Simulation and Analysis of Deformation Characteristics of Moulded Bag Solidified Soil Embankment

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Abstract. Centrifuge model test and finite element simulation were used to study the stability of solidified soil embankment in offshore mold bags. Through centrifugal model test, the settlement, pore water pressure variation and consolidation deformation of the foundation in the filling and filling stage of the mold bag solidified soil embankment are analyzed and compared with the actual engineering monitoring results. The test results show that the centrifugal model test and finite element simulation results are similar under normal construction conditions, the foundation deformation is mainly settlement, the pore water pressure basically dissipates within six months after the completion of embankment filling, and the foundation failure mode is caused by insufficient bearing capacity. The model test results are consistent with the actual engineering monitoring results.

1. Introduction
In our country, because the shallow beach formed by soft clay used riprap slope levees to build revetment and seawall, a large amount of sand and stone is needed. With the state's control of resources, earth and stone resources are becoming increasingly scarce, some areas try to develop new forms of embankment, and the film bag solidified soil embankment arises at the historic moment. This technology was first used in a dam in Tianjin Port. It uses solidified soil as a new type of dam structure at the center of the dam. This technology can make full use of dredged soil in the harbor basin without the need for conventional resources such as sand and gravel, and has great social benefits. In this paper, the finite element calculation results of the sea embankment with film bag solidified soil are compared and analyzed with the centrifugal model experiment results, and the regular findings are summarized, which provides a basis for the theoretical research and design calculation method of the technology.

2. Project overview
A breakwater in Tianjin Port is a slope dike, all of which are filled with bags, the filling material is solidified soil, the protective surface is a concrete membrane bag, and the soft foundation treatment method is to set up plastic drainage boards. The foundation soil is divided into four layers according to the historical origin. According to the actual cross-sectional dimensions of the sea embankment of solidified soil relying on the engineering model bag, a calculation model is established by using PLAXIS elastic-plastic finite element analysis software to simulate the construction process of the
embankment and the drainage consolidation process of the foundation soil, calculate and analyze the deformation and pore water pressure changes of the foundation soil during the whole construction process and in a period after completion, and compare with the actual observation data. According to the geological survey report, the calculation parameters for different soils are shown in Table 1.

Table 1 Numerical Model Deformation Calculation Parameters

| Soil Type | \( \gamma \) (kN/m³) | \( k \) (m/day) | \( c \) (kPa) | \( \phi \) | \( E_{50}^{\text{ref}} \) (kPa) | \( E_{\text{wed}}^{\text{ref}} \) (kPa) | \( E_{uw}^{\text{ref}} \) (kPa) | \( m \) |
|-----------|----------------|----------------|-------------|-----|-----------------|----------------|----------------|-----|
| Silt      | 16.2           | \( 4.1 \times 10^{-5} \) | 11.1        | 9   | 1500             | 1650             | 4600             | 0.8 |
| Silty soil| 17.8           | \( 5.6 \times 10^{-5} \) | 17          | 12  | 2000             | 2800             | 5500             | 0.7 |
| Silty clay| 19.6           | \( 2.4 \times 10^{-4} \) | 23.5        | 20  | 3500             | 4300             | 8000             | 0.55|
| Silty soil| 20             | \( 3.5 \times 10^{-2} \) | 21.6        | 26  | 4500             | 5600             | 9500             | 0.5 |

The actual observation value of the settlement at the center of the section and the result of finite element analysis are plotted as a curve according to the construction progress as shown in Figure 1.

![Figure 1](image1.png)

Figure 1 comparison diagram of measured settlement and finite element calculation settlement

![Figure 2](image2.png)

Figure 2 lateral displacements - time curve at 0 depth of section

After the completion of the project on June 28, the settlement of the central point still shows an increasing trend, and the calculated value is in good agreement with the measured value. The actual observation value of the lateral deformation of the surface layer at the edge of the section and the
depth of 3.0m is compared with the result of finite element analysis, which is plotted as a curve according to the construction progress, as shown in Figure. 2.

From the calculation results, it can be seen that the lateral displacement of soil is larger during the construction process, and the lateral displacement of soil still increases with time after the completion of the project, even though the lateral displacement of foundation soil still shows an increasing trend three months after the completion of the project. The results of finite element simulation and analysis are in good agreement with the development trend of the measured data, but are significantly smaller than the measured values in numerical value. The actual observation values of pore water pressure at the center line of the dam are compared with the results of finite element analysis by plotting curves according to the construction progress and different depths, as shown in Figure. 3.

![Figure 3 Observation and measurement curves of excess pore water pressure in cross section](image)

There are many observation data points at the depth of 1.5m and there are obvious fluctuations, which may be caused by the ebb and flow of the tide. In the finite element calculation, the data points are less, and it is more difficult to simulate the ebb and flow of the tide in one day. The calculated value is smoother and smaller than the measured value. The calculated value of hole pressure at the depth of 6.5m agrees well with the measured value.

3. Centrifugal model test

Centrifuge model test and numerical analysis are carried out according to the actual cross-section size of the sea embankment of the solidified soil relying on the engineering mold bag to study the stress distribution of the foundation, the variation law of the pore water pressure of the foundation, the overall stability and deformation of the solidified soil of the mold bag on the soft foundation, and to provide parameters for the design calculation method. Centrifugal model tests were carried out on a 400gt geotechnical centrifuge in Nanjing hydraulic research institute.

The scale of the model was selected as \( n = 50 \). The model foundation soil is taken from the field soil material, and the foundation strength index is used as the main analog quantity, while other parameters such as water content and bulk density are used as secondary parameters to approximately meet the similarity law. Solidified soil is prepared with field soil sample and 32.5 grade ordinary Portland cement. The cement content is 8 % and the water content is about 80 %. In order to improve the strength of solidified soil as soon as possible, 3 % of early strength agent is added. Plastic drain boards are simulated by casing (pouring fine sand) with a diameter of 1.4~1.5mm; In the experiment, the model-filled bag cloth was simulated by using non-woven fabrics with a unit mass of about 25g/m2, tensile strength of about 100N/50mm and elongation of about 30 %. The two pieces of stone cushion and face block stone are respectively simulated with 1~2mm and 5~10mm crushed stones, while the concrete face of the mold bag is simulated with C20 cement mortar, and the water content of the hydraulic fill mud is about 80 %.
The results of centrifugal model tests and numerical analysis show that the foundation deformation is mainly settlement without uplift, and the maximum settlement rate at the center of the dam is less than the empirical control value of 10~20mm/d, the maximum horizontal displacement is 100mm, and the horizontal displacement rate is less than the empirical control value of 4 ~ 6 mm / D. One year after the dam was completed; there was no sign of overall failure and instability. Therefore, it is stable and safe as a whole during the cofferdam and hydraulic fill construction period.

Three months after the completion of hydraulic fill, the method of increasing centrifugal acceleration is used to further study the overall failure pattern of foundation and dam. The acceleration has increased from 50g to 150g in design. In short, it can be considered that the height of the cofferdam and hydraulic fill has increased by 2times. According to the test results, the pore water pressure coefficient in the foundation has reached the critical state at this time, and the foundation settlement has also increased significantly, resulting in uplift of the foundation on the port side, and the maximum horizontal displacement has also increased from 10cm to 60cm when the dam is completed for one year, which indicates that the foundation has suffered instability and failure. It can be seen from the deformation vector diagram and grid diagram of the foundation that there is circular arc sliding failure on the port side.

4. Conclusion
Centrifuge model test and finite element calculation can truly reflect the actual stress and deformation of the membrane bag solidified soil cofferdam project. Pore water pressure basically dissipates within six months after the completion of embankment filling, and foundation consolidation reaches more than 86 %.

Under normal construction conditions, the deformation of the diaphragm bag solidified soil embankment is mainly settlement, no uplift occurs, and the overall stability of the foundation is good.

The construction technology of film bag solidified soil offshore cofferdam has strong practicability for soft foundation and fast construction speed.

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