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Research Article

Study on Strength and Permeability of Silt Soils Improving by Tung Oil and Sticky Rice Juice

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Tianluoshan site (5000~2500 BC), which belongs to the Hemudu culture, has suffered damages from the hydraulic effect like other Chinese earthen sites in moist circumstance. Tung oil and sticky rice juice, as Chinese traditional building materials, were chosen as the additives in this study. Tung oil has the property of good waterproofness, fast dry-up, and quick film-forming by oxidation. Sticky rice juice has the advantage of high glutinousness, good tenacity, and low expandability. The study is to figure out the best performing mixture of tung oil and sticky rice juice to decrease the permeability of soil and increase its strength to facilitate excavations at archeological sites enlarging the display of layers of cultures. Meanwhile, the color of the site soil after reinforcement must be maintained for a long time. From the direct shear tests and the falling head test of 9 specimens mixed in different mass ratios, it was confirmed that the optimal mass ratio of the tung oil, the sticky rice juice, and the soil was 5 : 10 : 85. The treated soil specimen of the optimal mass ratio had the largest increment of shearing strength. The self-standing height of the vertical soil wall increases correspondingly from 2.63 m to 6.18 m, which could enlarge the step height when excavating a deep earthen site and extend the display height at the protection stage. The treated soil at the optimal mass ratio also showed the largest decrement of permeability coefficient from 1.257×10^{-5} cm/s of the untreated soil to 1.627×10^{-6} cm/s, which could reduce the hydraulic effect to the soil. The microstructures of the 9 specimens in different mass ratios were observed by SEM. The results showed that the glutinousness of sticky rice juice could cohere soil particles together, and the tung oil could then form oxidation film wrapping around the particle groups. In order to meet the aesthetic requirements of earthen sites conservation, the surface color contrast tests were used to measure the color change induced by the two additives. The surface contrast tests showed that the treated soil at the optimal mass ratio had the minimum variation of the surface, which could satisfy the basic requirements of earthen sites protection.

1. Introduction

In China, many immoveable historical earthen sites are facing severe threat due to the natural environment and human activities, such as shrinkage, cracking, collapse, and erosion [1, 2]. According to air humidity or soil water content, the historical earthen sites are commonly divided into dry or moist earthen sites at present [3]. Thereupon, the damages of the historical earthen sites in dry or moist states in China present regional differences on account of the climate variation in different zones [4]. The research of conserving methods applied to the dry earthen sites is much more mature than to the moist earthen sites [5]. Thus, it is imperative and necessary to conduct the research of conserving methods applied to the moist earthen sites.

The threats to the moist earthen sites are caused by many factors such as seepage, illumination, and temperature. Seepage is the most important factor, which leads to much more severe damages [6]. It is of great significance and urgency to figure out how to strengthen the soil mass and increase the resistance of the hydraulic effect to protect the earthen sites. From the perspective of geotechnical engineering, it focuses on stability of the foundation pit of the sites during and after excavation. However, distinct differences exist in the protective measures between the earthen sites conservation and the modern foundation engineering [7]. The materials used in earthen sites to improve the property of soil mass are forbidden to change the appearance of soil mass and bring about other damages [8]. For example, a large-scale reinforced concrete has been commonly used to reduce the permeation and increase the strength of the soil in modern foundation engineering, while could not be used in the conservation of historical earthen sites. The existing research of the materials is mainly concentrated on chemical materials such as sodium silicate, silicone acrylic emulsion, and epoxy resin. However, many synthetic chemical materials are prone to aging and could bring environment pollutions [9–11]. Therefore, more effective natural materials need to be discovered and studied immediately.

Lots of historical classics have proven that tung oil and sticky rice juice were commonly used in the construction of city and palace walls in ancient China [12–14]. Most of the structures possess high strength and long durability. These materials and techniques are worth studying and adopting. Tung oil is squeezed by the seeds of tung trees, which is a Chinese specialty. Tung oil has the properties of waterproofness, fast dry-up, and high stability, especially film-forming by oxidation in air. The key components of tung oil is a mixture of fatty acid triacylglycerol, which makes it an environmental-friendly vegetable oil for industry purpose. Sticky rice is a widely distributed paddy in southeast China. The sticky rice juice is similarly a frequently used construction material in ancient China due to the property of high glutinousness, tenacity, and low expandability [15]. Chen [16] has studied the strength of mortar made of lime, clay, sticky rice juice, and black sugar syrup. However, the strength did not have a sufficient growth after 7 days and 28 days. Zhang et al. [17] have observed that it is the organic-inorganic interactions between the lime and sticky rice juice which provide the reinforcement. Li [18] has studied the hydrophobicity and carbonation protection of earthen monument using tung oil and lime, and the improved soil mass has shown a lower permeability. Most of the existing studies have shown that tung oil and sticky rice juice can provide good effects of reinforcement, respectively, along with other additives. However, there have been few studies to examine the improved effects by the mixture of tung oil and sticky rice juice together.

Most of Chinese earthen sites in moist circumstance are situated in the estuarine delta areas of some big rivers, such as the Hangzhou Bay. Silt soil accounts for more than 90% of the surface deposit in this area [19]. Hence, this study focused on the improvement of the silt soil provided by the sticky rice juice and tung oil. By studying the effects on the strength and permeation improvement, the optimal mass ratio of the additives could be obtained. The microstructures of the treated soil were observed by SEM to evaluate the microscopic effects of tung oil and sticky rice juice. Moreover, the surface color contrast tests were conducted to make sure the treatment of tung oil and sticky rice juice could maintain the aesthetic surface color.

2. Materials

2.1. Regional Situation and Profile Characteristics of the Tianluoshan Site. Tianluoshan site (30°01′N, 121°22′E) lies in Ningbo-Shaoxing Plain, south of Hangzhou Bay. The site is 30~40 kilometers away from the coastline of the East China Sea. Figure 1 shows that it is located on the northern flank of the Yuyao River Basin. The Hemudu site is about 7 km away to the southwest. Zhejiang Provincial Institute of Cultural Relics and Archaeology excavated the Tianluoshan site in 2004 and found that it belongs to the Hemudu sites group [20]. The site has a subtropical monsoon climate with abundant rainfall and various meteorological disasters including typhoon.

Based on archeological excavation, the strata have been divided into nine layers, including six cultural layers. As Figure 2 shows, the first layer is the surface soil, the second layer is mainly the silt layer, and the third to ninth levels are cultural layers. The total thickness of the strata is 220 cm in average. Among the nine layers of the strata, the second layer has the highest content of silt and lowest content of sandy soil as well. It could be easily seen in Figure 3(a) that the second layer is much thicker in the west than the other part of Tianluoshan site. It has been divided into two layers: 2a and 2b. The upper 2a layer is blue-gray silt, hard, and moist, mixed with a little sand and burned soil particles; the lower 2b is gray-black sandy silt. According to statistics, most of the collapse of steps occurred in the second layer of the soil. As is shown in Figure 3(b), the second layer of the soil collapsed, and the step was covered with deep cracks during typhoon season. The purpose of the study is to increase the self-standing height of the vertical soil wall while reducing the impact of seepage; so, the second soil layer is the key research object.

2.2. Preparation of Qiantang River Silt Soil. In view of the poor uniformity of soil samples obtained directly from the Tianluoshan site and other considerations, the representative Qiantang River silt soil (SY1) was chosen as the object in this study. The soil was taken from the estuary of Qiantang River and at the depth of 50 cm below the ground surface. The physical and mechanics properties of the soil are shown in Table 1. Before the manufacturing of the specimens, the silt soil was sieved by a 2 mm standard sieve and dried under 60°C for 48 hours. In order to compare the fit of the models, original silt soil samples in the second layer of the Tianluoshan site (SY2) are also obtained. As Table 1 and Figure 4 show, the XRD results of SY1 and SY2 are very similar, including grain-size composition, Atterberg limits, organic content, specific gravity, and mineralogical composition.

2.3. Preparation of Tung Oil. Tung oil could be divided into two types, which are raw tung oil and boiled tung oil. The raw tung oil is commonly used in medicine and chemical engineering. The boiled tung oil, which is produced from the

Figure 1: Location map of the Tianluoshan site.

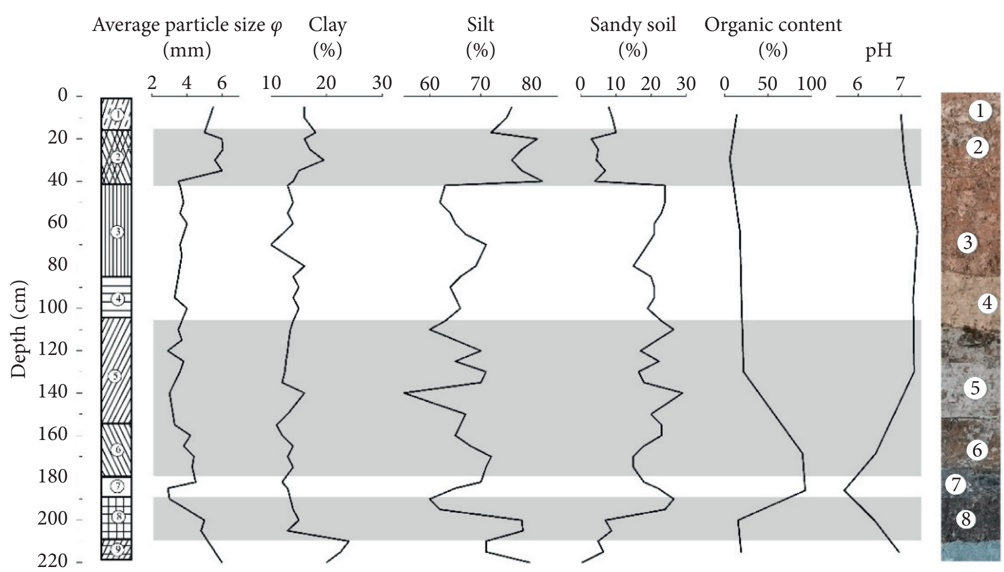


Figure 2: Curves of composition of particulate, organic content, and pH of 9 layers in the Tianluoshan site.

raw tung oil, is widely used to replace the paint oil in machinofacture and carpentry manufacture. In this study, the boiled tung oil was selected as the additive, as shown in Figure 5(a).

2.4. Preparation of Sticky Rice Juice. The sticky rice used in this study was common edible sticky rice purchased from Walmart, China. High quality sticky rice juice could be prepared by the method provided by Sun et al. [20]: weight 100 g dry sticky rice and immerse the rice in water to absorb moisture. Then, steam the rice for 1–1.5 h to gelatinizing the starch in the sticky rice. After statically cooling the rice paste down to 20–25°C in the laboratory, extract the supernatant by a needleless injector, as shown in Figure 5(b).

2.5. Manufacturing of Soil Specimens. Sufficient preprocessed dry soil was weighted and placed into a waterproof ceramics plate. Then, water was added to the dry soil by sprayer according to the optimal moisture content of 20.48%. After the sticky rice juice and the tung oil prepared before were added into the silt soil according to different mass ratios, the soil mixtures were stirred until smooth. Specimens with a diameter of 61.8 mm and a height of 20 mm were then manufactured by the cutting rings, and the surface of each specimen was scraped to flatten using a thin iron wire.

In this study, 9 types of specimens mixed in different mass ratios were manufactured. The 9 mass ratios of tung oil to sticky rice juice and to the silt soil were all named and are listed in Table 2. In the names, T represents the tung oil and R

Figure 3: Display steps of the Tianluoshan site. (a) Display steps in the west of the site. (b) 2nd layer of soil collapse in the west of the site.

Table 1: Grain-size composition, Atterberg limits, organic content, specific gravity, and mineralogical composition of the tested sediments (SY1 and SY2) evaluated by X-ray diffraction.

(A) Qiantang River silt soil	
Soil code	SY1
Atterberg limits	
Liquid limit	33.3
Plasticity index	9.1
Grain composition, %	
>0.05 mm	0
0.01~0.05 mm	75
0.05~0.005 mm	17
<0.005 mm	8
Organic content, %	1.8
Specific gravity	2700
Maximum dry density: g/mm^3	1.59
Mineralogical composition, %	
Quartz	50
Albite	27
Muscovite	14
Clinochlore	9
(B) Original silt soil samples in the 2nd layer of the Tianluoshan site	
Soil code	SY2
Atterberg limits	
Liquid limit	33.3
Plasticity index	9.1
Grain composition, %	
>0.05 mm	0
0.01~0.05 mm	72
0.05~0.005 mm	15
<0.005 mm	13
Organic content, %	2.2
Specific gravity	2700
Maximum dry density, g/mm^3	1.56
Mineralogical composition, %	
Quartz	53
Albite	5
Muscovite	28
Dickite	14

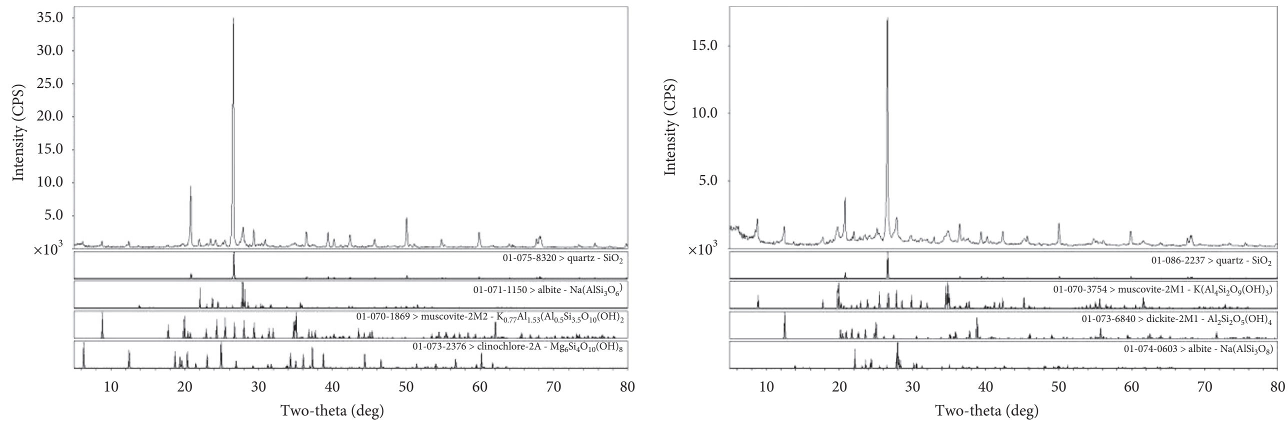
represents the sticky rice juice. The subscripts represent the mass percentage content of the two additives. For example, specimen $T_5R_{10}S_{85}$ means the tung oil has a mass content of 5% in the treated soil specimen, while the sticky rice juice has 10% and the silt soil has 85%. $T_0R_0S_{100}$ is the untreated soil, namely, the blank control specimen. For convenience, all of the phrases "mass ratio (s)" appeared hereinafter, if without special remark, represents the mass ratio of the tung oil to the sticky rice juice and to the silt soil.

3. Mechanical and Physical Properties Improvement of Soil Specimens

The experiments to test physical and mechanical properties of the soil samples were composed of two parts, which are the strength characteristics and the permeability.

3.1. Soil Strength Improvement Test. During the excavation of a deep earthen site, the "step method" is usually adopted to remain the vertical wall stable, as shown in Figure 6. The height of a step is mainly limited by the properties of the soil. According to the calculation, the maximal height of cohesive soil usually ranges from 1.5 m to 3 m. Taking consideration of the safety factor, the step height is usually set as 1~1.5 m when excavating in earthen site. This height is not conducive to observe and displays the cultural layer of the side wall. Hence, the improvements of the soil strength should increase the step height in this study.

To evaluate the improving effects on the soil strength treated by tung oil and sticky rice juice, the direct shear tests were conducted to measure the cohesion c and internal friction angle φ. Using the direct shear apparatus produced by Nanjing Soil Instrument Plant, the c and φ of the 9 types of specimens were tested. From Figure 7, it could be observed that the content of tung oil and sticky rice juice can both affect the value of c and φ. At the mass ratio of 5 : 10 : 85, specimen $T_5R_{10}S_{85}$ performed largest increments that the cohesion c increased from 14.43 kPa of the untreated specimen to 30.26 kPa, and the internal friction angle φ



(a) (b)

FIGURE 4: XRD results of soil samples. (a) XRD result of Qiantang river silt soil; (b) XRD result of original silt soil samples in the Tianluoshan site.

(a) (b)

FIGURE 5: The additives used in the soil improving. (a) Tung oil. (b) Sticky rice juice.

TABLE 2: 9 types of mass ratios of the treated soil specimens.

Name	$T_0R_0S_{100}$	$T_0R_5S_{95}$	$T_5R_0S_{95}$	$T_5R_5S_{90}$	$T_5R_{10}S_{85}$
Mass ratio	0 : 0 : 100	0 : 5 : 95	5 : 0 : 95	5 : 5 : 90	5 : 10 : 85
Name	$T_{10}R_5S_{85}$	$T_{10}R_{10}S_{80}$	$T_5R_{15}S_{80}$	$T_{15}R_5S_{80}$	—
Mass ratio	10 : 5 : 85	10 : 10 : 80	5 : 15 : 80	15 : 5 : 80	—

FIGURE 6: Steps in the north of the Tianluoshan site.

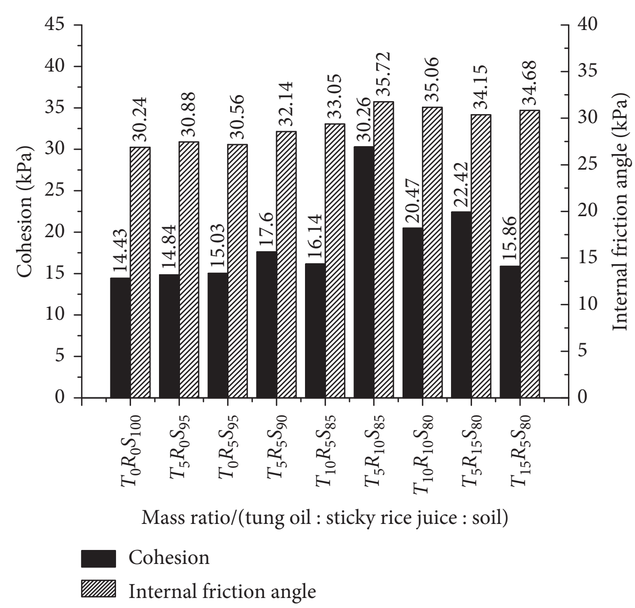


FIGURE 7: Shear strength indexes of the treated soil specimens.

increased from 30.24° to 35.72°. It meant that the mass ratio 5 : 10 : 85 was the optimal ratio when using sticky rice juice and tung oil to improve the strength of silt soil.

Inspecting the cohesion first, from specimens $T_0R_0S_{100}$, $T_0R_5S_{95}$, and $T_5R_0S_{95}$, the cohesion did not increase apparently when the soil was treated with only one kind of additive. It meant that when working, respectively, the viscosity of the sticky rice juice or the film-forming of the tung oil had a limited performance in soil improving. From specimens $T_5R_5S_{90}$, $T_5R_{10}S_{85}$, and $T_{10}R_5S_{85}$, the cohesions increase markedly and reached the maximum at the optimal mass ratio. The cohesions of specimens $T_{10}R_{10}S_{80}$, $T_5R_{15}S_{80}$, and $T_{15}R_5S_{80}$ began to decrease when the mass content of sticky rice juice and tung oil increased further.

It is worth mentioning that the cohesion of the treated soil decreased greatly when the content of tung oil was too high and the mass ratio of tung oil to sticky rice juice was bigger than 2, as specimens $T_{10}R_5S_{85}$ and $T_{15}R_5S_{80}$ have shown. It was suspected that if the samples were mixed with too much tung oil, the soil particles could not be combined tightly and cohered together to increase the cohesion.

The variation of the internal friction angle φ performed much more smoothly. The maximal value also appeared at the mass ratio of 5 : 10 : 85. When the tung oil content was too high, the internal friction angle did not have an obvious decrease. The smooth variation meant that the tung oil and the sticky rice juice had much less effects on the internal friction angle than on the cohesion.

From the perspective of geotechnical engineering, an earthen site under excavation is similar to a foundation pit when it comes to slope stability analysis. The difference is that the side wall should be vertical in the archaeology site. The classical soil mechanics have provided the computing method of self-stand height of vertical wall of cohesive soil [21], which means the maximal step height in the earthen site excavating, as shown in the following equation:

$$h = \frac{2c \times \tan\left(45^{\circ} + (\varphi/2)\right)}{\gamma}, \quad (1)$$

where h is the maximal self-standing height of the vertical wall of cohesive soil, c is the cohesion, φ is the internal friction angle, and γ is the unit weight of the soil. Using the c and φ obtained in the directing shearing tests, it could be calculated that the self-standing height of the untreated soil $h = 2.63$ m and treated soil in optimal mass ratio $h = 6.18$ m. The difference is more than two times. Taking 2 as a safety factor, the step height in the earthen site excavation could be larger than 3 m. The new height would be more suitable for observing and displaying the cultural layers.

3.2. The Permeation Tests. In southeast China, the hydraulic effects make a negative influence to the stability of earthen sites, which could induce many other kinds of damages. Hence, it is important to decrease the permeability coefficient of the soil to reduce the negative influence from hydraulic performance.

The falling head test, which is commonly used in soil mechanics, was used to measure the permeability coefficients of the treated soils to evaluate the improved effect on the permeability. The 9 treated soil specimens were placed in the laboratory for 7 days after manufacturing. Then, specimens were tested to measure the permeability coefficients by the TST-55A permeameter produced by Nanjing Soil Instrument Plant. The samples of each group were tested twice, and the average value was taken. After converting the average value to the permeability coefficient under standard temperature (20°C), the results were obtained as shown in Figure 8.

From Figure 8, the permeability coefficient decreased at first and then increased along with the increasing of the mass content of tung oil and sticky rice. Specimen $T_5R_{10}S_{85}$ had the smallest permeability coefficient of 1.627×10^{-6} cm/s among the 9 different specimens, which means the mass ratio 5 : 10 : 85 is also the optimal mass ratio when improving the permeability of the silt soil. Compared with the original value of 1.257×10^{-5} cm/s, the permeability could be decreased by one order of magnitude. This decrement implies tung oil and sticky rice could significantly reduce the hydraulic effect on the soil.

Comparing the specimens $T_0R_5S_{95}$ and $T_5R_0S_{95}$ to the untreated soil specimen $T_0R_0S_{100}$, the permeability coefficients decreased 31.3% and 38.6%, respectively. The results showed that either the viscosity of the sticky rice juice or the film-forming of the tung oil could reduce the permeability of the treated soil, respectively. Relatively speaking, the sticky rice juice seemed to have a slightly better effect on the improvement. When both of tung oil and sticky rice were added into the silt soil, the permeability could be decreased further by the cooperation of their properties, as the specimens $T_5R_5S_{90}$ and $T_{10}R_{10}S_{80}$ have shown.

Similarly, when the mass ratio of tung oil to sticky rice juice was larger than 2, the permeability coefficients of specimens $T_{10}R_5S_{85}$ and $T_{15}R_5S_{80}$ performed obvious increments. The increments indicated that the mass content of tung oil should be controlled under the reasonable ratio when treating the silt soil. The reason could be conjectured that the tung oil began to accumulate in the pores of soil when the mass content was too high. The lack of oxidation environment led apparent reduction of the film-forming procedures. The reduction made the tung oil inside the soil could not solidify smoothly and restrict the improvement of permeability.

4. Microstructure Observation

In order to take a deeper look at the treated soil, the 9 types of treated soil specimens were observed using the scanning electron microscope (SEM). Figure 9 shows the SEM results at the magnification times of 2000× after curing for 7 days under standard conditions (20°C and 50% humidity), while Figure 10 shows the SEM results after 120 days. Obviously, the microstructures of the 9 specimens could be divided into two types. Specimens $T_0R_0S_{100}$, $T_5R_0S_{95}$, and $T_0R_5S_{95}$ performed a kind of looseness without aggregation. The particles of the specimens cohered only by the inherent property of the soil. The microstructures of specimen $T_5R_5S_{90}$ to $T_{15}R_5S_{80}$, on the contrary, performed layer structure apparently. It could be observed clearly that several groups of particles were gathered and bounded to clusters by the additives. As time goes on, it can be observed that the oil film on the surface of specimen $T_{15}R_5S_{80}$ and specimen $T_{10}R_5S_{85}$ after 120 days are not as much as that after 7 days. When the oil film is lost, the gap between particles becomes more concentrated. While the adhesion between the particles of

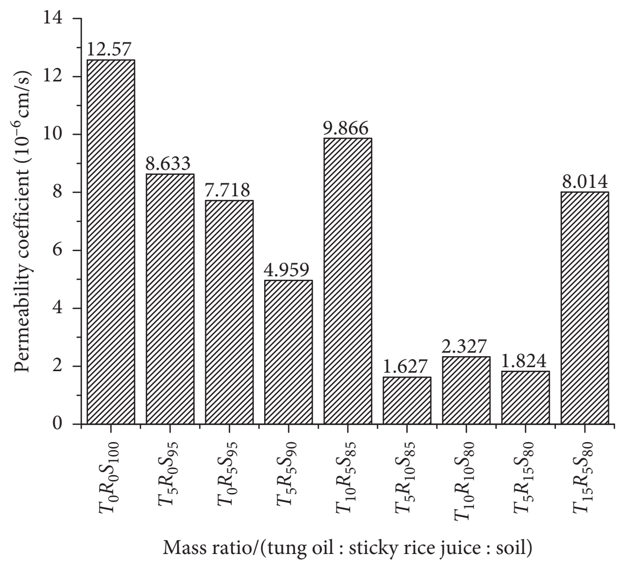


Figure 8: Permeability coefficients of the treated soil specimens.

specimen $T_5R_{10}S_{85}$ is more perfect as is shown in Figure 10. It can be inferred that the components with too much tung oil will squeeze rice juice at the beginning. Once tung oil volatilizes, rice juice will not be filled into the pores of soil particles later.

Specifically speaking, from specimen $T_5R_0S_{95}$ shown in Figure 9, it could be observed that the stickiness of sticky rice juice could just cohere the particles instead of bounding them into clusters. While specimen $T_0R_5S_{95}$ showed that the film-forming of tung oil could not cohere the soil particles to clusters neither. That was why the strength index c and φ of specimens $T_5R_0S_{95}$ and $T_0R_5S_{95}$ did not increase substantially. But the permeability coefficients of specimens $T_5R_0S_{95}$ and $T_0R_5S_{95}$ increased by either the stickiness of sticky rice juice or the film-forming of tung oil. It might be the enlargement of the fluid viscosity caused by the additives that increased the permeability coefficients during the permeability experiments. When both of sticky rice juice and tung oil were added into the treated soil, as specimen $T_5R_5S_{90}$ to $T_{15}R_5S_{80}$ performed, the specialties of the two additives began to cooperate. The soil particles were then cohered by the sticky rice juice, and the particle groups were bounded by the oxidation film provided by tung oil. At the optimal mass ratio 5 : 10 : 85, it could be observed that the soil particles of the specimen $T_5R_{10}S_{85}$ presented the best compactness and smallest porousness. The strength index c and φ and the permeability coefficient presented the best improvement accordingly. When the content of tung oil was too high, large porousness could be found in specimens $T_{10}R_5S_{85}$, $T_{10}R_{10}S_{80}$, and $T_{15}R_5S_{80}$. That is why these specimens presented abnormally high permeability coefficients and low cohesion c.

Particularly, the SEM results at the magnification times of 2000× of specimens $T_0R_0S_{100}$ and $T_5R_{10}S_{85}$, which represent the untreated soil sample and the treated soil with the optimal mass ratio. It could be found that the specimen $T_0R_0S_{100}$ has a rough surface. While the particles of specimen $T_5R_{10}S_{85}$ presented a smooth surface with high brightness, which showed that the tung oil could provide oxidation films around the particle groups cohered by the sticky rice and firm the particle groups further. The SEM results, to a certain extent, confirmed the supposition that the cooperation of the stickiness of sticky rice juice and the film-forming of tung oil could well improve the mechanical and physical properties of silt soil.

5. Surface Color Contrast

According to the basic requirement of earthen sites conservation, any protective measures should not change the appearance markedly. Hence, a simple digital imaging method, which was proposed in some other studies [22, 23] to measure and analyze colors of food surface, was used to study the color change of the 9 types of specimens.

The specimens were let stand in a shady and windless room with a temperature of 20°C for 7 days, 14 days, 30 days, 90 days, and 180 days. They were placed into the laboratory with all the lightproof curtain closed. Then, the specimens were taken photos at the vertical direction of the flat surface. The light used in the photographing was all provided by the fluorescent lamps of the laboratory. The digital camera used in the color measurement was EOS 7*D* made by Canon, with the prime lens EF 50 mm f/1.8 II made by Canon. Other settings of the camera are listed in Table 3. All of the other automatically optimizing functions such as "Peripheral illumin Correct" and "Auto Lighting Optimizer" were set off to avoid uncontrollable influences to the color of the photos introduced by the camera.

Different types of soil specimens were imported into the software Adobe Photoshop CC 2015 from the camera after the color measurement. A circle area for each specimen on the photo was cutoff first. The color values were analyzed by means of the Info Palette and Color Sampler tool. The

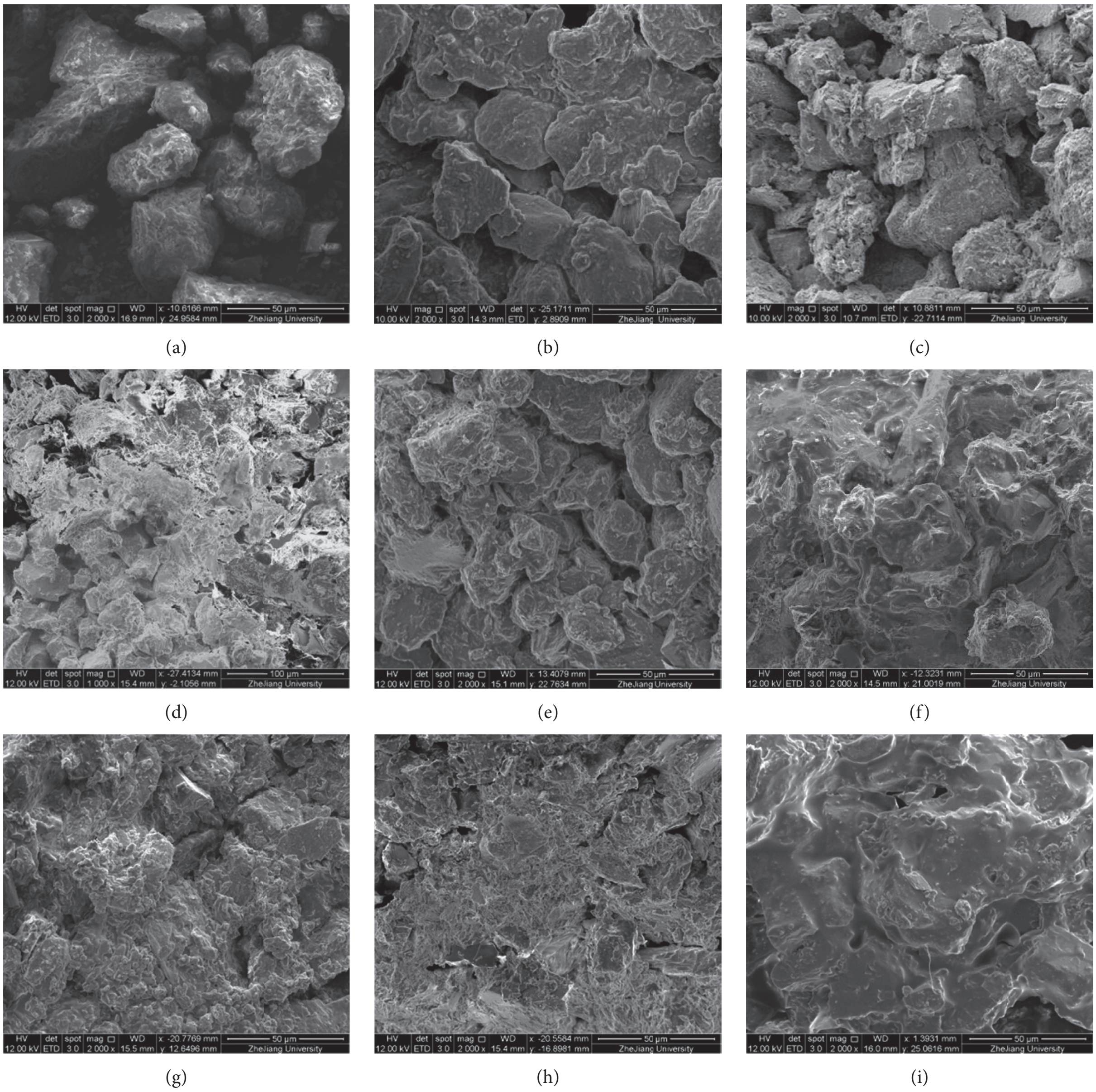


Figure 9: 2000× SEM results of the specimens mixed in different mass ratio (7 days, 20°C, and 50% humidity). (a) $T_0R_0S_{100}$. (b) $T_5R_0S_{95}$. (c) $T_0R_5S_{95}$. (d) $T_5R_5S_{90}$. (e) $T_5R_{10}S_{85}$. (f) $T_{10}R_5S_{85}$. (g) $T_{10}R_{10}S_{80}$. (h) $T_5R_{15}S_{80}$. (i) $T_{15}R_5S_{80}$.

sampler was set to sample the average color of 101×101 pixels around a selection point.

Looking at the appearance change process of 9 soil samples from 0 to 180 days, it could be seen that each soil sample has experienced the change process of color from dark to light. The change range of color of each soil sample is different. At 0 day, the color of 9 soil samples is darker, and the color difference between the soil samples is not apparent. With the passage of time, from 7 days to 180 days, 9 soil samples have experienced different surface color states. The color gradient is remarkable, which can be directly observed by the naked eye, as given in Table 4.

The $L^*a^*b^*$ color model is widely used in the industry and manufacture, especially in the field of display, which is composed of illuminance (L) and a and b of color. L represents luminance, equivalent to brightness, a represents the range from red to green, and b represents the range from blue to yellow. From Table 5, it could be observed visually that tung oil could blacken the treated soil and the L^* would decrease correspondingly, as shown in $T_5R_0S_{95}$. On the contrary, sticky rice juice could whiten the treated soil, and the L^*, a^*, and b^* would increase as shown in $T_0R_5S_{95}$. It can be seen from Table 5 that from day 0, the lightness values L^* of 9 groups of soil samples

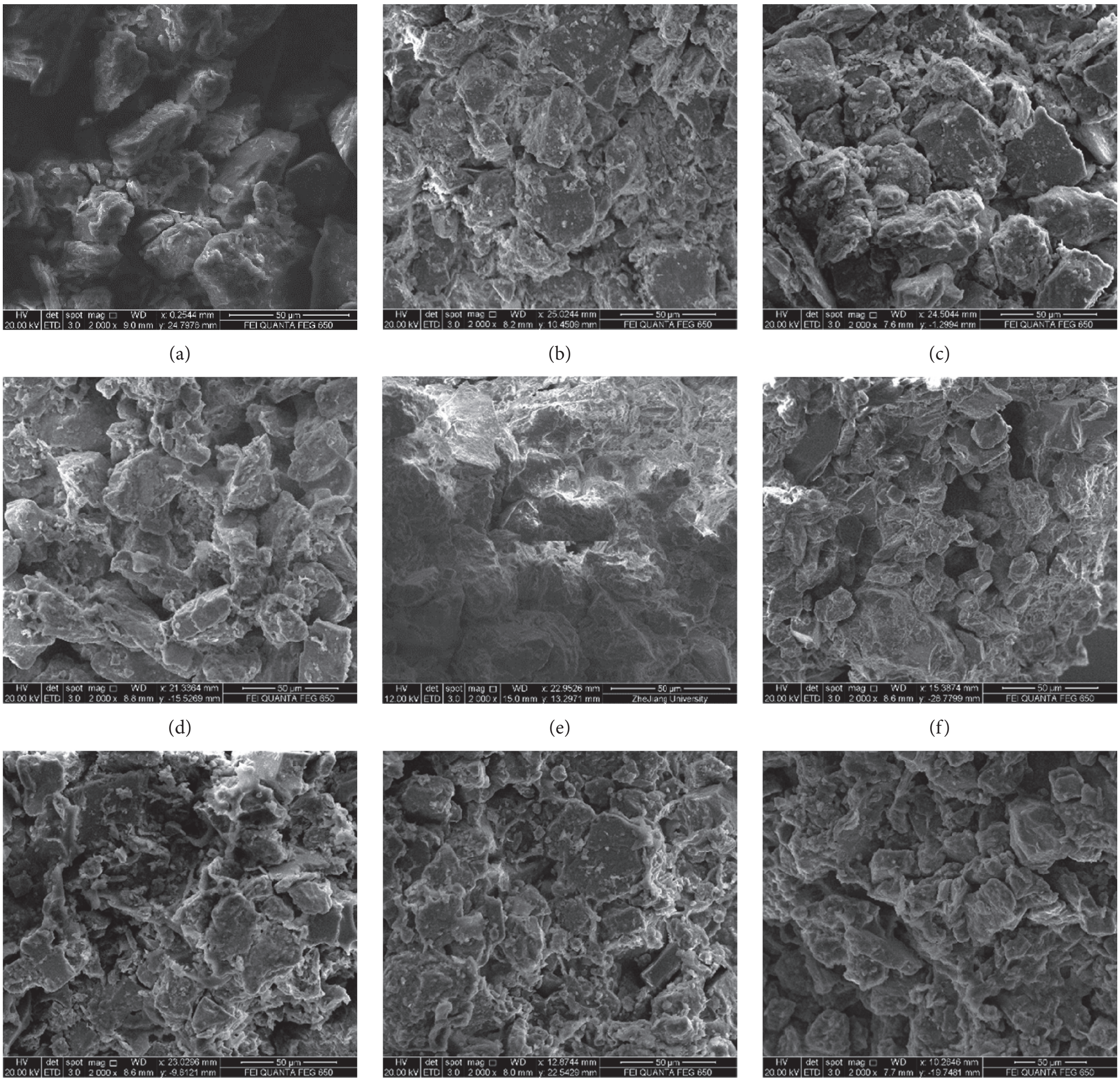


Figure 10: 2000× SEM results of the specimens mixed in different mass ratios (120 days, 20°C, and 50% humidity). (a) $T_0R_0S_{100}$. (b) $T_5R_0S_{95}$. (c) $T_0R_5S_{95}$. (d) $T_5R_5S_{90}$. (e) $T_5R_{10}S_{85}$. (f) $T_{10}R_5S_{85}$. (g) $T_{10}R_{10}S_{80}$. (h) $T_5R_{15}S_{80}$. (i) $T_{15}R_5S_{80}$.

Table 3: Camera settings of the surface color contrast experiment.

Focus mode	Picture style	Flash mode	Aperture value	Exposure time	ISO	Exposure compensation	Exposure program	White balance
Manual	Standard	Off	($f/2$)	1/125 s	400	0	Manual	Manual

increase rapidly, tend to be stable gradually, and remain stable and no longer change at 180 days; in this process, the color values a^* and b^* of 9 groups of soil samples change slightly but not much.

Eclectically, when the treated soil has an optimal mass ratio, the $T_5R_{10}S_{85}$ has a closest visual color and $L^*a^*b^*$ vales to the untreated soil $T_0R_0S_{100}$ and could meet the requirement of conservation.

Table 4: Color contract of specimens in different mass ratio during different durations.

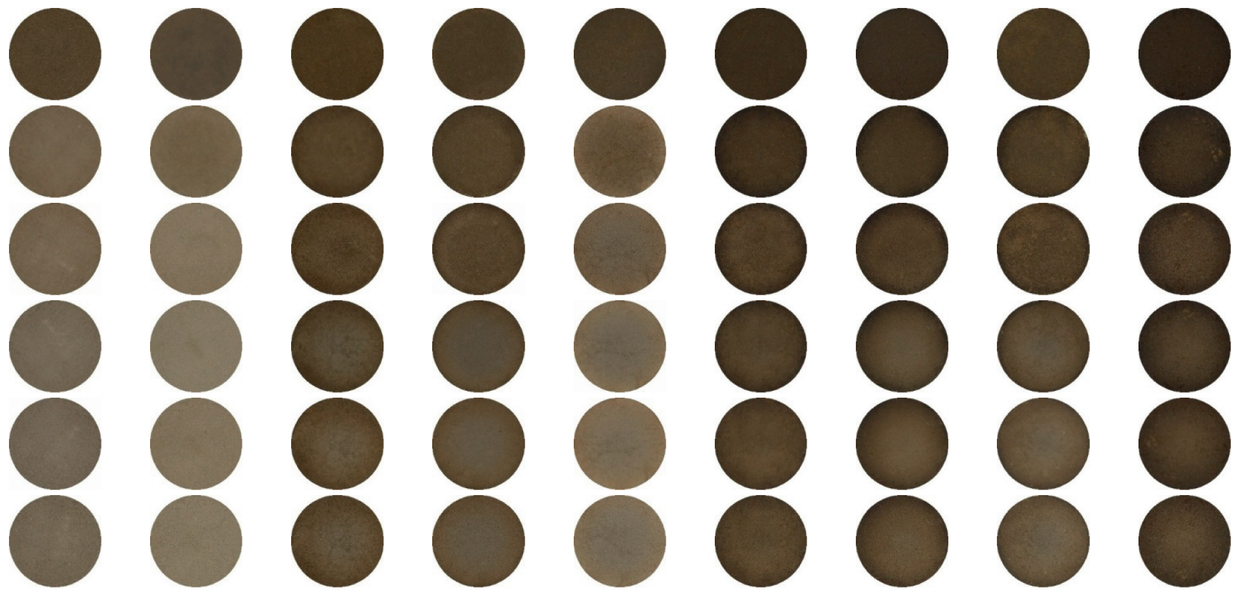
Days	Samples								
	$T_0R_0S_{100}$	$T_0R_5S_{95}$	$T_5R_0S_{95}$	$T_5R_5S_{90}$	$T_5R_{10}S_{85}$	$T_{10}R_5S_{85}$	$T_{10}R_{10}S_{80}$	$T_5R_{15}S_{80}$	$T_{15}R_5S_{80}$
0									
7									
14									
30									
90									
180									

Table 5: $L^*a^*b^*$ parameters of specimens in different mass ratio during different durations.

Days	Samples								
	$T_0R_0S_{100}$	$T_0R_5S_{95}$	$T_5R_0S_{95}$	$T_5R_5S_{90}$	$T_5R_{10}S_{85}$	$T_{10}R_5S_{85}$	$T_{10}R_{10}S_{80}$	$T_5R_{15}S_{80}$	$T_{15}R_5S_{80}$
0	L^*:32 a^*:3 b^*:16	L^*:35 a^*:3 b^*:16	L^*:28 a^*:4 b^*:17	L^*:28 a^*:3 b^*:14	L^{**}:30 a^*:3 b^*:15	L^*:23 a^*:3 b^*:12	L^*:24 a^*:3 b^*:10	L^*:29 a^*:3 b^*:15	L^*:20 a^*:3 b^*:10
7	L^*:46 a^*:3 b^*:16	L^*:44 a^*:3 b^*:17	L^*:33 a^*:4 b^*:18	L^*:33 a^*:3 b^*:17	L^*:37 a^*:4 b^*:16	L^*:26 a^*:3 b^*:14	L^*:28 a^*:3 b^*:14	L^*:31 a^*:3 b^*:16	L^*:25 a^*:3 b^*:13
14	L^*:48 a^*:3 b^*:16	L^*:53 a^*:2 b^*:16	L^*:34 a^*:4 b^*:18	L^*:33 a^{**}:4 b^*:17	L^*:43 a^*:2 b^*:14	L^*:31 a^*:4 b^*:17	L^*:30 a^*:4 b^*:16	L^*:32 a^*:4 b^*:16	L^*:30 a^*:4 b^*:15
30	L^*:49 a^*:2 b^*:13	L^*:54 a^*:2 b^*:16	L^*:37 a^*:3 b^*:14	L^*:37 a^*:2 b^*:12	L^*:45 a^*:2 b^*:13	L^*:32 a^*:4 b^*:16	L^*:38 a^*:3 b^*:16	L^*:32 a^*:2 b^*:14	L^*:32 a^*:4 b^*:15
90	L^*:48 a^*:2 b^*:14	L^*:53 a^*:2 b^*:16	L^*:39 a^*:3 b^*:16	L^*:41 a^*:2 b^*:14	L^*:48 a^*:2 b^*:14	L^*:33 a^*:4 b^*:17	L^*:40 a^*:3 b^*:18	L^*:43 a^*:2 b^*:15	L^*:35 a^*:4 b^*:17
180	L^*:49 a^*:2 b^*:14	L^*:54 a^*:2 b^*:16	L^*:39 a^*:3 b^*:16	L^*:41 a^*:2 b^*:14	L^*:48 a^*:2 b^*:13	L^*:34 a^*:4 b^*:17	L^*:40 a^*:3 b^*:18	L^*:32 a^*:3 b^*:16	L^*:32 a^*:3 b^*:16

6. Conclusions

(1) The study identified the improvements of Qiantang River silt soil using sticky rice juice and tung oil and evaluated the effects provided by the additives in different mass ratios. The optimal mass ratio was found to be 5 : 10 : 85. The addition of the two additives not only ensures the long-term protection effect of the Tianluoshan site but also increases the height of the potential exhibition platform.

(2) The optimal mass ratio performed the best improvement in the soil strength, which made the specimen had the largest shearing strength index of $c = 30.26$ kPa and $\varphi = 35.72°$, while the untreated soil had shearing strength index of $c = 14.43$ kPa and

$\varphi = 30.24°$. The self-standing height of the vertical wall could increase more than 2 times accordingly in this study.

(3) The treated soil in the optimal mass ratio also performed the lowest permeability. The coefficient could be reduced by an order of magnitude from 1.257×10^{-5} cm/s to 1.627×10^{-6} cm/s, which could reduce the negative influence from hydraulic performance.

(4) The SEM results showed that the viscosity of sticky rice juice could cohere the soil particles together, while the quick-drying of tung oil could provide compact oxidation film and bound the particles cohered by the sticky rice juice. It was suspected that the cooperation of the two additives at the optimal mass ratio could provide a double-film construction to decrease the permeability and increase the shearing strength obviously.

(5) The soil treated in the optimal mass ratio had the minimal variation of the soil surface, which could not be clearly observed megascopically. The variation could meet the requirement of soil sites conservation.

Data Availability

The data used to support the findings of this study are currently under embargo while the research findings are commercialized. Requests for data, 6/12 months after publication of this article, will be considered by the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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