Experimental study on improving red clay with sand at the foot of mountain

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Abstract. There is a large amount of red clay along a highway under construction in Southwest China. The red clay has high plasticity and small CBR which don’t meet the specification. This paper studied on red clay improvement by adding sand at foot of mountain. Research results show that the dry density of the improved red clay increases with the increase of the sand when the moisture content is the same. The optimum moisture content of improved red clay decreases with the increase of the sand. The maximum dry density increases with the increase of the sand. Liquid limit and plasticity index decrease after adding the sand. The CBR increases after adding the sand. The sand mixing ratio 4:6 was recommended to use in actual construction. And properties of improved red clay filler with the recommended ratio in actual construction meet the specification. Project implementation effect is very good.

1. Introduction
Red clay is a kind of clay formed by laterization of carbonate rock outcrop [1]. It is brown red or yellow brown clay with high plasticity, low compressibility [2]. Red clay generally has a high liquid limit and is easy to shrink due to water loss. Red clay is easy to cause some engineering accidents, such as pavement uplift, uneven deformation of foundation, slope instability, pavement cracking and building deformation [3-5]. It brings a lot of economic losses every year. However, there are very few regulations on red clay in current Chinese codes [6]. Therefore, it is very necessary to research on the properties and treatment methods of red clay.

There is a large amount of red clay along a highway under construction in Southwest China. In order to save the project cost and the occupied area of waste muck, the construction company plans to use red clay as the roadbed filling material. For the safety of the project, the engineering properties of red clay were tested before backfilling. Experiment on the improvement of mixed sand at the foot of mountain has been done.
2. Specification requirements for red clay subgrade filler

Some requirements for red clay subgrade filler are made in “Specifications for Design of Highway Subgrades” (JTG D30-2015). The liquid limit of filler should be less than 50% and the plasticity index should be less than 26. The minimum CBR of fillers is shown in table 1. These requirements should be met after the improvement of red clay.

Table 1. Minimum load ratio requirements for roadbed and embankment filler in the Specifications.

| Subgrade position | Depth below pavement bottom (m) | Minimum CBR (%) |
|-------------------|---------------------------------|-----------------|
| Upper road bed    | 0–0.3                           | 8               |
| Light, medium and heavy traffic | 0.3–0.8 | 5               |
| Extra and extremely heavy traffic | 0.3–1.2 | 5               |
| Lower road bed    | 0.3–1.2                          | 5               |
| Upper embankment  | 0.8–1.5                          | 4               |
| Light, medium and heavy traffic | 1.2–1.9 | 4               |
| Extra and extremely heavy traffic | 1.2–1.9 | 4               |
| Lower embankment  | 1.5 or less                      | 3               |

3. Nature of natural red clay and sand

3.1. Properties of natural red clay

Through laboratory tests, properties of natural red clay were obtained. Some properties were shown in table 2. As can be seen from table 2, the liquid limit is 53.9%. It is high liquid limit soil. The liquid limit and the CBR of red clay don’t meet the specification requirement. The red clay in this study can’t be directly used as filler for highway.

Table 2. Physical properties of red clay samples.

| Water Content(%) | Specific gravity | Density(g/cm³) | Liquid limit(%) | Plastic Limit(%) | Plasticity index | CBR(%) |
|------------------|------------------|----------------|----------------|-----------------|------------------|--------|
| 30.2             | 2.76             | 1.88           | 53.9           | 53.9            | 29.4             | 24.5   | 2.24  |

3.2. Properties of sand at the foot of mountain

In engineering, sand is generally river sand and sea sand. River sand and sea sand are produced by repeated collision and friction of natural stone under the natural state through the action of water for a long time. Its composition is relatively complex. They have a smoother indication.

Part of the project uses rock-sand. Rock-sand is the product obtained from weathering and decomposition of rocks throughout years. It is usually needs to be broken mechanically. Its particle size is less than 4.75mm. Rock-sand is irregularly shaped with multiple rhomboids and has a rough surface. Rock-sand often contains more impurities than river sand [6].

Sand at the foot of mountain in this study is the sand accumulated at the foot of the mountain after rock is weathered. Similar to rock-sand, sand at the foot of mountain is irregularly shaped with multiple rhomboids, has a rough surface and often contains more impurities. But unlike mountain sand, mountain sand is not machined. The grain size of the sand at the foot of the mountain is larger than rock-sand. The grain grading curve of sand at the foot of mountain is shown in figure 1. The maximum grain size of rock-sand is less than 40 mm. Other properties were shown in table 3.
Figure 1. Grain grading curve of rock-sand.

![Grain grading curve of rock-sand](image)

Table 3. Properties of rock-sand.

| Bulk density (g/cm$^3$) | Porosity (%) | Water absorption rate (%) | Sediment percentage (%) | Firmness (%) |
|-------------------------|--------------|---------------------------|-------------------------|--------------|
| tap loose               | tap loose    | mix 3:7                   | mix 4:6                 | mix 5:5      |
| 1.48                    | 1.28         | 44                         | 52                      | 3.2          |
|                          |              | 3.2                       | 3.6                     | 2.9          |

4. Analysis on the effect of improving red clay with sand at foot of mountain

With reference to study on red clay improvement with river sand, three sand mixing ratios were used when improving red clay with mountain sand. These three sand mixing ratios are 3:7, 4:6 and 5:5. Sand mixing ratio is the ratio of the mass of sand to the mass of red clay. The compaction test results of improved red clay are shown in figure 2. Liquid limit, plasticity index and CBR of improved red clay are shown in table 4.

![Curve of moisture content and dry density](image)

Seen from figure 2, dry density of improved red clay increases with the increase of the sand. The optimum moisture content of improved red clay decreases with the increase of the amount of the sand. The maximum dry density increases with the increase of the amount of the sand. When the sand mixing ratios is 3:7, the optimum moisture content of improved red clay is 19.8% and the maximum dry density is 1.57g/cm$^3$. When the sand mixing ratios is 4:6, the optimum moisture content of improved red clay is 18.8% and the maximum dry density is 1.62g/cm$^3$. When the sand mixing ratios is 5:5, the optimum moisture content of improved red clay is 15.3% and the maximum dry density is 1.69g/cm$^3$.

As can be seen from figure 2, liquid limit and plasticity index of red clay decrease after adding sand at foot of mountain. The CBR increases after adding the sand. When the sand mixing ratios is 3:7, the liquid limit, the plasticity index and the CBR of improved red clay all meet the specification. But
the liquid limit and the plasticity index very close to the limit. Considering that the stirring conditions during actual construction are not as good as the indoor test, the filler may not meet the specification when the sand mixing ratio 3:7 is used in actual construction. Therefore it is recommended to use the sand mixing ratio 4:6 in actual construction.

Table 4. Properties of improved red clay.

| Sand mixing ratio | Liquid limit(%) | Plasticity index | CBR(%) |
|------------------|-----------------|-----------------|--------|
| 0:1              | 53.9            | 24.5            | 2.24   |
| 3:7              | 49.4            | 24.4            | 31.7   |
| 4:6              | 45.6            | 21.8            | 35.8   |
| 5:5              | 40.5            | 19.3            | 34.2   |

Adopted sand-mixing ratio recommended in this paper during highway construction. Properties of improved red clay filler meet the specification. Project implementation effect is very good.

5. Conclusions

In this paper, the red clay is improved by adding sand at the foot of mountain. Conclusions are as follows.

(1) When the moisture content is the same, the dry density of the improved red clay increases with the increase of the amount of the sand. The optimum moisture content of improved red clay decreases with the increase of the amount of the sand. The maximum dry density increases with the increase of the amount of the sand.

(2) Liquid limit and plasticity index of red clay decrease after adding sand at foot of mountain. The CBR increases after adding the sand.

(3) When the sand mixing ratios is 3:7, the liquid limit, the plasticity index and the CBR of improved red clay all meet the specification.

(4) It is recommended to use the sand mixing ratio 4:6 in actual construction.

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