A simplified numerical model for evaluating sediment control by open-type sabo dams in the Joganji River basin

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Abstract. The present study proposes a method to estimate sediment runoff by introducing a dam function of the relationship between inflow sediment and sediment runoff through a slit dam. The model can process rainfall runoff, sediment yield and runoff of a mountainous basin, and the model is applied to the upper reaches of the Joganji River basin, which is known for its huge amount of sediment runoff and intense bed variation because of the sediment yield caused by the earthquake in 1858. The performance of the calculations of sediment control of the slit dam is evaluated by the model. The result indicates that sediment deposition is significantly changed by sediment runoff. The proposed method can be expected to evaluate sediment transport with sabo dams on a basin scale.

1 Introduction

The Joganji River basin has experienced a lot of sediment disasters because of the considerable sediment yield of approximately 0.1 billion m³ that was caused by mountain collapse as a result of the earthquake in 1858 [1]. Some of the sediment movements caused by the earthquake built up natural landslide dams. Natural landslide dams broke twice, 14 days and 59 days after the earthquake, generating a large-scale outburst flood and sediment deposition on the alluvial fan of the Joganji River [1].

Evaluating the effect of the open-type sabo dam (slit dam) on sediment runoff control and studying sediment transport within a basin with sabo dams and slit dams are important [2,3]. The present authors have been studied modeling sediment deposition and sediment runoff at slit dams and the dam installation method through a model that processes rainfall runoff, sediment yield, and runoff of a mountainous basin (Storm Induced Multi-Hazards Information Simulator [SiMHiS]), which was developed by Yamanoi and Fujita [4].

In the present study, we propose a method to estimate sediment runoff through a slit dam by introducing a dam function of the relationship between inflow sediment and sediment runoff through a slit dam. The SiMHiS model with the proposed method is applied to the upper reaches of the Joganji River basin to evaluate the performance of the calculations of sediment control of the slit dam by the model.

2 Method

The SiMHiS is composed of rectangular unit slopes and linear unit stream channels in its topography, in the same manner as Egashira et al. [5]. Darcy’s law and the Manning equation are applied to the lateral saturated flow and overland flow on unit slopes, respectively.

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The sediment transport formula of Ashida-Michiue [6] is applied for the bed load and suspended load calculations of unit stream channels.

Setting up the effect of a slit dam using topographical properties such as dam height and width of the slit is difficult because the spatial resolution of the unit stream channel is not sufficient to express the slit dam topographically. Therefore, the method to estimate the sediment runoff requires an approach that is independent of the topographic properties.

Relationships between inflow sediment and sediment runoff through the slit dam are formulated focusing on the duration time at which the backwater is formed and sediment runoff during the duration time.

Figure 1 shows a schematic diagram of sediment runoff through the slit dam, where \( Q \) is the runoff, \( T \) is the duration during which sediment runoff is stopped by the backwater, \( t_1 \) and \( t_2 \) are the times at which the backwater is formed and cleared, respectively, \( Q_b \) is the runoff of the bed load, \( Q_{b10} \) is the bed load runoff at the

![Image](https://doi.org/10.1051/e3sconf/202341506021)

**Table 1.** Parameters for dam function and patterns of calculations.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T ) (hours)</td>
<td>4</td>
<td>Runs 0-3</td>
</tr>
<tr>
<td>( R_{b1} ) (-)</td>
<td>0</td>
<td>Run 0</td>
</tr>
<tr>
<td>( R_{b1} ) (-)</td>
<td>0.5</td>
<td>Run 1</td>
</tr>
<tr>
<td>( R_{b1} ) (-)</td>
<td>2</td>
<td>Run 2</td>
</tr>
<tr>
<td>( R_{b1} ) (-)</td>
<td>10</td>
<td>Run 3</td>
</tr>
</tbody>
</table>

\( R_{b1} \): Ratio of multiplier to \( Q_{bin} \)

**Table 2.** Particle-size distribution of supplied sediment (s) and bed material (b).

<table>
<thead>
<tr>
<th>Diameter (m)</th>
<th>s %</th>
<th>b %</th>
<th>Diameter (m)</th>
<th>s %</th>
<th>b %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00057</td>
<td>51</td>
<td>2</td>
<td>0.0099</td>
<td>7</td>
<td>24</td>
</tr>
<tr>
<td>0.0021</td>
<td>23</td>
<td>5</td>
<td>0.036</td>
<td>1</td>
<td>35</td>
</tr>
<tr>
<td>0.0075</td>
<td>12</td>
<td>12</td>
<td>1.31</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>0.027</td>
<td>6</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.** Hydrological and hydraulic parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D_1, D_2 ) (m)</td>
<td>0.1, 0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \kappa_1, \kappa_2 ) (mm/s)</td>
<td>3, 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \lambda ) (-)</td>
<td>0.467</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( E_m ) (m/s)</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( N ) (m(^{-1/3}))</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( D_1, D_2 \): depth of soil layer, \( \kappa \): saturated hydraulic conductivity, \( \lambda \): porosity, \( N \): equivalent roughness coefficient, \( \alpha \): regime coefficient, \( n \): Manning’s roughness coefficient, \( E_m \): depth of mixing layer and deposition layer, respectively.

![Fig. 2.](image) (a) Location of the Joganji River basin, (b) locations of a rain gauge, sabo dams, and the Myoju Sabo dam within the Joganji River basin with contour lines every 500 m, (c) unit channels and unit slopes of the Joganji River basin.

![Fig. 3.](image) Temporal changes in gauged rainfall and simulated storm water runoff.
The parameters are to be defined by flume tests. Since the relationships between inflow sediment and sediment runoff through the slit dam differ depending on whether the overflow of the slit dam occurs, the equations are out of the application range when the overflow of the slit dam occurs in the present study.

Therefore, in the present study, \( Q_{\text{boul}} \) is defined as follows:

\[
Q_{\text{boul}}(t_1 \leq t < t_1 + T) = 0 \\
Q_{\text{boul}}(t_1 + T \leq t < t_2) = Q_{b1} \frac{t - (t + T)}{t_2 - (t_1 + T)} 
\]

(1) \( Q_{b1} \) and \( Q_{b2} \) are the bed load runoff when the backwater cleared. The value of \( Q_{boul} \) before \( t_1 \) and after \( t_2 \) can be calculated by the equilibrium bed load equation. However, it is inappropriate to apply the equation during the period from \( t_1 \) to \( t_2 \) because of the complicated local variation of the topography and hydraulic condition around the slit dam.

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### 3 Condition and settings

#### 3.1 Joganji River basin

A mountainous basin located in the upper reaches of the Joganji River basin was selected for application of the proposed method. Figure 2(a) shows location of the Joganji River basin. Figure 2(b) shows locations of a rain gauge, sabo dams, and the Myoju Sabo dam within the Joganji River basin with contour lines every 500 m.

Figure 2(c) shows unit channels and unit slopes, the area of the target basin is approximately 200 km², and the elevation ranges from 300 m to 3,000 m. There are twelve main sabo dams and slit dams within the basin. Sediment runoff, deposition, and water level are observed around the Myoju Sabo dam (slit dam with a shutter [7]).

The topography model for the SiMHiS is built using elevation data provided by the Geospatial Information Authority of Japan (GSI).

### 3.1.2 Target storm event

A storm event was selected focusing on peak runoff and duration time for the backwater was formed at the Myoju Sabo dam. The design peak runoff for the Myoju Sabo dam is approximately 2,000 m³/s, and the backwater is expected to be formed by 100 m³/s.

A storm event that occurred from 17th July to 18th July in 2004 was selected. Hourly rainfall data provided by the Japan Meteorological Agency (JMA) was used for rainfall runoff. Figure 3 shows temporal changes in hourly rainfall as determined by the rain gauge (Fig. 2). The maximum 24-hour rainfall was 174 mm, and the maximum hourly rainfall was 45 mm.

Simulated runoff is shown in Figure 3. Peak runoff is approximately 800 m³/s, which is half of the design runoff of the Myoju Sabo dam. Since this implies that overflow of the slit dam does not occur, Equations (1) and (2) are within the application range. From the viewpoint of the field survey, it is considered that while runoff exceeds 100 m³/s (red line in Fig. 3), the backwater is formed. Therefore, from 23:10 of the 17th to 7:20 of the 18th, the backwater is assumed to be formed and the time accounts for a quarter of the total runoff event.

#### 3.1.3 Settings

In order to test the relationship between sediment runoff from the slit dam (the Myoju Sabo dam) and sediment deposition in the slit dam, variables \( T \) and \( R_{bi} \) are introduced. Here, \( T \) is the duration time when sediment runoff is stopped by the backwater, and \( R_{bi} \) is the ratio of \( Q_{blos} \) to obtain \( Q_{blos} = R_{bi} \cdot Q_{blos} \). Table 1 shows the values of \( T \) and \( R_{bi} \), which is the multiplier to \( Q_{blos} \) used to obtain \( Q_{blos} \) and patterns of calculations.

The Myoju Sabo dam is located around the center of the unit channel. Therefore, bed load runoff from the outlet of the unit channel is regarded as bed load runoff from the Myoju Sabo dam, and sediment deposition of the unit channel is regarded as sediment deposition of the dam. Since the height of the dam is not considered in this calculation, changes in the river bed may exceed the dam height under particular conditions. Bed load runoff from the Myoju Sabo dam is calculated using Equations (1) and (2).

Assuming the suspended load does not contribute to river bed change in the steep river of the present study, the suspended load is not considered. Therefore only bed load is supplied at the outlet of two upper unit stream channels in the equilibrium condition. Table 2
shows the particle-size distribution of supplied sediment and bed material. That of supplied sediment is determined by the sieving tests for sampling materials at the bare slope within the target area, and the distribution of bed material is determined by the iterative calculations during several ten years. The hydrological and hydraulic parameters are determined by general settings for mountainous areas in Japan (Table 3).

The initial condition for the stream bed is set by simulating 30 mm of hourly rainfall for 24 hours followed by no rainfall for 24 hours.

4 Results

Figures 4 and 5 show the temporal changes in bed load runoff through the Myoju Sabo dam ($Q_b$) and elevation of the sediment deposition of the Myoju Sabo dam ($Z_b$), respectively. The amount of degradation of elevation ($Z_b$) becomes larger according to an increase in $R_{b1}$, as shown in Runs 1 to 3. The result indicates that sediment deposition is significantly changed by sediment runoff. The effect of the sediment runoff on changes in elevation was significant in Run 3. The total amounts of sediment volume without porosity in Runs 0 to 3 were $3.83 \times 10^5$ m$^3$, $0.92 \times 10^5$ m$^3$, $1.08 \times 10^5$ m$^3$, and $2.19 \times 10^5$ m$^3$, respectively.

Introducing sediment runoff calculation into existing models becomes easier using the simulation in the present study with surveyed topography and bed load data.

5 Conclusion

The present study proposed a simplified method to estimate sediment runoff through a slit dam by introducing a function of the relationship between inflow sediment and sediment runoff through a slit dam. The model is applied to the Joganji River basin, which is known for its huge amount of sediment runoff and intense bed variation because of the sediment yield caused by the earthquake in 1858.

The result indicates that sediment deposition is significantly changed by sediment runoff. At the same time, the result means that the effect of sabo facilities such as the sabo dam can be considered by introducing the proposed dam function in the calculation of basin scale by the unit-slope and unit-channel model (e.g., the SIHMS). Although additional verification will be required, the method is expected to evaluate sediment transport with sabo dams in a basin scale. The authors are going to improve the function based on flume tests and sediment-hydraulic approaches.

References