Experimental Study on Shear Behavior of Expansive Soil Modified by Gravel Sand

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Abstract. Using the strain-controlled direct shear equipment, some direct shear experiments were carried out on the soil samples of Nanyang expansive soil with different gravel ratios under the specific water content, and the shear strength, cohesion and internal friction angle of the expansive soil samples were studied. The experimental results show that the shear strength of the expansive soil samples increases with the increase of vertical pressure. As the proportion of gravel sand increases, the shear strength of expansive soil samples increases to varying degrees. The shear strength of expansive soil increases significantly when the proportion of gravel sand is in the range of 10%~40%, and the shear strength of remolded soil is the highest when the gravel sand content is 10% under the lower vertical pressure. Under the higher vertical pressure, the shear strength of the remolded soil is the largest when the gravel content is 20%, and the shear strength of expansive soil is close to that of pure expansive soil when the proportion of gravel sand is 50%. The cohesive force of the sample increases first and then decreases sharply with the increase of the proportion of gravel sand, and is maximum when the content of gravel sand is 10%. The internal friction angle increases first and then decreases slowly with the increase of the proportion of gravel sand, and is maximum when the gravel sand content is 40%. The results show that gravel sand can effectively enhance the shear strength index of expansive soil, which can be used as a good engineering application material for improving expansive soil.

1. Introduction
Expansive soil is a kind of special soil with extremely unstable properties. It has obvious deformation characteristics which are not conducive to engineering construction, such as expansion and attenuation of bearing capacity of soil after it absorbs water, and shrinkage deformation after soil loses water. With the development of infrastructure construction in various countries of the world, the engineering problems in the area of expansive soil distribution have become increasingly prominent. Uneven vertical or horizontal expansion and contraction deformation of the soil will cause displacement, cracking, tilting and even destruction of the building. Therefore, in the construction of the project, we should make the best use of the excellent properties of expansive soil, avoid or improve its undesirable properties, and continuously improve the safety application value of expansive soil in various engineering applications.
In recent years, scholars have carried out a large number of research and application research on shear properties of expansive soil modification. Zhuang et al. [1] improved the expansive soil through phosphorus tailings. The experimental analysis found that the cohesion and internal friction angles were linearly negatively correlated with the amount of blending. Zhao et al. [2] conducted an experimental study on the improvement of expansive soil of iron tailings sand, and believed that the optimal blending ratio of iron tailings should be 30%. Domestic and foreign scholars [3-6] have also carried out some experimental research based on biological enzymes to improve expansive soil. Shen et al. [7] increased the shear strength of expansive soils based on the angle of the composite modifier to reduce the strong expansion ratio. Deng et al. [8] studied the strength of polypropylene fiber reinforced expansive soil based on optimal moisture content. Huang et al. [9] used image processing technology to extract crack parameters from the surface crack image of soil samples and tested the saturated shear strength. Yang et al. [10] obtained the shear strength index values of expansive soils using weathered sand, lime, cement and fly ash at different shear rates. Zhang et al. [11] developed lime and coal gangue to improve the engineering properties of expansive soil. Chen et al. [12] carried out fiber reinforced lime to improve the engineering properties of expansive soil. Zha et al. [13] carried out calcium carbide slag to improve the experimental study of expansive soil. Bian et al. [14] used lime to improve the strength test of expansive soil, and proposed a formula for calculating the shear strength of the initial moisture content and ash mixing rate. Sun et al. [15,16] developed alkali slag and waste tire rubber powder to improve the indoor experimental study of expansive soil. At present, in the modification test of expansive soil, the research results of using gravel sand to improve the shear characteristics of expansive soil are still in the blank.

In this paper, the expansive soil of Nanyang City was taken as the research object. Under the condition of the same water content of the sample, the soil samples with different gravel content were prepared and some direct shearing experiments were carried out. Through shearing experiments, the indexes of shear strength, cohesion and internal friction angle of soil under different vertical pressures were obtained to analyze the effects of gravel sand content on soil shear strength, cohesion and internal friction angle. The research results can provide a new idea for the engineering application of improving the expansive soil.

2. Experimental materials and methods

2.1. Experimental materials

The natural expansive soil used in the experiment was taken in the construction section of the South-to-North Water Diversion Project in Nanyang City of Henan Province. The state of natural expansive soil on the surface of the land is shown in Figure 1. The basic physical and mechanical parameters of the natural soil were then determined by laboratory experiments as follows: the natural density is 1.93 g/cm\(^3\) and the natural moisture content is 18.7%. Gravel sand is a widely used engineering material, which is cheap and easy to obtain. Gravel sand material was obtained by screening from the ordinary sand, and then the gravel sand material was washed and dried.

2.2. Experimental equipment and methods

The main equipment of the experiment: constant temperature oven, soil sample analysis sieve, strain control type direct shear instrument (including dial indicator, permeable stone, etc.), electronic balance and laboratory special ring cutter. Before the direct shear experiment, the soil was uniformly reshaped according to the experimental specifications. In the experiment, the particle size used is 1mm, and the optimum moisture content of the sample was set as 18%. On the basis of this water content, the expansive soil samples with the gravel content of 0%, 10%, 20%, 30%, 40% and 50% were prepared respectively. Soil samples were prepared in a ring cutter with a radius of 30 mm and a thickness of 20 mm. To ensure the reliability of the experiment, six test soil samples were prepared for each dosage. The samples were subjected to shear experiments under different vertical pressures in sequence. Figure 2 shows the expanded soil samples after partial shearing.
3. Experimental results and analysis

3.1. Experimental data

According to the requirements of the experimental results, record the dial gauge value when the soil sample undergoes shear failure during the experiment. The shear strength of the specimen was obtained by the dynamometer correction coefficient. The specific values of the shear strength index are shown in Table 1. According to the experimental results of the expansive soil samples under different gravel sand content, the shear strength of the specimen under different vertical pressures was plotted as an intuitive data graph. The specific values are shown in Figure 3.

| Pressure (kPa) | Gravel sand ratio (%) |
|---------------|-----------------------|
|               | 0         | 10        | 20        | 30        | 40        | 50        |
| 100           | 76.55     | 98.95     | 95.22     | 91.48     | 85.88     | 65.35     |
| 200           | 103.65    | 129.69    | 127.82    | 126.02    | 120.36    | 100.75    |
| 300           | 132.56    | 164.43    | 166.43    | 161.56    | 157.83    | 136.16    |
| 400           | 160.58    | 195.17    | 198.64    | 194.1     | 193.3     | 170.56    |

Figure 3. Shear strength of expansive soil samples

It can be seen from Figure 3 that the shear strength of the remolded soil sample gradually increases with the increase of vertical pressure under the same water content condition regardless of the proportion of gravel sand of the sample. The shear strength curves of the six groups of expansive soil samples show linear distribution changes. When the gravel sand content is 0%, the slope of the straight line is the smallest, and when the gravel sand content are 10%, 20%, 30%, 40% and 50%, the linear slope of the sample are very close. Compared with the pure expansive soil sample, the shear strength of the expansive soil is improved after being incorporated into the gravel sand.
In the relationship between the shear strength of the sample and the amount of gravel sand, when the vertical pressure of the remolded soil sample is constant, the shear strength increases first and then decreases with the increase of the proportion of gravel. At the lower vertical pressures of 100kPa and 200kPa, the shear strength of the remolded soil is the largest when the sample gravel content is 10% and the expansive soil content is 90%. At higher vertical pressures of 300kPa and 400kPa, when the sample gravel content is 20% and the expansive soil content is 80%, the shear strength of the remolded soil is the largest, but the shear strength is lower than the lower vertical pressure. The degree of the change is small, and the shear strength of 10%~40% is very close. According to the comprehensive analysis, when the content of gravel sand of the expansive soil is 10%, it can be used as the optimal gravel sand to improve the shear strength test proportion of expansive soil.

3.2. Effect of gravel sand content on cohesion and internal friction angle

Cohesive force and internal friction angle are important indexes for the shear strength of cohesive soil. According to the above experimental results, the friction angle (φ) and cohesion (c) of soil in different water content were calculated by using the formula of molar stress circle. The results are shown in the following table 2.

In order to more intuitively reflect the influence of different gravel sand content on the shear strength index of expansive soil, the data of Table 2 was plotted as the relationship between the shear strength index and the amount of gravel sand. The results are shown in Figure 4 and Figure 5 below.

| Gravel sand ratio (%) | 0   | 10  | 20  | 30  | 40  | 50  |
|----------------------|-----|-----|-----|-----|-----|-----|
| φ (°)                | 15.64 | 17.78 | 19.01 | 19.31 | 19.62 | 19.32 |
| c (kPa)              | 47.26 | 66.88 | 62.01 | 58.61 | 49.73 | 30.95 |

Figure 4. The internal friction angle curve

Figure 4 shows that the friction angle of the sample increases first and then decreases with the increase of the proportion of gravel sand. When the gravel content of the sample increases from 0% to 10%, the cohesive force of the sample increases sharply. When the gravel content of the sample increases from 10% to 40%, the internal friction angle of the specimen increases, and the internal friction angle reaches a maximum of 19.62° when the gravel content is 40%. When the gravel content of the sample increases from 40% to 50%, the internal friction angle of the sample gradually becomes small.

In the figure 5, it can be found that the cohesive force of the sample increases sharply with the increase of the proportion of gravel sand, and then gradually decreases. The sand content increases from 0% to 10%, and its cohesive force rapidly increases to a maximum of 66.88 kPa. The sand content increases from 10% to 50%, the cohesive force gradually decreases, and the minimum content is 30.95 kPa when the sand content is 50%.
According to the comprehensive analysis, when the moisture content of the sample is the same, the gravel sand content affects the cohesion and internal friction angle of the remolded soil sample. The cohesive force of the sample reaches the highest when the gravel content is 10%. The reason may be that when the coarse sand content is small, the mechanical properties are controlled by the expansive soil. With the increase of coarse sand content, the self-cohesive force of the expansive soil is weakened. When the proportion of gravel sand exceeds 40%, the effect is gradually weakened. The internal friction angle of the sample reaches the highest at the gravel content of 40%, and the internal friction angle increases with the coarse grain sand content. The internal skeleton effect increases rapidly in the soil, so the internal friction angle increases rapidly. When the coarse-grained sand content exceeds a certain value, the expansive soil is distributed between the gravel sands inside the sample. During the shearing process, the expansive soil acts as a lubricant for the relative displacement of the coarse particles due to shearing. The internal friction angle is rapidly reduced.

4. Conclusion

In this paper, some direct shear experiments were carried out on Nanyang expansive soil samples with different gravel content. According to the experimental results, the following conclusions can be obtained:

(1) In the direct shear experiments, the shear strength of the expansive soil sample increases with the increase of the vertical pressure, and the overall form shows a linear change trend. When the gravel sand content is 0%, the slope of the straight line is the smallest. The slope of the straight line is approximately the same when the amount of gravel sand is 10%~50%. With the increase of gravel sand content, the shear strength of soil increases first and then decreases, and the optimum amount is 10%.

(2) In terms of the influence of gravel sand content on cohesion and internal friction angle, when the gravel content increases from 0% to 10%, the cohesive force and internal friction angle of the expansive soil sample increases rapidly, and the cohesive force reaches the maximum value; When the gravel sand content increases from 10% to 50%, the cohesive force decreases rapidly, the internal friction angle increases first and then decreases, and the internal friction angle reaches a maximum when the gravel sand content is 40%.

(3) Through laboratory experiments, it is shown that the content of gravel sand has certain influence on the shear strength characteristics of expansive soil, and the overall experimental results meet the expected objectives of the experiment. In the expansive soil improvement experiment, the test results mainly depend on the choice of experiment materials. We should give full play to the advantages of different components of the sample, take advantage of the length and complement each other, and provide reference for the application of expansive soil engineering. In the follow-up study, we are supposed to conduct a deeper analysis based on the interaction angle between gravel and expansive soil.

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