Study on quick consolidation method of strong drainage combined with compaction

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Abstract. In this paper, a quick consolidation technique for silt and silty clay foundation with strong drainage combined with compaction is developed through field test. The whole construction period is only 70 days. A strong drainage system is put forward. The whole reinforcement process only needs two inserts and pulls. During the tamping process, the strong drainage system works continuously and saves much time. After consolidation, the bearing capacity of the foundation meets the requirements, and the soil properties are greatly enhanced. The influence depth of consolidation is at least 10 m.

1. Introduction

With the rapid economic development of China’s coastal areas, land resources are becoming increasingly tight. The use of dredged soil in harbor basins and waterways to fill the land and then strengthen the foundation has become an important means of alleviating the shortage of land resources. Land reclamation nearby not only solves the problem of dredging soil overcast, but also solves the source of backfill formation in the land area behind the port. It reduces secondary marine pollution caused by overcast. It has significant social and economic benefits [1].

At present, mainly Reinforcement methods of filled foundation are vacuum preloading method, surcharge preloading method and vacuum-load consolidation method etc. During the construction of vacuum preloading method, it is necessary to lay 0.8m ~ 1.0m thick black sand working cushion and yellow sand drainage cushion, install plastic drainage boards with a depth of 15m ~ 20m and a spacing of 0.9m ~ 1.0m, and exhaust at least 90d at full load. This method has a high cost and a long construction period. And treatment measures need to be taken when reinforcing saturated silt and silty clay with high permeability coefficient, such as installing a clay sealing wall around the reinforcement area, which further increases the project cost [2,3]. Surcharge preloading requires a large amount of sand and gravel, which is not suitable for areas lacking sand and gravel such as Tianjin [4,5].

In addition, the dynamic compaction method is also a common method of foundation reinforcement. It is generally applicable to the treatment of gravel soil, sand, low saturation silt and cohesive soil, collapsible loess, miscellaneous fill and plain fill. Generally, it is not suitable for foundation with high
saturation, such as silt and cohesive soil, because the water is not easy to be discharged in the process of foundation reinforcement [6].

At present, there are a large number of silt and silty clay hydraulic fill foundation [7]. Therefore, it is necessary to explore and develop a rapid reinforcement method for the dredger fill foundation with good permeability, such as silt and silty clay foundation. For this purpose, this paper combines the advantages of dynamic compaction method and drainage consolidation method, and develops a set of strong drainage combined with compaction rapid foundation reinforcement technology through field test.

2. Project overview

The field test was carried out somewhere in Linhai New Town, Tianjin Binhai Tourist Area. The test site is a rectangle with a length of 83m and a width of 45m. The test area is close to the sea and the groundwater level is 1.8m below the ground.

The foundation of the reinforced area is divided into two layers. The first layer is filling layer. It is mainly gray and spreads throughout the site. It is mainly silt and silt silty clay, with a thickness of about 6m, which has not yet been completely consolidated. It is loose and extremely low in strength, with a plastic index of 8.5 to 11.1. The second layer is silt silty clay and silty clay layer. It is marine sedimentary soil layer. The colour is gray-brown. It has medium compressibility and widely distributed in the field. This soil layer does not penetrate the soil layer. Its density is 1.75g / cm$^3$ ~ 1.86g / cm$^3$ and plasticity index is 14.5 ~ 23.5.

The field test started on November 7, and completed on January 20 of the following year. The construction period is 74 days. However, the construction period of vacuum preloading method is generally larger than 3 months.

3. Construction process

The strong drainage combined with compaction method consists of two parts: dynamic compaction system and strong drainage system. Dynamic compaction system can quickly strengthen the foundation. Strong drainage system can reduce the water level of the foundation before dynamic compaction to prevent the foundation pit from flooding during dynamic compaction. And it can speed up the dissipation of the ultra-static pore pressure of the foundation after dynamic compaction.

The construction process of the strong drainage combined compaction method is briefly summarized as follows: a strong drainage system is set up in the foundation, and the groundwater level is lowered to a certain depth, and then the dynamic compaction is carried out, and then the strong drainage is continued to accelerate the consolidation of the foundation and repeatedly compacted. After several times of dynamic compaction and strong drainage, foundation reinforcement is completed.

The setting of strong drainage system is shown in figure 1. Excavate drainage ditch along the periphery of the reinforced area, and arrange peripheral sealing pipes on the inside of the drainage ditch. The pipes distance is 2m and the pipe length is 8m. During the construction, the sealing pipe continues to pump until the compaction construction is completed. Inside the site, drainage pipes are arranged before the first tamping. The length of drainage pipes is 6m. The spacing of drainage pipes is 2m and the row spacing is 4m. The row spacing is equal to the spacing of the tamping points. Drainage pipes and sealing pipes are made of PVC pipe of Φ32mm ~ Φ50mm with holes at the lower part of 2m. The upper part of drainage pipes and sealing pipes are connected to water collecting pipes. Collecting pipes are made of PVC pipe of Φ50mm ~ Φ63mm. Then collecting pipes are connected to vacuum device. The vacuum pressure is provided by a vacuuming device to forcibly discharge the water in the foundation and discharge it into the water collecting ditch. Joints are sealed with glue and then wrapped with cling film to ensure the tightness of the entire system and prevent unnecessary loss of vacuum pressure.
The reinforcement area was compacted three times of point tamping and a time of full tamping. The first time of point tamping contained two times and each time contained 4 ramming. The second time and the third time of point tamping contained 6 ~ 8 ramming. After each time of point tamping, the pore water pressure must dissipated 75% before the next time of tamping. Energy of three times of point tamping are 1000kN • m, 1700kN • m and 2700kN • m. The arrangement of ramming point was shown in figure 2. After point tamping, full tamping is performed. The full tamping energy is 500kN • m. Full tamping needs overlap and its overlap should not be less than 1/4 of the hammer bottom. After tamping is completed, the surface soil is compacted with a 10t-12t roller, and compacted 3 to 5 times until there is no wheel track.

Figure 1. Strong drainage system.

Figure 2 shows the arrangement of tamping points in the process of three times of point tamping. The spacing between tamping points is 4m, as same as that of drain pipe in figure 1. After trial tamping, it is found that the drainage system will not be damaged by tamping basically. So it is unnecessary to pull out the drainage system in the reinforcement area during the first time of point tamping. During the compaction, the drainage system can work continuously, which saves the time needed to plug in and pull out the drainage system, and accelerates the dissipation of excess pore pressure in the foundation. During the second time of point tamping, pull out the drainage pipe in the reinforcement area, insert it into the centre of the first time of point tamping, continue the drainage
work, and keep the drainage system working continuously during the second time and the third time of point tamping. Before full tamping, the drainage system shall be removed. After full tamping and rolling, the reinforcement work shall be completed. Therefore, during the whole reinforcement process, the strong drainage system only needs to be plug in and pulled out twice.

4. Analysis of reinforcement effect
In order to determine the effect and depth of dynamic consolidation, soil sampling, standard penetration test, static penetration test and shallow plate load test were carried out before and after dynamic consolidation.

4.1. Standard penetration test analysis
In order to compare the improvement of soil strength index before and after foundation consolidation, standard penetration test is carried out after each compaction, as shown in table 1.

| Depth(m) | Before tamping | After the first time of point tamping | After the second time of point tamping | After the third time of point tamping |
|---------|----------------|--------------------------------------|----------------------------------------|----------------------------------------|
| 0m~6m   | 0.9            | 3.1                                  | 9.5                                    | 11.5                                   |
| 6m~10m  | 2.1            | 2.7                                  | 3.8                                    | 4.6                                    |

As can be seen from table 1, at the depth of 4m~6m, the increase of soil strength is very obvious. At the depth of 6m~10m, there is a certain increase in soil strength. The influence depth of reinforcement is more than 10m.

4.2. Cone penetration test
The result of cone penetration test is shown in table 2 and table 3.

| Depth(m) | Before tamping | After the first time of point tamping | After the second time of point tamping | After the third time of point tamping |
|---------|----------------|--------------------------------------|----------------------------------------|----------------------------------------|
| 0m~6m   | 243.5          | 2268.3                               | 4332.7                                 | 6429.9                                 |
| 6m~10m  | 534.5          | 678.8                                | 1117.6                                 | 2359.3                                 |

| Depth(m) | Before tamping | After the first time of point tamping | After the second time of point tamping | After the third time of point tamping |
|---------|----------------|--------------------------------------|----------------------------------------|----------------------------------------|
| 0m~6m   | 1.73           | 24.11                                 | 32.8                                   | 68.67                                  |
| 6m~10m  | 10.61          | 12.78                                 | 19.29                                  | 33.91                                  |

As can be seen from table 2 and table 3, at the depth of 4m~6m, the increase of resistance of cone tip and side friction is very obvious. At the depth of 6m~10m, there is a certain increase in resistance of cone tip and side friction. The influence depth of reinforcement is more than 10m.

4.3. Bearing capacity
Shallow plate load tests were carried out before and after reinforcement as shown in figure 3 and figure 4.
It can be seen from the two figures that the characteristic value of the bearing capacity of the foundation before reinforcement can be taken as 20KPa and 160kpa after reinforcement. After reinforcement, the bearing capacity is greatly increased, which meets the design requirement.

5. Conclusion
Based on the field test, this paper developed a set of strong drainage combined with compaction fast consolidation technology for silt and silty clay foundation, and obtained the following conclusions.

(1) The whole construction period of the foundation consolidation by the combination of strong drainage and compaction method is only more than 70 days, which is far less than vacuum preloading method.

(2) When the foundation is consolidated, it needs three times of point tamping and one time of full tamping. The dynamic drainage system designed in this paper only need two times of inserting in and pulling out. In addition, the continuous work of the dynamic drainage system in the process of compaction accelerates the dissipation of excess pore pressure and saves a lot of time.

(3) After reinforcement, the bearing capacity of the foundation meets the requirements. The soil properties are greatly improved. And the depth of influence of reinforcement is at least 10m.

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