Study on Trap Efficiency of Frontal Slope Angle of the Steel Open Type Sabo Dam by the SPH-DEM Method

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1. Introduction

On the unresolved aspects regarding one of the countermeasures to debris flow, the destruction to steel open type Sabo dam has been reported many times. For example, there are different degrees of damage that occurred about steel open type Sabo dam in both the debris flow in 2014 Nagiso and 2015 Kanto and Tohoku region, respectively. Although the impact load of the debris flow can be reduced by increasing the angle of the front inclination angle of steel open type Sabo dam, whether there is an effect on the trapping efficiency of debris, such as capture rate, energy absorbing and overflow risk, is still an unknown subject. In this study, the trapping efficiency of different slope angles of the steel open type Sabo dam in stony debris flow will be discussed by employing the SPH method by employing the open-source, DualSPHysics. (The code is from https://dual.sphysics.org/). The interaction between fluid particles and fluid-solid particles is calculated by the SPH method, and solid-solid particles by the DEM method.

2. Steel open type Sabo dam model

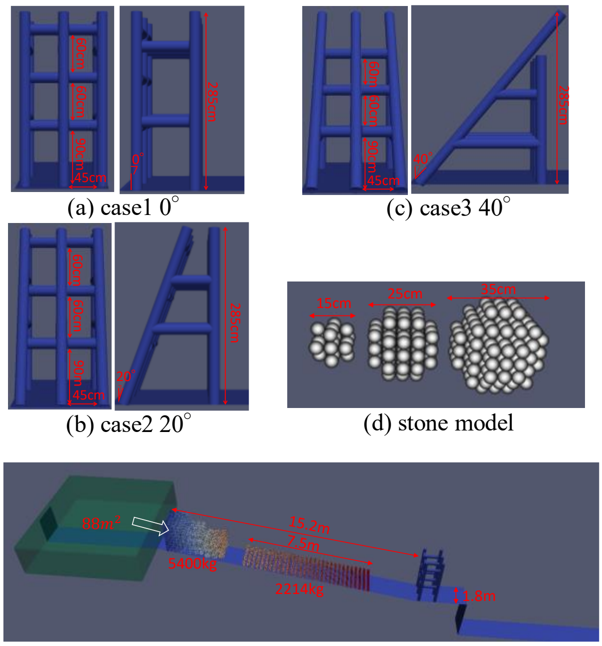
Three cases are modeled by changing the frontal slope of steel open type Sabo dam to 0°(case1), 20°(case2), and 40°(case3). The total time is set to 80.0s and the distance of particles to 0.05m. The stony debris flow is simulated by approximately one million particles, which consists of a water road, water, and stones (weight 2.6). The water road is 15.2m long and 1.8m wide with 10°. There are three sizes of stones with diameters of 15cm, 25cm, 35cm set in the upstream field with the volume ratio of 1:1:1 (total 5400kg). In front of the stones, a riverbed of 7.5m long is modeled by laying small stones (2214kg). The water supply is dam break by 88 m3 of fluid. The parameters of DualSPHysics and DEM are shown in Table 2 and Table3, respectively. Not considering the coefficient of kinetic friction and restitution of the stone but another discussion.

Table. 1 DualSPHysics condition

Step algorithm	Symplectic algorithm
Kernel function	Wendland kernel
Viscosity constant	α=0.01
Boundary condition	Dynamic boundary condition
Shifting condition	Both for fixed and boundary
Interaction between solid-solid	DEM
Program calculation	GPU

Table. 2 DEM condition

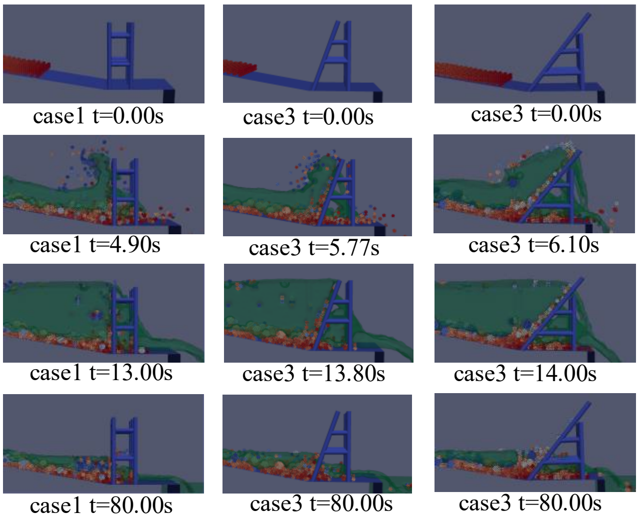
Property	Stone	Sobo dam
Young's modulus (GPa)	32	210
Poisson's ratio	0.242	0.388
Kinetic friction coefficient	0.001	0.400
Restitution coefficient	0.95	0.10



(a) case1 0°
(c) case3 40°
(b) case2 20°
(d) stone model
(e) All figures

Fig1. The stony debris flow model

Table. 3 Flow process



3.Simulation results

3.1 Motion process

In case1, the stony debris flow impacts steel open type Sabo dam, part of the water flowed through the dam (mainly from the lowermost portion through), part of the reverse flow happens owing to the reaction force, causing the highest stone along the frontal slope climb to 1.83m at 4.9s and finally there are total 360kg stones through. In case2, the frontal slope is changed to 20°, causing the stones to climb up to 2.10m at 5.1s along the slope after impact, while being propelled upward by the fluid flowing through it, and there are 414kg stones through. In case3, the frontal slope is significantly steeper, reaching 40°, which increases the stone's capacity to climb up the slope after contact, increasing the chances of going through the dam. Almost no backflow occurs compared to the case1 and the highest stone along the slope climb to 3.00m at 6.1s and there are 407kg stones through finally.

3.2 Energy absorbing for fluid

The steel open type Sabo dams are set on a horizontal platform of 3.0m in length and 1.8m in width at the downstream field. Only the energy of the fluid is considered here because most of the stones are blocked and the fluid passes through. There is no gravitational potential energy change in the platform so that only the kinetic energy is used to show the decelerate work, which is derived from the momentum equation:

$$E = \frac{1}{2}mv^2 \qquad (1)$$

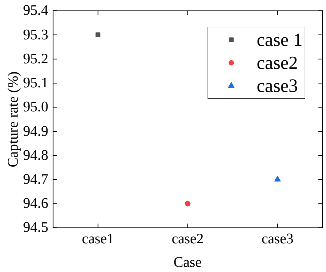


Fig. 2 Capture rate

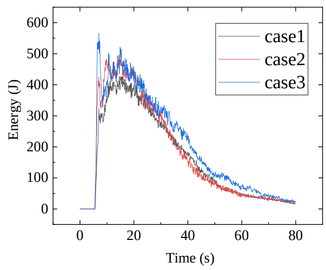


Fig. 3 Kinetic energy

where the mass of a particle is 0.325kg, and the velocity of the fluid flow at the moment of entering and leaving the platform is calculated by using the post-processing in the SPH method. The maximum energy of the case1 is 426J, case2 and case3 are 1.16 times and 1.33 times of case1 respectively (see Fig. 3).

3.3 Overflow

Case1 starts to overflow at 5.3s and lasts for a total of 21.2s, where the maximum weir height is 3.05m at 13.0s. Case2 starts to overflow at the 5.5s and ends at 19.0s, a total of 3 times of overflow phenomena can be observed, the longest is less than 2.0s, and in which case the maximum weir height is 2.92m at 13.8s. Case3 starts to overflow at 5.2s and lasts for a total of 26.8s, where the maximum weir height is 2.80m at 14.0s.

4. Conclusions

From the results of the simulation:

(a) Increase the frontal slope angle of the steel open type Sabo dam, the capture rate is reduced. As a result, the stones will climb along the slope and pass through it from the gap and top.

(b) Increase the frontal slope angle of the steel open type Sabo dam, the decelerate work is weaker.

(c) With increasing the angle of the frontal slope, the overflow is more likely to occur, because more fluid rises along the slope after impact and crosses it.

(d) Although the area of fluid contact with the dam in case1 is smaller and subject to less friction, the energy consumption is greater than in case2 and case3, so the effect of the angle of frontal slope is greater than the frictional force for the ability to absorb energy.