Long-Term Performance of the Water Infiltration and Stability of Fill Side Slope against Wetting in Expressways

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Abstract: Different settlements and instabilities of unsaturated subgrade subjected to wetting have been paid increasing attention in the southeast coastal areas of China. However, the treatments are costly when they are used in engineering. In addition, the long-term performances of the treatments are unclear. Based on seepage theory for unsaturated soils, a novel subgrade using a capillary barrier was proposed in this study to reduce the different settlements and stabilities. Compared with previous studies, a capillary barrier was merely applied in the landfill. The long-term performance and feasibility of a capillary barrier applied in a tilted subgrade slope is worthy of study, particularly in humid climates. Using Geo-Studio, the feasibility was verified by comparing a conventional subgrade with a subgrade using a capillary barrier in southeast coastal areas in terms of pore-water pressure, water content, settlement, and the safety factor. The numerical results showed that the subgrade using a capillary barrier could provide significant improvements in the performance of reducing the impact of pore-water pressure distribution it suffered from, so as to lead to smaller different settlements. The vertical settlement of the pavement using a capillary barrier over a 1 year period was 1 cm. Compared with a conventional subgrade, the settlement fell by 94%, and the safety factor increased by 15% for the subgrade using the capillary barrier.

Keywords: unsaturated subgrade; capillary barrier; distress control of wetting

1. Introduction

With the development of social economy and the requirements of modern transportation, expressways have become a focus during city construction [1]. Different from buildings, strict requirements are considered for the foundation of expressways such as the evaluation index of the expressway (i.e., fast, security, economy, and comfort). However, many problems still exist after an expressway's construction. Firstly, the safety of the expressway is affected directly by the instability of the subgrade. Secondly, if different settlement occurs on the expressway pavement, the driving speed is reduced. Moreover, the impact force caused by slowing down the driving speed is further exacerbated by the extent of the unevenness of the expressway pavement. Therefore, a vicious circle is formed, which further affects driving safety and causes huge economic losses [2]. These problems have seriously affected the use of expressways, especially in areas in southeast coastal provinces where the economy is developing rapidly. They are located in the region of a continental monsoon climate zone with relatively high rainfall in China. Therefore, in these areas, the subgrades have been greatly affected after completion by atmospheric conditions that include rainfall and evaporation. The instability and different settlement become more prominent under the influence of wet conditions [3].

For expressways, the foundation soil is located above the groundwater table isoline and is in an unsaturated state. In the unsaturated subgrade, the volumetric moisture content increases with rainfall. Therefore, the strength of the foundation soil is minimized, and it leads to instability and different settlement of the subgrade. In order to prevent
instability and reduce different settlements after completion, a long–short pile composite foundation [4,5] is adopted. This enables piles of different lengths and stiffnesses to carry more loads with a decrease in the proportion of the load on the soil in the subgrade. Moreover, it makes up for the decrease in the soil strength caused by wetting deformation. However, the pile foundation greatly increases the cost of an expressway’s construction, and the long-term performance of the pile is still unclear. The composite foundation using foamed cement banking (FCB) as a replacement is another effective treatment measure [6]. FCB is a light-weight material with low density, high strength, and low permeability. By minimizing its weight and permeability, the instability and settlement problems are effectively delayed due to the wetting deformation of the expressway pavement. However, FCB is still in the research stage. The influencing factors of its strength and permeability are still unclear. Wang [7] used a soil stabilizer to reinforce the silty clay for the subgrade. He studied the pavement’s performance with a mixture composed of the best proportion, which provided the basis and reference for similar engineering applications. Apart from using a soil stabilizer, Zhao [8] proposed that the recycled fine soil of construction waste with a diameter under 5 mm could be used in expressway subgrade. The soil was validated as a good subgrade material through basic experiments. However, the existing improvements were all treatment methods based on materials without considering the wetting distress on the long-term performance. The construction cost has increased because of these methods, and long-term performance under wetting and drying cycles is unclear. Hence, we propose effective measures to block the infiltrating rainwater in the subgrade through a capillary barrier.

A capillary barrier has been widely used in landfill cover systems, because of its advantages of long service life, ease of construction, and environment conservation [9,10]. It consists of fine layers over coarse layers, which are composed of different properties. Soil properties are very important in engineering. Different soil particles play an important role in the subgrade soil, which affect soil erodibility and the infiltration rate of water. Arunrat et al. [11] pointed out the variations in soil properties and explained how soil erodibility is affected. Wang et al. [12] showed that the different properties and the different poultry compost amendments to the soils resulted in distinct runoff, sediment yield, and soil erodibility values. With the different permeability coefficients of these two soil layers under unsaturated conditions, the fine-grained layer, used as a buffer, can store and transfer infiltrating water effectively [13]. Ross [14] and Stormont [15] derived the evaluation index of capillary barriers through the theory of the permeability coefficients of two soils. The evaluation index is the distance downslope, called the diversion length. It has been verified that a capillary barrier can effectively block the infiltrating rainwater within the diversion length [16,17]. Rahardjo [18] proposed that a capillary barrier could be used to protect the slope. The waterproof effect of a capillary barrier was verified through field tests and through the same way the application of a capillary barrier to the slope was studied and found to be feasible. Wu et al. [19] proposed that a capillary barrier could be applied as a cover barrier to protect the expressway subgrade from wetting distress. Previous studies focused on the effect and mechanism of a capillary barrier applied to landfills in dry climates. However, the performance of a capillary barrier in humid climates is still unclear. In other words, the performance of a capillary barrier applied to a slope shoulder is still unclear in humid climates in China’s southeast coastal areas. Meanwhile, the environment of expressways in the southeast coastal areas of China is generally humid compared with the relatively dry landfill cover system. Due to the presence of these peculiarities, it is necessary to verify the rationality of the application of the capillary barrier on the expressway.

This paper firstly explains the mechanism of moisture migration in the unsaturated subgrade and proposes effective measures to block the infiltrating rainwater in the subgrade through capillary barrier. Then, the anti-seepage effect of the capillary barrier is introduced. Comparing the numerical simulation results of the subgrade with or without a capillary barrier, the feasibility of applying a capillary barrier to the subgrade was verified. Finally,
the results were evaluated and focused on the role of the capillary barrier in the anti-seepage performance by simulating their changes in moisture content, pore-water pressure, settlement, and safety factor of the subgrade under rainfall conditions in the southeast areas of China.

2. Reinforcement Mechanism of Subgrades with a Capillary Barrier

In the southeast coastal areas of China, the groundwater table isoline is generally below the original ground, and the subgrade is generally in an unsaturated state. Therefore, the soil strength is directly influenced by the distribution of matric suction in the subgrade soil. The matric suction is a manifestation of the energy produced by the water in the soil due to the capillary effect. Numerically, it is equal to the pore-air pressure minus the pore-water pressure \((u_a - u_w)\). Based on the M-C model, Fredlund and Rahardjo [20] proposed a formula for the shear strength of unsaturated soil:

\[
\tau_u = c' + (\sigma - u_a) \tan(\phi') + (u_a - u_w) \tan(\phi^b)
\]  

(1)

where \(\tau_u\) is the shear strength of unsaturated soil; \(c'\) is effective cohesion; \(u_a\) is the pore air pressure; \(u_w\) is the pore-water pressure; \(\phi'\) is the effective internal friction angle; \(\phi^b\) is the shear strength increase rate with the change in matric suction. Figure 1 shows the traditional subgrade structure. After the expressway is completed, the pavement is an asphalt layer with good waterproofness. However, the fill slope is generally exposed in the atmosphere. When it rains, moisture flows into the subgrade from the slope shoulder. Because the subgrade is under unsaturated conditions, the soil suction in the subgrade is large, and the suction at the shoulder slope is small. Moisture gradually inflows into the subgrade soil along the suction gradient line. It is worth noting that the almost horizontal water flow is unsaturated flow. Therefore, the moisture content of the subgrade soil continues to increase, and the suction continues to decrease. According to formula (1), it can be seen that the reduction in shear strength is directly influenced by the reduction in suction, which may lead to the shear deformation and instability of the subgrade. Figure 2a shows the soil water characteristic curve of the subgrade soil. The water-entry value was approximately 6 kPa and the air-entry value was approximately 28 kPa. The difference between the water-entry value and the air-entry value of the subgrade soil was approximately 22 kPa. However, the standard design value of the vehicle load on the expressway was only 10.5 kPa [21]. Therefore, the strength change caused by the wetting subgrade should not be ignored.

![Figure 1. Schematic diagram of a standard subgrade (unit: mm).](image-url)
Figure 2. (a) Soil water characteristic curves and (b) permeability function of soils used in the subgrade.

In order to avoid the decrease in soil strength due to the presence of rainfall, this paper proposes to add a capillary barrier on the fill slope to protect the subgrade. The fine-grained soil in the capillary barrier was filled with the soil near the expressway. Gravel or sand was used as the coarse-grained soil. The fill slope soil from the surface to bottom was the fill near the expressway, gravel, and subgrade soil. Figure 2 shows the soil water characteristic curves and permeability coefficient curves of the two soils. The unsaturated permeability coefficients were estimated using the Mualem model [22].

\[
k = k_s \varepsilon_e^{0.5} \left( \frac{\varepsilon_e}{\psi} \int \varepsilon_e \frac{dS_e}{\psi} / \int \frac{dS_e}{\psi} \right)^2
\]  

(2)
where $k_s$ is equal to the saturated permeability coefficient; $S_e$ is equal to the effective saturation; $\psi$ is equal to the soil suction. The slope in the soil water characteristic curve of the coarse-grained soil was steeper because of its large pores. Thereby, its water-holding capacity was worse, and the permeability coefficient curve was also steeper. The volumetric water content and permeability coefficient have a nonlinear distribution under different suction ranges. The suction where the permeability coefficients of two soils are equal is the critical failure suction, as shown in Figure 2b, which is the suction at point A.

With the water content continuously increasing when it rains, soil suction decreases. Rainwater enters the capillary barrier along the slope shoulder and inflows into the fill due to the fact of gravity. When soil suction is higher than the critical failure suction, the permeability coefficient of the fill is higher than that of the gravel. At this time, water accumulates only at the interface between the gravel and the fill. It does not breakthrough into the gravel layer. Because the capillary barrier is tilted, the moisture accumulated at the interface is drained laterally along the interface. When soil suction is less than the critical failure suction, the capillary barrier fails. At the interface, the diversion length is the distance from the point where the suction is equivalent to the critical failure suction to the surface of slope. It was evidently shown that the capillary barrier is effective within the diversion length. Walter [23], Tami [24], and Aubertin [25] pointed out that the diversion length of the capillary barrier was influenced by the slope angle, thickness of the fine-grained soil, the properties of the fine-grained and coarse-grained soils, layer thickness, rainfall condition, etc. They all focused on the landfill cover system. Compared with the landfill, the slope length of the subgrade is relatively shorter, and the blocking effect of rainwater is better.

3. Calculation Model of the Subgrade with a Capillary Barrier

It is difficult to study wetting deformation using an analytical solution. For one thing, the soil water characteristic curve and the permeability coefficient equation of soils are both nonlinear. For another, the strength constitutive relationships of soils are complicated. To quantitatively analyze the deformation and stability of the subgrade protected by a capillary barrier during the rainfall, Geo-Studio 2018 R2 software (version 9.1.1.16749) was used to carry out a numerical simulation study in this paper. Geo-Studio is an overall analysis tool for a set of geological structure model software. The test sections in this paper included SLOPE/W (slope stability analysis module), SEEP/W (groundwater seepage analysis module), and SIGMA/W (rock and soil stress and deformation analysis module).

3.1. Mesh and Model

Figure 3 shows the model of the subgrade with a capillary barrier. The figure on the horizontal axis means the distance from the road’s central line. The figure on the vertical axis means the height of the pavement to the bedrock. A subgrade section was selected in Guangzhou. The height of the foundation was 20 m. The height of the subgrade was 6 m. The slope of the shoulder was 1:1.5. Due to the symmetry of the subgrade, the simulation only took half of the subgrade for the research. This paper studied two subgrade models: (1) a conventional subgrade; (2) a subgrade using a capillary barrier. The conventional subgrade was composed of a single soil layer, while the subgrade protected by a capillary barrier added a capillary barrier on the slope shoulder. The subgrade soil was used as fill with a thickness of 0.3 m. The thickness of the gravel was 0.2 m.
3.2. Material Properties

The physical properties of soils for the subgrade with a capillary barrier are shown in Tables 1 and 2. Based on the data in Figure 4, the coefficient of uniformity of the gravel was 14 and that of the fill soil was 6.4. The coefficient of the curvature of the gravel was 2.8 and that of the fill soil was 1.2. According to the Standard for Classification of Engineering Soils [26], the fill soil was classified as the silty clay of well gradation, and the gravel was well graded. The soil involved in this paper included foundation soil, subgrade soil, and gravel. In view of the similar moisture migration properties of the foundation and the subgrade, the identical hydraulic characteristic parameters were used for the subgrade and the foundation to facilitate the study. In the numerical simulation, the soil water characteristic curve of the subgrade soil was based on the test data from Jun Luo [3]. The soil water characteristic curve of the gravel was based on the test data used by Morris et al. [27]. The saturated permeability coefficient of the soil was measured by the constant head method. However, the unsaturated permeability coefficient equation was predicted on the basis of the soil water characteristics using the van Genuchten functions as shown in Figure 2. The ideal elastoplastic M-C model was adopted as the mechanical model for the deformation, and the strength parameters of the foundation soil and subgrade soil were determined by consolidated drained triaxial tests. The results of the triaxial shear test are shown in Table 1. The gravel was only 0.2 m thick due to the fact of its small thickness. In order to ensure the calculations were convenient, the strength characteristics were set to elastic materials and the data, listed in Table 1, were selected based on the elastic modulus test by Yuedong Wu et al. [28].
Table 1. The physical properties of various soils for the subgrade with a capillary barrier.

| Type of Soil Layer | Maximum Dry Density (g/cm³) | Optimum Moisture Content (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Index |
|--------------------|----------------------------|------------------------------|------------------|-------------------|-----------------|
| Foundation         | 1.675                      |                              | 82               | 23                | 11              |
| Subgrade           | 1.675                      |                              | 82               | 23                | 11              |
| Gravel             | 2.168                      |                              |                  |                   |                 |

Table 2. Strength properties of the various soils for the subgrade with a capillary barrier.

| Type of Soil Layer | Bulk Density (kN/m³) | Elastic Modulus (MPa) | Poisson's Ratio | c’ (kPa) | ϕ’ (°) | ϕb (°) |
|--------------------|----------------------|-----------------------|-----------------|----------|--------|--------|
| Foundation         | 18.3                 | 20                    | 0.35            | 1        | 23     | 11     |
| Subgrade           | 18.3                 | 20                    | 0.35            | 5        | 26     | 13     |
| Gravel             | 18.3                 | 40                    | 0.35            | -        | -      | -      |

Figure 4. Grain size distribution of the soils.

3.3. Simulation Steps and Boundary Conditions

In order to simulate the impact of rainfall on the expressway, it was necessary to eliminate other factors that cause settlement. This paper simulated the following four steps.

The first step was to perform an analysis on the stress and deformation (SIGMA/W) of the subgrade. The design load on the pavement (AB) was set to complete the load and geo-stress balance. According to the expressway design code, the standard design load of the pavement was 10.5 kPa. The left and right boundaries (i.e., AF and DE) were set to the displacement boundary condition, restraining in the horizontal direction. The bottom boundary (EF) was set to the displacement boundary conditions, restraining in the horizontal and vertical directions.

The second step was to conduct a water seepage analysis (SEEP/W) on the subgrade and design the flow boundary conditions on the shoulder slope (BC) and the ground (CD). The annual precipitation in Guangdong, eastern Guangxi, Fujian, Jiangxi, and most of Zhejiang along the southeast coast of China is 1500–2000 mm. The middle and lower reaches of the Yangtze River are 1000–1600 mm. The Huaihe River, Qinling Mountains, and the Liaodong Peninsula have an annual precipitation of 800–1000 mm. Moreover, the
seasonal distribution is uneven, with summer accounting for approximately 50% of the annual rainfall. Particularly, in this study, we focused on the long-term performance of the subgrade. The subgrade soil can store water. Unsaturated drainage still occurs from the topsoil when it does not rain. Therefore, the most extreme rainfall intensity was selected, which was 1000 mm in the summer and the rainfall on the rainfall surface was set to $1.27 \times 10^{-7}$ m/s. In order to fully study the law of subgrade infiltration, the duration was chosen as 365 days, which considered the humid climate in the eastern coastal area. Due to the large stiffness and small deformation, we assumed that the impermeable bedrock was the bottom of the groundwater. Considering the surface runoff, the set flow boundary was a flow boundary condition that allowed for correction. The bottom boundary condition (EF) was the pressure head boundary condition. Assuming that the initial water level was 3 m below the ground, the pressure head of EF was set to 17 m.

The third step was to perform stress and deformation analysis (SIGMA/W) on the subgrade at the corresponding time. Using the stress conditions in step 1 and the pore-water pressure results at different moments in step 2 as suction conditions, the deformation response in the wetting conditions was calculated. The boundary conditions were the same as in Step 1 and Step 2. The results obtained were calculated with the load and geo-stress balance as the starting point.

In the fourth step, the slope stability analysis (SLOPE/W) of the subgrade was performed. The initial stress condition was the result of step 3. The initial pore-water pressure distribution condition was the result of step 2. The boundary conditions were the same as in step 1.

4. Numerical Simulation Results

4.1. The Law of Moisture Migration in the Subgrade

When the conventional subgrade was subjected to rainfall, the rainwater flowed from the slope shoulder of the expressway to the inside of the subgrade soil, as shown in Figure 5a. This led to a decrease in the pore-water pressure of the soil near the shoulder. But far away from the expressway shoulder, the distribution of the pore-water pressure was almost unaffected. This was mainly due to the effect of gravity, which limits the scope of moisture migration. The influence range of the rainfall in the conventional subgrade was approximately 3 m.

Compared with the conventional subgrade, the subgrade using a capillary barrier was far less affected by rain. In the subgrade with a capillary barrier, water was mainly diverted laterally from the fine-grained soil of the capillary barrier. The distribution of the pore-water pressure in the subgrade and the foundation was almost horizontal, but the flow was concentrated at the bottom of the expressway’s slope shoulder. In order to more effectively minimize the impact of rainfall on the pore-water pressure in the foundation, it is recommended that a drainage ditch connecting the fine-grained soil layer be constructed at the base of the slope during the site’s construction to facilitate drainage.

It is worth noting that the impermeability of the pavement is very important for the subgrade using a capillary barrier. If there are many cracks in the expressway pavement, rainwater will infiltrate into the subgrade along the cracks, which will lead to a decrease in the pore-water pressure of the subgrade. Under this condition, the suction in the subgrade soil is first reduced to a critical failure suction, and the capillary barrier loses its blocking effect.
Figure 5. Pore-water pressure distribution in (a) traditional subgrade; (b) the subgrade with a capillary barrier at the end of the year.

Due to a deeper-seated slide, which often happens on the top of the slope, the pore-water pressure at the interface I-I was taken as the abscissa, and the elevation was taken as the ordinate (the elevation of CD was 0) to quantitatively study the impact of rainwater on the pore-water pressure, which is plotted as Figure 6. Under the action of rainwater, the soil in the middle and upper layers of the conventional subgrade was greatly affected. In the upper soil, the largest pore-water pressure was $-31$ kPa; in the middle soil, the pore-water pressure was maintained at approximately $-25$ kPa; the bottom soil was almost unaffected by rain and almost coincided with the hydrostatic pressure distribution. This distribution curve was not the same as the wetting law of a single-layer of soil [29], which is mainly due to the different intrusion surfaces of rainwater. The lateral slope in the subgrade was the rainwater immersion surface.
Figure 6. Pore-water pressure profiles at section I-I.

The subgrade using a capillary barrier was less affected by rain, and its pore-water pressure distribution almost coincided with the hydrostatic pressure distribution line. It can be seen that the blocking effect of the capillary barrier on the subgrade was more obvious. The capillary barrier used as a landfill cover system has been proven to be unsuitable for humid climates [16,17], but as a subgrade protection layer, the capillary barrier is suitable for humid climates. This is mainly due to the short length of the tilted slope in the subgrade, which is completely within the diversion length. In the middle and upper soils, the pore-water pressure in the subgrade protected by a capillary barrier is lower than that of the conventional subgrade. The difference between the two subgrades shows a nonlinear distribution, and the maximum was 57 kPa. Compared with the traditional capillary barrier, the pore-water pressure was reduced by 180%. It can be seen that the impact of the rainfall on the strength of subgrade cannot be ignored. It is worth noting that the value of $\phi^b$ in Formula (1) was generally different from that of $\phi$. Therefore, the contribution of the pore-water pressure to the shear strength was also different from that of the additional stress ($\sigma$).

Figure 7 shows the change trend in the volumetric moisture content with elevation. The volumetric moisture content in the subgrade (elevation 0–6 m) was basically constant, which was mainly because the pore-water pressure in the subgrade was basically greater than the inflow value of the fill. In this case, a very small change in the water content caused a huge change in the pore-water pressure. The water-holding capacity of conventional subgrade was basically maintained at 0.17, while the water content of the subgrade with capillary barrier was at 0.14. Compared with the conventional subgrade, the moisture content of the subgrade protected by the capillary barrier was reduced by 18%.

Figure 7. Volumetric water content profiles at section I-I.
4.2. Settlement and Deformation Law

Changes in the pore-water pressure caused changes in the shear strength. Figure 8 shows the deformation vector arrows of the subgrade protected by a capillary barrier. The subgrade with a capillary barrier was basically not affected by rainfall, while settlement still occurred. This was mainly because the slight change in the pore-water pressure at the bottom of the expressway shoulder slope caused the strength in the uplift area of the slip surface to decrease, which led to the shear deformation of the subgrade.

Figure 8. Deformation vector arrows of the subgrade with a capillary barrier.

Figure 9 shows the change trend in the expressway’s pavement AB settlement with horizontal displacement. In the nonaffected area, the settlement of the conventional subgrade was relatively small, which was only 1 cm. While in the affected area, the settlement was large, which was up to 16 cm. Large different settlements occurred at the shoulder and in the subgrade. The different settlement was up to 15 cm. However, the subgrade using a capillary barrier had a ground settlement of approximately 1 cm in the affected zone and the noninfluenced zone. The different settlement was also relatively small. Surprisingly, even if the pore-water pressure in the subgrade did not change, the subgrade still had a certain amount of settlement. This was mainly caused by the shear deformation of the foundation.

Figure 9. Comparison of the settlement in the different subgrades.

4.3. Variation Law of Safety Factor

The safety factor can be used to reflect the possibility of slope instability to a certain extent. As the subgrade and foundation are influenced by rainfall, the pore-water pressure in the traditional subgrade decreased, which reduced the overall safety factor of the subgrade.
The safety factor was reduced from 1.35 to 1.15 in one year as shown in Figure 10, and the decrease in the safety factor with time was nonlinear. The safety factor of the subgrade protected by the capillary barrier was almost unchanged. This was mainly due to the better blocking effect of the capillary barrier. In one year, the safety factor of the subgrade using a capillary barrier increased by 15% compared to the traditional subgrade.

Figure 10. Comparison of the safety factor in the different subgrades.

5. Conclusions

In this study, we first proposed effective measures to block the infiltrating rainwater in the subgrade through a capillary barrier. Secondly, using the numerical simulation method, we conducted studies on the mechanism and stability of the capillary barrier used in the subgrade to control distress against wetting. The subgrade with a capillary barrier could effectively use the different permeability coefficients of the different types of soil to achieve an anti-seepage effect, which minimized the deformation of the subgrade and increased stability. Using the numerical simulation method, this paper analyzed the pore-water pressure distribution, settlement, and safety factor of the conventional subgrade and the subgrade protected by the capillary barrier. Through a comparison of the numerical results of the two subgrades, the following conclusions were drawn:

1. The pore-water pressure of the subgrade protected by the capillary barrier was hardly affected by rainfall. Compared with the conventional subgrade, the pore-water pressure was reduced by 180%, and the pore-water pressure distribution was close to the hydrostatic pressure distribution. The moisture content of the conventional subgrade was effectively reduced by approximately 18% by using a capillary barrier;
2. The settlement of the subgrade using a capillary barrier was uniform and small, and is only 1 cm. Compared with the conventional subgrade, the settlement was reduced by 94%. The safety factor of the subgrade using a capillary barrier was almost unchanged. Compared with the conventional subgrade, the safety factor increased by 15%;
3. In humid climates, it is feasible to use subgrades with a capillary barrier to reduce the deformation and stability problems caused by humidification.

6. Recommendations for Future Study

This was a preliminary study that merely focused on the feasibility of a capillary barrier for the subgrade. The parameters of soil were selected from the literature to study the feasibility. In the future, specific subgrade soils will be used to conduct experiments for more in-depth research. Furthermore, the capillary barrier was used as the cover layer for natural materials without manual treatments, which can effectively block the infiltrating rainwater. It can be applied in many areas including slope stability. It can prevent rainwater infiltration so as to improve the slope’s stability. However, it cannot be applied in humid
climates due to the fact of its poor water storage capacity. In the future, more studies should be carried out on improving its water storage capacity by using new materials with high water storage capacity and methods so as to be applies more in engineering.

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