



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 13, Issue 1, January 2024

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.423

9940 572 462

6381 907 438

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Study on Physical Clogging of Upward Inclined Drainage Pipe in Slope

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ABSTRACT: In order to investigate the physical clogging mechanism of upward inclined drainage pipes on slopes, comparative analysis was conducted through indoor model experiments. The occurrence and development patterns of physical clogging in drainage pipes placed in different permeable strata during slope operation were examined. The results showed that: Initially, the drainage discharge of the drainage pipes fluctuated significantly, with less fluctuation observed in soil with well-graded particle size distribution and high compaction density. The drainage discharge of the drainage pipes was greatly influenced by the soil permeability coefficient, and there was a positive correlation between drainage discharge and permeability coefficient. The smaller the specification of geotextile, the smaller the drainage discharge. The clogging of drainage holes can be divided into two typical stages. In the initial stage, mechanical clogging predominates, which takes a shorter time. With the increase of operating time, chemical clogging is produced due to the groundwater, composition of slope rock and soil, as well as chemical reactions in the drainage holes themselves. Additionally, biological clogging occurs under the conditions of slope biological activities and intermittent drainage, ultimately resulting in comprehensive three-dimensional clogging of the drainage pipes. This stage develops slowly and takes a longer time.

KEYWORDS: Slope; Inclined drainage pipe; Physical silting

I. INTRODUCTION

Currently, upward inclined drainage holes are widely used in engineering slope projects both domestically and internationally for deep-seated slope drainage. Actual operation of these projects has shown that as long as the spacing and depth of the holes are designed properly, upward inclined drainage holes can function effectively during the early stage of slope remediation projects. However, with the increase of operating time, it is common to encounter situations where drainage from the holes becomes inadequate or ceases completely. Due to the weakening or failure of the drainage hole functionality, the stability of the slope engineering cannot be assured, which can have serious consequences on the safety and stability of the project. It can even lead to significant property damage or injuries to personnel. Research on the clogging mechanism of upward inclined drainage holes in slope engineering is still in its early stages both domestically and internationally, and there is relatively limited research on the long-term performance of deep-seated upward inclined drainage holes and measures to address clogging.

This article aims to conduct material and structural performance tests on the current typical design schemes and operating conditions of upward inclined drainage holes on slopes. It also involves carrying out model simulation experiments to study the occurrence mechanism and development patterns of clogging in the intermittent drainage operation of upward inclined drainage holes.

Paper is organized as follows. Section II provides an introduction to the drainage measures for engineering slopes and the research status of drainage pipe clogging. Section III presents the experimental parameters and plan for modeling the clogging characteristics of drainage holes in different permeable strata. Section IV analyzes the results of indoor model experiments on drainage holes in different permeable strata. Finally, Section V presents conclusion.

II. RELATED WORK

Since groundwater is one of the main factors that affect the deformation and stability of slopes [1][2], ensuring a smooth drainage is essential for the safety slopes [3][4]. In slope treatment projects in engineering fields such as highways [5], power, water conservancy [6], and geotechnical engineering [7], the arrangement of horizontally inclined drainage holes is often used as a common drainage treatment method. In practical engineering, the design of inclined drainage hole

arrangement is often based on specifications or simple arrangements using experience and flow calculation formulas. This sometimes leads to improper placement of inclined drainage holes, resulting in their failure to function effectively and meet drainage requirements. In some cases, drainage hole arrangements may be excessively dense or increased in quantity without proper justification, leading to wasteful engineering practices. The key to a successful drainage hole design lies in accurately understanding geological data and the patterns of groundwater activity. Typically, methods such as drilling or electrical prospecting are employed, combined with geological surveys, to determine the direction, velocity, and flow rate of groundwater. Based on this information, appropriate underground drainage structures are selected and finalized. The design and research of drainage hole arrangement primarily focuses on seeking the optimal design for a specific project's needs. There are currently two approaches in the research on drainage hole arrangement design by scholars:

The first approach involves using finite element analysis to study the distribution of seepage fields with different drainage hole arrangement schemes. This allows for a comparison of drainage effects and economic evaluations of different designs, aiming to find the optimal layout and propose drainage hole arrangement guidelines. This method is a major research approach [8]. The second approach is based on the drainage mechanism of fractured rock masses and proposes a basic model for the arrangement of drainage holes in mountains [9]. An optimized drainage hole arrangement method was proposed in the design research for the slope drainage project of the Three Gorges Permanent Ship Lock. This method delves deeper into the drainage mechanism of slope rock masses and utilizes principles of statistics to establish a drainage hole optimization model based on parameters such as the orientation and size of drainage holes and the distribution of rock structural planes.

In summary, there have been significant achievements in the research on road subgrade seepage fields and drainage design in China. Deep drainage pipes have been increasingly used in slope reinforcement projects. However, overall, both domestically and internationally, research in this area is still in its early stages. As time has passed, these types of drainage pipes have encountered varying degrees of blockage. There is limited reporting on the long-term performance of deep inclined drainage holes and the research on measures to remove blockage.

There is limited research on the long-term performance of inclined drainage holes both domestically and internationally, while there is more research on blockage of similar drainage facilities (such as relief wells) in hydraulic engineering. Studies have shown that the main reason for the decrease in the effectiveness of relief wells is blockage, which refers to the phenomenon of material deposition and accumulation in the pores of the permeable medium, leading to pore clogging. The causes of blockage can generally be divided into mechanical, chemical, biological, and comprehensive categories, each with its specific characteristics [10][11]. In the study of blockage in relief wells in hydraulic structures, the focus has mainly been on the chemical causes of blockage, with an emphasis on the analysis of precipitates. Initial research has been conducted on their sources, composition, and conditions of formation. However, there is limited research on the occurrence and development of blockage itself, with only indirect studies available. Therefore, it is of great significance and practical importance to conduct in-depth research on the occurrence and development rules of blockage in the operation process of inclined drainage holes in slope engineering. This research can lead to the development of new technologies to prevent or delay blockage, as well as the proposal of operation and maintenance plans. These efforts will greatly improve the long-term effectiveness of slope management projects and reduce the costs associated with operation and maintenance.

III. EXPERIMENTAL MODEL

The dimensions of the model box are 1500mm (L) x 1500mm (B) x 1500mm (H). The frame surrounding the box is made of stainless steel equal angle steel, with a specification of 100mm x 100mm x 5mm. The top of the model box is open, while the other five sides are made of 12mm thick organic glass. On the front side, four holes are appropriately positioned, with the aperture corresponding to the drainage pipes. On the side, four holes are also appropriately positioned, with the aperture corresponding to a bundle of transparent flexible hoses. Two holes are made either on the bottom plate of the model box, the back bottom, or other suitable locations. One hole has a diameter corresponding to the front drainage pipes, which is used for emptying the water from the model box. The other hole has a diameter corresponding to four transparent flexible hoses, which is used for observing the water level at low water level (Figure 1).



Fig. 1. Experimental Model Box

This experiment primarily focuses on the mechanism and conditions of blockage in drainage holes. Therefore, the determination of the scale does not require high precision. Taking various factors into consideration, a scale ratio constant of $SL=5.0$ is chosen for the drainage holes in this experiment. A 20mm PVC pipe is used to simulate the real 100mm drainage pipe.

IV. EXPERIMENTAL SOIL GRADATION

According to the experimental requirements, sand, fine sand, silt, and clay are selected and proportioned in a certain ratio as the test materials to simulate the geological strata. The particle gradation and compaction of the soil mass loaded into the model box are determined in the experiment to ensure that the permeability coefficient is as close as possible to the desired simulated permeability coefficient. The particle gradations and compactness for different magnitudes of permeability coefficients used in the experiment can be seen in Figures 2 to 4.

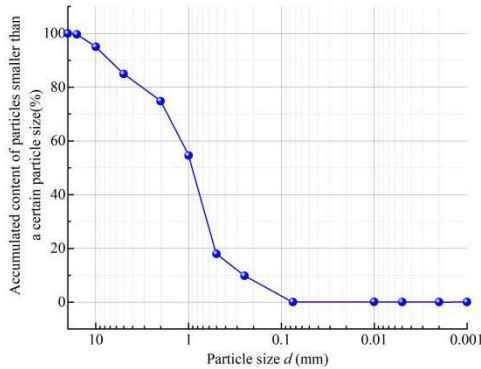


Fig. 2. Particle size distribution graph ($k=1.0 \times 10^{-3} \text{ cm/s}$)

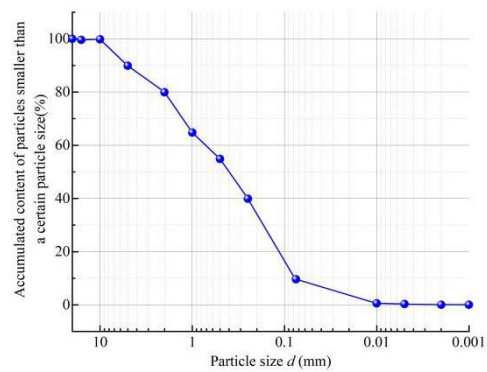


Fig. 3. Particle size distribution graph ($k=1.0 \times 10^{-4} \text{ cm/s}$)

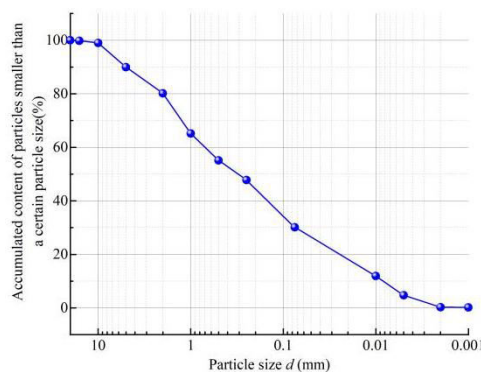


Fig. 4. Particle size distribution graph ($k=1.0 \times 10^{-5} \text{ cm/s}$)



Experimental plan

In order to effectively simulate the clogging characteristics of drainage holes in different permeable strata, multiple sets of drainage model tests were conducted for different permeable strata and different types of drainage holes. Through the model tests, the drainage conditions, clogging conditions, and flushing particle situations of different types of drainage holes in different permeable strata were obtained. Please refer to Table 1 for the experimental plan.

Table1. Experimental Plan

Group Number.	Permeability Coefficient k (cm/s)	Drainage Pipe Composition
A ₁	1.0×10 ⁻³	A ₁₋₁ Φ2cm flower tube wrapped with geotextile (100 mesh)
		A ₁₋₂ Φ2cm flower tube wrapped with geotextile (200 mesh)
A ₂	1.0×10 ⁻⁴	A ₂₋₁ Φ2cm flower tube wrapped with geotextile (100 mesh)
		A ₂₋₂ Φ2cm flower tube wrapped with geotextile (200 mesh)
A ₃	1.0×10 ⁻⁵	A ₃₋₁ Φ2cm flower tube wrapped with geotextile (specification 100)
		A ₃₋₂ Φ2cm flower tube wrapped with geotextile (100 mesh)

V. EXPERIMENTAL RESULTS

Simulate the continuous drainage conditions of three different combinations of slope drainage holes as shown in Table 1, including the drainage process during rainfall and the post-rainfall drainage conditions. This analysis will provide information on the drainage timetable of the drainage holes as well as the clogging situation. The drainage flow rate from the drainage pipes will be recorded every 5 minutes.

(1) Analysis of experimental results for drainage pipes of the same model but different permeability coefficients
 To simulate the influence of different slope soil types on drainage from the drainage pipes, experiments were conducted using three different soil types with varying permeability coefficients. The drainage data was collected and analyzed for each type of soil after stabilizing with the same geotextile (Fig.5). It can be observed that due to the complexity of groundwater movement and the influence of artificial timing and measurement errors, the data after 48 hours still exhibit significant fluctuations. However, there is a positive correlation between drainage volume and permeability coefficient. Additionally, as the permeability coefficient decreases, the soil contains more fine particles and has higher compaction, resulting in smaller fluctuations in drainage volume.

The overall drainage volume of group A3-1 is approximately 75% of that of group A1-1 for each five-minute interval, indicating a significant difference. Moreover, the drainage volume of A3-1, which has the smallest permeability coefficient, is approximately 85% of that of A2-1 with a comparatively smaller permeability coefficient. This indicates that the composition of the slope soil significantly influences the drainage from the drainage pipes.

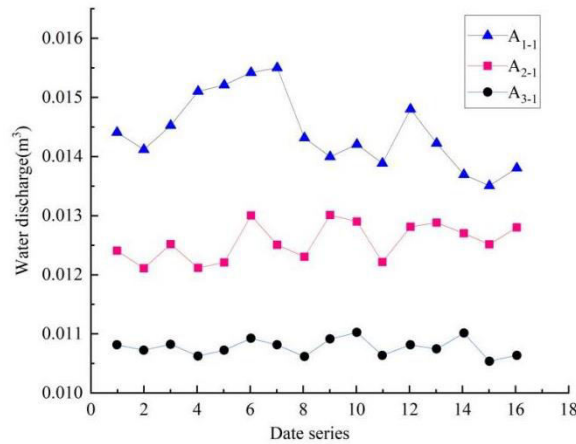


Fig. 5. Drainage volumes for different permeability coefficients

(2) Analysis of experimental results in the initial and final stages of drainage
 By analyzing and organizing the initial data and the data after 48 hours (Fig. 6), it can be observed that there is a significant fluctuation in the drainage volume during the early stage. Additionally, soils with smaller permeability coefficients, higher fine particle content, and greater compaction exhibit smaller fluctuations in drainage volume. After 48 hours, the data become relatively stable, and there is a reduction in the drainage volume compared to the initial stage. This indicates that after the installation of the drainage pipes, soil particles undergo movement under the influence of groundwater. The groundwater flow field also undergoes changes. Initially, all pores of the drainage pipes can achieve maximum drainage. However, as the soil particles move, the drainage holes may become clogged, resulting in a decrease in the drainage volume. This process is relatively short, and the fact that the drainage volume stabilizes after 48 hours in the laboratory indicates that the seepage field has essentially re-stabilized.

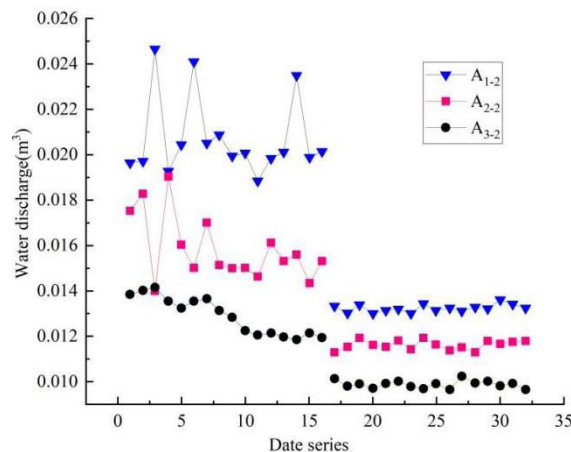


Fig. 6. Comparison chart of initial and final drainage volumes

The clogging of drainage holes can be divided into two typical stages. In the initial stage, mechanical clogging is dominant, and it occurs relatively quickly. After the completion of drainage hole construction and the start of drainage, the soil particles undergo movement under the influence of groundwater until they reach a relatively stable stage. This is manifested by the entry of more soil particles into the outer pores of the geotextile. The presence of soil particles in some of the outer pores of the geotextile reduces their drainage capacity, but they do not completely block the pores, resulting in a loss of drainage capacity. This stage usually occurs within a relatively short period of time after the drainage hole construction, and it serves as the basis for mid to later-stage clogging.

As the slope's soil and rock mass stabilizes with the migration of groundwater, the clogging of the drainage holes continues to slowly develop with the increase in operational time, leading to the mid to later-stage clogging. During this stage, chemical clogging occurs due to chemical reactions between groundwater, the composition of the slope's soil and rock mass, and the drainage holes. Additionally, biological clogging occurs due to the biological activities on the slope and intermittent drainage. At the same time, mechanical clogging also continues to develop slowly. The

combined effects of mechanical, chemical, and biological clogging gradually intensify until no drainage occurs. Eventually, the clogging evolves into a comprehensive and three-dimensional clogging of the drainage pipes, where the clogging materials inside and outside the pipes exhibit good integrity. Based on field investigations, the continuous development of comprehensive clogging from initial clogging to mid to later-stage clogging, resulting from soil particle migration and the redistribution of the seepage field, until no drainage occurs, is a relatively long process compared to the initial clogging stage.

(3) Analysis of experimental results on drainage volumes of different types of geotextiles.

According to the data in the table, it can be observed that different types of geotextiles buried in the same soil with the same permeability coefficient have significant fluctuations and differences in the initial drainage volume. By comparing the drainage volume data after 48 hours (Fig.7), it can be seen that different types of geotextiles still have an impact on the drainage volume in the same soil layer after 48 hours. The difference in drainage volume between different types of geotextiles is around 5%. Compared to the influence of the soil layer on the drainage volume, the type of geotextile has a relatively smaller effect on the drainage volume, but it still demonstrates a clear correlation. That is, the denser the geotextile, the smaller the drainage volume.

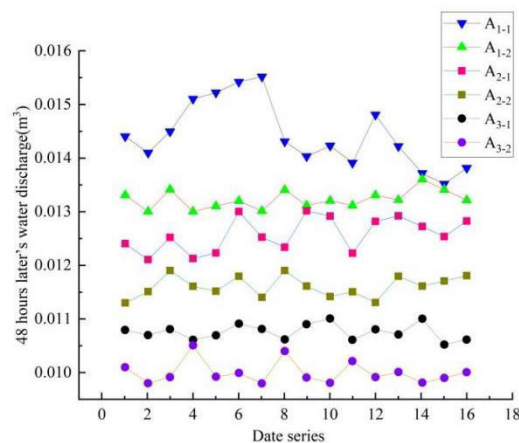


Fig. 7. Different types of geotextiles and their drainage volumes

(4) Microscopic analysis of sediment blockage

After 48 hours of drainage, the geotextile in group A1 was removed for scanning electron microscope (SEM) analysis to further study the mechanism of geotextile blockage. SEM images of A1-1 can be seen in Figure 8-9, while SEM images of A1-2 can be seen in Figure 10-11. From the SEM images, it can be observed that during the initial stage of blockage, the main cause is the intrusion of soil particles into the outer pores of the geotextile, which leads to blockage. However, the soil particles do not completely fill up the pores, resulting in complete drainage failure in those pores. Meanwhile, only a small number of fine particles enter the inner surface of the geotextile, failing to form a three-dimensional mutually reinforcing blockage with the external clogging material. Furthermore, comparing the SEM images of the geotextile after the two experiments, it is evident that the geotextile used in A1-2 has a higher density since it has a finer specification (200 mesh) compared to A1-1 (100 mesh). The SEM images clearly show more clogging material in the A1-2 group. This indicates that the denser the geotextile is in terms of the coverage around the drainage pores, and the smaller the pore size, the faster the clogging occurs.

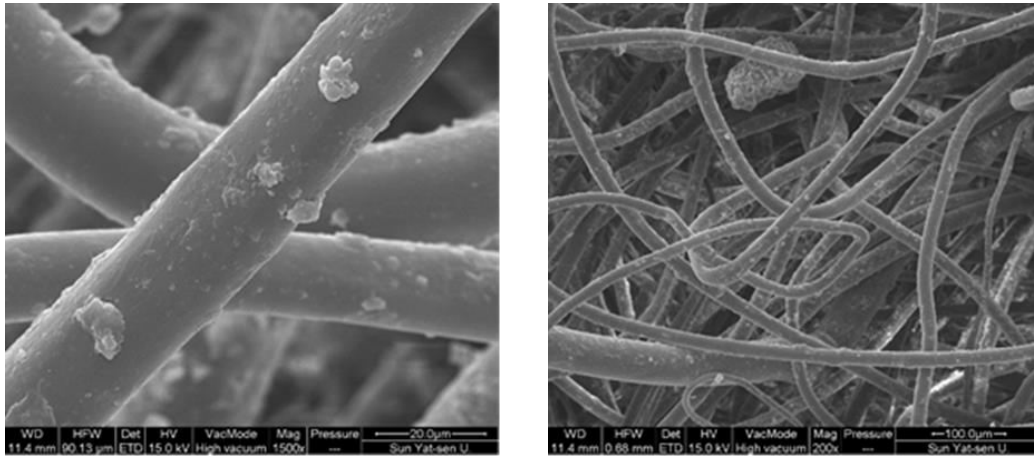


Fig. 8. A1-1SEM images of the geotextile after internal blockage

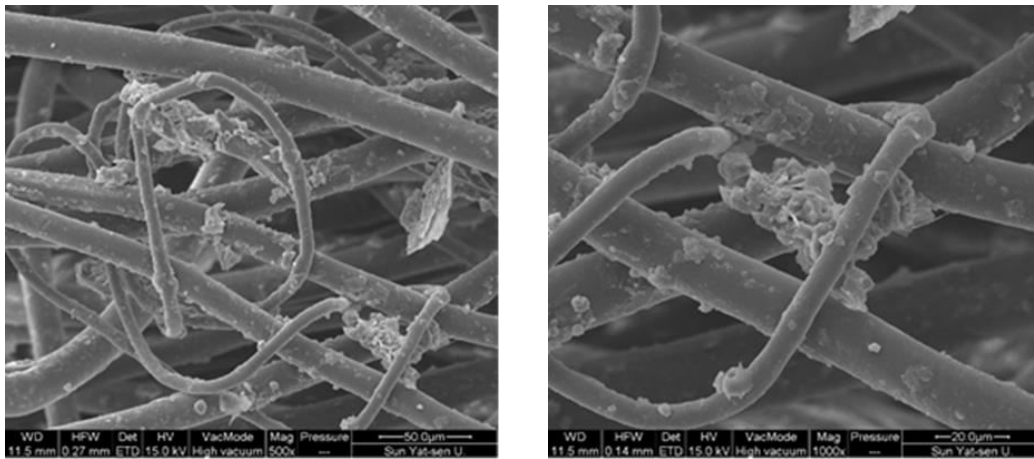


Fig.9. A1-1SEM images of the geotextile after internal blockage

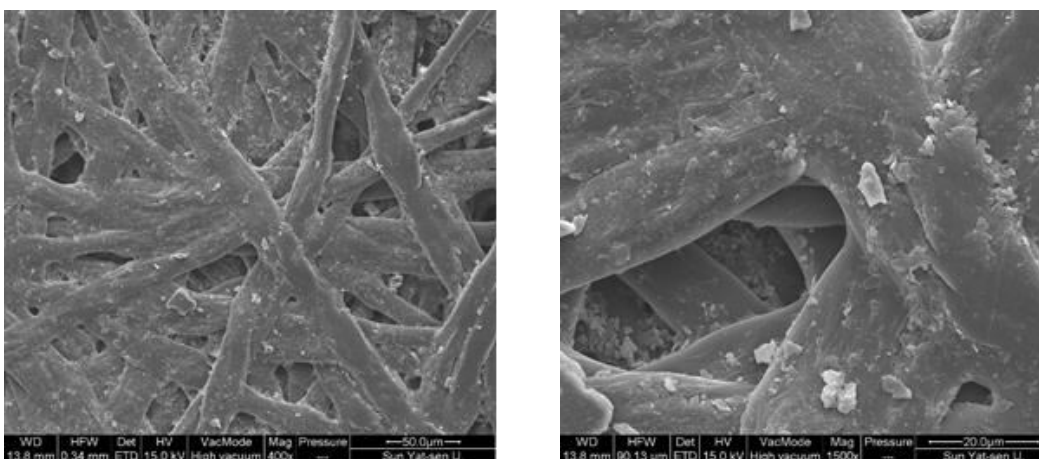


Fig. 10. A1-2SEM images of the geotextile after internal blockage

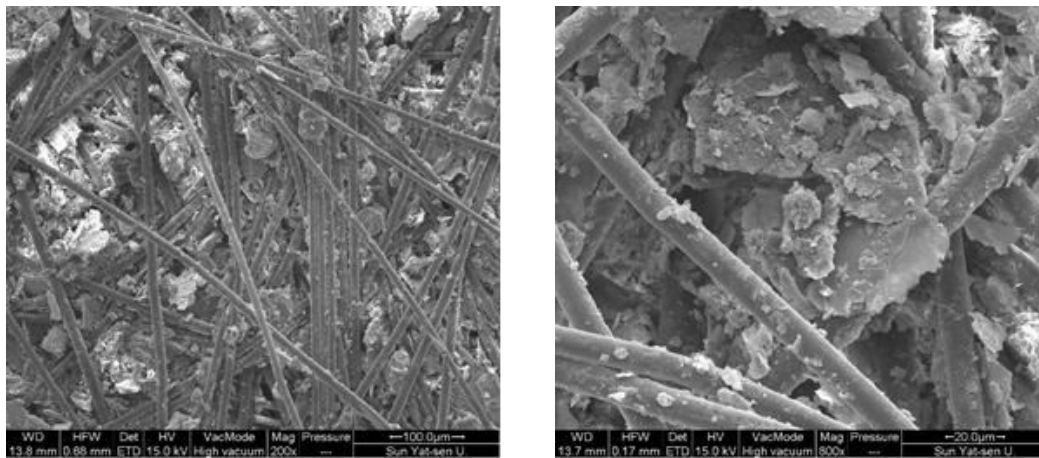


Fig. 11. A1-2SEM images of the geotextile after internal blockage

VI. CONCLUSION

- (1) The initial drainage flow rate in drainage pipes often exhibits larger fluctuations, while soils with well-graded particle size distribution and high compaction density tend to have smaller fluctuations.
- (2) The drainage flow rate in the pipes is greatly influenced by the soil permeability coefficient, showing a positive correlation with it. The flow rate is also influenced by the specification of the geotextile, although its impact is relatively smaller compared to the geotextile specification in rock and soil structures. A denser geotextile leads to a lower drainage flow rate. At the same time, a denser geotextile with smaller pore size also results in faster clogging, where small drainage pore size due to external materials is an important reason behind the severe physical blockage of drainage pores.
- (3) Clogging of drainage pores can be divided into two typical stages. During the initial stage, mechanical blockage is predominant, which occurs relatively quickly. As time progresses, chemical blockage occurs due to groundwater, the composition of slope rock and soil, and chemical reactions within the drainage pores. Additionally, biological blockage forms due to slope biological activities and intermittent drainage conditions. Mechanical blockage continues to develop slowly. A combination of mechanical, chemical, and biological blockage gradually intensifies until complete drainage failure occurs, resulting in a three-dimensional and comprehensive blockage of the drainage pipes. This stage develops slowly and requires a longer time.

VII. ACKNOWLEDGEMENT

This work was supported by Research and development project of Hunan Chemical Geological Engineering Survey Institute Co., Ltd.

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