Analysis of Influencing Factors on Durability of Sludge Flow Solidified Soil

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Abstract. In order to transform a large amount of dredged sludge into sustainable development of land resources, this paper takes the submarine dredged sludge in Dalian Bay as the research object, and uses the composite solidified material composed of cement, fly ash and phosphogypsum to carry out flow solidification treatment. Through laboratory experiments, the influence of curing temperature, dry-wet cycle and freeze-thaw cycle on the sludge flow solidified soil was studied. The results showed that: (1) When the fly ash-cement mass ratio RFC=0.65 and the cement-sludge mass ratio RCS=0.09-0.16, the unconfined compressive strength of the sludge flow-solidified soil is 1.04 times the outdoor curing environment. (2) When RCS=0.11~0.14 and RFC=0.65, the strength loss rate of the sludge solidified soil after the first dry-wet cycle is the highest, respectively 43% and 50%. (3) When RCS=0.09~0.16 and RFC=0.65, after the third freeze-thaw cycle, the strength loss rate of the sludge solidified soil is the smallest of the first five times.

1. Introduction

China has a sea area of about 4.7 million square kilometers, with more than 7,600 islands, large and small. Every year, a large amount of dredged sludge will be produced by river channel dredging and coastal engineering construction. The treatment of silt has always been a focus of the attention of scholars in the geotechnical community. Dredged silt has the characteristics of high water content and low strength, which is difficult to use directly and occupies a lot of land resources. Through the fluid curing treatment, it can make full use of its fluidity and self-hardenign characteristics, without rolling and forming, and directly carry out pumping construction.

As the construction industry boomed, some problems also emerged, such as the structural failure during the service period prematurely so that it can no longer be used. This is mainly due to insufficient understanding of the durability of its structure. Hu Xiaopeng analyzed the influence law and mechanism of environmental parameters such as freezing temperature and freezing time on concrete service performance. Nassif and Choi analyzed the influence of early freezing on the pore structure of concrete during service, and revealed the mechanism of early freezing on the pore structure of concrete. Zheng Jun used a new compaction tube sample to conduct an experiment to...
study the effect of the dry-wet cycle on the bearing strength of the new solidified soil, indicating that its strength rose to the peak when the dry-wet cycle reached 4 times. Zheng Xu et al. studied the effect of dry and wet cycles on the physical and mechanical properties of carbonized solidified soil through laboratory experiments, and compared it with cement solidified soil at the same dosage. Sun Jing et al. used GDS dynamic triaxial tests to study the changing rules of the dynamic parameters of silty sand after multiple freeze-thaw cycles at different negative temperatures. Jihui Ding et al. analyzed the factors affecting the strength of silt flowing soil through different curing ages and curing conditions. Tan Yunzhi et al. used the volcanic ash reaction of kaolin to effectively improve the long-term strength of solidified soil. Ding Jihui et al. analyzed the influence of curing agent dosage and age on the performance of solidified sludge by designing parallel and orthogonal experiments.

In summary, most scholars in the past have conducted research on the durability of materials in concrete, silt soil, and contaminated soil containing metal particles such as organic matter. However, there is little research on flowing solidified soil. In this paper, the silt fluid solidified soil is maintained for a certain age, and several dry and wet cycles and freeze-thaw cycles are carried out. This can more realistically simulate the service environment of the solidified soil, and then explore the impact on its durability, and provide a reference for engineering practice.

2. Test materials and ratio

2.1 Test Materials
The sludge used in the test was taken from the submarine dredged sludge in Dalian Bay. Its water content was 54.4%, and its liquid limit and plastic limit were 42.7% and 22.5%, respectively. Among them, the liquid limit is measured by a photoelectric liquid-plastic limit combined tester, and the plasticity is determined by the rubbing strip method. The solidification material is a composite solidification material mainly made of cement and fly ash. The cement is PO42.5 ordinary portland cement. The fly ash is an industrial waste discharged by the power plant.

2.2 Test Mix
According to the fluidity requirements, the sludge used in the test is made into a flowing sludge with an initial moisture content of 160%, and then the curing agent is added and fully stirred. Define RCS as the cement-sludge mass ratio, and define RFC as the fly ash-cement mass ratio. Designed with 1L silt slurry, cement: 110g~200g, namely RCS=0.09~0.16; fly ash is 35%~80% of cement quality, that is RFC=0.35~0.8; phosphogypsum: 10g.

3. Analysis of test results

3.1 Curing Temperature
Take out 8 groups of samples and perform curing under the conditions of indoor curing temperature 25℃ and 35℃ and outdoor curing. The outdoor storage time is 60d, and the average temperature difference between day and night is 18℃.

Figure1. shows the relationship between unconfined strength and RCS when RFC=0.65. It can be seen from Figure 1. that under three different curing environments, the strength of the samples under the 35℃ curing environment is the highest, and the strength of the solidified soil under the 25℃ environment is the lowest. With the increase in the amount of cement and fly ash, the strength of the solidified soil increases, and the strength value of the samples at 35℃ and outdoor curing increases rapidly. When RCS=0.09~0.16 and RFC=0.65, the strength of the solidified soil at 35℃ is 1.04 times the strength of the solidified soil in the outdoor environment. When RCS=0.09~0.14 and RFC=0.65, the strength value of the solidified soil under 25℃ environment curing does not increase much. When the cement content RCS increased from 0.14 to 0.16, the strength increased by 1.87 times.

It can be seen from Figure 2. that when RCS=0.14, under different curing conditions, as the amount of fly ash increases, the variation law of the unconfined compressive strength of the solidified soil is
also different. The change law of the strength of the solidified soil in the outdoor and 35°C environment is the same, both decrease first and then increase with the increase of the fly ash content. With the increase of fly ash content, the strength value of solidified soil at 25°C increases slowly. When RCS=0.09~0.16 and RFC=0.65, the strength of the solidified soil at 35°C is 1.19 times that of the solidified soil in the outdoor environment.

![Figure 1](image1.png)

**Figure 1. Relationship between qu and RCS (RFC=0.65)**

![Figure 2](image2.png)

**Figure 2. Relationship between qu and RFC (RCS=0.14)**

### 3.2 Dry and Wet Cycle Test

It can be seen from Figure 3. That as the amount of cement increases, the strength of the fluid solidified soil gradually increases. As the number of dry and wet cycles increases, the strength of the silt-solidified soil decreases first and then increases, and finally the strength value continues to decrease. When RCS=0.11~0.16 and RFC=0.65, the strength value of the silt-solidified soil decreased significantly after the first dry-wet cycle was completed. After continuing with the second dry-wet cycle, the strength value of the sludge flow solidified soil increased again. With the increase of the number of cycles, the strength value continues to decrease. The strength change value of the mud solidified soil with 3 cycles and 4 cycles is very small. When RCS=0.09 and RFC=0.65, as the number of cycles increases, the strength of the silt solidified soil continues to decrease. The first three cycles have little effect on the strength of the solidified soil. The fourth time the strength changes suddenly, and the fifth cycle is completed after the sample has been completely destroyed, the unconfined compression test can no longer be carried out.

It can be seen from Figure 4. That when RCS=0.11~0.14 and RFC=0.65, the strength loss rate of the sludge flow solidified soil after the first dry-wet cycle is the highest, respectively 43% and 50%. When RCS=0.09 and RFC=0.65, the strength value of the solidified soil after the first and second cycles is basically unchanged, and the maximum strength loss rate of the solidified soil after the fourth cycle is 51%. When RCS=0.16, i=1~5, the strength loss rate Ki=9%~24%, and the second time the strength loss rate is 9%.
3.3 Freeze-thaw Cycle Test

It can be seen from Figure 5 that when RCS=0.09~0.16 and RFC=0.65, the strength loss rate of silt-solidified soil after the first dry-wet cycle is 33%~38%. After the first 5 dry-wet cycles, the stress loss rate of the solidified soil showed a trend of decreasing first and then increasing, and the stress loss rate of the third time was the smallest of the previous five times. When RCS=0.09 and RFC=0.65, compared with the first dry-wet cycle, the stress loss rate gradually decreased after the second and third dry-wet cycles, K2=24%, K3=14%. When RCS=0.11~0.16 and RFC=0.65, the third freeze-thaw strength loss rate is the smallest, being 18%~30%. The fifth freeze-thaw cycle has the greatest impact on the stress loss rate of the sludge flow solidified soil, with the strength being lost by about half.

4. Conclusion

When RCS=0.09~0.16 and RFC=0.65, the strength of the solidified soil at 35℃ is 1.19 times the strength of the solidified soil in the outdoor environment. When RCS=0.14 and RFC=0.65, the amount of solidified material is small. After the freeze-thaw cycle of 3~5, the material is similar to plastic material. When unconfined compression is applied, Plastic shear failure of the sludge flow solidified soil. When RCS=0.16 and RFC=0.65, the strength loss rate of the first 5 dry and wet cycles to the fluidized solidified soil is K1=9%~24%, and the minimum stress loss rate of the second time is 9%. When RCS=0.11~0.16 and RFC=0.65, the third freeze-thaw strength loss rate is at least 18%~30%, in the order of i=1, 2, 4, 5, and the difference between K4 and K5 is 1%~3%, the fifth freeze-thaw cycle has the greatest impact on the stress loss rate of the sludge flow solidified soil, and the
strength is lost by about half. The influence of the dry-wet cycle and freeze-thaw cycle on the fluidized solidified soil is not only related to the number of cycles, but also to the ratio of the solidified material.

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