Test Study on the Feasibility of Filling Expressway Subgrade with Carbonaceous Mudstone

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Abstract: The feasibility of using carbonaceous mudstone as expressway subgrade filler is studied through laboratory test. Firstly, the influence of overburden soil pressure on the strength change and argillization of carbonaceous mudstone during seasonal wetting and drying cycles is studied. Test results show that serious argillization occurs when carbonaceous mudstone immersed in water; the overburden soil pressure can partially inhibiting the swelling deformation, strength reduction and argillization of carbonaceous mudstone; California Bearing Ratio (CBR) of the carbonaceous mudstone increases as the overburden soil pressure increase, but gradually decreases as the number of wetting and drying cycles increase and become stable after 6 cycles, and the stable value of CBR doesn’t meet the requirements of the roadbed and upper embankment, but meets the requirement of the lower embankment; the carbonaceous mudstone studied in the test could be directly used as the lower embankment filler, but could not be directly used as the roadbed and upper embankment filler. Secondly, experiment of improving carbonaceous mudstone by cement is conducted, and results show that the CBR of carbonaceous mudstone improved with cement meets the requirements of the roadbed and upper embankment, and cement-improved carbonaceous mudstone is suitable for filling the expressway roadbed and upper embankment.

Keywords. Carbonaceous mudstone, wetting and drying cycle, CBR, overburden soil pressure, cement-improve.

1. Introduction
After Liu-Nan Expressway (Liuzhou to Nanning, which located in Guangxi, China) was being opened to traffic, a large number of longitudinal and transverse cracks (figure 1) have appeared on the pavement of some sections, and differential settlements (figure 2) have appeared between road slabs. Field surveys have shown that a large number of carbonaceous mudstone was distributed along these sections. Considering the fact that subgrade filler is in great demand, coupled with inconvenient
transportation, as well as other factors, carbonaceous mudstone was used as subgrade filling in the carbonaceous mudstone distribution region along the Liu-Nan Expressway.

Under normal service conditions, with the alternation of rainy and dry seasons, the subgrade filler is in a state of repeated wetting and drying cycles. During the rainy season, as the rainfall infiltration and groundwater level rise, the moisture content of the subgrade filler increases; during the dry season, as the soil moisture evaporation and decline of groundwater table, the moisture content of the subgrade filler decreases. During the repeated wetting and drying cycles, the change of moisture content resulting from dry-wet circulation is the main reason for carbonaceous mudstone slaking [1] and the porosity increase by the formation of large cracks and fissures [2]; slaking and porosity increase damage the structure of the carbonaceous mudstone, and reduces shear strength significantly [3]. The safety coefficient of carbonaceous mudstone embankment slope gradually decreases with the rainfall infiltration and potential sliding surface also have the tendency of extending into the embankment [4], because the strength decreases as water content increase [5-7] which induced by rainfall infiltration. As mentioned above, wetting and drying cycles decrease the strength of carbonaceous mudstone, but the influence of overburden soil pressure on the strength decrease and argillization of carbonaceous mudstone during wetting and drying cycles has not been studied. This paper, through laboratory tests, studies the influence of overburden soil pressure on the strength change and argillization of carbonaceous mudstone, and also conducts a test study on the improvement of carbonaceous mudstone with cement.

All the tests in this paper were conducted in accordance with the relevant provisions of “Test Methods of Soils for Highway Engineering (JTG E40-2007)” [8].

2. Test Materials
The carbonaceous mudstone samples used in the tests were obtained from K24+300 of the Guangxi-Nanning Ring Expressway, with a sampling depth of 4.0 m. The basic physical property indexes of the carbonaceous mudstone samples are as shown in table 1, and the particle size distribution curve is shown in figure 3. As may be seen from figure 3, before compaction in lab, the content of gravel (particle size from 2 mm to 60 mm) and sand (particle size from 0.075 mm to 2 mm) are 87.1% and 12.9%, respectively; after compaction in lab, the content of gravel and sand are 80.0% and 20.0%, respectively. This shows that carbonaceous mudstone is easily broken.

| Table 1. Basic physical properties of carbonaceous mudstone. |
|-----------------|-----------------|------------------------------|-----------------|-----------------|
| Liquid limit    | Plastic limit   | Plastic index                | Maximum dry     | Optimal moisture |
| %               | %               |                              | density         | content         |
| 55.9            | 24.2            | 32                           | 1.54            | 15.7            |

Figure 1. Cracks on the pavement.  
Figure 2. Differential settlements between road slabs.
3. Wetting and Drying Cycle Test

3.1. Sample Preparation
The samples used in the wetting and drying cycle tests have diameter of 152 mm and height of 120 mm. The dry density of the sample is 1.54 g/cm³, and the moisture content is 15.7%. The static sample compaction method is used in the preparation of the samples.

3.2. Process of Wetting and Drying Cycles
A wetting and drying cycle test is composed of a saturation process and an air-drying process. After the sample preparation is completed, the bottom of the sample is immersed in water, in order to cause the sample to become saturated under capillary action. Then the water level is gradually raised, until the sample is completely immersed below the water surface. The sample then remains immersed in the water for 48 hours, after which the saturation process is completed. After saturation, the sample is removed from the water and placed in the shade, where it is air-dried until its moisture content corresponds to the ratio for sample preparation (15.7%), and then the air-drying process is completed.

In order to study the deformation and strength change characteristics of carbonaceous mudstone under non-pressure conditions, the tests of 0, 2, 4, 6 and 8 wetting and drying cycles of carbonaceous mudstone under non-pressure conditions have been conducted.

The effects of overburden soil pressure on the argillization and strength change of carbonaceous mudstone was also studied in this paper. According the “Specifications for design of highway subgrades (JTG D30-2004)” [9] and “Specifications for Design of Highway Asphalt Pavement (JTG D50-2017)” [10], the overburden soil pressure applied to the upper roadbed (which induced by pavement structure), lower roadbed (which induced by pavement structure and upper roadbed), upper embankment (which induced by pavement structure and roadbed) and lower embankment (which induced by pavement structure, roadbed and upper embankment) are about 10 kPa, 20 kPa, 30 kPa and 40 kPa, respectively. So the tests of 2, 4, 6 and 8 wetting and drying cycles with the overburden soil pressures of 10 kPa, 20 kPa, 30 kPa and 40 kPa were conducted.
3.3. Results and Analysis

3.3.1. Deformation of Samples in the Process of Wetting and Drying Cycles. During the process of the dry and wet cycles, the absolute expansion rate and the relative expansion rate are calculated respectively based on formulas below:

\[ \delta_a = \frac{h_i - h_0}{h_0} \]  \hspace{1cm} (1)

\[ \delta_r = \frac{h_i - h_{f(i-1)}}{h_{f(i-1)}} \]  \hspace{1cm} (2)

Where \( \delta_a \) and \( \delta_r \) respectively represent the absolute and relative expansion rates; \( h_i \) is the height of the sample after the \( i \)th saturation; \( h_0 \) is the initial height of sample; \( h_{f(i-1)} \) is the height of sample after the \( (i-1) \)th air-drying, for the first cycle \( h_{f(0)} = h_0 \).

The changes in the absolute and relative expansion rates of the samples with the number of wetting and drying cycles are shown in figures 4 and 5, respectively.

![Figure 4](image1.png)  \hspace{1cm}  ![Figure 5](image2.png)

**Figure 4.** The relationship between absolute expansion rate and number of wetting and drying cycles.  \hspace{1cm}  **Figure 5.** The relationship between relative expansion rate and number of wetting and drying cycles.

It may be seen from figures 4 and 5 that, under a certain overburden soil pressure, the absolute expansion rate shows a gradually increasing trend as the number of cycle increases and tends to stable after 6 cycles; the relative expansion rate shows a gradually decreasing trend and tends to stable after 6 cycles. In addition, with the same number of wetting and drying cycles, the overburden soil pressure has a large impact on the absolute and relative expansion rates of the samples. Under the action of the overburden soil pressure, both expansion rates gradually decrease with the increase of overburden soil pressure, indicating that the overburden soil pressure plays a significant role in inhibiting the expansion deformation of carbonaceous mudstone.

3.3.2. Particle Analysis Tests. After saturation, argillization occurs in the soil of carbonaceous mudstone, and large particles are refined in the water. Because the absolute and relative expansion
rates are tend to stable after 6 cycles, indicate that the argillization of carbonaceous mudstone is complete after 6 cycles, the particle size distributions of the samples after 0, 2, 4, 6 wetting and drying cycles under non-pressure condition were conducted, and the particle size distributions of the samples after 6 wetting and drying cycles with the overburden soil pressures of 10 kPa, 20 kPa, 30 kPa and 40 kPa were conducted. The particle analysis test results are shown in table 2 (the wetting and drying cycle “0” in table 2 refers to the particle analysis test results after the first saturation after sample preparation).

Table 2. Results of particle analysis after different cycles.

| Overburden soil pressure /kPa | Cycles | Particle size distribution /% |
|------------------------------|--------|------------------------------|
|                              |        | Gravel (2~60mm) | Sand (0.075~2mm) | Silt (0.002~0.075mm) | Clay (<0.002mm) |
| 0                            | 0      | 0               | 28.7             | 69.1               | 2.2            |
| 0                            | 2      | 0               | 25.6             | 69.9               | 4.5            |
| 0                            | 4      | 0               | 23.3             | 72.2               | 4.5            |
| 0                            | 6      | 0               | 25.6             | 69.9               | 4.5            |
| 10                           | 0      | 0               | 23.8             | 72.2               | 4.0            |
| 20                           | 0      | 0               | 27.5             | 69.7               | 2.8            |
| 30                           | 0      | 0               | 29.6             | 68.0               | 2.4            |
| 40                           | 0      | 0               | 31.3             | 66.5               | 2.2            |

As may be seen from figure 3, after sample preparation and before saturation, the content of gravel and sand are 80.0% and 20.0%, respectively. It may be seen from table 2 that, after the first saturation, the particle size of the carbonaceous mudstone decreases significantly, and the content of gravel, sand, silt and clay are 0%, 28.7%, 69.1% and 2.2%, respectively, and particle size distribution changes small during subsequent wetting and drying cycles, indicating that serious argillization occurs when carbonaceous mudstone first immersed in water. It also may be seen from table 2 that, with the same wetting and drying cycle, the content of the sand gradually increases as the overburden soil pressure increases, and the content of silt and clay gradually decreases as the overburden soil pressure increases, indicating that overburden soil pressure can partially inhibit the argillization of the carbonaceous mudstone.

3.3.3. CBR Test. CBR test has been conducted after the carbonaceous mudstone undergone 0, 2, 4, 6, 8 wetting and drying cycles under non-pressure conditions, and the tests of 2, 4, 6 and 8 wetting and drying cycles under the pressure of 10 kPa, 20 kPa and 40 kPa. The results of the CBR tests are shown in figure 6.

Figure 6. The relationship between CBR and number of wetting and drying cycles.
As may be seen from figure 6, CBR of the sample gradually decreases as the number of wetting and drying cycles increase and become stable after 6 cycles, and the result of the test is in agreement with previous studies[11, 12]; with the same number of cycles, CBR increases as the overburden soil pressure increase, and the result is consistent with the study on silty sand[13], indicating that the overburden soil pressure plays a significant role in inhibiting strength reduction during wetting and drying cycles. After 8 cycles, CBR of the sample applied 10 kPa, 20 kPa, 30 kPa and 40 kPa pressure are 1.30, 2.28, 3.71 and 5.50, respectively; according the “Specifications for design of highway subgrades (JTG D30-2004)”[9], the required minimum CBR for upper roadbed, lower roadbed, upper embankment and lower embankment are 8, 5, 4 and 3, respectively, and the overburden soil pressure applied on the surface of upper roadbed, lower roadbed, upper embankment and lower embankment are 10 kPa, 20 kPa, 30 kPa and 40 kPa, respectively, so that after 8 wetting and drying cycles, the CBR of the sample doesn’t meet the requirements of the upper roadbed, lower roadbed and upper embankment, but meets the requirement of the lower embankment. That is to say, carbonaceous mudstone can be directly used as lower embankment filler, but may not be directly used as roadbed and upper embankment filler.

4. Cement-Improved Carbonaceous Mudstone Test

As mentioned above, the carbonaceous mudstone used in the tests are not able to meet the minimum strength requirements of expressway roadbed and upper embankment filling, and thus appropriate improvement measures should be taken to improve its strength, so cement improve carbonaceous mudstone is conducted.

The mass ratio of the cement and dry carbonaceous mudstone is 2%, 4%, 6% and 8%, and the water-cement ratio is 0.6.

The improvement of the carbonaceous mudstone involves the following steps: weigh a certain mass of carbonaceous mudstone (the water content of carbonaceous mudstone is 15.7%); weigh a certain mass of cement based on the mass ratio of the cement and dry carbonaceous mudstone, weigh a certain mass of water based on water-cement ratio, and prepare cement slurry; then uniformly spray the cement slurry on the carbonaceous mudstone and uniform mixing; in accordance with the dry density (that is 1.54g/cm³) of the mixture of carbonaceous mudstone and cement, fill the mixture into the CBR test tube using the static pressure method; finally, cure the sample for 28 days, then conduct the wetting and drying test and CBR test.

The CBR test results of the cement-improved carbonaceous mudstone are shown in figure 7.

![Figure 7. The relationship between CBR and number of wetting and drying cycles.](image)

It may be seen from figure 7 that the CBR of the cement-improved carbonaceous mudstone increases as the cement ratio increase, but decreases as the number of wetting and drying cycles increases. When the cement ratio is 2%, the CBR of the cement-improved carbonaceous mudstone
meets the requirements of minimum strength of lower roadbed and upper embankment fillings (for lower roadbed the minimum CBR is 5%, for upper embankment the minimum CBR is 4%); when the cement ratio is 4%, the CBR of the cement-improved carbonaceous mudstone meets the requirements of minimum strength of upper roadbed fillings (for upper roadbed the minimum CBR is 8%). So that cement-improved carbonaceous mudstone is suitable for filling the expressway roadbed and upper embankment.

5. Conclusions
The feasibility of using carbonaceous mudstone as subgrade filler is studied, and the main conclusions are as follows:

1. Serious argillization occurs when carbonaceous mudstone immersed in water, but overburden soil pressure can partially inhibit the argillization.
2. As the number of wetting and drying cycles increases, the absolute expansion rate of the carbonaceous mudstone gradually increases, while the relative expansion rate gradually decreases, and both become stable after 6 cycles. The absolute and relative expansion rates gradually decrease as the overburden soil pressure increases.
3. The CBR of carbonaceous mudstone gradually decreases as the number of wetting and drying cycles increases, and tends toward stability after 6 cycles, at which time CBR doesn’t meet the requirements of minimum strength of roadbed and upper embankment filler. With the same number of wetting and drying cycles, the CBR of carbonaceous mudstone gradually increases as the overburden soil pressure increases.
4. The carbonaceous mudstone studied in the test could be directly used as the lower embankment filler, but could not be directly used as the roadbed and upper embankment filler.
5. The CBR of cement-improved carbonaceous mudstone gradually increases as the cement ratio increase, but gradually decreases as the number of wetting and drying cycles increase. The improved carbonaceous mudstone with 2% cement can be used as lower roadbed and upper embankment filler, and the improved carbonaceous mudstone with 4% cement can be used as upper roadbed filler.

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