A Research on Filling Subgrade with Shallow Silt Soil Based on the Solidification Mechanism and Quality Control

Tianyue Zhang

School of Civil and Transportation Engineering, Beijing University of Civil Engineering and Architecture, Beijing 100044, China

964633527@qq.com

Abstract

The shallow silt soil with high moisture content and heavy metal content cannot be used to fill subgrade directly. This paper analyzes solidification mechanism, which refers to improve the soil to meet the requirement of subgrade filling by adding curing agent to it, and quality control to find out the way to reduce the compressibility and moisture content of the shallow silt soil in order to make the construction more reasonable, standardized and accurate.

Keywords

Shallow silt soil, subgrade engineering, solidification mechanism, quality control.

1. Introduction

At present, dredging and replacement treatment, in-situ solidification and backfill treatment are the main methods to deal with the shallow silt soil. The treatment of dredging and replacement is easily conducted, and can thoroughly clean the silt. However, due to the high cost of transportation and borrowing soil and the requirement of a large area to place the discarded silt, it is not suitable for those economically developed, but land scarce areas. For instance, the Pearl River Delta region deposits a large amount of silt, but its land resources are precious and limited. Because of the requirement of a large area as the spoil ground and the high cost of transportation, it is difficult to conduct dredging and replacement treatment.

Taking into account the factors, including land acquisition, earthwork transportation and environmental protection, the in-situ solidification treatment possesses more social and economic benefits. There are three methods to solidify silt: high compaction, high-temperature sintering, and the addition of a curing agent. High compaction equipment is expensive and inefficient, while the capability of high-temperature sintering is limited and its cost is high. Compared to the above two methods, adding a curing agent is more economical.

This paper mainly focuses on the method of adding a curing agent which can improve the soil, reduce the compressibility and moisture content so that the soil can meet the filling requirement of subgrade and the standard of construction. The relevant design and conduction can be conducted under the guidance of the regulations related to in-situ solidification of silt soil in the document Soil Stabilizing Admixtures (CJ/T486-2015). However, the technical parameters, such as the curing agent ratio and dosage, and construction technology should be in accordance with the requirement of the specific project and determined by tests. In addition to the improvement of technology, standardized intervention measures and the modular combination of technical improvements and management procedures should be involved in the quality control over the solidification effect in order to take quality control of filling subgrade with shallow silt soil.

2. The Properties of Solidified Silt Soil and Solidification Mechanism

In this paper, the silt soil in the project test site of a freight yard is used as the object. By analyzing the properties of silt samples in the test area and assessing the solidification effect, an in-depth understanding of the properties of solidified silt soil and the process of solidification mechanism can be acquired.

2.1 Physical and Mechanical Parameters of the Silt Soil

In the study, the method of borehole sampling was conducted to collect samples from the soft soil layer in the test site, and the test on physical and mechanical properties of silt soil samples was carried out according to the national standard Standard for Soil Test Method. Table 1 and Table 2 illustrate the main physical and mechanical parameters of silt soil collected from different locations in the test site.

Table 1 Physical and Mechanical Parameters of the Original Silt Soil in the Test Site

Number	Natural Moisture Content （%）	Natural Density （g/cm3）	Grain Density -	Natural Void Ratio -	Compressibility0.1~0.2MPa （MPa-1）	Compression Modulus 0.1~0.2MPa （MPa）
Jz-III 155-10-1	57.2	1.64	2.63	1.521	1.52	1.36
Jz-III 155-10-2	60.1	1.62	2.62	1.589	1.66	1.26
Jz-III 155-3-1	67.5	1.57	2.58	1.753	1.85	1.18
Jz-III 155-7-1	62.1	1.61	2.62	1.638	1.76	1.20

Table 2 Physical and Mechanical Parameters of the Original Silt Soil in the Test Site

Number	Liquid Limit （%）	Plastic Limit （%）	Plasticity Index （%）	Liquidity Index （%）	Saturation （%）	Organic Matter （%）	Quick Shear	
							φ (°)	c (kPa)
Jz-III155-10-1	45.5	27.3	18.2	1.64	98.9	-	3.2	6.3
Jz-III155-10-2	45.3	27.6	17.7	1.84	99.1	-	2.7	6.1
Jz-III155-3-1	47.5	28.1	19.4	2.03	99.4	6.45	2.2	5.8
Jz-III155-7-1	43.5	26.1	17.4	2.07	99.3	5.18	2.8	6.4

From Table 1 and Table 2, it can be seen that the silt soil in the test site is in fluid-plastic state, with high natural moisture content, up to over 65%. In some locations, the surface of the silt contains a lot of waste residue of fish and shrimp, with organic matter contents from 5% to 10%, which shows that it can be classified as organic soil. Generally, in the quick shear test, the cohesion force (c) is in the range from 5.8 to 6.4, and the friction angle is from 2.2° to 3.2°. From the parameters, the properties of the silt in the test site can be classified as extremely low shear strength, high void ratio, and high compressiblity.

2.2 Analysis of Chemical Elements in the Silt

In order to determine the composition of chemical elements in the silt of the pond, random sampling was adopted in the test site to obtain 120.6g samples. A high-speed multi-element analyzer was used to analyze the chemical elements in silt samples. The results are presented in Table 3:

Table 3 Chemical Elements in the Silt of the Sample Pond

Elements	Ti	Al	Si	Fe	Mg	Ca	K	Na
K Value	0.00	1.16	0.30	0.00	4.50	1.00	0.00	0.00
Concentration	4.00	80.00	207.00	10.00	10.00	10.00	10.40	11.50
Blank Reading	0.00	145.00	40.00	3.00	132.00	243.00	109.00	154.00
Reference Reading	162.00	1283.00	1349.00	515.00	421.00	443.00	1510.00	580.00
Sample Reading	64.00	621.00	1197.00	361.00	167.00	271.00	1073.00	136.00
Sample Content (%)	0.66	12.81	75.51	2.90	0.45	0.57	2.97	0.00

L.O.I: 0.00%   Component Content: 95.86%

It can be seen that in the samples, the content of Si element is highest, reaching 75.51%, and followed by the content of Al element with 12.81%. The difference between these two main elements is huge. However, the content of other elements is relatively low: the content of K is 2.97%, Fe is 2.90%, Ti is 0.66%, Ca is 0.57, Mg is 0.45%, and Na is not found in the sample.

3. Solidification Mechanism

From the above tables about the main physical mechanical parameters and chemical properties of the silt soil at different locations in the test site, it can be seen that two properties of the silt are high organic matter and high content of heavy metal, so it is necessary to solidify free heavy metals in the silt.

3.1 Effective Components in the Curing Agent

The effective components in the curing agent can produce more sufficient hydration and hydrolysis reaction in the alkaline environment created by the curing agent itself to produce various hydration gelatinous substances. These gelatinous substances will bind the fine particles in the silt, make them aggregate and form a skeleton structure supported by hydrated gel, thereby improving the strength and stability of the silt. Based on the properties of the silt samples, the powder curing agent which contains a component that can react with the silt in high organic content is planned to be adopted. It can solidify the heavy metals in free state, reduce compression ratio, enhance shear strength, reduce moisture content, which meets the requirement of environmental protection.

3.2 Mechanism of the Curing Agent

The mechanical properties of the silt soil are determined not only by the strength of the basic structural unit, but also by the cohesive force among them. The contact among the dispersed parts in the clay can increase its cohesive force, thus improving the strength of the whole soil. The solidified silt is a kind of earthwork material, appropriate for construction, and made by mixing the silt and the curing agent in proper proportion, stirring and hardening. This solidification technology originates from Japan, the United States and other countries, and adopts a kind of composite solidified material which can make the silt, water and the curing agent interrelate, interact with each other, make up for some defects of a single material in solidification reaction, and greatly enhance the strength and stability of the solidified soil.

3.3 Stability Principle of Solidified Materials

Through analyzing the physical and chemical properties of the samples collected from the test site, it can be found that the shear strength is very low, while both void ratio and compressibility are high. More importantly, the organic content in some samples is high, with a range from 5% to 10%. Therefore, a targeted method should be adopted for further treatment of the silt soil. Apart from that, the analysis of chemical elements has shown that the content of heavy metal, like Fe, is higher than that of ordinary soil samples, which may lead to environmental pollution. Therefore, when adding the curing agent, the solidification of free heavy metal ions should be taken into account in order to reduce environmental pollution caused by the precipitation of metal ions from the silt soil.

The solidified material particles and the silt particles can fill each other, and form a close packed structure. Because the strength and hardness of solidified material are high, after the hydration, some particles in the solidified material will not be hydrated. The unhydrated part can also serve as a “micro aggregate filling” and “skeleton support” among the hydrated part.

The effective active components in the activator can be used to promote the complex gel effect, and some active components can be retained to steadily increase the strength for a long time. This complex reaction can change the properties of the surface charge in the silt soil particles, reduce the repulsive force between them, break the absorption liquid film of the soil particle, improve absorption force between them, achieving stable equilibrium of the moisture content in the silt soil, as well as form crystalline salt so that it can make the subgrade filled with solidified soil never be drier or wetter than the one with untreated soil.

3.4 Properties of Curing Agent

This kind of solidified material, mainly composed of hydraulic components, possesses good water stability and frost resistance. After physical compaction, it can show better overall strength, water stability and non-permeable property, and can be used as a fine subgrade filling material. As a new, practical and environment friendly material, the solidified soil can be used in the subgrade construction of the road, storage yard, separation levee, revetment, river bed reinforcement, construction cushion and other soil engineering. The solidified soil with different strength can meet the requirements of different engineering and design. As a high quality material for coastal soft soil subgrade construction, the solidified soil has the following properties: good integrity, high subgrade bearing capacity, low permeability and small settlement.

In terms of the mechanism, the solidified soil is a kind of high-strength silicate reaction, while in terms of its structural property, it is similar to the pile of the cement injection pile. It is widely accepted for its strength and life span. Theoretically, this kind of material can remain for over 100 year without attenuation.

4. Construction Process of the High Moisture Content Solidified Silt Soil

Quality control focuses on the selection and quality inspection of the curing agent, as well as quality control and standardized management of the solidification process.

4.1 The Selection and Quality Inspection of the Curing Agent

It is of great significant to choose appropriate raw materials and curing agents. Only by choosing an appropriate curing agent in conformity to the property of the silt, can the solidification effect be fully played, the economic cost be lower, and the construction be more reasonable, standardized and accurate. Besides, at the early stage of construction, the density of filling and compaction should be strengthened and the development of settlement deformation should be effectively controlled in order to keep away from the problem that settlement deformation rate is too high in the early stage, while the settlement deformation duration is too long in the later stage.

This curing agent has a reliable performance in stabilizing base materials and good properties of slab entirety, water stability, dry shrinkage resistance, and frost resistance. Its strength is high in the early stage, and will continuously increase in the later stage. It can be obtained from in-situ resources, which makes the construction more convenient.

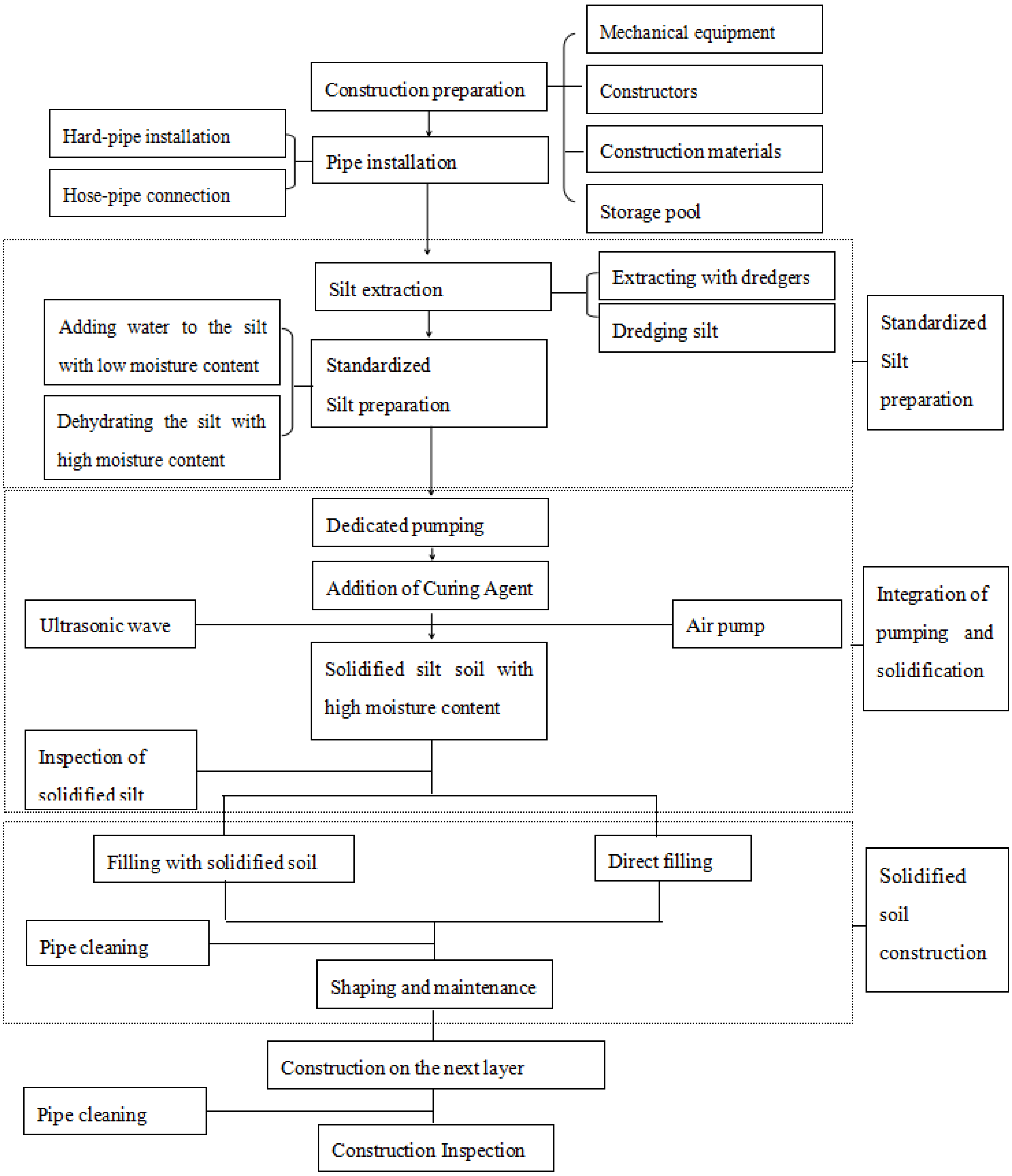

Figure 1 the Construction Process of the High Moisture Content Solidified Silt Soil

Besides, the fly ash in the curing agent contains a large amount of active silica and active alumina which can react with calcium oxide at room temperature, and produce stable hydrated calcium silicate and hydrated calcium aluminate. These two chemical reaction products can make a great contribution to hardening the mixture and improving its strength. In addition, lime can provide a calcium-rich environment and accelerate the hydration rate of fly ash. Sulfate ions dissolved in gypsum can react with active alumina, and produce ettringite, which can improve the strength in the early stage.

The curing agent can be used after its fineness, setting time, stability and shrinkage are checked out. In order to test the solidification effect of the powder curing agent on soil, compaction test should be conducted to gain the result about the infinite lateral compression strength, and a freezing and thawing cycle test should be carried out to assess its stability of frost resistance. Two samples are required to be collected according to the standard. One of the samples is used for test, while the other one is used to be submitted to arbitration department for re-inspection if needed, and should be kept it sealed for about half a year.

4.2 Quality Control Methods of the Solidification Process

4.2.1 Preparation

In the process of preparation, it is necessary to conduct a field research, prepare related construction test equipment and solidification material, drain away water in the ponds and ditches, and remove impurities in the silt in time, such as block stone with particle size more than 8cm, brick slag, tree roots, fishing nets, and garbage. The volume of the silt to be treated is determined by the length and width of the area for treatment, and the thickness of solidification treatment. The volume of curing agent is also determined by these factors.

4.2.2 Determination of Moisture Content

The instruments, such as microwave oven, electronic scale and porcelain bowl are needed to do an on-site determination of moisture content. The specific steps are as follows: fill the bowl with some silt, measure its weight, heat it in the microwave oven for 5 to 10 minutes until the silt becomes dry, and then measure the weight of the dried bowl and silt. The weight difference is the weight of water.

The optimum moisture content of silt for on-site agitation is in a range from 40% to 60%. If the moisture content is higher than the standard, the silt should be spread out to dry until the content decreases. If the content is too low, it is not available for on-site agitation, which may lead to an uneven mixture and insufficient reaction between the curing agent and the silt. On the contrary, the reaction time of the curing agent and the silt will be prolonged and the physical index of solidified soil will be reduced. The agitation can be operated until the moisture content of the silt is close to the optimum one.

4.2.3 Agitation and Solidification of the Silt

Putting the curing agent into an in-situ silt solidification agitator, then the cement and liquid curing agent will be injected into the mixing head through two independent pipes. When the mixing head begins to work, these two kinds of admixture will be blended into the silt together, as Figure 2 shows.

Figure 2 Mixing Head of Silt Solidification Machine

The volume of cement and liquid curing agent is determined by the volume of silt to be treated and the proportion of each admixture in the test. The control methods of the volume of each admixture in construction are as follows.

(1)In the control of cement volume, the data, including the capacity of each cement tank truck, cement injection time and estimated volume of silt treatment need to be recorded during the test. The volume of the silt to be treated can be determined by calculating the capacity of each cement tank truck, the designed proportion of the cement. In addition, according to the thickness of the silt to be treated, the size of the area for silt treatment can be obtained. Based on the capacity of the cement tank truck, the scope of silt treatment work by a single cement tank truck can be controlled. With the cement injection time, the added volume of cement per unit time can be obtained, based on which the construction progress can be controlled.

(2)The added volume of liquid curing agent is controlled mainly by the flowmeter equipped on the high-pressure pump. By recording the water discharge of the high-pressure pump and time, the added volume of liquid curing agent can be calculated. With the designed proportion of each admixture and the added volume of cement per unit time, the added volume of liquid curing agent can also be worked out. Therefore, the added volume of the liquid curing agent can be strictly controlled. After the injection, the cement and liquid curing agent need to be fully stirred from bottom to top and from outside to inside until the color is uniform and the thickness meets the standard. A dedicated agitator should be selected for stirring, repeatedly kneading and grinding the mixture in the process to make the curing agent and the silt fully contact with each other, resulting in maximizing the activity of the curing agent, and stimulating the gel to solidify the soil.

4.2.4 Flattening and Compaction

If the strength of the solidified soil can meet the requirement of flattening, it should be flattened and compacted as soon as possible. The time for flattening and compaction should be determined by the moisture content and solidification strength of the solidified soil. If the moisture content is low (generally lower than 40%), the flattening and compaction work can be commenced after completing agitation and solidification. If the moisture content is high, the flattening and compaction work should be operated two or three days later, because of the time lag of solidification.

4.2.5 Solidified Silt Maintenance

After flattening and compaction, the solidified silt should be made in a uniform color without any substances covered by curing agent, and protected from water seepage and rain, and placed in the storage area to be solidified for a standard time (28d). When the solidified silt soil reaches a certain curing age, its subgrade bearing capacity should be determined on site to judge whether it can still satisfy the design requirements.

5. Standardized Management of Construction

Standardized management means following some certain principles and methods of management to improve the overall quality of engineering management. Compared with ordinary methods of management, it is more specific and scientific. In order to comprehensively improve the quality of engineering management, standardized management should be integrated into it to provide a firm foundation for the development of engineering activities.

5.1 Informatization

Informatization management should be implemented throughout the whole construction process to share information. In order to improve the quality of the construction, it is necessary to establish an information-based logical structure that meets the requirements of the construction in which software is used to screen and process the shared information in order to obtain the information needed for the construction. Operation layer is the most fundamental level in the informatization management of engineering. In the process, managers must be familiar with the operation procedures of this information-based system, and be able to process the experimental information and construction information into modules and statements, providing important basis for the management. Management should collect engineering information and transmit the instructions from superiors in time. The decision makers should carry out a comprehensive analysis and choose a mathematical model based on the information provided by the subordinates.

5.2 Test Management

The indicators of solidified soil inspection include leaching rate, increasing ratio and compressive strength. To carry out the test, the quality of the test should be guaranteed by the test management. The on-site test management can be improved from three aspects: regulation system, employee management and technical management.

Regulation system should clarify the responsibility of each part, formulate responsible personnel management regulation, improve the sample collection and maintenance regulation, and instrument and equipment management regulation.

Employee management should strengthen employee training, improve their business capability and sense of responsibility, and put an end to fabrication and irresponsibility.

Technical management should adopt scientific means to strengthen controls over the process, and ensure the sample sealed in the process of submission and the authenticity of the experimental data.

Test management should take regulation system as the basis, employee and equipment management as the methods, and technical management as a guarantee, aiming to put an end to fabrication.

5.3 Third-party Inspection

Engineering quality shows that the construction can meet the standard of related regulations and the requirements in the contract, including the safety, technology function. It is also the sum of all the properties of the construction, such as durability, environmental protection, and so on. The third-party inspection plays a significant role in quality control.

The third-party inspection should pay attention to the following aspects. First, the inspection standard should be clarified and unified. The index and process of the inspection should be unified in order to make it easier to sort out and use the test results. Second, the function of the inspection should be understood. Inspection aims to find out the defects which are ignored in the process. If the inspection is only regarded as a regulated step, its original function will be lost. Third, repeated inspection carried out by both the construction sector and inspection sector should be avoided be because it will waste time and resources. Fourth, the key parts omitted in the document should be also inspected. In the document, some key parts are not listed. However, with long experience, these parts may have an impact on the stability of the whole construction, so it is essential to inspect them.

6. Conclusion

(1) In order to ensure the quality of powder curing agent, it is necessary to test all of the indicators in it and its solidification effect.

(2) To make the quality of powder curing agent meet the standard, it is essential to control the moisture content, silt solidification and agitation process, the compaction of solidified soil and maintenance.

(3) The quality control over the construction--filling subgrade with solidified silt --includes the quality control of solidification machine, solidification process and construction standardized management. The quality inspection of the curing agent should cover the quality of the curing agent itself and the property of the soil mixed with the curing agent. The solidification process control should be carried out under the guidance of related regulations. The standardized management of construction should be handled in the light of related regulations from three aspects: informatization, test management and third-party inspection.

(4) Only by effectively controlling the regulation system, strengthening employee training, improving technical inspection of the process, can the standardized test management meet the requirements of on-site test, and can the experimental data show the actual situation.

(5) It is the most critical to select appropriate raw materials and curing agent. Only by selecting relatively appropriate curing agent for the silt with different properties, can the curing agent fully play its role in solidification effect and economic cost, and can also make the construction be more reasonable, standardized and accurate.

(6) In the early stage of construction, strengthening the density of filling and compaction and effectively controlling the development of the settlement deformation can avoid the problem that the settlement deformation rate in the early stage is high, while the duration of settlement deformation in the later stage is long.

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