Research on Deformation Characteristics of New Breakwater Structure

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Abstract. With the increasingly stringent of environmental protection requirements of the China, there is fewer and fewer land reclamation projects, so the related research on dredged soil treatment technology has become a hot spot. A new type of mud-sand interbedded structure is put forward in this paper. The dredged soil is filled in membrane bag and interbedded with sandy membrane bag, which gradually forms a stable new seawall core structure. From the finite element simulation results, it is known that the maximum displacement of mud-sand interbedded structure is 2.73 m. After the calculation, the top surface of the mud-sand interbedded structure is 1.9 m from the back surface, and the compression of the mud-sand interbedded structure is mainly occurs in the middle of the body, the bottom and top are less compressed. The design and construction of the breakwater meets the engineering requirements, and it is a feasible and fast breakwater technology on soft soil foundation.

1. Introduction

Offshore breakwaters are barriers against wind and wave erosion in coastal areas. In the past few decades, the types of breakwaters have emerged in an endless stream [1-2]. However, most of them are made of rock, sand or membrane bag soil. With the shortage of sand and rock and the continuous increase of price, the construction cost of breakwaters increases greatly [3-4]. On the other hand, dredged soil disposal, which is produced by dredging of waterway every year, brings great pressure to related enterprises. How to utilize resources without affecting the environment is the bottleneck of dredged soil treatment.

So far, in addition to the traditional slope breakwater type, new types of structures such as large-diameter vertical cylinder breakwater, vertical caisson structure and semicircle breakwater have appeared which are more suitable for the deep water area [5]. The sand dike with bag has been widely used in domestic water conservancy projects. After entering the 21st century, the breakwater with mold bag solidified soil as core material was appeared.

According to the current national and industrial standards, the application of filling bag breakwater technology stipulates that sandy soil with a content of less than 10% should be selected as the filling material, and the application of silty soil completely exceeds the technical limit [6]. Silty soil will affect the stability and operation safety of breakwater structure due to poor permeability of filling material,
2. New type Breakwater Structure

The project team of zhongjiao Tianjin harbor engineering research institute co., ltd. intends to make full use of the resources of the soft foundation and use silty soil as the filling material of the breakwaters. They proposed a mud-sand interlayer structure of breakwaters, which is formed with a large filling-mud bag combined with a filling-sand bag of sand. The construction of a large filling-mud bag and a filling-sand bag is conducted in layered intervals. The upper and lower filling bags can be used as a fast transverse drainage channel. As the filling bag body is drained on both sides, the consolidation of soil body inside the filling bag can be greatly accelerated, and the quick filling of the breakwaters can be realized. In this study, the filling process of a new type of breakwaters is analyzed by theoretical research, simulation analysis and field test, in order to provide theoretical support for the design and construction of the new type of breakwaters.

2.1. Basic Mechanism

Large-scale filling mud bags and filling sand bags are used for layer filling. Sand layer is used as horizontal drainage layer and upper load to drain and consolidate soft layers which reduce water content of soft soil, improve physical and mechanical indexes of treated soil layer, increase bearing capacity of foundation, and provide a relatively good construction condition for subsequent construction step by step. When breakwater construction, it will replace the dredged fill with very low strength. In order to form a permanent structure, drainage boards can be laid downward at the top of the breakwater after the breakwater has been formed and reached certain strength to reinforce the soil of below breakwater. When necessary, some surcharge loads can be added to increase the strength and reduce the later deformation.

2.2. Section Design

When the starting of the construction of breakwater, Jing ba and geotechnical soft drainage are laid at the bottom of the breakwater, and the thickness of sand filling bags is 0.3m-0.6m, mud filling bags is 0.8m-1.5m; and earth filling filter cloth is laid on the top of the breakwater body, and soil bags are pressed and protected. In order to form a permanent structure, drainage boards are laid downward at the top of breakwater body when it is reached certain strength.

The construction methods are as follows:

1) In order to ensure that workers can go to the site for the construction of Geotextiles and filling bags, the first step is to lay Jing ba on the mud surface, so as to form a certain bearing capacity of the mud surface, and to lay geotextile on the surface of Jing ba manually.

2) Setting up a well as a vertical drainage channel, directly connected with the sand layer, draining water by submersible pump, lowering water level, so that water in the sand layer can be effectively discharged, and the top of the well is higher than the top of the breakwater, and the bottom of the well is lower than the soft drainage than 20 cm.

3) The filling bags are made of plastic geotextiles. The transverse tensile strength of the sewing position shall not be less than strength of the woven geotextiles. Then filling construction is carried out by hydraulic filling method. The filling bags will squeeze silt under the action of self-weight. After sinking to a certain depth, the filling bags will continue to be constructed on the filling bags, consolidating and draining for 1-5 days, and the newly laid bags will continue to squeeze silt and sink. Repeat the process of filling sand bags and mud bags until the top of the certain level.

4) Laying the upper geotechnical filter cloth.

5) In order to form a permanent structure, drainage boards can be laid downward at the top of the breakwater after the breakwater has been formed and reached certain strength, this method can reinforce the soil below the filling breakwater. When necessary, some surcharge loads can be added to increase the strength of the foundation after consolidation and reduce the later deformation so as to meet the use requirements.
3. Simulation Analysis of New Type Structure

The structure of the breakwater is simulated and analysed by using the finite element software of PLAXIS3D. The model of the mud-sand interbedded breakwater is shown in Figure 1.

![Figure 1. Analysis model of breakwater](image)

The bottom layer of the breakwater body is filled sand bag with a thickness of 0.4m. The bottom of the sand bag is 2.8m below the ground and its width is 32m. The below mud bag with a thickness is 1 m and the width is 30 m. Then a layer of mud bag and a layer of sand bag are continued to be filled in intervals until the top of the breakwater. The top layer of the breakwater body is sand bag. The top width of the breakwater body is 21.6 m, which is 4.6 m above the bottom. There are six sand bags and five mud bags. The width of the mud bag in the breakwater body is 2 m more than that of the next mud bag, and the width of the sand bag is 0.4 m more than that of the next mud bag. Drainage well is set in the middle of the breakwater body to ensure that the water level in the well is maintained at the bottom of the breakwater body during construction. In the model, the "drainage line" is used to simulate drainage well. The breakwater is a symmetrical structure, only half of which is used in modelling. The whole model is 70m in length and 22.6m in height. The material parameters of foundation soil and bags are shown in Table 1.

| Name                      | sand | filling soil | Dredger Fill | 1 Silty Clay | 2 Silty Clay | 3 Silty Clay | Geotextile |
|---------------------------|------|--------------|--------------|--------------|--------------|--------------|------------|
| Natural Severity (kN/m³)  | 17   | 13.8         | 13.6         | 18.8         | 17.6         | 18.6         | /          |
| Saturated unit weight     | 20   | 18.8         | 16           | 20           | 18           | 19           | /          |
| Modulus of elasticity     | 107.5e3 | /            | /            | /            | /            | /            | /          |
| Poisson's ratio           | 0.3  | 0.3          | 0.3          | 0.3          | 0.3          | 0.3          | /          |
| Cohesion(kPa)             | 1    | /            | /            | /            | /            | /            | /          |
| Friction angle (°)        | 26   | /            | /            | /            | /            | /            | /          |
| Shear expansion angle     | 1    | /            | /            | /            | /            | /            | /          |
| Revised compression index | /    | 0.189        | 0.289        | 0.189        | 0.201        | 0.179        | /          |
| Revised inflation index   | /    | 0.038        | 0.058        | 0.038        | 0.0402       | 0.036        | /          |
| lateral Stress Parameters | /    | 1.1          | 0.9          | 1.1          | 1            | 1.1          | /          |
| in Normal Consolidation   | /    | /            | /            | /            | /            | /            | 30         |
| Stiffness of elastic axis| /    | /            | /            | /            | /            | /            | /          |
| (kN/m)                    | /    | /            | /            | /            | /            | /            | 30         |
| Thickness (m)             | /    | 1.2          | 2.8          | 1.2          | 6            | 8            | /          |
| Permeability coefficient  | 1    | 0.03         | 1.03e-3      | 0.03         | 1.35e-3      | 1e-3         | /          |
The model adopts step-by-step calculation. The breakwater body is filled from bottom to top. In the first calculation step, the first layer of sand bags, the first layer of mud bags and the second layer of sand bags are added. Consolidation is adopted and the calculation time is 5d. In the second calculation step, add the second layer of mud bag and the third layer of sand bag, and calculate the same for 5d. Then a layer of mud bag and a layer of sand bag are added to each calculation step, and the calculation is performed for 5 days until the breakwater body is completely added in the fifth calculation step, and then the breakwater body is consolidated for 30 days, and the calculation is performed for 55 days.

The calculation results are as follows. As can be seen from Figure 2, the maximum displacement of the mud-sand interbedded breakwater body is 2.73m, which occurs at the top of the breakwater body. Before model deformation, the top elevation is 4.6m and the ground elevation is 0. After calculation, the top of the breakwater body is 1.9m above the ground, which is meeting the requirements of later construction. The maximum vertical deformation of the breakwater body itself is 1.38m, the larger compression occurs in the middle of the breakwater body, and the compression at the bottom and top of the breakwater body is smaller.

![Figure 2. Schematic diagram of breakwater settlement](image1)

![Figure 3. Schematic diagram of pore water pressure](image2)
Figure 4. Schematic diagram of volumetric strain

Figure 3 is a picture of the excess pore pressure of the model. As can be seen from the figure, the excess pore pressure of the breakwater body is close to zero, because the breakwater body has good drainage conditions and the excess pore pressure dissipates quickly. There is still excess pore pressure in the foundation that has not dissipated, which is indicating that consolidation has not yet been completed and settlement will occur in the later stage.

Figure 4 is a picture of the total volume strain of the mud-sand interbedded breakwater body. As can be seen from the figure, the strain of the upper part of the breakwater body structure on the ground is larger, and the strain of the mud bag is larger, and the strain of the sand bag is smaller.

After the calculation, the total vertical displacement on the top of the breakwater body is 2.73m, and the vertical displacement at the center of the breakwater body is 0.68m m. During the whole calculation stage, the breakwater body is compressed by 2.05m, with a compression ratio is 27.7%.

Figure 5. Final state of calculation of breakwater

Figure 5 is a shape comparison diagram before and after consolidation of mud-sand interbedded breakwater body, wherein the dark colour figure is the deformation diagram after consolidation. From the diagram, the shape of the breakwater body can be basically seen after construction and continuous consolidation for one month.
By simulating the filling process of the breakwater body, the following results are obtained through calculation:

1. The maximum displacement of the mud-sand interbedded breakwater body is 2.73m. After the calculation, there is 1.9 m between the top of the breakwater body and the ground, the breakwater body meets the requirements of later construction.
2. The compression of the breakwater body occurs mainly in the middle of the breakwater body, with smaller compression at the bottom and top.
3. The compression ratio of mud-sand interbedded breakwater body is 27.7%.

4. Conclusions
This paper puts forward a new type of silt-sand interbedded structure. According to many years of relevant engineering experience of the project team, a practical and possible construction scheme was put forward.

According to the proposed construction scheme of the new clay-sand interbedded structure, finite element simulation analysis is carried out according to the construction sequence. The calculation results show that the final settlement of the new structure meets the construction requirements, and the compression of the breakwater body mainly occurs in the middle of the breakwater body.

Both the design and construction of the breakwater body meet the engineering requirements, and it is a feasible and fast breakwater construction technology on soft soil foundation.

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