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Research Article

Study on the Influence of Seepage Conditions with Different Rainfall Intensities on the Structural Evolution of Soil-Rock Mixture Filler

Yueyue Wang[1], **Xuesong Mao**[1], **Qian Wu**[1], **and Zeyu Dai**[2]

[1]*School of Highway, Chang'an University, Xi'an, Shannxi 710064, China*
[2]*Taiyuan Institute, China Railway Engineering Design and Consulting Group Co., Ltd, Taiyuan, Shanxi 030000, China*

Correspondence should be addressed to Xuesong Mao; xuesongmao@chd.edu.cn

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The rainfall conditions cause seepage in the soil-rock mixture (SRM) filler subgrade, leading to the loss of fine particles and the change of soil structure, which eventually leads to large uneven deformation or instability of the subgrade. The particle loss test device was applied to conduct the seepage test of SRM filler, monitor the change process of permeable quality, fine particle loss and sedimentation of filler under different rainfall conditions, and analyze the evolution process of soil structure and sedimentation characteristics. The result shows that the rainfall intensity affects the permeability of the filler, and then accelerates the loss of fine particles under water migration. With the condition of the same rainfall duration, the hourly water permeability increased firstly and then gradually stabilized with the rainfall duration. The total water permeability mass, fine particle loss, and real-time sedimentation increased with the rainfall intensity. With the same rainfall condition, the maximum hourly water permeability under short-term heavy rainfall condition is about three times that under heavy rainfall condition, which is more serious for the internal erosion of SRM filler. The total water permeability mass, fine particle loss, and real-time sedimentation increased with the rainfall intensity. The stages of skeleton remodeling and relative stability are the most serious stages of filler skeleton structure damage. The sedimentation deformation of filler has hysteresis, resulting in the occurrence of sedimentation much later than the loss of fine particles and skeleton deformation. After the rainfall stops, with the loss of fine particles and water dissipation, the filler will occur secondary sedimentation, resulting in an increase in the final sedimentation as the rainfall intensity increases, making it possible for subsidence damage of the roadbed to occur both during and after the rainfall. Extreme rainfall conditions (short-term heavy rainfall) have the most obvious effect on the structural damage of the subgrade.

1. Introduction

In the process of road construction in mountain land, soil-rock mixture (SRM) filler is widely used in embankment filling. Studies have shown that rainfall is the key to induce catastrophic changes in SRM filler [1, 2], especially in recent years when extreme weather and climate anomalies are frequent and significant. The frequency and intensity of heavy precipitation and the total amount of precipitation show an increasing trend over an increasing number of areas in China [3, 4], and the frequency and intensity of future extreme weather events will become the "new normal". Of these, 45% of China's road operational safety problems are caused by water damage. These diseases are closely related to the water infiltration conditions, and the changes in the structural and mechanical properties of the filler caused by them. Raindrop impact (RI) play an important role in slope erosion processes [5], on this basis, the infiltration of water will not only increase the self-gravity of subgrade soil, but also take away the fine particles in the SRM filler [6, 7], which changes the original gradation structure and makes the filler skeleton void, thus affecting its mechanical properties. Hence, the seepage condition under the influence of rainfall has an important influence on the stability and bearing capacity of SRM filling subgrade.

To study the infiltration phenomenon of soil triggered by rainfall conditions and the resulting deformation and mechanical property laws, lots of research was investigated by many scholars. A part of scholars proposed that the stone content [8–10] and water content [11–14] have important effects on the mechanical properties of the SRM filler under rainfall conditions. Li et al. [15, 16] studied the influence of moisture content and dry density on the permeability coefficient of wide graded gravel soil by triaxial permeability test. Liu et al. [17] obtained the "jumping" phenomenon of shear stress, volumetric strain characteristics, and shear strength variation of SRM filler under different moisture content by large direct shear test. Tang et al. [18] used the direct shear test at the freeze-thaw interface of SRM, and found the effect law of water content and stone content on the change of shear strength at the freeze-thaw interface of SRM. Gu and Huang [19] explored the relationship between water content and shear stress-shear displacement curves of SRM in a landslide area of China. Kim et al. [20] studied the effects of water content on unsaturated soil slope stability under rainfall conditions, and concluded the hysteresis affect the mechanical properties. The above research results all reflect that moisture and boulders have certain quantitative and qualitative relationships on the seepage characteristics of SRM. However, this relationship is based on the loss of fine particles [6, 7], and the dynamic evolution process of fine particles has been further explored rarely.

Some scholars have also conducted some studies on the mechanism of rainfall-induced slope instability. He et al. [21] conducted a study on the deformation properties of carbonaceous shale as embankment filler under rainfall conditions, revealing and the evolution of slope stability under seepage. On the basis of considering seepage and fluid-solid coupling, Nguyen and Likitlersuang [22] studied the influence mechanism of shear strength and hydraulic parameters on slope stability during rainfall infiltration. Han et al. [23] analyzed the influence of rainfall intensity on the deformation and instability of loose deposits by using an indoor large-scale model platform, and explored the change process of volumetric water content during rainfall infiltration. Zuo et al. [24] studied the seepage, deformation, and failure process of different gradation loose accumulation landslide under rainfall conditions. Rui and Wang [2] and Du and Ni [25] used finite element theory to investigate the effects of rainfall intensity and rainfall duration on the seepage field of residual soil slopes under rainfall infiltration. Most of the above studies have focused on soil water movement parameters (internal factors) and rainfall intensity (external factors) leading to soil mechanics and deformation damage mechanisms. Nonetheless, studies on the changes of filler skeleton caused by water transport, and the key nodes leading to the deformation damage of roadbed have not been conducted systematically.

Based on the above research, this paper applied the self-developed particle loss test device for SRM filler, simulating different rainfall conditions. Under different rainfall intensities, it conducted particle loss tests for SRM filler, which dynamically monitored the changes of SRM loss and sedimentation, and analyzed the permeability characteristics of filler and the loss law of fine materials. On this basis, combined with the development process of sedimentation deformation, the law of sedimentation development caused by the fabric evolution of SRM filler under different seepage is discussed. The research results of this paper will help to understand the structural evolution mechanism of SRM filler subgrade under the action of seepage, and provide reference for the design, construction, and disease prevention of this subgrade.

2. Materials and Methods

2.1. Materials. The particle size range of SRM filler used in this test material is 0.075~60 mm. The stone content of the filler is 74.5%, among them, $P_{<5}$ = 25.5% ($P_{<5}$ is the particle size content less than 5 mm). The uniformity coefficient C_u is 26, and coefficient of curvature C_c is 2.09. The optimum moisture content is 4.58% and the maximum dry density is 2.27 g/cm^3. The boundary point between coarse particles and fine particles is 5 mm [26, 27]. The "stone" with particle size greater than 5 mm in the filler forms a soil skeleton by nesting and stacking, which is difficult to be lost by water dragging. The "soil" with particles less than 5 mm is filled between the pores of the skeleton, and this part is more likely to be lost under seepage, so the fine particles mentioned in the text refer to the particles with a particle size of less than 5 mm.

2.2. Test Apparatus. During the operation of the road, rainwater is mainly infiltrated into the embankment from the side slopes and the roadside surface, and the infiltration of water makes the fine particles lost together with it. To analyze the loss of fine particles, the self-developed test device was used to test the particle loss of SRM filler. The device contains rainfall system, bearing cylinder, sedimentation monitoring system, and a particle collector. The test device is shown in Figure 1. The rainfall system provides a stable and controllable seepage condition for the soil column model, which is mainly composed of water tank, water level controller, valve, water pipe, glass rotor flowmeter, connector, and porous water box. Among them, the flowmeter (Figure 2(a)) is LZB-3WBF type, and its specifications are liquid type 1-10 ml/min and 6-60 ml/min, which can accurately monitor and adjust the intensity of the test rainfall. The porous water box is lined with 40 mm thickness of clean fine sand (Figure 2(b)), which composition is black quartz sand, and the function is to disperse the water flow and avoid the concentrated water flow to scour the soil column. The bearing cylinder is made of Plexiglass, with a height of 300 mm, an outer diameter of 420 mm, an inner diameter of 400 mm and a thickness of 10 mm. There are 5 mm holes evenly set at the bottom of the cylinder to facilitate the loss of water and fine particles during the test. The composition of the sedimentation monitoring system are three dial indicators which fixed on the top surface of the model (Figures 2(c) and 2(d)). A particle collector is used to collect the mud-water mixture that seeps out during the test.

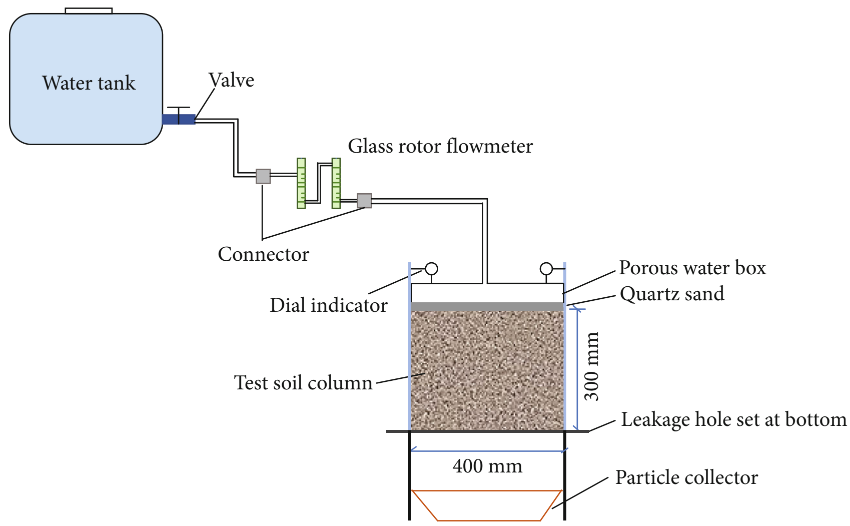

Figure 1: Particle loss test device.

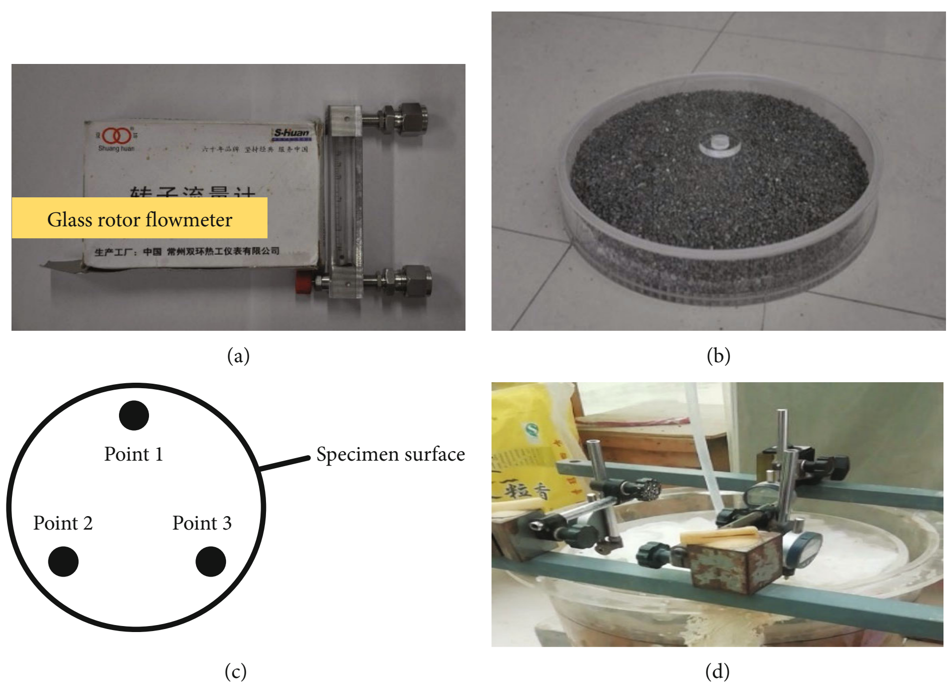

Figure 2: Components of test equipment: (a) LZB-3WBF type glass rotor flowmeter; (b) porous water box with quartz sand; (c) sedimentation measuring point; (d) actual layout of the dial indicator.

2.3. Methods. A water outlet hole is set 2 cm above the surface of the filler, so that the water immersion conditions for this test is 2 cm head (Figure 3), and the head remains constant during the test. Based on the classification of rainfall levels by the China Meteorological Administration, to investigate the seepage characteristics of embankment filler under different rainfall conditions, this paper mainly considers two scenarios: the same rainfall duration but different rainfall intensity (I, II) and the same rainfall amount but different rainfall intensity (II, III). A comparative test was conducted on groups I and II under the same rainfall duration (12 h), to analyze the mechanism of moderate rain and rainstorm conditions on the particle loss of SRM filler. The comparison test of groups II and III were carried out to analyze the influence of rainstorm and short-term heavy rainfall on the evolution of filler structure under the same rainfall amount (70 mm). The specific rainfall scheme is shown in Table 1. The filler samples under different rainfall conditions were filled in two layers at the optimum moisture content, one layer per 15 cm, and the compactness was 94%.

The particle loss test mainly monitored the permeable quality, the loss of fines components, and the sedimentation of the top surface of the specimen in real time. Through the separation of the collected slurry mixture, the permeable

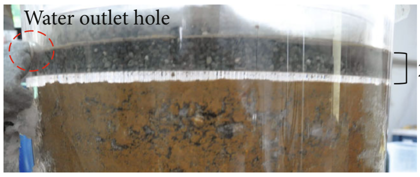

Figure 3: Maintain 2 cm of water head on the surface of the specimen.

quality and fine particle loss were obtained, so as to analyze the influence of rainfall conditions on the filler particles and their structures under seepage. By monitoring the percentage reading on the top surface of the model, the real-time sedimentation and the final sedimentation were obtained, which reflected the deformation of the filler aggregate caused by the loss of fine particles. After the test, the filler was divided into two layers for sampling. The variation of particle size distribution of the filler was tested by screening test to indirectly reflect the deformation mechanism of the filler structure.

3. Results and Discussion

3.1. Permeability Characteristics of SRM Filler. Changes in rainfall intensity alter the permeability of the filler, and can change the internal structure of the filler. Figure 4 shows the curves of per hour permeable quality under different rainfall intensities. Under the same rainfall duration (Figure 4(a)), the permeable quality of each sample increased rapidly at first and then slowly with the rainfall duration. The total water permeability mass increased significantly with the increase of rainfall intensity (Figure 5). When the filler water content reaches saturation, the infiltration water continued to leak out from the bottom of the soil sample and entered the "leakage stage". The hourly exudation quality of the sample in this stage was approximately equal to the infiltration quality (with a small variation). The slope of the curve shows an increasing trend, indicating that with the infiltration and migration of rainwater in the filler, the pore channel between particles gradually became interpenetrated and wider, resulting in the enhancement of the filler permeability. Therefore, the higher the rainfall intensity, the faster the filler can reach the "leakage stage".

Figure 4(b) and Figure 5 point out that the total water permeability mass was relatively large under the condition of short-term heavy rainfall, and the maximum hourly water permeability under this condition was about three times that under the condition of heavy rainfall. It indicated that the filler permeability was enhanced, and the internal erosion of the SRM filler was more serious under extreme rainfall condition (short-term heavy rainfall).

3.2. Analysis of Fine Particle Loss Characteristics

3.2.1. Effect of Rainfall Intensity on Filler Particle Loss. The mud-water mixture collected in the experiment was processed to obtain fine particles with particle size less than 5 mm at different times. Time-varying curves of particle loss from SRM filler under different rainfall conditions (Figure 6) and the images of mud-water mixture seeped from SRM filler under rainstorm conditions (Figure 7) were further obtained. The time-varying process of loss mass of solid particles can be divided into three stages: (i) The process before the fine particle loss reaches the maximum in the seepage process is called the rapid loss of fine particles stage, where it is easy to make part of the smaller particle size loss in the filler under the action of seepage. It shows that the loss quality of fine particles increased, and the water seepage was turbid (Figure 7(a)). (ii) The second stage is the skeleton remodeling stage. As the test proceed, the fine particles in the percolation channel are gradually carried away, so that the skeleton formed by the large particles is exposed and a new erosion surface is formed. The skeleton structure is restructured and adjusted under the action of seepage. With the continuous small loss of fine particles, the lost water is gradually clear (Figure 7(b)). (iii) When the loss of fine particles is close to 0, the third stage is entered - the relative stability stage. After the erosion of the water flow, the filler have a relatively stable structure, and the water flow continue to destroy the new erosion surface. The relative stability state is destroyed again, then the granular material is flushed out (Figure 7(c)), which made the composition of the filler change, and the curve shows a local increase in the mass of particle loss.

(1) Particles Loss under Different Rainfall Intensities with the Same Rainfall Duration. It can be seen from Figures 6(a) and 6(b) that the mass of fine particles lost per unit time increased and the shorter the time of the first stage (rapid loss of fine particles stage) with the rainfall intensity under the same rainfall duration. The ratio of the loss fine particle mass to the fine particle component mass in the initial filler was defined as the fine particle loss rate. Combined with Figure 8(a), with the increase of rainfall intensity, the total mass of particle loss and the fine particle loss rate enlarged, and the fine particle loss rate under heavy rainfall condition was 1.39 times higher than under medium rainfall condition. The larger the permeable quality per hour, the stronger the ability of carrying fine particles between pores, and the more obvious the loss of fine particles, which made it easier for skeleton remodeling and affected the stability of the filler structure.

(2) Particles Loss under Different Rainfall Intensities with the Same Rainfall Amount. Similarly, it can be shown from Figures 6(b) and 6(c) and Figure 8(b) that the higher the rainfall intensity, the steeper the slope of the curve, and the greater the mass per hour lost, the total mass and the fine particle loss rate for the same rainfall. The particle loss rate under short-term intense rainfall conditions is 1.68 times higher than under heavy rainfall conditions. Due to the high intensity of short-term heavy rainfall and serious erosion of the filler, a large number of fine particles were lost with the rapid transport of water at the beginning of the test. The rapid loss of fine particles stage occurred quickly, resulting in that stage not being monitored in Figure 6(c). And the time experienced by the particle loss process was much

Table 1: Rainfall scheme.

Number	Rainfall pattern	Rainfall amount/mm	Rainfall intensity/(mm/h)	Rainfall duration/h
I	Moderate rain	15	1.25	12
II	Rainstorm	70	5.83	12
III	Short-term heavy rainfall	70	20	3.5

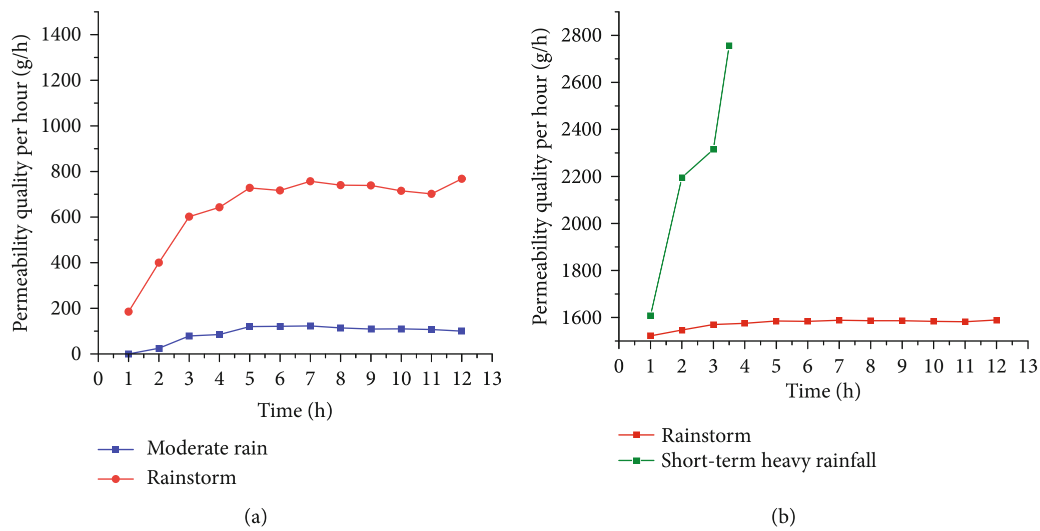

Figure 4: Permeability quality per hour of samples under different rainfall conditions: (a) permeability quality per hour under different rainfall intensities with the same rainfall duration; (b) permeability quality per hour under different rainfall intensities with the same rainfall amount.

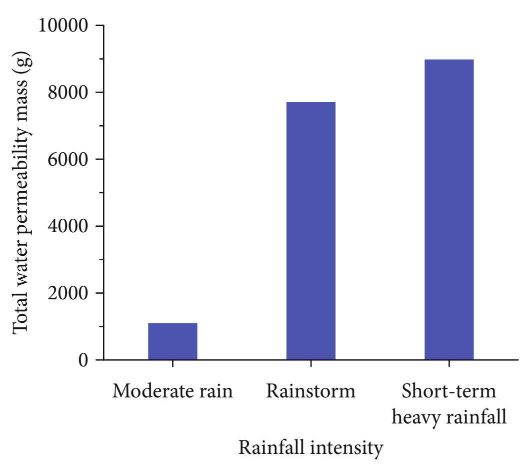

Figure 5: Total water permeability mass under different schemes.

earlier. In addition, the large loss of fine particles caused larger pores between the skeletons and smoother transport channels, resulting in a greater total water permeability mass under the short-term heavy rainfall condition than under the rainstorm condition, further proving that the stronger the permeability, the looser the filler skeleton; ultimately, this resulted in severe damage to the subgrade.

3.2.2. Vertical Migration Rule of Fine Particles. Figure 9 shows the comparison of the particle size composition of the upper and lower filler of the samples under different rainfall intensities. Under the same rainfall duration, the percentage of grain groups 0 ~ 5 mm and 10~20 mm in the upper layer of the filler under moderate rainfall and rainstorm intensity scouring was less than that in the lower layer (Figures 9(a) and 9(b)), but the variation of particle content under rainstorm condition was greater than that under moderate rainfall condition. It indicated that under the slower water migration rate, with the rainfall intensity, the downward migration of the fine-grained components increased.

With the same total rainfall, the percent content of fine particles in the upper layer of grain group 0 ~ 2 mm was smaller than that in the lower layer under the short-time intense rainfall condition (Figures 9(b) and 9(c)), and the change was significantly larger than that under the heavy rainfall condition. It indicated that with the rainfall intensity, the rainwater infiltration rate was faster, and the loss of fine particle components was more serious, resulting in larger changes in the filler gradation composition.

The above analysis showed that the law of fine particle loss of filler had a significant impact on the upper and lower levels of SRM filler. On this basis, with the rainfall intensity, the impact on the stability and structural integrity of the subgrade was stronger and faster. The migration of particle components made the internal structure of local roadbed loose, and gradation uniformity change. This phenomenon can further lead to skeleton structure damage, and even

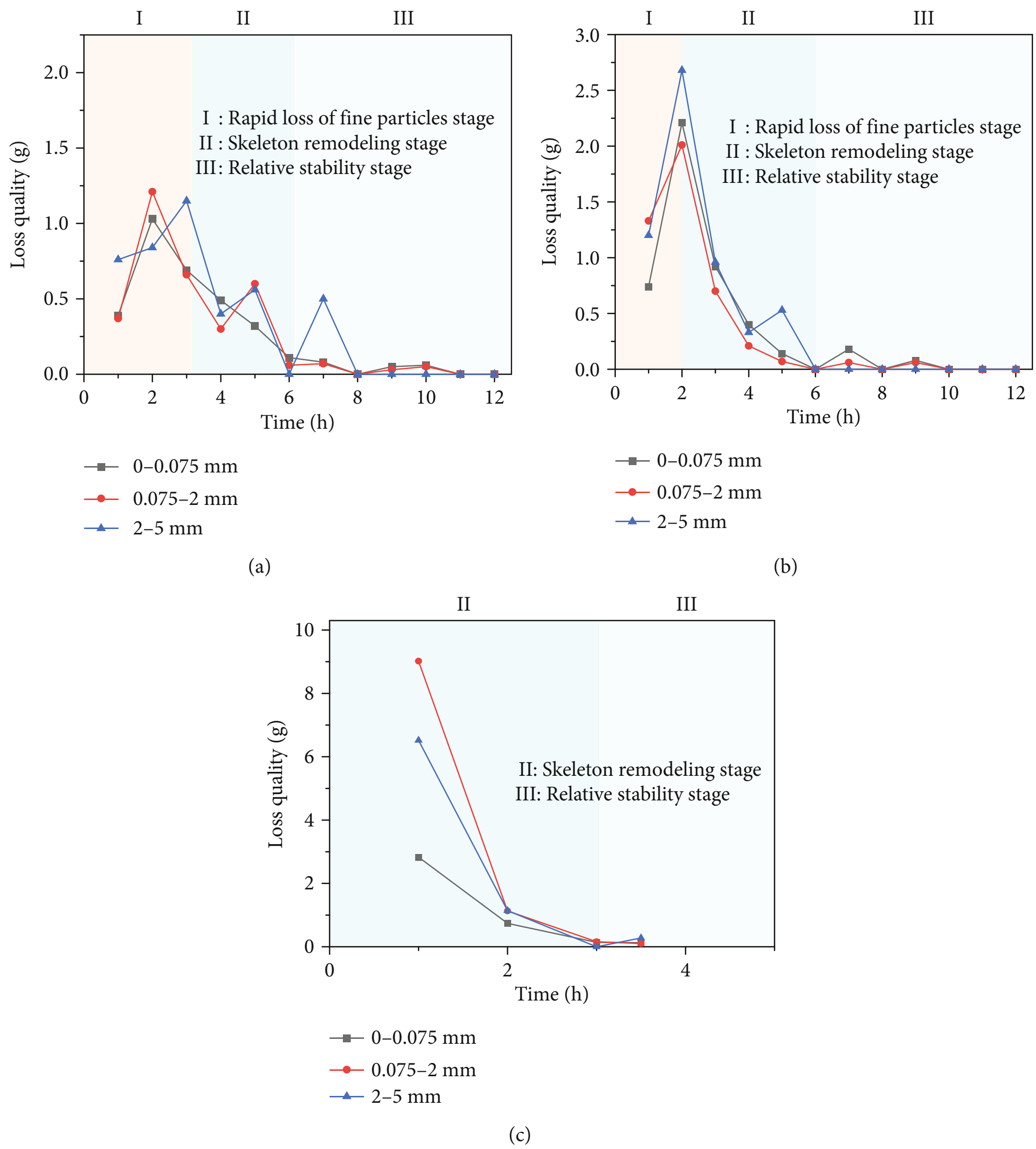

FIGURE 6: Time-varying curve of particle loss from SRM filler under different rainfall conditions: (a) moderate rain condition; (b) rainstorm condition; (c) short-term heavy rainfall condition.

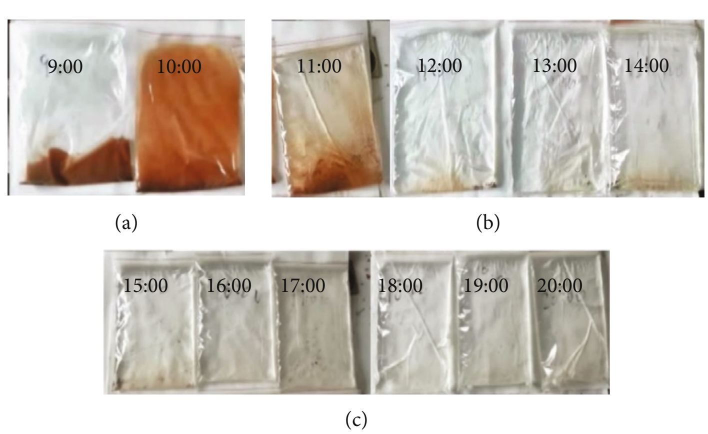

FIGURE 7: Image of slurry mixture exuded by the filler under heavy rain: (a) rapid loss of fine particles stage; (b) skeleton remodeling stage; (c) relative stability stage.

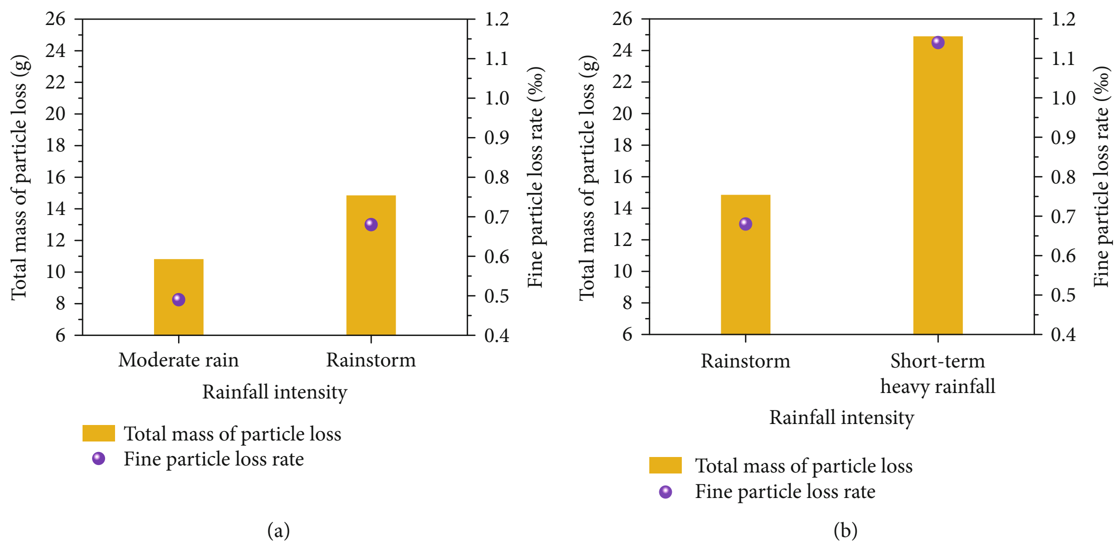

Figure 8: Variation of fine particle loss mass in filler under different rainfall conditions: (a) fine particle loss mass under different rainfall intensities with the same rainfall duration; (b) fine particle loss mass under different rainfall intensities with the same rainfall amount.

directly form "cavitation" inside the subgrade (Figure 10), which eventually led to subgrade damage under the comprehensive influence of various functions.

3.3. Analysis of Filler Sedimentation Characteristics

3.3.1. Real-Time Sedimentation Characteristics

(1) Real-Time Sedimentation Characteristics under Different Rainfall Intensities with the Same Rainfall Duration. The sedimentation characteristics of the filler reflect well the degree of damage to the skeletal structure of the filler by the rainfall intensity. Under the same rainfall duration, the real-time sedimentation of the filler under rainstorm condition was greater than that under moderate rainfall condition (Figure 11(a)). In the stages of rapid loss of fine particles and skeleton remodeling, the slope of the curve was smaller in the early stage and then increased with the rainfall duration. In the relative stability stage, the curve gradient increased significantly.

Combined with the analysis of the loss process of fine particles, a large number of fine particles were lost, and the skeleton structure was relatively complete in the rapid loss of fine particles stage, where the sedimentation of the filler was less. In the skeleton remodeling stage, the fine particles produced continuous vertical migration under wetting and impact dragging. The large particle block rock was soaked by water, the internal friction angle decreased, and the large particles were embedded and squeezed each other, producing an obvious relative displacement, and resulting in a certain sedimentation deformation of the filler. In the relative stability stage, the loss of fine particles was almost zero, while the sedimentation volume continued to increase and slope of the curve rose sharply. From the above change law, it can be seen that the occurrence of sedimentation lagged far behind the loss of fine particles and skeleton deformation, indicating that the sedimentation deformation of the filler had a lag under the influence of rainfall. The skeleton remodeling and relative stability stages were the most serious stages of the filler skeleton structure damage.

(2) Real-Time Sedimentation Characteristics under Different Rainfall Intensities with the Same Rainfall Amount. It can be seen from Figure 11(b) that under the same rainfall condition, with the increase of rainfall intensity, the real-time sedimentation of filler showed a significant upward trend. Especially in the extreme rainfall condition (short-term heavy rainfall), the fine particles in the skeleton remodeling stage (1 ~ 3 h) were strongly dragged by the impact of water, which lost more mass and grew faster in sedimentation, indicating that the initial sedimentation deformation of the filler was almost not affected by hysteresis. In the relative stability stage (3 ~ 3.5 h), the damage of the filler skeleton led to the larger sedimentation, and the sedimentation deformation had the tendency to develop continuously. At the time of 3.5 h, the sedimentation of short-term heavy rainfall (0.053 mm) was 10 times of the rainstorm condition (0.005 mm), indicating that the rapid infiltration of water would seriously destroy the filler skeleton structure in a short period of time. The large uneven sedimentation of the filler would reduce the service life of the road and seriously endanger road traffic safety.

3.3.2. Characterization of the Final Sedimentation. Continued to monitor the sedimentation of the specimen after the rainfall stopped. When the change value of sedimentation was less than 0.01 mm, it was considered that the specimen had reached a stable state at this time, and the average value of the three displacement meters was taken as the final sedimentation. Figure 12 reflects the changes of the final sedimentation under different rainfall conditions. Analysis showed that the sedimentation values of the filler under different rainfall conditions had increased after the rainfall had

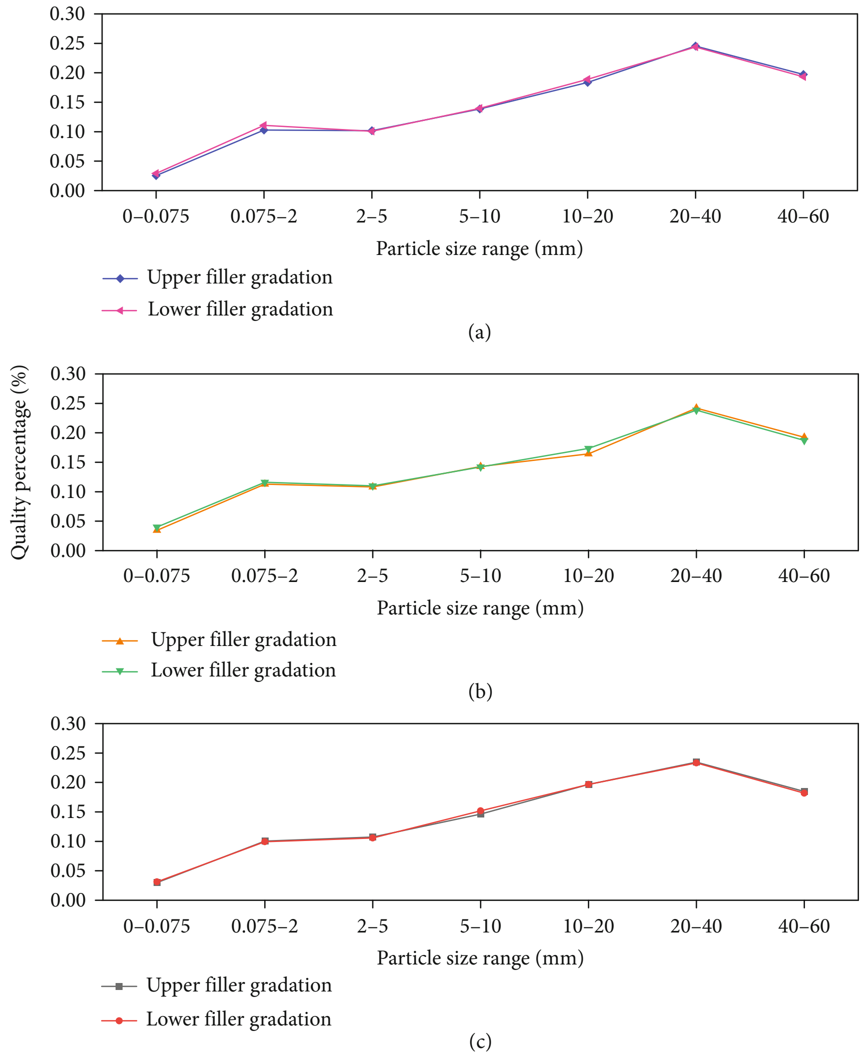

Figure 9: Comparison of particle size composition between upper and lower layers of filler under different rainfall conditions: (a) moderate rain condition; (b) rainstorm condition; (c) short-term heavy rainfall condition.

Figure 10: "Cavitation" in filler after water scouring.

stopped, indicating that the filler would also have secondary sedimentation. Obviously, the late sedimentation variation of the filler was greater under extreme rainfall condition (short-term heavy rainfall). It can be seen from the above analysis that under the erosion of short-term heavy rainfall, the total water permeability mass and the loss of fine particles were the largest, and the skeleton structure inside the filler had been severely damaged, so the sedimentation deformation would continue to develop after the rainfall. Under the excitation of rainfall, the evolution of SRM filler structure would affect the final sedimentation deformation, which made it possible to cause subsidence damage of the roadbed during and after rainfall.

3.4. Discussion. First of all, this section focuses on the analysis of the differences between this paper and other scholars, including the following three points: (1) With regard to the seepage characteristics of SRM (soil-rock mixture), relevant studies have shown that the impact force of raindrops is an important factor leading to the movement of soil particles [28]. On this basis, rainwater and clay minerals will rapidly produce strong hydration and electrostatic effects, resulting in the disintegration of particles into finer particles, the above external and internal factors together affect the erosive

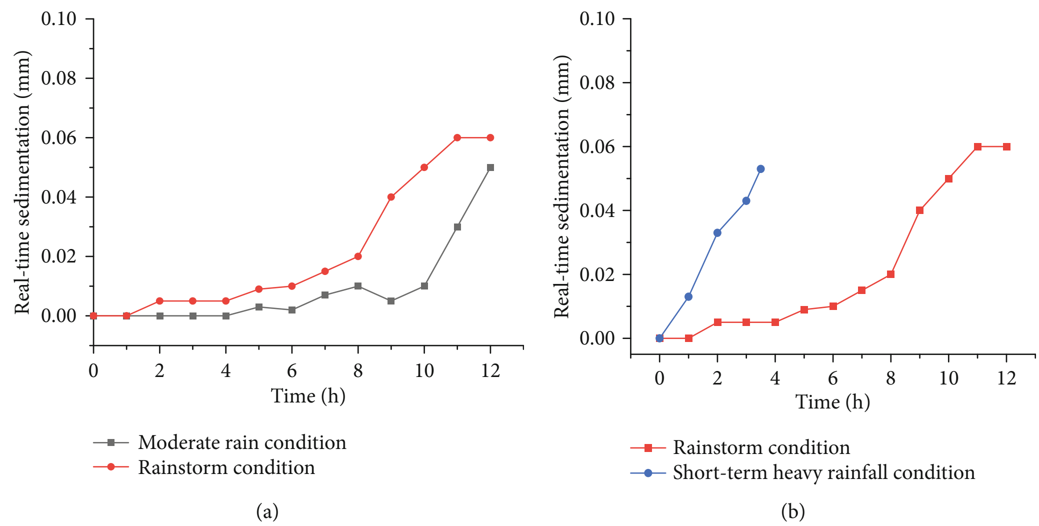

FIGURE 11: Real-time sedimentation of filler under different rainfall conditions: (a) real-time sedimentation under different rainfall intensities with the same rainfall duration; (b) real-time sedimentation under different rainfall intensities with the same rainfall amount.

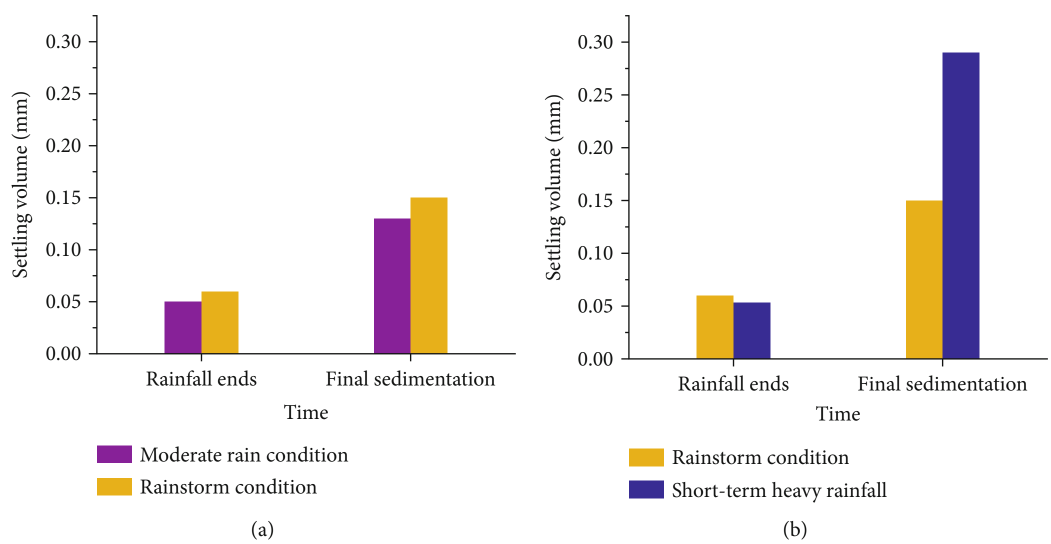

FIGURE 12: Variation of final sedimentation of fill under different rainfall conditions: (a) final sedimentation under different rainfall intensities with the same rainfall duration; (b) final sedimentation under different rainfall intensities with the same rainfall amount.

effect of seepage on the soil. In addition, some scholars have also studied the mechanism of the influence of rainfall intensity on the seepage characteristics of SRM. Through the above studies, it is only obtained that under the erosion of rainfall, the fine particles in the roadbed or slope will be transported with it, but the specific process and dynamic changes of the transport are rarely explored. Therefore, this paper starts from studying the process of fine particle loss, and defines three stages of particle loss under different rainfall intensities, which are: rapid loss of fine particles, skeleton remodeling, and relative stability stage; and explores the vertical migration law of fine particles under different conditions. (2) In this paper, the influence mechanisms of different rainfall amounts and rainfall intensities on SRM filler roadbeds are studied by permeability quality, fine particle loss quality and settlement parameters, respectively, with richer and more comprehensive research objects. In contrast, most current studies focus only on the analysis of individual study objects (stone content, clast shape, particle loss, etc.). (3) Some scholars only focus on the seepage action leading to settlement and collapse of SRM subgrade, and study the mechanism [23, 29]. In this paper, based on the analysis of the settlement of filler under different rainfall intensities in Section 3.3, it is found that the settlement deformation of SRM filler has hysteresis. Combined with the concept of three stages of particle loss, it is further proposed that the skeleton remodeling and relative stability stages are the most serious stages of filler skeleton structure destruction. It also points out that the secondary settlement is more destructive to SRM filler, and the finding has an important warning effect on the water damage disaster prevention and control of SRM filler subgrade.

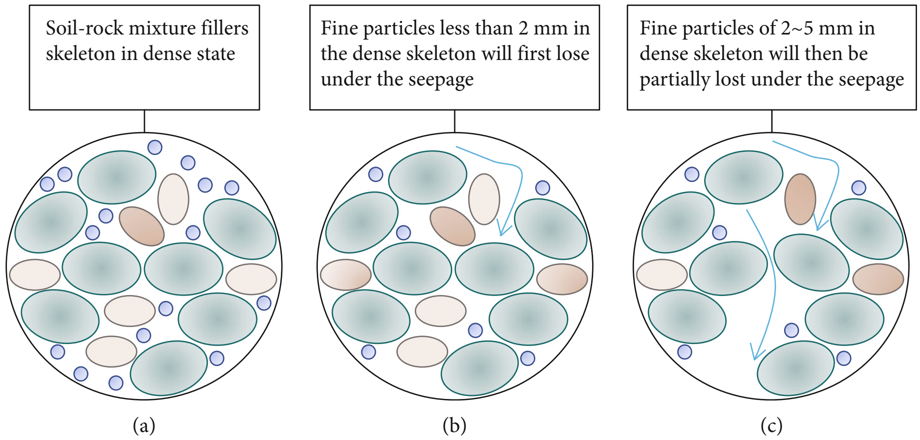

Figure 13: Schematic diagram of the skeleton structure of a binary grain mixture: (a) Status 1; (b) Status 2; (c) Status 3.

SRM filler is a very complex discontinuous medium material, which is a mixture of stones with certain size, soil as a filling component, and pore space [30]. Well-graded SRM filler has a dense and stable nature, which takes coarse particles as the skeleton, and fine particles fill in the pores between coarse particles (As shown in Figure 13(a)), and mainly the coarse particles assume the role of skeleton. The denser the particle group as the skeleton, the greater the strength and deformation modulus of the SRM, and it can reduce the impact energy of rainwater to a greater extent. Under the action of rainfall, the particle size distribution of the SRM is wider, the pore space between coarse particles is larger, the pore water pressure of SRM material dissipates faster, and the surface water will seep down more quickly. Porosity and pore structure characteristics are the main reasons affecting the permeability of SRM filler, but the influence of fine particle migration on the pore structure of SRM is ignored.

Generally speaking, as the rainfall intensity and rainfall duration increase, the volume of surface water has enlarged, and the rate of infiltration to the interior of the embankment is faster, leading the water flow between the filler is more unobstructed. Meanwhile, the seepage process of water in the SRM will firstly take away the fine particles less than 2 mm (Figure 13(b)). When the channel opens, 2 ~ 5 mm particles will gradually lose (Figure 13(c)), and then some larger particles may also lose, resulting in a change in the fine grain content of the SRM, the degree of skeletal compactness is reduced. When the fine particles that share the role of skeleton with the coarse particles are carried away under the action of seepage, the strength of the skeleton structure of the filler is reduced [31, 32], and the mechanical properties of the skeleton structure will change and be damaged under the action of external load or self-weight. Therefore, the variation of permeability, fine particle loss, and real-time sedimentation of SRM filler with rainfall intensity are essentially caused by the migration and loss of fine particles. In addition, after the rainfall stops, due to the weak water holding capacity of SRM filler, the pore water pressure in the filler skeleton dissipates over time, resulting in the weak skeleton structure strength at large pores. Under the action of load and self-weight, the filler skeleton will undergo secondary consolidation, and the sedimentation will continue to increase.

In further research, it is proposed to reveal the evolution process of mechanical properties of SRM filler from the perspective of seepage flow-particle, loss-structure, and adjustment-strength change, to deepen the knowledge of mechanical properties of such filler, and to provide theoretical support for engineering design and construction.

4. Conclusions

(1) Rainfall intensity affects the permeability of filler, and then accelerates the loss of fine particles under water migration. The hourly water permeability of the filler increased rapidly at first and then gradually slowed down with the rainfall duration. Under the same rainfall duration and rainfall conditions, the permeable quality and fine particle loss increased with increasing rainfall intensity, respectively. The greater the permeability, the wider the pore space of the filler will be penetrated, the looser the filler skeleton, and the remodeling and destruction of the skeleton lead to the evolution of the filler structure. With the migration of water, the percentage contents of 0 ~ 5 mm and 10 ~ 20 mm particles in the upper layer of the filler were smaller than those in the lower layer, and the variation amplitude increased with the increase of rainfall intensity

(2) The sedimentation characteristics of the filler well reflect the damage degree of rainfall intensity on the filler skeleton structure. Under the same rainfall duration and rainfall conditions, respectively, the real-time sedimentation increases with rainfall intensity. The stages of skeleton remodeling and relative stability are the most serious stages of filler skeleton structure damage. The occurrence of sedimentation lags is far behind the skeleton deformation, indicating that the sedimentation deformation of the filler has a lag under the influence of rainfall

(3) Under the condition of short-term heavy rainfall, the permeability of SRM filler is the largest, and the loss of fine particles and the sedimentation are

the highest, indicating that the filler skeleton is the most seriously damaged. Extreme rainfall conditions (short-term heavy rainfall) have the most obvious damage to the subgrade structure

(4) Under the condition of lag of sedimentation deformation, a large number of particles loss and the dissipation of water between pores lead to secondary sedimentation of the filler, which makes the final sedimentation value increase with the increase of rainfall intensity, and makes it possible to cause subsidence damage of the subgrade during and after rainfall. Therefore, it is necessary to continuously monitor the overall stability and possible disasters of the subgrade after rainfall

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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