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Study on Siltation Resistance of Composite Inclined Drainage Pipe

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ABSTRACT: In order to study the anti-silting mechanism of inclined drainage pipes on slopes, the occurrence and development of silting of composite drainage pipes in strata with different permeability and different particle gradation are compared through indoor model tests. Results show that when the permeability coefficient is 7.0×10^{-4} cm/s, the pore size of the screen outside the drain pipe affects the drainage capacity. The larger the mesh number of the outside filter material, the smaller the water leakage of the drain pipe, and the drainage capacity with 12 meshes is only 75% of that with 10 meshes. When the permeability coefficient is 1.0×10^{-5} cm/s, the inclusions with different pore diameters in the inner and outer pipes have great influence on the displacement, and the difference of displacement can reach 40%. Under the same structural conditions, the smaller the permeability coefficient of the soil layer, the larger the water seepage of the drainage pipe.

KEYWORDS: Slope; Inclined drainage pipe; Anti-silting

I. INTRODUCTION

At present, the method commonly adopted for deep slope drainage in mountainous roads, both domestically and internationally, involves the use of upward-sloping drainage holes with a PVC plastic pipe wrapped in a geotextile structure. While this approach initially proves to be effective in draining water, its drainage function gradually deteriorates and may even fail during operation. Consequently, the long-term effectiveness of slope treatment projects becomes compromised, posing risks to the stability of the infrastructure and traffic safety. Research on the long-term performance of upward-sloping drainage holes in roads, both domestically and internationally, is relatively scarce, whereas there is a greater focus on studying the blockage of similar drainage facilities (such as pressure relief wells) in water conservancy engineering.

Through a large amount of practical experience, it has been found that improving the drainage capacity and durability of upward-sloping drainage holes is not only important in terms of the design structure of the drainage holes, but also in the selection of drainage pipe materials, the filter pipe diameter of the drainage material, and the outer filter material. Based on this, this paper adopts a new type of composite replaceable upward-sloping drainage hole method, and conducts indoor experiments to study the clogging of new types of drainage holes on highway slopes, to explore their occurrence and development rules.

Paper is organized as follows. Section II provides an overview of the current research on slope drainage measures and drainage pipe clogging problems. Section III details the experimental parameters and design of the newly proposed double-layered structure drainage pipe model. Section IV analyzes the indoor model test structure of the new drainage pipe. Finally, Section V presents conclusion.

II. RELATED WORK

Groundwater is one of the most active and critical factors leading to slope instability [1]. Research found that for every 0.1H increase in groundwater table elevation (H being the slope height), the stability coefficient of the slope can decrease by up to 0.24 [2]. Therefore, there is a consensus in the engineering community that "nine out of ten slope failures are water-related" and that "treating water-related issues is a priority when dealing with slope instability".

Currently, the most commonly used method for draining groundwater from slopes is to install drainage holes. Compared to other slope drainage measures, the major drawback of the currently used drainage pipes is that they are prone to blockage. Research conducted by Zhang Luqing and others has found that after a certain period following the completion of engineering projects, drainage holes can effectively drain water and reduce water pressure. However, after some time in operation, the drainage pipes often get clogged with silt and lose their drainage functionality [3].

In fact, to address the issue of drainage pipes being prone to blockage and losing their drainage effectiveness, various measures have been taken. As early as the late 1980s, France started using the siphonic drainage method for highway slope drainage. Fuhongyuan et al. [4] invented a slope double-wall self-flow drainage pipe consisting of upper and lower fan-shaped drainage pipes. M. Kopecky et al. [5] suggested that horizontal inclined drainage is an effective measure to control landslides. Xie Jinghui [6] in dealing with the clogging issue of drainage pipes during operation, studied the clogging mechanism of flexible drainage pipes by taking into account factors such as hydraulic gradient, soil type, and the area of the drainage pipe wall using the gradient ratio test and the geotextiles gradient ratio criterion. Sun Hongyue et al. [7] introduced a negative-pressure drainage method for inclined slope drainage pipes. This method divides the pipe into two segments: an upper sealed section and a lower permeable section, with a siphonic drainage pipe passing through the sealed section and entering the bottom of the permeable section. By utilizing the hydraulic head difference, the siphonic drainage is naturally initiated, generating negative pressure to accelerate drainage and remove accumulated sediments within the hole. Huang Xin [8] studied the clogging mechanism and effect of flexible slope drainage pipes, revealing the variations in the seepage field and drainage effect of flexible permeable pipes under clogging effects. Currently, Hong Kong is also using a double-layered pipe drainage system in which only the upper half of the pipe cross-section is perforated for water infiltration, and only the inner pipe is covered with geotextile.

Regarding clogging issues in drainage pipes covered with outside material, as early as 1995, Cui Zhongxing, Wang Zhigang, and others found that geotextile clogging mainly depends on hydraulic conditions, the aperture distribution of the geotextile, and the particle size distribution of soil. Moreover, unidirectional water flow is more prone to cause clogging than water flow with repeated changes of direction [9]. In the following decades, many scholars conducted extensive research on geotextile clogging, and Zhu Jiangying improved the testing apparatus based on the existing gradient ratio (GR) test and conducted a series of clogging tests and clogging prevention studies [10]. Meng Jian [11] analyzed the types of drainage hole clogging through indoor experiments and studied the clogging mechanisms in karst regions. Wu Shunchuan [12] simulated drainage holes using the air unit method, determined the soil-water characteristic curve based on the Van Genuchten (VG) model, and conducted numerical simulation analysis using Geo-Studio software to explore the effects of drainage hole setting parameters on slope stability under rainfall infiltration conditions.

III. MODEL EXPERIMENTS

EXPERIMENTAL MODEL

The model box has dimensions of 1500mm (L) × 1500mm (W) × 1500mm (H). There are 4 holes of 20mm in diameter on the front face at appropriate positions. On the side face, there are 4 holes corresponding to a transparent thin hose. On the bottom plate of the model box, the back bottom, or other suitable positions, there are 2 holes. One hole corresponds to the drainage pipe on the front face and is used for emptying the water from the model box. The other hole corresponds to 4 transparent thin hoses and is used for observing the water level at low water level (Figure 1).



Fig. 1. Experimental Model Box

The drainage pipe adopts a double-layer structure. The outer layer pipe is made of corrugated blind pipe with an outer diameter of 8cm, while the inner layer pipe is made of PVC pipe with an outer diameter of 4cm. The PVC pipe is randomly drilled with holes (Figure 2). After preparing the inner and outer pipes, the inner pipe is inserted into the outer pipe, and both ends are securely fixed by stuffing geotextile.



Fig. 2. Experimental Drainage Pipe

Experiment on Soil Gradation

According to the experimental requirements, sand, fine sand, silt, and clay are selected and proportioned in a certain ratio as the experimental materials for simulating the stratum. The typical particle gradation of the permeability coefficient of different orders of magnitude used in the experiment can be seen in Figure 3 and Figure 4.

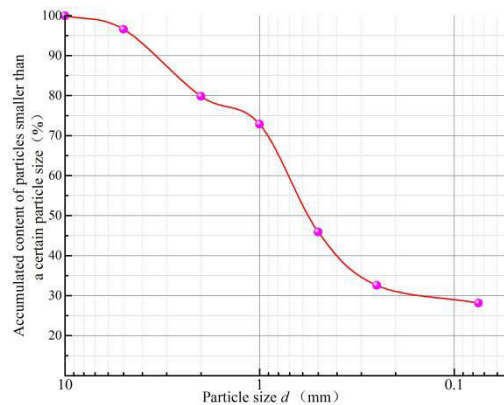
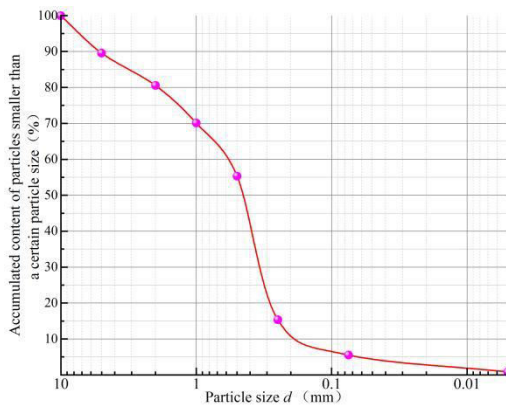


Fig. 3. Particle size distribution graph ($k=7.0 \times 10^{-4}$ cm/s) Fig. 4. Particle size distribution graph ($k=1.0 \times 10^{-5}$ cm/s)

Experimental plan

In order to compare the drainage and clogging conditions of different aperture screens as outer casing and different screens as inner casing, the experimental plan is shown in Table 1.

Table1. Experimental Plan

Group Number.	Permeability Coefficient k (cm/s)	Number of Pores (number)	Drainage Pipe Composition
B ₁	7.0×10^{-4}	2	B ₁₋₁ Outer Pipe ϕ 8cm Wrapped Screen for chaotic silk blind pipes (10 mesh) Inner Pipe ϕ 4cm Translation: Wrapped screen for



			PVC floral pipes (140 mesh)
			B ₁₋₂ Outer Pipe φ8cm Wrapped Screen for chaotic silk blind pipes (12 mesh) Inner Pipe φ 4cm Wrapped screen for PVC floral pipes (200 mesh)
B ₂	1.0×10 ⁻⁵	2	B ₂₋₁ Outer Pipe φ 8cm Wrapped Screen for chaotic silk blind pipes (10 mesh) Inner Pipe φ 4cm Translation: Wrapped screen for PVC floral pipes (140 mesh)
			B ₂₋₂ Outer Pipe φ8cm Wrapped Screen for chaotic silk blind pipes (12 mesh) Inner Pipe φ 4cm Wrapped screen for PVC floral pipes (200 mesh)
B ₃	1.0×10 ⁻⁵	2	B ₃₋₁ Outer Pipe φ 10cm Wrapped Screen for chaotic silk blind pipes (10 mesh) Inner Pipe φ 5cm Wrapped Screen for chaotic silk blind pipes (140 mesh)
			B ₃₋₂ Outer Pipe φ 10cm Wrapped Screen for chaotic silk blind pipes (18 mesh) Inner Pipe φ 8cm Wrapped Screen for chaotic silk blind pipes (200 mesh)

IV. EXPERIMENTAL RESULTS

A model permeability test was conducted on three different combinations of drainage holes listed in Table 1 to obtain the drainage time and clogging conditions of the new drainage holes. The drainage volume of the drainage pipe was counted every 5 minutes as a unit.

(1) Analysis of B₁ Test Results

The permeability coefficient of the sand used in the model test is 7.0×10^{-4} cm/s. The ratio of the pore sizes between the filter material of the outer pipe wrap screen and the filter material of the inner pipe wrap screen ranges from 14 to 17. The drainage time curve can be seen in Figure 5. The clogging conditions of the outer and inner drainage pipes after the experiment can be seen in Figure 6.

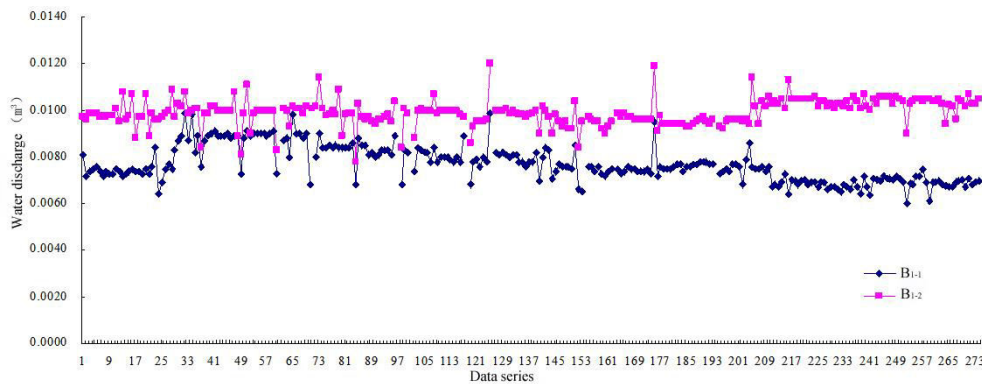


Fig. 5. B₁ Drainage time curve chart



Fig. 6. B₁ Drainage pipe after the end of the experiment

According to the test results, it can be concluded that the pore size of the filter material used in the outer pipe wrap screen affects the drainage volume of the drainage pipe under certain conditions of the soil layer. The larger the mesh size of the outer filter material, the smaller the drainage volume of the drainage pipe. In particular, the drainage volume of B₁₋₁ is only about 75% of B₁₋₂. After continuous long-term drainage, the drainage volume of B₁₋₁ (with smaller pore size) slightly decreases, indicating slight clogging. On the other hand, the drainage volume of B₁₋₂ hardly decreases, indicating very minor particle clogging. In the initial stage of drainage, the drainage volume of B₁₋₁ (with smaller pore size) exhibits an upward trend, with an increase of approximately 25%. This may be related to the directional movement of particles attached to the drainage accessories in the initial stage of drainage. After the drainage test, there is relatively little clogging material on both the inner and outer pipe wraps, possibly due to the lack of fine particles (clay particles) in the test materials.

(2) Analysis of B₂ Test Results

The permeability coefficient of the sand used in the model test is 1.0×10^{-5} cm/s. The ratio of the pore sizes between the filter material of the outer pipe wrap screen and the filter material of the inner pipe wrap screen ranges from 14 to 17. The drainage time curve can be seen in Figure 7. The clogging conditions of the drainage pipes after the experiment can be seen in Figures 8.

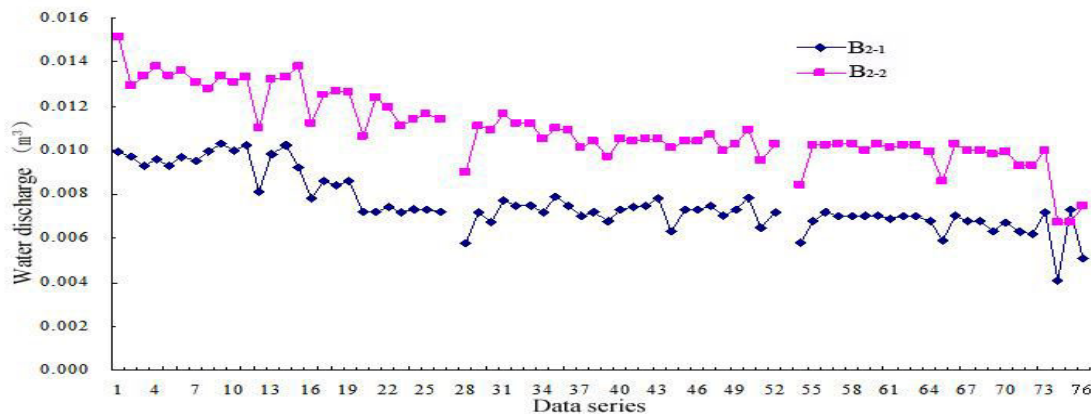


Fig. 7. B₂ Drainage time curve chart



Fig. 8. B₂₋₁ Drainage pipe after the end of the experiment (a) B₂₋₂ Drainage pipe after the end of the experiment (b)

According to the test results, it can be concluded that there is a significant difference in drainage volume between B₂₋₁ and B₂₋₂, reaching approximately 40%. This indicates that the pore sizes of the inner and outer pipe wraps have a significant influence on the drainage volume. Both of them have certain clogging conditions, but not severe. They are capable of discharging particles corresponding to the pore size of the filter material. Larger particles entering the pipe from the outer layer can be effectively filtered out by the inner pipe. This condition is consistent with the drainage hole structure in the B₁ test condition. The smaller the permeability coefficient of the soil layer, the slightly larger the seepage volume. This may be because fine particles are easily carried away by the flowing water.

(3) Analysis of B₃ Test Results

The permeability coefficient of the sand used in the model test is 1.0×10^{-5} cm/s. The ratio of the pore sizes between the filter material of the outer pipe wrap screen and the filter material of the inner pipe wrap screen ranges from 11 to 14. The drainage time curve can be seen in Figure 9. The clogging conditions of the drainage pipes after the experiment can be seen in Figures 10. According to the test results, it can be noted that there is a difference in drainage volume between B₃₋₁ and B₃₋₂, but the difference is not significant. B₃₋₁ experiences some clogging during the mid-phase of drainage but then recovers its original drainage capacity, while B₃₋₂ experiences clogging in the later stages and shows no signs of self-recovery. This indicates that external intervention is required to restore its original drainage capacity.

When the drainage volume is slightly larger, fine particles adhering to the random blind pipes can be easily washed away. Compared with the B₂ test condition, this condition has a slightly smaller drainage volume, suggesting that the drainage capacity of the random blind pipe's inner pipe is slightly inferior to that of the PVC inner pipe.

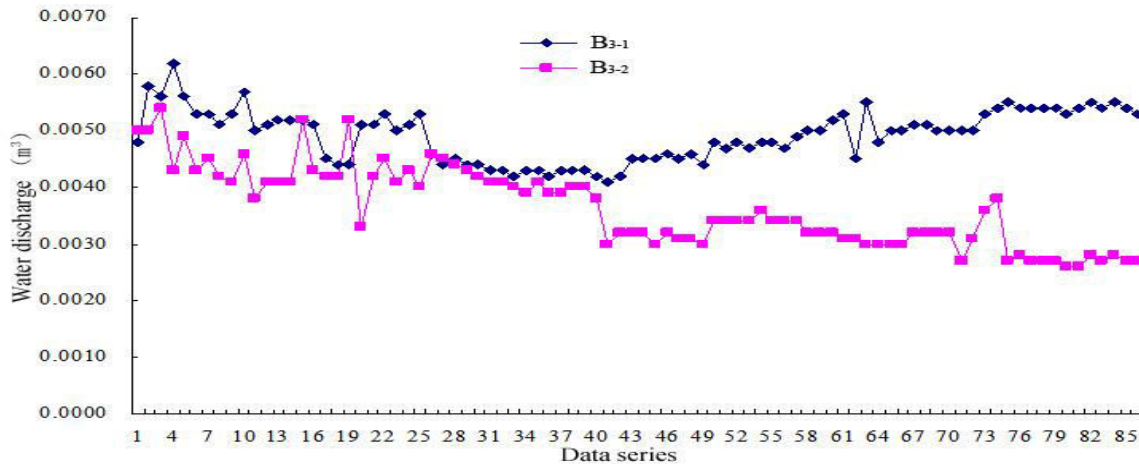


Fig. 9. B₃ Drainage time curve chart

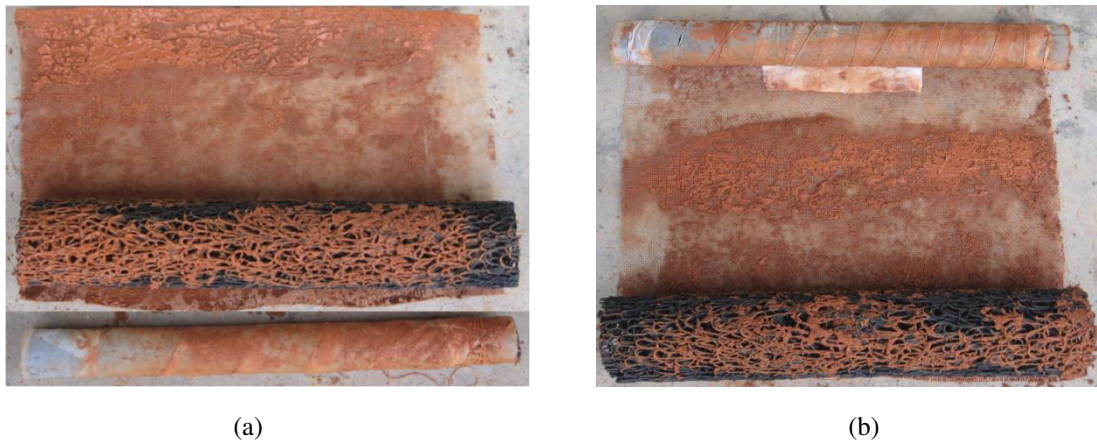


Fig. 10. B₃₋₁ Drainage pipe after the end of the experiment (a) B₃₋₂ Drainage pipe after the end of the experiment (b)

V. CONCLUSION

- (1) The new composite drainage pipe is a double-layer replaceable drainage pipe. In the same soil layer, the larger the mesh number of the filter material wrapped around the inner and outer pipes, the smaller the water infiltration volume.
- (2) Under the same structural conditions, drainage pipes with smaller soil permeability coefficients have slightly higher water infiltration volumes, and fine particles are easily carried away by water. The drainage capacity of the random blind pipe's inner pipe is slightly inferior to that of the PVC inner pipe.
- (3) The ability of the filter material wrapped around the new composite drainage pipe to resist clogging is significantly higher than that of conventional drainage pipes. Depending on the particle size distribution of the soil on-site, filter materials with suitable pore sizes can be selected. In the later stage of clogging, the new composite drainage pipe has advantages such as extracting the inner pipe, cleaning, replaceability, and increased durability. It is suitable for promoting and applying in deep drainage of structures such as slopes, roadbeds, and tunnels.

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