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Numerical Simulation on Debris-Flow Deposition and Erosion Processes Upstream of a Check Dam with Experimental Verification

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Synopsis

The understanding of behavior and mechanism of debris flow, and the study of preventive measures are very important in order to manage the sediment disaster in the river basin and prevent the downstream hazards. A check dam is commonly used for preventing the sediment disaster due to debris flow by storing the harmful sediment discharge. The numerical simulations and experiments have been carried out to investigate the mechanism of debris flow deposition process upstream of a check dam, and flushing out of deposited sediment due to erosion process by a normal scale flood flow. A new deposition equation to calculate debris flow deposition upstream of a check dam is also developed. The simulations and experiments have been performed using closed type and grid type check dams.

Keywords: debris flow, check dam, erosion/deposition, numerical simulation, experiments

1. Introduction

Debris flows are common in mountainous areas throughout the world, which contain varying amounts of mud, sand, gravel, boulders, and water. In addition to causing significant morphological changes along riverbeds and mountain slopes, these flows are frequently reported to have brought about extensive property damage and loss of life (Takahashi, 1991; Hunt, 1994; Huang and Garcia, 1997). Therefore, the understanding of behavior and mechanism of debris flow and the study of preventive measures are very important in order to manage the sediment disaster in the river basin and prevent the downstream hazards. To reduce the debris flow hazards, it is common to couple structural and non structural preventive measures. Preventive measures require the consideration of the various scenarios and involve the evaluation of hydrological, hydraulic, sediment size distribution, topographical and other parameters.

Fig. 1 shows the number of occurrence of debris flow, landslide, and slope failure disaster from 1982 to 2007 in Japan. Fig. 2 shows the historical trend line of number of losses of life due to sediment disasters such as debris flow/landslide, slope failure and floods in Nepal and Japan. There is decreasing trend of loss of life due to the development of countermeasures against sediment hazards.

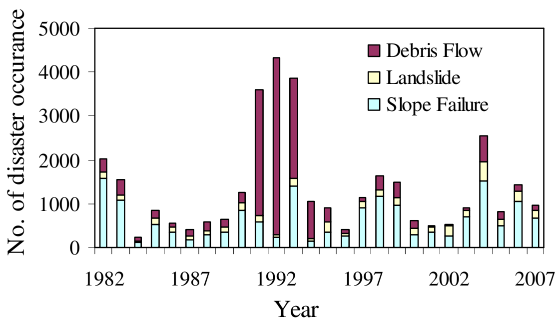

Fig. 1 The number of debris flow, landslide and slope failure disaster occurrence in Japan (Data of debris flow from 1991 to 1993 include pyroclastic flow caused by the eruption of Mt. Unzen Fugendake in Nagasaki prefecture)

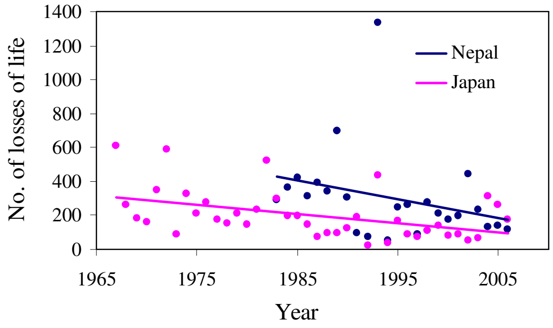

Fig. 2 Trend of number of losses of life due to sediment disasters in Nepal and Japan

Photo 1 A grid dam constructed to prevent downstream sediment disaster of debris flow at Hirayu River, Gifu Prefecture, Japan

Check dams are one of the effective structural counter measures for debris flow control. Photo 1 shows a grid type check dam constructed to prevent sediment disaster in downstream area due to debris flow at Hirayu River in Jinzu River drainage basin, Gifu Prefecture, Japan. Check dams can effectively store the debris flow as long as there is an adequate storage capacity, when check dam loses such storage capacity, the check dam can not capture enough sediment to reduce the debris flow (Mizuyama et al., 1998). Check dams can be distinguished as closed and open types. In closed type check dam, it is difficult to prevent from losing its trapping capacity unless sediments are continuously removed, whereas open type dams may keep their trapping capacity without any need of artificially removing the sediment (Bovolin and Mizuno, 2000).

The main objective of this study is to develop a numerical model and to investigate the debris flow deposition process upstream of a check dam, and flushing out of deposited sediment due to erosion process by a normal flow discharge. The simulations and experiments have been performed using closed type and grid type check dams. A debris flow deposition model for upstream of a check dam is developed based on the mechanism of static pressures. The constitutive equations of Takahashi et al. (1997) and those of Egashira et al. (1997) are chosen for the study on deposition process upstream of a check dam. A new deposition velocity equation to calculate debris flow deposition upstream of a check dam is also developed. To simulate the debris flow deposition upstream of a closed or a grid type check dam, a deposition model and a model of grid dam blockage by large sediment particles in the case of a grid dam, are incorporated in a flow model of the solid-liquid mixture of debris flow. A riverbed erosion model under unsaturated bed condition is used to simulate the erosion process of deposited sediment upstream of a check dam.

2. Numerical model

2.1 Basic governing equations

The flow of the solid-liquid mixture is described using one dimensional depth averaged equations for the mass conservation of a sediment water mixture, the mass conservation of sediment particles and momentum conservation of the flow mixture as

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}=i_b \qquad (1)$$

$$\frac{\partial (Ch)}{\partial t}+\frac{\partial (CM)}{\partial x}=i_b C_* \qquad (2)$$

$$\frac{\partial M}{\partial t}+\beta\frac{\partial (uM)}{\partial x}=gh\sin\theta - gh\cos\theta\frac{\partial h}{\partial x}-\frac{\tau_b}{\rho_T} \qquad (3)$$

where $M\ (=uh)$ is flow flux in x direction, u is the mean velocity, h is flow depth, i_b is erosion (>0) or deposition (≤ 0) velocity, C is the sediment concentration in the flow, C_* is maximum sediment concentration in the bed, β is momentum correction factor equal to 1.25 for stony debris flow (Takahashi et al., 1992), g is the acceleration due to gravity, θ is bed slope, τ_b is bottom shear stress, ρ_T is mixture density $(\rho_T=\sigma C+(1-C)\rho)$, σ is density of the sediment particle, and ρ is density of the water.

The equation for the erosion/deposition process to change in bed surface elevation is described as follows:

$$\frac{\partial z_b}{\partial t} + i_b = 0 \tag{4}$$

where z_b is erosion or deposition thickness of the bed measured from the original bed surface elevation.

The erosion and deposition velocity that have been given by Takahashi et al. (1992) are used as follows. Erosion velocity, if $C < C_\infty$;

$$i_b = \delta_e \frac{C_\infty - C}{C_* - C_\infty} \frac{M}{d_m} \tag{5}$$

Deposition velocity, if $C \geq C_\infty$;

$$i_b = \delta_d \frac{C_\infty - C}{C_*} \frac{M}{d_m} \tag{6}$$

where δ_e is erosion coefficient, $\delta_e =$ 0.0007; δ_d is deposition coefficient, $\delta_d =$ 0.01; d_m is mean diameter of sediment and C_∞ is the equilibrium sediment concentration described as follows (Nakagawa et al., 2003), if $\tan\theta_w > 0.138$, a stony type debris flow occurs, and

$$C_\infty = \frac{\tan\theta_w}{(\sigma/\rho - 1)(\tan\phi - \tan\theta_w)} \tag{7}$$

If $0.03 < \tan\theta_w \leq 0.138$, an immature type debris flow occurs, and

$$C_\infty = 6.7\left\{\frac{\tan\theta_w}{(\sigma/\rho - 1)(\tan\phi - \tan\theta_w)}\right\}^2 \tag{8}$$

If $\tan\theta_w \leq 0.03$, a turbulent water flow with bed load transport occurs, and

$$C_\infty = \frac{(1+5\tan\theta_w)\tan\theta_w}{\sigma/\rho \ -1}\left(1 - \alpha_0^2 \frac{\tau_{*c}}{\tau_*}\right)\left(1 - \alpha_0^2 \sqrt{\frac{\tau_{*c}}{\tau_*}}\right) \tag{9}$$

where ϕ is the internal friction angle of the sediment, and

$$\alpha_0^2 = \frac{2\{0.425 - (\sigma/\rho)\tan\theta_w/(\sigma/\rho - 1)\}}{1 - (\sigma/\rho)\tan\theta_w/(\sigma/\rho - 1)} \tag{10}$$

$$\tau_{*c} = 0.04 \times 10^{1.72\tan\theta_w} \tag{11}$$

$$\tau_* = \frac{h\tan\theta_w}{(\sigma/\rho - 1)d_m} \tag{12}$$

in which θ_w is water surface slope, τ_{*c} is the non-dimensional critical shear stress, and τ_* is the non-dimensional shear stress.

2.2 Deposition model upstream of a check dam

In the upstream region of a check dam, sediment concentration is higher than that of equilibrium state and becomes maximum sediment concentration due to existence of the check dam, and the yield stress exceeds the driving force, then debris flow stops and deposition occurs, before filling up upstream of the check dam. This mechanism of deposition is incorporated in momentum equation of the flow mixture of debris flow as considering yield stress in the bottom shear stress. The bottom shear stress is evaluated as follows:

$$\tau_b = \tau_y + \rho f_b |u| u \tag{13}$$

where τ_y is the yield stress and f_b is the coefficient of resistance.

(1) The constitutive equations and bottom shear stress

The constitutive equations of Takahashi et al. (1997) and those of Egashira et al. (1997) are chosen for the study on deposition process upstream of a check dam. The constitutive equations of Takahashi et al. (1997) for a fully stony debris flow are described as follows. The expression for the shear stress is as

$$\tau = \tau_y + a_i \sin\alpha_i \left\{\left(\frac{C_*}{C}\right)^{1/3} - 1\right\}^{-2} \sigma d_m^2 \left(\frac{\partial u}{\partial z}\right)^2 \tag{14}$$

$$\tau_y = p_s \tan\phi \tag{15}$$

where a_i is experiment constant, α_i is the collision angle of the particle ($a_i \sin\alpha_i$ =0.02) (Takahashi, 1991), z is coordinate perpendicular to bed and positive upward in the normal direction of flow and p_s is static pressure which can be expressed as follows:

$$p_s = f(C)(\sigma - \rho)Cgh\cos\theta \tag{16}$$

in which $f(C)$ is described as

$$f(C) = \begin{cases} \dfrac{C - C_3}{C_* - C_3} & ; \quad C > C_3 \\ 0 & ; \quad C \le C_3 \end{cases} \tag{17}$$

where $C_3 = 0.5$ is the limitative concentration which p_s affects.

By substituting the constitutive equations of Takahashi et al. (1997) into the momentum conservation equation under a steady and uniform flow conditions, the bottom shear stress for a stony debris flow is derived as follows:

$$\tau_b = p_s \tan\phi + \frac{1}{8}\rho\frac{(\sigma/\rho)}{\{(C_*/C)^{1/3} - 1\}^2}\left(\frac{d_m}{h}\right)^2 |u|u \tag{18}$$

An immature debris flow occurs when C is less than $0.4C_*$ and bottom shear stress is described as follows:

$$\tau_b = \frac{\rho_T}{0.49}\left(\frac{d_m}{h}\right)^2 u|u| \tag{19}$$

The Manning's equation is used to determine the bottom shear stress in the case when C is less than 0.02 as follows:

$$\tau_b = \frac{\rho g n^2 u|u|}{h^{1/3}} \tag{20}$$

The constitutive equations of Egashira et al. (1997) are described as follows. The shear stress is as

$$\tau = p_s \tan\phi + \sigma k_d (1 - e^2) C^{1/3} d_m^2 \left(\frac{\partial u}{\partial z}\right)^2 + \rho k_f (1 - C)^{5/3} / C^{2/3} d_m^2 \left(\frac{\partial u}{\partial z}\right)^2 \tag{21}$$

where e is the restitution of sediment particles, k_d and k_f are empirical constants, $k_d = 0.0828$ and $k_f = 0.16$. The static pressure is described as follows:

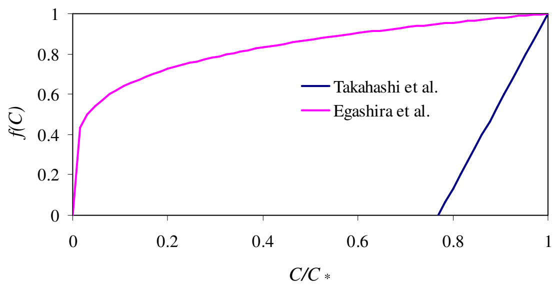

Fig. 3 Plots of *f(C)* according to Takahashi et al. (1997) and Egashira et al. (1997), C_*=0.65

$$p_s = f(C)(\sigma - \rho)Cgh\cos\theta \tag{22}$$

in which $f(C)$ is described as

$$f(C) = \left(\frac{C}{C_*}\right)^{1/5} \tag{23}$$

By using the constitutive equations of Egashira et al. (1997), the bottom shear stress is derived as follows:

$$\tau_b = p_s \tan\phi + \rho\frac{25}{4}\{k_d(\sigma/\rho)(1 - e^2)C^{1/3} + k_f(1 - C)^{5/3}/C^{2/3}\}\left(\frac{d_m}{h}\right)^2 |u|u \tag{24}$$

Eq. (17) and Eq. (23) are represented in Fig. 3, from which the roles of the both constitutive equations assigned to static pressures or yield stresses are evident. The static pressures in Eq. (16) are influential when sediment concentration is higher than C_3, while in Eq. (22) they are predominant even for lower sediment concentrations.

(2) Deposition velocity model

The deposition velocity models given by previous researchers such as Takahashi et al. (1992), Egashira et al. (2001) and others are proportional to the flow velocity, and deposition upstream of a check dam can not be calculated, when the flow velocity becomes zero, also the calculated deposition upstream of check dam is too small. Therefore, a new deposition velocity equation for upstream of a check dam is derived. Upstream of a check dam, deposition usually takes place when yield stress exceeds the equilibrium shear stress, before filling up the sediment storage

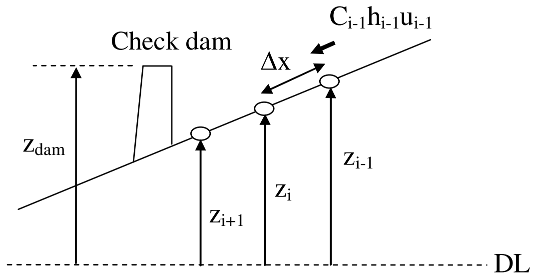

Fig. 4 Definition sketch of deposition upstream of a check dam

capacity. In the upstream area of a check dam, if bed elevation z_i is less than elevation of the dam crown z_{dam} at calculation point i (Fig. 4), the sediment discharge from the upstream will deposit in the distance increment of calculating point Δx when yield stress exceeds the equilibrium shear stress. The sediment discharge per unit width from the upstream is described as follows:

$$qs_{up} = C_{i-1}h_{i-1}u_{i-1} \tag{25}$$

Effective non-dimensional shear stress on the bed responsible for the deposition should be $\tau_{*e}-\tau_{*y}$ and deposition velocity is written as follows:

$$i_{dep} = K_{dep}(\tau_{*e}-\tau_{*y})\frac{C_{i-1}h_{i-1}u_{i-1}}{C_*\Delta x} \tag{26}$$

where i_{dep} is the deposition velocity upstream of a check dam (if $z_i < z_{dam}$ or $z_{i+1} > z_i$ and $\tau_{*y} > \tau_{*e}$), K_{dep} is constant, τ_{*e} is the non-dimensional equilibrium shear stress and τ_{*y} is the non-dimensional yield stress. These non-dimensional stresses are described as follows:

$$\tau_{*e} = \frac{\rho_T gh\sin\theta}{(\sigma-\rho)gd_m} \tag{27}$$

$$\tau_{*y} = \frac{(\sigma-\rho)Cgh\cos\theta\tan\phi}{(\sigma-\rho)gd_m} \tag{28}$$

2.3 Grid dam blockage model

The opening of a grid dam is blockaded by large sediment particles in debris flow. This blockade phenomenon is influenced by the width of dam opening, the maximum particle diameter of sediment, and the sediment concentration of debris flow (Ashida and Takahashi, 1980; Ashida et al., 1987; Mizuyama et al., 1995; Mizuno et al; 2000; Takahashi et al., 2001b, 2002; Miyazawa et al., 2003, Satofuka and Mizuyama, 2006). Takahashi et al. (2001b) proposed stochastic model of blocking caused by formation of an arch composed of several boulders. They clarified the relationship between the probability of blockage of grid and parameters such as boulder's diameter, sediment concentration and clear spacing of dam. Based on this probability of blockage model, growing rate formula of grid dam developed by Satofuka and Mizuyama (2006) is used as follows:

$$i_b' = i_b - a_2\frac{Chu}{C_*\Delta x} \tag{29}$$

where a_2 coefficient parameter depends on the instantaneous blockade probability of grid and influence of horizontal beam, the details can be found in Satofuka and Mizuyama (2006).

2.4 Erosion model upstream of a check dam

The large boulders deposited upstream of a check dam can not be transported by a normal scale of flood flow. If we remove large boulders deposited upstream of a grid dam or blockaded large boulders at open spaces of grid, deposited sediment upstream of grid dam may be transported to the downstream of grid dam by a normal scale flood flow due to the erosion process. Thus, the grid dams will have debris flow storage capacity to control the next debris flow event in monsoon season. Hence, a one-dimensional mathematical riverbed erosion equation proposed by Takahashi et al. (1992) is used to simulate the erosion process of deposited sediment upstream of a grid dam as follows:

$$\frac{i_b}{\sqrt{gh}} = K\sin^{3/2}\theta\left\{1-\frac{\sigma-\rho_T}{\rho_T}C\left(\frac{\tan\phi}{\tan\theta}-1\right)\right\}^{1/2} \cdot\left(\frac{\tan\phi}{\tan\theta}-1\right)\left(C_\infty - C\right)\frac{h}{d_m} \tag{30}$$

where K is a numerical constant.

The condition setup for installation of closed dam proposed by Takahashi et al. (2001a) is used.

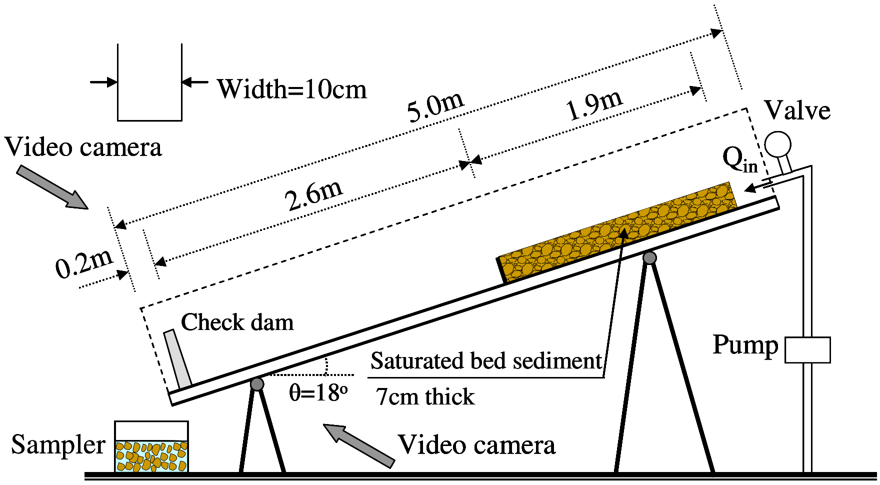

Fig. 5 Experimental flume setup

3. Laboratory experiments

A rectangular flume of 5m long, 10cm wide and 13cm deep flume is used for the experiments. The slope of flume is set at 18 degrees. The details of experiment setup are shown in Fig. 5. Silica sand and gravel mixtures sediment with 1.9m long and 7cm deep is positioned 2.8m upstream from the outlet of the flume by installing a partition of 7cm in height to retain the sediment. This sediment bed is saturated by water. Sediment materials with mean diameter d_m = 2.53mm, maximum diameter $d_{\max}$ = 15mm, maximum sediment concentration at bed $C_* = 0.65$, angle of repose $\tan\phi = 0.72$ and sediment density σ = 2.65g/cm^3 are used. The particle size distribution of sediment mixture is shown in Fig. 6. Check dams are set at the 20cm upstream from the end of the flume. Four types of check dam; one closed dam of 8cm in high and three open type grid dams with various spacing of grid are selected for the study. The details of the check dam types are shown in Fig. 7.

Debris flow is produced by supplying a constant water discharge 260cm^3/sec for 10sec from the upstream end of the flume. Debris flow produced in the experiments is the fully stony type debris flow and the largest particles are accumulated in the forefront. Debris flow deposition patterns upstream of check dams are captured by two standard video cameras located at side and above the flume end.

The deposited sediment upstream of a grid dam may not be effectively transported downstream of the dam by a normal scale flood flow because the large boulders deposited upstream of the grid dam can not be transported by a normal scale flood flow. If we remove some large boulders deposited upstream of a grid dam, the deposited sediment upstream of the grid dam may be transported to the downstream by a normal scale flood flow. The experiments on flushing out of deposited sediment upstream of the check dam

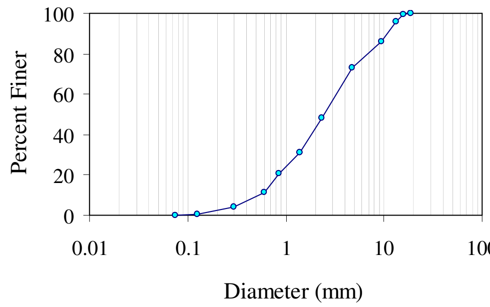

Fig. 6 Particle size distribution of bed sediment

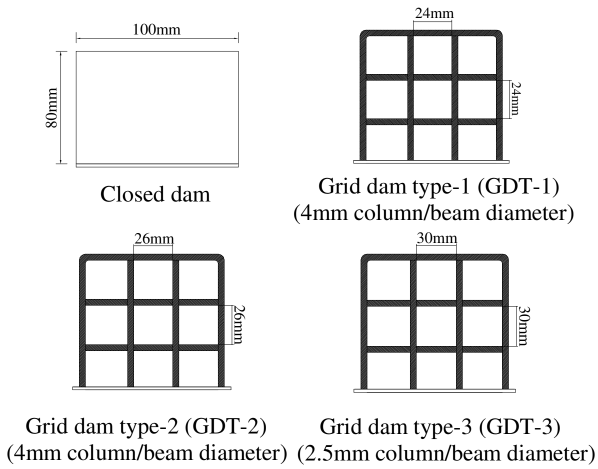

Fig. 7 Check dam types

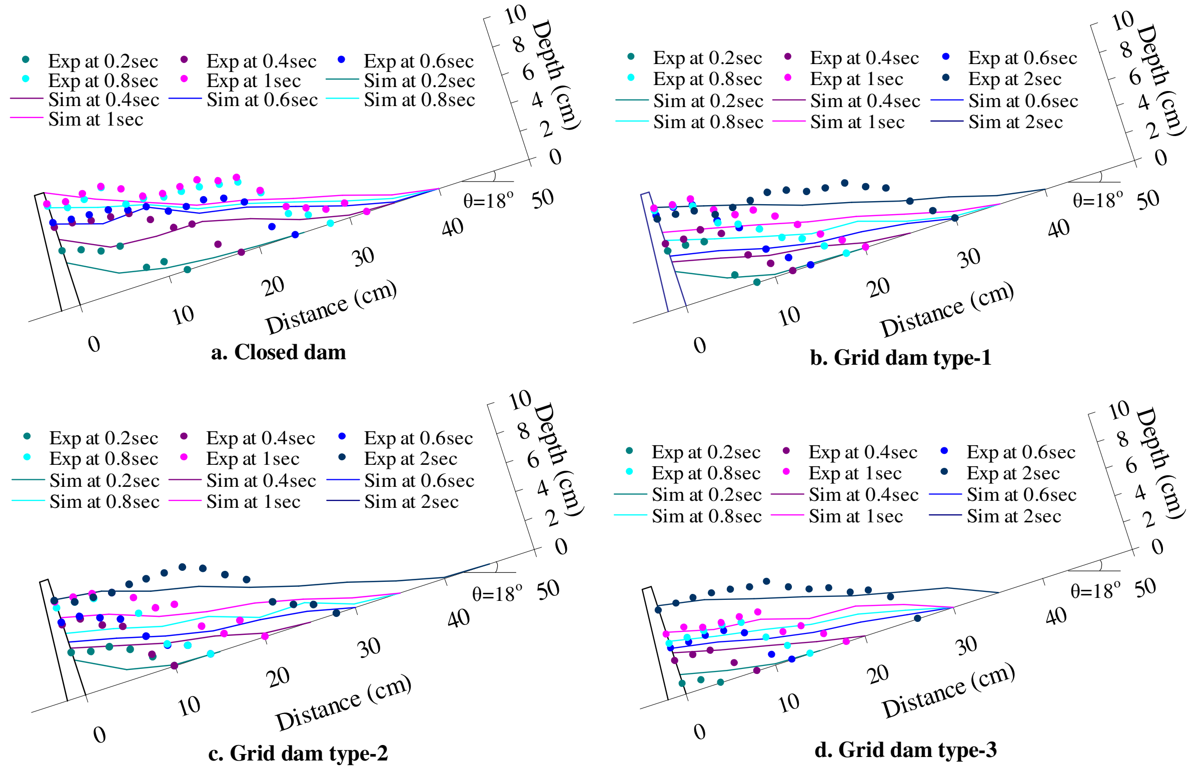

Fig. 8 Simulated and experimental results of debris flow deposition upstream of a check dam (using proposed deposition velocity model of upstream of a check dam and the constitutive equations of Takahashi et al.)

are carried out in two cases, with removing and without removing some large boulders from the upstream of the check dam. In CASE-I: clear water discharge at a rate of 260cm^3/sec is supplied for 15sec after removing some large boulders deposited upstream of the check dam. In CASE-II: clear water discharge at a rate of 260cm^3/sec is supplied for 15sec without removing any large boulders from the upstream of the check dam, the deposited sediment can not be effectively transported to the downstream, after that some deposited large boulders are removed, then again clear water discharge at a rate of 260cm^3/sec is supplied for 15sec to check the flushing out of deposited sediment. The erosion process of deposited sediment is analyzed from the images shot by video cameras.

4. Results and discussions

To simulate the debris flow deposition upstream of a check dam, the blockage of grid by large sediment particles, and the erosion of deposited sediment upstream of a check dam, numerical models described in 2.2, 2.3 and 2.4 are used, respectively. The calculation conditions of the numerical simulation are as follows; the grid size Δx =5cm, the time interval $\Delta t = 0.001$sec, $\rho = 1.0$g/cm^3, n =0.04 (in Eq. (20)), e=0.85 (in Eq. (24)), K_{dep}= 1.0 (in Eq. (26)) and K = 0.1 (in Eq. (30)).

4.1 Debris flow deposition upstream of a check dam

Fig. 8 shows the simulated results using proposed deposition velocity model of upstream of a check dam and the constitutive equations of Takahashi et al. (1997), and experimental results of debris flow deposition upstream of a closed type or a grid type check dam. The calculated results of the debris flow deposition upstream of a check dam using the constitutive equations of Egashira et al. (1997) are shown in Fig. 9. From the both figures, the simulated results of deposition depth upstream of a check dam are quite consistent with the experimental results at the front and near the check dam parts. However, some discrepancies can be found in the shape of deposition between the simulated and experimental

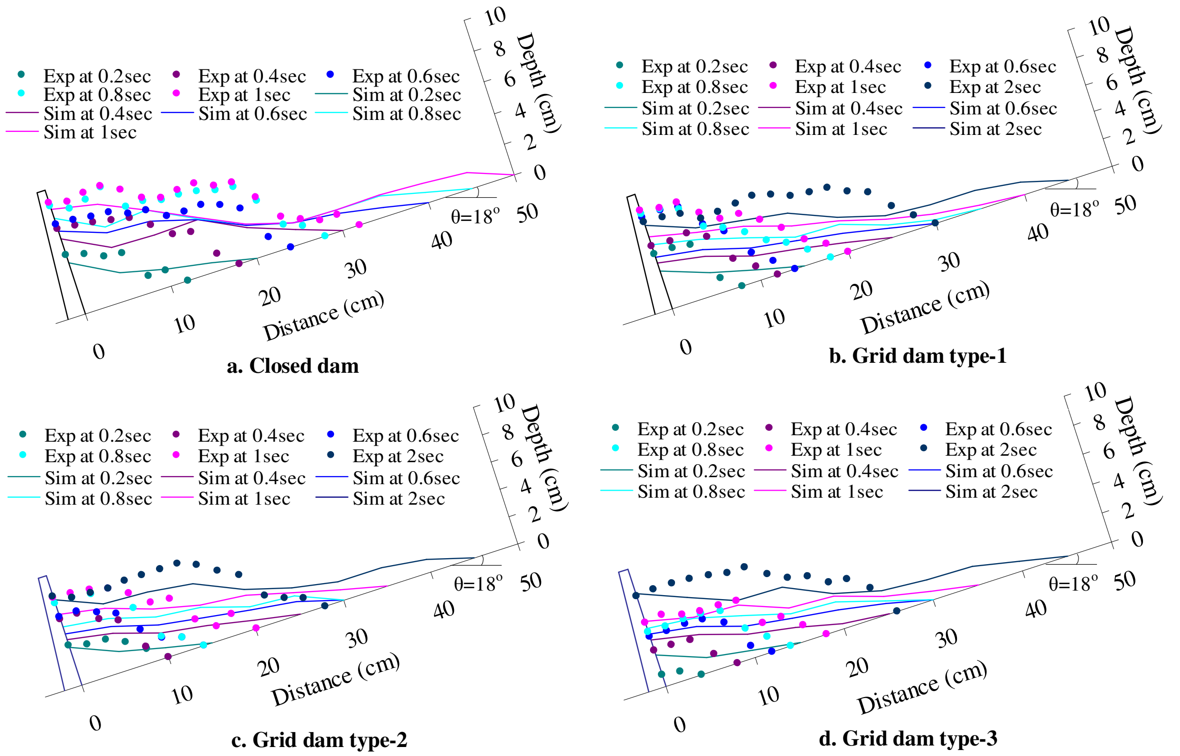

Fig. 9 Simulated and experimental results of debris flow deposition upstream of a check dam (using proposed deposition velocity model of upstream of a check dam and the constitutive equations of Egashira et al.)

results at the most upstream part of the deposition, which may be due to the effect of the air entrapped in the fluid, which results from churning up the flow, when a debris flow from the upstream collides with the check dam or the deposited surface; and high turbulence is generated at upstream end of the deposition, in the experiments.

The experiments are carried out in the fixed bed condition, in which the debris flow jumps due to the collision with a check dam or the deposited surface and flows on it. The deposited sediment in the most upstream area of the deposition is eroded by the coming debris flow from the upstream and the many sediments discharge downstream, which affects in the experimental results on depth of sediment deposition in the most upstream area.

The debris flow deposition phenomenon upstream of a closed or a grid dam could be calculated by the proposed deposition velocity model and both the constitutive equations. Some variations are found in the simulated results with the comparison between Fig. 8 and Fig. 9, which may be due to the effect of the static pressures. The static pressures in Eq. (16) are influential when sediment concentration is higher

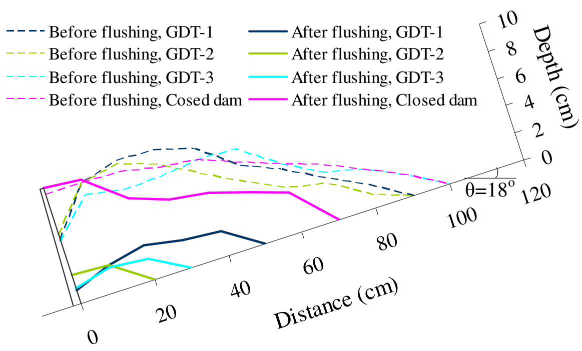

Fig. 10 Experimental results of flushing out deposited sediment due to erosion and variations in depth, CASE-I

than the limitative concentration C_3, while in Eq. (22) they are predominant even for lower sediment concentrations. In the simulation results, by using the constitutive equations of Egashira et al. (1997), the deposition shapes are reproduced larger in area with compared to the results obtained from the constitutive equations of Takahashi et al. (1997), because of the yield stress is highly predominant even for lower sediment concentration in the constitutive equations of Egashira et al. (1997) (Fig. 3).

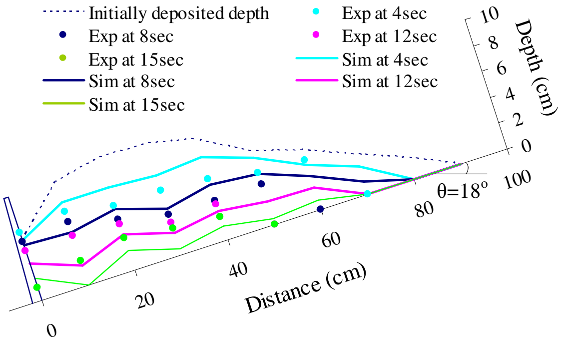

Fig. 11 Simulated and experimental bed variations of deposited sediment due to erosion, CASE-I, GDT-1

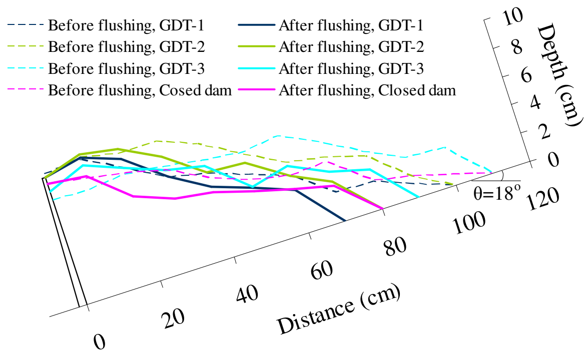

Fig. 14 Experimental results of flushing out deposited sediment before removing large boulders, CASE-II

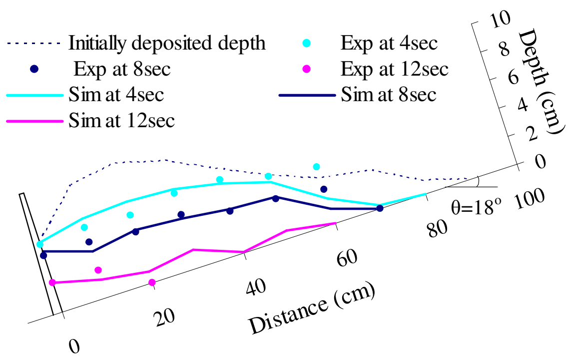

Fig. 12 Simulated and experimental bed variations of deposited sediment due to erosion, CASE-I, GDT-2

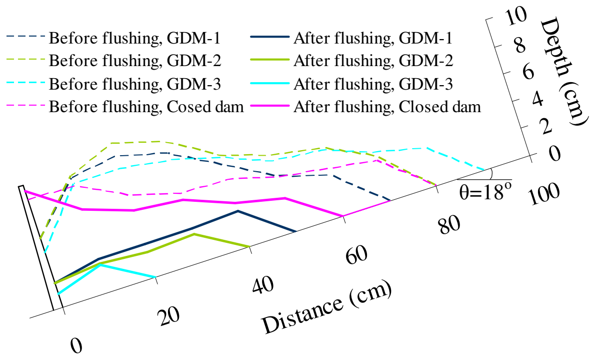

Fig. 15 Experimental results of flushing out deposited sediment after removing large boulders, CASE-II

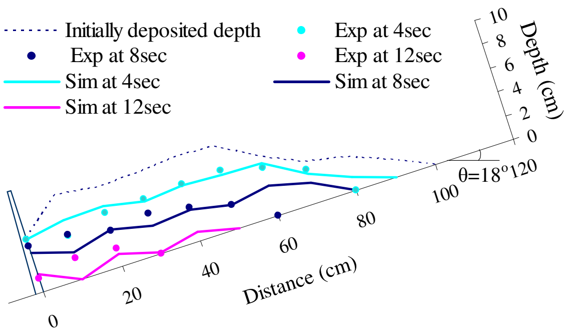

Fig. 13 Simulated and experimental bed variations of deposited sediment due to erosion, CASE-I, GDT-3.

4.2 Erosion of deposited sediment

CASE-I

Fig. 10 shows the experimental results of the time variation in shape of deposited sediment upstream of the check dams due to erosion process after supplying the normal flow discharge. In which, dashed line indicates initially deposited depth of sediment and continuous line indicates depth of deposition after the erosion. The sediment deposited upstream of a grid dam is flushed out more effectively than the closed dam. The erosion process of deposited sediment upstream of grid dams is investigated using a one-dimensional riverbed erosion model and comparison between experimental and simulated results are shown in Fig. 11, Fig. 12 and Fig. 13 for Grid Dam Type (GDT)-1, GDT-2 and GDT-3, respectively. Deposited sediment upstream of grid dams is effectively transported to the downstream due to the erosion process by a normal flow discharge. Thus, the grid type check dams will have debris flow storage capacity to control the next debris flow event. In the numerical simulation, measured mean diameter 3.21mm of deposited sediment is used.

CASE-II

In this case, firstly clear water discharge is supplied without removing any blockaded and deposited large boulders from the upstream of a grid

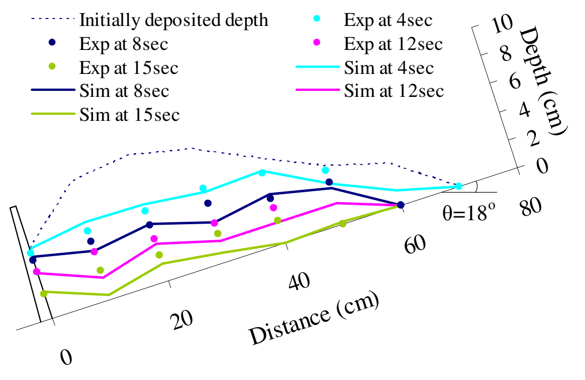

Fig. 16 Simulated and experimental bed variations of deposited sediment due to erosion, CASE-II, GDT-1

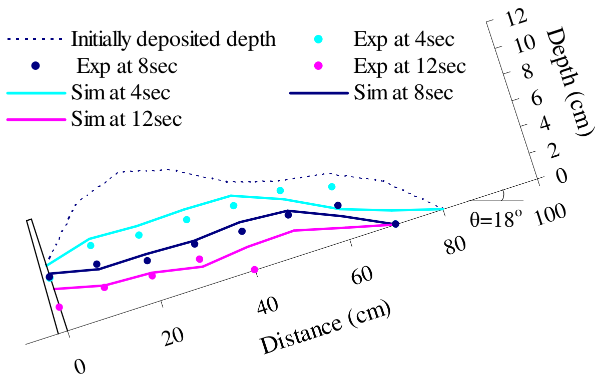

Fig. 17 Simulated and experimental bed variations of deposited sediment due to erosion, CASE-II, GDT-2

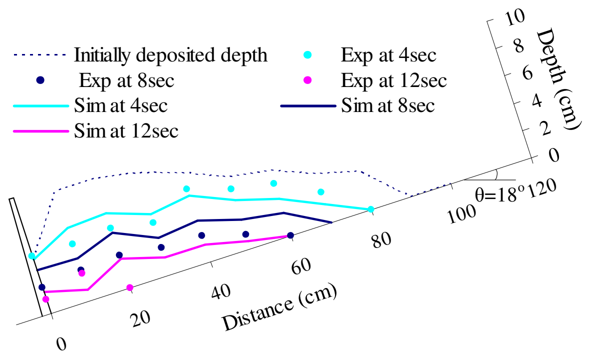

Fig. 18 Simulated and experimental bed variations of deposited sediment due to erosion, CASE-II, GDT-3

dam, and Fig. 14 shows the experimental results of erosion of deposited sediment, in which deposited sediment may not be effectively transported to downstream. After that some blockaded and deposited large boulders from upstream of a grid dam are removed, then again clear water discharge is supplied, and Fig. 15 shows the experimental results of erosion of deposited sediment by supplying a flushing discharge after removing some large boulders, where dashed line indicates the deposition shape after removing boulders at the end of first water supply. The deposited sediment could not be flushed out effectively due to erosion by water supplying before removing large boulders. Fig. 16, Fig. 17 and Fig. 18 show the comparison of the simulated and experimental results of variations in deposition shape upstream of GDT-1, GDT-2 and GDT-3, respectively at different time steps due to erosion process after removing some large boulders from upstream of the grid dam.

In all three types of grid dam, deposited sediment upstream of grid dam could be effectively transported to the downstream due to the erosion process by normal flow discharge, when some large boulders blockaded in open spaces of grid and deposited upstream of the grid dam, are removed. The simulated results of erosion process of deposited sediment upstream of the grid dam are in good agreement with the experimental results.

5. Conclusions

The numerical model is developed to simulate debris flow deposition, and erosion upstream of a check dam. A new deposition equation to calculate debris flow deposition upstream of a check dam is also developed based on the mechanism of effective non dimensional shear stress on the bed. The debris flow deposition phenomenon upstream of a closed or a grid type check dam can be calculated by the proposed deposition velocity model and both the constitutive equations of Takahashi et al. (1997) and Egashira et al. (1997). The simulated results of debris flow deposition upstream of a check dam, and the erosion of deposited sediment using a one-dimensional riverbed erosion model agree well with the experimental results. The deposited sediment upstream of a grid dam can be flushed out more effectively than that of a closed dam due to erosion process by a normal scale of flood flow when some deposited large boulders are removed. From the results, it is shown that the grid type check dam can keep their sediment trapping capacity more effectively than the closed type check dam.

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実験的検証を伴う砂防ダム上流における土石流の堆積・侵食過程の数値解析

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要　旨

土石流メカニズムの理解と予防策についての研究は, 流域内の土砂管理や土砂災害の防止のために重要である。通常，透過型の砂防ダムは土石流を貯えることにより土砂災害を防ぐものとして使われている。砂防ダム上流での土石流堆積過程及び通常洪水流による堆積土砂侵食のメカニズムを研究するため, 数値解析と実験を行った。砂防ダム上流での土石流堆積を計算する新たな式を明らかにした。解析と実験は不透過型砂防ダムと格子型砂防ダムを用いた。

キーワード：土石流，砂防ダム，侵食/堆積，数値解析，実験