Analysis of Monitoring in Displacement For Vacuum Combined Stack Preloading about Soft foundation Sluice

Hai-sheng JIN¹, Rui-qun MA², Xiang-ming XU¹, Guo-chang GE³*

¹ Wenzhou Oufei Economic Development Investment Co., Ltd., Wenzhou 325025, China
² Agricultural, rural and Water Conservancy Bureau of Wenzhou Economic and Technological Development Zone, Wenzhou 325025, China
³ Zhejiang Guangchuan Engineering Consultation Co., Ltd., Hangzhou 310020, China
* Corresponding author: zjggc2007@163.com

ABSTRACT: Soft soil foundation treatment methods mainly include soil replacement cushion method, dynamic compaction method, drainage consolidation method, etc. Drainage consolidation methods mainly include: vacuum preloading method, stack preloading method and vacuum combined stacking preloading method. Among them, the vacuum preloading method has obvious advantages in treating large areas and deep soft foundations. This paper describes the process of soft soil foundation vacuum combined with stack preloading reinforcement. Through the monitoring of the vacuum preloading process, we mainly analyzed the monitoring results and development trend of horizontal displacement.

1 Foreword
In the 1980s, my country began to conduct preliminary research on vacuum preloading. The First Navigation Bureau of the Ministry of Communications, Tianjin University, and Nanjing Institute of Water Conservancy Research and other units re-explored and researched the vacuum preloading method. After several years of hard work, breakthroughs have been made in equipment, technology and mechanism, and the vacuum degree under the membrane can reach 85~92kPa. This technology has been successfully applied in the reinforcement application of Tianjin Xingang soft foundation, and in 1985 Passed the national technical appraisal in December. After decades of continuous exploration and research at home and abroad, this law has become increasingly perfect, and has been widely promoted, and has achieved good economic benefits. It has become an effective and widely used method to strengthen soft soil foundations and hydraulic fill soil foundations. At present, my country's vacuum preloading method has been in the world's leading level in some aspects.

2 Project Overview
This paper selects the Xi-River Drainage Sluice in the first phase of Oufei reclamation project on the offshore area of eastern Zhejiang as the research object. The designed flow rate of the sluice is 498m³/s, 7 holes 6m, and a net width of 42m. It is responsible for flood control and drainage. Surroundings are protected by earth-rock cofferdams. The foundation soil to be treated in the cofferdam is deep and natural marine soft soil, mostly in fluid plastic state, with poor physical and mechanical properties, high water content, low bearing capacity, and large thickness. Therefore, vacuum combined with stack preloading method is used on the project to reinforce the soft foundation. The layout of the sluice is shown in Figure 1.
3 Reinforcement scheme design

3.1 Area division

The treatment of sluice soft foundation is not only an issue of the bearing capacity, but also the comprehensiveness, integrity, and the coordination and transition of settlement deformation. The settlement of natural soft soil foundation is large, and the sluice floor and the soil are prone to void phenomenon. On the basis of the bearing capacity requirements, measures are taken to increase the stack height and increase the depth of drainage slabs for the large settlement and deformation areas of the empty boxes and wing walls connected on both sides.

The total area of soft soil foundation to be treated in this cofferdam is 15190m². According to the above design ideas, the treatment area is divided into A zone and C zone. Block A is the sluice chamber section, which adopts the vacuum combined low-stack preloading mode, the drainage plate is set to 18m, and the 1.5m high earth and stone materials are piled on the vacuum membrane, with a total area of 6700m². Block C is empty tanks and wing walls on both sides of the sluice. Vacuum combined high stack preloading mode is required. The drainage board is set to 28m, and the vacuum membrane is piled with 3.5m high earth and rock materials. The total area is 8490m², which can reduce the subsequent settlement. The amount. The location of Area A and Area C is shown in Figure 2.
Figure 2  The location of Area A and Area C

3.2 Construction plan
The main controllable processes of vacuum preloading are as follows: cleaning the site → measuring and setting out → inserting board equipment and materials into the site, surface treatment → laying a layer of woven geotextile → inserting drainage board → laying sand cushion → laying filter pipe → laying One layer of woven geotextile → two layers of sealing film → installation of vacuum gauge, settlement mark → vacuum, combined stacking → effect detection.

According to the vacuum preloading construction experience of the tidal flat silt of the reclamation project, a set of vacuum pumps are uniformly distributed per 1000m², and the power of the vacuum pump is 7.5kW.

The vacuum preloading time is 3 months. Construction monitoring should be carried out during the construction process. When the vacuum preloading constant load meets the following standards, the pump can be stopped and unloaded: ① The settlement rate observed for 5 consecutive days is less than 2mm/d; ② The bearing capacity is not less than 75kPa.

4 Monitoring implementation and data analysis

4.1 Monitoring implementation
The field observation items of the vacuum preloading project include: vacuum degree observation, settlement observation, pore water pressure observation and horizontal displacement observation, etc. The purpose of horizontal displacement observation is to prevent excessive lateral shrinkage and deformation causing the foundation to be unstable, which will affect the safety of the cofferdam.

According to the requirements of the design documents, the horizontal displacement adopts a deep tube to measure the lateral displacement of the soil along the depth. Three measuring points are arranged around the sea side of the reinforced area, and one measuring point is arranged on the side of the enclosed area. The frequency of observation is: 1 time/day in the first month; 1 time/5 days in the next two months. The layout of the horizontal displacement monitoring project is shown in Figure 3.
4.2 Monitoring data analysis

The deep horizontal displacement is obtained from the deformation of the inclinometer tube buried in the soil. The bottom elevation of the inclinometer tube is -32m, and the displacement to the reinforcement area is taken as positive when recording. The measured lateral displacement curves of X1 and X2 monitoring holes are shown in Figure 4~5.
Comprehensive analysis of the above lateral displacement curve, we can get the following conclusions:

1) The maximum horizontal displacement on the west side (hole X1) is 102.6mm, and the maximum horizontal displacement on the east side (hole X2) is 115.3mm. The horizontal displacements on both sides are equivalent, but the maximum horizontal displacement on the west side occurs at an elevation of -6m, and the maximum horizontal displacement on the east side occurs on the surface.

2) It can be seen from Figure 4 and Figure 5 that the magnitude of the horizontal displacement gradually decreases with the increase of the depth, indicating that the influence of the vacuum load in the horizontal direction decreases with the increase of the depth. On the one hand, because the stiffness of the soil increases with the increase in depth, on the other hand, because the vacuum gradually decreases with depth under the action of well resistance.

3) Comparing Figure 4 and Figure 5, it can be found that the horizontal displacement of the east and west sides has a sudden change at an elevation of -6m, and the overall soil layer has lateral translation to the east. At an elevation of -6m, there is a demarcation between sand silty layer and silt sand. It is guessed that under the action of horizontal seepage caused by vacuum negative pressure, the sand in the silty sand layer is lost, and finally a slip surface is formed.

In order to better show the relationship between the horizontal displacement of the soil at different depths at the edge of the preloading zone over time, part of the depth monitoring data of hole X2 (more complete data monitoring) is selected, and the curve of the horizontal displacement of the soil at different depths with time is drawn, as shown in the figure 6.

![Figure 6](image_url)  
**Figure 6**  
Horizontal displacement of the soil at different depths with time

It can be seen from the figure:

1) According to the lateral displacement curve of the surface soil in Figure 6, the lateral shrinkage caused by vacuum negative pressure is about 175mm, and the lateral extrusion caused by stacking is about 80mm. The final horizontal displacement of the surface appears as shrink, shrinkage is about 95mm. During the entire pre-compression process, the foundation is in a lateral shrink state, and the vacuum pre-compression is in a dominant position.

2) It should be pointed out that although the vacuum preloading is under the premise that the total stress remains unchanged, the effective stress is increased by reducing the pore pressure, which improves the stability of the foundation. However, excessive surface shrink will have an adverse effect on the surrounding environment, and vacuum combined stacking can just reduce this effect.
5 Conclusion
This article relies on the construction example of the built sluice in the first phase of Oufei reclamation project, utilizing vacuum combined with preloading to strengthen the soft soil foundation, and through analyzing and sorting on-site monitoring data, it has an overall grasp of the preloading process.

(1) The on-site monitoring arrangement of vacuum combined preloading is introduced in detail, including monitoring content, monitoring plan and purpose, monitoring frequency and specific arrangement of monitoring instruments. At the same time, the precautions and method skills in the monitoring process are given.

(2) Vacuuming makes the foundation shrink isotropically, and the foundation tends to be stable; stacking makes the foundation settle vertically and extrude laterally, which is prone to shear failure. Vacuum combined with stacking can just reduce this effect. The horizontal displacement is the largest on the surface and follows. The depth gradually decreases to verify the reinforcement characteristics of the two methods.

Acknowledgments
This paper was financially supported by Zhejiang Province Water Resources Department Science and Technology Planning(RB1614, RC1733).

References
[1] Ye Borong. The development and engineering record of vacuum preloading reinforcement method[J]. Foundation Treatment, 1995(03): 1-10.
[2] Cong Ruijiang. Reinforcement of super large area of soft soil foundation by vacuum preloading[J]. Foundation Treatment, 1996(02): 30-37.
[3] Shang J Q, Tang M, Miao Z. Vacuum preloading consolidation of reclaimed land: a case study[J]. Canadian Geotechnical Journal, 1998, 35(05): 740-749.
[4] Kjellman W. Consolidation of clay soils by means of atmospheric pressure[C], Conference on soil stabilization. MIT Boston, 1952, 5: 32-34.
[5] Arutjunian, R.N, Vacuum-Accelerated Stabilization of Liquefied Soils in Landslide Body[J], Proc. of VIII ECSMFE, 1983.
[6] Chu J, Yan S W, Yang H. Soil improvement by the vacuum preloading method for an oil storage station[J]. Géotechnique, 2015, 50(06): 625-632.
[7] Mohamedelhassan E, Shang J Q. Vacuum and surcharge combined one-dimensional consolidation of clay soils[J]. Canadian Geotechnical Journal, 2002, 39(05): 1126-1138.