

## FUNDAMENTAL HYDRAULIC FLUME TESTS FOCUSED ON SEDIMENT CONTROL FUNCTION USING A GRID-TYPE HIGH DAM

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### ABSTRACT

In Japan, the recent check dam (sabo dam) construction has been the open-type of the continuity of sediment routing from upstream to downstream a reach in a river basin. Not only in Japan but also in other countries, a lot of experimental and numerical research has been conducted on sediment control using open-type sabo dams. Plans for size and location have been drawn up for grid-type sabo dams with heights of around 20 meters, which is the highest grid-type sabo dam in Japan, in the Amahata river in Yamahashi Pref., where a lot of sediment are yielded and deposited in numerous torrents due to heavy rainfall in 1982. Flume tests are conducted using a straight channel to determine the grid size of a grid-type sabo dam and to confirm its sediment control function. Subsequently, several runs of flume test were conducted supposing several types of debris flow regimes such as steady and uniform debris flows and quasi-steady debris flows, and taking into account sediment transport mode corresponding to bed slope and longitudinal bed profiles in the basin.

In the present study, the sediment control functions of the “grid-type high dam (GHD)”, which is defined as a grid-type sabo dam with a height over 15 m, were examined using several experimental data sets such as the dimensionless sediment runoff volume which is defined as the ratio of runoff sediment volume to inflow sediment volume, temporal changes of mean diameter, sediment concentration and sediment discharge rate passing through the check dam. Addi-

tionally, preliminary flume tests for sediment control using a kind of “steel wire-nets” near the vertically upper parts of the grid were conducted focusing on the simple and the effective countermeasures for the sediment storage in a sabo dam, in order to control the sediment runoff passing through the sabo dam after a lot of sediment is deposited in the sabo dam.

**KEY WORDS:** *grid-type sabo dam, high dam, debris flow, flume tests, sediment control with steel nets*

### INTRODUCTION

There are two kinds of sabo dams (check dams), which are closed and open-type. Recently, in Japan, open-type check dams are constructed taking into account the sediment continuity from upstream to downstream reach in a basin, though there are some matters to be newly solved for sediment control function by the closed type sabo dam. There have been a lot of experimental and numerical researches for sediment control with open-type check dams in all over the world (e.g., ASHIDA *et alii*, 1980, 1987; MIZUYAMA *et alii*, 1997 & 2000, ARMANINI *et alii*, 2001; CHEN *et alii*, 1997; HEUMADER, 2000; LIN *et alii*, 1997; WU *et alii*, 2003; SATOYUKA *et alii*, 2005 and TAKAHARA *et alii*, 2007), the minimum grid size of grid-type check dam, which is a kind of open-type check dam, is practically set to be less than twice of 95 % size of sediment distribution of bed material,  $d_{95}$ . Based on previous experimental data, in the technical standards establishing for sabo mas-

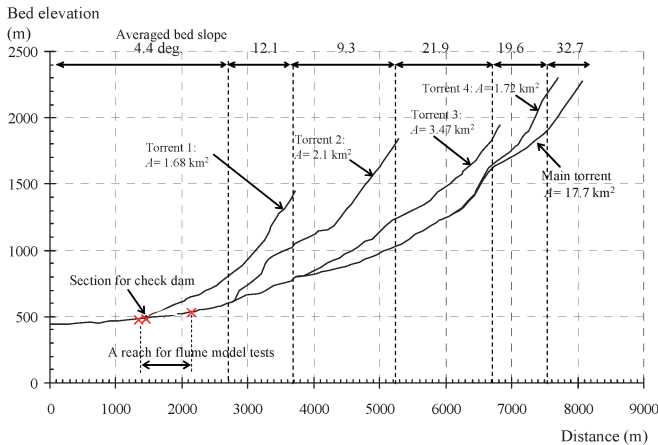


Fig. 1 - Longitudinal bed profiles

ter plan for debris flow and driftwood (2007) by the National Institute for Land and Infrastructure Management in Japan, it is recommended that the minimum grid size of grid-type check dam is  $1.0 \times d_{95}$ .

On the other hand, it is well known that the countermeasures for huge sediment movements such as debris flows and flash floods due to heavy rainfall are needed using an effective check dam with height over 15m taking into account a plan size of storage sediment volume in a dam, costs of check dam's construction in comparison to sediment control with many small size of check dams. Herein, supposing that we define a grid-type check dam with height over 15 m as "grid-type high dam", which is shortly called as "GHD" in present study, there are no researches for sediment control function using such kind of high dam.

There are a lot of experimental researches focusing on debris flows and saturated soil mass movements in steep slope channel, in which bed slope is over 12 degrees and those mass movements have high speed in a flume. It was reported that large boulders could make "arch structure" at the grids in a slit dam in case of debris flows with non-uniform sediment. However, the movements of those boulders are not active in case of debris flow over mild slope bed considering sediment transport modes. There are few researches focusing on sediment control function with a GHD considering sediment transport modes over a bed in storage area of the dam. In present study, several runs of flume tests are conducted for countermeasure using GHD to evaluate the plan for constructing the check dam in a view of sediment transport modes and the appropriate grid size of GHD is discussed using flume data such as temporal changes of debris flow discharge, sedi-

ment concentration, bed profiles and mean diameter. After deciding the grid size, preliminary flume tests focusing on effect of flow discharge size on sediment storage are evaluated with/without steel nets on the grid, which is supposed as one method for controlling easily sediment and for easy maintenance.

## SEDIMENT TRANSPORTATION MODE OKUSAWA RIVER BASIN

Figure 1 shows longitudinal bed profiles of the Okusawa River. The basin is located in Amahata River basin in the Fuji River in Yamanashi Prefecture. The geologic characteristic is classified into sedimentary rock in the Paleozoic and the Mesozoic. Huge volume of sediment was yielded by landslides and debris flows due to heavy rainfall, whose rainfall intensity was 49.5 mm/h and its accumulated rainfall depth in one day was 386 mm, in 1982 in Okusawa creek in Amahata River basin. It is reported that about 0.8 to 1.0 million  $m^3$  of sediment is deposited in the parts of torrents, and that huge sediment transportation still now takes place in the basin. A plan to construct a GHD with around 20 meters high in Okusawa creek in the basin, in which the watershed area is 16.6  $km^2$  and mean bed slope near the section is  $1/13.5$  ( $= 4.2$  deg.), is proposed for 400 thousand  $m^3$  of sediment volume including pore. In this paper, we will call define sediment volume including pore as "apparent sediment volume".

## WATER DISCHARGE AND SEDIMENT CHARACTERISTICS IN THE BASIN

Figure 2 shows the schematics of sediment transport mode (e.g., EGASHIRA, 2006) from mountainous region to downstream reach on a fan. Sediment trans-

Fig. 2 - Sediment transport mode (e.g., EGASHIRA *et alii*, 2006)

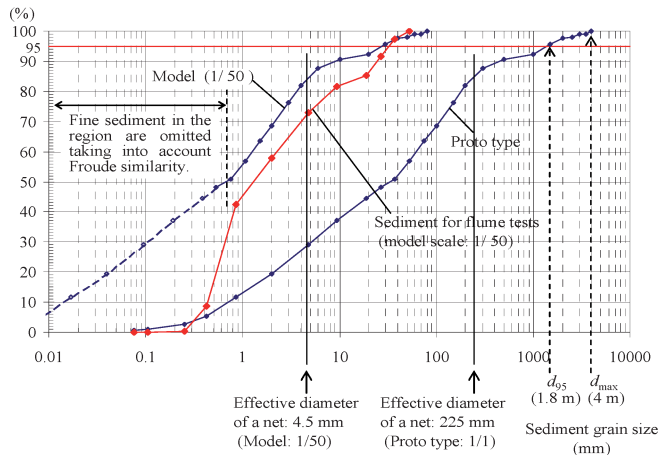
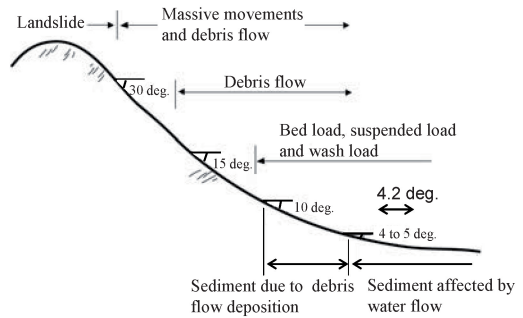


Fig. 3 - Sediment grain size distribution

port mode is debris flow (in other words, sediment laden flow which has two layers of both clear water and hyper-concentrated sediment mixture flow) referring to Fig. 2, when bed slope is  $1/13.5 (= 4.2 \text{ deg.})$ . We suppose three kinds of sediment transport modes in present flume tests, and those are as follows: a) Debris flow due to natural landslide dam break (Type NL), b) Steady and longitudinally uniform debris flow (Type U) and c) Quasi-steady debris flow with a hyper-concentrated front part (Type QS).

Type NL can be rarely formed in the mild slope torrent but the flow scale and magnitude can be large because of huge size of floods due to break and outburst of natural landslide dam. On the other hand, the flow patterns of Type U and Type QS can model equilibrium debris flow for the bed slope. In order to evaluate sediment control with GHD, it is better to suppose several kinds of debris flow modes.

Figure 3 shows the sediment grain size distribution sampled in the torrent bed. The distribution is wide; i.e., maximum size of sediment is about 4000 mm and minimum size is 0.1 mm, and mean diameter,  $d_m$ , is 258 mm and 95 % size of sediment

grain size distribution,  $d_{95}$ , is 1800 mm. In the figure, the sediment grain size distribution used in flume tests (model) is also shown.

The clear water discharge is  $185 \text{ m}^3/\text{s}$  in the peak value (design discharge of clear water), which is estimated using rainfall intensity (49 mm/h), watershed area and peak runoff coefficient (0.8) based on previous maximum rain fall observed in 1982. A steady clear water supply is set taking into account large boulders movements in critical condition for uniform and non-uniform sediment particles in clear water flow (e.g., JSCE 1999).

On the other hand, critical erosion capacity of bed large boulders by debris flows (ITO *et alii*, 2007) is calculated using calculated data obtained by one dimensional numerical simulation introducing erosion/deposition rate formula data for debris flow (ITO *et alii*, 2003) along a main channel as shown in Fig. 1. Minimum clear water discharge for large boulders' movement was estimated as  $60 \text{ m}^3/\text{s}$  (proto type) and the minimum discharge for every component of sediment particles was estimated as  $160 \text{ m}^3/\text{s}$  (proto type) in flume tests.

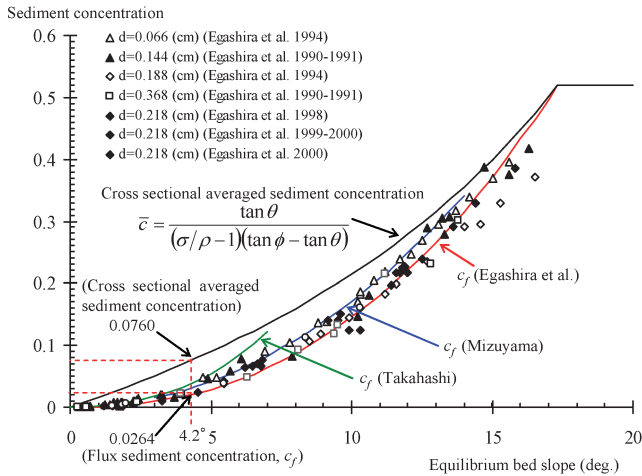


Fig. 4 - Relationship between equilibrium bed slope and sediment concentration

### SEDIMENT CONCENTRATION

There are two kinds of definition of volumetric mean sediment concentration such as cross sectional mean sediment concentration and flux sediment concentration (EGASHIRA *et alii*, 1997).

$$\bar{c} = \frac{1}{h} \int_0^h c \, dz \quad (1)$$

$$c_f = \int_0^h c u \, dz / \int_0^h u \, dz \quad (2)$$

in which  $c_f$  is the flux sediment concentration,  $c$  is the depth averaged (cross sectional) mean sediment concentration,  $h$  is the flow depth,  $c$  is the volumetric sediment concentration,  $u$  is the local mean flow velocity and  $z$  is the axis normal to flow direction.

Figure 4 shows experimental relationships between equilibrium bed slope and flux sediment concentration in debris flow with uniform sediment over an erodible bed. In the figure, several lines of estimation for  $c_f$  (e.g., Egashira *et alii*, 1997; JSCE 1999) are drawn to compare to flume data. The differences between  $c$  and  $c_f$  are remarkable in wide flow regime from debris flow to flow with bed loads, though these can take similar values over around 14 degrees in bed slope, and the setting for sediment discharge rate using  $c_f$  is important in debris flows in case that bed slope is mild such as  $1/13.5$  ( $= 4.2$  deg.).

In case of debris flow with non-uniform sediment, there is little knowledge for equilibrium sediment concentration because the effect of vertical and longitudinal sediment sorting and sieving on the flow are remarkable, and these are few researches for the flow conditions. However, it is expected that mean diameter of debris flow body except frontal part does not change very much, while sediment sorting is active in

a flow body. In present study, relationship between  $c_f$  and bed slope as shown in Fig. 4 can be applied for the setting of sediment supply. Initial bed is set as rigid bed considering sediment deposition in the dam.

### FLUME TESTS

#### HYDRAULIC CONDITION

Figure 5 shows an experimental flume, which is 30 cm wide, 80 m high and 20 m long, and the model scale is set to 1/50 referring to geometrical similarity. The flume is two parts, in which one is 12m in length with 4.2 degrees ( $= 1/13.5$ ) in downstream reach and the other is 8 m length with 16 degrees ( $= 1/3.5$ ) in upstream reach as shown in Fig. 5. A 40.0 cm high sabo dam (20 m in proto type) with grids is set at the downstream reach in the flume.

Herein, hydraulic parameters and geometrical values in present study are mainly shown in model values. Sediment supplying volume is set as  $0.6 \, \text{m}^3$  supposing that a storage area can be trap its volume. Fully saturated debris flow is formed in a channel for three kinds of flow regime (Type NL, QS and U) as shown in Fig. 5. Sediment supply and flow condition for three kinds of sediment transport mode is as follows:

- Type NL: Saturated sediment with height from 61.8 to 129 cm is quickly supplied with water in the upstream reach, where bed slope is 16 degrees. Channel B was used for the flume test as shown in Fig. 5, and bed was erodible bed in the reach 2.0 to 7.5 m from downstream end to prevent friction between sediment particles and bed surface from changing very much.

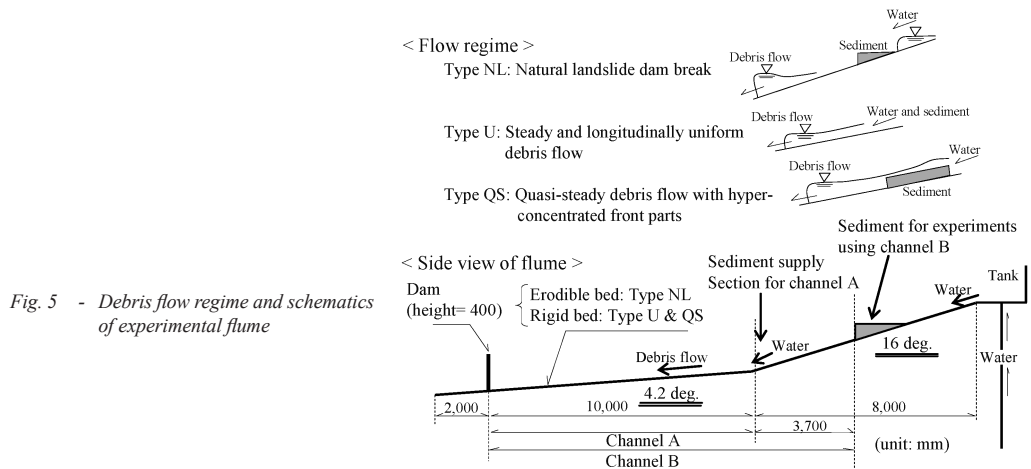


Fig. 5 - Debris flow regime and schematics of experimental flume

- b) Type U: Sediment and water is supplied steadily in upstream end of channel A
- c) Type QS: Sediment, which is 0.1 m in height, 3 m in length and 0.09 m<sup>3</sup> in apparent volume, is set on the bed in upstream reach of channel A to form a frontal part with hyper-concentrated flow at the beginning of Type U flow. Herein, the sediment volume corresponds to sediment deposition for 10 m in flow width, 1.6 m in erosion depth and 700 m in length in a torrent. In the experiment b) and c), crosspieces on the flume bed were set for roughness, and flow resistance of clear water flow and sediment-water mixture flow are confirmed so as to satisfy hydraulic conditions.

Pictures of flow regime are taken by a digital camera from side wall to obtain temporal changes of flow surface and bed surface. Flow rate of sediment-water mixture is measured at the downstream end of the flume and experimental data such as sediment concentration and grain size distributions are obtained. Cross sectional bed profiles are measured at several sections just after stopping debris flow to obtain longitudinal mean bed profiles, and temporal changes of bed surface were obtained.

In flume tests for steady debris flow, sediment and water were stopped twice within one run as follows: 380, 780, 1180 (Final stage) sec. (Type U) and 260, 660, 1060 (Final stage) sec (Type QS) in model scale. In Type NL, temporal changes of hydraulic parameters except longitudinal bed elevation and sediment runoff volume from downstream end were not measured because of high speed and large amount of volume.

As shown in Fig. 3, sediment grain size distribution has wide profile. Hydraulic parameters are deter-

mined using Froude similarity. Grain size in model is affected both by geometrical similarity and by Froude similarity. Herein, let us examine the influence of Reynolds shear stress on flow field using shear velocity Reynolds number defined as  $Re_* = u_* d/\nu$ , in which  $\nu$  is the kinematic viscosity of clear water. In case of  $Re_* > 20$  to 30, ripples can not be formed on the bed surface, and fine sediment particles less than 0.7 mm are omitted to avoid occurrence and formation of ripples and to avoid suspended flow in flume tests (See Fig. 3).

Table 1 is a part of experimental conditions. Table 2 shows the hydraulic conditions for the flows of Type and UQ. Table 3 shows physical characteristics of sediment particles. In those table,  $n$  is the Manning' bed roughness [m<sup>-1/3</sup> s],  $Q_w$  is the clear water discharge,  $c_f$  is the flux sediment concentration,  $\bar{c}$  is the cross sectional mean sediment concentration,  $h_0$  is the uniform flow depth,  $d_m$  is the mean diameter of sediment,  $h_0/d_m$  is the relative flow depth,  $\tau^*$  is the nondimensional bed shear stress defined as  $u_*^2 / \{(\rho-1)gd\}$ ,  $u_*$  is the shear velocity defined as  $\sqrt{gh_0 \sin \theta}$ ,  $\theta$  is the bed slope,  $Fr$  is Froude number,  $\sigma/\rho$  is the specific weight of sediment,  $c^*$  is the sediment concentration in non-flowing layer,  $d_{max}$  is the maximum diameter. The subscript of  $d$  respectively correspond to the percentage (%) size of sediment distribution, while  $k$  is the permeable coefficient of sediment and  $\phi_s$  is the interparticle friction angle of sediment particles. Flux sediment concentrations (e.g.,  $c_f < 0.0264$ ) are specified using Fig. 4 to form the steady debris flow over the rigid bed.

The clearance of the grids of a dam is selected so as to obtain several combination of distance for horizontal bar,  $L_v$ , and vertical bar,  $L_h$ . Figure 6 shows schematics

Run	Flow regime	(1) Horizontal $L_v/d_{95}$	Vertical $L_h/d_{95}$	(2) $V_s$ (l)	$c$ ( $c_f$ )	(3) $V_s$ (l)	(4)	(5) (m/s)	Remarks
1	NL	$L_v 1.0 \times L_h 1.0$		870	0.3	84.8	0.891	4.64	*Channel B *(6) = 95.4 (l)
2	NL	$L_v 1.0 \times L_h 1.25$		870	0.3	79.5	0.893	4.20	*Channel B *(6) = 133 (l)
3	NL	$L_v 1.0 \times L_h 1.5$		870	0.3	90.1	0.886	5.01	*Channel B *(6) = 74.2 (l)
4	NL	$L_v 1.5 \times L_h 1.5$		870	0.3	201	0.737	5.01	*Channel B *(6) = 106 (l)
5	NL	$L_v 1.5 \times L_h 1.5$		200 200 200	0.3	26.5 10.6 5.30	0.868 0.947 0.972	2.62 2.04 1.90	*Channel B *3 surges
6	NL	$L_v 1.0 \times L_h 1.5$		200 200 200	0.3	26.5 15.9 10.6	0.868 0.921 0.947	2.11 2.06 1.88	*Channel B *(7) $L_v/d_{95} = 1.5$ *3 surge
7	U	$L_v 1.0 \times L_h 1.5$		200 200 200	0.0735 (0.025)	36.8 16.0 9.00	0.816 0.920 0.952	0.550 ~0.589	
8	QS	$L_v 1.0 \times L_h 1.5$		200 200 200	0.0735~0.137 (0.025~0.075)	13.1 15.1 9.84	0.936 0.927 0.953	0.729 ~0.833	*Channel A *(7) $L_v/d_{95} = 1.5$ *(8) 3 surge,
9	U	$L_v 1.0 \times L_h 1.0$		200 200 200	0.0735 (0.025)	24.8 13.6 10.4	0.876 0.932 0.948	0.550 ~0.589	(400sec./1 surge) *3 surges
10	QS	$L_v 1.0 \times L_h 1.0$		200 200 200	0.0735~0.137 (0.025~0.075)	9.6 8.8 8.0	0.952 0.956 0.960	0.729 ~0.833	

In a table, (1) Ratio of the steel bar to bar distance to  $d_{95}$ , (2) Supplying volume of sediment (Apparent volume), (3) Sediment volume passing through a dam (Apparent volume), (4) Sediment trapping rate in a dam, (5) Velocity of frontal part of debris flow, (6) Sediment volume passing over a dam (Apparent volume), (7) Distance between bed and a nearest horizontal steel bar to the bed is  $L_v/d_{95} = 1.5$ . (8) Several surges of debris flow are supplied for measurements. Representative values of debris flow of type-"NL" without a dam are, in frontal part, as follows:  $c_f = 0.108$ ,  $h = 12.5$  cm (in case of 600 to 870 l of apparent supplying sediment volume)

Tab. 1 - A part of experimental cases for flume tests (in model scale)

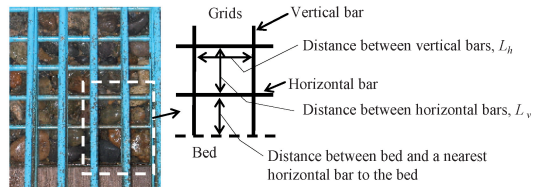
$n$ ( $m^{-1/3}$ s)	$Q_w$ (l/s)	$\bar{c}$	$c_f$	$h_0$ (cm)	$h_0/d_m$	$\tau_m$	$R_{*+} (= u_* d_m/\nu)$	$F_r$
0.0261	9.05	0.06	0.02	3.00	5.91	0.262	742	1.85

Tab. 2 - Hydraulic conditions of flume tests (Type U, QS)

$\sigma/\rho$	$c_*$	$d_m$ (mm)	$d_{max}$ (mm)	$d_{95}$ (mm)	$d_{84}$ (mm)	$d_{50}$ (mm)	$d_{10}$ (mm)	$d_{10}$ (mm)	$k$ (cm/s)	$\phi_s$ (deg.)
2.64	0.634	5.08	53	36	15	0.537	0.494	0.437	0.0922	38~40 deg

Tab. 3 - Physical characteristics of sediment particles for flume tests

Fig. 6 - Schematics of grids and definitions of several parts of grids



of grids and definitions for several parts of grids. In Table 1, for example, " $L_v 1.0 \times L_h 1.5$ " means that, for the grid, the ratio of the horizontal bar to bar distance,  $L_v$ , to  $d_{95}$  is 1.0 and the ratio of the vertical bar to bar distance,  $L_h$ , to  $d_{95}$  is 1.5, while distance between bed and a nearest horizontal bar to the bed is set as  $L_v/d_{95} = 1.5$ .

#### SEDIMENT AND PEAK DISCHARGE CONTROL WITH A DAM

Sediment trapping rate obtained by flume tests are shown in Table 1. Sediment control with the grids is discussed focusing on sediment runoff rate for debris flow modes. Herein, sediment runoff rate is defined as the ratio of sediment runoff volume passing through a

sabo dam to supplied sediment volume.

Figure 7 shows temporal changes of debris flow discharge in unit width and flux sediment concentration, which are measured at downstream end of the flume. Figure 8 shows temporal changes of mean diameter for runoff sediment passing through a dam. In the figure, time averaged mean sediment grain size in sediment within every water supply is also shown. The effects of distance between steel bars in the grid on sediment trapping are confirmed by Figs. 7 and 8. The sediment is trapped well in case of  $L_v 1.0 \times L_h 1.0$  (Run 9 and 10) in comparison to  $L_v 1.0 \times L_h 1.5$  (Run 7 and 8), and the mean diameter of runoff sediment passing through the grid gradually

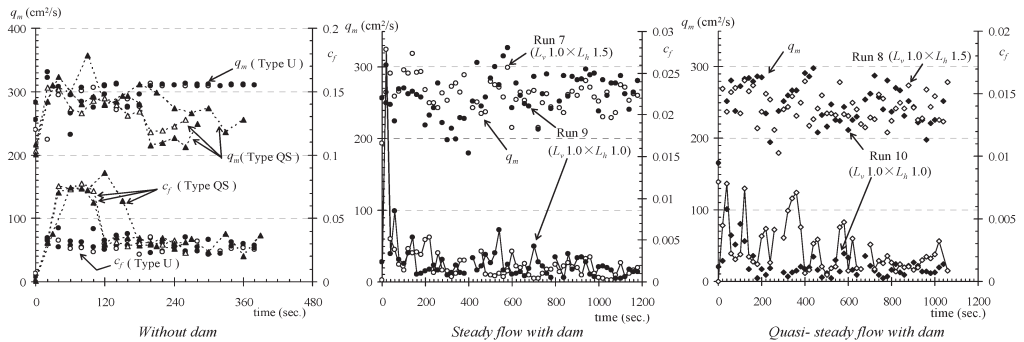


Fig. 7 - Temporary changes of flow rate of sediment-water mixture and flux sediment concentration at downstream end

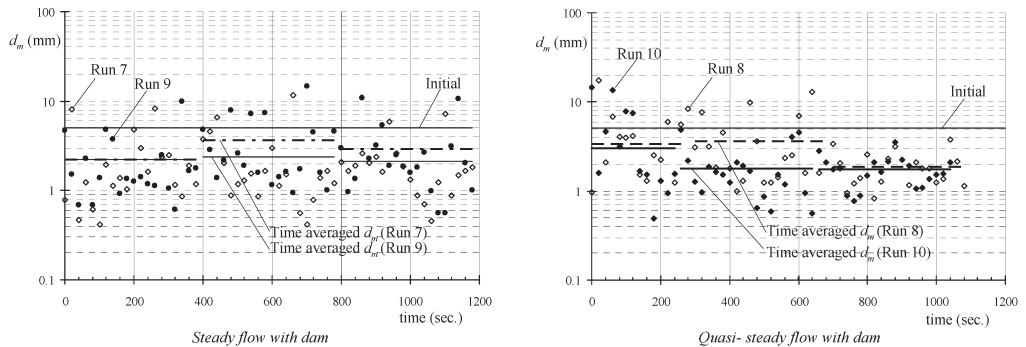


Fig. 8 - Temporary changes of mean diameter passing through a check dam at downstream end

decrease due to time development in Run 9 and 10, though the deviations for time averaged of  $d_m$  is large in Run 9. If we focus on sediment transport mode, the sediment runoff rate is still large just after a debris flow reaches a dam and then sediment particles are gradually deposited near the grids in Type U. There is some range of temporal change of mean diameter passing through a dam, because large boulders reach intermittently grids in Type U. In case of Type QS, the frontal part of debris flow has some large boulders, and the grids seem to be blocked easily by them.

Figure 9 shows relationship between  $L_{min}/d_{95}$  and sediment runoff rate passing through grids of a dam. The value of  $L_{min}/d_{95}$  shows the ratio of minimum clearance of a grid to  $d_{95}$ . The trapping rate of sediment in a dam and the sediment runoff rate from a dam are defined respectively as follows (e.g., HORIUCHI *et alii*, 2009):

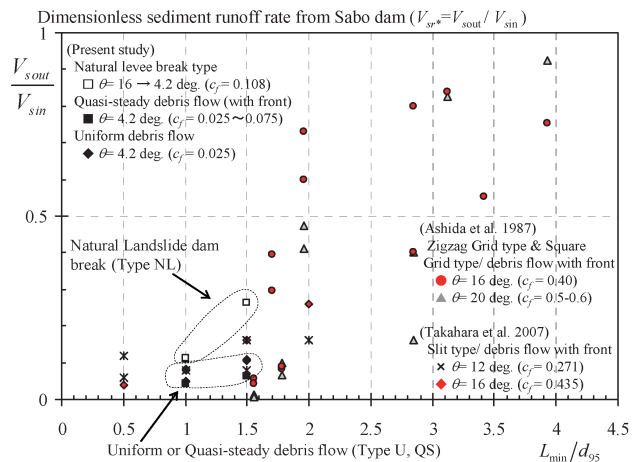


Fig. 9 - Relationship between dimensionless grid-scale and dimensionless sediment runoff rate passing through sabo dam

$$V_{sr*} = \frac{V_{sout}}{V_{sin}} = \frac{\int_0^{t_{out}} Q_{sout} dt}{\int_0^{t_{in}} Q_{sin} dt} \quad (3)$$

$$V_{st*} = \frac{V_{sin} - V_{sout}}{V_{sin}} = 1 - V_{sr*} \quad (4)$$

in which  $V_{sin}$  is the sediment supplying volume,  $V_{sout}$



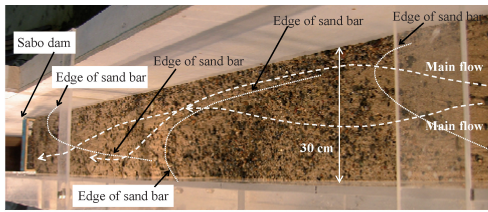


Fig. 10 - One example for channel shifting and formation of sand bars on the bed in a storage area of sabo dam

is the sediment runoff volume passing through the grids,  $Q_{sin}$  is the sediment discharge rate,  $Q_{sout}$  is the sediment runoff rate passing through the grids,  $t$  is the time,  $t_{in}$  is the sediment and water supplying time and  $t_{\infty}$  is the time when the sediment runoff from a dam continues. In the figure, previous experimental data (ASHIDA *et alii*, 1987; TAKAHARA *et alii*, 2007) is indicated focusing on bed slope of channel.

The sediment runoff rate depends slightly on bed slope as shown in previous research (ASHIDA *et alii*, 1987). The non-dimensional sediment volume such as supplying rate and runoff rate of sediment can be usually affected by initial bed slope and volume of storage area in a sabo dam. It seems that influences of those parameters on dimensionless sediment runoff volume are a little small because of small model scale of flume tests. Dimensionless sediment runoff rate changes suddenly in a range that  $L_{min}/d_{95}$  is 2.0 to 1.5 and takes about 0.05 to 0.1 in a range that  $L_{min}/d_{95}$  is 1.5 to 0.5. The value of dimensionless sediment runoff rate of Type U and QS takes lower value in envelope lines which can be estimated in Fig. 9. Sediment runoff rate of Type NL takes upper limit value on the envelope. Those differences in sediment control can be reasons why activities of large boulders in debris flows depend on sediment transport mode, referring to temporal changes of flux sediment concentration and mean grain size of sediment passing through the grids. Frontal part and flow body of a debris flow can transport large boulders in case of Type QS and Type NL, but the movements of sediment particles including large boulders are inactive in case of Type U. It is reported that the arch structure due to large boulders can be formed near the grids in steep slope channel (TAKAHASHI, 2000; 2007). The arch structures can be rarely seen in experimental run, though the arches were found in a few runs in case of Type NL.

It is confirmed that effective grids for sediment trap in a sabo dam are specified as follows:  $L_v$   $1.0 \times L_h$

1.0, which means that the distance of horizontal and vertical bars to  $d_{95}$  is unity respectively except 1st rung of grid from bed surface.

#### SEDIMENT CONCENTRATION WITH STEEL NETS

In the flume tests, appropriate distance between steel bars in the grids is specified to control well sediment runoff due to debris flow. However, when the sediment is deposited in a dam, bed slope decreases due to sediment deposition, and the sediment transport modes change from debris flow to clear water with bedloads. Spatial changes of bed and channel shifting due to sand bars are active (See. Fig. 10). Those movements cause sediment runoff to be large from vertically upper parts of the grids.

MIZUNO *et alii* (1996) proposed that additional steel bars needed to be vertically installed in order to reduce the sediment runoff volume from vertically upper parts of the grids by making steel bar to bar distance of the grids be small. However, influences of channel shifting and sand bars in the storage area of the dam on the sediment runoff passing through the dam are significant. It is quite difficult to estimate their movements, and it might not be always better way to reduce the sediment runoff from the grids using additional steel bars.

Herein, it seems better to use easy structure and to apply new idea for the countermeasure to control sediment runoff from the grid; using steel nets, setting up large boulders upstream reach of the grids and so on. We can consider the easy countermeasure for sediment control by easy installation and removing steel nets from the surface of the bars of the grids, while it is usual to fasten steel nets to the surface of bars in the grids. There are preliminary tests to capture debris flows with steel nets in field (e.g., TABATA *et alii*, 2004; JAPANESE FLEXIBLE BARRIER ASSOCIATION, 1996; WENDELER *et alii*, 2008) and in preliminary flume tests (e.g., DE NATALE *et alii*, 1997) for hyperconcentrated debris flow.

Flume tests were conducted to examine how bedloads prevent from running out heavily from the grids of sabo dam under the conditions that the clearance of the grids was set as the minimum size such as  $L_{min}/d_{95}=1.0$ . The model scale ( $\lambda_L=1/50$ ) and the setting of flume channel are set as same to flume experiment described above. Figure 11 shows schematics of a flume used in present tests and the flume is a part of the flume shown in Fig. 5. In order to simplify discussions and flume tests, sediment control function with/without steel nets



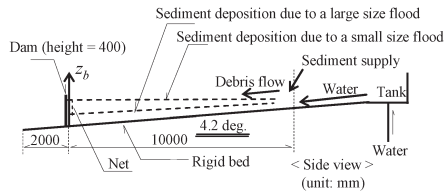


Fig. 11 - Schematics of experimental flume

is evaluated for sediment transportation by steady small size of flood, after a half part of storage area in a dam is approximately filled with sediment due to steady and large size of debris flow.

Next, let us discuss modelled steel nets. Figure 12 shows the setting of steel nets on the grids. Steel nets are set at upper part of grids and those nets are approximated using square nets instead of circle nets referring to a standardized article for steel nets, which is 300mm (e.g., Japan flexible barrier association). Effective diameter of circle nets is estimated as 240 mm considering overlaps of the nets, and the diameter of a net is approximated as 225 mm using square nets. Additionally, the errors for the shapes of the nets are 6.25% in length and 10.7 % in area.

Hydrograph for flume tests is specified as two kinds of steady flow discharge, which are 10.5 l/s and 3.39 l/s, respectively. Flow rate, 10.5 l/s and 3.39 l/s, corresponds to peak discharge, 185 m<sup>3</sup>/s, and minimum discharge, 60 m<sup>3</sup>/s, in design hydrograph, respectively. After sediment and water is steadily supplied within 14.8 min. by peak discharge until 6th rung of grids from a bed, the grids between 7th and 8th rung of grids are filled by small size of floods (3.39 l/s) within 35.4 min in case of with/without nets. Total time for sediment and water supply is 50.2 min.. Temporal changes of longitudinal bed profiles and sediment runoff volume were measured to confirm sediment control with steel nets.

Figures 13 and 14 show temporal changes of longitudinal profiles in a dam without/with nets. Figure 15 shows sediment trapping rate and runoff rate passing through a dam. In small size of flow discharge, the mobility of large components of sediment particles decreases due to decrease of bed shear stress, because of decrease of bed slope in a storage area of a dam. Sediment runoff of fine sediment increases without steel nets, and the grids with nets can fully capture

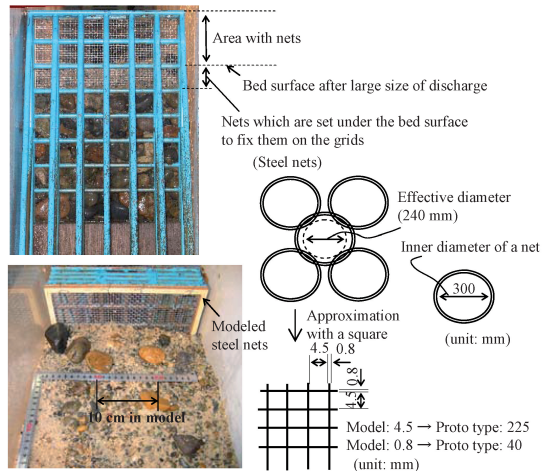


Fig. 12 - Schematics of modelled steel nets and setting for steel nets on the grids

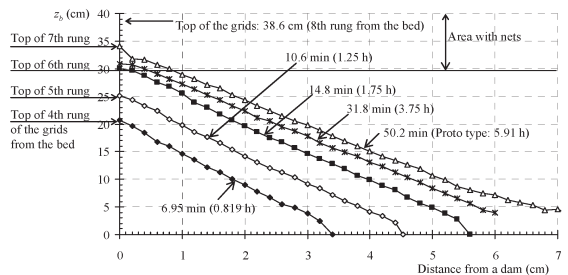


Fig. 13 - Temporal changes of longitudinal bed profiles without nets

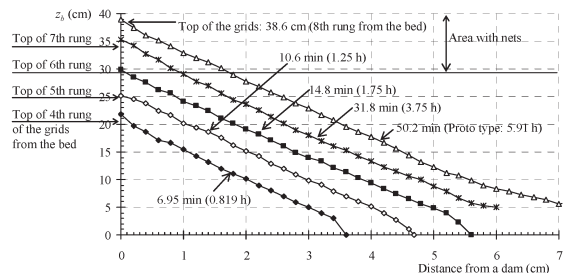


Fig. 14 - Temporal changes of longitudinal bed profiles with nets

supplied sediment. Sediment runoff rate becomes about 0.07 to 0.08 with nets, and decreases about 0.12 to 0.13 in comparison to flume data without nets (0.2).

Supposing that sediment control in a storage area of a sabo dam is additionally needed using a slit dam with steel grids, it is better to apply several easy methods such as 'double nets structures', 'rearrangement of large boulders' behind the grids on the bed surface and so on (HORIUCHI *et alii*, 2009). Sediment can be controlled well with nets structure in the upper part of grids in open-type sabo dam, when sand bars and channel

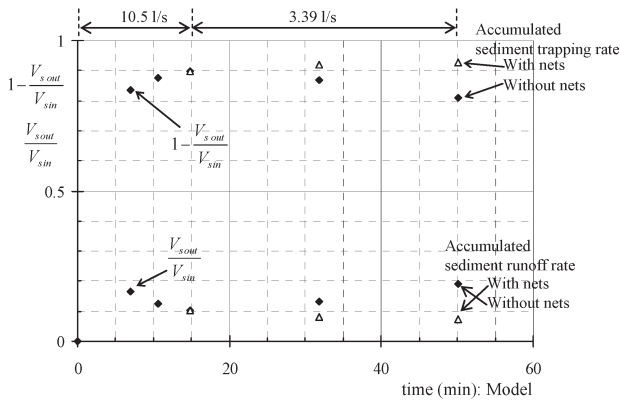


Fig. 15 - Temporal changes of accumulated sediment runoff rate passing through a dam and trapping rate in a sabo dam

shifting are dominant on the bed surface. One preliminary method for easy sediment control was proposed in present study using present flume tests.

In upper parts of the grids, it is necessary to consider the logs jamming in a storage area of the dam. This is a problem to be solved near future. Data collections for behaviour of large components of sediment particles are needed focusing on debris flow regime, bed condition, velocity of sediment particles and sediment concentration.

## CONCLUDING REMARKS

Several results were obtained by flume tests focusing on sediment control with the GHD. Those are summarized as follows.

- (1) Experimental conditions were specified supposing three kinds of debris flow regimes which were debris flow due to natural landslide dam break (Type NL), uniform debris flow (Type U) and quasi-steady debris flow (Type QS). Sediment concentration was set focusing on flux sediment concentration for uniform sediment.
- (2) Sediment trapping rate in a dam with grids was experimentally confirmed using the relationship between the ratio of minimum clearance to the grain size of d95 and dimensionless sediment runoff rate from a dam,  $V_{sout}/V_{sin}$ . Sediment runoff rate depended on debris flow regimes, and the sediment runoff from a dam was active in Type NL and the runoff rate was inactive in Type U and QS. Those differences in sediment runoff depend on mobility of large components of sediment particles. Data collections for behaviour of large components of sediment including boulders in non-uniform sediment particles are needed focusing on

flow regime of debris flow, velocity and sediment concentration in debris flows.

- (3) Experimental data supported that effective grids in a sabo dam are specified as follows:  $L_v 1.0 \times L_h 1.0$ , which means that the distance of horizontal and vertical steel bars to d95 is unity respectively except 1st rung of grid from bed surface.
- (4) Sediment runoff can be large from the upper part of grids in open-type sabo dam when sand bars and channel shifting are dominant on the storage area of sediment in high dam. It is better to apply several easy methods such as 'double nets structures', 'rearrangement of large boulders' behind the grids and so on, while the clearance of the grids are set as minimum value.

One preliminary method, which is sediment control with flexible steel nets, is proposed to control sediment runoff due to small size of floods and its control function was confirmed using flume data.

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