Experimental study on flocculation-Vacuum-Electroosmosis method for strengthening soft soil foundation in coastal area

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Abstract. In view of the traditional vacuum preloading method to reinforce soft soil foundation, puts forward a new method of foundation reinforcement: flocculation-vacuum-electroosmosis method, and indoor test, the test shows that flocculation - the vacuum - electroosmosis method can greatly reduce the moisture content of reinforced soil, enhance the vane shear strength, and the reinforcement effect was homogeneous.

1. Introduction

In the process of urbanization, the demand for land resources is also increasing gradually. As the most common land resources in coastal cities, coastal soil can be put into engineering construction if utilized, and the demand for land resources can be effectively solved. However, the coastal soil has the characteristics of high moisture content and low strength, so it cannot be directly constructed on the coastal soil, so it needs to be strengthened.

In the soft soil foundation treatment technology, vacuum preloading method is widely used. Although it has the advantages of not affecting the surrounding environment, low project cost and relatively environmental protection, problems such as uneven reinforcement effect and the inability of deep soil to get effective reinforcement also emerge.

In order to optimize the unfavorable factors of vacuum preloading, scholars improved the vacuum preloading method and carried out research [1]-[6], for example, the combined vacuum preloading method, the graded vacuum preloading method, the supercharging vacuum preloading method, etc. Although some effects have been obtained by using these methods, these combined reinforcement methods are only a simple combination, and do not solve the disadvantages of the vacuum preloading method.

An important factor that leads to the decrease of the drainage rate of vacuum preloading is that the fine particles around the drainage plate cause the blockage of the drainage plate filter membrane, and the flocculant makes them settle through the binder of the colloids, thus achieving the effect of dehydration [7]-[10], reduction of vacuum preloading drainage is one of the important factors of fine particles in the drainage plate surrounding drainage plate filter membrane siltation, the flocculant by bonding colloidal particles, to make them happen settlement so as to achieve the effect of dehydration in the early stage of the vacuum preloading adding flocculants can make fine particles under the action of flocculant, coagulation, reduce the content of fine particles, have greatly alleviated the effect of the drainage plate filter membrane siltation. In vacuum preloading consolidation effect is not ideal factor is uneven, because the drain as the sole drainage channels of vacuum preloading method, the reinforcement effect of surrounding soils in the drain is superior to far away from the drain soil reinforcement effect, electroosmosis method is by inserting electrodes in the soil, under the action of electric field, the
hydration cation of anode to cathode, anode part can enhance the soil, in the vacuum preloading method, make the anode is inserted into the away from the soil of drain can solve the problem of uneven vacuum preloading method.

To sum up, the addition of flocculant in so electroosmosis method can improve the drainage rate of vacuum preloading and the reinforcement effect, this article flocculation - the vacuum - from the electroosmosis method of indoor model test before and after the reinforcement of soil moisture content, bearing capacity and displacement for the analysis of the reinforcement effect of the method, expected this kind of method can be applied to the engineering construction in the future.

2. test material

2.1 Test soil sample
The soil samples tested came from the coastal soil of Yancheng city, Jiangsu Province. After drying and sieving, they were combined into a soil sample with an moisture content of 80%. The basic properties of the soil are shown in Table 1.

| Specific gravity | Osmotic coefficient | Moisture content | Liquid limit | Plastic limit | Plastic index |
|-----------------|---------------------|------------------|--------------|--------------|--------------|
| 2.713           | $2.76 \times 10^{-6}$ | 78%              | 30.77        | 13.86        | 16.91        |

2.2 Flocculant reagent
CPAM (cationic polyacrylamide with molecular weight of 12 million), APAM (anion polyacrylamide with molecular weight of 12 million) and NPAM (non-ionic polyacrylamide with molecular weight of 12 million) were selected in this test. The best flocculant was selected by sedimentation column test.

2.3 Test instrument
This test instrument includes: 500ml measuring cylinder, beaker, pipette, magnetic stirrer, glass rod, model box, connector, vacuum pump, saturated bucket, plastic drain plate, power supply, conductor, cathode iron bar, anode ring, etc.

3. Test steps
1. CPAM (cationic polyacrylamide), APAM (anionic polyacrylamide) and NPAM (non-ionic polyacrylamide) were selected as flocculants;
2. In the beaker is put in the 0.1 g flocculant adding 100 g water, and stir in the magnetic stirrer to 200 r/min 60 min configured to 0.1% concentration of flocculating agent, in the same way, in turn, with 0.2%, 0.5% concentration of flocculant, the flocculant solution and 30 g 600 g tidal flats soil after full mixing in the beaker with a glass rod in 500 ml measuring cylinder once every 5 min record spate separation surface height and observe 6 h, screened the best flocculating agent concentration, on the basis of the optimal concentration, Weigh 15g, 30g and 45g of flocculant solution and 600g of tidal flat soil, fully stir them in a beaker with a glass rod and pour them into a 500ml measuring cylinder to record the height of the mud-water separation surface every 5min and observe them for 6h to determine the best ratio of flocculant content and get the best flocculant content.
3. Put the polyethylene film on the inside of the model box, put the soil sample and flocculant solution in turn, stir them evenly and let them stand for 24h, then take out the supernatant;
4. Circular iron rod inserted on the edge of the distance model box where 30 mm as anode, location in the center of the ring (250 mm) model box edge with iron bars as a cathode, and at the cathode side inserting plastic drainage plate, plastic drainage plate and manual joint saturated cylinder wire hose connected to Yin and anode conductor access to power, finally put the polyethylene film and seal with waterproof tape around the cement to seal up in the soil samples;
Trials every hour on the displacement monitoring, test after the use of miniature vane shear instrument in horizontal direction from cathode to anode 30 mm each, 60 mm, 90 mm, 120 mm and 150 mm in monitoring the vane shear strength of soil in the vertical direction is divided into the surface from soil surface (0 mm), middle (150 mm) from the soil surface, the bottom (300 mm) from the soil surface to monitoring data, and the moisture content test again on measuring point position.

4. Test plan
The test scheme of this flocculation-vacuum-electroosmosis is shown in Table 2.

| Test number | Drainage method | Vacuum degree (KPa) | Electroosmatic intervention time (h) | Potential gradient (V/cm) | Electric voltage (V) |
|-------------|-----------------|---------------------|--------------------------------------|--------------------------|---------------------|
| T1          | F-VP-E          | 85                  | 0h—off-test                          | 1.0                      | 18                  |
| T2          | F-VP-E          | 85                  | When the vacuum drainage rate is 50g/h—off-test | 1.0                      | 18                  |
| T3          | F-VP-E          | 85                  | The vacuum displacement is less than 100g for 5h continuously—off-test | 1.0                      | 18                  |

Model experiment in three groups were electroosmosis (T1) simultaneously with the vacuum, vacuum drainage rate in 50 g/h when the electroosmosis (T2), vacuum drainage every 5 h displacement less than 100 g of electroosmosis (T3), which is suitable for flocculation F - VP - E - vacuum - electroosmotic drainage way, appear in test every 5 h displacement less than 100 g, is seen as drainage difficulty, stop the test.

5. Test results and analysis

5.1 Flocculation settlement curve

![Flocculation settlement curve](image)

FIG. 1 Sedimentation curves of flocculants of different concentrations
Figure 1 shows the flocculation settlement curve of CPAM, APAM and NPAM with different concentrations. It can be seen that the settlement amount is positively correlated with the time. The concentrations with the best flocculation effect of the three flocculants are 0.1% CPAM, 0.2% APAM and 0.1% NPAM respectively, and the height of mud-water separation surface is 270mL, 280mL and 275mL.

Figure 2 CPAM is 0.1%, 0.2%, 2.5% dosage of APAM, 0.1% NPAM (15 g), 5.0% (30 g), 10% (60 g) flocculation settlement curve, it can be seen that with the increase of time, less settlement stabilize until no longer changes, the final settlement is the most optimal dosage of 2.5% than the 0.1% of CPAM, 2.5% 0.2% of the content than APAM, than the dosage of 2.5% and 0.1% NPAM, mud separation surface height, respectively is 266 ml, 268 ml, 264 ml, According to the test results, 0.1% NPAM with 2.5% doping ratio was selected as the best flocculant dosage in this test.

5.2 water discharge

FIG. 2 Sedimentation curves of flocculants with different dosage ratios

FIG. 3 Water discharge change curve
As shown in FIG. 3, 32.5Kg, 32.55Kg and 32.5kg of water were precipitated from T1-T3 through flocculant, and the final displacement of T1-T3 was 50.15 Kg, 52.7 Kg and 53.65 Kg. T1's displacement in the early stage is much higher than that of the other two groups, but with the passage of time, the displacement gradually decreases until it remains unchanged, while T2 and T3, after electroosmotic intervention, show a linear "stepwise" upward trend, and gradually decrease until it remains unchanged after a period of time.

5.3 Variation rule of shear strength of cross plate

Vane shear strength measured by micro vane shear instrument, in the horizontal direction, the distance from the cathode 30 mm, 60 mm, 90 mm, 120 mm, 150 mm, and in the vertical direction of the surface layer of soil (soil surface 0 mm), middle (150 mm) from the soil surface, the underlying (300 mm) from the soil surface unearthed sample test, vane shear strength due to excessive data points, take them to compare the average of the same position, as shown in figure 4, in the horizontal direction, the farther the distance cathode position, the smaller the vane shear strength, however, In the vertical direction, the shear strength of the cross plates in the three groups of tests showed a trend of surface >, middle > and bottom >. This is due to the vacuum preloading process, at the cathode side of the drain of the vacuum degree is higher, discharge or more water, and water content of the soil sample making 30 mm at the cathode is low, vane shear strength is higher, distance 150 mm drain of soil samples near the anode, in the soil under the action of electroosmosis, makes the distance 150 mm drain the moisture content is low, vane shear strength is high, compared to the T1, T2, vane shear strength on the surface of T3 than T1 increased 2.1 KPa, an increase of 0.7 KPa, T2In the middle layer, T3 increased 2.47kPa compared with T1 and 1.47kPa compared with T2; in the bottom layer, T3 increased 3.13kPa compared with T1 and 1.93kPa compared with T2, which also proved that T3 group had the best reinforcement effect.

6. Conclusion
In this paper, the flocculation settlement test and the indoor model test of flocculation-vacuum-electroosmosis were carried out to determine the best flocculant, and the reinforcement effect of
flocculation-vacuum-electroosmosis was evaluated from the two indexes of displacement and shear strength of the cross plate after the test.

(1) Flocculation settlement tests were carried out for CPAM, APAM and NPAM at different concentrations and ratios. It was determined that 0.1%NPAM was the best flocculant concentration and 2.5% was the best flocculant ratio.

(2) The displacement of the three groups of model tests was 50.15kg, 52.7kg and 53.65kg respectively, indicating that the drainage effect was better in the flocculation-vacuum-electroosmosis method.

(3) In the vane shear test, while a group of three groups of experiment result of the worst is vacuum electroosmosis simultaneously, but it's on the surface layer, middle, and at the bottom of the shear strength were reached 13.2 kPa, 11.8 kPa, 9.1 kPa, also greatly improved the initial soil shear strength, illustrates the flocculation - the vacuum - electroosmosis method, the reliability of the reinforced soil mass;

(4) Compared with the three groups of model tests, the cross plate has the highest shear strength, the largest displacement and the best overall reinforcement effect when the electroosmosis is involved when the drainage is difficult (5h drainage is less than 100g).

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