Research on key technology of cement mixing plie on clay layer with high plasticity index

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Abstract. Cement mixing pile is one of the common methods for road embankment foundation reinforcement, which can improve the bearing capacity, reduce the post-construction settlement caused by embankment loading, and increase the overall stability of embankment. In this paper, through field tests, lab tests and theoretical analysis, the factors affecting the quality of cement mixing piles in deep high plasticity clay soil are analyzed and the results of field tests and lab tests are compared, and finally the key construction parameters and relevant pile strength data in deep marine clay soil area are derived for similar projects.

Keywords: Cement mixing pile; high plasticity clay; six times stir and four times spray.

1. Introduction

The foundation of embankment generally needs ground improvement to improve its bearing capacity, reduce settlement and improve the overall stability of the embankment. The common methods are replacement method, pre-loading method, crushed stone pile method, cement mixing method, etc.

The commonly used cement mixing pile method has the characteristics of fast construction speed and reliable quality in soft soil, but the adoption of cement mixing pile has certain requirements on soil quality. Section 7.3.2 of the Technical Code for Ground Treatment of Building (JGJ 79-2012)[1] stipulates that when cement soil mixing piles are used to treat clay soils with plasticity index greater than 25, their applicability must be determined by field and laboratory tests.

Currently, many scholars are conducting certain explorations on the application of cement mixing piles in high plasticity clay soils. The current research shows that the pile formation quality of mixing piles in high plasticity soils is closely related to the water content of the treatment soil layer, liquid plasticity index, etc. However, the current research mostly focuses on the local adjustment of construction equipment to improve the stirring performance.

For example, Liu Zongguang et al[2] improved the piling quality of cement mixing piles by optimizing the number of layers and blade angle of the mixing wing of the processor and changing the processor and other related technical measures in the project of three runs of an international airport. Wang Chuang et al[3] analyzed the cement mixing pile project in an operation area of Lianyungang inland port area, similarly, the expected effect of cement mixing pile can be achieved by appropriately increasing the output power of power head, appropriately increasing the spacing of two-blade mixing head and increasing the mixing time, etc., to ensure that the soil can be fully mixed.

The clay soil with high plasticity index is not easy to be mixed evenly when treated by mixing method. Increasing the moisture content rate will lead to a significant decrease in strength, such as Li Li[4] studied the reinforcement of silty clay soil in Foshan area by cement mixing pile, and the research showed that for the silty clay soil with high moisture content and high plasticity index, the effect of powder spray reinforcement of soft soil is obviously better than slurry spray.

Studies in the handbook of foundation treatment manual[5] show that when the water content of the soil varies between 50% and 85%, the strength of the cement soil can be increased by 30% for every 10% reduction in water content.

There are few studies on cement mixing pile reinforcement in high plasticity clay soils, and the plasticity index of the high plasticity clay soil involved in the above study only reaches about 34, which is much lower than the maximum plasticity index of 69 in this project. Therefore, this paper is very important for the study of the key technology of cement mixing pile construction in clay with high plasticity index.

2. Overview

2.1 General situation of project

The project is located in Palaniac City, Manila region, part of the section is by the sea. The design cement soil mixing pile diameter is 0.8m, pile length from 6m to 20m, pile spacing of 1.3m and 1.5m, the design unconfined compressive strength value is 1.7MPa.

2.2 Stratum

Geological data reveal that there are deep soft layers distributed in the strata where the project is located, the thickness is about 6m~18m, and the average number of standard penetration blows is 1.5. The ground water is 2m to 4m below the surface. The overall main strata in the project site are as follows:

(1) Sandy clay (CL-CL), low to medium content clay silt (ML-MH), and contains a small number of fine gravel particles. The layer thickness is 1.5~5.5m, and the standard penetration number is 3~16 blows.

(2) Fine sand (SM), containing a small amount of shells. Standard penetration test number 6 to ~22 blows. The thickness of the soil layer is 3~12m.

(3) Hard clay (CL) or high plastic clay silt (ML) contains a small amount of sand. Standard penetration test number is 10~52 blows.

(4) Interlayer between dense sand and underlying rock, brown, dense to very dense sand (SM) or gravel.

2.3 Plastic and liquid index

The plastic index, liquid index water content are calculated based on the 41 boreholes in the geological exploration data, as shown in Figure 1.

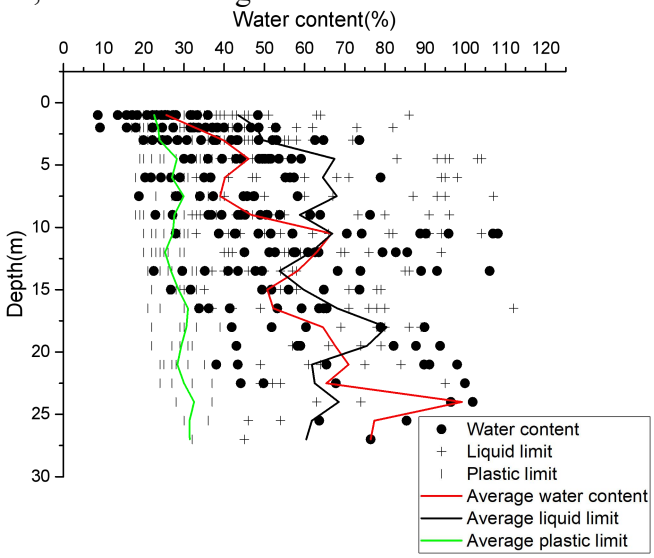


Fig. 1 Liquid limit, plastic limit and water content vs depth

According to the analysis of laboratory test data, the range of highly plastic soil layer is mainly concentrated in the elevation below 4.5m to 27m depth, and the plasticity index is basically greater than 30, and the maximum value is 68. Above 10m, the natural water content is low; Below 10m, the natural moisture content is basically near the liquid limit. According to the scope of

reinforcement and soil layer parameters, the soil layer difficult to be strengthened by mixing pile is above 10m.

3. Laborabory test

3.1 Test parameters

It was found that the high plastic clay mixed with cement block in the previous test pile, and failed to form pile. The reason of not piling is mainly because the plasticity index of soil layer is high, the moisture content is low, and the cement slurry can not be evenly mixed with the soil. Therefore, the laboratory test is mainly to explore the water pre-stirring to improve the mixing performance, and another purpose is to verify the strength of the cement soil after the water pre-stirring.

The water-cement ratio in this test is 0.8 and 1.0. The cement content is 12%, 16% and 20% respectively. Figure 2 shows the indoor test model of cement soil. Figure 3 shows the excavated samples taken from the site.

Fig. 2 Cement mixed soil sample

Fig. 3 Soil sample

3.2 Laboratory test results

Figure 4 and Figure 5 show the photos of cement soil sample mixed directly with cement slurry without adding water and the photos of cement soil after pre-mixing with water, respectively. When the cement slurry is added directly, the soil sample quickly becomes dry and solidified, and the sample is clumpy or lumpy. The cement mixed soil solidifies quickly and cannot be stirred evenly, and the sample cannot be molded. After the sample is pre-stirred with water, the water added is 15% of the weight of the soil, the original soil is stirred with water into soft clay, and then the cement slurry is stirred, the mixing performance is better.

Fig. 4 Soil sample without pre-striring

Fig. 5 Soil sample with pre-stiring

The age of indoor cement soil sample testing is 40d. The 28d unconfined compressive strength is calculated according to literature [5].

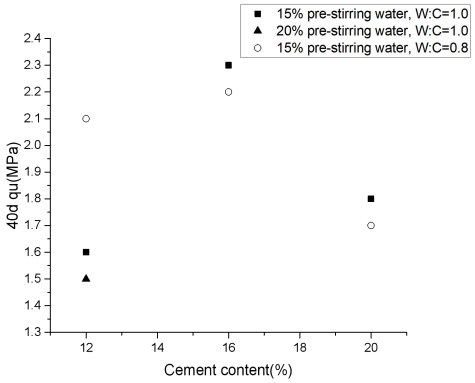


Fig. 6 The 40d test result

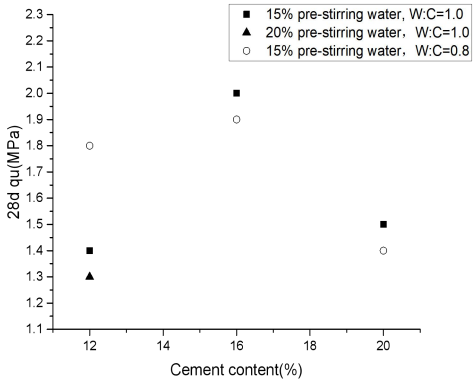


Fig. 7 Calculated 28d results

According to Figure 6, the unconfined compressive strength measured for 40 days is all above 1.5MPa, among which the overall strength of cement soil with 16% content is the highest and the minimum value is 2.2MPa; the unconfined compressive strength of samples in the two groups with 12% content water-cement ratio of 1.0 is the lowest, which is 1.5MPa and 1.6MPa, respectively. The minimum and maximum unconfined compressive strength of 28d are estimated to be 1.3MPa and 2.0MPa respectively.

According to the current research, cement content and strength should be positively correlated, and the test results show that the overall strength of 20% cement content is lower than that of 16% cement content, which may be related to the lack of shaking table and the high plasticity of soil layer, which is difficult to completely stir evenly. Figure 8 shows the section of cement soil sample after unconfined compressive strength test. Small clay blocks are difficult to be completely mixed both indoors and on site. During indoor mixing, the soil sample sticks to the reamer head in clumps, resulting in local clay layer aggregation and reducing the strength of the sample. Limited by construction conditions, no repeated tests were carried out.

Fig. 8 The failure plane of cement mixed pile

4. Field tests

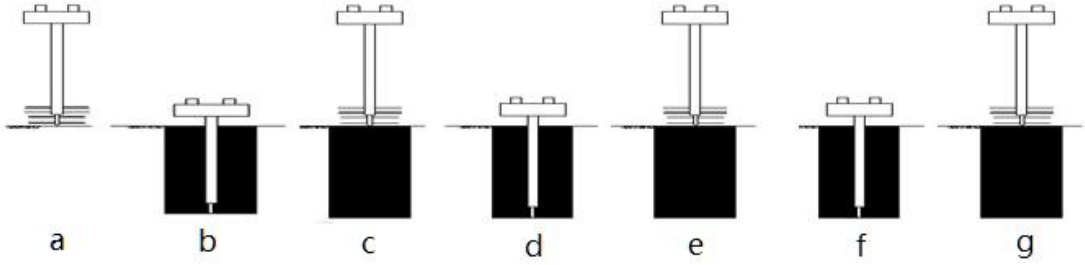
The field test is mainly based on the parameters obtained in the laboratory test. In addition, it is necessary to obtain the large-area field construction parameters and the strength relationship between the field cement mixing pile and the laboratory test sample.

The site construction equipment adopts PH-5D-55 enhanced single-axis cement mixing pile machinery, the pile diameter is up to 1000mm, the drilling speed is 0.05-2.7 m/min, the core pile length is up to 23m, and the net height from the ground is 700mm.

4.1 Parameters of field tests

The design test parameters are as follows: cement content 12%, 16% and 20%, water-cement ratio 0.8 and 1.0, and pre-mixing water consumption 600~800L.

The test construction procedure is shown in Figure 9.



a. Location；b. Penetration down with water；c. Lifting with water；d. Penetration down with cement slurry；e. Lifting with cement slurry；f. penetration with cement slurry；g. Lifting with cement slurry；

Fig. 9 The construction process of cement mixing pile

4.2 In-situ density and water content tests

The natural density and moisture content of soil in site was tested by sand filling method. Since water is seen at a depth of 2.5m, the field density test is only for soil above the water level.

The data of soil density and water content determined by sand filling method are shown in Table 1.

Table 1. The natural density and water content

Sample No.	Density （g/cm3）	Dry density （g/cm3）	Water content （%）	Depth （m）	Note
1	1.565	1.120	29.7	1.35	Silty clay, with silty sand
2	1.629	1.264	28.9	1.35	Silty clay, with silty sand
3	1.557	1.106	40.7	1.60	Black clay
4	1.473	0.978	50.6	1.60	Black clay
5	1.468	1.208	21.6	1.84	Silty clay
6	1.433	1.340	21.9	1.84	Silty clay, with sand and gravel

According to the above test, the average density of 1.35m-1.84m soil layer above the water level is about 1.52g/cm3, in which the water content of black clay is 45.4%, and the average water content of silty clay is 25.5%.

（a）Four times stirring and four times spraying （b）Six times stirring and four times spraying

Fig. 10 The contrast of four times stirring and six time stirring

As can be seen from Figure 10, the obvious cement shell appeared in the early test pile, and the phenomenon of mixing cement blocks and clay in the middle has basically disappeared, and the six puddling and four spraying can basically stir the cement slurry and clay evenly. However, there are also small clay blocks in the excavation pile, which cannot be completely stirred evenly.

Figure 11 shows the drilling core sample.

Fig. 11 Core sample

4.3 Unconfined compression test

Core samples of the three holes have been test, and the test results are shown in Table 2.

Table 2. Unconfined compression strength of core samples

Hole No.	Depth(m)	qu(MPa)	Age(d)
TC-02	2.20-3.30	8.6	16
	4.32-5.29	1.4	
	5.29-6.20	3.8	
	5.29-6.20	4.8	
	6.20-7.85	5.8	
TC-03	0-0.44	2.5	15
	2.20-3.27	2.5	
	2.20-3.27	1.8	
	3.27-4.43	2.8	
	4.43-5.30	1.2	
TC-06	0-0.70	3.1	15
	2.55-3.32	2.3	
	2.55-3.32	0.7	
	3.32-4.60	1.0	
	3.32-4.60	1.4	

According to the test results of piles on site, TC-02 and TC-03 are of good quality, and the average unconfined compressive strength of each pile is 4.9MPa and 2.2MPa at 15d age (core-taking at 15d after construction and strength measurement at 10d after placement (without maintenance)). As the highly plastic clay layer exists only at certain elevations, as shown in Figure 4-2, the surface layer is silty soil layer, and some soil layers also contain fine sand. Therefore, the above three pile test results only show that the unconfined compressive strength of cement-soil mixed pile in the medium and high plastic clay layer detected by field test is greater than 0.7MPa.

The results of the field test show that there are two groups of construction process parameters that meet the requirements: (1) six puddling and four spraying, cement content 165.8kg/m, water-cement ratio 1.0, spray speed 34.7L/min, pre-puddling water 77L/m, bottom pipe up lifting speed 0.63m/min; (2) Six mixing and four spraying, cement content 141.4kg/m, water-cement ratio 0.8, spray speed 28.3L/min, water pre-mixing water 89L/m, bottom pipe up lifting speed of 0.71m/min.

5. Summary

In this paper, key construction technologies of cement mixing pile in high plastic clay layer are studied through laboratory tests and field tests, and key construction parameters and cement-soil treatment strength of cement mixing pile in high plastic clay are obtained. Specific conclusions are as follows.

(1) The indoor and on-site strength of the reinforced high-plastic clay cement mixing pile is 1.5MPa~2.3Mpa and above 0.7MPa, respectively.

(2) The highly plastic clay with a plasticity index of up to 69 uses six puddling and four spraying, which can improve the problem of uneven mixing to a certain extent. For the first two water spraying, the water spraying volume is controlled to increase the water content by about 15% at most. According to the pile diameter of the site construction of 800mm, the pre-puddling water volume is about 100L per meter.

There are still some problems about the strength and homogeneity of cement mixed pile in clay with high plasticity index, more research are needed to conducted on the application of cement mixed pile on high plasticity index clay.

References

[1] Technical code for ground treatment of buildings (JGJ 79-2012). Ministry of Housing and Urban-Rural Development of the Peoples's Republic of China, 2012.

[2] Liu Zongguang, Shen Tao. Discussion on improving construction quality of DCM piles in high plasticity clay at sea. Port Engineering Technology, 2020, 57(S1): 141-144.

[3] Wang Chuang, Wang Shining, Yin Ziqiang. The Application of cement mixing pile in soil with high plasticity index. Material Research, 2020, 6: 23-25.

[4] Li Li. Study on improving effect and application of cement mixing pile on soft soil with high moisture content and high plasticity index. Soil Engineering and Foundation, 2005, 19(4): 64-66.

[5] Gong Xiaonan. Ground improvement of foundation (Third edition), China Architecture & Building Press, 2008.