Study on experimental evaluation method of improvement of over-wet complex soil by cement

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Abstract. In order to ensure the over-wet complex soil excavated from Xinxu River Project in Nanning city of Guangxi Province can be used to fill the surrounding road embankment, cement soil specimens were prepared by adding different dosage of cement. The author studied the influence of cement contents on test evaluation method of improved soil by preparing the cement soil specimens and carrying out the comparative tests of CBR, cube and cylinder unconfined compressive strength. The experimental results show that the CBR test has high sensitivity to cement content and good strength correlation, should be selected for the evaluation method of cement stabilized over-wet complex soil. It is suggested that the improved soil with 3% ~ 5% cement content should be used as the embankment filler under the road by taking the economy into consideration.

1. Introduction

The solid excavated from Xinxu River in Nanning city of Guangxi is considered as over-wet complex solid. This high water-holding soil of high viscosity always contains expansive minerals. It is featured by strong hydrophilicity and water holding capacity, poor water permeability, low carrying capacity and easy deformation. The "spring" phenomenon in the construction makes the soil unable to be compacted [1]. The content of organic matter in Xinxu River soil is high, which will lead to high plasticity, high shrinkage, high compressibility, low permeability and low strength soil [2]. It has become a consensus of scholars to improve the over-wet complex soil and make it a qualified filling. However, there are few studies on finding more feasible evaluation method of improved over-wet complex soil.

Qin X G et al. studied that the over-wet clay improved by calcium carbide residues is better than that improved by quicklime by California Bearing Ratio (CBR), unconfined compressive strength and modulus of resilience [3]. Gong Cheng et al. tested the bearing capacity of wet soil subgrade that improved by lime mixing method through field rebound deflection experiment [4]. Zhang J L detected and evaluated over-wet soil that improved by NCS curing agent through indoor dry density, compaction test and unconfined compressive strength test [5]. Through consolidation test and permeability test of undisturbed over-wet soil, Cheng P F studied the consolidation and deformation characteristics of undisturbed soil under freeze-thaw cycle [6]. Du Y J discussed the internal
relationship between the strength of calcium carbide residues improved soil and pH value, pore size distribution and content of pozzolanic reaction products from the microscopic view \cite{7}. Xu R Q discussed the influence of organic matter on the physical and mechanical properties of cement stabilized soil and the curing effect of XGL2005 \cite{8}. Wei L experimentally studied the particle composition of low liquid limit silt in the coastal area of Beibu Gulf and supported the characteristic analysis of complex soil \cite{9}.

This paper is based on the environmental comprehensive improvement project of Xinxu River in Nanning City, Guangxi Province. Through the sampling of over-wet complex soil excavated in Xinwei River, and adding different dosage of cement, the comparative tests of $CBR$, cube and cylinder unconfined compressive strength were carried out to explore the effectiveness of different experimental methods on the strength evaluation of over-wet complex soil.

2. Test materials and methods

2.1. Test material

The author has taken test soil samples from bid 3 and bid 4 of PPP project of Xinxu River environmental comprehensive improvement project in Nanning City, Guangxi. The stratum of the whole project area is mainly composed of silty clay, silt, artificial accumulation plain fill, miscellaneous fill and plant layer cultivated soil of Quaternary late Pleistocene alluvial formation. The experimental soil samples of Xinxu River are shown in Figure 1, and the basic physical characteristics of the soil for the test are shown in Table 1.

| Natural water content (%) | Optimum Water Content (%) | Maximum dry density ($g/cm^3$) |
|--------------------------|---------------------------|--------------------------------|
| 23                       | 18.7                      | 1.68                           |

Figure 1. Test soil samples.

2.2. Test method

2.2.1. Test methodology.

In order to get better evaluation of over-wet complex soil improved by cement, The author improved the soil sample by adding different dosage of cement, and carried out comparative tests of $CBR$, cube and cylinder unconfined compressive strength. Due to the complexity of the soil samples taken from Xinxu River in the test, as many as possible test soil samples were selected to achieve error reduction and ensure the test results more rigorous and representative. The research of Li J shows that the difference of particle composition and structure of soil has an important influence on the $CBR$ value of silt, so the $CBR$ test was carried out according to the literature \cite{10}.

2.2.2. $CBR$ test.

According to the Specification for Highway Geotechnical Test (JTG 3430-2020), a certain amount of soil sample is added to the optimum moisture content±3%, after mixed and bagged, keep the stuffy materials overnight; the stuffy soil sample is taken out and the improved soil sample without cement is tested. A group of experiments has one mixed soil sample and 3 test specimens, adding 3% water to...
make the soil sample reach the optimal moisture content, fully mixing to make the cement fully hydrated, making the sample that need maintenance for 6 days. The sample was placed on the pavement material strength tester for experiment after soaking water for 1 day. The calculations involved in the experiment include:

\[ \delta_e = \frac{H_1 - H_0}{H_0} \times 100 \]  

(1)

Where is the expansion rate of specimen after soaking in water (%). is initial height of specimen (mm). is height of specimen after soaking in water (mm).

\[ \omega_a = m_3 - m_2 \]  

(2)

Where is water absorption of test specimen after soaking water (g). is composite mass of test tube and specimen after bubble water (g). is mass of test tube and specimen (g).

\[ \rho = \frac{m_2 - m_1}{2177} \]  

(3)

Where is dry density (g /cm³) of test specimen. is quality of test tube and specimen (g). 2177 is volume of test tube (cm³).

\[ P = \frac{CR}{A} \]  

(4)

Where \( P \) is unit pressure (kPa). \( C \) is force-measurement ring correction coefficient (kN/0.01 mm). \( R \) is penetration (0.01 mm).

\[ CBR_{(2.5mm)} = \frac{P}{7000} \times 100 \]  

(5)

\[ CBR_{(5mm)} = \frac{P}{10500} \times 100 \]  

(6)

Where \( CBR \) is California Bearing Ratio (%).

2.2.3. Cube compressive strength experiment.

On-site soil samples were taken and the amount of cement of 0%, 1%, 2%, 3%, 4% were added to make improved soil cube with the size of 70.7 mm x 70.7mm x 70.7mm. 3-days and 7-days compressive strength experiments were carried out. In a group of experiment, each mix matched per age. Six test specimens prepared with optimum moisture content per group. Maintenance of test specimens should be done before demoulding, then put the specimen on a universal pressure tester and load the specimen continuously and uniformly at a rate of 0.03–0.15 kN/s until the failure of the specimen is recorded, accurate to 0.01 kN.

The compressive strength of the specimen is calculated according to the following formula:

\[ f_{cu} = \frac{P}{A} \]  

(7)

Where is unlimited compressive strength of cement soil (MPa). \( P \) is failure loads (N). \( A \) is the cross-sectional area of specimen (mm²).
2.2.4. Experiment on unconfined compressive strength of cylindrical columns.
On-site soil samples were taken and the amount of cement of 0%, 1%, 2%, 3%, 4% were added to make cylindrical test blocks with the size of 100 \( mm \times 127 \ mm \) (test samples are shown in figure 2), 3-days and 7-days compressive strength experiments were carried out. In group of experiment, each mix matched per age. Six test specimens prepared with optimum moisture content per group. Maintenance of test specimens should be done before demoulding, then place the test specimens on the pavement material tester, load at the rate of 1\( mm / min \), and record the dial indicator reading when it is damaged.

\[
\sigma = \frac{CR}{A_0} \tag{8}
\]

Where is axial pressure (\( MPa \)), is cross sectional area of specimen(\( cm^2 \)).

3. Test results and analysis

3.1. CBR Test results and analysis

On the basis of the calculation formula of swell increment, dry density and CBR, and according to 98 compaction times, the test results are shown in Table 2 when the compaction degree is 0.96.

| Cement content (%) | Swell increment (%) | Average dry density of specimens (g/cm³) | CBR (%) Penetration depth |
|--------------------|--------------------|-----------------------------------------|--------------------------|
| 0%                 | 0.83               | 1.63                                    | 0.4                      | 0.4                      |
| 3%                 | 16.94              | 1.64                                    | 5.7                      | 6.8                      |
| 4%                 | 3.61               | 1.65                                    | 7.6                      | 8.7                      |
| 5%                 | 0.00               | 1.65                                    | 9.9                      | 11.2                     |

The CBR value of 2.5mm penetration depth in Table 2 is less than that of 5mm penetration depth, and the latter is taken to plot the CBR value of soil sample with 5mm penetration depth under different cement content, as shown in Figure 3:

Figure 3. The relationship curve between different cement content and CBR value is obtained when the penetration depth of soil sample is 5mm Numbering.
Table 2 shows that the change trend of expansion after adding cement is mainly divided into two stages: When the cement content is 0~3%, the expansion increases significantly; when the cement content is 3%~5%, the expansion decreases sharply to 0. The dry density of improved soil is increased by adding cement, but the increase is not obvious.

We can see from figure 3 that when the penetration depth is 5 mm, the cement content has a great influence on the CBR value of the improved soil. When the cement content from 0 to 3, the CBR value increases by about 28%, and when the cement content is from 4 to 5. The CBR value decreases with the increase of cement content, which indicates that a small amount of cement content can rapidly increase the CBR value of soil samples.

3.2. Experimental results and analysis of cube compressive strength
The test soil samples of Xinxu River are made into cube test models with the size of 70.7 mm×70.7 mm× 70.7 mm and the results obtained after the experiments are carried out according to the experimental steps are shown in Table 3.

| cement content (%) | 7-days average axial stress (MPa) | 21-days average axial stress (MPa) |
|--------------------|----------------------------------|-----------------------------------|
| 0%                 | 0.11                             | 0.14                              |
| 1%                 | 0.14                             | 0.15                              |
| 2%                 | 0.14                             | 0.17                              |
| 3%                 | 0.18                             | 0.21                              |
| 4%                 | 0.19                             | 0.21                              |

Table 3 shows that with the increase of cement content and age, the unconfined compressive strength of improved soil cube increases to a certain extent. Take the unconfined compressive strength test for 3 days, when the cement content ~ from 0 to 2, the unconfined compressive strength increased by about 27%; When the cement content is from 2% to 3%, the unconfined compressive strength increased by about 29%; When the cement content is from 3% to 4%, the unconfined compressive strength increased by about 5.6%; However, the growth rate is not as significant as that of CBR value, and the 7-day unconfined compressive strength growth is more gentle, so it is difficult to evaluate the reasonable amount of cement.

3.3. Experimental results and analysis of unconfined compressive strength of cylinder
The test soil samples of Xinxu River are made into cylindrical test models with the size of 100 mm×127 mm and the results are shown in Table 4.

| cement content (%) | 7-days average axial stress (MPa) | 21-days average axial stress (MPa) |
|--------------------|----------------------------------|-----------------------------------|
| 0%                 | 0.10                             | 0.10                              |
| 1%                 | 0.12                             | 0.12                              |
| 2%                 | 0.21                             | 0.24                              |
| 3%                 | 0.34                             | 0.39                              |
| 4%                 | 0.44                             | 0.45                              |

From Table 4, it can be seen that with the increase of cement content and age, the unconfined compressive strength of improved soil cylinder increases obviously, which can be used as the evaluation method of cement improved over wet soil. However, compared with the CBR test evaluation method, the operation of cylinder unconfined compressive strength is more complex and the test cycle is longer.
4. Conclusion

(1) The dry density value of improved over-wet soil that was improved by cement fluctuates little with the increase of cement content, which shows good compaction characteristics.

(2) Over-wet soil that was improved by cement can be used as embankment filler under road. The cement content of 3-5% is appropriate by taking the difference of economy, laboratory test conditions and field production conditions into consideration.

(3) When evaluating the strength characteristics of cement modified super-wet soil, the CBR test evaluation method has high sensitivity to cement content, good strength correlation and simple operation.

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