Innovative Experimental Teaching and Practice of Direct Shear Test of Root-Soil Complex

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Abstract. In view of the problems existing in the soil mechanics experiment teaching process, this paper carries on the soil mechanics experiment teaching reform, combined with the characteristics of abundant vegetation in Yunnan Province, and considered the goal requirement of training innovative talents, the innovative experiment project was established. Based on the direct shear test of pure soil, the direct shear test of root-soil complex was carried out by adding plant root system into the sample to analyze the influence of plant root system on the index of shear strength of soil. Through the innovative experimental project, the students' practical ability and the ability of analyzing problems were improved, the students' experimental enthusiasm was aroused, the students' innovative ability was strengthened, and the teaching quality of soil mechanics experiment was improved.

Keywords: Soil Mechanics · Experimental Teaching Reform · Root-Soil Complex · Direct Shear Test

1 Introduction

Soil mechanics experiment is a required professional practice course for civil engineering major. After learning, students can have the understanding of the basic concepts (e.g.: water content, density, specific gravity and liquid-plastic limit of soil, etc.) and basic principles (e.g.: direct shear, consolidation) of soil mechanics strengthened and get the practice ability improved [2, 3]. In consideration of the importance of soil mechanics experiment in teaching, most colleges and universities with civil engineering major in China set this course, but in practical teaching process, it has the shortcomings of too much observation and validation tests but too little comprehensive and open tests, and lack of relations among the test items in soil mechanics experiment, which makes the experiment a donkeywork and the students lack the enthusiasm, hence adverse to cultivating students' innovation ability. Before the experiment, teachers have explained the objective, process and phenomenon of experiment, but students are not impressed with this part and get little from the experiment, which is contradictory to the original intention of setting the teaching link of soil mechanics experiment. In order to change this situation and improve the scientificity and validity of soil mechanics experiment teaching process, domestic scholars did a lot of work and made numerous useful teaching attempts, such

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as setting virtual simulation experiment [8] and interesting soil mechanics experiment [5]. These attempts enriched the teaching methods and the classroom teaching contents of soil mechanics experiment and improved the students' enthusiasm for soil mechanics experiment.

In combination with the characteristic of abundant vegetation in Yunnan Province and relying on the advantage that Yunnan is relatively earlier than others to carry out highway slope vegetation recovery technology in China, this paper carries out teaching reform and tries to perform shear strength test on root-soil complex in soil mechanics experiment course, gets the index of shear strength of root-soil complex and then compares it with that of pure soil for further analysis, so as to avoid the disadvantage of emphasizing on theory and ignoring experiment, increase students' interests in participating in soil mechanics experiment and improve students' scientific research ability, thus fulfilling the teaching objectives of soil mechanics experiment.

2 Teaching Design for Innovative Soil Mechanics Experiment

As a kind of active material, plant root system can penetrate, enwind and consolidate the soil [11]. The root system mainly comprises of protein, sugar and fat, similar to high polymer material [4]. The cell wall of root system is interwoven by extension network and cellulose microfilament network with certain tensile property [6], so it can be considered as reinforced material [1]. Plant root system can form a root network with the soil particles to fix the plants firmly into the soil, just like playing a reinforcing role on the soil [9, 10]. The root system and soil compose a special composite: root-soil complex [12]. Many research results show that, plant root system exists in the soil, which can increase the cohesion of soil [7].

Compared with direct shear test of pure soil, the shear test of root-soil complex is innovative, and relevant guidebooks for soil mechanics experiment do not contain the explanation on the operation steps and test data processing of it. So students shall design the experiment themselves. In consideration that students have little opportunity to touch scientific research and their scientific research ability is insufficient, teachers will provide students with related literatures on shear test of root-soil complex for study, so that students can compile the reports on specimen acquisition and making, experiment process and data processing according to the literatures, and then carry out experiment upon teacher's review and approval. The whole process from specimen acquisition to preparation of soil sample is independently finished by students. In the process, students get better perceptual knowledge on soil and then combine the theory with practice. This is not only of vital importance for understanding and accepting soil mechanics experiment course, but also serves as an indispensable and important perceptual basis for cultivating high-level innovation ability.

3 Research and Practice of Innovative Soil Mechanics Experiment Teaching

3.1 Preparation of Specimen

Direct shear test of root-soil complex mainly requires the following instruments: strain-controlled direct shear apparatus, cutting ring with inner diameter of 6.18 cm and height of 2 cm, scale with range of 5–10 cm and division value of 0.01 mm, vernier caliper, etc. A certain amount of clay is dug in the campus and then sieved, but the sampling is somehow difficult as the soil is relatively loose. Moreover, the buried depth of plant root system is not deep and undisturbed soil containing plant root system is not suitable for direct shear test, so remoulded soil containing plant root system is adopted for direct shear test. Steps of preparing remoulded soil specimens containing plant root system are as follows: first weigh proper amount of sieved air-dried soil, calculate the required water content according to that required by test, pave the soil sample in a water-repellent plate, spray the expected water with a spraying device, fully stir it, put it into a drier and fasten the cover, then soak it for 24 h for use. The root system of sticktight is adopted in this experiment. Vertical root system is added into the soil sample. Restricted by the size of specimen, the specimen is 2 cm high. The root system of sticktight collected in the field is cut into vertical root system of 2 cm long according to the diameter of 1.0 mm, and then vertically put the one root system, two root systems and three root systems into the middle of the earth column. Then direct shear test is done on the pure soil and root-soil complex according to the operation steps in the literature.

3.2 Test Data

The test data are recorded to draw the curves with Origin. The relationship curves between shear displacement and shear stress of specimens are shown in Figs. 1, 2, 3 and 4.

It can be learnt from Figs. 1, 2, 3 and 4 that, all specimens show a trend that the shear stress gradually increases as the shear displacement increases, and that the larger the vertical stress is, the larger the shear stress required for specimen damage will be. This is because that the specimen has a relatively loose structure at the beginning of test, so the shear stress required for shear failure of specimen is small. As the testing

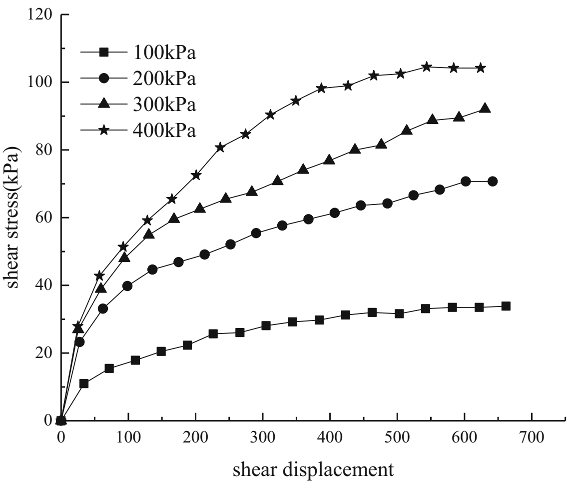

Fig. 1. The curve of shear strength of pure soil specimen under different vertical pressures

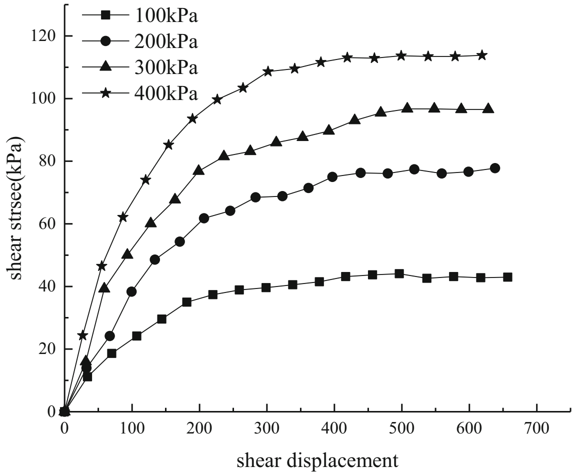

Fig. 2. The curve of shear strength of specimen containing one root system under different vertical pressures

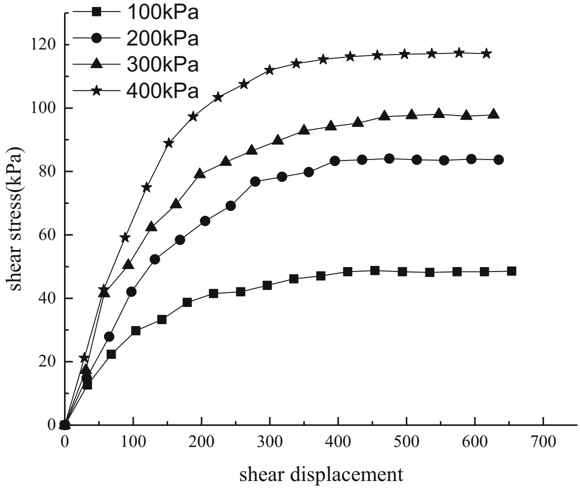

Fig. 3. The curve of shear strength of specimen containing two root systems under different vertical pressures

time increases, the soil particles are gradually compacted when the specimen is under the action of vertical stress, which makes the shear stress required for shear failure of specimen increase. As the shear displacement gradually increases, the shear surface of specimen gradually decreases, and the increase amplitude of shear stress required for shear failure of specimen slows down. The maximum shear stresses under different vertical stresses of different specimens are recorded in Table 1, which visually expresses

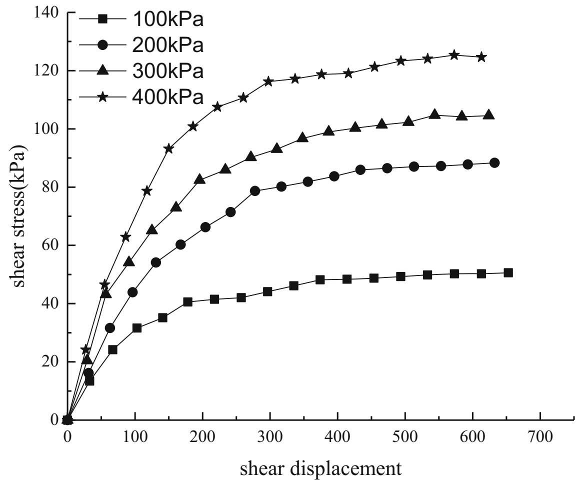

Fig. 4. The curve of shear strength of specimen containing three root systems under different vertical pressures

Table 1. Maximum shear stress under different vertical pressures of different specimens

Vertical stress σ (kPa)	Maximum shear stress τ (kPa)			
	Pure soil	One root system	Two root systems	Three root systems
100	33.85	42.97	48.55	50.59
200	70.68	77.75	83.70	88.35
300	92.07	96.53	97.84	104.53
400	104.16	113.83	117.18	124.62

the changes of data. Origin is used to draw the bar chart of the data in Table 1, as shown in Fig. 5.

It can be seen from Fig. 5 that, under the action of the same vertical stress, the more plant root systems the specimen contains, the larger the shear stress required for shear failure of specimen will be. For example, when the vertical stress is 100 kPa, the shear stress required for failure of pure soil specimen will be 33.85 kPa; when the specimen contains 1, 2 and 3 plant root system(s), the shear stress required for failure of specimen will be 42.97 kPa, 48.55 kPa and 50.59 kPa respectively. On the other hand, when the specimens contain the same number of plant root systems, the shear stress required for failure of specimen bears a positive correlation relationship with the vertical stress. When the specimen contains 1 plant root system and the vertical stress is 100 kPa–400 kPa, the shear stress required for shear failure of specimen will be 42.97 kPa, 77.75 kPa, 96.53 kPa and 113.83 kPa respectively.

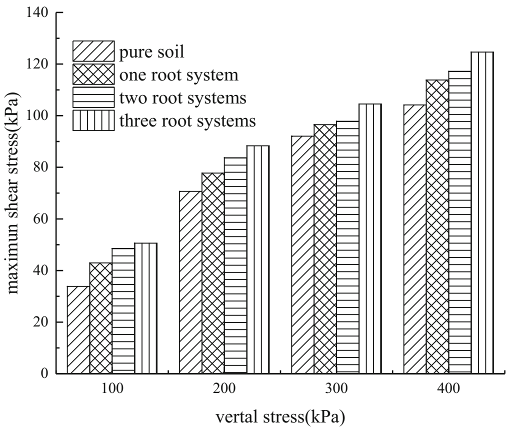

Fig. 5. Bar chart of maximum shear stress of different specimens

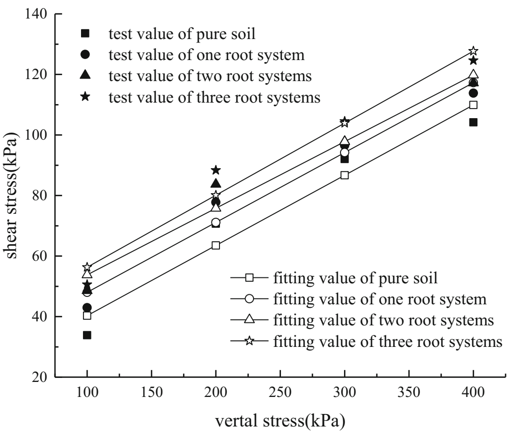

Fig. 6. Shear strength test values and fitting values of specimens

When the dots of vertical stress and the maximum shear stress in Table 1 are traced and connected according to the test data, it is discovered that the shear stress bears a linear relationship with the vertical stress, conforming to the Coulomb's law. The internal friction angle φ and the cohesion c of specimen can be calculated based on the dip angle of straight line and the intercept on Y-axis. But the practice of tracing the dots and connecting them into lines is greatly affected by the drawing ability of students, so the error may be large. In view of this, students are required to calculate the index of shear strength of root-soil complex by data fitting. When the test data are processed, teachers will provide the data processing software Curve Expert and the students will input the σ and τ values of test and then perform linear fitting to get the c and φ values of root-soil complex through simple data conversion, thus avoiding the error in test data processing. The test value and fitting value of Table 1 are shown in Fig. 6.

Table 2. The c and φ calculation value of specimen

Specimen	Pure soil	One root system	Two root systems	Three root systems
c (kPa)	17.1	24.9	31.8	32.5
φ (∘)	13.07	13.01	12.41	13.39

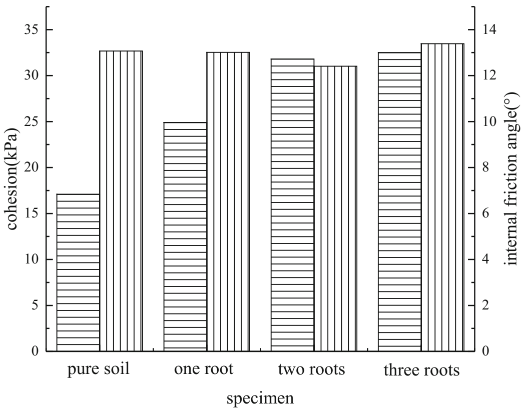

Fig. 7. Bar chart of cohesion and internal friction angle of specimen

It can be learnt from Fig. 6 that the shear strength lines of specimens are basically parallel, indicating that the internal friction angles of specimens are not greatly different. That is to say, plant root system imposes little influence on the internal friction angle of soil. For the specimens added with plant root system, the intercept on Y-axis is greater than that of pure soil specimen. The more the plant root systems are added into the specimen, the larger the intercept of the shear strength line on Y-axis will be, indicating that the larger the cohesion of specimen will be. That is to say, plant root system increases the cohesion of soil.

The c and φ values of specimens are obtained based on the dip angle of each straight line in Fig. 6 and the intercept on Y-axis, as shown in Table 2.

Data in Table 2 are used to drawn a bar chart with two Y-axes, as shown in Fig. 7. In the chart, the left Y-axis represents the cohesion of specimen and the right Y-axis represents the internal friction angle of specimen.

The test data in Table 2 and Fig. 7 indicate that, plant root system imposes little influence on the internal friction angle of soil but great influence on the cohesion of soil. To be specific, the internal friction angle of pure soil is 13.07º and the largest change in internal friction angle of root-soil complex is 13.39º, indicating a small change amplitude. The cohesion of pure soil is 17.1 kPa, and the largest change in cohesion of root-soil complex is 32.5 kPa, indicating a large change amplitude.

4 Conclusions

In order to analyze and compare the influence of plant root system on the index of shear strength of soil, the students prepare the pure soil specimen and root-soil complex specimen by themselves according to relevant literatures provided by the teacher. To check the teaching effect, anonymous questionnaire survey is done on the students majoring in civil engineering, grade 2017. The results show that, compared with simple pure soil shear test, more than 90% students are willing to accept the innovative direct shear test of root-soil complex. The teaching reform enhances the students' ability of learning literature and mastering the latest research results on one hand, and enhances the students' ability of practical operation and test data analysis and raises their interest in participating in soil mechanics experiment on the other hand. The biggest benefit is that students change from "passive learning" to "active learning" and can combine the theories with practice and apply the basic theories learnt into engineering practice.

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