Laboratory Test on Sludge Solidification at the Bottom of Baiyangdian Lake

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Abstract. Taking Baiyangdian lake bottom sludge as object, cement and gypsum as curing agent are used for solidifying through the laboratory test. The results show that the unconfined compression strength and bearing capacity of solidified soil increase with the increase of cement content when the ratio of plaster to cement and curing time are constant. The unconfined compression strength and bearing capacity of solidified soil with cement content of 10% and gypsum to cement ratio of 10% are the highest. The strength of solidified soil is basically stable on 7d. The strength of solidified soil of 14d (28d) is linear with that of 7d. The mean value of the ratio of unconfined compression strength on 14d (28d) to unconfined compression strength on 7d is 1.28 (1.29). The cohesive forces of solidified soil increases with the increase of cement content. When the cement content is constant, the law of the angle of internal friction is not obvious. The ultimate bearing capacity of ground determined by shear strength index is higher than that determined by unconfined compression strength index and the average values of the 14d (28d) ratio is 2.48(2.76).

Introduction

The sludge at the bottom of the lake has fine clay and low permeability coefficient. The traditional method of drainage consolidation such as preloading and vacuum preloading cannot meet the needs of engineering construction. At present, common methods of silt treatment at home and abroad include harmlessness treatment of silt (microbiological method, chemical method, electrochemical method, plant repair method), solidification treatment technology and lightweight treatment of silt.

Fan zhaoping \(^{[1]}\) found that the increase of organic mass no longer has a greater impact on curing effect after organic matter exceeds the limit dosage. Cao yonghua \(^{[2]}\) studied the effects of curing agent coordination ratio on permeability and strength of solidified sludge. Xunyong \(^{[3]}\) analyzed the feasibility and practicability of strengthening soft soil with industrial iste fly ash and phosphogypsum. Shi yannan et al. \(^{[4]}\) developed three kinds of curing agents with good effects through single mixing test, orthogonal test and anti-permeability and anti-shear test. Liang qibin et al. \(^{[5]}\) believed that the preparation of building materials is an important way to utilize dredged sediment resources. Zhang tiejun et al. \(^{[6]}\) studied the change law of moisture content of loose soil formed by adding quicklime to dredge silt with high water content through a large number of laboratory tests. Shi weicheng \(^{[7]}\) introduced various methods of treating dredged mud at present, and analyzed the characteristics. GUI yue et al. \(^{[8]}\) found that the addition of phosphogypsum is equivalent to adding dry materials, which can improve the early strength of the materialized soil in a short term. Zhu wei et al. \(^{[9]}\) pointed out that humic acid has an inhibitory effect on cement hydration, and there is a limit of humic acid content on the impact of unconfined compression strength and failure strain of silt solidified soil. TB Vidya, RK Dutta, B Mohanty \(^{[10]}\) found that the unconfined compression strength of bentonite increased with the increase of lime content. C Liu, RD Starcher \(^{[11]}\) found that the introduction of cement into soft soil can increase the unconfined compression strength and increase with the increase of curing time and curing stress.
At present, several common curing agents are lime, cement and industrial wastes. Lime curing agents can greatly increase the concentration of Ca\(^{2+}\) in soil solution. Cement curing agents have the following effects on soil curing: C-S-H and C-A-H gels generated by cement hydration reaction, which are attached to the surface of particles and form Ca(OH)\(_2\). The curing mechanism of industrial wastes curing agent is similar to that of lime and cement curing agent. The experiment took the silt at the bottom of Baiyangdian lake as the object, and took cement and gypsum as the curing agent. Through the laboratory test, the effect of curing agent content on the strength of solidified soil is studied, providing the experimental basis for the environmental treatment in Baiyangdian area.

**Experiment Scheme**

The experimental soil sample is taken from the dredged river in Xiong’an New Area and belongs to soft clay with high water content. The unit weight of soil is 18.2 kN·m\(^{-3}\), the moisture content is 67.84%, the void ratio is 1.32, the plastic limit is 34.6%, and the liquid limit is 69.9%.

Cement and plaster are used as curing agents in the test. Cement content (\(R_c\)) is 4%, 6%, 8% and 10% of total silt respectively. When the cement content is certain, the influence of plaster content on the strength of solidified soil is studied. Ratio of plaster to cement (\(R_{gc}\)) is 10%, 20%, 30% and 40%.

The solidified soil samples are installed into the cylindrical grinding tool at maintenance box of 25°C and 100% humidity. When curing 7 days, 14 days, 28 days respectively, the unconfined compression strength and unconsolidated undrained test are used to obtain the regularity between the strength of solidified soil and the content of curing agent.

**Unconfined Compression Strength**

Figure 1 shows the failure of unconfined compression strength samples of solidified soil at \(R_c = 10\%\). The failure forms of the solidified soil were mostly brittle failure, and with the increase of cement content, brittle failure became more obvious. At \(R_c = 10\%\), the sample failure can hear obvious crack sound, and the fracture surface can separate the debris.

![Figure 1. The failure of solidified soil at \(R_c = 10\%\).](image)

Figure 2~4 show that when curing time and \(R_{gc}\) remain unchanged, unconfined compression strength of solidified soil increases with the increase of \(R_c\). \(q_u7d\), \(q_u14d\) and \(q_u28d\) are the unconfined compression strength of solidified soil at 7 days, 14 days and 28 days, respectively. Unconfined compression strength of solidified soil is highest when \(R_c = 10\%\) and \(R_{gc} = 10\%\). \(q_u7d\), \(q_u14d\) and \(q_u28d\) is 641kPa, 722kPa and 823kPa, respectively. It is respectively 20.37, 11.88 and 22.88 times of the strength of \(R_c = 4\%\) and \(R_{gc} = 10\%\). When \(R_c = 4\%\) and \(R_{gc} = 40\%\), unconfined compression strength of solidified soil is lowest. It is respectively 0.66, 0.62 and 0.83 times of the strength of \(R_c = 4\%\) and \(R_{gc} = 10\%\).
The maximum value of \( q_{u14d} / q_{u7d} \) is 1.93, the minimum value is 0.95, the average value is 1.28, and the coefficient of variation is 0.21. Figure 7 shows that the maximum value of \( q_{u28d} / q_{u7d} \) is 1.58, the minimum value is 1.09, the average value is 1.29, and the coefficient of variation is 0.13.

\[ q_{u14d} = 9.74291 + 1.16765q_{u7d} \]  
\[ q_{u28d} = 0.74098 + 1.27549q_{u7d} \]

**Unconsolidated and Undrained Shear Strength Index**

In the Figure. 6~9, \( c_{u14d} \) and \( c_{u28d} \) are the cohesive forces of solidified soil at 14 days and 28 days, respectively. \( \varphi_{u14d} \) and \( \varphi_{u28d} \) are the angle of internal friction of solidified soil at 14 days and 28 days, respectively.

Figure 6 and Figure 7 show that the cohesive forces of solidified soil increases with the increase of cement content. Figure 8 and Figure 9 show that the angle of internal friction of solidified soil has not obvious law with \( R_c \) and \( R_{gc} \). The maximum value of \( c_{u28d} / c_{u14d} \) is 4.52, the minimum value is 0.51, the average value is 1.70, and the coefficient of variation is 0.58. The maximum value of \( \varphi_{u28d} / \varphi_{u14d} \) is 1.69, the minimum value is 0.04, the average value is 0.70, and the coefficient of variation is 0.73.
The Ultimate Bearing Capacity of Ground of Solidified Soil

The actual design parameter adopted in the project is the bearing capacity of ground. In laboratory tests, unconfined compression strength and unconsolidated undrained shear strength index are commonly used to represent the bearing capacity of ground. The commonly used Terzaghi formula is used to calculate the bearing of ground capacity.

When bearing capacity is calculated according to unconfined compression strength index, the calculation assumes that: $\varphi = 0, c = q_u / 2, d = 0$. Terzaghi formula is:

$$f_u = 2.57q_u$$  \hspace{1cm} (3)

When bearing capacity is calculated according to unconsolidated undrained shear strength index, the calculation assumes that: $b = 0, d = 0$. Terzaghi formula is:

$$f_{uu} = N_c c_u$$  \hspace{1cm} (4)
In Figure. 10 and Figure. 11, \( f_{u7d} \), \( f_{u14d} \), and \( f_{u28d} \) are respectively the bearing capacity of ground of solidified soil in 7 days, 14 days and 28 days based on the unconfined compression strength index. \( f_{u14d} \) and \( f_{u28d} \) are respectively the bearing capacity of ground of solidified soil in 14 days and 28 days based on the unconsolidated undrained shear strength index. Figure. 10 shows the relationship between \( f_{u28d}(f_{u14d}) \) and \( f_{u7d} \). The fitting results are linear, and the correlation coefficients are 0.95951 and 0.98359. The fitting results are as follows:

\[
f_{u14d} = 25.03928 + 1.16756 f_{u7d}
\]

(5)

\[
f_{u28d} = 1.90433 + 1.27549 f_{u7d}
\]

(6)

Figure. 11 shows the relationship between \( f_{u28d} \) and \( f_{u14d} \). The fitting results are linear, and the correlation coefficients is 0.94478. The fitting results are as follows:

\[
f_{u28d} = 118.88216 + 1.02794 f_{u14d}
\]

(7)

Figure. 12~13 show the ratio of bearing capacity of ground of the two calculation methods. The mean value of \( f_{u14d}/f_{u14d} \) \((f_{u28d}/f_{u28d})\) is 2.48 (2.76), and the coefficient of variation is 0.18 (0.24).

Figure 12. \( f_{u14d}/f_{u14d} \sim R_c \) and \( R_{gc} \) relationship. Figure 13. \( f_{u28d}/f_{u28d} \sim R_c \) and \( R_{gc} \) relationship.

**Conclusion**

(1) The unconfined compression strength of solidified soil increases with the increase of cement content. When the cement content is certain, the influence of ratio of plaster to cement on unconfined compression strength has a peak value. The unconfined compression strength of solidified soil on 14d and 28d show a linear relationship with the unconfined compression strength on 7d. The mean values of \( q_{u14d}/q_{u7d} \) and \( q_{u28d}/q_{u7d} \) are 1.28 and 1.29 respectively, and the coefficient of variation is 0.21 and 0.13 respectively, and their variability is small.

(2) The cohesive forces and the angle of internal friction of solidified soil increase with the increase of cement content. When the cement content is certain, the influence law of ratio of plaster to cement is not obvious. The mean values of \( \phi_{u28d}/\phi_{u14d} \) \((\phi_{u28d}/\phi_{u14d})\) is 1.70 (1.69), and the coefficient of variation is 0.58 (0.73), and their variability is large.

(3) The bearing capacity of ground of solidified soil on 14d and 28d (28d) show a linear relationship with the bearing capacity of ground on 7d(14d). The bearing capacity of ground determined by unconsolidated undrained shear strength index is greater than that determined by unconfined compression strength index. The mean values of \( f_{u14d}/f_{u14d} \) and \( f_{u28d}/f_{u28d} \) are 2.48 and 2.76 respectively, and the coefficient of variation is 0.18 and 0.24 respectively.
References


