Experimental Study of the Sediment Trap Effect of Steel Grid-Type Sabo Dams

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Landslides caused by rain often take the form of earth flows when they reach their final stage in river valleys. Conventional steel grid- or slit-type sabo dams were originally developed for debris flows containing boulders at their leading edge and do not contain earth flows as effectively as they contain the flows for which they were designed. If the volume behind these types of dams is not quickly filled by a debris flow, subsequent earth flows pass through the dam, because these subsequent flows are composed of less coarse rock and gravel. Therefore, we designed and built several model sabo dams with closely-spaced horizontal units. We then conducted hydraulic experiments focusing on the effects of these closely-spaced horizontal units, with the objective of ensuring that they capture materials in the later phases of debris flows. Experimental results indicated that this new design of sabo dam is better at capturing finer sediments in both debris flows and earth flows.

1. INTRODUCTION

Steel grid-type sabo dams are considered to have a minimal impact on riverine ecology because, under ordinary conditions, they do not block the river course. For this reason, recent research has focused on this type of dam. The grids are constructed of steel pipes set in a lattice pattern. However, the larger the grid is, the more skill is required for its assembly; this one of the primary restrictions associated with these dams. Consequently, authorities are interested in other sabo dam designs that may be equally effective at trapping sediment but require fewer pipe units. Takahara et al. (2007) described the characteristics of steel pipe slit-type dams that use vertical or horizontal units to trap earth flows. They found that it is possible to develop sabo dams that are capable of efficiently trapping sediment on stream beds with a gentle slope, where sediment transport takes the form of earth flows, using lattices composed of vertical and horizontal units of differing diameters.

According to *Ishikawa* [1985] and *Suwa* [1988], debris flows are characterized by an initial concentration of the largest components of rubble, followed by finer sediments. However, once the dam becomes filled with trapped sediments, finer sediments can be carried away by subsequent flooding events. Any large sediment flow through a dam will thus have an effect downstream.

Numerous studies have been conducted on steel

grid-type sabo dams [e.g., *Ashida et al.* 1980,1987; *Mizuno et al.* 1996, 1987; *Mizuyama et al.* 1995; *Takahashi et al.* 2001a, 2001b; *Watanabe et al.* 1980], but none appears to have assessed the downstream effects that occur when these dams fail to trap sediment. The purpose of this study was to develop a dam that is highly efficient at trapping sediment when it is situated on a gentle gradient, and to test various versions of the design using hydraulic experiments.

2. MATERIALS AND METHODS

The experiments used a scale of 1:40. Sand (particle size: 0.84 mm) was bonded to the channel bottom. **Figure 1** shows a diagram of the channel and **Figure 2** shows the gradation of the sediment used in the experiment.

2.1 New dam concept

The experiment focused on outflows of trapped sediments following debris flows. We employed a new design of sabo dam with the goal of blocking such outflows. **Figure 3** shows a conventional sabo dam (Type 1) and **Figure 4** shows the experimental design (Type 2). The experimental dam differs from the conventional dam in that it has thin, closely-spaced, horizontal units attached to the downstream side of the dam. The spacing from the bottom horizontal unit to the ground was adjustable, as shown in **Figure 4** (c). Three Type 2 configurations (Types 2-1, 2-2, and 2-3) were

constructed and tested; the horizontal units were spaced 0.5, 1.0, and 2.0 times the D_{95} of the experimental sand, respectively. **Figure 5** shows a Type 3 dam; in this dam, horizontal units had identical diameters to those in Type 2, but they were located on the upstream side of the dam. **Figure 6** shows an upstream inclined grid-type model dam, with the horizontal units and vertical units equally spaced. **Figure 7** shows an upstream inclined slit-type dam with horizontal beams spaced 3.0 times the D_{95} of the experimental sand, a 3.0×1.5 grid-type dam. The models shown in **Figures 1, 5, 6,** and **7** were constructed and tested for comparison with the experimental designs (**Figure 4**).

2.2 Experimental conditions

Table 1 shows the experimental conditions and cases used in this study. The channel slope (θ) was set at 16° (Conditions and) and 12° (Conditions and). Water discharge (Q) was set at 2.5 l/s (Conditions and) and 3.0 l/s (Conditions and). Conditions and assumed a debris flow, while Conditions and assumed an earth flow. “ T_1 seconds” indicates the period of time during which sediment (in either a debris flow or an earth flow) is trapped behind the sabo dam, ending when subsequent flow from the upstream tip of the accumulated sediment has stopped and no further washing occurs. T_2 was a

fixed time period set for subsequent flows. Q , T_1 , and T_2 were set based on data obtained from a preliminary experiment. Conditions I and II assumed that the reservoir was filled with sediment from the river flow during time T_1 . Conditions III and IV assumed that the river flow was not sufficient to fill the reservoir with sediment during T_1 .

All model dams were tested under Conditions and . All dams were also tested under

Fig.1 Experiment channel

Fig.2 Grain size distribution of the using materials

Fig.3 type-1 model

Fig.4 type-2 model

Fig.5 type-3 model

Fig.6 grid-type model

Fig.7 grid 3.0x1.5 type model

Table1 Experimental cases

Run-No.	condition	dam model	θ (°)	Q (ℓ / s)	V (ℓ)	T_1 (s)	T_2 (s)	mode
1		type-1	16	2.5	32.2	7	20	debris flow
2		type-2 - 1						
3		type-2 - 2						
4		type-2 - 3						
5		type-3						
6		grid						
7		grid-3.0×1.5						
8		type-1	12	3.0	47.2	25	20	earth flow
9		type-2 - 1						
10		type-2 - 2						
11		type-2 - 3						
12		grid-3.0×1.5						
13		type-1	16	2.5	16.1	2	15	debris flow
14		type-2 - 1						
15		type-2 - 2						
16		type-2 - 3						
17		type-3						
18		grid						
19		grid-3.0×1.5						
20		type-1	12	3.0	23.6	10	15	earth flow
21		type-2 - 1						
22		type-2 - 2						
23		type-2 - 3						
24		grid-3.0×1.5						

Conditions and with the exception of Type 3 and grid-type dams; these were not included because they have closely-spaced units and should be able to trap a large quantity of sediment when the channel gradient is 12° (Conditions and).

2.3 Measured parameters

We estimated the sediment trap rate (%), f_1 , and outflow rate (%), f_2 , and assessed the performance of the sabo dam design based on these two parameters. Equations (1) and (2) were used to calculate f_1 and f_2 . V was the volume of sediment used in the experiment, V_1 was the volume trapped behind the dam model during time period T_1 , and V_2 was the runoff volume during the time period at T_2 . **Figure 8** provides diagrams for V_1 and V_2 .

$$f_1 = (V_1 - V_2)/V \times 100(\%) \quad (1)$$

$$f_2 = V_2/V \times 100(\%) \quad (2)$$

3. EXPERIMENTAL RESULTS AND OBSERVATIONS

Figure 9 illustrates the experimental results.

3.1 Channel gradient of 16° and sediment trap conditions

Under Condition I, the dam models did not differ greatly in sediment trap rate (f_1); see **Fig. 9-I**. In contrast, under Condition III (**Fig. 9-III**), which assumed that the reservoir would be less than completely full of sand after T_1 , f_1 values were lower for the Type 1 and 3.0 × 1.5 grid-type dams.

We observed a grain-size sorting effect in the sediment downstream of the dam in Condition I with a 16° gradient. Sorting was characterized by the presence of boulders at the leading edge of the flow mass. It resulted in sediment's being trapped by all grids upstream of the dams and in completely full sand reservoirs. This finding explains why the models did not differ greatly in the volume of sediment washed downstream during subsequent flows. **Photo 1** illustrates the sediment capture; no sediment appeared in dam reservoirs, but only behind the grid-type sabo dams upstream. Conversely, in Condition III, large quantities of gravel and finer materials were washed downstream during T_2 . Type 1 and 3.0×1.5 grid-type sabo dams, which lacked closely-spaced horizontal units, were unable to trap this sediment. Therefore, f_2 values were higher for Type 1 and 3.0×1.5 grid-type sabo dams than for other types of sabo dams.

Thus, additional horizontal units appear to be unnecessary in sabo dams located in steep riverbeds (gradients of 16° or more), because their reservoirs can be expected to fill completely after a single sediment flow.

3.2 Sediment trapping on a 12° gradient

We did not observe any grain-size sorting under experimental Conditions II (**Fig. 9-II**) or IV (**Fig. 9-IV**). Sediment flowed through the upstream steel grid-type sabo dams without being trapped. Downstream, the Type 2 sabo dam exhibited a high sediment trap rate. **Photo 2** illustrates a typical case of trapping, clearly showing the larger particles that entered the dam and were trapped by the horizontal reinforcing units. This result was due to the characteristic pattern of earth flows: particles (corresponding to "boulders" and "cobbles" in this model) were not gathered at the leading edge of the moving sediment mass. This design exhibited a high trap ratio under this condition and under Condition IV, which also assumed only a half-full volume trapped by the dam.

Fig.9 Experimental results

3.3 Sediment trapping and grid spacing

We tested three versions of the Type 2 sabo dam; trap rates did not differ under any experimental conditions. Interestingly, rates did not differ even on a 12° gradient, where sand entered the reservoir as an earth flow.

Under such conditions, Type 2-3, which had the

widest spacing, yielded the greatest advantages in terms of its influence on the adjacent environment.

3.4 Utility of new dam types on streams with gentle gradients

In terms of capacity and the construction process, it is more efficient to construct sabo dams on gentle slopes than on steep slopes. Our results indicated that conventional steel grid-type sabo dams on gentle slopes are relatively efficient at trapping granular flows. In addition, steel slit-type dams on gentle slopes (Conditions and) are often able to trap driftwood due to their closely-spaced horizontal units. Sediment is subsequently captured behind the driftwood. If a flow contains no driftwood to be trapped, sediment is likely to pass through the dams, as shown in several of the cases tested in this study.

The Type 2 model, which incorporates closely-spaced horizontal reinforcing beams, exhibited high trapping efficiency even on gentle slopes where size-sorting processes do not occur. This design can be used in situations where earth flows are expected.

The high sediment trap rates (f_i) of the Type 3 and grid-type dams provide further evidence that the Type 2 designs are likely to be relatively effective for trapping sediment on riverbeds with gentle slopes.

4. CONCLUSIONS

We obtained the following findings:

1. A granular flow in a riverbed with a gentle slope takes the form of an earth flow. Therefore, steel grid- or slit-type sabo dams, which are designed to allow the passage of certain materials, are not as functionally stable as currently believed, because they are designed to take advantage of the natural size-sorting processes in a debris flow.
2. The proposed dam design, incorporating thin horizontal units, shows considerable potential for trapping sediment in both primary and subsequent flows on gentle slopes, which do not necessarily exhibit the size-sorting process associated with sediment retention.

ACKNOWLEDGEMENTS: The authors are grateful to JFE Kenzai for supporting this project.

REFERENCES

- Ashida, K. and Takahashi, T. (1980): Study of debris flow control: Hydraulic function of grid type open dam, *Annuals. Disaster Prevention Res. Inst., Kyoto Univ.*, No. 23B-2, pp. 433–441 (in Japanese with English synopsis).
- Ashida, K. Egashira, S. Kurita, M and Araki, H. (1987): Debris

Photo.1 Experimental result (condition type2)

Photo.2 Experimental result (condition type2)

- flow control by grid dams, *Annuals. Disaster Prevention Res. Inst., Kyoto Univ.*, No. 30B-2, pp. 441–456 (in Japanese with English synopsis).
- Ishikawa, Y. (1985): Debris flows in the Name River, *Journal of the Japan Society of Erosion Control Engineering*, Vol. 37, No. 5, pp. 24–29 (in Japanese).
- Mizuno, H. and Mizuyama, T. (1996): Experimental study of a grid dam with narrow pipe interval of upper grids, *Journal of the Japan Society of Erosion Control Engineering*, Vol. 49, No. 4, pp. 3–8 (in Japanese with English abstract).
- Mizuno, H. Minami, N. and Mizuyama, T. (2000): Experimental study of controlling debris flow by a consecutive series of open-type steel dams, *Journal of the Japan Society of Erosion Control Engineering*, Vol. 53, No. 1, pp. 19–25 (in Japanese with English abstract).
- Mizuyama, T. Kobashi, S. and Mizuno, H. (1995): Control of passing sediment with grid-type dams, *Journal of the Japan Society of Erosion Control Engineering*, Vol. 47, No. 5, pp. 8–13 (in Japanese with English abstract).
- Suwa, H. (1988): Focusing mechanism of large boulders to a debris-flow front, *Annuals. Disaster Prevention Res. Inst., Kyoto Univ.*, No. 31B-1, pp. 139–151 (in Japanese with English abstract).
- Takahara, T. and Matsumura, K. (2007): Evaluation of sediment trap of ability based on sediment made and members distance, *Journal of the Japan Society of Erosion Control*

Engineering, Vol. 60, No. 4, pp. 55–60 (in Japanese with English abstract).

Takahashi, T. Nakagawa, H. Satofuka, Y. and Wang, H. (2001): Simulation of debris flow deposition by open-type sabo dam, *Annals. Disaster Prevention Res. Inst., Kyoto Univ.*, No. 49B-2, pp. 133–139 (in Japanese with English synopsis).

Takahashi, T. Nakagawa, H. Satofuka, Y. and Wang, H. (2001):

Stochastic model of blocking for a grid-type dam by large boulders in debris flow, *Journal of Hydroscience and Hydraulic Engineering*, Vol. 45, pp. 79–84 (in Japanese with English abstract).

Watanabe, M. Mizuyama, T. and Uehara, S. (1980):

Deliberation about structure against debris flow, *Journal of the Japan Society of Erosion Control Engineering*, Vol. 32, No. 4, pp. 40–45 (in Japanese).