Improvement technology research on red clay of Yuzhan expressway

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Abstract. There is a lot of red clay along the Yuzhan expressway. In order to use local materials, improve the efficiency of economy and protect the environment, it is proposed to use red clay of Guangxi as roadbed material. Through the experiments, the influence of different mix amount of sand and lime on red clay properties, feasibility of soil improvement is demonstrated and the influence regularities of strength index are analyzed. The results provide important reference for design and construction of expressway.

1. Introduction

Red clay is derived from carbonate rocks by laterization. Red clay is brownish red or tawny, and it has the characteristics with high plasticity, low compressibility and high strength. Red clay is mainly distributed in the Southwest and South of China. In Guangxi, red clay is universally distributed in Guilin, Liuzhou ad Guigang area, and it is closely related to local engineering construction. Red clay has become the main type of building foundation soil and material in Guangxi.

As early as 1980s, China began to research the engineering characteristics of red clay. One of the representatives is Geotechnical characteristics of red clay by Yuan Wan and Gao Dai[1]. Zeng Zhaotian et al. analyzed the geological characteristics and genesis of red clay in Guangxi Karst areas, and he found that the geological section of red clay in Guangxi showed obvious stratification phenomenon[2]. Zeng Jun tried to add lime to improve red clay, he found that lime could effectively improve the mechanical properties of red clay and the optimum mix amount is 8%[3]. Yang Jun et al. added weathered sand to improve high liquid limit red clay. He found that weathered sand can significantly improve CBR value, resilient modulus and internal friction angle, however, the shear strength, unconfined compressive strength and cohesion were decreased[4]. Ye Qiongyao and Cheng Tao used sand to improve red clay and tried to find the optimum mix amount[5-6]. Luan Chuanbao studied the effect of fly ash on properties of red clay[7]. Liu Zhikui researched the effects of cement content and age on engineering properties of red clay[8].

The soil structure and composition of red clay in Guangxi areas are different, and the optimum mix amount of sand and lime to improve red clay are varied. The detailed and in-depth study on red clay improvement technology for engineering practice needs to be further explored.
2. Project profile

Yuzhan expressway is 106.54 kilometers long, it connects Yulin city and Zhanjiang city, it passes through Lianjiang city, Suixi city, Zhanjiang city and finally reaches Donghai island. The project located in monsoon subtropical climate. In this area, summers are long, winters are short and temperature difference is small. The average annual rainfall is more than 1300mm, most rainfall is from May to September and influenced by monsoons and typhoons.

Along the expressway, there is a lot of red clay, and it is proposed to use local red clay of Guangxi as roadbed material. Although the requirements about roadbed filling of high liquid limit red clay are referred in the Specifications for Design of Highway Subgrades and Technical Specification for Construction of Highway, but the classification benchmark, slope of application and disposal methods are not mentioned. Therefore, the influence law of different sand or lime content on water and mechanical property of red clay is studied.

3. Materials and programs

3.1. Materials

Soil sample: the samples are from work area II in Luchuan county(mileage number K3+300~K28+980), and the geomorphic type in there is Guangxi southeast hilly region. The maximum sample depth is 20m, and the wet samples are brownish red, homogeneous, and dense.

| Moisture content (%) | Specific gravity of soil | Soil density (g/cm³) | Saturation(%) | Void ratio |
|----------------------|-------------------------|---------------------|---------------|------------|
| 28.6                 | 2.76                    | 1.93                | 1.50          | 94.6       | 0.831      |
| liquid limit (%)     | plastic limit (%)       | plasticity index   | sand >0.075(%) | silt 0.075~0.002 (%) | clay <0.002(%) |
| 53.1                 | 28.1                    | 25.0                | 0.32          | 57.47      | 42.21      |

Sand: the sand used for improvement is local natural sand, and it is well graded. The grain composition and grading curve of sand are showed in table 2 and figure 1. The content of sand are 15%, 30% and 45%, and the meaning of mixing ratio is the mass ratio of dry sand and dry soil.

| The percentage of soil particles less than a certain size in the total soil mass (%) |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| particle size 1.0mm              | particle size 0.5mm              | particle size 0.25mm             | particle size 0.1mm              | particle size 0.075mm            |
| 100.0                           | 99.1                            | 63.0                            | 8.0                             | 1.8                             |

Figure 1. Grading curve of sand.

lime: the lime used for improvement is over II level quicklime, the content of CaO is 80.8%, the content of MgO is 4.8%
3.2. Experiment program
Addition of sand: filter the representative red clay and sand through the 2mm sieve respectively. Add the sand to red clay in 0%, 15%, 30% and 45% proportion, then operate the heavy compaction test after sprinkling water and curing 24 hours. Finally, the optimum moisture content and maximum dry density of the improved soil were obtained. The results are shown in the table 3. The liquid and plastic limit, permeability, capillary rise, CBR, and shrinkage tests of improved red clay are also be tested.

Table 3. The optimum moisture content and maximum dry density of the improved soil by sand.

| Proportion of sand (%) | Optimum moisture content (%) | Maximum dry density (g/cm³) |
|------------------------|------------------------------|-----------------------------|
| 0                      | 13.7                         | 1.81                        |
| 15                     | 11.5                         | 1.99                        |
| 30                     | 11.3                         | 2.01                        |
| 45                     | 9.4                          | 2.07                        |

Addition of lime: filter the representative red clay through the 2mm sieve. Add the lime to red clay in 0%, 3%, 5% and 7% proportion. All the samples are cured for 28 days, then used for liquid and plastic limit, compaction and CBR tests.

4. Results

4.1. The improvement effect of sand on red clay
As the results shown in table 3, with the increase of sand content, the optimum moisture content of improved red clay is gradually reduced and the maximum dry density is gradually increased. This indicates that the sand can improve the hydrophilicity of red clay, and it is also beneficial to the compaction, strength and stability of subgrade.

Figure 2. The relation curve of the proportion of sand and CBR value.

In the figure 2, it can be seen that with the increase of sand content ratio, the CBR value is increased. When the proportion of sand is 15%, the CBR value is 3.86%. When the proportion of sand is 30%, the CBR value is 4.65%. When the proportion of sand is 45%, the CBR value is 6.31%. It is obvious that the requirements of the specification can be meet by adding the sand over 15% percentage.

Table 4. The limit moisture content of different proportion of sand.

| proportion of sand/| 0   | 15  | 30  | 45  |
|---------------------|-----|-----|-----|-----|
| liquid limit /%     | 53.9| 45.6| 40.4| 37.0|
| plastic limit /%    | 29.4| 27.4| 22.5| 19.6|
| plasticity index    | 24.5| 18.2| 17.9| 17.4|

In the table 4, it can be seen that the addition of sand can reduce the liquid limit, plastic limit, and plasticity index obviously. This is because the interaction of sand particles changes the composition and microstructure of particles after mixing with sand. At the same time, some clay minerals are
replaced by the sand. Therefore, the indexes are significantly decreased. When the proportion of sand increased from 0% to 15%, the liquid limit and plasticity index decreased respectively, reaching 8.3% and 6.3. At this time, the improved soil can already meet the standard of boundary moisture content of roadbed (liquid limit <50%, plasticity index <26).

![Figure 3. Curve of capillary water rising height and time with different sand content ratio](image)

The rising speed and height of capillary water have a great influence on the stability of embankment. The consolidation, settlement and deformation of subgrade can be completed quickly if the rise of capillary water can be completed as soon as possible. The process of capillary water rising height of red clay is fast at first and then slow down gradually. And as the height of the rise gradually increases (or spreads over time), the speed is slower and slower, and gradually stabilizes (or eventually approaches zero). With the increase of sand content, the capillarity phenomenon, rising height and the rising speed are decreased. It can be seen that sand-mixing improvement of red clay can effectively reduce the moisture migration caused by capillarity in the soil, which is conducive to improving the stability of embankment.

4.2. The improvement effect of lime on red clay

Table 5. The optimum moisture content and maximum dry density of the improved soil by lime.

| Proportion of lime (% | Optimum moisture content (%) | Maximum dry density (g/cm³) |
|----------------------|------------------------------|-----------------------------|
| 0                    | 13.7                         | 1.81                        |
| 3                    | 10.8                         | 1.89                        |
| 5                    | 11.1                         | 1.84                        |
| 7                    | 10.7                         | 1.87                        |

Table 5 shows the changes of different lime content, optimal moisture content and maximum dry density. After improved by lime, the optimal moisture content of red clay is decreased and the maximum dry density is increased, but the undulatory change rule is not consistent with the monotonic change of mixing sand. The reason is that the red clay mainly relies on the internal pores and intergranular pores in the soil to store water, after adding lime, the small particles were joined to form large ones, which had little effect on the volume of water storage in the internal pores. Therefore, the phenomenon that increasing the proportion of lime can not make the liquid limit decrease appears.

Table 6. The limit moisture content of different proportion of lime.

| Proportion of lime (%) | 0  | 3  | 5  | 7  |
|-----------------------|----|----|----|----|
| liquid limit (%)      | 53.9| 42.8| 42.1| 41.3|
| plastic limit (%)     | 29.4| 23.8| 24.1| 24.5|
| plasticity index      | 24.5| 19.0| 18.0| 16.8|
As it can be seen from Table 6, the plasticity indexes after the lime improvement are significantly improved compared with the natural red clay. However, the increase of lime proportion cannot improve the effect obviously, and there is no significant difference of the index values between different lime proportion.

![Figure 4. The relation curve of the proportion of lime and CBR value.](image)

The relation curve of the proportion of lime and CBR value is shown in Figure 4. With the increase of lime proportion, CBR value becomes substantial risen. When the proportion of lime is 3%, the CBR value is 51.67%, and it can meet the CBR value requirements of road bed and subgrade filling in the code.

5. Conclusions
(1) Sand and lime can significantly improve the water-bearing and mechanical properties of red clay. The improved red clay can meet the requirements of subgrade filling, and the method can be applied to improve red clay.

(2) With the increase of sand content, the optimum moisture content, liquid limit and plastic limit, plastic index and capillary intense rising height are decreasing, the maximum dry density and CBR value are increasing. When the proportion of sand is 15%, the CBR value is 3.86%, and the requirements of the specification about CBR can be meet.

(3) All the indexes of red clay are improved obviously after the lime was added in. Instead of showing a monotonous change rule with the increase of lime content ratio, it presents the undulatory changes, and there is little difference between the index values of different lime content ratio. When the proportion of lime is 3%, the CBR value is 51.67%, and the requirements of the specification about CBR can be meet.

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