thoroughly the pressure vacuum mechanisms, the reinforce effects, the enhancement of the security and stability of the surrounding buildings, etc. [4]

During vacuum pumping the vacuum in gravel well is larger than the vacuum in the surrounding soil and it is transmitted from the sand well to the surrounding territories. This transition needs a certain period of time and will not affect the boundary water level but reduce the original atmospheric pressure in soil pore water at a commence stage. With sand wells vacuum degrees rise, the water level in the border zone reinforce the role of atmospheric pressure started to decline to reach equilibrium.

The hole-pressure in the foundation during the vacuum preloading can be expressed as follows.

\[ u = P_a h + r_w h \]  
\[ P_{nh} = P_a - P_v z \]

In which, \( P_a \) is the atmospheric pressure, \( P_{nh} \) is the remaining atmospheric pressure in depth \( h \), \( P_v \) is the vacuum suction in strengthening the same site, while in the surface area of consolidation (\( h=0 \)) stands for the vacuum degrees under the membrane.

If there were a pressure measuring tube and pressure height of the water level is \( d \), then:

\[ r_w d + P_a = r_w h + P_{nh} \]
\[ \Delta = h - d = (P_a - P_{nh})/r_w = P_{vh}/r_w \]

In which, \( \Delta \) is the date for measuring the depth of water level decline (to the ground as the base). On the ground \( h=0 \) department, the \( \Delta \) is the largest, with deep \( z \) increasing, \( \Delta \) is reduced gradually. The relationship between these two situations can be denoted by using Figure 1. If \( h=\Delta \), \( h=h_0 \) is the biggest decreasing depth \( \Delta_{\text{max}} \) of border water level.

The unsaturated soil may be formed by the decreasing of water level in the boundary area. But the concretion distortion is the main soil distortion in the reinforce area and the main factor to influence the boundary distortion, so the distortion can be calculated and analyzed as the saturated soil. For the influence of the soil distortion in the reinforce area, the water level in the boundary will decrease and the concretion distortion will occur in the soil, which will cause the annexed subsiding and plane displacement towards the reinforce area. Meanwhile, the air and water penetrating in the boundary will cause the relatively low vacuum degree in the reinforce region and weaken the reinforce effect. The shape coefficient in the reinforce region can be defined as follows,

\[ \alpha = A/L \]

In which, \( A \) stands for the area of the reinforce region, \( L \) for the boundary perimeter of the reinforce region. According to field measure of actual projects, the bigger the value of \( \alpha \) is, the better the reinforce effect will be, and vise versa. So the reinforce effect is better in square region than in narrow region.
In the process of vacuum preloading to reinforce the groundwork of the road in Tanjing Harbor, the vacuum pressure led to the plane displacement of the soil in the reinforce region[16]. Field measure showed that the plane displacement was largest in the ground surface and decrease sharply with the increasing of depth. The soil crazed near the ground surface a few meters away from the reinforce region. Since no construction and other related establishment existed nearby the project region, the plane displacement hadn’t caused bad aftermath. But to some projects especially where there is important construction nearby, this plane displacement usually will bring great harm and must be concerned sufficiently.

4. Measures to decrease the environmental influence of vacuum preloading dredging project

With the advantage of dependable result of reinforce, short time of preloading, simple construction equipments, economical cost of building, low noise, no environmental pollution and so on, vacuum preloading can be used to consolidate the soft roadbed. Through the effort which technology workers have made for many years in China, this technique has already reached higher level and has made large contribution to engineering construction of soft land area along the sea. Up to now, according to imperfect statistics, the amount of consolidating soft foundation area by vacuum preloading technique is more than 3,500,000 m², which has gained huge economic returns and social benefits. However, the study of vacuum preloading technique is a very complicated topic. Basing on present study, the reasonable advices on decreasing the environmental influence and improving the vacuum preloading work craft are as follows:

(1) The method of vacuum combination surcharge preloading. The super-static hydraulic pressure in soil will be produced by the method of surcharge preloading and the soil can be consolidated with the dissipation of the super-static hydraulic pressure. Combine the method of vacuum drain preloading and the surcharge preloading, the pressure between the soil and vertical drainage body will become larger, which will accelerate the water draining from soil and strengthen the reinforce effect. Although this method has the extensive foreground of engineering application, the technique of construction is not completely mature. We should make further study and reform the technic and work craft, reduce the construction cost and save work period as far as not to influence the reinforce effect.

(2) The method of under-water vacuum preloading. By this method better reinforce result can be acquired than vacuum preloading on land. As figure 2 shows, before laying membrane and air exhaust, barometric pressure Pa and water column rwh act on hole water and the pressure of hole water is \( u = P_a + r_{wh} \). After laying membrane and air exhaust, the pressure under the membrane is reduced to \( P_v \), the pressure of hole water is \( u = P_v \) and reduces by \( \Delta u = P_a + r_{wh} - P_v \). Correspondingly, the valid stress increases by \( \Delta \sigma = P_a + r_{wh} - P_0 \) and the valid stress increases by \( r_{wh} \) than vacuum preloading on land. So the deeper the water is, the better the result of reinforce is. But this method is adapt to construction under water, so
the rising and falling of water level, the flush of wave flow and the pressure of water must be taken into consideration. And the work craft under water is more complex, so the suitable work craft and equipments should be chosen to make sure that the sealed condition is good enough to get the ideal reinforce result.

(3) Constructing techniques and equipment. To enhance the reinforcement effect, improve construction conditions, reduce costs and adapt to the boundary conditions near the reinforce area, the rapid and appropriate sealed techniques should be researched and developed. With the expanding of single reinforce area, the requirements of membrane materials and preliminary technical increased, not only to choose suitable materials, but also to develop suitable technology and adopt equipment for the spot felt repair. Meanwhile, the leakage detection devices need to be collocated to discover and solve problems in time.

Generally, vacuum preloading can enhance the concretion degree and carrying capacity of the surrounding soil to some degree. But the harm brought by the settlement volume, the level displacement and settlement, should be avoided in the foundation projects.

5. Conclusion

The vacuum pre-pressing technique has been applied and developed for 20 years in China. Now it has achieved international advanced level. The water level has been analyzed when vacuum pressure technique had been using, so as to the effective reinforcing depth and effect, the related environmental problems of impacting the border. Some reasonable advices on decreasing the environmental influence and improving the vacuum preloading work craft are put forward, reinforcing technique of associating vacuum with electroosmosis and underwater vacuum pre-pressing technique, construction techniques, equipment and the development of alternative materials.

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