Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-456

Performance investigation of a newly proposed drainable pipe fitting

Enquête sur les performances d'un nouveau raccord proposé de tuyau d'évacuation

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ABSTRACT: We propose a versatile drainage system that incorporates drainage inlets for pipe fittings that can connect to standard steel and PVC pipes. In existing drainage pipe systems, soil entering from small openings clogs the drainage path and is a cause for concern. With the proposed pipe fittings, however, it is possible to freely design the drainage inlet shape, position and inflow path, thereby reducing the amount of soil entering the drainage route. In this study, drainage performance and sediment control capabilities of the newly proposed drainable pipe fittings were investigated through laboratory and full-scale model experiments. Consequently, it was found that the drainable pipe fittings ultimately possessed equivalent drainage performance to conventional drainage pipes with better control of sediment discharge. Further inlet shape improvements can provide effective drainage systems for geotechnical engineering sites.

RÉSUMÉ: Nous proposons un système d'écoulement polyvalent qui intègre des entrées d'évacuation grâce à un raccord de tuyauterie pouvant se connecter à des tuyaux standard en acier ou en PVC. Dans les systèmes de canalisations d'écoulement existants, la terre pénètre par de petites ouvertures et bouche l'entrée des conduites d'écoulement et constitue un problème. Néanmoins, avec le raccord de tuyauterie proposé, il est possible d'établir librement la forme, l'emplacement et l'afflux des ouvertures d'écoulement, réduisant ainsi la quantité de terre entrant dans les voies d'écoulement. Dans cette étude, les performances des écoulements et les capacités de contrôle des sédiments du nouveau raccord de tuyauterie a écoulement proposé ont été étudiées en laboratoire et sur modèles à grande échelle. Par conséquent, il a été constaté que les raccords de tuyau d'écoulement possèdent finalement des performances d'écoulement équivalentes à celles des tuyaux d'écoulement conventionnels et peuvent mieux contrôler l'écoulement des dépôts de sédiments. D'autres améliorations de la forme peuvent fournir un système d'écoulement efficace pour les sites d'ingénierie géotechnique.

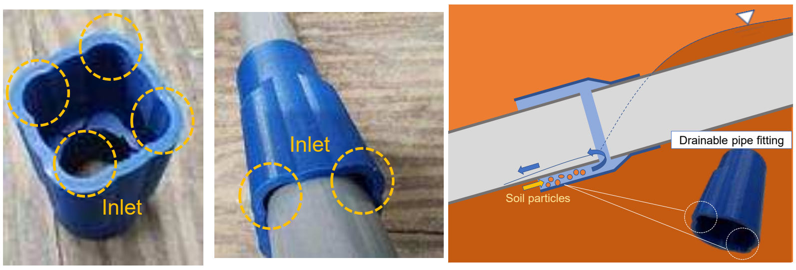
Keywords: Drainage system; underground pipe; permeability test.

1 INTRODUCTION

Limited methods exist for draining excessive water from natural slopes or existing earth structures. Drainage pipe systems, which drive a perforated steel pipe into ground with high phreatic surfaces offers not only the advantage of requiring a relatively small construction space and small workforce, but also the ability to increase the rigidity of the penetration area owing to a nailing effect (Saito et al., 1968). However, challenges arise when soil material intrudes into the pipe and clogs the drainage holes, leading to a rapid decline in drainage efficiency. Additionally, the loosening of the ground along the drainage route due to the induction of soil also causes concern. In this study, a new pipe fitting is proposed with a drainage function and mechanism to reduce soil leakage into the drainage route by directing the flow against gravity. Here, the performance of the newly developed pipe fitting was investigated through laboratory and full-scale model tests.

2 DRAINABLE PIPE FITTING

The pipe fitting proposed in this study is designed to have drainage functionality at the joint connecting the prefabricated PVC or steel pipes. This drainable pipe fitting, as shown in Figure 1, features a bulge on the side that serves as the drainage inlet. Generally, drainage pipes are installed with a 5-degree upward slope. The drainable fitting is used with the drainage



(a) Photos of drainable pipe fitting *(b) Drainage mechanism*
Figure 1. Overview of the newly proposed drainable pipe fitting.

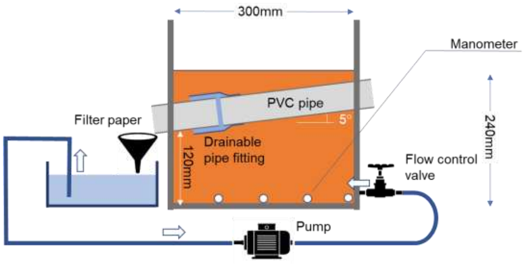


Figure 2. Laboratory model test.

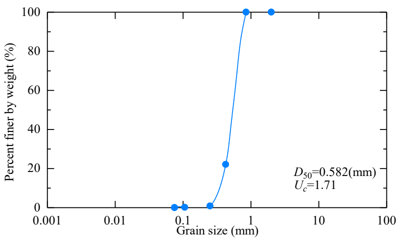


Figure 3. Particle size distribution.

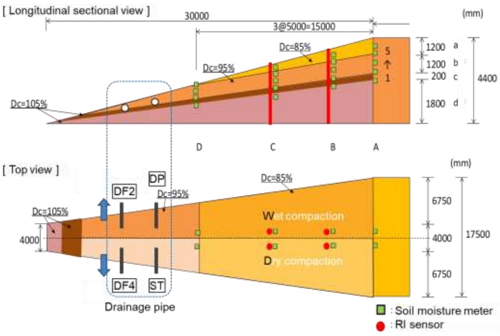


Figure 4. Overview of full-scale model.

Figure 5. Alignment of drainage pipe.

inlets at the lower slope position, as illustrated in Figure 1. This configuration allows groundwater to flow upward through the drainage inlet into the drainage route and then to drain from the end of the non-perforated pipe. As a result, less soil particles are expected to enter the drainage route, because they would have to defy gravity to flow upward. Furthermore, the use of prefabricated pipes garners the advantage of applying existing drilling and pipe installation methods without modification. Incorporating multiple fittings increases the number of drainage inlets, and as drainage positions are specified, it is also possible to strategically lower the phreatic surface using this system.

3 EXPERIMENTAL PROCEDURES

3.1 Laboratory model test

Figure 2 illustrates an overview of the model test. The model box has internal dimensions of 300mm width, 300mm height, and 200mm depth, allowing the installation of the drainage pipe at a 5-degree upward angle from the central part of one side of the model box with a water inlet at the lower part of the upstream side. Drainage from the outlet of the pipe was collected in an attached tank through filter paper and recirculated by a pump. During the test, volumes of drainage water and soil were measured periodically. To simulate materials prone to enter the drainage path, silica sand No. 5 ($G_s = 2.67$) was used. Figure 3 shows the particle size distribution of the soil test material. Through maximum and minimum density tests, a maximum void ratio of 1.050 and a minimum void ratio of 0.708 were obtained. When making the soil model, dry samples were compacted in 10 layers to a height of 240mm to achieve a void ratio of 0.70 (as determined from a separately conducted permeability test ($k = 3.4\times10^{-3}$ m/sec). To prevent drainage during the experiment, the soil model was first saturated up to lower part of the drainage pipe. Then, the flow control valve was adjusted to establish a constant hydraulic gradient while monitoring the manometers at the inflow section to confirm a steady state. The water level was raised every 1cm until soil leakage became significant and the drainage pipe was completely clogged.

3.2 Full-scale model test

The performance of the proposed drainage systems was investigated on a full-scale embankment model (Figure 4) constructed at Kobe Airport. The drainage systems tested consist of four types, as shown in Figures 5 and described as follows: DF4 and DF2 are the drainable fittings proposed in this study, with 4 and 2 drainage inlets, respectively; ST is a steel drainable fitting that incorporates drainage functionality into existing anchor rods, maintaining the same shape with two drainage inlets; and DP is a perforated PVC pipe installed for comparison purposes. All the drainage systems were inserted at an upward angle of 5-degrees from the slope surface to a depth of 2 meters. Drainable fittings were connected to pipes at every 50 cm, including at the tip (DF4, DF2, ST). ST, a selfdrilling type of pipe made of rust-resistant steel, had high rigidity and allowed for being driven into position using impact. Placements for DP, DF2, and DF4 were pre-augured before insertion to ensure that the auger holes had stable walls. The pipes were then inserted and installed. Drainage from the drainage pipes was collected in acrylic containers, and the drainage water and soil were measured periodically. Additionally, during the measurement period, the drainage process was recorded with a time-lapse camera, and days with drainage were recorded.

4 EXPERIMENTAL RESULTS AND DISCUSSIONS

First, we discuss the results of the laboratory model tests. Before testing the drainage fittings, model tests were conducted using PVC pipe with small hole perforations and an inner diameter of 31mm. Soil entered from the upper holes of the perforated pipe regardless of the drainage process for the soil sample. To compare the drainable pipe fitting systems, all the holes on the upper surface of the perforated pipe without the drainable pipe fittings and those upstream of the drainable pipe fitting were sealed with waterproof tape. Figure 6 shows the results of the perforated pipe model test. During the test, due to sensitivity issues with the manometers, hydraulic gradient was calculated by dividing the difference between the water level in the inflow section manometer and the height of the lowermost hole by the horizontal distance. As the hydraulic gradient increased, the drainage volume also increased linearly. In the case of the perforated pipe, there was a constant amount of soil leakage even at low hydraulic gradients; however, a significant amount of soil leakage was observed once the hydraulic gradient exceeded 0.2.

Next, we conducted experiments using a drainable pipe fitting. The experimental results are shown in Figure 7. Although it is difficult to directly compare the absolute values of the hydraulic gradient, the trend of increasing drainage volume with increasing hydraulic gradient is the same. At low hydraulic gradients, soil leakage was not observed; however, once soil began to leak, it increased exponentially, and clogging due to soil leakage made it impossible to continue the experiment above a hydraulic gradient of 0.2. The drainable pipe fittings had a drainage design with a 5-degree upward angle at the inflow section, which resulted in a greater flow velocity than gravity acting on soil particles. This design could not sufficiently prevent soil from leaking.

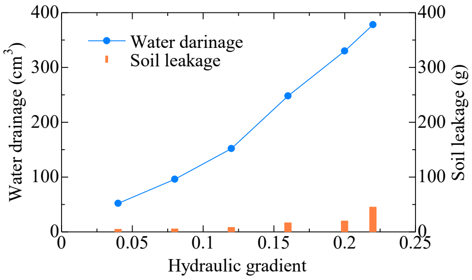


Figure 6. Test results for perforated pipe.

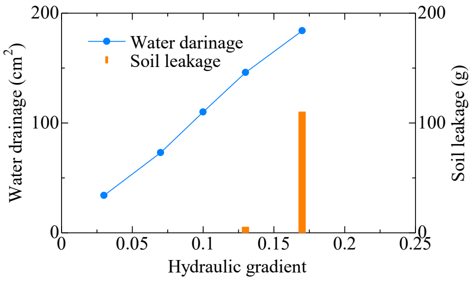
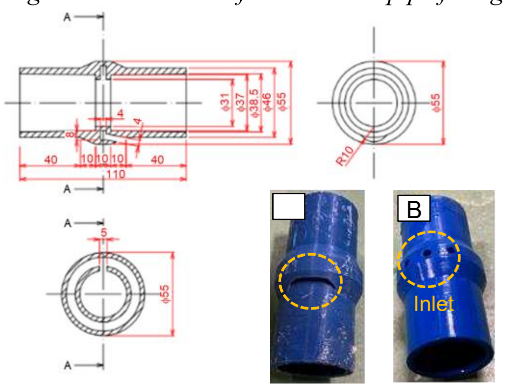
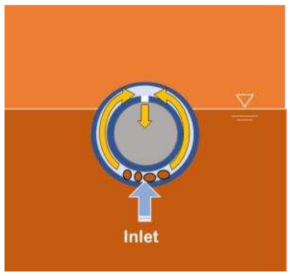


Figure 7. Test results for drainable pipe fitting.



(a) Shape and photos

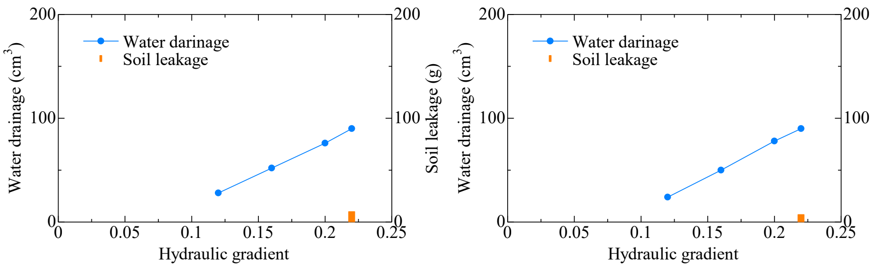


(b) Drainage mechanism

Figure 8. Modified drainable pipe fiting.

Therefore, as shown in Figure 8, we improved the fitting design. The modified drainable pipe fitting utilized an inlet at the bottom of the drainage pipe and a drainage route confluence point at a higher position inside the drainage pipe, creating a structure with greater height differences. We prepared two different inlet shapes, denoted as A and B. Figure 9 shows the test results using the modified drainable pipe fittings. There was no significant difference in the results between fittings A and B. The results showed that the inlet shape had little impact on the drainage and sediment control functions on the same internal structure. Compared to before the improvement, soil leakage was reduced; however, once the hydraulic gradient exceeded a certain threshold, soil leakage became excessive, making it difficult to continue the experiment. As mentioned earlier, direct comparison of the absolute values of the hydraulic gradient was not appropriate, so we compared the drainage components based on the relationship between drainage volume and soil leakage, as shown in Figure 10. In the case of the perforated pipe, soil leakage was observable even at low drainage volumes, whereas the proposed drainable pipe fittings hardly had any soil leakage. Nevertheless, it was evident that significant soil leakage occurred once the drainage volume exceeded a certain threshold, which appeared to be strongly dependent on the rate of water level rise.

Drainage and soil leakage in the full-scale embankment test were measured over six separate periods. Figure 11 shows the precipitation during each measurement period. There was little to no substantial rain between autumn and winter, while precipitation increased significantly from early spring to the rainy season, resulting in variations during the measurement period. Figures 12 and 13 show the measured drainage and soil leakage, respectively. It is difficult to compare the type of drainage pipe since the installation locations and soil conditions were different. However, it is evident that there is not a significant difference in drainage volume between perforated pipes and drainable pipe fittings. This suggests that drainable pipe fittings provide a comparable drainage performance to perforated pipes. On the other hand, soil leakage was rarely observed during periods of low precipitation and was most pronounced with perforated pipes. Observation from time-lapse cameras revealed that drainage occurred only on days with substantial rainfall exceeding 30mm. Tensiometers indicated that the conditions for perched water to accumulate in this embankment occurred with daily rainfall of around 25mm. Below this threshold, water dissipated through surface runoff or evaporation without generating perched water, indicating that the drainage system is effective during times when free water, such as perched water, is generated.



(a) Shape A *(b) Shape B*

Figure 9. Test results for modified perforated pipe.

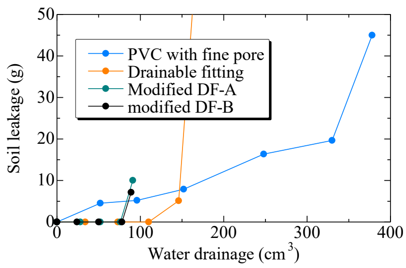


Figure 10. Relationship between water drainage and soil leakage.

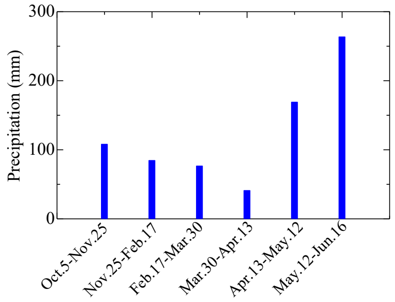


Figure 11. Precipitation during measurement period.

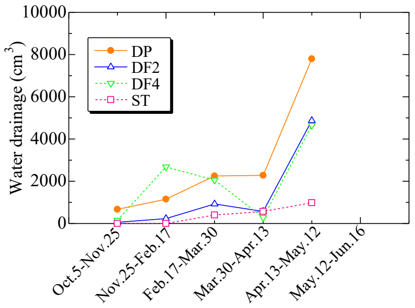


Figure 12. Drainage volume during measurement period.

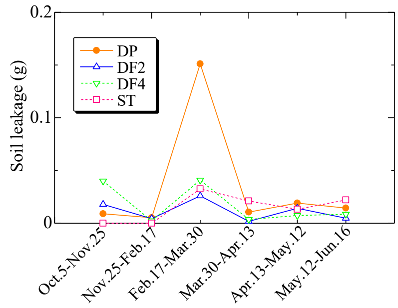


Figure 13. Soil leakage during measurement period.

5 CONCLUSIONS

In this study, we conducted model experiments to investigate the drainage function and soil leakage control function of drainable pipe fittings with a new drainage mechanism. As a result, we found that the new drainable pipe has sufficient drainage capacity and offers soil leakage control under low hydraulic gradients.

REFERENCES

Saito, M., Uesawa, H., Menjo, S. and Yasuda, Y. (1968) Effect of drainage for stability of embankment slopes by perforated pipes on the New Tokaido Line, *Railway Technical Research Report*, 631, pp.1-18 (in Japanese).