Effects of drainage pipes against slope failures due to rainfalls by using 1g physical model tests

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1 INTRODUCTION

Rainfall-induced sediment disasters like slope failures, debris flows and landslides have been serious in recent years and will be enhanced by global climate change. In addition, they become a significant source of damages and fatalities worldwide. In order to reduce those natural disasters, we have been investigating shallow slope failures due to rainfall through model tests. According to the model tests, the slope failures initiated from the slope toes where the infiltrated rainwater accumulated and the pore water pressures (PWPs) at the toes changed to be positive (e.g. Chueasamat et al., 2018). Therefore, if the accumulated rainwater drains from the slope toe, the stability of the slope may be kept. In this study, we introduced the drainage pipe installed in the filter gabion to drain the accumulated rainwater around the slope toe. The objective of this study is to investigate the effects of drainage pipes on slope stabilization.

2 METHODOLOGY

The experimental models consisted of two materials: Kasumigaura sand as the permeable surface layers and DL clay as the firm foundation of the slope. The model is shown in Figure 1. The dimensions of the slope were 122cm in height (including 100cm height DL clay and 22cm height Kasumigaura sand), 42cm in crest width, 70cm in breadth and 184 cm in base length. The incline of the slope was 45 degrees. The dimensions of the filter gabion were 20cm in width, 30cm in slope length and 21cm in height. Two different diameters of pipes: outer diameters = 60 mm and 114 mm were used.

Firstly, the base firm foundation was constructed by compacting DL clay at the maximum dry density D = 100% and the sand surface layer was compacted by the relative density D_r = 25%. The gabion filled with a material, which was satisfied with five filter laws used in Fill dam regulation (e. g. MAFF, 2003) and named filter material, was placed at the slope toe and then the drainage pipe was installed. After that the rainfall intensity I = 60mm/h was applied to the slope models. Three cases with different pipe diameters and different pipe length ratio R_p were conducted.

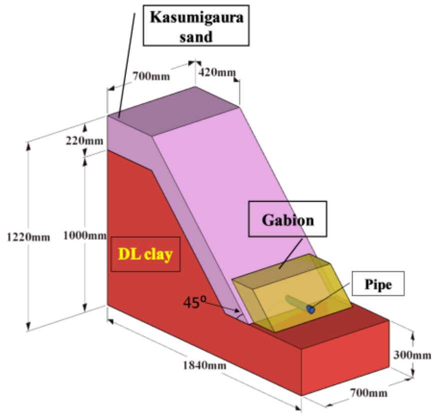

Fig. 1. Experiment slope model.

Table 1. Initial conditions of slope model.

Case	Pipe length in sand layer (mm)	Pipe outer diameter (mm)	R_p (%)	Initial conditions			
				DL clay		Kasumigaura sand	
				ρ_d (g/cm^3)	S_r (%)	ρ_d (g/cm^3)	S_r (%)
1	154	60	70	1.52	58.1	1.48	39.1
2	77	114	35	1.52	51.0	1.48	28.7
3	154	114	70	1.52	55.3	1.48	26.7

$$R_p = \frac{100\left(l_p - l_g\right)}{l_s}, \qquad (1)$$

where R_p = Ratio of pipe inserted in the sand layer, l_s = Lateral length of sand layer, l_g = Lateral length of gabion, and l_p = Length of pipe. The small holes of the pipes were only drilled at the part inserted to the sand surface layer. The details of experimental test conditions are shown in Table 1. The displacements were calculated by using Particle Image Velocimetry (PIV) analysis method (White et al., 2003).

3 EXPERIMENT RESULTS

Figures 2 and 3 show the PWP distributions and amounts of water drained from the pipes, respectively. In Case 1, the drainage of water started at around 70 min (see Fig. 3). There was no positive PWP in the sand layer before drainage started. After that the areas around the slope crest and the slope toe changed to almost saturated condition at around 80 min.

*Tokyo University of Agriculture and Technology, ** National Institute for Rural Engineering, Slope failure, Rainfall

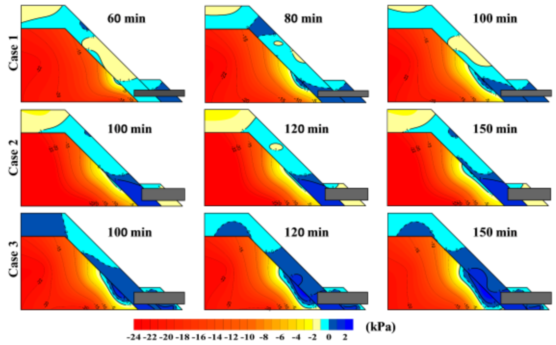

Fig. 2. PWPs distributions with elapsed time.

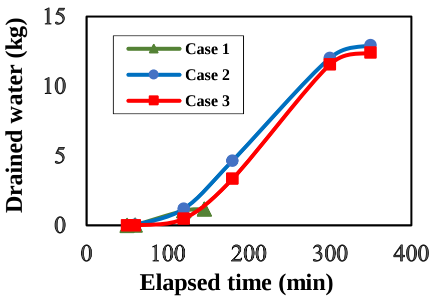

Fig. 3. Amounts of drained water vs. elapsed times.

Meanwhile in Case 2 the drainage of water started at around 60 min. In this case, the area where positive PWP values occurred was larger than those in Case 1. The similar situations were seen at 100 min (see Fig. 2). The area with positive PWP values extended gradually to the upper part of the slope. The drainage from the pipe in Case 2 became slightly larger than that in Case 1 as shown in Fig. 3. In Case 3, by comparing to Cases 1 and 2, all the area of the sand layer except slope shoulder area became almost saturated at 100 min. After 100 min, the drainage occurred. The PWP values increased slowly around the slope toe. It could be seen from Fig. 3 that the rate of drainage increased rapidly after 100 min and became constant. The tendency was similar to that in Case 2.

Figure 4 shows the seepage velocity vectors evaluated from PWP data. It was found that the rainwaters infiltrated almost straight towards DL clay layers at the crest in all the cases especially it was obvious in Case 3. In Cases 1 and 2, the high seepage velocities were found around the slope shoulder areas. They became small around the slope toe and drainage of rainwaters occurred from the slope through the pipe. Meanwhile in Case 3, most of the rain waters infiltrated towards the DL clay layers. In this case, the seepage velocity was almost the same in most of the parts of the sand layer. The vectors showed that drainage from the slope also occurred through the pipe after 100 min.

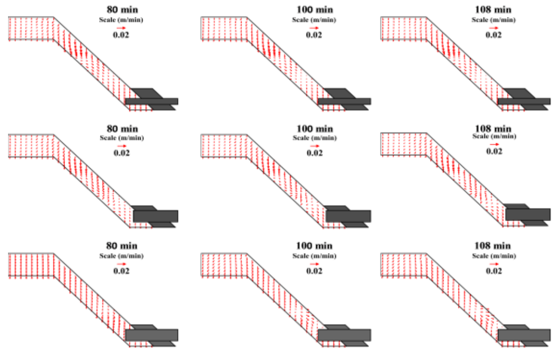

Fig. 4. Seepage velocity vectors.

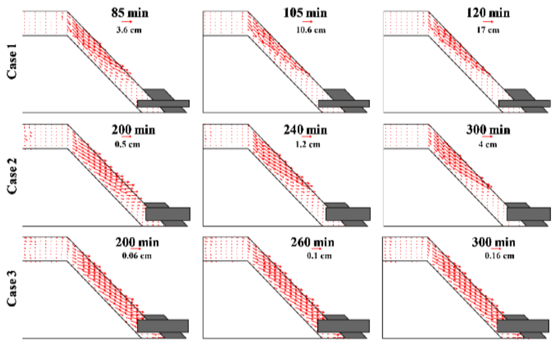

Fig. 5. Displacement vectors due to rainfall.

Figure 5 shows the displacement vectors. The arrows express each maximum displacement value and the direction of the slope movements. The large displacements observed only in the sand layers. In Case 1, the displacement started from near the shoulder of the crest and then increased rapidly. However, in Case 2 they started from the top of the gabion and extended slowly to the upper part of the slope. The displacements were obviously rather smaller than those in Case 1. In Cases 3, only small movements discovered till the end of the 5 hours of rainfall supply. In comparison of Cases 1 and 2 with Case 3, displacement was drastically reduced as increase in pipe diameter and pipe length installed to sand layer.

4 CONCLUSIONS

The results obtained in this study showed that the large diameter of pipe with R_p=70% in Case 3 gave the most desirable results. Only in Case 3 there was no failure. It was concluded that the failure reduction depended on the length and the diameter of the drainage pipe that was inserted to the sand layer through the gabion. This research was supported by JSPS (Grant No. 18H02296).

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