ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.2.1.P145

Consolidation Analysis of Soft Foundation of Airport Hydraulic - Filled Sand with Surcharge Preloading

Haiwang Liu [1], Chi Ma [2], Zhaoyun Xiao [3, 4, a], Dan Yang [3], Haojie Zhu [4], Shanjing Huang [4]

[1] Fujian Panport Airport Construction Co., Ltd., 361000, Xiamen;

[2] Shenzhen Research and Design Institute of China Academy of Railway Sciences, 518054, Shenzhen

[3] Huaqiao University, 361021, Xiamen;

[4] China Civil Engineering (Xiamen) Technology Co., Ltd, 361021, Xiamen.

[a] zyxiao@hqu.edu.cn

Abstract: The foundation treatment of a new airport reclamation project in Xiamen has been completed. Due to the design change of the elevation of the landmark, the post-construction settlement of some ultra-deep silt foundations does not meet the design requirements. It is proposed to carry out secondary foundation treatment by means of surcharge preloading. Through on-site tests method, a comprehensive evaluation of the treatment effect of surcharge preloading is carried out. The conclusions are as follows: The development laws of measured data such as surface settlement, layered settlement, and pore-water pressure are relatively consistent; Preloading with surcharge has a relatively good effect on treating such ultra-soft foundations filled with dredged sand and can meet the requirements for post-construction settlement and differential settlement, making up for the deficiency of primary foundation treatment and providing a reference for subsequent similar projects.

Keywords: secondary foundation treatment; surcharge preloading; ultra-deep silt of hydraulic-filled sand; on site monitoring

1. Introduction

The runway area of Macau International Airport was built on an artificial island with extremely soft and deep silt. This area was mainly reclaimed from the sea [1]. The main area adopted the surcharge preloading method to deal with differential settlement, and the effect was quite good. The water depth in the construction sea area of Kansai Airport was approximately 15 to 20 meters [2]. The surcharge preloading method was adopted, providing a reference for the subsequent construction of reclaimed airports. The foundation treatment of Hong Kong International Airport put forward suggestions that the surcharge preloading method was suitable for treating soft foundations, etc. [3]. The runway of Wenzhou Airport adopted surcharge preloading due to the soft foundation, and it has been working well so far [4]. Ningbo Airport used the sand drain surcharge preloading method to reinforce the deep silt and soft foundation of the airfield pavement [5]. The foundation of Zhoushan Airport reinforced the runway by the bagged sand drain surcharge preloading method, and the treatment effect was good [6]. The runway of Pudong Airport faced the problem of soft soil foundation settlement and adopted surcharge preloading to treat the soft soil foundation [7]. There are not many cases of building airports on dredged fill foundations at home and abroad. From the above cases, it can be seen that using the surcharge preloading method to treat the soft foundation of coastal airports is a safe and reasonable approach.

The construction land of a new airport was reclaimed on a large scale. Due to the latest planning adjustment, the elevation was raised by 2 meters. For the areas where the thickness of silty soft soil exceeded 10 meters, the predicted post-construction settlement had already exceeded 25 centimeters, which did not meet the land delivery requirements. For this reason, secondary foundation treatment was carried out for the settlement problem of the deep silt foundation faced by the runway dredged sand filling project. In this test area, the secondary foundation treatment adopted the surcharge

ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.2.1.P145
preloading method with a one-time and continuous load of 8 meters. The research results can provide reference and guidance for similar projects.

2. Project Overview

The thickness of the soft soil in the original sea area of the new airport site was unevenly distributed, with the thickest part exceeding 17 meters. This test area is located in the planned North Runway No. 1 area on the east side of the site, covering an area of approximately 5,577 square meters. The thickness of the silt layer on the site ranges from 9.5 to 15.0 meters. According to on-site settlement monitoring and calculation studies, the post-construction settlement of some soft foundations on the site where the thickness of the silt layer exceeds 10 meters does not meet the land use requirements of the airport's airfield area. Due to the tight schedule, the surcharge preloading method with continuous and uninterrupted loading was adopted to treat the ultra-soft foundation.

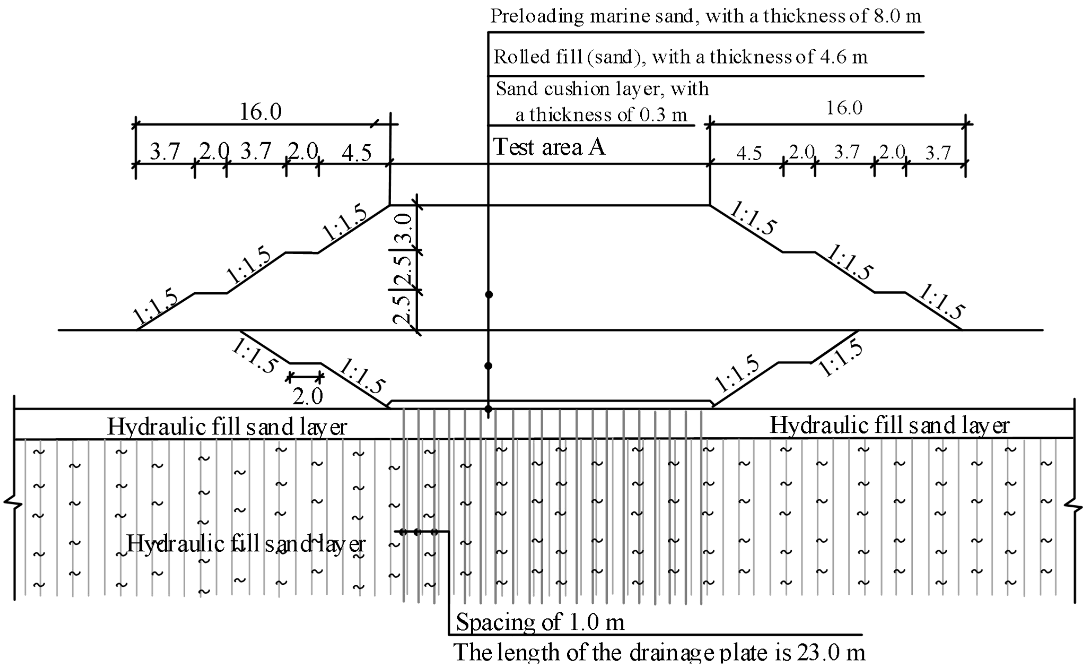

Fig. 1 Overloading preloading secondary foundation treatment profile

3. Surcharge Preloading Design and Monitoring Plan

3.1 Embankment Loading Design Scheme

The sand on the site surface was relatively compact, which made it impossible for the plastic drainage boards to be inserted smoothly. The site was excavated to an elevation of 4.0 meters, then a 0.3-meter-thick sand cushion layer was filled and plastic drainage boards were driven in. The plastic drainage boards were arranged in a square pattern with a spacing of 1 meter between them. Each plastic drainage board had a cross-sectional dimension of 100 mm by 5 mm and a length of 19 meters. Then the filled earth (sand) was rolled to the elevation of the ground surface. Due to the tight schedule, continuous loading was carried out for 15 days, and the preloading sand (soil) with a height of 8.0 meters was completed by loading with a slope of 1:1.5. The filling and loading time was 180 days.

3.2 Monitoring Scheme

Monitor the changes in site settlement rate, settlement amount, and pore water pressure during the secondary preloading period. Settlement plates are placed on the top surface of the sand cushion

ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.2.1.P145
layer to monitor the total settlement amount, with a total of 5 points. Layered settlement markers and settlement measurement rings are respectively arranged at the lower, middle, and upper parts of the silt layer to monitor the settlement amount of different layers, with a total of 3 points. Pore water pressure gauges are arranged in 3 groups, with 3 gauges at the lower, middle, and upper parts of each group to monitor the dissipation of excess pore water pressure in the silt layer. The layout plan of the monitoring points is shown in Figure 2. The monitoring frequency is once a day during the earth filling construction period, once every 3 days during the earth filling break period, and once a week after the earth filling is completed. At the same time, the pore water pressure is monitored by a combination of manual and automatic monitoring methods to ensure the accuracy and frequency of monitoring and to enable timely reflection of the monitoring data.

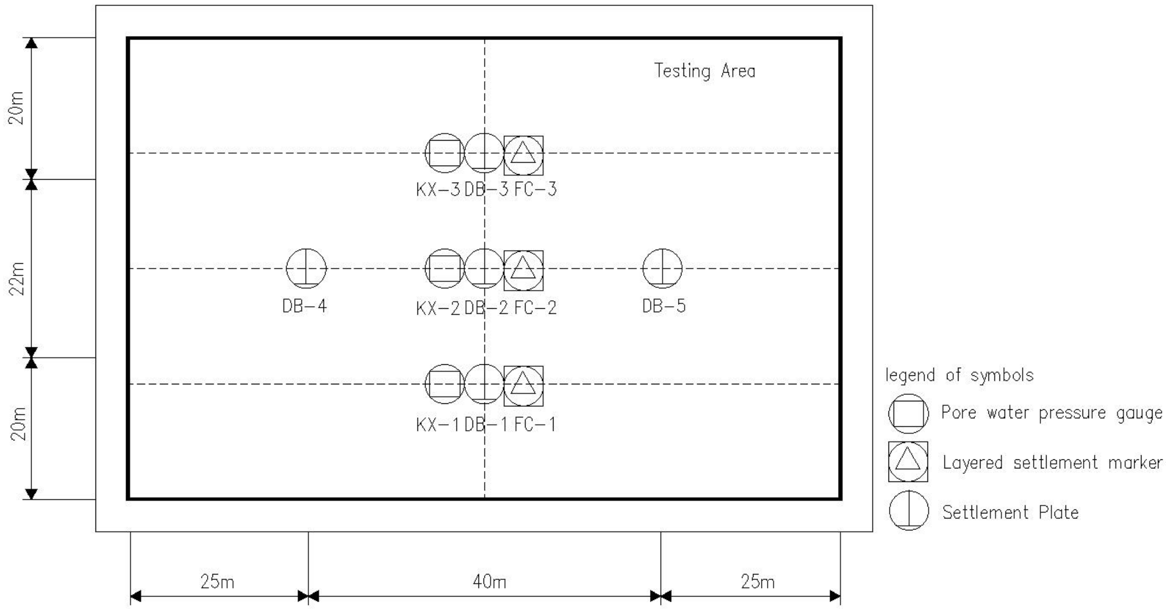

Fig. 2 Layout plan of monitoring points in the test area

4. Monitoring Data and Regularity Analysis

4.1 Analysis of Surface Settlement Monitoring Data

The surface settlement variation curve during the entire filling process is shown in Figure 3, and the surface settlement rate curve is shown in Figure 4. As can be seen from the figures, the surface settlement consists of three stages. The first stage is the settlement during the filling period from 0 to 45 days when filling to the elevation of the original ground surface. The second stage is the 15-day loading period from 45 to 60 days. The third stage is the settlement after the end of the loading from 60 to 206 days. The thickness of each layer during the layered backfilling and rolling is 30 cm. During the backfilling process, the surface settlement develops linearly, with an average settlement rate of 2.65 mm/d. In the first stage, the surface settlement ranges from 103.4 to 125.3 mm. This settlement amount is caused by the rebound and recompression of the excavated and unloaded soil mass.

After the start of the second stage, the surface settlement rate increases significantly, and the settlement develops rapidly. The average settlement rate during the loading period is 11.5 mm/d. After full loading, the settlement rate gradually slows down, and the settlement curve gradually becomes gentler. When it reaches 206 days, the maximum surface settlement reaches 690 mm. The surface settlement rates at various points are between 0.3 and 0.5 mm/d, and the slowdown of the settlement rate is relatively stable.

ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.2.1.P145

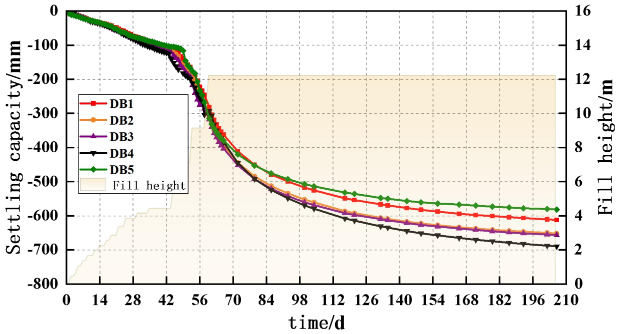

Fig. 3 Surface settlement monitoring curve

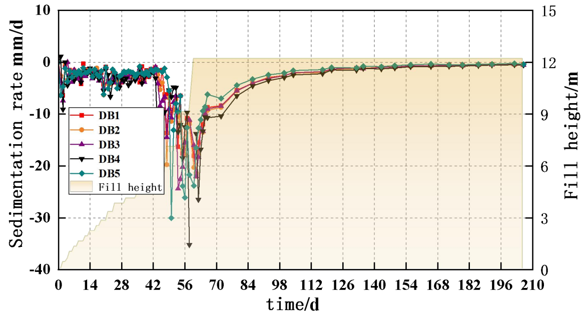

Fig. 4 Monitoring curve of surface settlement rate

4.2 Analysis of Layered Settlement Monitoring Data

Three layered settlement monitoring points (FC1 - FC3) were selected at the central position within the test area to monitor the layered settlement magnitudes at five different depths on the upper, middle, and lower parts of the silt at each point. The monitoring curves are shown in Figures 5, 6, and 7. As can be seen from the figures, the settlement trends of Layer 1, Layer 2, and Layer 3 are similar. The settlement rates increase rapidly during the surcharge loading and then become gentle with the passage of time. Basically, the compression amount of the shallow soil layer is relatively large, and the change rate is high during loading, while the compression amount of the deep soil layer is not obvious, and the settlement rate is small during loading. The settlement trends at the same depth positions of different monitoring holes are also the same. The settlement development law of the silt layer is also similar to that of the surface settlement. During the backfilling and rolling process, the layered settlement increases slowly and linearly. During the loading period, the layered settlement rate accelerates and increases. With the progress of surcharge loading, the layered settlement rate gradually decreases. Currently, the maximum value of the layered settlement curve converges at 539 mm. The layered settlement amount is larger at the upper part and smaller at the lower part in space. The maximum layered settlement reaches 539 mm, which is located at the top position of the silt in the center of the test area. At the bottom of the silt at each point, a settlement of more than 100 mm is generated. At the same time, the distance between the ordinates of two layered settlement curves (that is, the settlement difference) represents the compression amount of the soil mass between the two magnetic rings. According to the compression amounts of the soil masses at each layer, it can be seen that in the entire soil layer, generally speaking, the compression amount of the soil mass between the magnetic rings decreases as the depth increases, and the settlement mainly occurs in the upper silt layer. The compression rate at the top of the silt is the largest, reaching a maximum of 5.5%. The monitoring data of the layered settlement reflects that the surcharge preloading has a significant effect on the treatment of the shallow soil mass, and the effect of the preloading treatment decays as the depth increases.

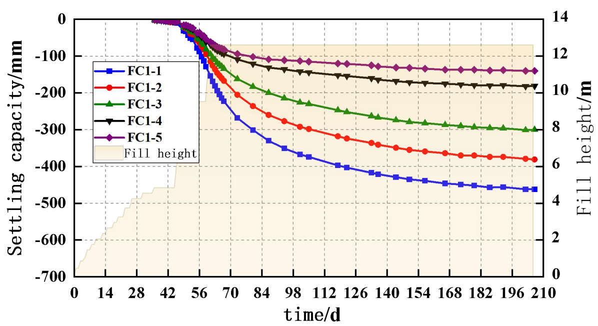

Fig. 5 Layered settlement 1 monitoring curve

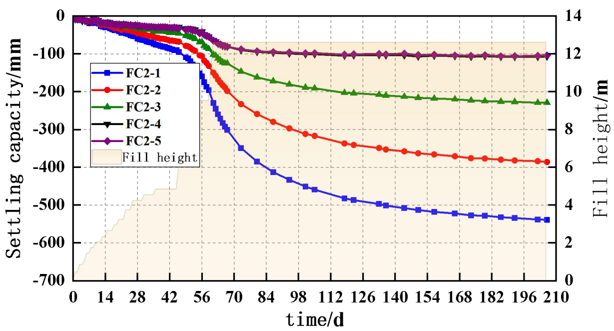

Fig. 6 Layered settlement 2 monitoring curve

ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.2.1.P145

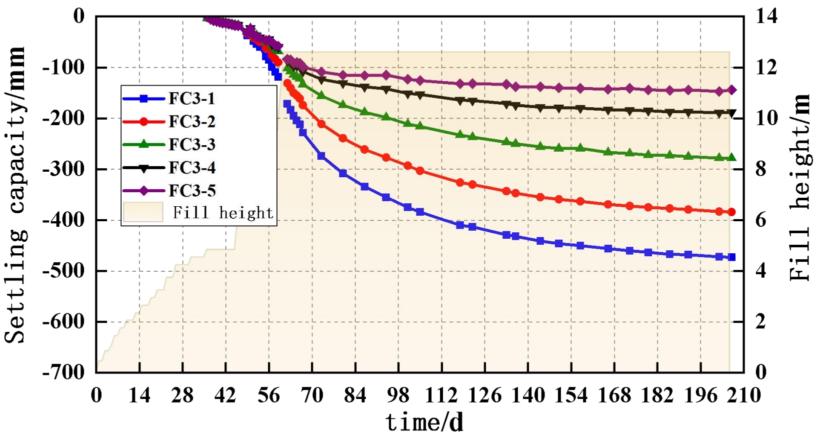

Fig. 7 Layered settlement 3 monitoring curve

4.3 Analysis of Pore Water Pressure Monitoring Data

Three pore water pressure monitoring points (K1 - K3) were respectively arranged at the positions corresponding to the layered settlement points within the test area to monitor five different depths at the upper, middle, and lower parts of the silt at each point, so as to immediately reflect the increase and dissipation of the excess pore water pressure under the action of surcharge loading, as shown in Figures 8 - 10.

According to the monitoring results of pore water pressure, during the entire loading process of the foundation, due to the load acting on the upper part of the foundation, the pore water pressure in the foundation soil will gradually increase. And the pore water existing in the soft soil cannot be drained out in time within a short period, so the excess pore water pressure is generated. The initial pore water pressure is basically equal to the hydrostatic pressure. During the period of layered rolling and backfilling, the pore water pressure basically remains unchanged. Due to the small thickness of the layered rolling and the unloading rebound, the pore water pressure slightly increases during backfilling, but it also dissipates relatively quickly. Basically, no excess pore water pressure is generated during the backfilling process. At the top position of the silt, which is close to the upper sand layer, the pore water is quickly drained out along the sand layer during the loading and full-loading processes, and the change in the excess pore water pressure is not obvious. During the surcharge loading process, the maximum excess pore water pressure generated at each point is located in the middle of the silt, and the maximum excess pore water pressure generated is 94 - 109 kPa. Thanks to the effect of the plastic drainage boards in the foundation soil, the pore water in the foundation soil is gradually drained out, and the excess pore water pressure gradually dissipates. As time goes by, the pore water pressure at each monitoring point is gradually dissipating. The excess pore water pressure in the middle of the silt has dissipated by about 84 kPa (lasting for 105 days). Up to now, the excess pore water pressure is 1 - 19 kPa, and the excess pore water pressure within the range of about 3 meters deep from the top of the silt has basically completely dissipated.

Based on the on-site measured data, the final settlement amounts of the ground surface from 1 to 5 are calculated by the traditional prediction method. The final consolidation degrees and final settlement amounts of the soil layers at each measuring point [8] are shown in Table 1.

It can be seen from Table 1 above that, as predicted by the three traditional methods, the consolidation degrees of each measuring point are all greater than 90% and fall within the range of 90% - 92%. The differential settlement is relatively small. As shown in Figure 3, the settlement rate is less than 0.5 mm/d, which meets the unloading and land delivery standards. This indicates that the surcharge preloading method takes a relatively short time and has a good treatment effect.

ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.2.1.P145

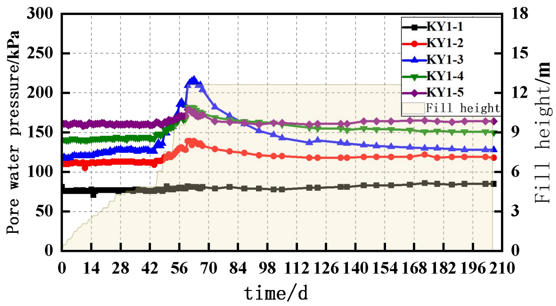

Fig. 8 Monitoring curve of pore water pressure 1

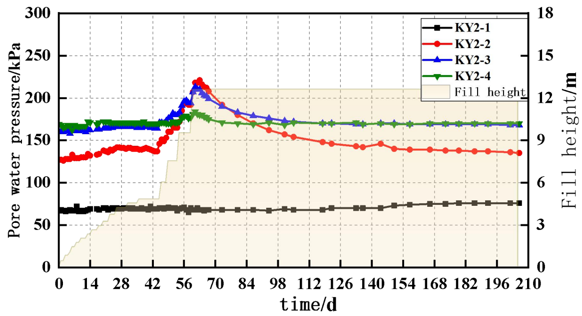

Fig. 9 Monitoring curve of pore water pressure 2

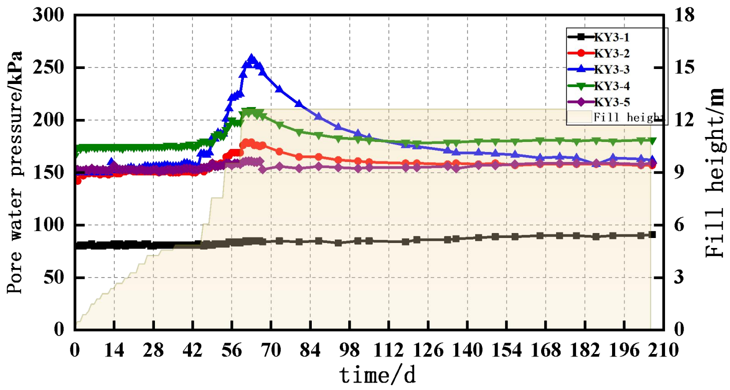

Fig. 10 Monitoring curve of pore water pressure 3

Table 1 settlement and consolidation calculation of each point

	Predicted values			Consolidation degrees		
Measuring points	Three-point method	Asaoka method	Hyperbolic method	Three-point method	Asaoka method	Hyperbolic method
DB1	677	680	678	90%	90%	90%
DB2	716	711	720	91%	91%	92%
DB3	722	717	722	91%	91%	92%
DB4	758	753	770	91%	90%	92%
DB5	643	649	631	90%	92%	90%

5. Conclusion

The following conclusions are obtained through the consolidation analysis of the soft foundation treatment by surcharge preloading at the airport:

Through manual and automatic monitoring of the soft foundation treatment by surcharge preloading, it can be found that the settlement and compression deformation of the soft soil layer is slow during the foundation treatment and compaction period, develops rapidly during the surcharge loading period, and tends to be stable after the surcharge loading is completed. The excess pore water pressure shows a consistent change law: the pore pressure hardly changes during the compaction period, increases rapidly during the surcharge loading period, and almost completely dissipates after the surcharge loading is completed. The measured results show that the surcharge preloading has a relatively ideal effect on treating the ultra-soft silt foundation of the hydraulically filled sand, and the drainage and compression effect of the silt layer is good, which is beneficial to controlling the post-construction settlement and differential settlement.

The surface settlement rates at all locations are less than 0.5 mm/d, the consolidation degrees are all greater than 90%, the post-construction settlement is less than 25 mm, and the differential settlement is relatively small. This has made up for the deficiencies of the first foundation treatment and meets the requirements for land delivery. Therefore, the surcharge preloading method has a

ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.2.1.P145
relatively good effect on treating such ultra-soft foundations filled with dredged sand and can meet the requirements for post-construction settlement, which can provide a reference for similar projects in the future.

Acknowledgment

This research was funded by Industry-University Cooperation Funding Project of Universities in Fujian Province. (No. 2023Y4007).

References

[1] Liu Yixiong, Tang Yisheng. Foundation treatment of the artificial island of Macau International Airport [J]. China Harbour Engineering,1994,(03):54-64..

[2] Zhao Zhendong. Construction of Kansai International Airport on the sea in Japan and its submarine foundation treatment [J]. World Earthquake Engineering,1992,(01):37-40+44.

[3] Koutsoftas D C , Foott R , Han Df Elt L D . Geotechnical Investigations Offshore Hong Kong[J]. Journal of Geotechnical Engineering, 1987, 114(2):87-105.

[4] Zhang Lei, Gao Yufeng, Wang Jun. Study of deformations of Wenzhou Airport over-consolidated soft clay foundation under cyclic aircraft loading[J]. Journal of China Three Gorges University(Natural Sciences), 2013,35(03):59-64+68.

[5] Zhu Xiangrong, Pan Qiuyuan, Bian Shouzhong, et al. Strengthening of soft clay ground of Ningbo Airport runway by surcharge precompression[J].Chinese Journal of Geotechnical Engineering, 1992,(S1):30-38.

[6] Xie Xinyu, Zhu Xiangrong, Pan Qiuyuan, et al. Effects of Zhoushan Airport runway improved by surcharge precompression combined with vertical drains[J]. China Civil Engineering Journal, 2000, 33(3):60-65.

[7] Ren Yi. Study on preloading settlement monitoring of west taxiway soft soil subgrade near the 4th runway at Shanghai Pudong International Airport[J].Urban Roads Bridges & Flood Control, 2014,(05):50-52+55+7-8.

[8] Su Junjian, Xia Chaoqun. Application of construction survey data for ground strengthening by loading pre-pressure[J]. Port & Waterway Engineering, 2009,(03):128-131.