Experimental Study on Wharf yard Foundation Reinforced by Drain Board and Dynamic Consolidation Method

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Abstract. The intelligent reconstruction project of the old wharf yard faces the problems of soil layer uneven horizontal distribution, hard concrete shell layer on the surface and high groundwater level of the site. Improper treatment can easily induce uneven settlement of the foundation, which will affect the normal operation of the intelligent wharf. Based on the actual project, this paper carries out the experimental research on the dynamic consolidation effect of the foundation with or without the drain board, compares and analyzes the monitoring and detection results of the foundation under two working conditions, and gives the calculation formula of the effective consolidation depth. The results show that: the insertion of the drain board can quickly dissipate the excess pore water pressure caused by the dynamic consolidation construction, and effectively shorten the consolidation time of the soft soil foundation; Compared with the area without drain board, the effect of foundation reinforcement is more obvious in the drain board area, in the range of effective reinforcement depth, it is more conducive to improve the mechanical properties of soft clay layer; Groundwater level is an important factor affecting the effective reinforcement depth of dynamic consolidation foundation, in the coastal areas with high water level, reasonable and effective precipitation measures should be considered; The estimation range of effective reinforcement depth correction coefficient is given, which can provide a reference for the design and construction of foundation dynamic consolidation in similar sites.

1. Introduction
With the rapid development of intelligent information, the harbour industry has entered the expansion and transformation period. In the future, promoting the construction of intelligent harbour and strengthening the transformation of old wharf yard will be the strategic focus and development direction of most port enterprises.

The intelligent reconstruction project of old wharf yard generally faces many problems, due to the influence of reinforcement technology, the horizontal distribution of soil layer is extremely uneven, and there are hard shell layers such as concrete layer and chain block on the site surface. If the reinforcement measures¹² are not appropriate, it is easy to induce uneven settlement of foundation in the operation stage, which seriously affects the normal use of the wharf yard. Therefore, it is urgent to choose reasonable soft foundation reinforcement measures.

The dynamic consolidation³ method and preloading method are widely used in foundation treatment, but the preloading method has a long reinforcement period, and needs a large number of load blocks, so the cost is relatively high; Although the dynamic consolidation method has the advantages of good reinforcement effect, short construction period, the groundwater level of the
coastal site is high, and the underlying soil layer of the hard shell is usually saturated soft clay layer, which has poor physical mechanical properties. It is difficult to increase the strength after treatment. In comparison, the method of dynamic consolidation with drain board\cite{4,5} is the most direct and effective measure to meet the needs of the wharf yard foundation reinforcement.

At present, many scholars have carried out research on the effect of different soft soil foundation treatment with drain board dynamic consolidation method, but the research on the saturated soft clay foundation with hard shell layer are less. Based on the Tianjin Port intelligent terminal yard project, this paper carries out the experimental study on the dynamic consolidation effect of the foundation with or without the drain board, combined with the test data, the calculation formula of effective reinforcement depth\cite{6,7} is given, which provides a reference for guiding the design and construction of large area wharf yard site foundation reinforced by dynamic consolidation.

2. Project overview

Due to historical reasons, the land site of the project has been used as the yard, and the landfill has been repaired, renovated and leveled for many times. Moreover, the site has not been formally treated. The road and yard are arranged freely and scattered.

A 2.0m-7.0m thick miscellaneous fill structure layer is distributed on the site surface, which is mainly composed of brick, mass concrete, During drilling, local cores are columnar or fragmentary, and some of them contain reinforcement, which is suspected of concrete construction waste; Under the miscellaneous fill, there is a clay layer with a thickness of 2.0m-6.5m, which is in flow plastic and soft plastic state, belonging to high compressibility soil, with uneven soil quality, mixed with silt, muddy clay silt and silty clay. The distribution of surface soil layer is uneven, and the distribution regularity of horizontal shallow soil strength and thickness is poor. The design elevation of the site is +5.0m, the buried depth of the static water level is 0.3m-2.6m.

3. Experimental design

The area with 3.0m thick hard shell layer on the surface and uniform distribution of underlying soil layer is selected as the test area. Before the trial compaction, 2500kN.m cylinder hammer is selected to break the hard shell layer on the surface. The drain board area is 20.0m×20.0m, the drain board are arranged in 8 rows and 8 columns of squares, the buried depth of the drain board is 10.0m, the spacing is 1.0m, and the leakage of the board head is 2.0m. In order to facilitate the analysis, the area without drain board with the same geological characteristics is taken for dynamic consolidation, and the detection items and dynamic compaction construction parameters are the same as those of the drain board area. The drain board field effect is shown in Figure 1.

![Figure 1. Field effect drawing of drain board test area.](image)

A group of pore water pressure monitoring points (4 pore pressure sensors in each group, with the buried elevation of +1.0m, -1.0m, -3.0m, -5.0m) are buried in the center of the two test areas to observe the pore pressure changes of deep soil; the field compaction is carried out at the four corners of the pore water pressure monitoring points according to the principle of "less compaction for many times and gradual compaction", After each tamping, the site shall be leveled and rolled. The construction parameters of dynamic consolidation are shown in Table 1. After compaction, heavy dynamic penetration test and vane shear test are carried out at the tamping points of the two test areas. The plane design of the drain board test area is shown in Figure 2.
Table 1. Construction parameters of dynamic consolidation.

| Tamping energy (kN m) | Tamping times | Tamping times per pass | Distance between adjacent tamping points (m) |
|-----------------------|---------------|------------------------|--------------------------------------------|
| 2000                  | 3             | 8                      | 1.0                                        |

Figure 2. Design plan of drain board test area.

4. Analysis of test results

4.1. Analysis of pore water pressure

Figure 3 shows the variation curves of soil layer pore water pressure in the drain board and non drain board area. It can be seen from the figure that under the action of dynamic consolidation, the pore water pressure in each test area increases, and the increase range of pore water pressure decreases along the depth of soil layer; Compared with the non drain board area, the peak value of pore water pressure in the drain board area is smaller, and the dissipation rate is significantly faster after each compaction, which indicates that the drain board is can effectively improve the drainage conditions of the soft clay layer under the hard shell layer, accelerate the consolidation speed of the soft soil foundation, and provide conditions for the next step of construction.

4.2. Analysis of dynamic penetration test results

Figure 4 shows the distribution curve of dynamic penetration number of each soil layer along the depth after the compaction. It can be seen from the figure that the dynamic penetration number of soil layer in the drain board area is significantly higher than that in the non drain board area, which indicates that the drain board dewatering measures can effectively improve the mechanical properties of soil layer; the growth trend of soil strength gradually decreases along the depth, and the growth effect is most obvious at the elevation +2.0m to -1.0m, At the elevation of -3.0m, the dynamic penetration number of the drain board area hardly increases, which indicates that the effective reinforcement depth of the energy level rammer is about 8.0m, which indicates that the effective reinforcement depth of the energy level rammer in the drain board area is about 8.0m.
4.3. Analysis of vane shear test results

Figure 5 shows the vane shear strength distribution curve of soft clay soil before and after dynamic consolidation. It can be seen from the figure that the vane shear strength has been improved to varying degrees after reinforcement. The shear strength of soil in the drain board area is significantly higher than that in the non drain board area, and the strength growth trend gradually decreases along the depth, indicating that drain board can effectively improve the mechanical properties of soft clay foundation, and the reinforcement effect is more obvious. In the elevation of -3.0m and below, the shear strength in the drain board area has no obvious increase, which corresponds to the results of dynamic penetration test. It further shows that the effective reinforcement depth of the inserting area is about 8.0m under the action of 2000kN·m tamping energy; In the elevation of -2.0m and below, the vane shear strength in the non drain board area has no obvious increase, in comparison, the effective reinforcement depth of the drain board area is shallow, which indicates that the water level is one of the main factors affecting the effective reinforcement depth of the foundation dynamic compaction. In the area with high groundwater level, reasonable and effective precipitation measures should be considered.

5. Discussion on effective reinforcement depth

The effective reinforcement depth of dynamic consolidation is one of the key factors in design and construction. Affected by the complexity of foundation soil and construction parameters, its theoretical calculation method has not been fundamentally solved, many scholars have also made a lot of research, T H Wang[8] summarized more than 40 effective reinforcement depth calculation methods according to different geological and construction parameters, and finally it is suggested to use the modified Menard formula to estimate the effective reinforcement depth.
\[ H = \alpha \cdot (Mh)^{1/2} \]  

\( H \) is the effective reinforcement depth (m); \( \alpha \) is the correction coefficient; \( M \) is the rammer weight.

Combined with the research results, the proposed correction coefficient \( \alpha \) is as follows: when considering groundwater, \( \alpha = 0.49 \), when the groundwater is not considered, \( \alpha = 0.51 \), its value is obviously beyond the range of backfill soil foundation proposed by T H Wang (\( \alpha = 0.20-0.40 \)), indicating that due to the influence of surface hard shell layer, the tamping energy is more easily transferred to the underlying soft clay layer, and the reinforcement effect is more obvious.

6. Conclusion
(1) For the saturated soft clay foundation with hard shell layer on the surface, the installation of drainage board can quickly dissipate the excess pore water pressure caused by dynamic compaction construction, effectively shorten the consolidation time of soft soil foundation, and strive for time for the next normal construction.

(2) Through the comprehensive analysis of the results of dynamic penetration test and vane shear test, it is concluded that compared with the non drain board area, the effect of dynamic compaction in the inserted drain board area is more obvious, and the mechanical properties of soft clay layer are effectively improved within the effective reinforcement depth.

(3) Groundwater level is one of the main factors affecting the effective reinforcement depth of dynamic consolidation foundation, In coastal areas with high water level, reasonable and effective precipitation measures should be considered.

(4) Based on the analysis of the test data, combined with the calculation formula of the effective depth, the estimation range of the correction coefficient is given, at the same time, it is verified that the surface hard shell layer is easier to transfer the ramming energy to the underlying soft clay layer, and the reinforcement effect is more obvious.

In this study, the reinforcement effect of drain board dynamic consolidation method is clarified, and the construction technology of large-area wharf yard foundation treatment is determined, which can provide a reference for the similar foundation reinforcement design and construction.

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