Study on Progressive Failure of Landslide Dam

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INTRODUCTION

Processes leading to landslide dam failure can be classified into three types: erosion due to overtopping, instantaneous slip failure, and progressive failure. Progressive failure remains poorly understood. We conducted flume experiments and numerical simulations to obtain knowledge of progressive failure of landslide dam.

EXPERIMENTS ON OUTFLOW DISCHARGE

1. Method

A schematic diagram of the flume is shown in **Fig. 1**. We modified this flume to create a cross slope to reproduce a half-section of a valley. The landslide dam was composed of homogeneous silica sand with water contents of 5 %. We used two types of sand varying in mean diameter (**Table 1**). We supplied water at a constant flow rate; the flow rate was different in each experiment (**Table 1**). We recorded the dam deformation process and fluctuations in the reservoir water level.

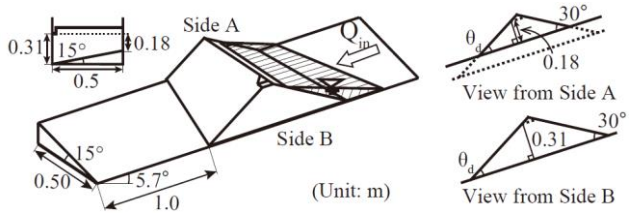

Fig. 1 Schematic diagram of the flume

Table 1 Experimental conditions

	Mean diameter of sand, d_{in} (mm)	Inflow discharge, Q_{in} (ℓ/s)	θ_d (°)
CASE 1-1	0.460	0.25	30
CASE 1-2		0.5	
CASE 1-3	1.33	0.25	
CASE 1-4		0.5	
CASE 1-5			20

2 Results and discussion

The dam failure process is shown in **Fig. 2**. Initial collapse occurred partially at the dam toe because the dam was eroded by seepage flow. Subsequently, partial slip failures occurred continuously, causing the collapse to propagate upward. Eventually, dam height dropped abruptly due to dam erosion by overtopping flow.

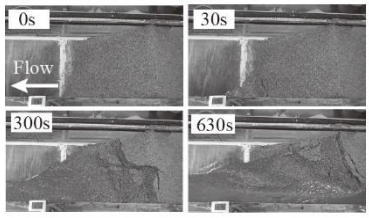

Fig. 2 Failure process (CASE 1-3)

Fig. 3 shows the outflow hydrograph; the reservoir water began to overflow at 0 seconds. The peak discharge for CASE 1-2 was unusually high, because a large-scale slip occurred and the resulting collapsed soil mass was washed away by water (**Fig. 4**).

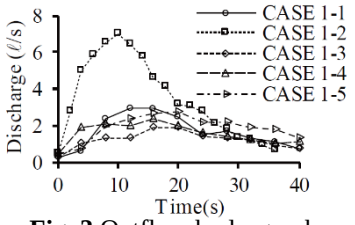

Fig. 3 Outflow hydrograph

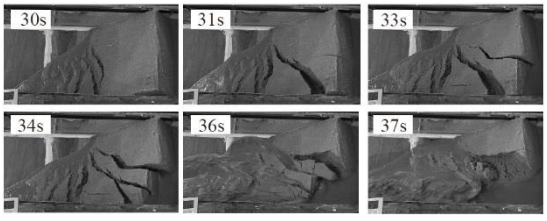

Fig. 4 Large-scale slip failure (CASE 1-2)

EXPERIMENTS ON DAM DEFORMATIOM PROCESS

1 Method

A schematic diagram of the flume is shown in **Fig. 5** and experimental conditions are shown in **Table 2**. The landslide dam was composed of homogeneous dry silica sand. We supplied water at 1 ℓ/s, and then drained the reservoir water to maintain a constant reservoir water level.

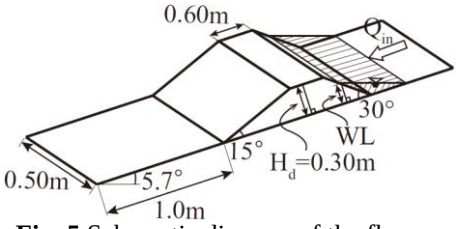

Fig. 5 Schematic diagram of the flume

Table 2 Experimental conditions

	Mean diameter of sand, d_m (mm)	Reservoir water level, WL (m)
CASE 2-1	0.460	0.26
CASE 2-2	0.948	
CASE 2-3	1.33	
CASE 2-4		0.21
CASE 2-5		0.16

2 Results and discussion

The shape of the dam when the reservoir began to overflow depended on the reservoir water level (**Fig. 6a**). The dam height was large when the reservoir water level was high (**Fig. 6a**). Therefore, high peak discharge values occurred when the reservoir water level was high (**Fig. 6b**). In this experiment, the sand diameter did not greatly affect outflow discharge (**Fig. 6b**).

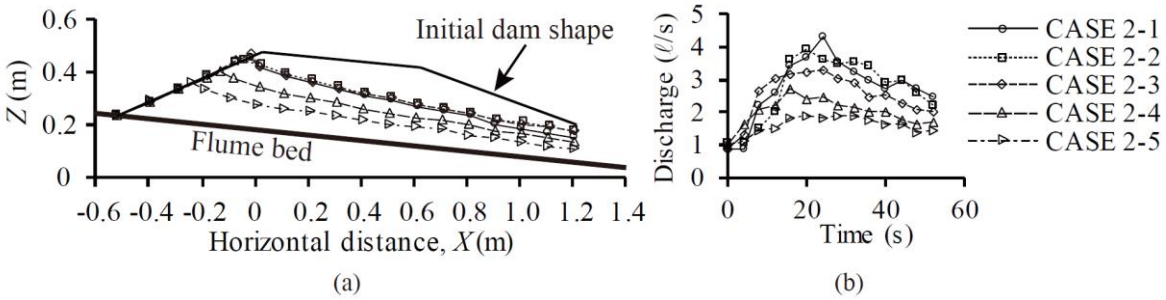

Fig. 6 (a) Shape of the dam when the reservoir began to overflow and (b) outflow hydrograph.

NUMERICAL ANALYSIS OF PROGRESSIVE FAILURE

We modeled the process of landslide dam deformation caused by seepage flow by adapting a simulation model composed of an unsteady 2-D infiltration model and a 1-D debris flow model (Satofuka et al., 2009). We incorporated a slope-collapse model into this simulation model. **Fig. 7** shows model results for the dam deformation process. The model qualitatively reproduced the process of dam deformation and the rise in reservoir water level.

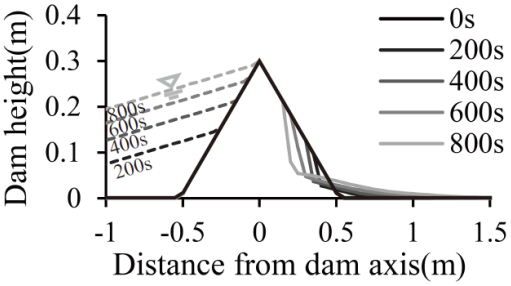

Fig. 7 Dam deformation process

CONCLUSIONS

Experimental results showed that an unusually high peak discharge occurred when large-scale slip occurred and collapsed soil mass was washed away by water. The shape of the dam when the reservoir began to overflow depended on the reservoir water level.

The adapted simulation model qualitatively reproduced the process of dam deformation and the rise in reservoir water level.

Keywords: Landslide dam, outburst, progressive failure, numerical simulation, flume experiments