Comparative analysis of field test of dredger fill foundation reinforced by vacuum preloading method without sand cushion

Yao Xie* [a,b], Junlong Hu[a,b,c], Jing Wang[a,b,c], Deyong Wang[a,b,c]

[a] CCCC Fourth Harbor Engineering Institute Co., Ltd, Guangzhou, Guangdong, 510230, China
[b] Key Laboratory of Environment and Safety Technology of Transportation Infrastructure Engineering, CCCC, Guangzhou, Guangdong, 510230, China
[c] Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), Zhuhai, Guangdong, 519082, China

* Corresponding author: hjunlong@cccc4.com

Abstract. In order to explore the difference between vacuum preloading without sand cushion and gravel pile, sand pile, and surcharge combined sand pile technology on the reinforcement effect of soft soil foundation, comparative tests were carried out in four areas at the test site. The test results show that the vacuum preloading technology without sand cushion has good drainage performance. After using this technology, a hard-shell layer with high strength can be formed on the surface of the foundation, and the foundation treatment effect of the combined sand well technology is close to that of the vacuum preloading method. The study also found that the reinforcement uniformity of the sand-free cushion vacuum preloading method is weak, and the settlement is uneven during the process. The results of this study provide theoretical support for the comparison and selection of design schemes for soft soil foundation reinforcement.

Keywords: Vacuum preloading method without sand cushion; gravel pile; sand pile; Loaded combined sand pile; field test.

1 Introduction

With the increase in human engineering activities, the demand for land in the world continues to increase, especially in coastal countries and cities. Although China's coastal cities are economically developed, the per capita area is very small. With the continuous development of urban scale, the demand for land is also increasing. The lack of land resources seriously restricts the development of cities. Reclamation provides an important way to solve the problem of land scarcity and the effective use of coastal tidal flat resources. The Netherlands is the first country to implement reclamation. The scale of reclamation projects is huge [1], and more than 40 % of the land is formed by reclamation. Japan has long carried out large-scale land reclamation activities, and its Kansai International Airport built on the sea is a typical project [2]. China's

D. Li et al. (eds.), *Proceedings of the 2023 9th International Conference on Architectural, Civil and Hydraulic Engineering (ICACHE 2023)*, Advances in Engineering Research 228,
https://doi.org/10.2991/978-94-6463-336-8_13

coastal cities have also carried out a series of land reclamation projects according to their own characteristics. For example, Macao's area was only 11.6 km^2 in the early 20th century and reached 32.8 km^2 in 2015. The entire area of Macao International Airport was built by dredging and reclamation. Shanghai Yangshan Deepwater Port Project is an important land reclamation project in China. In modern society, more and more countries and regions have begun to use coastal tidal flat resources for reclamation.

China's reclamation projects usually use dredged soil as a dredger material. Because the dredged soil itself has the characteristics of high-water content, high void ratio, and low strength, it must be treated before it can be used for engineering construction. At present, the methods for reinforcing dredger fill at home and abroad mainly include vacuum preloading method, surcharge preloading method, vacuum-surcharge combined preloading method, cement-soil mixing method, electroosmosis method, vibroflotation gravel pile method, et al. Among them, the vacuum preloading method has become an ideal method for treating dredger fill due to its advantages of low cost, simple construction, and strong adaptability [3]. In the past, the dredger fill needed to be dried for a long time before the vacuum preloading treatment to make its surface have a certain bearing capacity, and then it was treated with the vacuum preloading method with sand cushion. In recent years, a vacuum preloading technology without sand cushion has been developed. After the dredger fill is completed, it does not need to be dried or dried for a short time, and the shallow layer is subjected to vacuum preloading without sand cushion, so that the surface layer has a certain bearing capacity and shortens the construction period. However, the understanding of dredger fill is still insufficient. Field tests are carried out on dredger fill to study the engineering characteristics of different construction techniques to reinforce dredger fill foundation, and to evaluate the reinforcement effect of different construction techniques, which can provide an objective and scientific basis for engineering design and construction.

2 Ground treatment scheme

This study intends to carry out the comparison between the vacuum preloading method without sand cushion and the other three foundation treatment construction methods, namely the gravel pile method, sand pile, and surcharge combined sand pile.

The vacuum preloading method is a kind of foundation treatment method in which a vertical plastic drainage belt or sand well is set up in soft clay, the sand layer is laid on it, and then the film is covered and closed. Air extraction makes the drainage belt and sand layer in the film in a partial vacuum state, excludes the water in the soil, and makes the soil pre-consolidated to reduce the later settlement of the foundation. This method was proposed by Professor W. Kjellman in 1952 [4]. It was first applied to engineering practice in 1958 [5], and the vacuum degree under the film can be maintained at about 80 kPa [6]. Many scholars [7] [8] in China have also done a lot of research on this technology. The research shows that the vacuum degree under the film is positively correlated with the reinforcement efficiency and effect, and the higher the vacuum degree is. The higher the efficiency, the better the effect. In addition, the length of the drainage plate and the degree of bending water also have an important influence on the treatment effect. The vacuum preloading method without sand cushion is not different from the conventional vacuum preloading method in principle. The sand cushion in the conventional method is removed in form, and the negative pressure is directly introduced into the soil through the drainage plate.

Gravel pile technology [9] [10] refers to the use of vibration or impact load to squeeze the pile pipe with the bottom of the valve-type spud can into the stratum. After the hole is formed in the soft foundation, the gravel is put into the pile pipe from the feeding port of the pile pipe, and then the pile pipe is compacted and pulled up to form a dense gravel pile and form a composite foundation with the soil around the pile. The reinforcement principle of this method in soft soil foundation is mainly to reduce the stress in soft soil, thereby reducing the consolidation settlement of the foundation, forming a drainage channel, and accelerating the drainage consolidation speed.

The sand pile [10] [11] is a kind of sand column, which is formed by using the method of impact or vibration to sink the steel casing into the foundation soil at a certain distance, then squeeze it into the hole, and then the sand is poured into the pipe and vibrated. A sand pile is a kind of composite foundation of the granular pile. It is one of the commonly used methods for soft foundation treatment. This treatment method plays a role in squeezing and compacting the entire foundation. The sand pile itself bears most of the load of the superstructure and foundation with its greater stiffness than the surrounding soil, thus forming a composite foundation with the surrounding reinforced soil. It can improve the bearing capacity of the foundation, reduce settlement, and prevent vibration liquefaction. It is suitable for the treatment of miscellaneous fill, cohesive soil, and deep loose sand foundation. Sandpile is divided into compacted sand pile and drainage sand pile. The former has a larger section and closer spacing. The pile has a higher bearing capacity and a larger deformation modulus. It forms a composite foundation with compacted soil between piles and bears the load transmitted by the foundation together. It can be used for collapsible loess, miscellaneous fill, and cohesive soil foundation. The latter is mainly used as a measure of foundation drainage, which can increase the permeability of pore water, shorten the drainage distance, and improve the bearing capacity of the soil. Generally, the diameter is smaller (20 ~ 30 cm) and the spacing is larger (more than 1.5 m).

Stacked load combined with sand pile [10] is to increase the load on the upper part of the original sand pile foundation, to accelerate the drainage consolidation rate of the soft soil foundation.

2.1 Test scheme

The research is based on the dredger fill site of a land formation project in Guangdong Province. As shown in Figure 1, the site is set up in four test areas, namely Area A, Area B, Area C and Area D. The area of each area is 20 m * 20 m. The four areas adopt different foundation treatment methods. Among them, Area A adopts gravel pile treatment technology, gravel pile spacing is 1. 2 m, gravel pile diameter is 0. 6 m; the sand pile treatment process is adopted in the B area, the sand pile spacing is 1. 2 m, the sand pile diameter is 0. 6 m; the combined treatment process of piled sand piles is adopted in the C area. The spacing of sand piles is 1. 2 m, the diameter of sand piles is 0. 6 m, and the three-level stacking is carried out according to the design requirements. Zone D adopts a vacuum preloading treatment process without sand cushion, and the spacing of drainage plates is 1. 2 m. Among them, the gravel pile treatment process in area A adopts gravel pile and sand doping. The ratio of sand and gravel in the first 10 meters is 1:1, and the ratio of sand and gravel in the last 10 meters is 7:3.

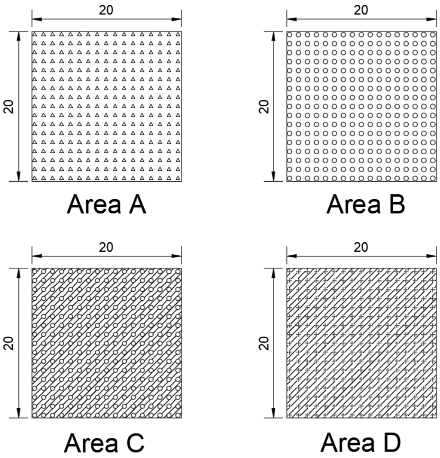


Fig. 1. Site layout diagram

2.2 Construction key point

The sand pile construction is arranged in a square, with a pile spacing of 1.2 m and a pile diameter of 0.6 m. The square arrangement is adopted, and the compacted sand pile penetrates the silt layer by one time the pile diameter. The construction requirements of the sand pile are as follows: the sand material of the sand pile is medium coarse sand, the mud content should not be more than 5 %, and a small amount of gravel with a particle size of less than 50 mm can be mixed in the sand material. According to the test pile technology, the filling coefficient of the sand pile is set to 1.3.

The gravel pile construction adopts a square layout, the pile spacing is 1.2 m, the pile diameter is 0.6 m, and the gravel pile penetrates the silt layer twice the pile diameter.

The requirements of the drainage plate insert board are as follows: the marking height and the top elevation of the drainage plate are determined according to the drawings, the height of the insert board is determined according to the drawings, the depth of the insert board is allowed to deviate by ± 20 cm, and the spacing of the drainage plate is 1.2 m×1.2 m. After the application is completed, the top surface of the drainage plate should be exposed to 250 mm.

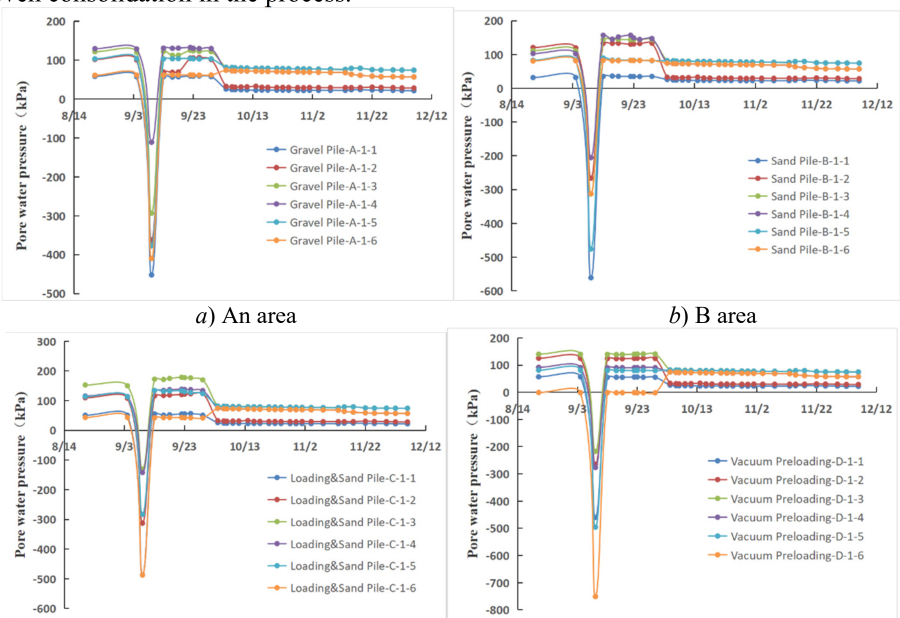
Loading requirements: According to the loading plan, all levels of load are applied, and the graded loading strength does not exceed the design grading requirements. The first stage load is 0.5 m, the second stage load is 2.0 m, and the third stage load is 1.5 m.

3 On-site monitoring data and analysis

The pore water pressure measuring points and settlement observation points are set up in four regions A, B, C, and D, and six pore pressure measuring points are set up in a single region. The arrangement of measuring points in the four regions is consistent.

After the sand pile is formed, the quality inspection should be carried out at a certain time interval. According to the " Technical code for the ground treatment of buildings, 7.2.5: the silty clay foundation should not be less than 21 days, the silt foundation should not be less than 14 days, and the sand and miscellaneous fill foundation should not be less than 7 days. The backfill of this project is clay, and the bottom is silt and clay. It should be detected after the completion interval of sand pile construction is more than 21 days. The monitoring results are as follows.

Figure 2 are the pore water pressure change curves of A, B, C, and D areas respectively. The initial pore water pressure distribution in A, B, and C areas is approximately the same, and the pore water pressure value of the No.6 measuring point in the D area, that is, no sand cushion vacuum preloading method area, is close to 0. In the later stage of the test, the pore water pressure in each region is stable. During the test, there is a large difference in pore water pressure between the treatment process area (C area) and the vacuum preloading area without sand cushion (D area), indicating that there is uneven consolidation in the process.



a) An area *b*) B area

c) C area *d*) D area

Fig. 2. The variation curve of pore water pressure

Settlement monitoring results are as follows.

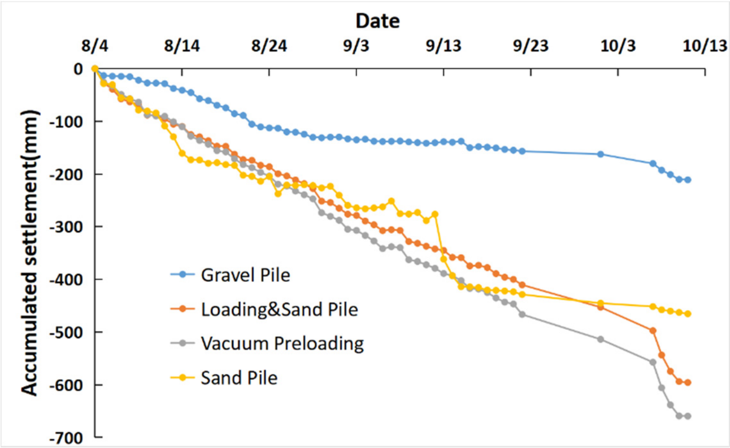


Fig. 3. Settling curve

Figure 3 is the average settlement curve of the four regions, and the settlement is calculated by the average value of each measuring point in the region. From the diagram, the settlement of the gravel pile method area is always smaller than that of other areas, because the pores of the gravel pile are large, and the fine particles in the soft soil foundation are easy to enter the pile body, affecting the permeability of the pile body. On the other hand, the gravel pile has a high bearing capacity and interacts with the soft soil foundation to form a composite foundation. The deformation of the foundation needs to be coordinated during drainage consolidation. While the pile itself resists deformation, it also pulls the soil around the pile to resist and reduce deformation. The deformation of the vacuum preloading area without sand cushion is the largest. Under the action of negative pressure and drainage body formed by vacuum preloading, the water of soft soil is rapidly discharged, and the foundation is rapidly consolidated to form a certain strength. The settlement of the surcharge combined sand pile area is close to that of the vacuum preloading area without sand cushion, mainly because the surcharge reaches a similar negative pressure effect, while the sand pile is like the drainage body in the vacuum preloading, which can quickly discharge the free water in the soil.

Figure 4 shows the variation curve of the standard penetration number with depth in each area. The test object of a standard penetration test is soft soil in this area, so the data does not represent the average bearing capacity in this site. It can be seen from the figure that the standard penetration law of each area is generally close, and the number of hits of soil in 0 ~ 4 m is large. Among them, the number of hits in the vacuum preloading area without sand cushion is the largest. The main reason is that the vacuum degree under the membrane on the surface is large, and the drainage consolidation effect is more significant. In the range of 4 ~ 14 m, the number of hits is similar, and the number of hits is about 1. In the range of 14 ~ 18 m, the SPT of soft soil increases rapidly.

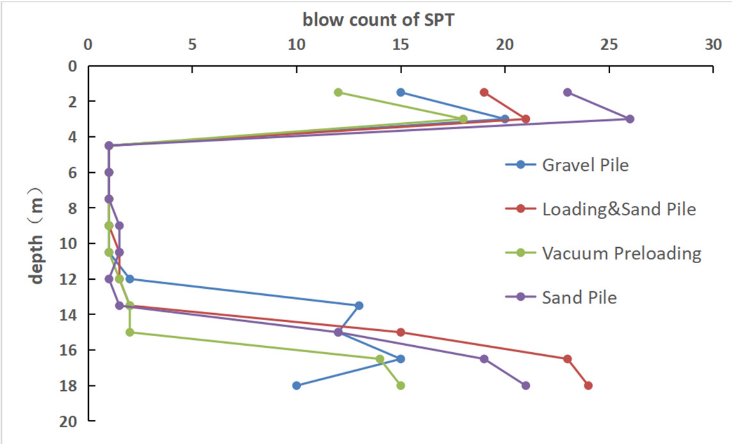


Fig. 4. The depth distribution curve of the SPT

4 Conclusions

In this paper, through field tests and corresponding monitoring tests, the reinforcement effects of four foundation treatment processes, including vacuum preloading without sand cushion, gravel pile method, sand pile, and sand pile combined surcharge, are compared, and analyzed. The main conclusions are as follows:

(1) The pore water pressure distribution of sandpile combined surcharge technology and sand-free cushion vacuum preloading method is more dispersed during the treatment process, and the obvious uneven settlement may occur during the construction process.

(2) Gravel pile has a high bearing capacity of the foundation, and can reduce the deformation of the foundation after forming a composite foundation with soft soil. The vacuum preloading method without sand cushion has good drainage performance and a good foundation reinforcement effect. The effect of sand pile combined surcharge technology is second only to the vacuum preloading technology without sand cushion, and the effect of drainage body formed by sand well under the action of surcharge.

(3) The SPT depth distribution of the soft soil foundation treated by the four methods is consistent. Among them, the surface layer of the vacuum preloading method without sand cushion has the largest number of hits, indicating that the method forms a hard-shell layer with greater strength after reinforcement.

Although this paper compares the reinforcement effects of the four technologies through field tests, only the strength changes of the soil are analyzed, and the overall foundation-bearing capacity is not compared and analyzed. In addition, for different soft soil foundations, the reinforcement effect of the technology will also be different. Further analysis and evaluation will be carried out to provide a reference for engineering practice.

References

1. Du Dongju, Yang Aiwu, Liu Ju, et al. Tianjin Binhai Reclamation [M]. Beijing: Science Press, 2010.
2. Takeshi Suzuki. Economic and geographic background of land reclamation in Japanese ports[J]. Marine Pollution Bulletin, 2003, 47(1): 226-229.
3. H. Mahfouz Ali, Liu Hanlong, C. F. Chiu. Laboratory study for effects of vacuum preloading on physical and mechanical properties of soft clayey soils[J]. Journal of Southeast University (English Edition), 2005, 21(1): 85-90.
4. Kjellman W. Consolidation of clay by mean of atmospheric pressure. In Proceeding of a Conference on Soil Stabilization, MIT, Boston, 1952, 258-263.
5. Halton G, Loughney R, Winter E. Vacuum stabilization of subsoil beneath runway extension at Philadelphia International Airport. Proe. of IV. ICSMFE, 1965, 61-65.
6. Lian Feng, Gong Xiaonan, Zhang Changsheng. Analysis of the effect of vacuum preloading on soft foundation treatment [J]. Industrial Architecture, 2007, 37 (10): 58-62.
7. Zhang Qinghua, Tang Liansheng, Liao Huarong, et al. Calculation and application of effective stress increment of soil mass under vacuum preloading [J]. Journal of rock mechanics and Engineering, 2006, 25 (Add 2): 3565-3571.
8. Song Peige. Application of vacuum preloading method in soft soil foundation reinforcement in Wenzhou and research on environmental effects [D]. Hangzhou: Zhejiang University of Technology, 2010.
9. Liu Mengjie, Chang Guanglei. Comparative study on on-site static load tests of composite foundation with crushed stone piles and wrapped crushed stone piles [J]. Highway, 2022, 67 (09): 61-69.
10. Zheng Gang, Gong Xiaonan, Xie Yongli, Li Guangxin. Overview of the Development of Foundation Treatment Technology [J]. Journal of Civil Engineering, 2012, 45 (02): 127-146.
11. Lin Ming, Liang Hang, Liu Xiaodong, Li Jianyu. The offshore compaction sand pile construction method and its application in the island tunnel engineering of the Hong Kong Zhuhai Macao Bridge [J]. China Harbour Construction, 2012 (04): 72-77.