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Changes in Particle Size Composition under Seepage Conditions of Reclaimed Soil in Xinjiang, China

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Abstract: The distribution of reclaimed soil particle size under seepage conditions after the management period will directly determine the success or failure of reclamation work. The geotechnical experimental method was used in this paper to study the changes in the granulometric composition of soil. The results show that the granulometric composition of the reclaimed soil varied obviously at different depths. The granulometric composition of the soil at a depth of 10 cm was not much different from undisturbed reclaimed soil (URS). At a depth of 30 cm, as the sharp decrease of the content of fine particles resulted in coarser reclaimed soil, the soil became more uniform, with an increase in porosity and water content. At a depth of 50 cm, the fine particle content was generally slightly lower than that of URS. At a depth of 70 cm, the fine particle content of the soil greatly exceeded that of the URS, with the finest soil particles and lowest porosity. The main reason for the above-mentioned changes of granulometric composition in the reclaimed soil was the seepage in soil caused by irrigation during the management period. The research results can provide a reference for management after land reclamation at non-metallic mines in Xinjiang, China.

Keywords: Xinjiang; land reclamation; management period; soil particle size; fluid flow in reclaimed soil

1. Introduction

There are vast non-metallic mineral resources in the northern foothills of the Tianshan Mountains in Xinjiang, and the large-scale exploitation of mineral resources is bound to cause irreversible damage to the fragile geological environment and ecological environment in this region. Non-metallic mines in this region include limestone, dolomite, and granite mines. The open-pit mining method is mainly adopted. Large and deep open pits, and a large number of massive hard waste rocks (Figures 1 and 2), will be formed after mining. For mines whose damaged lands are grassland and woodland, the land will be reclaimed after the pits are closed. To reclaim the land, the waste rock is backfilled into the open pits first, and then the surface of the land is covered with soil and vegetation is planted. In order to ensure the survival rate of the vegetation, a one-year management period is set. The quality of the reclaimed soil after the management period will directly determine the success or failure of the reclamation work [1], and the distribution of soil particle size will directly affect the soil fertility, texture, and water holding capacity [2].

Figure 1. Open-pit mining area.

Figure 2. Waste rock piles.

In recent years, research [3–17] on the physical properties of reclaimed soils has achieved great success. Research on the granulometric composition of reclaimed soil mainly included the following aspects: Using multifractal theory to analyze the granulometric composition of reclaimed soil [18–20], granulometric composition analysis of reclaimed soils under different reclamation methods [21–24], granulometric composition of reclaimed soil before and after reclamation in different years [25–27], and using spectrum analytical methods to analyze the granulometric composition of reclaimed soil [28]. The previous research mainly focused on the granulometric composition of reclaimed soil in coal mining areas, with clay soil or loam soil as the main type of reclaimed soil. Different test methods were used to study the granulometric composition of reclaimed soil under different reclamation modes or in different years. There has been less research directed at sandy loam, taking into account the effect of the irrigation water during the management period, to study the changes in the particle size of the soil at different depths or with different overlaying soil thickness under different compaction circumstance.

In view of the limitations of the past studies and the importance of soil particle size to reclamation work, this study takes the typical sandy loam at the non-metallic mines in the northern foothills of the Tianshan Mountains in Xinjiang as a research object. An in-situ test method was used for the first time to simulate the compaction effect of reclamation machinery on reclaimed soils. Furthermore, field sampling, indoor geotechnical experiments, and mathematical statistical analysis were applied to study the changes in the granulometric composition of the reclaimed soil under seepage conditions after a one-year management period.

2. Materials and Methods

The reclaimed soil in-situ test was conducted at the Changji Groundwater Balance Experiment Site in Xinjiang. The reclaimed soil was taken from a limestone ore mine in Dabancheng, which belongs to the northern foothills of the Tianshan Mountains in Xinjiang. The soil was calcic brown soil and belonged to sandy loam, with a bulk unit weight of 12.646 kN/m^3, a porosity of 57.71%, and a water content of 11.76%. The lower part of the reclaimed soil was backfilled with the waste rock produced by the limestone mining.

A total of 6 test barrels were used in this test (Figures 3–6). The depth of the test barrels was 2 m. The test was divided into 2 groups. In one group, the barrel was backfilled by overlaying soil with a thickness of 30 cm, 50 cm, and 70 cm without compaction, while in the other group, the overlying soil was compacted once by a track-type bulldozer. The lower part of the reclaimed soil was backfilled with limestone waste rocks. The plate load test (Figure 7) was used to simulate the compaction of the bulldozer based on the intensity of pressure of the bulldozer on the ground, which was different from previous conventional drop weight tests. In the management period, watering was conducted in accordance with the empirical value of the irrigation volume and the number of times of irrigation in the land reclamation and management period of the mine area in the foothills of Xinjiang Tianshan Mountains (Figures 8 and 9). The irrigation volume was related to the thickness of the soil layer. The thicker the soil layer was, the greater the irrigation volume would be. Irrigation was carried out a total of three times in the period of management. After one year of management, samples were taken at depths of 10 cm, 30 cm, 50 cm, and 70 cm depending on the thickness of the overlaying soil, and the weight of each sample was 400 g. The samples were then taken into the laboratory for particle size analysis. Sieving analysis was adopted as the soil has a high content of sand and low content of clay (Figure 10). At the same time, the undisturbed soil samples were taken at the corresponding depth for laboratory tests of its density and water content.

Figure 3. Empty cylindrical test barrels.

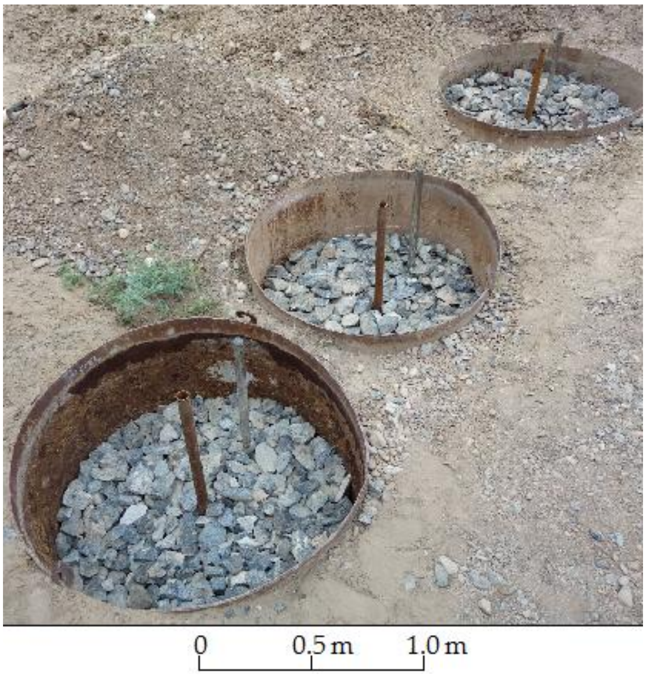

Figure 4. Backfilled waste rock in lower part of test barrels.

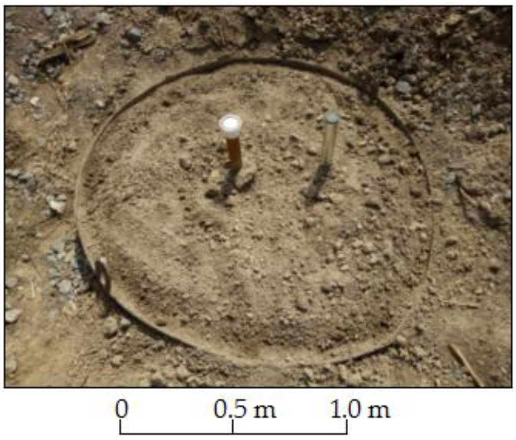

Figure 5. Uncompacted reclaimed soil test barrel.

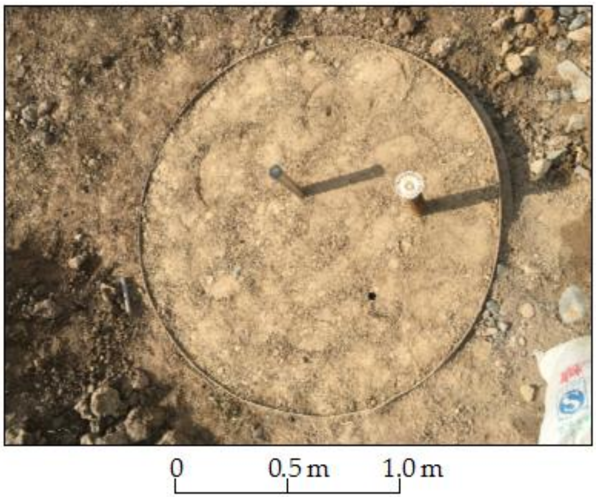

Figure 6. Reclaimed soil after one-compaction test barrel.

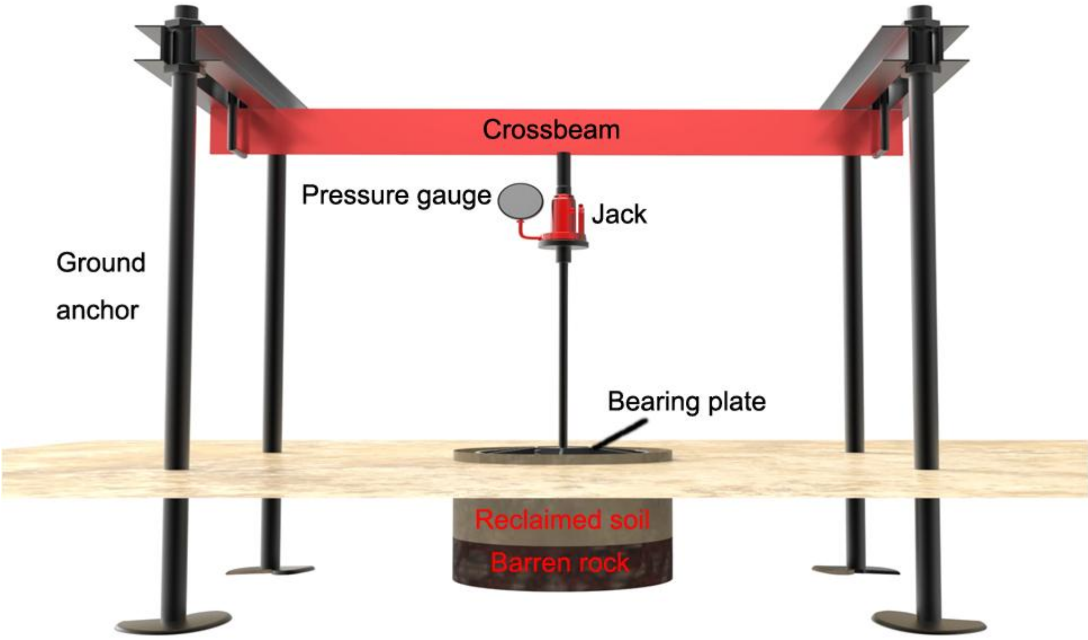

Figure 7. Illustration of the setup for plate load test.

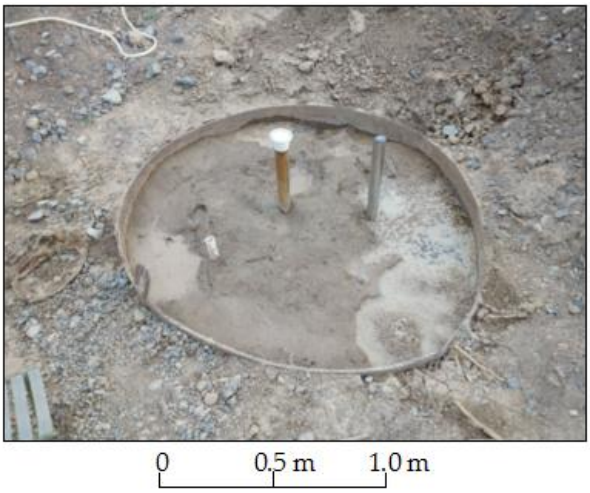

Figure 8. Uncompacted reclaimed soil test barrel after irrigation.

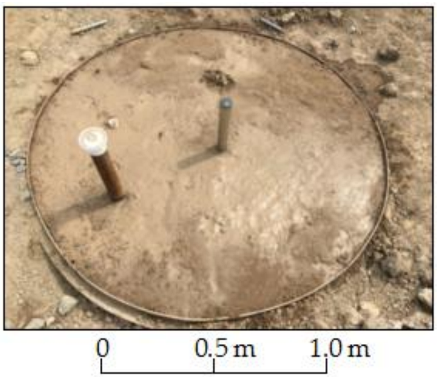

Figure 9. One-compaction reclaimed soil test barrel after irrigation.

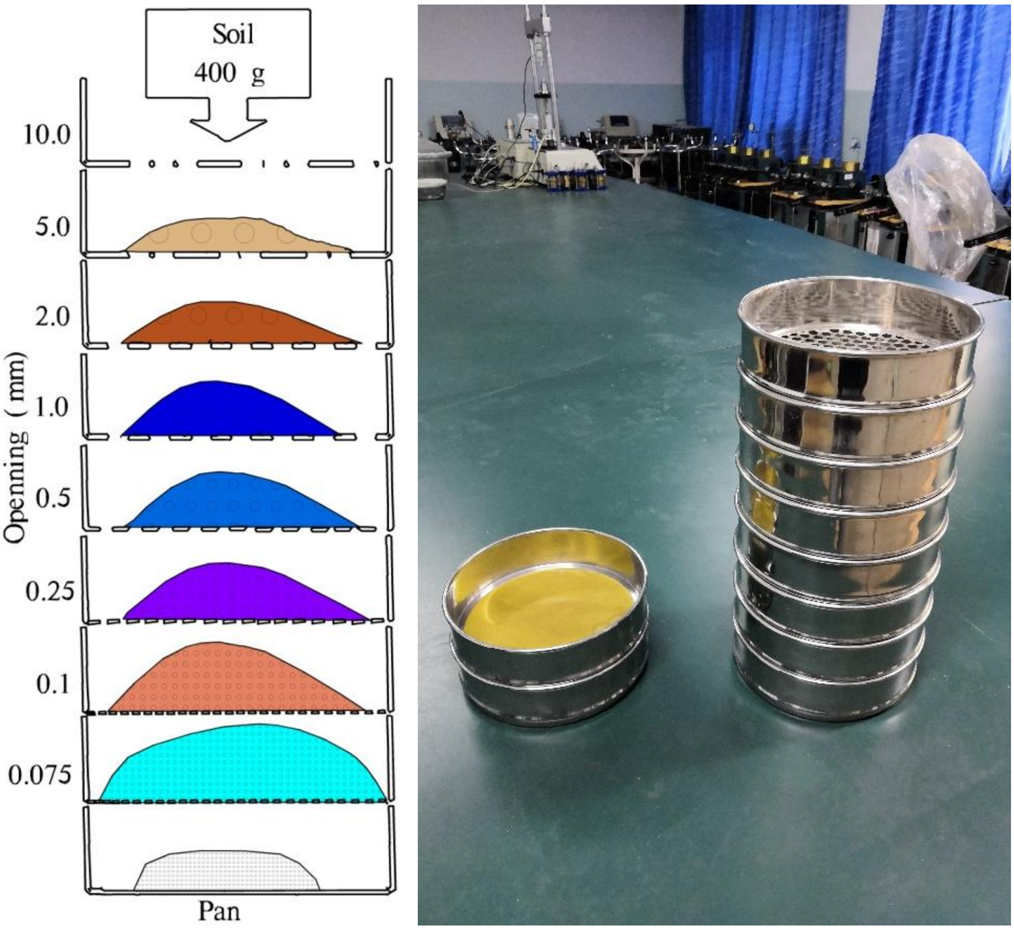

Figure 10. Sieving method.

3. Results and Discussions

3.1. Experimental Data Processing

A total of 18 soil samples were obtained after a one-year management period for particle size analysis. This sampling can be conducted at the depth of the interface between the reclaimed soil and waste rock, mainly because varying degrees of subsidence (Figure 8) occurred in the overlaying soil of the reclaimed soil due to surface irrigation during the one-year period of management, and some of the soil particles could enter the lower part of the waste rock. In order to ensure the accuracy of the physical properties of soil (density, porosity, water content), another three samples were taken from each depth. Table 1 lists the experimental results.

Table 1. Results of the reclaimed soil particle size analysis after a one-year management period.

Test Barrel No.	Sampling Depth (cm)	Percentage (%) of Soil with Particle Size Less than d_x (mm) by Mass								Characteristic Particle Size (mm)				C_u	n	θ (%)
		≤10.0	≤5.0	≤2.0	≤1.0	≤0.5	≤0.25	≤0.1	≤0.075	d_{10}	d_{30}	d_{50}	d_{60}			
A1	10	100	100	93.54	91.11	70.53	40.08	4.43	0.8	0.12	0.20	0.32	0.39	3.20	0.542	13.70
A1	30	100	100	94.19	90.44	71.38	13.96	2.42	0.28	0.23	0.32	0.39	0.43	1.92	0.520	23.28
A2	10	100	100	91.41	83.26	74.58	43.68	6.33	1.03	0.11	0.18	0.29	0.36	3.13	0.489	13.60
A2	30	100	100	94.35	81.15	66.22	26.32	0.85	0.32	0.16	0.28	0.38	0.45	2.85	0.503	23.23
B1	10	100	100	95.76	92.33	73.95	36.60	2.65	0.30	0.13	0.22	0.33	0.39	2.90	0.536	13.93
B1	30	100	100	98.96	93.16	71.91	15.41	4.61	1.13	0.21	0.31	0.39	0.43	2.09	0.523	23.73
B1	50	100	100	98.56	96.11	71.68	37.58	3.83	0.53	0.13	0.22	0.33	0.38	2.88	0.510	21.52
B2	10	100	100	97.01	91.06	69.66	42.71	7.41	0.98	0.11	0.19	0.30	0.39	3.48	0.504	14.00
B2	30	100	100	97.35	93.50	61.90	23.40	3.45	0.87	0.15	0.29	0.41	0.49	3.15	0.520	23.81
B2	50	100	100	89.35	82.90	61.75	35.10	2.15	0.35	0.13	0.22	0.37	0.48	3.58	0.513	16.07
C1	10	100	100	96.10	88.75	57.90	31.95	2.47	0.45	0.14	0.24	0.41	0.53	3.88	0.530	14.09
C1	30	100	100	97.83	92.30	45.20	7.67	0.67	0.32	0.27	0.40	0.54	0.62	2.25	0.525	24.01
C1	50	100	100	98.83	92.98	64.63	26.43	1.68	0.28	0.15	0.28	0.39	0.46	3.04	0.511	23.51
C1	70	100	100	98.70	96.73	80.08	60.18	18.7	8.50	0.08	0.14	0.20	0.26	3.23	0.472	20.93
C2	10	100	100	97.02	95.19	79.14	39.46	6.33	0.95	0.12	0.20	0.31	0.36	3.11	0.515	13.85
C2	30	100	100	96.29	89.74	67.84	25.66	5.73	0.50	0.14	0.28	0.38	0.44	3.24	0.520	24.19
C2	50	100	100	97.90	94.52	68.34	30.24	3.71	0.88	0.14	0.25	0.37	0.43	3.13	0.504	22.28
C2	70	100	100	98.49	96.84	80.16	60.23	21.8	6.67	0.08	0.09	0.19	0.26	3.20	0.492	22.44
URS	-	100	90.97	87.56	81.83	63.70	39.58	5.45	0.70	0.12	0.19	0.34	0.45	3.77	0.577	13.58

Note: Test barrel A represents overlaying soil thickness of 30 cm, B represents overlaying soil thickness of 50 cm, and C represents overlaying soil thickness of 70 cm; 1 represents uncompacted, and 2 represents compacted; A1 represents that the overlaying soil thickness is 10 cm and is uncompacted. d_{10} is the effective particle. d_{50} is the average particle size. $C_u = d_{60}/d_{10}$ is the non-uniform coefficient of the soil; $C_u \geq 5$ indicates non-homogeneous soils, and $C_u < 5$ indicates homogeneous soils. URS represents a sample of undisturbed reclaimed soil. n represents porosity. θ represents volumetric water content.

3.2. Granulometric Composition Analysis of Reclaimed Soil after the Management Period

3.2.1. Analysis of the Factors Affecting the Changes in Granulometric Composition of Reclaimed Soil after the Management Period

According to the Kalkiski soil classification system for soil particle sizes [29], 0.25 mm was used as the classification standard to distinguish between fine sand and medium sand; in the international standard for soil particle size classification, 0.2 mm is used as the classification standard to distinguish between coarse sand and fine sand, while in soil science and soil mechanics, 0.1 mm is taken as the classification standard to distinguish between fine and coarse particles. In order to reflect the change in the granulometric composition of reclaimed soil after the one-year management period, 0.25 mm, 0.1 mm, and d_{50} were studied as the focus of analysis. For the data on the granulometric composition of the reclaimed soil after the one-year management period (Table 1), variance analysis was done with the use of the multivariate in the general linear model in IBM SPSS Statistics (IBM, Chicago, IL, US); the percentage of particles with a size of ≤0.25 mm, ≤0.1 mm, and d_{50} were used as the dependent variables, and soil thickness and sampling depth as fixed factors. Table 2 lists the results of variance analysis. The results show that soil thickness has an insignificant effect on particle distribution ($p > 0.05$), and sampling depth has a significant effect on particle distribution ($p < 0.05$). The overlying soil of non-metallic mines in the northern foothills of the Tianshan Mountains in Xinjiang is mainly composed of sandy soil with a large amount of sand. In order to reflect the changes in the grain size of reclaimed soils at different depths, especially the changes of the fine particles, the percentage of soil particles with a size of ≤0.25 mm was used in the comparison of particle sizes at different depths. Table 3 lists the comparative analysis results. The results show that the fine particle content at the depth of 70 cm is significantly different from those at other depths ($p < 0.05$), and there is also a significant difference between the fine particle content at the depth of 10 cm and that at the depth of 30 cm ($p = 0.039$). The difference between the fine particle content at the depth of 70 cm and the depth at 30 cm is the most significant ($p = 0.002$).

Table 2. Test results of the inter-subject effect after variance analysis.

Source	Dependent Variables	III-Type Sum of Square	*df*	Mean Square	*F*	Sig.
Correction Model	≤0.25 mm	2179.926 [a]	5	435.985	3.987	0.023
	≤0.1 mm	506.317 [b]	5	101.263	25.118	0.000
	d_{50}	0.066 [c]	5	0.013	3.352	0.040
Intercept	≤0.25 mm	17,383.524	1	17,383.524	158.963	0.000
	≤0.1 mm	713.252	1	713.252	176.922	0.000
	d_{50}	1.161	1	1.161	293.865	0.000
Soil Thickness	≤0.25 mm	12.190	2	6.095	0.056	0.946
	≤0.1 mm	2.179	2	1.090	0.270	0.768
	d_{50}	0.005	2	0.003	0.677	0.527
Sampling Depth	≤0.25 mm	2017.396	3	672.465	6.149	0.009
	≤0.1 mm	440.730	3	146.910	36.441	0.000
	d_{50}	0.065	3	0.022	5.492	0.013

Note: [a] R square = 0.624 (adjusted R square = 0.468); [b] R square = 0.913 (adjusted R square = 0.876); [c] R square = 0.583 (adjusted R square = 0.409). Sig. = significance, the values are the statistical p value, if $p < 0.05$, the difference is significant.

Table 3. Results of multiple comparative analyses.

Dependent Variables	(I) Sampling Depth (cm)	(J) Sampling Depth (cm)	Difference in the Means (I−J)	Standard Deviation	Sig.	95% Confidence Interval	
						Lower Limit	Upper Limit
≤0.25 mm	10	30	14.0100 [a]	6.03754	0.039	0.8553	27.1647
		50	12.0758	6.75017	0.099	−2.6315	26.7832
		70	−20.7917 [a]	8.53837	0.031	−39.3952	−2.1882
	30	10	−14.0100 [a]	6.03754	0.039	−27.1647	−0.8553
		50	−1.9342	6.75017	0.779	−16.6415	12.7732
		70	−34.8017 [a]	8.53837	0.002	−53.4052	−16.1982
	50	10	−12.0758	6.75017	0.099	−26.7832	2.6315
		30	1.9342	6.75017	0.779	−12.7732	16.6415
		70	−32.8675 [a]	9.05631	0.003	−52.5995	−13.1355
	70	10	20.7917 [a]	8.53837	0.031	2.1882	39.3952
		30	34.8017 [a]	8.53837	0.002	16.1982	53.4052
		50	32.8675 [a]	9.05631	0.003	13.1355	52.5995

Note: [a] The difference of means is significant at 0.05 level; Sig. = significance.

3.2.2. Analysis of the Granulometric Composition of Reclaimed Soil after the Management Period under Different Overlaying Soil Thickness

The data of Table 1 is plotted into the gradation cumulative curve of the soil particles, where the abscissa is the particle size (mm), and the ordinate is the mass (cumulative percentage) content of the soil which is smaller than a certain particle size. The figure shows the relative content of each particle group in the soil, and it is the basis for calculating d_{10}, d_{30}, and other characteristic values. The uniformity or the gradation of the soil can be roughly judged according to the slope of the curve. A steep curve indicates that the soil particles are relatively uniform, and the quality of corresponding granular group is relatively centralized. The situation is the opposite when the curve is gentle.

The accumulative curve of the soil particle gradation with an overlaying soil thickness of 30 cm is shown in Figure 11. It shows that when the overlaying soil thickness is 30 cm, regardless of if it is compacted or not, the fine-grained soil content at the sampling depth of 30 cm is significantly smaller than that of the undisturbed reclaimed soil (URS). This is because this depth is the interface between soil and waste rock. The 30 cm overlaying soil is thin and the water would seep into the soil during irrigation, and the seepage process can easily carry the fine particles of the soil down to the pores in the large waste rocks. Fine particle content of the uncompacted reclaimed soil is even smaller than the compacted reclaimed soil at the depth of 30 cm. This is because the surface soil is compacted, the water seepage is slow, and less fine particles would be carried down to the waste rock layer compared with the uncompacted reclaimed soil. In the actual irrigation process, it can also be found that the uncompacted reclaimed soil would display a higher settlement in the process of irrigation compared with the compacted one (Figures 8 and 9). At the depth of 10 cm, the content of fine particles of compacted soil are slightly higher than that of the URS and uncompacted soil, which is mainly because the compaction results in an increase in the content of fine particles [20,23].

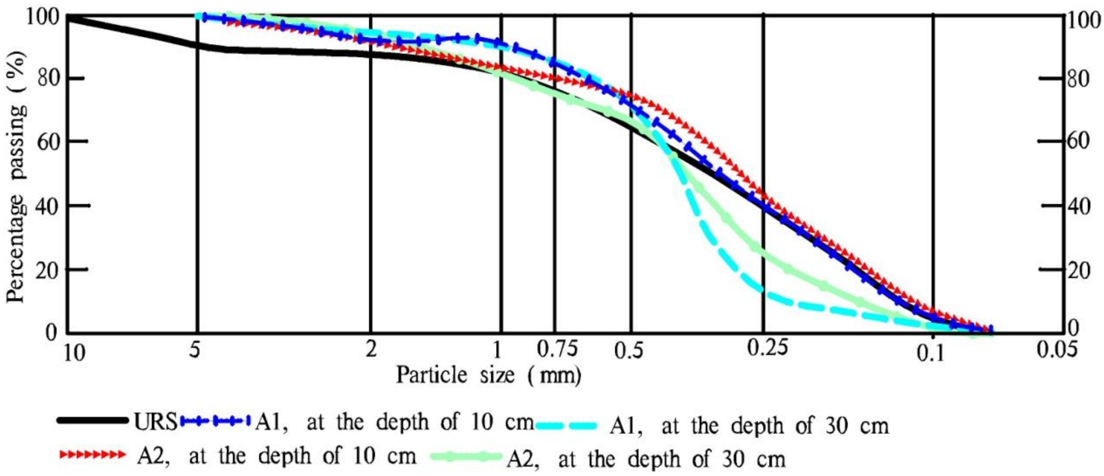

Figure 11. Accumulative curve of particle gradation of soil with overlaying soil thickness of 30 cm (A1 and A2).

The accumulative curve of the soil particle gradation with an overlaying soil thickness of 50 cm is shown in Figure 12. When the overlaying soil is 50 cm thick, the irrigation volume is larger than that of the 30 cm overlaying soil, and when the thickness of the soil overlayer increases, the seepage time in the soil would be longer. The results show that the fine particle content is significantly less than that of the URS at the depth of 30 cm. Furthermore, the fine particle content in the uncompacted reclaimed soil is much less. This is also the result of the seepage in the soil; that is, the water seeps downward after irrigation, and the seepage is fast in uncompacted soil with a large downward seepage force, resulting in a large loss of fine particles at the depth of 30 cm. At the depth of 50 cm, which is the junction of soil and waste rock, the fine particle content is close to that of the URS. This is mainly because the soil layer is thick and the seepage is slow at this depth, with a smaller seepage force, and thus the loss of fine particles is insignificant.

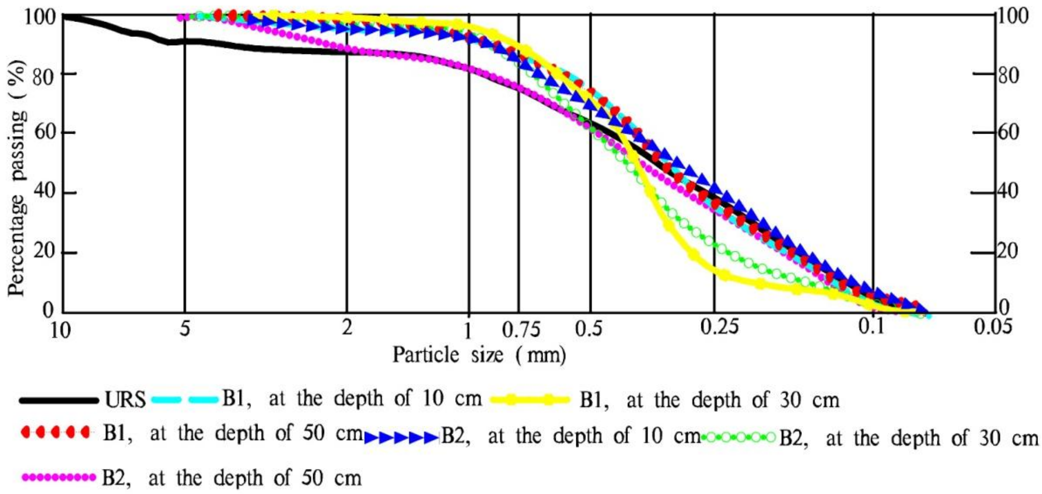

Figure 12. Accumulative curve of particle gradation of soil with overlaying soil thickness of 50 cm (B1 and B2).

The accumulative curve of the soil particle gradation with an overlaying soil thickness of 70 cm is shown in Figure 13. The thickness of the overlaying soil and the irrigation volume are further increased. The greatest change compared with overlaying soil thicknesses of 30 cm and 50 cm is that the fine particles sharply increase at the depth of 70 cm (the junction of soil and waste rock). This is because, as the soil layer becomes thicker, the fine particle content of the soil would increase, and the downward seepage of the soil would get slower. The finer particles are formed into sedimentation at the depth of 70 cm, resulting in a sharp increase in the fine particles.

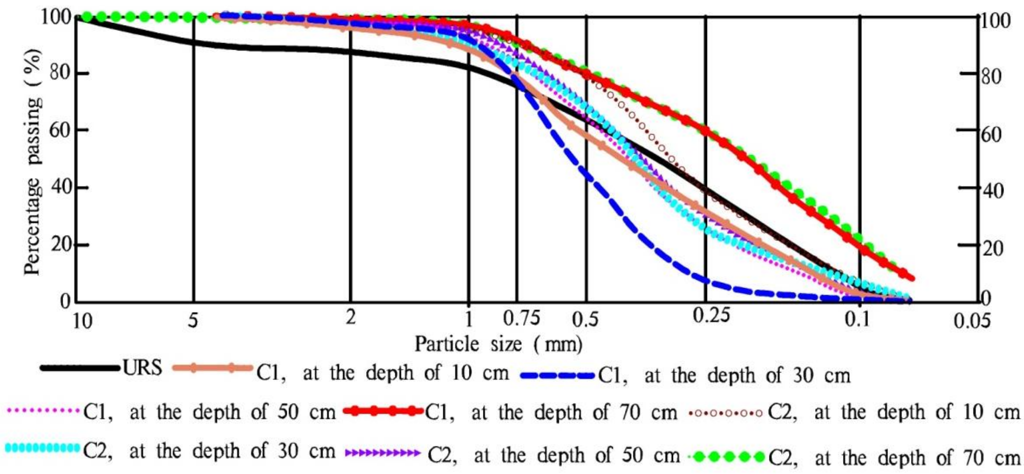

Figure 13. Accumulative curve of particle gradation of soil with overlaying soil thickness of 70 cm (C1 and C2).

3.2.3. Analysis of Change in Granulometric Composition of Reclaimed Soil at Different Depths after the Management Period

Figures 14–16 show that after the one-year management period the content of fine particles at the depth of 10 cm is not significantly different from that of the URS, and the content of fine particles of compacted reclaimed soil is slightly higher than that of the URS. This is because the surface compaction results in an increase in the content of fine particles. At the depth of 30 cm, the content of fine particles is lower than that of the URS, and the lowest value arises in the test barrel of uncompacted overlaying soil with a thickness of 70 cm, followed by the test barrels of the uncompacted overlaying soil with thicknesses of 50 cm and 30 cm. At the depth of 50 cm, the fine particle content is slightly lower than that of the URS, while at the depth of 70 cm, the fine particle content is much higher than that of the URS. The main reason for the above-mentioned phenomenon is the irrigation during the management period. The irrigation volume varies with different overlaying soil thicknesses. The thicker the overlaying soil is, the greater the irrigation volume would be. After irrigation, the water starts to flow downward along the pores of the reclaimed soil from the surface. The seepage speed is fast in uncompacted soil and slow in compacted soil. Therefore, from the surface to the deeper part of the reclaimed soil, the seepage speed gradually slows down, and the seepage volume becomes smaller. The seepage speed on the surface of the reclaimed soil is large, with great seepage volume and large downward seepage force, and it could carry the coarse and fine particles in the soil downward, causing the subsidence of the entire surface of the soil and making it dense. Therefore, the content of the fine-grained soil at the depth of 10 cm does not change much compared with the fine particle content of the URS. At the depth of 30 cm, the seepage speed becomes slower and could only carry fine-grained soil into the pores of deep soil; the uncompacted reclaimed soil was loose and the porosity is large, causing the fine-grained soil to move downward, and resulting in a great loss of fine-grained soil. At the overlaying soil thickness of 70 cm, the fine-grained soil content deceases the most greatly because the irrigation volume reaches the maximum. At a depth of 50 cm, the seepage speed further slows down, thus the fine particle content is only slightly reduced. At the depth of 70 cm, the seepage velocity is the slowest, and most of the fine particles are gathered here.

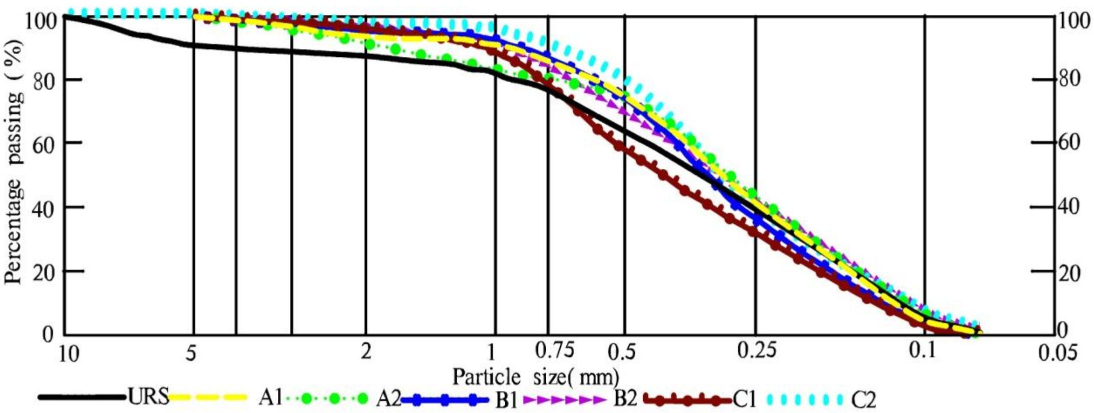

Figure 14. Accumulative curve of particle gradation of soil at the sampling depth of 10 cm.

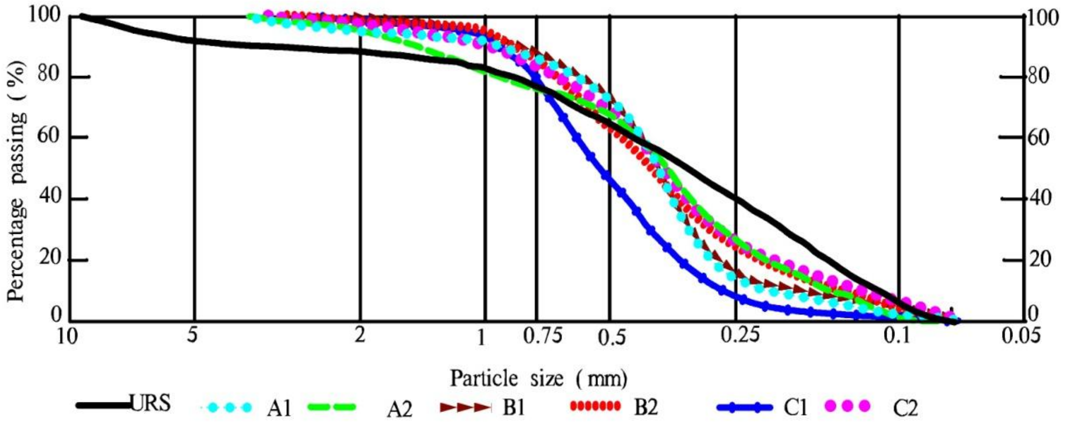

Figure 15. Accumulative curve of particle gradation of soil at the sampling depth of 30 cm.

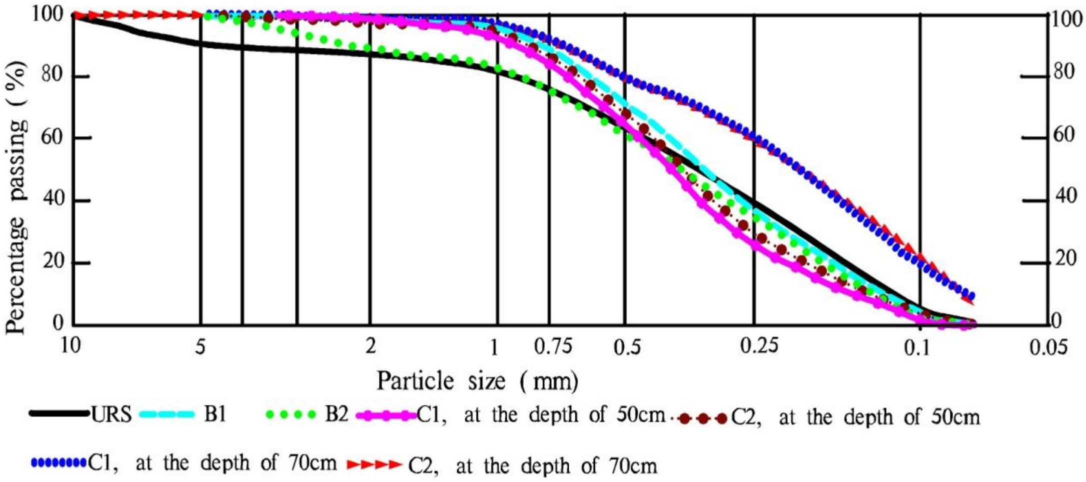

Figure 16. Accumulative curve of particle gradation of soil at the sampling depths of 50 cm and 70 cm.

3.2.4. Effects of Changes in Granulometric Composition of Reclaimed Soil to Physical Properties after the Management Period

The bivariate correlation analysis method in SPSS was used to analyze the correlation between the variation of soil particle size (especially the change of fine particles) and the physical properties, such as porosity, water content, and soil homogeneity of reclaimed soil. Table 4 lists the degree of correlation between the percentage coposition of soil with a particle size less than or equal to 0.25 mm or 0.1 mm, d_{10}, d_{50}, the coefficient of inhomogeneity C_u, the porosity, and the water content of the soil after the management period; the correlation coefficient grading used Spearman. The results show that there is a significant correlation between the percentage coposition of soil with a particle size less than or equal to 0.25 mm or 0.1 mm, d_{10}, d_{50}, C_u, and the water content of the soil after the management period, and they are unrelated only to the porosity of the soil after the management period. The porosity of the soil is related only to d_{50}. The water content of the soil after the one-year management period is only related to the percentage coposition of soil whose particle size is less than or equal to 0.25 mm, d_{10}, and d_{50}.

Table 4. Spearman grading correlation coefficient results.

			≤0.25 mm	**≤0.1 mm**	d_{10}	d_{50}	C_u	n	θ
Rho of Spearman	≤0.25 mm	Correlation coefficient	1.000	0.727 [a]	−0.967 [a]	−0.904 [a]	0.532 [b]	−0.393	−0.742 [a]
		Sig. (bilateral)	-	0.000	0.000	0.000	0.019	0.096	0.000
		N	19	19	19	19	19	19	19
	≤0.1 mm	Correlation coefficient	0.727 [a]	1.000	−0.812 [a]	−0.806 [a]	0.404	−0.353	−0.365
		Sig. (bilateral)	0.000	-	0.000	0.000	0.087	0.138	0.124
		N	19	19	19	19	19	19	19
	d_{10}	Correlation coefficient	−0.967 [a]	−0.812 [a]	1.000	0.914 [a]	−0.581 [a]	0.368	0.686 [a]
		Sig. (bilateral)	0.000	0.000	-	0.000	0.009	0.121	0.001
		N	19	19	19	19	19	19	19
	d_{50}	Correlation coefficient	−0.904 [a]	−0.806 [a]	0.914 [a]	1.000	−0.279	0.484 [b]	0.611 [a]
		Sig. (bilateral)	0.000	0.000	0.000	-	0.247	0.036	0.005
		N	19	19	19	19	19	19	19
	C_u	Correlation coefficient	0.532 [b]	0.404	−0.581 [a]	−0.279	1.000	0.007	−0.419
		Sig. (bilateral)	0.019	0.087	0.009	0.247	-	0.977	0.074
		N	19	19	19	19	19	19	19
	n	Correlation coefficient	−0.393	−0.353	0.368	0.484 [b]	0.007	1.000	−0.068
		Sig. (bilateral)	0.096	0.138	0.121	0.036	0.977	-	0.781
		N	19	19	19	19	19	19	19
	θ	Correlation coefficient	−0.742 [a]	−0.365	0.686 [a]	0.611 [a]	−0.419	−0.068	1.000
		Sig. (bilateral)	0.000	0.124	0.001	0.005	0.074	0.781	-
		N	19	19	19	19	19	19	19

Note: [a] represents that when the confidence level (double test) is 0.01, the correlation is significant. [b] represents that the correlation is significant when the confidence level (double test) is 0.05.

The data of correlations was formed into a scatter plot with straight lines (Figures 17 and 18). Figure 17 shows that the percentage content of soil with particle size less than or equal to 0.25 mm is basically consistent with the change trend of the C_u values and the percentage content of the soil whose particle size is less than or equal to 0.1 mm; d_{10} and d_{50} are basically consistent with the change trend of the soil water after the management period, and are basically contrary to the change trend of the percentage content of soil with particle size less than or equal to 0.25 and 0.1 mm. Soils with particle size less than or euqal to 0.25 mm and 0.1 mm are all fine-grained soils, and the changes in their contents are mainly affected by the seepage of irrigation water in the reclaimed soil during the period of management, and therefore their changes are positively correlated; the value of the non-uniform coefficient C_u is less than 5, indicating that the reclaimed soil all belongs to homogeneous soil. The non-uniform coefficient of the reclaimed soil after the management period is basically smaller than that of the URS, indicating that the soil becomes homogeneous under the seepage of water; and the reduction of the precentage content of soil whose particle size is less than or equal to 0.25 mm indicates that fine particles have decreased, and the soil is basically composed of coarse particles with a good uniformity. When the fine particle content decreases, the value of the characteristic particle size d_{10} and d_{50} would be greater, reflecting a coarser particle size of the soil on the whole. Table 4 shows that the water content of the reclaimed soil after the one-year management period is corelated to the precentage content of the soil with particle size less than or equivalent to 0.25 mm, as well as to d_{10} and d_{50}. Figure 17 shows that after the one-year management period, the water content of the reclaimed soil is positively corelated to d_{10} and d_{50}, and negatively corelated to precentage content of the soil whose particle size is less than or equivalent to 0.25 mm. This indicates that the coarser the soil is, the higher the soil water content will be. This is because the water content of the reclaimed soil is generally higher at the depth of 30 cm. This position also happens to be the location with the lowest content of fine particles. At the depth of 10 cm, the water content is low due to the impact of evaporation of the ground, while at this position the particles are relatively finer.

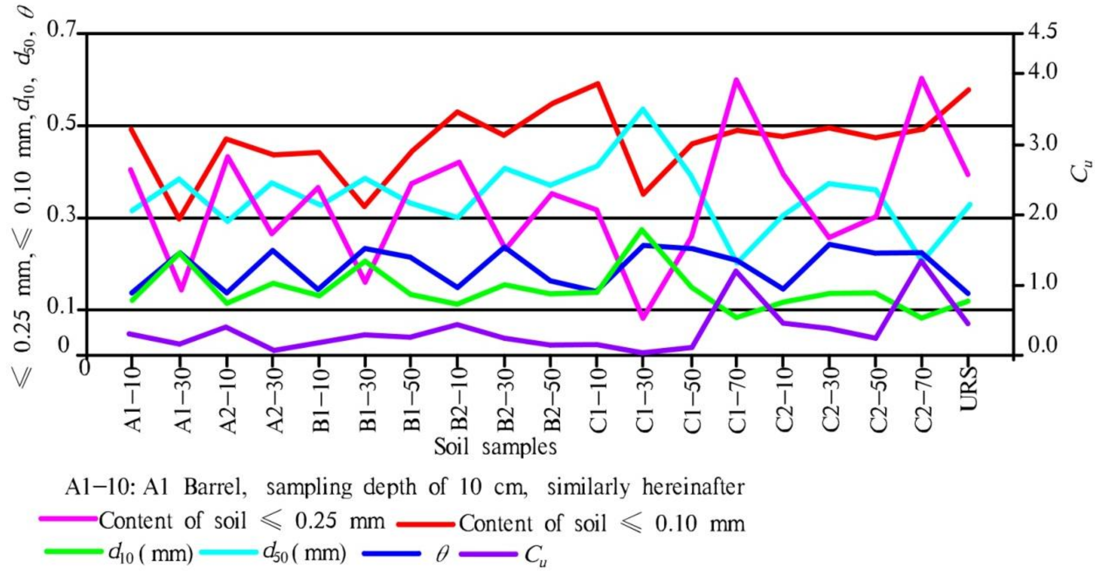

Figure 17. Scatter plot with straight lines of percentage content of soils ≤0.25 mm and ≤0.1 mm, d_{10}, d_{50}, C_u, and θ.

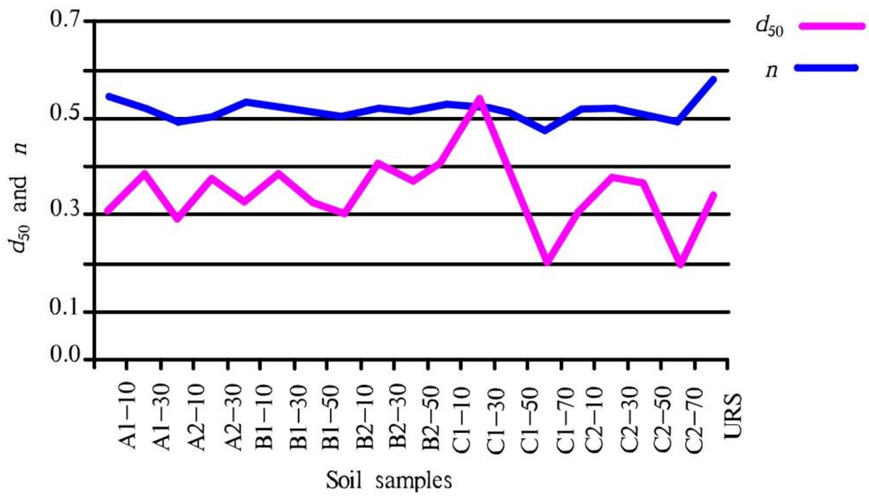

Figure 18. Scatter plot with straight lines of d_{50} and n.

Figure 18 shows that the overall porosity is positively correlated to d_{50}, indicating that the coarser the particles of the reclaimed soil are, the greater the porosity will be. This is quite opposite to the general distribution of porosity in the soil. This is because, if the particle sizes are completely uniform, the porosity of coarse-grained and fine-grained soils will be the same. However, the porosity of coarse-grained soils is usually smaller than that of fine-grained soils, and the pores of coarse-grained soils will be filled with smaller fine particles, while the pores of fine-grained soils will have none or less smaller fine particles to fill in. The porosity of the reclaimed coarse-grained soil is larger than that of the fine-grained soil, because the fine particles in the coarse-grained soil are carried into the deeper part of the reclaimed soil, resulting in a bigger pore volume and porosity.

This paper only includes the uncompacted and one-compaction circumstances, and there were no tests for the situation of multiple compactions. In the future period of this study, the effect of the number of times of compaction on the change in granulometric composition of the reclaimed soil after the management period will be carried out. According to the results of the granulometric composition of the soil after the one-year management period, the most important factor affecting the change in granulometric composition is the transport of the water in the unsaturated zone of the reclaimed soil. The future research could be conducted with a focus on the transport mechanism of the water in reclaimed soil under different overlaying thickness and compaction circumstances.

4. Conclusions

Studying the distribution of fine particles in reclaimed soil is very important for mined land reclamation. This paper uses geotechnical experimental methods to analyze the granulometric composition and the index of physical properties of the reclaimed soil in seepage conditions after a one-year management period. Through experimental results and data analysis, we can conclude that the content of fine particles in reclaimed soil at the depth of the interface between the soil and waste rock varies greatly under seepage after the management period; the thicker the overlaying soil is, the higher the fine particle content at this depth. The sampling depth of reclaimed soil has a significant effect on the granulometric composition of reclaimed soil. The most significant difference is between the depth of 70 cm and 30 cm. The fine particle content varies at different depths of reclaimed soil. The fine particle content at the depth of 10 cm is not much different from that of the URS. The fine particle content of reclaimed soil which has been compacted once at the depth of 10 cm is slightly higher than that of the URS. The fine particle content at the depth of 30 cm is generally lower than that of the URS, and reclaimed soil generally becomes coarser, and the fine particle content of the uncompacted reclaimed soil decreases more significantly. The fine particle content at the depth of 50 cm is slightly lower than that of the URS. Finally, the fine particle content increases sharply at the depth of 70 cm, and is greater than that of the URS.

By comparing the fine grain content of reclaimed soil with the physical properties of soil, we can see that the fine particle content affects the physical properties such as the homogeneity, porosity, and water content; the overall change is that the coarser the particles are, the more uniform the soil particles, the higher the water content, and the larger the porosity will be.

The results of this paper can provide a basis for guaranteeing the survival rate of vegetation in the reclaimed area of Xinjiang during the management period.

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