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Preliminary Study on Rainfall Infiltration of a Homogeneous SAP-Enhanced Cover

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Abstract. In order to improve the anti-seepage performance of the cover, this paper proposed to use super absorbent polymer (SAP) particles to improve the water storage capacity of the soil, and mixed them into the soil to build an SAP composite soil cover, but the law of water movement in which is not clear. In this paper, a series of soil column model tests were carried out to measure the changes of pore water pressure and volume water content in SAP composite soil cover at different depths. The results showed that under the extreme rainfall condition of once-in-a-century in Nanjing, the infiltration amount of SAP was only 12.7ml, while that of homogeneous sandy soil cover is 2510ml, indicating that the anti-seepage performance is good.

Keywords. Landfill, cover system, super absorbent polymer, unsaturated flow, impervious performance

1. Introduction

In recent years, due to the insufficient anti-seepage capacity of some landfill cover systems, leachate leakage, surface water and groundwater quality are relatively low in the detection, and the pollution to the environment is more serious in the rainy season. At the same time, the leakage of leachate will lead to uneven settlement of the landfill and slope instability. Therefore, the anti-seepage ability of the covering system is an important index in the construction of sanitary landfill at present [1].

Cover has been widely used as an anti-seepage measure in landfills, slopes, tailings dams and other structures [2-3]. But, the permeability of unsaturated clay is greatly affected by suction [4], and the long-term and economic performance of synthetic material covers need to be further studied. In order to overcome the shortcomings, the capillary barrier covers [5] had attracted attention. However, in humid areas, rainfall exceeds the water storage capacity of fine-grained soil. Water breakdown will occur. In order to improve the water storage capacity of the covering system, Chen [6] chose to mix biochar into the upper fine-grained soil of the capillary barrier cover systems to

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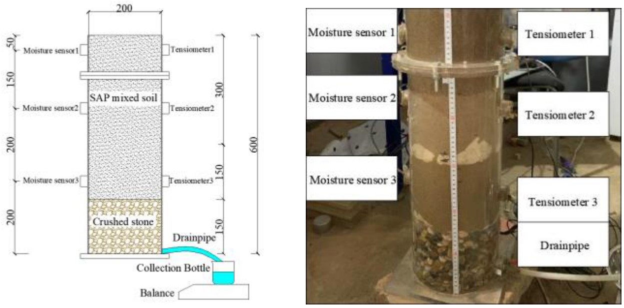
enhance the water storage capacity of the fine-grained soil with the porosity and adsorption characteristics of biochar. However, the amount needed was too large.

In order to improve the water storage capacity of cover soil, this paper put forward a new form of cover soil, which mixed super absorbent polymer (SAP) [7] into the soil to build SAP-enhanced soil cover (see figure 1). However, the existing theory can not accurately explain the unsaturated permeability characteristics of SAP mixed soil and the water transport law. Therefore, this paper analyzed the water movement law of SAP-enhanced soil cover through soil column model test, and preliminarily studied the anti-seepage performance under extreme rainfall conditions in humid climate.



a) Design diagram (unit: mm) b) Physical figure

Figure 1. Layout of soil column test.

2. Soil Column Model Test

2.1. Test Plan

In order to study the water migration law and anti-seepage performance of the SAP-enhanced soil cover, two groups of soil column tests were carried out in this paper, as listed in table 1. By comparing the results, the improvement of SAP on the water storage capacity and water blocking effect of the cover layer was studied.

Table 1. Test plan.

Test ID	Test type	Depth 0-30cm	Depth 30-45cm	Test objective
1	Single homogeneous sandy soil cover(HSSC)	Sand	Sand	Reference test
2	Single homogeneous 1% SMS cover(SMSC)	SAP mixed soil(SMS)	SAP mixed soil(SMS)	Reference test

2.2. Test Instrument

The soil column model was shown in figure 1. An instrument hole was set on the both sides of the side wall at the height of 20cm, 40cm and 55cm from the bottom, which were used to bury the tensiometer and moisture sensor [8] to measure the pore water pressure (negative value) and volumetric moisture content of soil at different depths. For purpose of measuring the amount of water infiltration, a drainage hole was set on the bottom, which was connected with a PU transparent conduit with a diameter of

10mm to collect the infiltration water of the cover into the collection bottle, and the balance on the ground, was used for measurement.

2.3. Material Properties

The materials used in the test mainly included sand and SAP particles.

2.3.1. Physical Properties of Sand

The sand used in the test was gray and dense flake fine sand, which was formed by the accumulation of Yangtze River floodplain and ancient river channel. Figure 2 gives the sand particle size distribution curve. The content of fine particles with particle size less than 0.075mm was 26.3%, and uneven coefficient Cu was 3.58. Curvature coefficient Cc was 1.05, poor gradation. According to the Soil Engineering Classification Criterion [9], the sand belonged to silty sand.

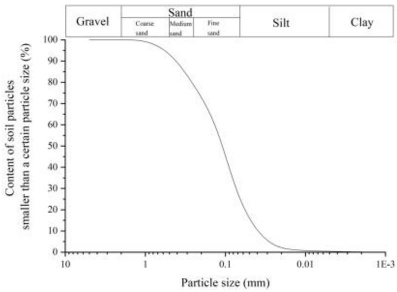


Figure 2. Particle size grading curve of sand in Nanjing.

2.3.2. Physical Properties of SAP Particles

The SAP particles used in the experiment were white particles with particle size of 120-180 mesh (0.083-0.122 mm). SAP particles mainly rely on osmotic pressure [10] to complete the water absorption and drainage of particles. The SAP particles used in the experiment absorb 200 times pure water, as shown in table 2.

Table 2. Properties of SAP particles.

Appearance	Absorption of pure water	Absorption amount (0.9 brine water absorption rate)	Centrifugal water retention	Pressurized absorption capacity	PH value	Bulk density
Pure white granules	200 g/g	57 g/g	30 g/g	18 g/g	6.2	0.64 $g.cm^{-3}$

3. Test Result

3.1. Variation Law of Pore Water Pressure

In figure 3, the initial pore water pressures were -5.9kPa and -22.7kPa, respectively. The difference came from the stronger water storage capacity of the SAP mixed soil than the sandy soil. It took about 20s for the wetting front to pass through 5cm in the HSSC, and the pore water pressure rose to -0.1kPa. In comparison the time spent in the HSMSC was 0.5h, and the pore water pressure at the wetting front is -2.2kPa. This was mainly due to the high water storage capacity of the SAP mixed soil, which reduced the rate of infiltration of the wetting front and the level of pore water pressure. As shown in figure 4, it took 8 minutes for the wetting front to pass through 20cm in the HSSC. The average descending velocity was 3.2×10^{-4}m/s, while the other is 6.9×10^{-5}m/s, which was one order of magnitude larger than the saturated permeability coefficient. Different from the HSSC, the pore water pressure of the HSMSC did not decrease significantly after the wetting front, which was mainly due to the fact that the pore water pressure at a depth of 20 cm was close to the static pore water pressure distribution line. This also showed that the SAP mixed soil had a strong water storage capacity.

In figure 5, for the HSSC, it took about 16 minutes for the wetting front to drop to 40cm, and the pore water pressure rose to -0.1kPa. The average descending velocity was 4.1×10^{-4}m/s. However, the pore water pressure of the HSMSC began to increase at 17h and reached a maximum value of -8.1kPa at 20h. Compared with the descending speed of the wetting front at the depth of 20 cm, that at the depth of 40 cm was reduced by one order of magnitude. After the wetting front passed, different from the other depths, the pore water pressure of the both cover at 40cm did not decrease significantly.

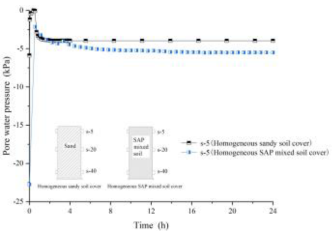


Figure 3. Development of pore water pressure at 5cm.

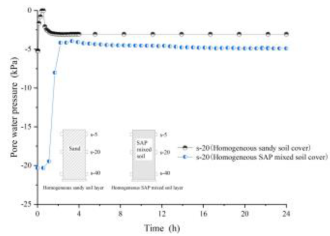


Figure 4. Development of pore water pressure at 20cm.

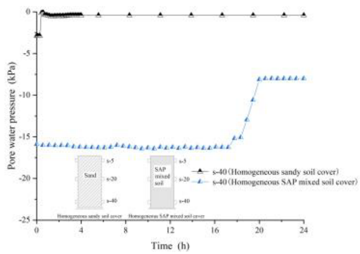


Figure 5. Development of pore water pressure at 40cm.

3.2. Variation Law of Volumetric Water Content

Figure 6 shows the development law of the volumetric water content at 5 cm in the soil column with time. The initial volumetric water content was about 0.15. Similar to the change law of pore water pressure, the water content measured by the moisture sensor in the HSSC rapidly increased to 0.36 at the beginning (about 20s). However, the volumetric water content at 5 cm in the HSMSC increased to 0.44 at 0.5h. Different from the change law of pore water pressure, the volumetric water content of the

HSMSC after wetting had little change. The different changing laws of pore water pressure and volumetric water content may be caused by the hydraulic hysteresis effect and the slow water loss rate of SAP particles. It can be seen in figure 7 that the volume water content at 20cm depth of HSSC rose to 0.36 at 8 min, similar to the variation law of pore water pressure. Unlike the rapid rise of pore water pressure in HSMSC, the rise phase of volume water content took about 6 hours and converged to 0.28 at 7h. This is mainly because the water in SAP mixed soil can be stored not only in pores, but also in SAP particles. SAP particle water storage speed was slower than that of pores.

In figure 8, during the wetting process, the volumetric water content at a depth of 40 cm in the HSSC rose to 0.3 in about 16 minutes, similar to the change law of pore water pressure. The volumetric water content of the homogeneous SAP mixed soil began to increase at 17h, rose to 0.26 at 18.8h, and then did not change. This variation law was similar to the variation law of pore water pressure.

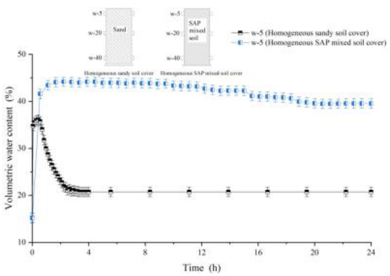


Figure 6. Development of volumetric water content at 5cm.

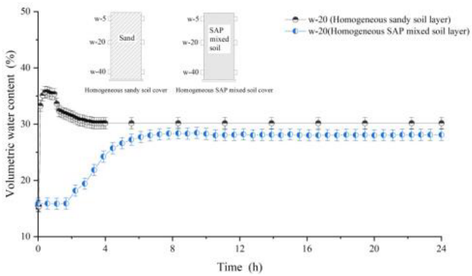


Figure 7. Development of volumetric water content at 20cm.

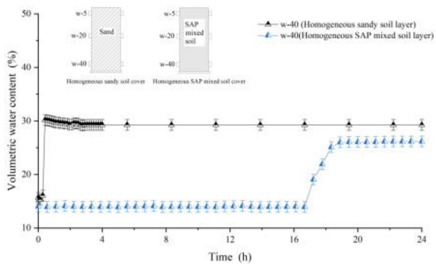


Figure 8. Development of volumetric water content at 40cm.

3.3. Anti-seepage Effect of the Homogeneous SAP Mixed Soil Cover

Table 3 gives the water breakdown time and leakage of different covers. The water breakdown of the HSSC occurred at about 20 minutes, and the breakdown time of the HSMSC was extended to 17 hours, showing that the anti-seepage performance of the HSMSC had been greatly improved. The infiltration amount of the HSSC was 2510.3ml, and the infiltration amount of the HSMSC was 12.7ml. The water infiltration amount had been greatly reduced, which was only 2% of the HSSC. It was proved that the composite soil formed by incorporating SAP into the soil had strong anti-seepage and water storage capacity.

Table 3. Breakthrough time of different cover systems.

Test name	Breakdown time	Leakage
Homogeneous sandy soil layer	20 min	2510.3ml
Homogeneous SAP mixed soil layer	17h	12.7ml

4. Conclusions

In this paper, a series of soil column model tests were used to analyze the variation law of pore water pressure and water content at different depths in a single-layer HSC and a single-layer HSMSC, and revealed the influence of SAP on the water migration law. The following conclusions are obtained:

(1) During the process of water loss, the pore water pressure of the SAP mixed soil decreased rapidly, while the volumetric water content decreased significantly slower, and there was a strong hysteresis effect. This is mainly because the water storage of SAP mixed soil was composed of pores and SAP particles.

(2) Different from the conventional compacted soil cover, the top volume water content (water storage capacity) of the HSMSC was the largest during the wetting process. As depth increased, volumetric water content (water storage) decreased. This was mainly due to the strong water retention of SAP particles during the rainfall process, and the SAP mixed soil at the top stored a sufficient amount of water.

(3) Under the extreme rainfall conditions that occurred once in a century in Nanjing, the infiltration of the HSMSC was 12.7 ml, indicating that although water breakdown occurred, the leakage was extremely small, and compared with ordinary single HSSC, the breakdown time of the soil cover was greatly delayed, the leakage was reduced by about 200 times, and the anti-seepage performance was good.

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