

CONCEPT ON SUSTAINABLE SAND MINING MANAGEMENT IN MERAPI AREA

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Mt. Merapi is one of the most active volcanoes in the world and located at 30 km north-northeast from Yogyakarta, Indonesia. A large amount of sediment supply from Mt. Merapi area is serious threat to people, but works also as an important natural resource for people. Thus, the sediment from the volcano has given both advantages and disadvantages. Sustainable sediment management is urgently required to mitigate the sediment disasters and provide the people with benefits. It is considered that sand mining activity and installation of groundsills can be used as one of the tools to control the sediment disasters and the regional development. In this study, we discussed the basic management concepts of sand mining and groundsill installation for such sustainable sediment management.

Key Words : *sustainable sediment management, sand mining, groundsill, Mt. Merapi, bed deformation analysis*

1. INTRODUCTION

Mt. Merapi is one of the most active volcanoes in the world¹⁰. It is located at the vicinity of Yogyakarta city in central Java Island, Indonesia. **Fig. 1** shows the location of Mt. Merapi. Mt. Merapi has been giving various volcanic activities, such as eruptions, lava flows, pyroclastic flows, glowing clouds, volcanic ash falls and volcanic debris flows. The produced sediment has been causing many disasters for local residents. Particularly, pyroclastic flows due to collapse of lava dome or lava tip result in disasters and a tremendous amount of volcanic loose deposits on the its slope. Pyroclastic flows have run down during the last 100 years^{2, 10}, and occurred most on southwest slope from 1961 to 1997. The total number of debris flows recorded from 1931 to 1996 was more than 500 times.

The locations of sediment deposits are shown in **Fig. 1**. Sediment in Mt. Merapi has good quality and is popular as construction material. The sand mining activities have given some advantages for rural/local people and local governments. Total number of mining workers in Mt. Merapi area amounts to about 21,000 man/day. The local government of Magelang Regency obtained benefit from the sand mining activities and the regency income is Rp.

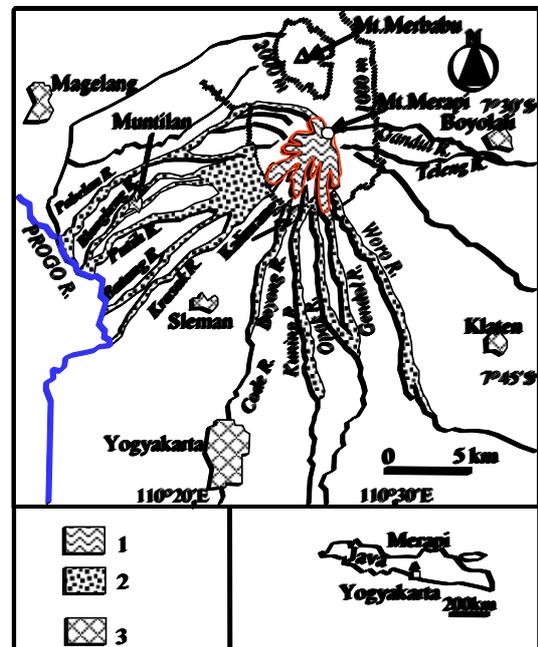


Fig.1 Location of sediment deposits in Mt. Merapi. (1: Summit lava dome and andesitic lava flow, 2: volcanislastic deposits from Merapi volcano, 3: main cities.^{6), 7)} Blue line : Progo River. Inside of the red line is volcanic active basin. Outside of the red line is non volcanic basin)

2,218,000,000 (from fiscal 1998)⁵. Hence, ban of sand mining damages the economic condition of both

local people and local governments. However, uncontrolled sand mining has caused problems in the watershed such as instability of groundsills, bridges and so on due to bed degradation. Especially in the lower reach of the Progo River, since 1970, bed degradations are observed at 10-30 cm/year. Aquatic and riparian habitats are also destructed due to natural and artificial armoring. If the sand mining can be controlled, it can be one of measures to prevent sediment disaster and contribute to the rural economy. In this paper, the basic concepts of such sustainable sediment management assisted by sand mining and sabo works are discussed.

2. SEDIMENT BALANCE

The current sediment balance in Mt. Merapi is influenced by sediment production, sediment mining and sediment discharge to sea as shown in Fig. 2.

(1) Sediment production

Fig. 3 shows the sediment production from lava production (volcanic active basin) and land surrounding Merapi area (non-volcanic basin). Both locations are shown in Fig.1. The lava production data from 1890 to 1992 has been compiled by Siswawidjono et al⁸⁾ and it is varied widely from less than 10^6 m^3 to more than $20 \times 10^6 \text{ m}^3$. The cumulative volume is proportionally increased and the annual average lava production rate estimated base on the the cumulative volume of lava is around $1.2 \times 10^6 \text{ m}^3/\text{year}$. The sediment production from non-volcanic basin is estimated at 20% of the sediment production from volcanic active basin²⁾ ($= 0.24 \times 10^6 \text{ m}^3/\text{year}$). Thus, the total annual average sediment production rate, Q_{spm} , is equal to $1.44 \times 10^6 \text{ m}^3/\text{year}$. The assumed sediment discharge into the Progo river is equal to Q_{spm} ($=1.44 \times 10^6 \text{ m}^3/\text{year}$).

(2) Sand mining volume

The sand mining volume in the upper area in 2000 was estimated at $5-6 \times 10^6 \text{ m}^3/\text{year}$ ¹⁾. Sand mining is also performed in the lower reach area, especially in the Progo River. The mining rate in the lower Progo River is estimated at about $1.07 \times 10^6 \text{ m}^3/\text{year}$ ⁴⁾.

(3) Sediment outflow to sea and future condition

According to DGWR report, the hydrological and topographical conditions in the lower Progo River are as follows. The annual average discharge is $83.1 \text{ m}^3/\text{s}$. The mean diameter of bed material is 1 mm, the average river width is 200 m, and the average bed slope is 0.0015. Under this condition, the sediment discharge in the lower Progo River, Q_{st} , is estimated

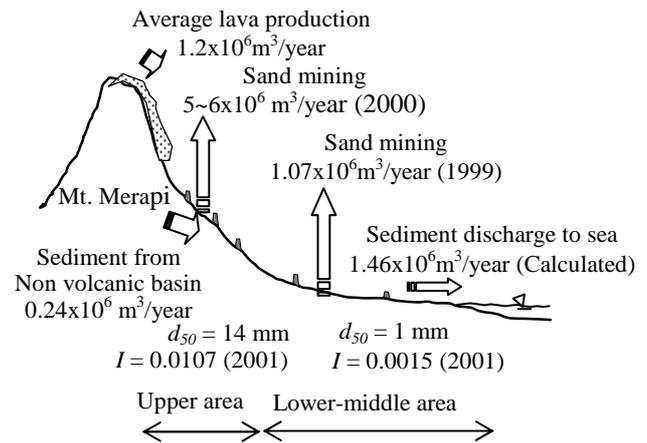


Fig.2 Sediment balance in Mt. Merapi area

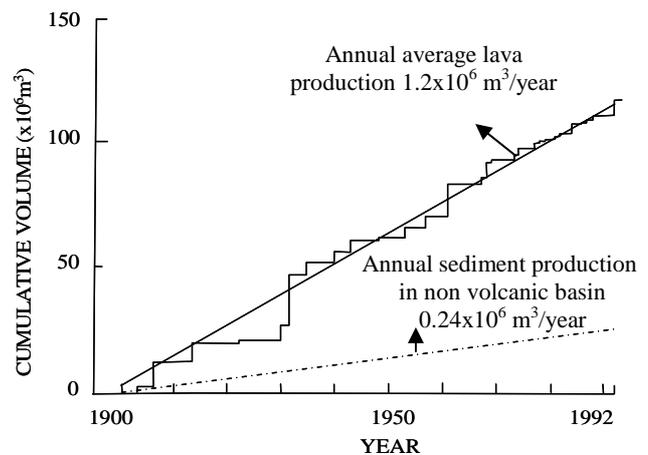


Fig.3 Cumulative volume of the lava productions in Mt. Merapi and the sediment production in non volcanic basin.

at $1.46 \times 10^6 \text{ m}^3/\text{year}$ using Ashida and Michiue's bed load transport formula³⁾. This result shows that the annual average sediment discharge is almost equal to the annual average sediment production rate. Therefore, the sediment discharge to sea balances with the sediment production rate. However, actually total sand mining in the foot hill area and the lower Progo River are $6.07-7.07 \times 10^6 \text{ m}^3/\text{year}$. Thus, the bed degradation has occurred in the lower Progo River. If sand mining activities in the upper reach is not suppressed, sediment does not supplied to the lower reach for a long term. Under this condition, the slope decreased from 0.0015 until the static equilibrium slope of sediment transport ($=0.000156$).

3. CONCEPTS OF SUSTAINABLE SAND MINING MANAGEMENT

(1) Sand mining management concept

In this chapter, the allowable sand mining volume, Q_{sa} , is determined under equilibrium sediment transport conditions. Fig. 4 shows the procedure to calculate Q_{sa} . First, the designed bed slope, i_{bd} , is decided. To determine i_{bd} , it depends on how deep the riverbed degradation took place and how much

the sand mining volume will be taken. Next, the allowable degradation depth (height of groundfills) is decided by based on the available budget. In consequence of these steps, the number of groundfills and the longitudinal distance between groundfills are obtained. In the 3rd step, sediment discharge to sea, Q_{s1} , is calculated for the designed bed slope. In this paper, Ashida-Michiue's equation is used to calculate Q_{s1} . Finally, Q_{sa} is equal to $Q_{spm} - Q_{s1}$. For example, $i_{bd} = 0.001$, Q_{s1} is $0.82 \times 10^6 \text{ m}^3/\text{year}$. Thus, under this condition, the allowable sand mining volume is $0.62 \times 10^6 (=1.44 \times 10^6 - 0.82 \times 10^6) \text{ m}^3/\text{year}$. Relation between i_{bd} and Q_{sa} is shown in Fig. 5. The maximum allowable sand mining volume is $1.44 \times 10^6 \text{ m}^3/\text{year}$.

(2). The sediment hazard

By the controlled sand mining activity, an extra empty of capacity in the sediment reservoirs is useful to contribute the rural economy and control the river bed elevation in lower reach. However, the sediment supply rate, Q_{supply} , from the Mt. Merapi changes very much. Thus, it is very important to determine the allowable sediment supply to the lower Progo River, Q_{s2} , for each i_{bd} to prevent sediment hazard. Here, it is assumed that Q_{s2} is defined as sediment supply rate that causes i_{bd} to return to the original bed slope ($i_b = 0.0015$). Q_{s2} is equal to $Q_{spm} + Q_{sa}$. For example, if the designed bed slope is 0.001, Q_{s2} is $2.06 \times 10^6 (=1.44 \times 10^6 + 0.62 \times 10^6) \text{ m}^3/\text{year}$. Relation between i_{bd} and Q_{s2} is shown in Fig. 6. If Q_{supply} is less than or equal to Q_{s2} , series of groundfill is never buried with sediment. But if Q_{supply} is much bigger than Q_{s2} , it will cause bed aggradation and groundfills are buried after a long time. For example, if a huge eruption occurs with the sediment production rate of $25.0 \times 10^6 \text{ m}^3/\text{year}$ like 1930, it is predicted that the bed slope changes from i_{bd} to the equilibrium bed slope with $25.0 \times 10^6 \text{ m}^3/\text{year}$ ($=0.015$). If the bed increases rapidly, it can cause some serious problems in the lower reach such as ineffectively of irrigation intake function⁹⁾. Considering the actual situation of the volcanic activities in Mt. Merapi, a buffer zone such as a sand pocket is strongly required.

4. SUSTAINABLE SAND MINING COMBINED WITH SABO WORKS

Sand mining management concept is discussed in Chapter 3. However, the concept is established under equilibrium sediment transport condition. In this chapter, one dimensional bed deformation analysis is performed for the lower reach of the Progo River and two management concepts on the sand mining and

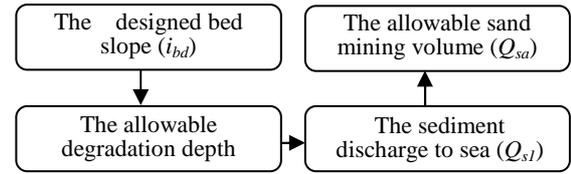


Fig.4 Flowchart to determine the allowable sand mining volume, Q_{sa}

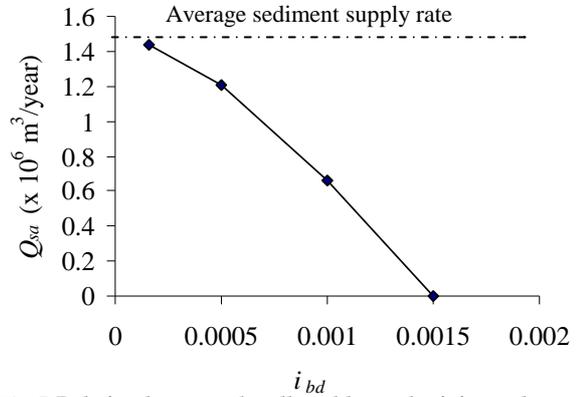


Fig.5 Relation between the allowable sand mining volume, Q_{sa} , and the designed bed slope, i_{bd}

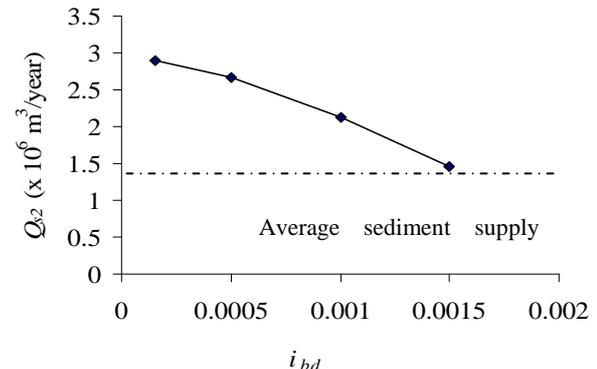


Fig.6 Relation between the allowable sediment supply, Q_{s2} , and the designed bed slope, i_{bd}

the groundfill installation are discussed.

(1) Simulation Model

The basic equations of a simulation model of one dimensional bed deformation analysis are shown as follows. The used model is the standard well-used one dimensional bed deformation model. Mass and momentum equations of water are as follows.

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left(\frac{Q^2}{A} \right) = -gA \frac{\partial z}{\partial x} - gAI_e + \frac{\partial}{\partial x} (A\sigma_{xx}) \quad (2)$$

where, t is the time, x is the coordinate along the longitudinal direction, A is the cross-section area of water, Q is the water discharge in main channel, g is the gravity, ρ is the water density, z is the water surface elevation, I_e is the energy slope and σ_{xx} is the turbulence stress. Ashida and Michiue's

formula³⁾ is used for the estimation of sediment transport rate. Equation of continuity of sediment discharge is:

$$B_w \frac{\partial z_b}{\partial t} + \frac{1}{1-\lambda} \frac{\partial Q_b}{\partial x} = 0 \quad (3)$$

where, B_w is the channel width, λ is the porosity of bed material, z_b is the riverbed elevation.

(2) Hydraulic conditions

The simulation is carried out using the averaged geometric and hydraulic characteristic values of the lower reach of the Progo River. These data are the same as the data used in Section 2 (3). The calculation length is 30 km. Normal water depth is used for the downstream boundary conditions.

Calculations are performed under 6 conditions. The initial longitudinal bed geometry is drawn in Fig. 7. In Case 1, initial bed slope is 0.0015 and 3 groundsills are installed on the original bed. The height of each groundsill is 2.7m and the longitudinal interval between groundsills is 9km. Under this groundsill install condition, the designed bed slope becomes 0.0012. Supplied sediment discharge is the equilibrium sediment transport rate with the slope 0.0012 ($= 0.0338\text{m}^3/\text{s}$). Hence, $0.0119\text{m}^3/\text{s}$ ($= 0.0457\text{m}^3/\text{s} - 0.0338\text{m}^3/\text{s}$) can be used as sand mining. In Case 2, the hydraulic condition is the same as that in Case 1 except for the installation level of groundsills. The crest of groundsills has the same level as the bed surface. When the bed has been degraded because of sand mining and so on, groundsills will be installed as Case 1 to increase the bed surface. When the initial bed level should be kept, groundsills will be installed as Case 2. Cases 3 and 4 will be used for the discussion on the installation order of groundsills. Only 1st groundsill is installed as an initial condition in Case 3 and the 2nd groundsill and the 3rd groundsill are installed after 1 year and 2 years, respectively. The other hydraulic condition is the same as that in Case 1. Only 3rd groundsill is installed as an initial condition in Case 4 and the 2nd groundsill and the 1st groundsill are installed after 1 year and 2 years, respectively. The other hydraulic condition is the same as that in Case 1. Bed variation characteristics under large sediment supply conditions are discussed using Cases 5 and 6. The initial bed slope between groundsills is 0.0012. In Case 5, the supplied sediment discharge during the first year is the same as the sediment discharge in the 1930's huge eruption ($= 0.790\text{m}^3/\text{s}$). Supplied sediment discharge in the following 4 years is the equilibrium sediment transport rate with the slope 0.0012. In Case 6, the supplied sediment discharge during the first year is

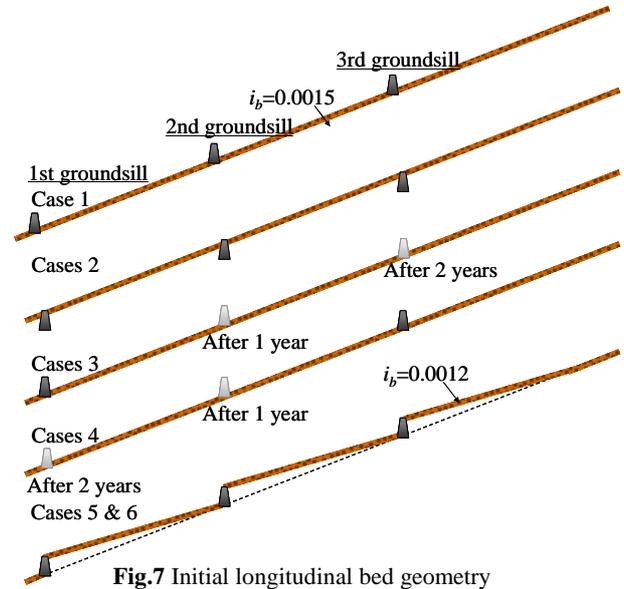


Fig.7 Initial longitudinal bed geometry

the two times as the equilibrium sediment transport rate with the slope 0.0015 ($= 0.0463\text{m}^3/\text{s} \times 2$). Supplied sediment discharge in the following 4 years is the equilibrium sediment transport rate with the slope 0.0012.

(3) Results and Discussion

Fig. 8 (a) shows the temporal change of bed geometry in Case 1. The bed deformation between groundsills is very fast and bed slope becomes mild with time. Bed level at 18km from the downstream end decreases with time in the first year and increases in the following years. Fig. 9 (a) shows the temporal change of the sediment transport rate between the 2nd groundsill and the 3rd groundsill in Case 1. The figure indicates that the bed at 18km is degraded until 8 months, because the sediment transport rate at 18km is more than sediment transport rate at 19km. These results indicate that the bed deformation between groundsills in the first year is the adjustment process of bed geometry to the local flow condition. On the other hand, after 8 months, sediment deposition takes place at 18km due to the effect of the upstream sediment supply conditions. The sediment transport rate at 10km is still smaller than the equilibrium sediment transport rate with the bed slope 0.0012 ($= 0.0338\text{m}^3/\text{s}$) at 5 years. Hence, approaching to the equilibrium state takes very long time under this condition.

Fig. 8 (b) shows the temporal change of bed geometry in Case 2. The bed degradation in the downstream of 3rd groundsill is invisible after 1 year. This result indicates that the effect of small sediment supply condition ($= 0.0338\text{m}^3/\text{s}$) propagates to downstream very slowly. Here, let me try to use the very slow propagation velocity to decide the installation order of groundsills. In Case 2, the 3 groundsills are installed at a time as the

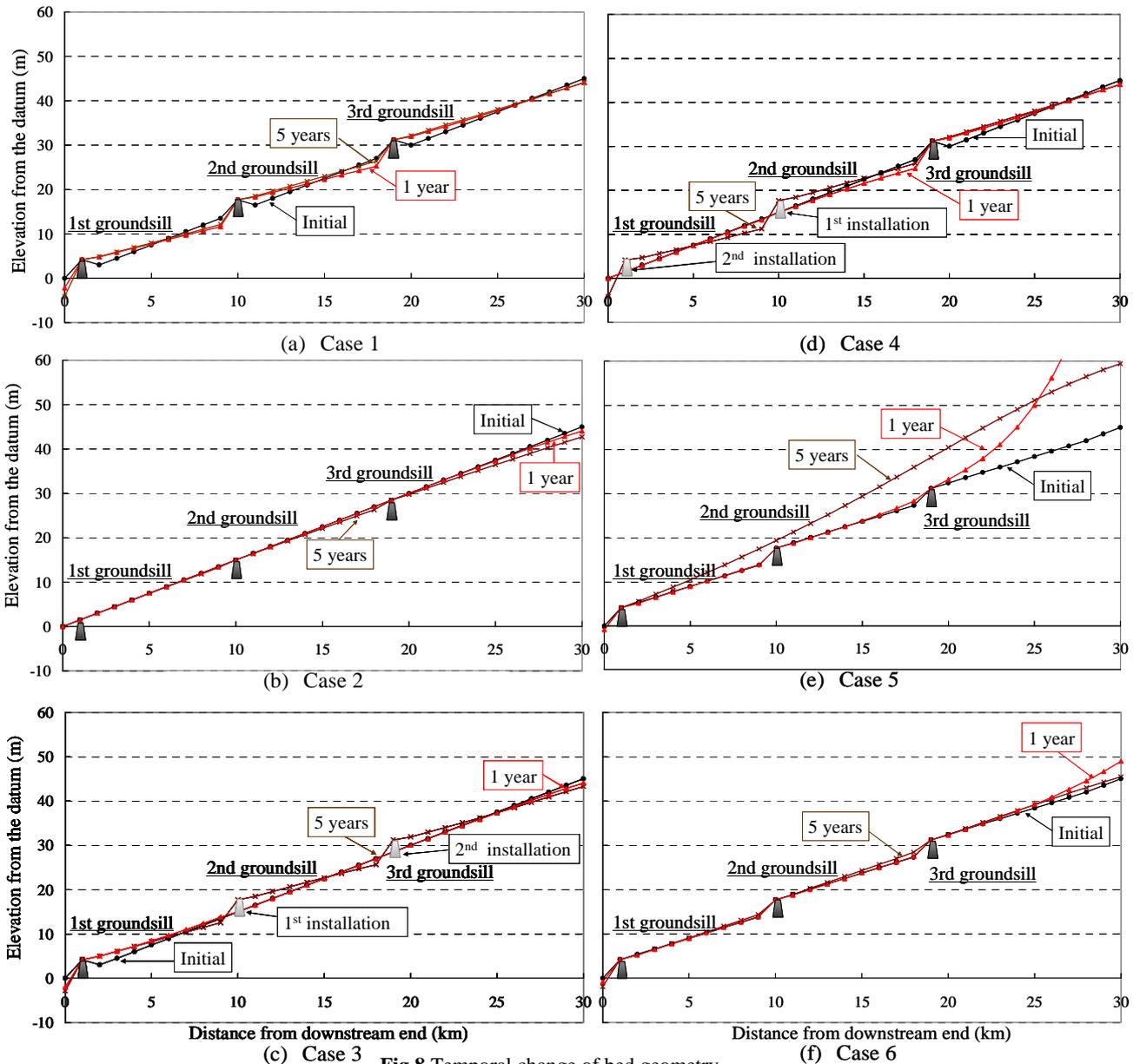


Fig.8 Temporal change of bed geometry

initial condition. However, in order to save budget (including interest for the budget), we had better construct only one ground sill first and the others are constructed at the following appropriate year. Fig. 9 (b) shows the temporal change of the sediment transport rate on 3 ground sills in Case 2. Sediment transport does not decrease on the 2nd ground sill and the 1st ground sill until 2 years and 4 years, respectively. As a result, if installation of crest of ground sill is the same as the bed surface to keep the original bed, not to increase the original bed, installation of the 2nd ground sill can be done at the 2 years and installation of the 1st ground sill is at the 4 years. It is economical that the ground sills are installed from upstream to downstream.

Fig. 8 (c) and (d) show the temporal change of bed geometry in Cases 3 and 4. Comparing among Cases 1, 3 and 4, bed degradation at the downstream

of ground sills (ex. 18km and so on) is suppressed in Case 3. Hence, the ground sills in Case 3 are the most stable and the depth of the basement under the bed can be shallow. As a result, the construction costs of ground sills can be saved. Fig. 9 (c) shows the temporal change of the sediment transport rate at the downstream end. In order to minimize the impact of ground sill construction on the ecosystem of the downstream of ground sills, the decrease range of sediment discharge should be smaller. From the view point of this, Case 3 has the smaller temporal change of sediment discharge (initial sediment transport is $0.0457\text{m}^3/\text{s}$). Hence, when ground sills are installed to increase the bed level (the crest of ground sills is higher than the bed surface), it is safe for human being, plants and animals that the ground sills are installed from downstream to upstream.

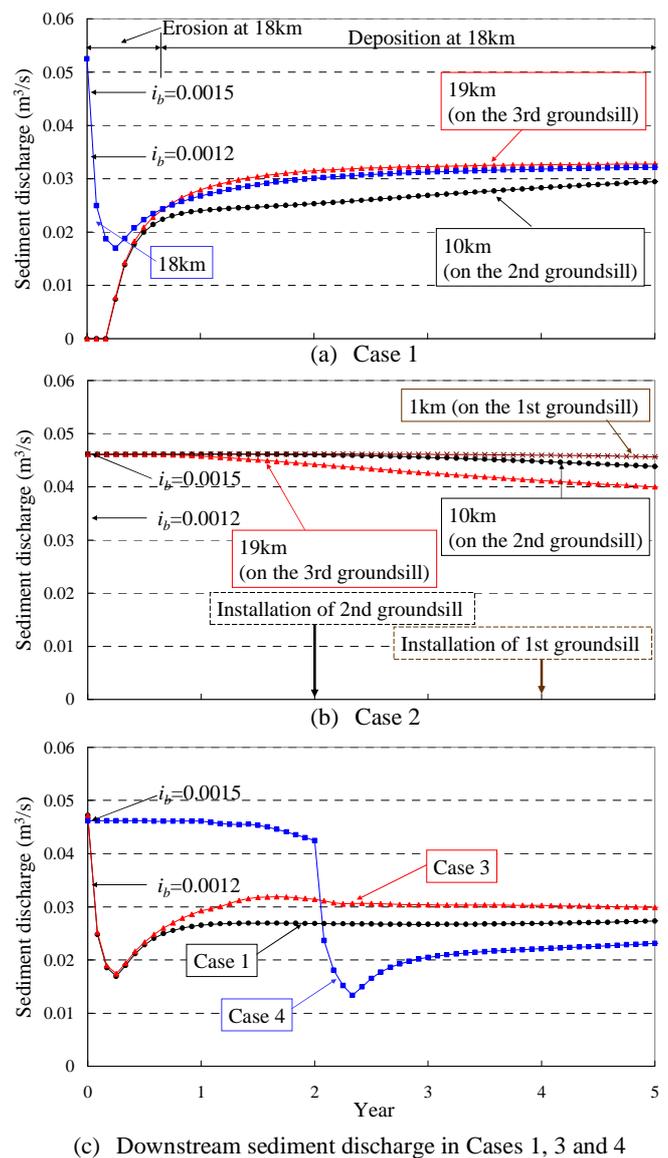
As discussed using **Fig. 6**, the sediment discharge with the original bed slope ($=0.0015$) can be one of the allowable maximum sediment discharge for sediment disaster prevention. However, as shown in **Fig. 3**, huge amount of sediment is supplied to rivers when the volcano is erupted. **Fig. 8 (e)** shows the temporal change of bed geometry in Case 5. Bed elevation from 25km to 30 km becomes very high after 1 year and overbanked sediment flood is expected. After 5 years, all the groundsills are filled with sediment and the slope becomes larger than 0.0015. Of course, these results depend on the upstream sediment supply condition. However, the data of the upstream of the Progo River is not enough to discuss the propagation characteristics of sediment supply by the volcanic eruption. Hence, the above mentioned sediment supply condition is applied as an example here. **Fig. 8 (f)** shows the temporal change of bed geometry in Case 6. As shown in **Fig. 8 (f)**, the bed deformation around the groundsills are very small because of the decrease in the sediment discharge peak during the propagation process to downstream. Hence, the allowable maximum discharge is underestimated, when the equilibrium conditions is assumed. As a result, the two times as the equilibrium sediment transport rate with the slope 0.0015 can be flowed without filled with groundsills.

5. CONCLUSION

In this study, sediment supply from mountainous area is considered as natural resources, and the basic concepts of sustainable sediment management assisted by sand mining and sabo works are discussed. In fact, sediment mining brings non-negligible economic effects to people and local government in Mt. Merapi area. On the other hand, uncontrolled sand mining forms sever bed degradation and damages to ecosystem in the lower river. Furthermore, the budget for river regulation works is restricted. It is considered that the suggested management concepts can be used for helping to determine the politics on the sand mining and the groundsills and sand pockets installtions.

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(c) Downstream sediment discharge in Cases 1, 3 and 4

Fig.9 Temporal change of sediment transport rate

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