

## Comparative Study on Field Tests of Two Kinds of Shallow Treatment of Soft Soil Foundation

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### Abstract

Through the vacuum preloading test with three different arrangements and the in-situ curing treatment at different depths, the treatment effect reached the expectation, indicating that both the vacuum preloading method and the in-situ curing method can achieve good reinforcement effect. Among them, the local curing method has remarkable effect on treating waste engineering mud, and its bearing capacity is far beyond expectation, which can be used as the foundation of high-grade highway. After the test, it is found that the real air filtration test area can also improve the treatment effect by reducing the distance between drainage plates, and the local curing treatment can further optimize the admixture content to achieve better reinforcement effect and further reduce the project cost. For the construction site with general bearing capacity requirements, vacuum filter tube or air pipe can be used to meet the requirements. For sites requiring higher bearing capacity, true air filter tube treatment can be used, and higher grade roadbed can be used in situ curing treatment.

### Keywords

Field Test; Engineering Waste Slurry; Vacuum Preloading; In Situ Curing; Foundation Bearing Capacity.

### 1. Introduction

In engineering construction, because it is difficult to meet the performance of the project directly to meet the use of the natural foundation, so often need to deal with these poor foundation soil, so that it can meet the requirements of engineering construction. Currently, the widely used bad foundation treatment methods mainly include replacement method, replacement method, dynamic compaction method, vacuum preloading method. Super soft soil foundation is also a kind of poor foundation, because super soft soil has: High moisture content, large compressibility, and shear strength is almost zero, and its characteristics of low permeability, which makes the processing is quite difficult, at this stage in vacuum preloading method has been at the scene of the actual verification, to fully cope with all sorts of bad characteristics, super soft soil and soil replacement method, displacement method need to out of soft soil, as well as high quality packing into, This not only presents a new problem of waste soil disposal, but also the high cost of high-quality fillers. The vacuum preloading method has advantages because it can directly reinforce the soft soil in situ. Vacuum preloading method is to form a drainage system in soft soil by setting drainage water and connecting drainage pipes in the soft soil. The drainage system is formed by connecting the rear drainage system and the vacuum system in a closed environment to separate water and soil from soft soil so as to achieve the purpose of reinforcement.

In recent years, local curing technology has emerged in China and been widely used in practical projects due to its advantages such as no need for construction, low construction cost, and the

reinforcement effect can meet the expected construction. Local curing technology was first widely used in foreign countries, and then introduced into China for localized application. Its construction form is shown in Figure 1.



**Fig 1.** In-situ curing technology

Local curing technology is through professional supporting machinery and equipment will be a certain ratio of curing agent and soft soil fully mixed, in a certain curing time to make the strength of soft soil quickly improved method, the curing agent used in the project generally include: cement, fly ash, etc., or a combination of them. Due to the high moisture content in the soft soil, after the addition of cement and other curing agent, the free water between the admixture and soil particles fully occur a series of chemical reactions, making the soil particles closely connected, forming a certain tensile strength, bending strength of the plate, can withstand the upper load, so as to achieve the reinforcement of the super soft soil foundation.

In the process of foundation engineering construction, there is often a lot of construction waste, such as waste mud. The waste mud often comes from the drilling pile and is carried out, with a high moisture content and high fluidity. In addition, the waste mud is usually transported and dumped due to serious pollution, so a large area of waste mud pool is formed. In this paper, relying on the waste mud pond treatment project of Yuhuan Economic Development Zone, the shallow foundation treatment technology of mud pond in the development zone is adopted respectively by vacuum preloading method and in-situ curing method, and the reinforcement effect of different treatment methods is compared, and the treatment technology is further subdivided and optimized. For vacuum preloading method, after processing the goal of the bearing capacity of 50 kpa, on the surface of the mud sedimentation in the experiment, membrane pore water pressure in the vacuum pressure and mud under the data such as monitoring, finally to accomplish the foundation soil reinforcement for vane shear test and load test of the synthetic analysis of the condition of vacuum preloading method after processing performance of the foundation. For the in-situ curing method, the target bearing capacity is 80kPa after treatment. After the test, cross plate shear strength test and load plate test were carried out to analyze its performance. Finally, the characteristics of shallow layer treatment technology under various working conditions are compared comprehensively, and their characteristics are analyzed to provide reference for the practical application of engineering.

## 2. Engineering Overview

The mud in the mud pool is gray and black, and the average depth of mud is about 2m. The physical properties of mud are obtained by in-situ soil taking at different depths in the mud pool through experimental analysis, as shown in Table 1. The shape of mud pool is shown in Figure 2. After taking two location within the mud pit mud vane shear strength test of mud soil shear strength changes with depth curve as shown in Figure 3, the two position measuring point a vane shear strength, mud pools top surface due to the existence of the shear strength of its natural shell layer than central waste pulp increased, the total area of 4000 square meters,

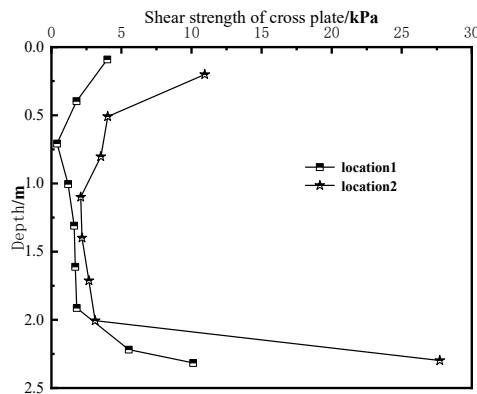
waste mud pools During the test, the mud pool was divided into four treatment areas: three vacuum preloading treatment areas and one local curing area. See Figure 4 for the specific division of experimental areas.

**Table 1.** Physical properties of slurry

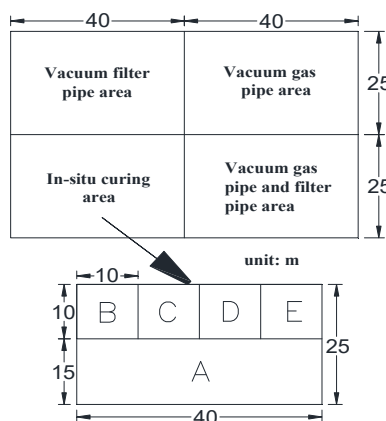
Soil depth/m	Water content/ $\omega$	Wet density/ $\rho$	Liquid limit/ $w_L$	Plastic limit/ $w_P$	Plasticity indexes/ $I_p$	Particle size (mm)		
						>0.075	0.075-0.005	<0.005
	%	g/cm <sup>3</sup>	%	%	---	%	%	%
0.2-0.4	65.5	1.59	54.9	24.4	30.5	12.7	60.8	26.5
0.6-0.8	62.8	1.62						
1.1-1.3	61.1	1.63						



**Fig 2.** Original appearance of slurry pond on site.



**Fig 3.** Shear strength curves of cross plates at different point positions varying with depth



**Fig 4.** Field test division

### 3. Field Test Scheme

Before construction, the floating water on the surface will be drained, and then the surface of the mud pool will be cleaned. The vacuum preloading test area is divided into three areas, each treatment area is 1000 square meters, and each area adopts different layout methods. Vacuum filter district: the same as the common vacuum preloading method arrangement, on top of the mud pit laying woven cloth, then drain into the mud pool, after the band drain can connected to the filter tubes, film formation airtight environment again laid the last will filter tubes are connected to the vacuum pump to form a complete vacuum drainage system, the layout as shown in Figure 5.



**Fig 5.** Vacuum filter pipe area

True air pipe area: after the drainage plate is set, a hand-shaped joint is installed on the top of the drainage plate, as shown in Figure 6. The hand-shaped joint directly connects the drainage plate with the vacuum pipe, and then covers the film to form a closed environment. Finally, it forms a vacuum drainage system together with the vacuum pump, as shown in Figure 7.

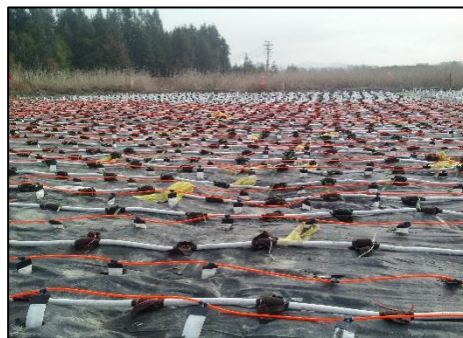


**Fig 6.** Vacuum gas pipe area



**Fig 7.** Hand joint

True air filter area: True air filter area including the use of the filter tubes and trachea cross linked to drain, in the same way will drain, vacuum filter tube, vacuum tube, vacuum pump of the vacuum drainage system, the first open gas district in testing the vacuum pump, vacuum tube first began to work, according to the dynamic monitoring results after 1 to 2 months after vacuum suction filter district, Suction in the gas tube area and the filter area are mutually independent suction systems, which can be called two-stage vacuums. The specific arrangement is shown in Figure 8. In the vacuum preloading test area, the drainage board of the vacuum filter tube and the real air tube area is arranged in a square way, and the real air filter area is arranged in a plum shape. The spacing of drainage board is set to 0.8m, and the depth of drainage board depends on the depth of mud in the mud pool.



**Fig 8.** Vacuum gas pipe and filter pipe area

In-situ curing test area: The test area is divided into five zones, which are divided into zones A, B, C, D and E according to different curing depths. The specific curing modes of each zone are shown in Table 2.

**Table 2.** Curing mode of curing area

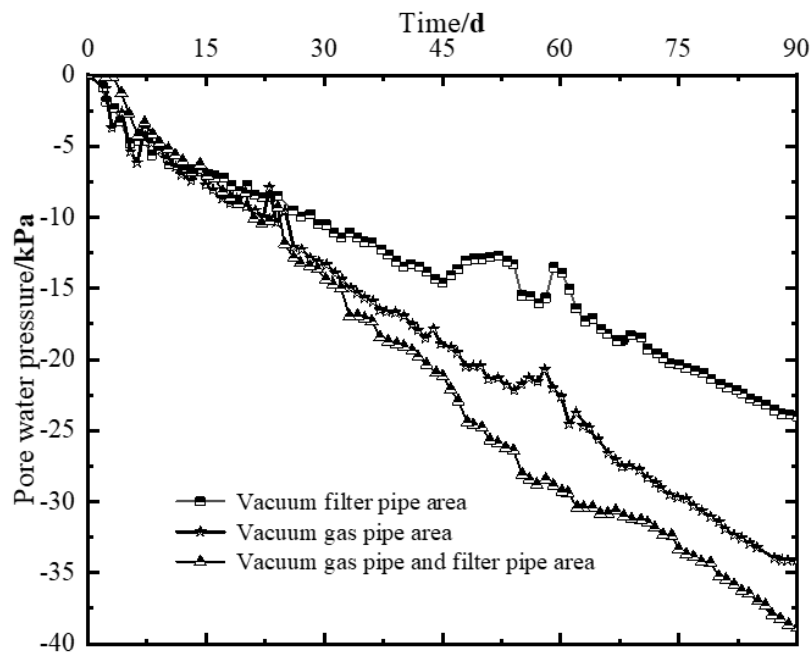
Test area	Composition of curing agent	Curing depth
A	Cement + fly ash	1.3m
B	Cement + fly ash	1.4m
C	Upside:0~1.2.m, cement + fly ash Underpart:1.2~1.9.m, low cement content	1.9m
D	Upside:0~1.1.m, cement + fly ash Underpart:1.1~2.3m, low cement content	2.3m
E	Upside:0~1.1.m, cement + fly ash Underpart:1.1~2.3m, low cement content	2.5m

The surface is cleaned before curing, and the surface floating water and weeds are cleaned before curing. The content of curing agent is determined as 70kg/m<sup>3</sup> after laboratory test, which is the ratio between curing agent and in-situ soil, and the mass ratio between admixture cement and fly ash is determined as 1:2. Curing to each small area divided into size is 5 m x 2.5 m block respectively for curing processing, for each block junction after mixing to increase after curing layer integrity, finally used construction machinery for various curing area leveling, leveling in the experimental area after laid iron plate preloading process, and iron as the next area of construction machinery bearing surface.

## 4. Test Results and Analysis

### 4.1. Vacuum Preloading Method

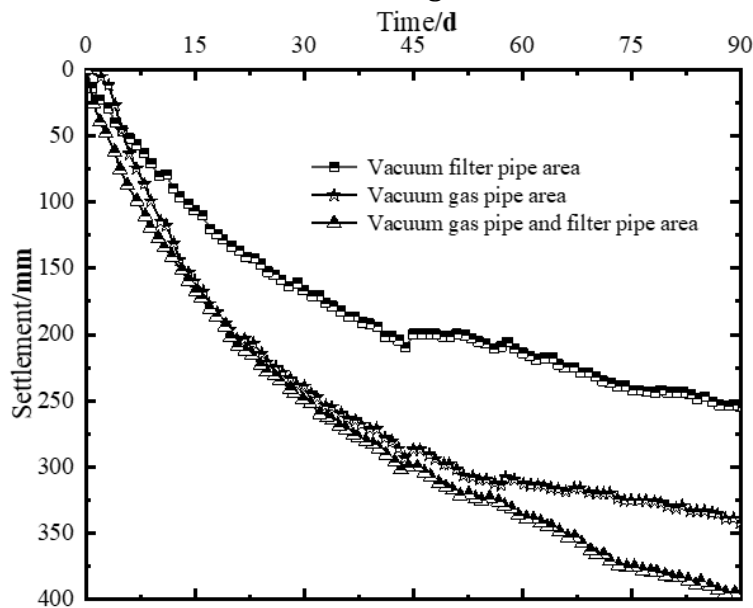
The pore water pressure in mud at a depth of 1.2 meters in the vacuum preloading test area was monitored within 90 days, and the dissipation curve of pore water pressure in the gas filtration area, gas pipe area and gas filtration area over time was shown in Figure 9.



**Fig 9.** Variation curves of pore pressure in different vacuum zones with time dissipation

The vacuum degree in the mud pool is kept at about 80kPa. With the application of vacuum pressure, the free water between soil particles is conveyed to the drainage pipe by vacuum pressure and discharged finally, realizing the separation of water and soil. The pore water pressure reflects the pore water pressure value between soil particles. The contact between soil particles changes from soil-water-soil to the contact between soil particles, which increases the effective stress of soil. The larger the final dissipation value of pore water pressure is, the more free water is discharged from the soil, and the more pressure between soil and water is converted into effective stress between soil particles. According to the dissipation curves of pore water pressure over time in different vacuum test areas, the pore water pressure dissipates gradually with the increase of time as the vacuum pressure is applied under three different vacuum configurations. The dissipation value of pore water pressure in the true air duct area is larger than that in the vacuum filter area, because: Vacuum filter tube drainage board and connection using filter cloth wrapped with filter tubes, and the filter cloth pore lead to larger pressure of vacuum pump parts in contact with the atmosphere, passing on the drain of vacuum pressure has some losses, whereas true air district due to drainage plate are connected by hand sub with the trachea cut off from the atmosphere, thus could be complete vacuum pressure is passed on to the drain, It can drain more free water and dissipate more pore water pressure. The final pore water pressure dissipates the most in the true air filter area. In the same area, due to the increase of effective stress, its bearing capacity improves the most and the reinforcement effect is better. This is because the presence of large amounts of small soil particles in the mud, under the action of vacuum pressure, gathered a large number of soil particles near the drain with the increase of time near the drain form dense soil column, due to the airtight sex of the soil column, cause the vacuum attenuation in the soil, to discharge, obstacles in the free water and gas zone by using two stage vacuum filter can solve this problem,

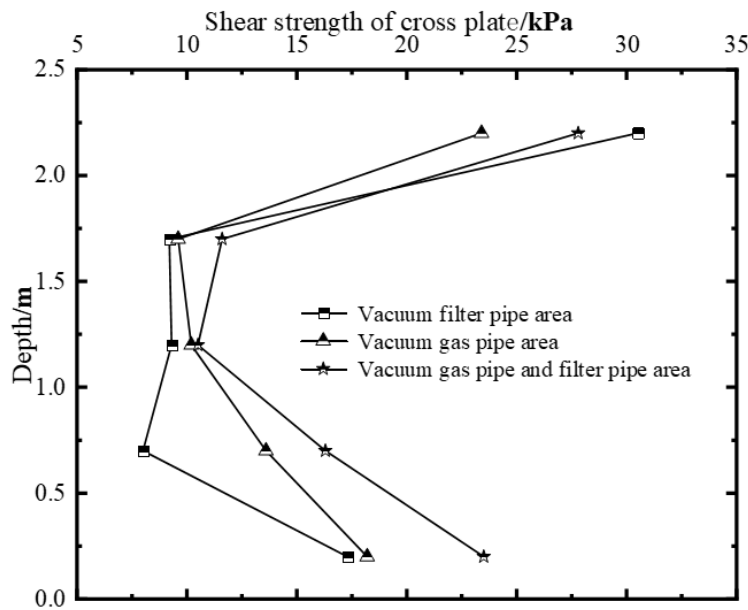
When the soil column has formed near the drainage plate of the air duct area in the air filter area, applying the vacuum pressure of the filter area immediately can increase the vacuum pressure in the mud pool again, remove more free water in the mud pool, obtain more dissipation of pore water, and improve the reinforcement effect. However, due to the connection mode of the air filter tube and the drainage plate, The dissipation value of pore water pressure in the gas filter area increases slightly compared with that in the gas tube area. The settlement value within 90 days is monitored. Due to the action of vacuum pressure, free water is discharged from mud. Under the action of soil particle weight, soil particles are in close contact with each other, which shows the change value of surface height on the whole, and the settlement curve varies with time. As shown in Figure 10.



**Fig 10.** Subsidence curves with time in different vacuum area

Due to the change of the sedimentation value and drainage is directly related to, in the mud pit displacement is larger, the surface subsidence value, the greater the vacuum degree of vacuum filter district in between drain and filter tubes losses, so passing on the drain of the vacuum degree is low, have a certain influence on displacement, displacement is small, so compared with gas district and gas filter area smaller values of the settlement. The true air duct area maintains a better vacuum degree relative to the air filter area, and the initial vacuum degree imposed on the drainage plate is greatly improved compared to the filter area, so it can discharge more free water and produce greater settlement. The true air filter area can reduce the influence of vacuum loss caused by soil column to a certain extent, and open the air filter area to further drain the mud pool after the blockage in the air duct area. Therefore, the free water discharged from the air filter area is more, which is manifested as a larger settlement value. The larger settlement indicates that more soil particles are converted into direct contact between soil particles, and the increase of effective stress can provide greater bearing capacity, so the reinforcement effect is better.

After the test, cross plate shear tests were carried out on in-situ soil of different depths in vacuum filter zone, air filter zone and air filter zone, and the curve of shear strength of cross plate varied with depth. As shown in Figure 11.

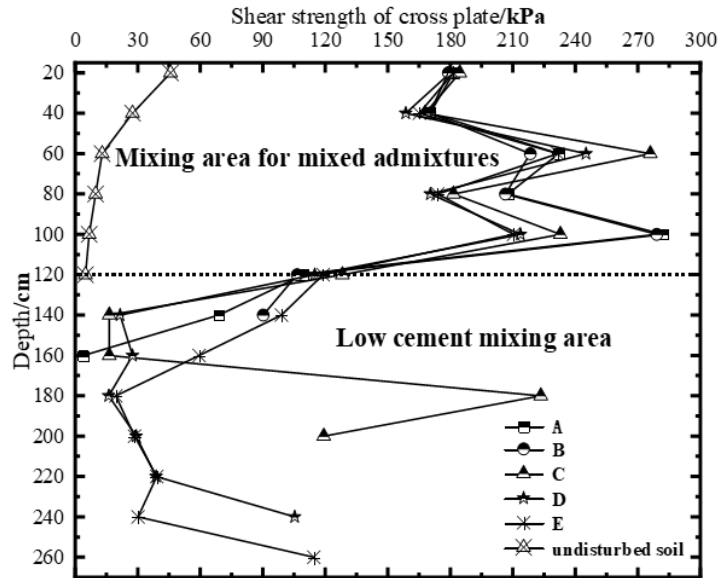


**Fig 11.** Shear strength curve of cross plate with depth in different vacuum regions

Diagram for each vacuum test vane shear tests are carried out in different depth, as shown in figure shows that the surface layer and the mud at the bottom of the shear strength is higher, due to the vacuum pressure applied on the top of the drainage plate, vacuum pressure on the drainage board has certain attenuation, so keep good vacuum pressure, the top of the drainage of mud drainage effect more apparent soil effective stress is higher, The shear strength of the cross plate is higher than that of the central soil. The bottom strength is high because the cross plate soil range exceeds the depth of the silt, from the original good foundation shear strength, therefore, than the middle mud soil shear strength. Each vacuum treatment area in the depth of the average shear strength vertical dashed lines as shown in figure, gas filter area of the highest average shear strength of 18.4 kPa, this is because the true air filter area can not only guarantee of mud soil applying vacuum pressure, but also can solve drainage soil particles near the drain late siltation in vacuum pressure attenuation of the problem, Therefore, adopting the arrangement of air filter zone can strengthen the mud pool better and obtain higher shear strength.

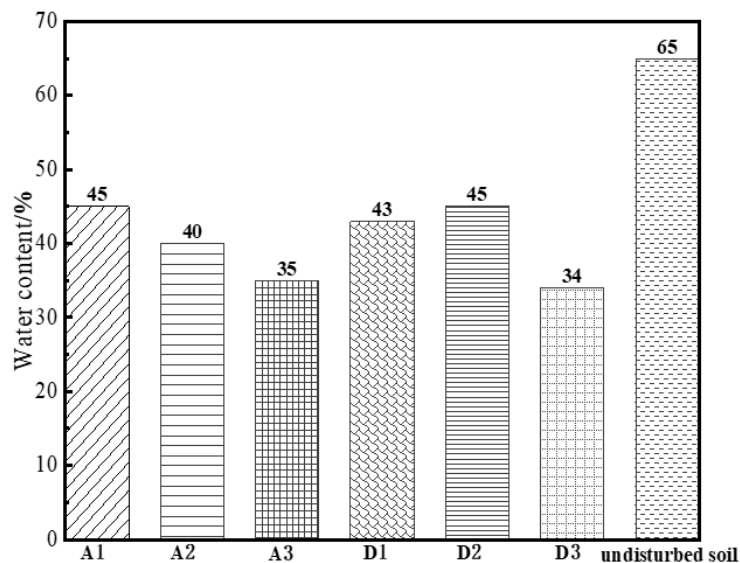
#### 4.2. In-situ Curing

Cross plate shear test was performed on the soil after solidification in each solidification zone, and the experimental results are shown in Figure 12. By different curing depth under different curing test in-situ vane shear strength depth curves available: various curing blocks of shallow vane shear strength after curing is much higher than that of undisturbed soil shear strength, shows that in situ curing technology of mud pools curing effect is very obvious, can greatly improve the bearing capacity of the original mud pools, good reinforcement effect. Comparing different curing block vane shear strength is known to vary with depth values, show different curing blocks in different depth of the vane shear strength of the same because plus additive dosage are consistent, therefore solidified soil strength after curing, the depth of 1.2 meters depth of solidified soil strength declined, Because under 1.2 m depth admixtures for a single low dosage of cement, so compared with 1.2 m in the depth of solidified soil strength declined, shows that the strength of the solidified soil size is associated with plus the kinds of additive quantity, the higher the strength of solidified soil, the greater the dosage of after mixed with other types of curing agent can greatly improve the performance of solidified soil, increase the whole curing effect, Such as reducing the dry shrinkage produced after cement is added.



**Fig 12.** Shear strength curve of cross plate with depth in different curing area

Moisture content: For solidified zone A and D, in-situ soil samples were randomly taken from three points in each zone, and moisture content of soil samples in solidified zone A and D was determined by test. As shown in Figure 13. Diagram of A, D area take solidifying found after the determination of its moisture content, soil solidified soil moisture content, two curing area shows that large area of solidified soil with small area after curing can achieve consistent effect, the minimum can achieve the moisture content of 34%, compared with 65% of the undisturbed soil moisture content, soil moisture content have dropped dramatically after curing, This is because after the addition of admixtures such as cement and fly ash, admixtures can fully produce a series of chemical reactions with the water in the mud to form crystals, consume a lot of water in the mud, and stick the soil particles together. This undoubtedly greatly increases the effective stress in the soil, and the original loose mud particles are gathered together to form a cement soil slab structure with overall performance, which greatly improves the bearing capacity of the original mud soil.



**Fig 13.** Water content in different cured areas

### 4.3. Loading Test Results

The load plate test can judge the bearing performance of the treated foundation intuitively. The load plate test is carried out on all the test areas of the vacuum preloading test area. The size of the load plate is 1m\* 1M square steel plate, and the test results are shown in Figure 14.

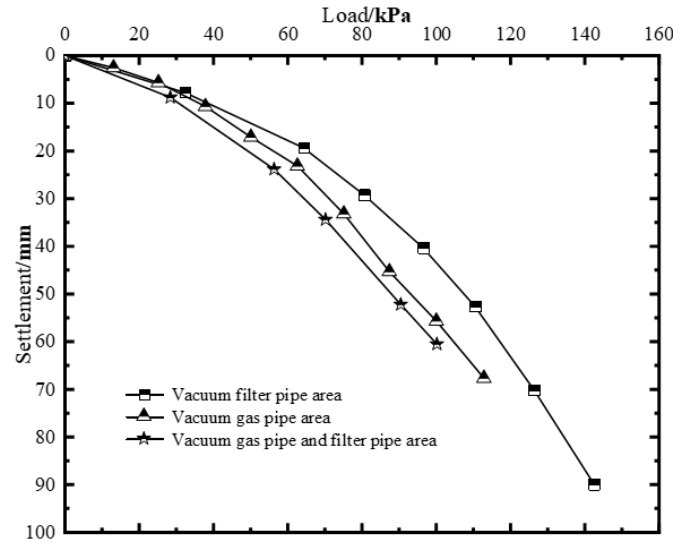


Fig 14. Plate load test in vacuum preloading test area

According to the load plate test results of each test area, the load value corresponding to the settlement of the field plate load test when the settlement reaches 0.02 times the width of the load plate is taken as the characteristic value of the foundation bearing capacity, then the foundation bearing capacity of the true air filter area, the true air pipe area and the vacuum filter area can be written as follows: 66kPa, 57kPa and 51kPa all meet the requirement that the target bearing capacity of the vacuum preloading test area reaches 50kPa after treatment. The load plate test of the solidified zone shows that the bearing capacity of the solidified zone is 160kPa when the settlement reaches 12mm, and the settlement value has not reached 0.02 times the width of the load plate, indicating that the solidified zone bearing capacity is far greater than 160kPa. It fully meets the requirement of the target bearing capacity of 80kPa in the curing test area. As shown in Figure 15.

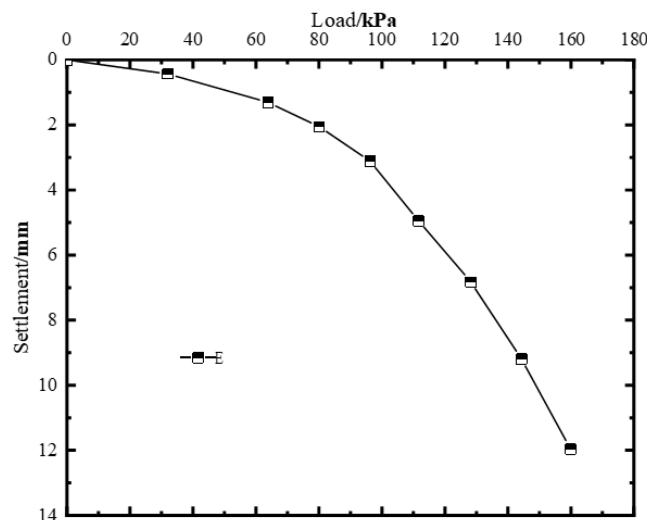


Fig 15. Plate load test of curing E zone

In the loading plate test of the solidified test area, the loading equipment can only be loaded to 160kPa, but the settlement at this time has not reached 0.02 times of the load plate width required by the specification, so a smaller load plate is used, the size is: At 0.5m\*0.5m, load plate test was carried out again on the remaining blocks of the solidified zone to determine the characteristic value of the final solidified zone bearing capacity. The test results are shown in Figure 16.

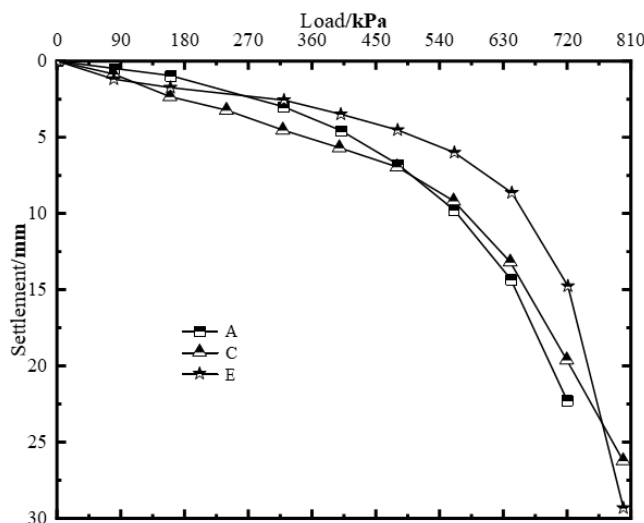


Fig 16. Plate loading test of curing zone A, C and E

A smaller load plate was used to conduct A load plate test on the cured zone again. The test results showed that the characteristic values of the bearing capacity obtained in the curing zone A, C and E were all greater than the target bearing capacity of 80kPa. The characteristic values of the bearing capacity in the curing zone A, C and E were: 240kPa, 280 kPa, 320 kPa, far greater than 80kPa, indicating that the use of in situ curing technology to treat mud pool fully meet the requirements. Curing A, C, E in different depth shows the bearing capacity is also different, the results show that with the increase of curing depth, foundation bearing capacity is improved after curing, it is because after curing water dirt on the top of form the whole piece of board, mud mud formed after join admixtures plate stiffness is much larger than in mud, So hard on board and bottom mud formation under the soft double-layered foundation, when after the upper load, load by the hard upper layer to lower mud can produce stress diffusion effect, thus improving the bearing capacity of foundation to achieve the purpose of reinforcement, when curing depth increases, the stress diffusion effect is better, is passed to the bottom mud load is smaller, The bearing capacity of treated double-layer foundation is increased. Because the curing depth of zone E is the highest, the characteristic value of bearing capacity is the highest.

## 5. Conclusion

In recent years due to the rapid expansion of construction projects, to produce large amounts of construction waste, such as the processing of construction waste pulp is a major problem, the processing of waste slurry is often done by tank car carrying pile up, made of waste mud DuiQi foundation bearing capacity is extremely low, can't be used as building foundation, typically take into after processing can be conducted on the production. Methods for sludge treatment for vacuum preloading method as well as the recent emergence of mud treatment technology in situ curing method, this article is based on the above two methods of treatment of waste mud, relying on yuhuan project waste pulp processing, field respectively for the two kinds of processing methods of field test, and on the basis of the original technology is improved,

on the basis of considering the bearing performance and the factors, The comprehensive evaluation of the mud foundation after treatment draws the following conclusions:

The engineering properties of waste mud in the area are understood through in-situ soil collection from the mud pond.

Through the vacuum preloading test with three different arrangements and the in-situ curing treatment at different depths, the treatment effect reached the expectation, indicating that both the vacuum preloading method and the in-situ curing method can achieve good reinforcement effect in the treatment of engineering waste slurry. Among them, the local curing method has remarkable effect on treating waste engineering mud, and its bearing capacity is far beyond expectation, which can be used as the foundation of high-grade highway.

The real air filter test area can also improve the effect after treatment by reducing the distance between drainage plates, and the local curing treatment can further optimize the admixture content to achieve better reinforcement effect and further reduce the project cost. For the construction site with general bearing capacity requirements, vacuum filter tube or air pipe can be used to meet the requirements. For sites requiring higher bearing capacity, true air filter tube treatment can be used, and higher grade roadbed can be used in situ curing treatment.

The construction period of vacuum preloading treatment is about May to June, while the construction period of in-situ curing treatment only takes 2 months to complete. Under the condition of tight construction period, the selection of in-situ curing treatment can meet the requirements of construction period and bearing capacity.

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