

EFFECT OF DESIGN PARAMETERS ON ENERGY MITIGATION BY A DEBRIS FLOW BARRIER

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ABSTRACT

This paper presents debris mobility analysis results for a slit type debris flow barrier and the effect of its design parameters on the barrier's performance. Numerical simulation of various cases was performed using CFD program FLOW-3D with different heights and slit ratios of barrier. The result shows reasonably correlated relationships between the barrier's design parameters and energy mitigation by the barrier, which can contribute to an optimum design of the debris flow barrier.

Keywords: debris flow, multiphase simulation, debris flow barriers, slits.

1 INTRODUCTION

Debris flows, which flow with extremely rapid velocity and large volume, can cause economic and societal damages in urban areas. One of the methods to prevent this flow is to install debris flow barrier that blocks the mass and dissipates energy of the flow [1]. Many researchers investigated the mechanism involved in the debris flow barrier based on experiments [2]–[4] and by numerical studies [5]–[7]. Wenbing and Guoqiang [2] performed non-viscous debris flow experiment and examined the effect of slit size on debris flow trapping. Lim et al. [3] compared the trap effect of various slit type barriers with hydraulic model experiment. Choi and Kwon [4] investigated the role of spacing and angle of slit-type barriers on velocity reduction and trap ratio of debris flows in laboratory-scaled experiment. Kwan et al. [5] propose a staged debris flow with effect of multiple debris flow barrier and compare the results with numerical simulations. Armanini and Larcher [6] theorized and experimented debris flow barrier with single slit in a narrow basin and suggested a rational criterion for the design of barrier to control the bed/suspended load and its deposition. Campisano et al. [7] improved the evaluation of [6] by considering unsteady flow conditions to decrease inaccuracies of hypothesis of [6].

However, performance of slit type barrier against debris flows with respect to other design parameters still remains poorly identified. Moreover, many of researchers did not consider the effect of overflow when the debris flow first hit the barrier, which greatly influences the energy mitigation and trapping performance.

In this paper, energy mitigation and trap ratio for different types of barrier were obtained with variation of height and slit ratio. Numerical flow simulations were conducted for this study via a sediment-scour physics model implemented in a CFD program FLOW-3D which considers transport of both solid and liquid phases of debris flow. Reliability of the simulations with FLOW-3D was also checked by comparing the numerical solution with the results of Choi and Kwon [4].

2 NUMERICAL MODEL

2.1 Flow-3D

Flow-3D is a commercially available CFD software that can simulate many flow processes and it is capable of predicting the free-surface flows with high accuracy. The algorithm is



based on Volume of Fluid (VOF) method which was first developed by Hirt and Nichols [8]. The sediment scour model calculates the sediment transport processes including entrainment, deposition, bedload transport and suspended load transport by using empirical models for each process [9]. The velocity at which the grains leave the packed bed and settling velocity are calculated based on eqn (1) and eqn (2) respectively.

$$u_{lift,i} = \alpha_i n_b d_*^{0.3} (\theta_i - \theta_{cr,i})^{1.5} \sqrt{\frac{\|g\| d_i (\rho_i - \rho_f)}{\rho_f}}, \quad (1)$$

$$u_{settling,i} = \frac{\nu_f}{d_i} [(10.36^2 - 1.049 d_*^3)^{0.5} - 10.36], \quad (2)$$

where α_i is the entrainment coefficient of species i , n_b is the outward normal vector of the packed bed surface, θ_i is a shields parameter, $\theta_{cr,i}$ is a critical shields parameter, d_i is grain diameter, ρ_i is the mass density of sediment grains, ρ_f is mass density of fluid and ν_f is the kinetic viscosity of fluid. d_* is the dimensionless grain size given by eqn (3).

$$d_* = d_i \left[\frac{g(\rho_i/\rho_f - 1)}{\nu_f^2} \right]^{1/3} \quad (3)$$

Bed-load transport is the model of sediment transport due to rolling or bouncing over the surface of the packed bed of sediment and FLOW-3D provides three different equations for volumetric bedload transport rate of sediment q_i . In this study, Meyer-Peter and Muller equation was selected for bedload transport calculation (eqn 4).

$$q_i = c_i B_i [g(\rho_i/\rho_f - 1) d_i^3]^{0.5} (\theta_i - \theta_{cr,i})^{1.5}, \quad (4)$$

where c_i is the volume fraction of species i in the bed material and B_i is the bedload coefficient.

Suspended load transport is calculated by solving its own transport eqn (5).

$$\frac{\partial C_{s,i}}{\partial t} + \nabla \cdot (u_i C_{s,i}) = \nabla \cdot \nabla (D C_{s,i}), \quad (5)$$

where $C_{s,i}$ is suspended sediment volume concentration, u_i is sediment velocity, and D is the diffusivity.

2.2 Model in simulation

Channel for debris flow is simply modelled as shown in Fig. 1. Width and length of the modelled channel is 0.1m and 1.6m, respectively and barriers were located in the middle of channel. To investigate the effect of height and slit ratio on energy mitigation, 30 cases were simulated with 6 different heights H (20mm, 40mm, 70mm, 90mm, 110mm, 130mm) and 5 slit ratios $r = \frac{b}{B}$ (0, 0.1, 0.15, 0.2) (Fig. 2). Main properties of sediment used in the three-dimensional model is listed in Table 1.

3 RESULTS

3.1 Energy mitigation

Imaginary plane (Plane A) located 0.7m from barriers was created to get the kinetic flow energy. Then the energy distribution of each case was plotted in Fig. 3 and data sets with same slit ratio was group in same colours. In the case of closed barrier, kinetic flow energy decreases with increases of height. Slit-type debris flow barrier also exhibits a negative relationship with height of the barrier in general but its change is less influenced by the height change. However, the kinetic flow energy shows a positive relationship with the slit ratio.



Figs 4 and 5 show the variation of kinetic energy with change of impacted area of barrier. Data sets that have same slit ratio (Fig. 4) and height (Fig. 5) were expressed in same colours. Average inclination shown in Fig. 4 is steeper than that shown in Fig. 5 and it can be concluded that change of slit ratio influences more on the energy mitigation than change of height.

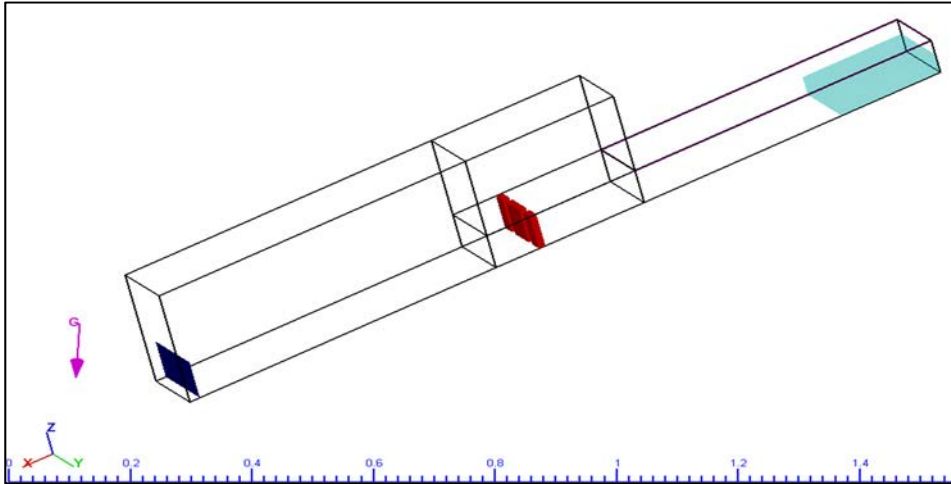


Figure 1: Three-dimensional model for debris flow channel.

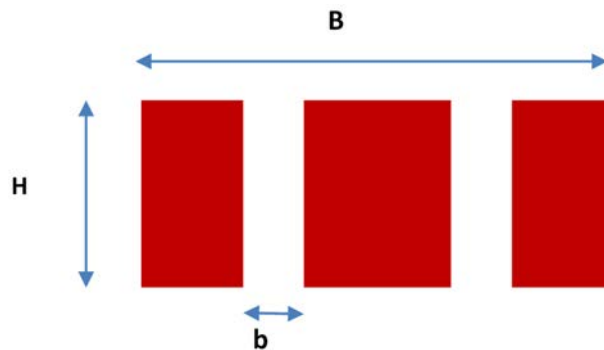


Figure 2: Design of barrier in the model.

Table 1: Input properties of sediment in three-dimensional model.

Item	Unit	Value	Item	Unit	Value
Initial Volume	m^3	0.001	Grain Density	kg/m^3	2650
Density	kg/m^3	1160	Grain Mean Diameter	mm	0.6
Critical Shields Number	1	0.05	Bed Load Coefficient	1	8
Entrainment Coefficient	1	0.018	Angle of Repose	Degree	32

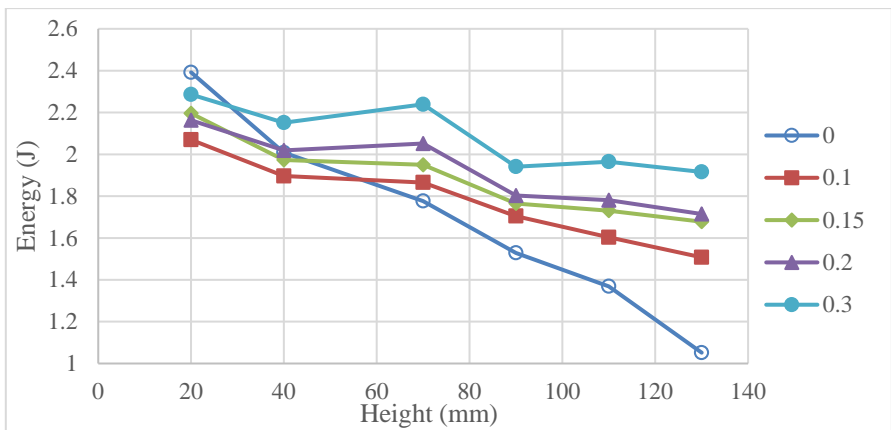


Figure 3: Distribution of debris flow energy with height/slit ratio change.

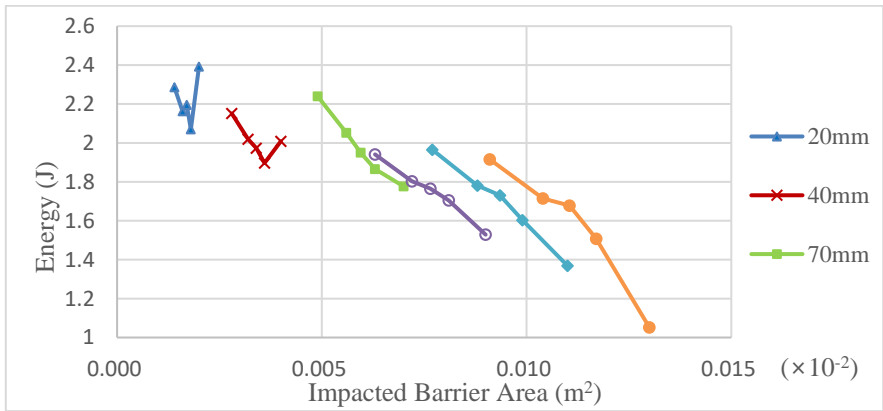


Figure 4: Distribution of debris flow energy with impacted barrier area (slit ratio change).

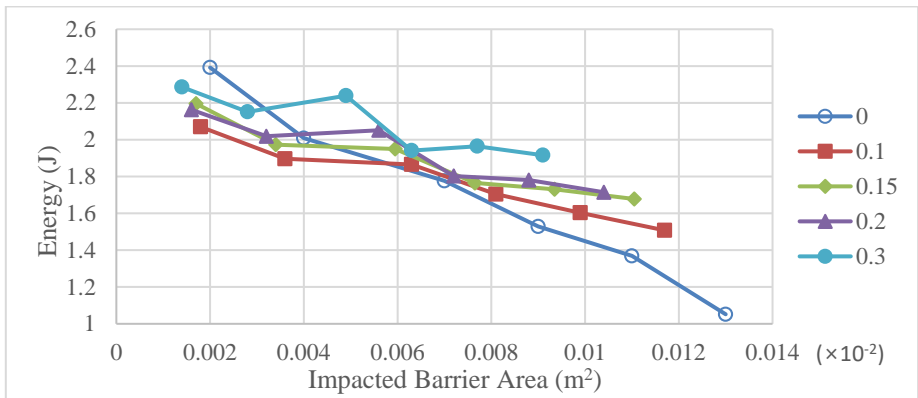


Figure 5: Distribution of debris flow energy with impacted barrier area (height change).



3.2 Trap effect

Fig. 6 plots trap ratios of packed sediment that deposited behind barriers. Trap efficiency can be calculated with an initial sediment mass of 1.043kg. The result shows that in all the open type barrier cases, the trap ratio increases drastically when the height of barrier changes from 70mm to 90mm. If the barrier height is less than 70mm, sediment deposited like Fig. 7 while sediment deposited on wider area like Fig. 8(a). Fig. 8(b) shows that change of deposited sediment volume with time is different between two groups.

Moreover, some effect of trapping decreases when the barrier height increases from 90mm to 110mm. Therefore, it seems that there must be a threshold and optimum value in the dimension of barrier to collect an effective trapped material.

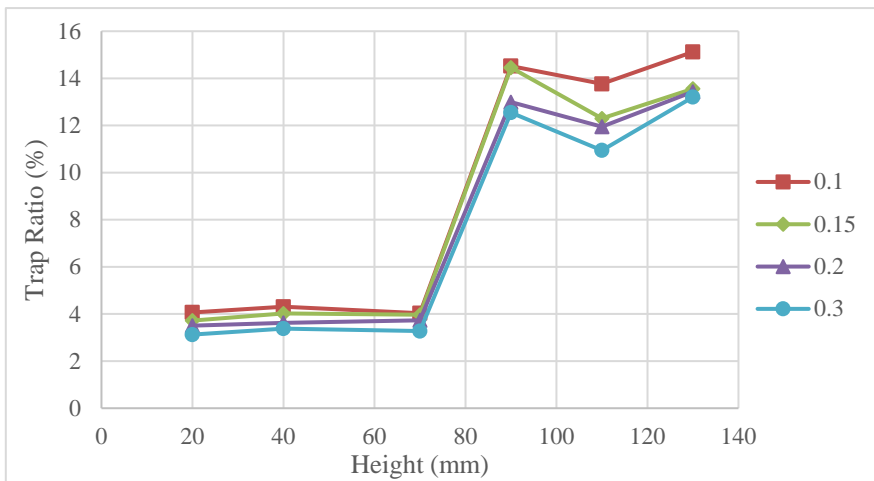


Figure 6: Distribution of trap ratio with change of design.

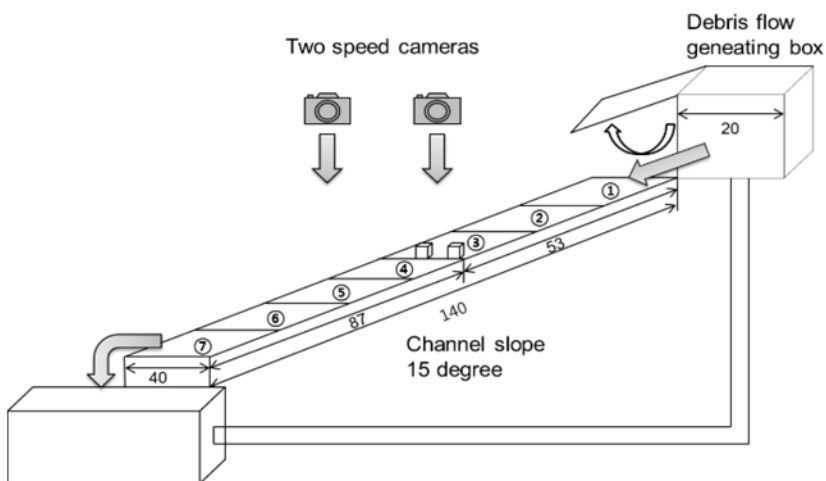


Figure 7: A schematic drawing of the experimental setup [4].

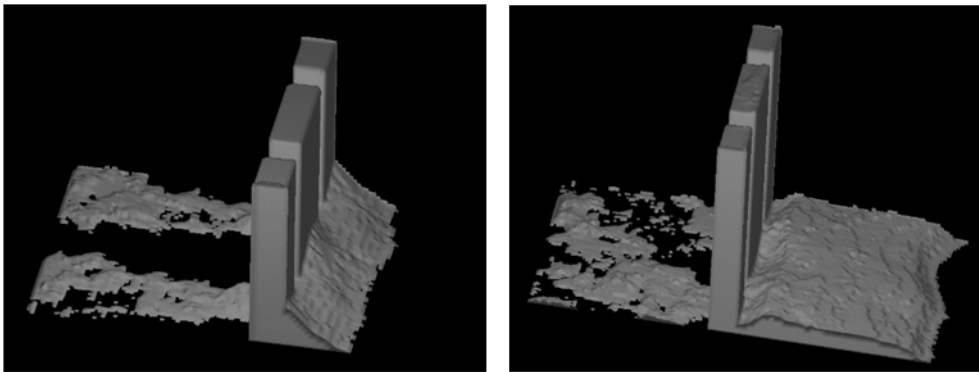


Figure 8: (a) Sediment deposition (height = 70mm); (b) Sediment deposition (height = 90mm)

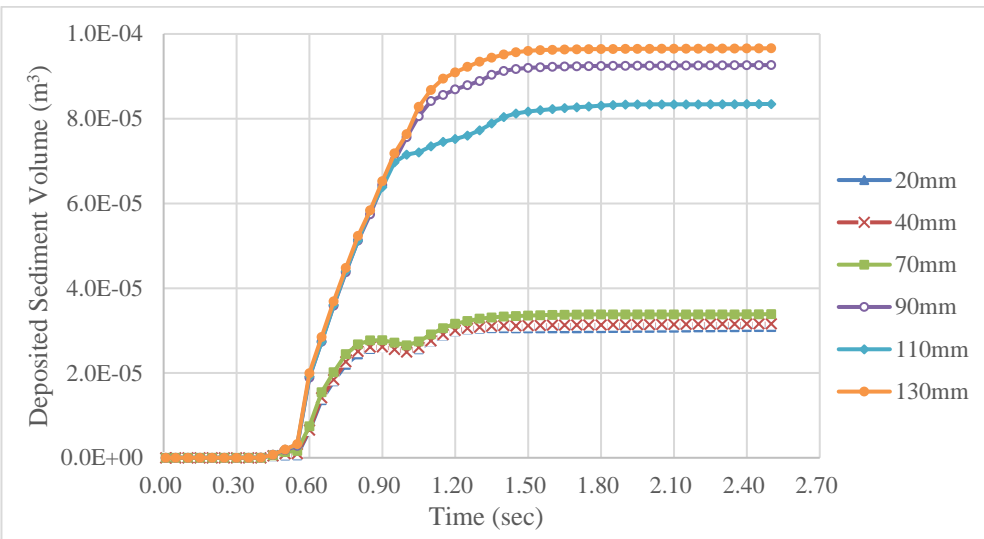


Figure 9: Deposited sediment volume change with time.

4 NUMERICAL VALIDATION

Choi and Kwon [4] performed laboratory-scaled experiment of slit-type barriers and analysed the roles of barrier arrangement on velocity reduction and trap ratio in debris flows. To check the reliability of the program, simulation that has same conditions with experiment of Choi and Kwon [4] was performed and the numerical solution was compared with experiment data.

4.1 Experimental condition

Choi and Kwon [4] used a mixture with 3.5kg of water and 1kg of Joomunjin standard sand (mean diameter 0.6mm) for debris flow generation. Schematic concept of experimental setup is shown in Fig. 7. Experiment was scaled down to 1/30 from an average barrier size in Korea so that scaled width, length of channel and width of barriers are 0.4m, 1.4m and 50mm

respectively. The barrier is located between section 3 and section 4 of channel and in order to consider the arrangement effect of barriers, 7 types of barrier with different angle of barriers (Fig. 10) were tested. To measure velocity data of debris flow, two speed cameras captured the speed of test particle and the pictures were analysed using particle tracking velocimetry program.

4.2 Comparison with numerical solution

Comparison between numerical solution and experimental data of flow velocity in section 5 is shown in Fig. 11. General trend of reduction ratio match well with the experiment. Besides, it supports conclusion of Choi and Kwon [4] that V type barrier arrangement shows higher velocity reduction than P type barriers. Error between numerical solution and experimental data considered to be induced by difference in method of measuring the debris flow velocity.

5 CONCLUSION

This study investigated the influence of design parameters (height and slit ratio) for a debris flow barrier based on the numerical flow simulation results. The performance of a barrier can be evaluated with kinetic flow energy and trap ratio for each case.

The distribution of energy in accordance with impacted barrier area was considered and it could be concluded that change of slit ratio influences more on energy mitigation than change

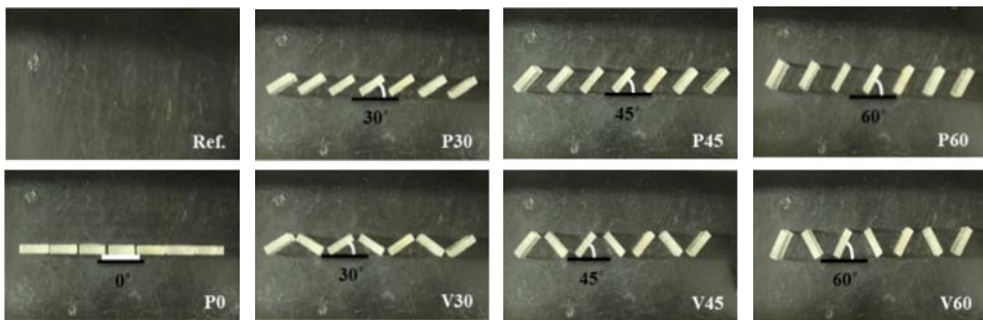


Figure 10: Arrangement of slit-type barriers [4].

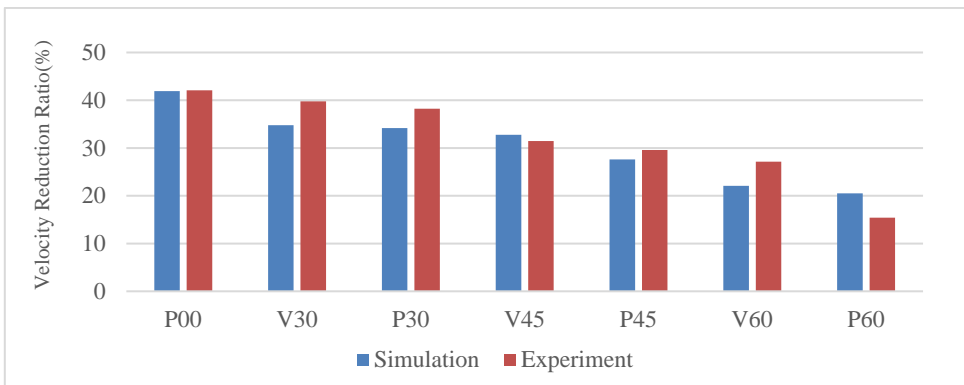


Figure 11: Velocity reduction ratio in section 5.

of height. As for the trap ratio, it seems that there might be sudden increase when the barrier height exceeds a threshold value. If the height is lower than the threshold value, most of the debris flows through the slits or over the barrier and the barrier is not capable of slowing down the flow to the settling velocity. It implies that a specific value of barrier height that greatly increases the trapping performance and energy mitigation should be considered in design of debris flow barrier.

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