Research on prediction of cement-soil cohesion based on strength test

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Abstract. In order to accurately predict the cohesive of cement-soil and better reflect the shear strength of cement-soil, through indoor strength tests and theoretical analysis, the influence of cement mixing ratio on shear strength and unconfined compressive strength is discussed. In the commonly used cement mixing ratio range (5%-30%), prediction formula of cohesive and unconfined compressive strength is proposed. The cohesive prediction model based on cement mixing ratio and age is further established. The results show that the unconfined compressive strength and cohesive strength of cement-soil increase with the increase of cement mixing ratio and curing age. There is a good linear relationship between cohesion and unconfined compressive strength. Based on nonlinear regression analysis, the prediction model of cohesive under the influence of multiple factors fits well with the test results.

1. Introduction
Cement soil is a mixture of soil and cement (curing agent), which is stirred and combined to form a mixture with certain strength after compaction and maintenance. It has the characteristics of low price, convenient access, high strength, good durability and so on, and is widely used in various engineering construction [1, 2, 3]. The shear strength of cement-treated soil refers to the ability to limit the cement soil resistance to shear failure. In various engineering practices, issues such as foundation pit support [4], slope stability [5, 6], and foundation reinforcement [7] are closely related to the shear strength of cement soil, and cohesive as an important index of shear strength is very important to evaluate the strength of cemented soil [8]. Scholars at home and abroad have conducted a lot of studies on the cohesion of cemented soil. Ruan et al. [9, 10] discussed the influence of cement mixing ratio and curing age on the cohesion through triaxial unconsolidated and undrained shear test. Chen et al. [11] analyzed the influence of sewage conservation environment on the cohesion of cement soil. Rosalia et al. [12] explored the influence law of adding recycled glass (RG) to cemented soil on cohesion of cemented soil. Through experiments, Zhao et al. [13] proposed that there is a linear relationship between soil-cement strength and square of cohesion. Ochepo et al. [14] predicted the cohesion by water-cement ratio, and believed that compared with age and cement content, water-cement ratio had a more significant influence on the cohesion.
It can be seen from the existing studies that the relevant studies mainly focus on the influence of a single factor on the cohesive, but there are few studies on the relationship between the compressive strength and cohesive and the prediction of cohesive of cemented soil. As the most important index for evaluating soil-cement strength [15], the unconfined compressive strength of soil-cement is particularly important for evaluating the effect of foundation reinforcement, and the compressive strength test is simple and reliable. At the same time, the increase or decrease of shear strength of soil-cement under different conditions is mainly reflected in the increase or decrease of cohesion, while the change of internal friction angle has no obvious rule [16]. Based on the tests of unconfined compressive strength and shear strength in the laboratory, the correlation between cohesion and unconfined compressive strength is put forward, and the prediction model of cohesion based on cement mixing ratio and curing age is established, which provides theoretical basis for the prediction of cohesion in engineering practice.

2. Test materials and test methods

2.1. Test materials
The test material was taken from a construction site in Wuhe County, the lower reaches of the Huaihe River Basin. The soil was gray yellow and belonged to soft plastic clay with low strength. The cement is P.O.32.5 ordinary Portland cement of Shangfeng Brand from Tongling City, Anhui Province. The basic physical indexes of the soil used in the test are as follows:

| Specific gravity $G_s$ | Liquid limit $w_l$/% | Plastic limit $w_p$/% | Plastic Index $I_p$/% | Soil composition/mm |
|-----------------------|---------------------|----------------------|-----------------------|--------------------|
| 2.67                  | 48.1                | 20.5                 | 27.6                  | >0.075             |
|                       |                     |                      |                       | 0.005~0.075        |
|                       |                     |                      |                       | <0.005             |

2.2. Test methods
In order to reflect the age, cement mixing ratio on the unconfined compressive strength and shear strength, the influence of the indoor according to the cement mixing ratio of 8%, 10%, 13%, the production of standard sample, to age for 7 d, 14 d and 28 d, 60 d, 90 d standard curing (curing temperature is $20 \pm 0.5 ^\circC$, relative humidity is 95% or higher).

The instrument used in the direct shear test is the direct shear tester, with a sample height of 20mm and a diameter of 61.8mm. The sample preparation and test process are strictly in accordance with the requirements in the "Standard for geotechnical testing methods: GB/T 50123—2019"[17]. Four levels of vertical pressure were applied at 100, 200, 300 and 400kPa, respectively, and the shear rate was 0.02mm/min.

The preparation of unconfined compressive strength test specimens is carried out in strict accordance with the method in "Specification for mix proportion design of cement soil: JGJ/T 233-2011" [18], the sample is 70.7 mm x 70.7 mm x 70.7 mm of the cube, the instruments used for pressure universal testing machine, the sample at a speed of 0.15 kN/s continuous uniform loading, until the sample damage, with a group of six specimen measured as the average of the group of unconfined compressive strength.

3. Text Test results analysis

3.1. Relationship between shear strength and cement mixing ratio
The shear strength of soil-cement is very important to analyze the failure process of soil-cement. Cohesion and internal friction angle are important indicators to characterize the shear strength. It is particularly important to analyze the variation of cohesion and internal friction angle with age in the experimental study under different cement mixing ratios.

Figure 1 (a) as the cohesive and cement mixing ratio and the relationship between age, can see the cohesive of soil increases with the increase of the cement mixing ratio, in the age of less than 28 d,
cohesive growth increased with the increase of cement mixing ratio, and when age greater than 28 d, cohesive with the increase of the cement mixing ratio of growth speed slow down gradually. The cohesion of soil-cement at 28 days of age is 0.6–0.9 times of that at 60 days. The cohesion of soil-cement at 28 days of age is 0.6–0.9 times of that at 60 days of age. It can be seen from Fig. 1 (b) that the increase of cement mixing ratio has a significant effect on the increase of internal friction Angle when the age of cement is short; however, when the age is greater than 14d, the internal friction Angle generally increases with the increase of age, but the increase range is small, and the cement mixing ratio has no significant effect on the internal friction Angle. It can be seen that cohesion is the main index affecting the shear strength of cement soil.

![Figure 1. The relationship between shear strength and cement mixing ratio](image)

3.2. Relationship between compressive strength and cement mixing ratio

Fig. 2 shows the variation rule of unconfined compressive strength of soil-cement cube samples with age and cement mixing ratio. It can be seen from the figure that, with the increase of age and cement mixing ratio, the strength of the sample increases continuously. In the same age, the unconfined compressive strength increases with the increase of cement mixing ratio and shows a good linear increase relationship. When the age is less than 28 days, the unconfined compressive strength increases rapidly; when the age is more than 28 days, the growth rate of unconfined compressive strength slows down with the increase of age. The strength of 28d is about 64%-71% of that of 90d. With the increase of age, cement hydration tends to be more sufficient, and the increasing of hydration products promotes the increase of cement's bonding strength to soil particles. When the cement is maintained for a certain period of time, the hydration reaction of the cement is basically completed, and the strength will gradually stabilize and reach a certain value. Through the analysis of the strength growth test data, it is found that the strength of cement soil increases with the increase of age, but the increase range is gradually decreasing. The strength growth amount of 60 days is basically more than 90% of the total growth amount of 90 days.
4. Research relationship of cohesion prediction

4.1. Relationship between cohesion and compressive strength

Studies have shown that there is a good correlation between unconfined compressive strength and cohesive strength of soil-cement [15]. Therefore, it is of great significance to establish the relationship between unconfined compressive strength and cohesive strength against the prediction of shear strength. It can be seen from the above test results that the increase or decrease of the shear strength of soil-cement under different conditions is mainly reflected in the increase or decrease of the cohesion. In order to study the relationship between unconfined compressive strength and shear strength, unconfined compressive strength and cohesion of soil-cement were taken as research objects, and function fitting was conducted with the research of Liu et al. [19] and Luo et al. [20], as shown in Fig. 3. The relationship between cohesion and unconfined compressive strength (1) was obtained.

\[ c = 0.227q_u \]  

(1)

Where \( c \) = cohesion; \( q_u \) = unconfined compressive strength. From (1) it can be seen that in the cement mixing ratio within a certain range (5% 30%), the cohesion of soil-cement increases with the increase of its unconfined compressive strength. The larger the unconfined compressive strength is, the greater the shear strength is. There is a linear relationship between the unconfined compressive strength and the cohesion, which is consistent with the research on the relationship between the two by relevant scholars [19, 20, 21].
4.2. Multi-factor effect
Cement mixing ratio and age will affect the unconfined compressive strength of cemented soil to some extent, thus affecting its cohesion. A more accurate cohesion prediction model should include cement mixing ratio and age at the same time. In a certain range of cement mixing ratio (5%-30%) and age (7d-90d), the cohesive of soil-cement increases with the increase of cement mixing ratio and age [18]. Therefore, with other conditions unchanged, the cohesive of soil-cement can be obtained by nonlinear regression from the two factors of cement mixing ratio and age.

Through multiple regression analysis, the prediction formula of cohesion can be obtained as follows:

\[ c = 0.31a_wT + 10.21a_w + 0.29T - 2.30 \]  

(2)

Where \( c \) = cohesive; \( a_w \) = cement mixing ratio; \( T \) = age. It can be seen from the model that the cement mixing ratio and age are both positively correlated with the cohesion of soil-cement. Compared with the age, the cement mixing ratio has a greater influence on the cohesion of soil-cement. The cohesion prediction model presented in this paper and the test data of Ruan et al. [9], Sun et al. [23], Wen et al. [24] and Tao [25] were used for verification and analysis, as shown in Fig. 4, it can be seen that the prediction model presented in this paper can better predict the cohesion of soil-cement.

![Figure 4. Comparison of predicted value and measured value of cohesion](image)

5. Conclusion
(1) The cohesive strength increases with the increase of cement mixing ratio and age. The cohesive strength increases rapidly within 28 days and then slowly after 28 days. The cohesive strength of 28 days is 0.6~0.9 times of that of 60 days.

(2) The unconfined compressive strength increases with the age and cement mixing ratio. When the age is 28 days, the unconfined compressive strength is about 64%-71% of the 90d strength.

(3) The relationship between the unconfined compressive strength and the cohesive in the range of 5%-30% cement mixing ratio is proposed, and the shear strength can be predicted according to the unconfined compressive strength.

(4) The prediction model of soil-cement cohesion is established and verified by the existing data. In engineering, the cohesion of soil-cement can be better predicted according to the cement mixing ratio and age.

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