CENTRIFUGE EXPERIMENT ON EFFECTIVENESS OF STEEL DRAINAGE PIPES FOR REINFORCEMENT OF LEVEES AGAINST FLOODING

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1. INTRODUCTION

River levees are the geotechnical structures constructed with the objective of providing the barrier for the area near to the river from the river-induced disasters. River levee is subjected to the increased seepage flow when there is flooding in the river channel. The increased seepage flow cause the rise in the phreatic surface which leads to the reduction of the shear strength and increase of the driving force in the potential slip surface (Rahardjo et al. 2011; Vandamme & Zou 2013). This phenomenon can lead to the failure of the levee in the absence of the proper reinforcing mechanism. The lowering of the phreatic surface (Rahardjo et al. 2003) through drainage or the soil nailing to increase the strength of levees (Li et al. 2008) is used as reinforcement for such problems. However, the reinforcement method that combines both the functions of the lowering the phreatic surface and increasing the overall stability of the structure through reinforcement could provide a better solution to such failures in levees. In this study effectiveness of the steel drainage pipes which are steel pipes with the numerous holes on the surface providing these both functions is examined in the levee subjected to seepage flow through the series of the centrifuge experiments.

2. EXPERIMENT CONDITIONS

Series of the centrifuge experiments were performed to study the effectiveness of the steel drainage pipes. In this paper, five different cases of the centrifuge experiment are presented. The different cases are tabulated in **Table 1**. Centrifuge experiments were performed at 20 G centrifugal acceleration using Mark III centrifuge facility at the Tokyo Tech (Takemura et al. 1999). In all the experiments, the foundation was prepared using 95% compacted Edosaki sand and embankment by 80% compacted Edosaki sand. The physical properties of Edosaki sand utilized in the experiment is tabulated in **Table 2.** For the reinforcement, tubular steel pipes having the length of 6m, the internal diameter of 60mm and an external diameter of 80mm in prototype scale was used. The end 1m section of the pipe was provided with the screw having a pitch of 160mm and made of the plate having the thickness of 10mm. Holes of the 20mm diameter at a spacing of 160mm was provided on the four sides of the tube for facilitating the drainage in the pipe. In the centrifuge experiment, a half section of the river levee having the total height of 6m and slope of 45^{o} was modeled. The schematic diagram of the model configuration with the location of sensors for the centrifuge experiment in the prototype scale is shown in **Fig. 1**. In all the cases of the experiment, initial condition was kept constant by maintaining the water table at the top of the foundation layer in 1g environment. Flood was then simulated in the 20g centrifugal environment by increasing the water level in the upstream reservoir made in the container.

Table 1 Different cases of centrifuge experiments

Cases	Level of reinforcement	Description of reinforcement
Case 1	Unreinforced	
Case 2	Reinforced (3 steel drainage pipes)	All pipes with drainage function
Case 3	Reinforced (3 steel drainage pipes)	1 pipe without drainage function (no holes in pipe)
Case 4	Reinforced (2 steel drainage pipes)	All pipes with drainage function
Case 5	Reinforced (3 steel pipes)	All pipes without drainage function

Table 2 Properties of the Edosaki sand used in experiments

Soil properties	Values
D50 (mm)	0.30
D10 (mm)	0.01
Coefficient of uniformity	38.00
Coefficient of gradation	8.53
Soil particle density (g/cm^3)	2.72
Optimum moisture content	14.5%
Initial water content of model ground	14.7%
Dry density for embankment (g/cm^3)	1.45
Dry density of foundation (g/cm^3)	1.72

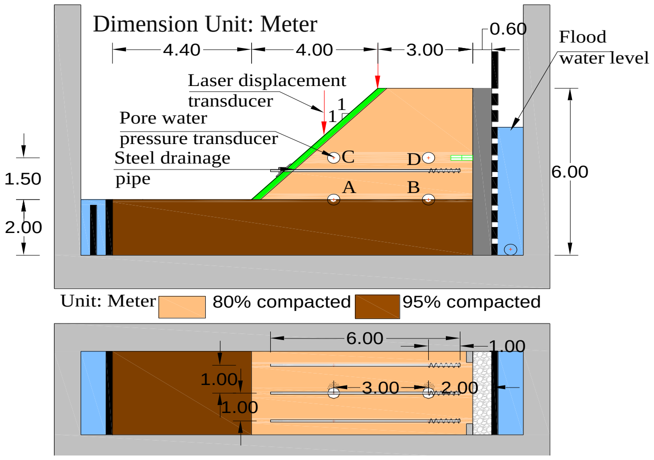

Figure 1 Model configuration for the centrifuge experiment

Keywords: Slope Reinforcement, Steel drainage pipes, Flood-induced deformation, River levees, Centrifuge
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3. CENTRIFUGE TEST RESULTS

Figures 2-5 show the model ground after experiment in Case 1, Case3, Case 4 and Case 5 respectively. In Case 1 when the model ground was subjected to the flood, with the rise of the pore water pressure in the slope, the retrogressive sliding causing the deep failure was observed. Whereas, in Case 2 no such failure occurred. In case 3 and Case 4 with the channelization of flow, erosion of the slope surface was observed. In Case 5 delayed but brittle and large failure was observed.

The use of the steel drainage pipes caused the restrained deformation in Cases 2-5. In Case 2 which had the highest degree of the reinforcement showed no significant deformation. The presence of the steel drainage pipe restricted the propagation of sliding zone thus resulting the shallower slip surface in reinforced cases.

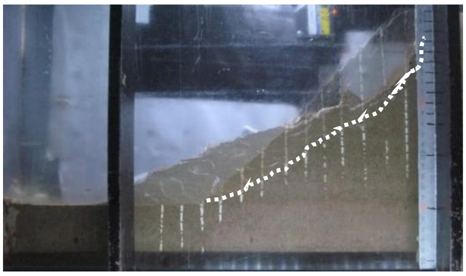

Figure 2 Model ground after experiment in Case 1

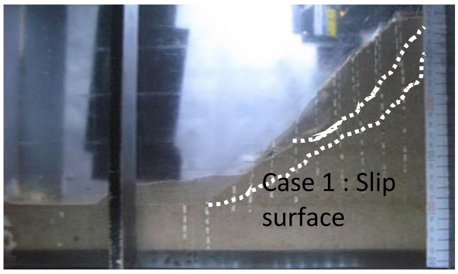

Figure 3 Model ground after experiment in Case 3

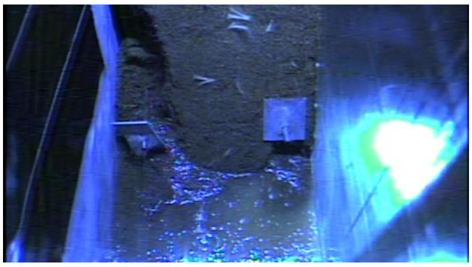

Figure 4 Model ground after experiment in Case 4

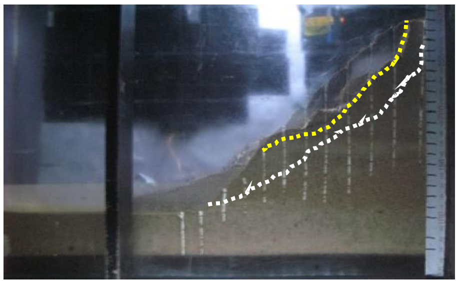

Figure 5 Model ground after experiment in Case 5

4. EFFECT AND CONTRIBUTION OF STEEL DRAINAGE PIPES

The installation of the steel drainage pipe increased the resilience against the flood. Flood height and duration of seepage flow to initiate failure and cause large failure in reinforced case was greater than the unreinforced case. Also, the propagation of the failure zone and size of the failure zone was restricted in the reinforced case. **Figure 6** shows the change in pore water pressure at a location “A” with the change in flood head for different cases. From the figure, it can be observed that the when drainage is allowed the rise of the pore water pressure is restricted indicating the lowering of the phreatic surface. **Figure 7** shows the time history axial force at 0.8m from the slope surface on the pipe and flood water head in Case 3. In the figure, it can be observed that with an increase of the flood water head, the axial force is developed in the pipe. Development of axial force tends to compensate the loss of shear strength caused due to the rise in pore water pressure in levee thus reduce deformation.

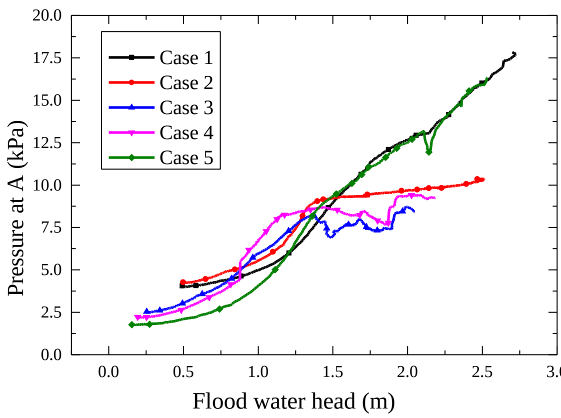

Figure 6 Pore water pressure change at A with flood head

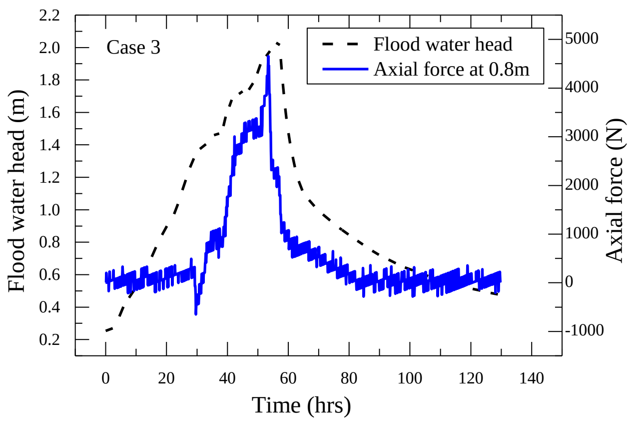

Figure 7 Time history of axial force and flood water head

6. CONCLUSION

The effectiveness of the steel drainage pipe in protecting the levee against seepage-induced failure was examined through the series of the experiment. The lowering of the phreatic surface through drainage and development of the axial force in the steel pipe increased the stability of the levee against seepage-induced failure with the installation of the proposed steel drainage pipes.

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