Numerical approach to predict flood/debris flow hydrograph due to landslide dam failure

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1. Introduction

Landslide dams are one of the significant natural hazards in the mountainous area all over the world. Landslides and debris flows due to heavy rains or earthquakes may block a river flow and create landslide dam naturally. After the formation of landslide dam, the prediction of outflow hydrograph will serve as an upstream boundary condition for subsequent flood routing to predict inundation area and hazard in the downstream. The outflow hydrograph depends on many factors like inflow discharge, impounded water volume, shape and size of the reservoir formed in the upstream of landslide dam, soil properties of the dam body, mode of failure etc. Peak discharge produced by such events may be many times greater than the mean annual maximum instantaneous flood discharge. Fig. 1 shows the comparison of peak discharge with mean annual maximum instantaneous flood discharge for some events of natural dam failure in Nepal. The recorded data of Budhigandaki river shows peak discharge due to LDOF is about 5.79 times greater than the mean annual maximum instantaneous flood discharge (about 16 km downstream). For similar event in Trishuli River is about 1.8 times greater than the mean annual maximum instantaneous flood discharge. One of the GLOF event in Dudh Koshi River, peak discharge is about 2.7 times greater than mean annual maximum instantaneous flood discharge (about 91 km downstream). In-depth knowledge of the mechanism of the dam failures and measured data are still lacking so a simulation model of the dam failure process will therefore be useful. In this context this study aims to predict the outflow hydrograph resulted from failure of landslide dam by sudden sliding through flume experiments and numerical simulations.

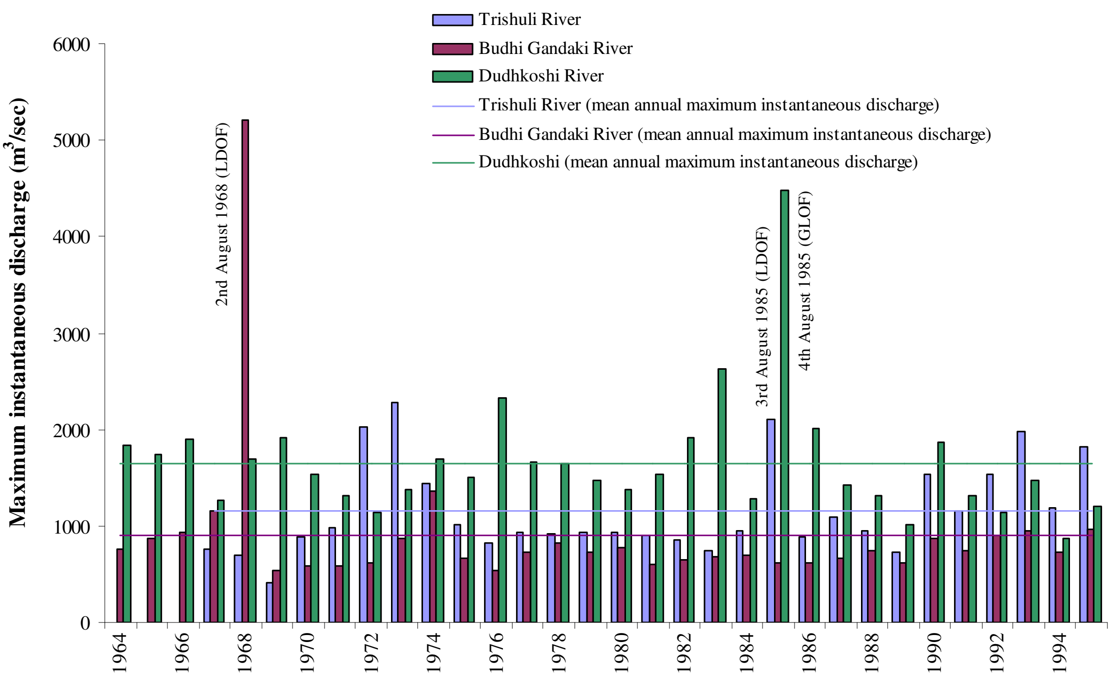

Fig. 1: Comparison of peak discharge with mean annual maximum instantaneous flood discharge for Landslide dam outburst flood (LDOF) & Glacier Lake Outburst Flood (GLOF) events (DHM: 1998,2004)

2. Numerical model

The model of the landslide dam failure to predict outflow hydrograph consists of three models. The flow chart of integrated model of landslide dam failure is shown in fig. 2. The seepage flow model calculates pore water pressure and moisture content inside the dam body. The model of slope stability calculates pore water pressure and moisture content inside the dam body. The model of slope stability calculates the factor of safety and the geometry of critical slip surface according to pore water pressure and moisture movement in the dam body. Simplified assumption is made for initial transformation of the dam after the slip failure. The slipped mass is assumed to stop at the sliding surface where slope is less than angle of repose and the shape of slipped mass is assumed as trapezium. The model of dam surface erosion and flow calculates dam surface erosion due to overflowing water. The details of each model can be found in Awal et al. (2007) and Takahashi and Nakagawa (1994).

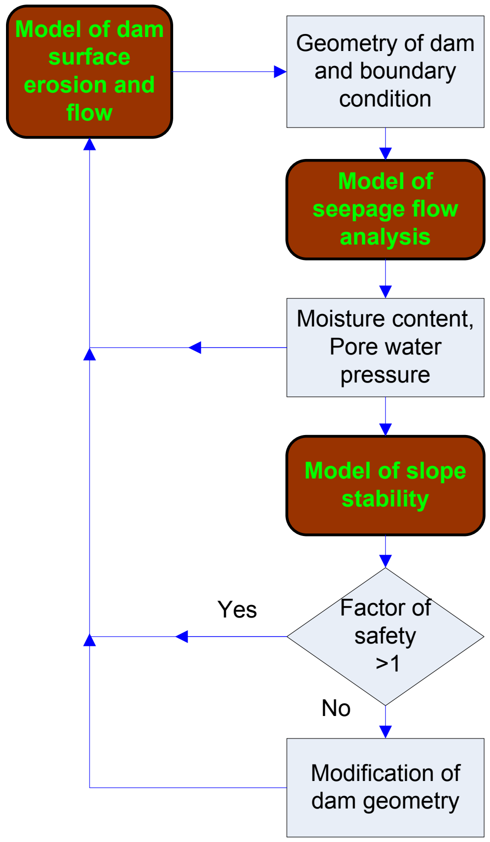

Fig. 2: Integrated model of landslide dam failure

3. Experimental study

Numerical simulation and flume experiments were performed to investigate the mechanism of landslide dam failure and resulting hydrograph. The schematic diagram of the flume and other accessories used in the experiment are shown in Fig. 3. Mixed silica sand of mean diameter 1mm is used to prepare triangular dam in the flume.

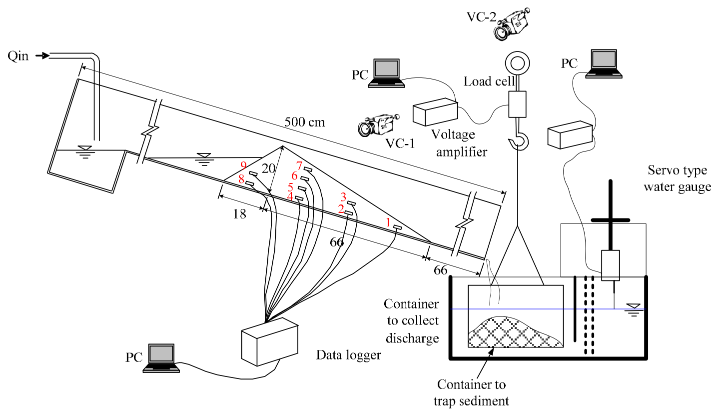

Fig. 3: Experimental setup

The shape of slip surface during sliding of the dam body was measured by analyses of video taken from the flume side. Water content reflectometers (WCRs) were used to measure the temporal variation of moisture content during seepage process. Load cell and servo type water gauge were used to measure sediment and total flow in the downstream end of the flume.

4. Results and discussions

Steady discharge of 30.5 cm^3/sec was supplied from the upstream end of the flume. The sudden sliding of the dam body was observed at 447sec in the experiment whereas in the simulation it was observed at 410sec. The simulated time was slightly earlier than the experimentally observed time that may be due to the assumption of immobile air phase in unsaturated flow and variation of saturated hydraulic conductivity. Fig. 4 shows the comparison of simulated and experimental slip surface. For the same experimental conditions, moisture content in the dam body was measured by using WCRs. Fig. 5 shows the simulated and experimental results of moisture profile at WCR-4, WCR-5, WCR-6, WCR-8, and WCR-9 which are in good agreement. The geometry of predicted critical slip surface was also similar to that observed in the experiment.

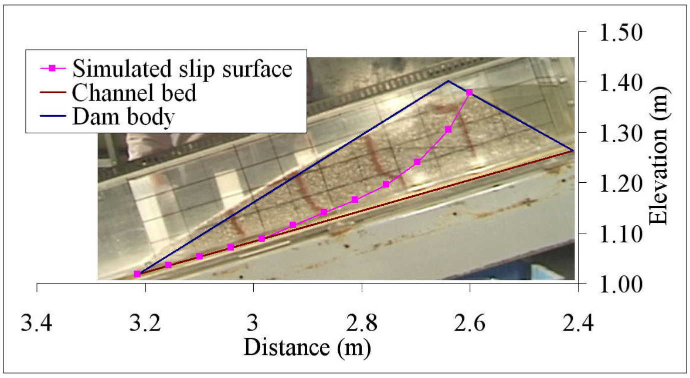

Fig. 4: Comparison of simulated and experimental slip surface

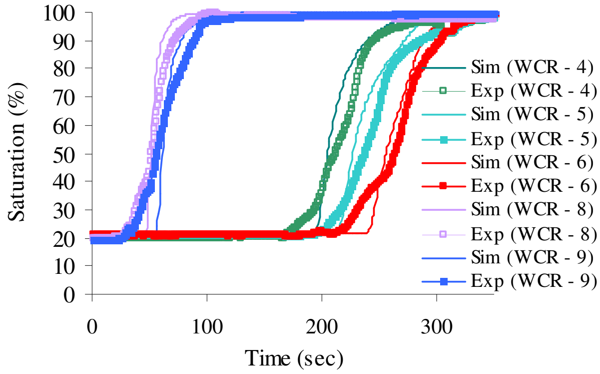

Fig. 5: Simulated and experimental results of water content profile for different WCRs

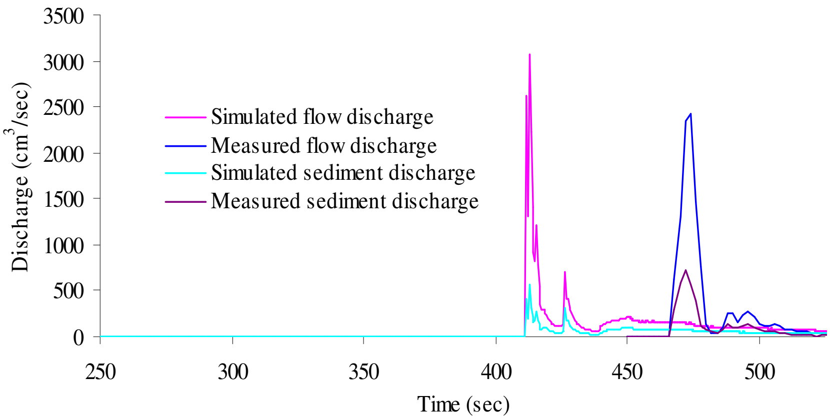

Fig. 6: Outflow hydrograph

Fig. 6 shows the simulated and experimental results of outflow hydrograph. There is some time lag between failure of dam and movement of slipped soil mass but in the model, the time necessary for such a deformation is assumed as nil so the simulated peak is earlier than experimental peak. Peak discharge depends on the shape of the dam body assumed after sliding and parameters of erosion and deposition velocity.

5. Conclusions

Sudden sliding failure of landslide dam was studied in the experimental flume. The movement of moisture in the dam body measured by using WCRs, critical slip surface observed in the experiment and predicted outflow hydrograph are close to the result of numerical simulation. The predicted hydrograph can be used for flood mitigation in the downstream. The model can be further extended to three-dimensions for the better representation of landslide dam failure.

Reference

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