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Vorgeschlagene Zitierweise/Suggested citation:
Ikhsan, Jazaul; Sulaiman, Muhammad; Fujita, Masaharu (2008): A Study on Sustainable Sediment Management in Merapi Volcanic Area. In: Sekiguchi, Hideo (Hg.): Proceedings 4th International Conference on Scour and Erosion (ICSE-4). November 5-7, 2008, Tokyo, Japan. Tokyo: The Japanese Geotechnical Society. S. 553-557.

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A STUDY ON SUSTAINABLE SEDIMENT MANAGEMENT IN MERAPI VOLCANIC 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 resources for people. Thus, the sediment from the volcano has given some advantages and disadvantages. Sustainable sediment management is urgently necessary to mitigate the sediment disasters and provide the people with benefits. It is considered that sand mining activity can be used as one of the tools to control the sediment discharge, and the regional development. In this paper we discussed the basic concept of such sustainable sediment management considering the sediment production, the topographical and hydrological condition, and the actual sand mining activity.

Key Words : *Mt. Merapi, sediment, sustainable management, control sediment, sand mining*

1. INTRODUCTION

(1) Volcanic activities

Mt. Merapi is one of the most active volcanoes in the world[8]. Mt. Merapi is located at approximately 30 km north of the city of Yogyakarta, Indonesia. Mt. Merapi has been giving various volcanic activities, such as eruptions, lava flows, pyroclastic flows, glowing clouds, volcanic ash falls and volcanic debris flows. Mt. Merapi has erupted once 5 years, or once 14 years for major eruptions during the last 200 years. In the last 50 years, Mt. Merapi erupted once 3 years, and major eruption occurred at an interval of 9 years. Mt. Merapi has still been producing actively a huge amount of sediment. The sediment has been causing many sediment disasters, and threatening 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 slope of Mt. Merapi. Pyroclastic flows have run down during the last 100 years on every slope of Mt. Merapi[2), 8)]. However, they have occurred most on southwest slope during 37 years from 1961 to 1997. The occurences of pyroclastic flows in 1998 and 2001 were limited on the western slope. However, in the eruption on June 2006, the pyroclastic flows took place in the Gendol River and the Woro River[5)] . The total number of debris flows recorded from 1931 to 1996 was more than 500 times. The debris flows were recorded in almost all the rivers on the slopes of Mt. Merapi[2)].

(2) Sand mining activities

The sediment can be important resources for people. The sediment deposit produced by the eruptions of Mt. Merapi has market value, and its quality attracts sand miners. The sand mining activities have given some advantages for rural/local people, local government and reduced sediment run off. Sand and gravel material in Mt. Merapi offer many benefits such as employment opportunity, and an increase in economical benefit to farmers.

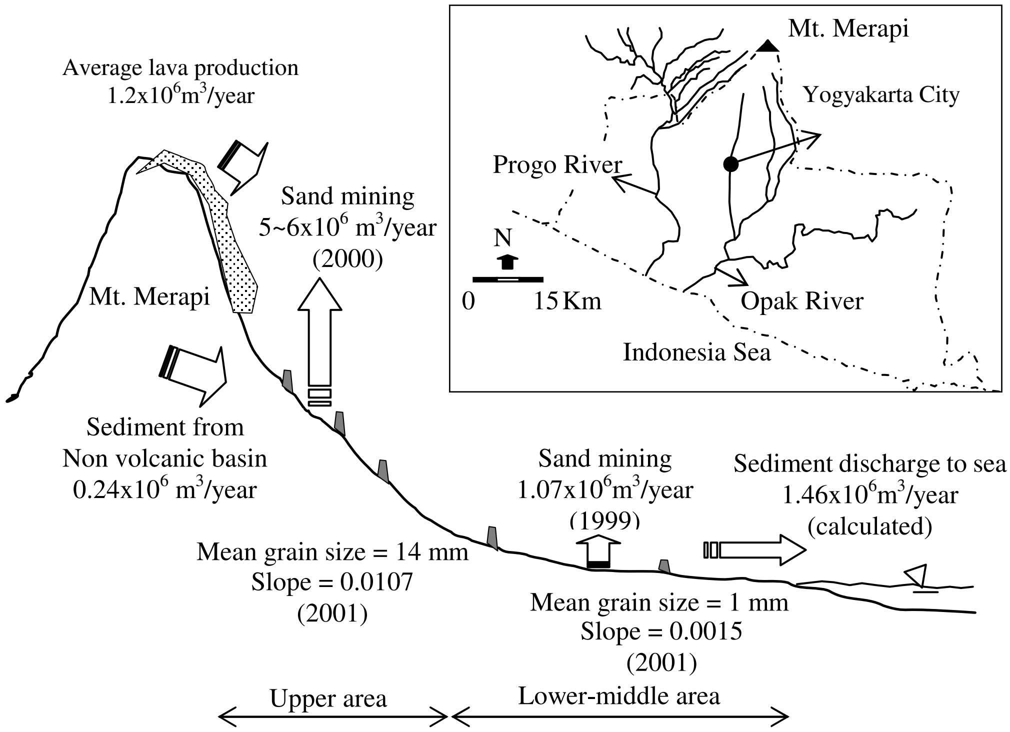

Fig.1 Sediment balance in Mt. Merapi area

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 increased from Rp. 236,000,000 (in fiscal 1997) into Rp. 2,218,000,000 (from fiscal 1998)[4). Klaten regency imposed a mining tax revenue of Rp 92,00,00 (in fiscal 1999) and Sleman regency imposed a mining tax revenue of Rp 500,000,000 (in fiscal 2000). It means that exploitation of sand and gravel material provides rural areas with considerable opportunities for economic development. However, uncontrolled sand mining has caused serious problems in the watershed such as unstableness of sediment control facility, bridge and irrigation intake by digging nearby, channel and riverbank instability due to riverbed degradation, and destruction of aquatic and riparian habitat due to natural and artificial armoring. As long as the sand mining is controlled, it can be one of measures for sediment control plan to give an extra empty in the sediment reservoirs and contribute to the rural economy. From this point, sustainable sediment management assisted by sand mining is urgently necessary to mitigate the above issues. In this paper, the basic concept of such sustainable sediment management assisted by sand mining is discussed.

2. SEDIMENT BALANCE

The current situation of sediment balance in Mt. Merapi area is influenced by sediment production, sediment mining and sediment discharge to sea. Figure 1 shows the current situation of sediment balance in Mt. Merapi area.

(1) Sediment production

The lava production data from 1890 to 1992 have been compiled by Siswowidjoyo et al., (1995)[6)]. The production volume of individual eruptive events is varied widely from less than 10^6 m^3 to more than 20 x 10^6 m^3, but the cumulative volume is proportionally increased and the annual average lava production rate is approximately estimated at around 1.2 x 10^6 m^3/year.

In Mt. Merapi area, sediment production from the non-volcanic basin can not be neglected. The sediment production from non-volcanic basin is estimated at 20% of the sediment production from volcanic active basin[2)], therefore, the annual average sediment production is equal to 0.24 x 10^6 m^3/year. Thus, the annual average sediment production rate from Merapi volcano (volcanic active basin) and non-volcanic basin, Q_{spm} , is 1.44 x 10^6 m^3/year.

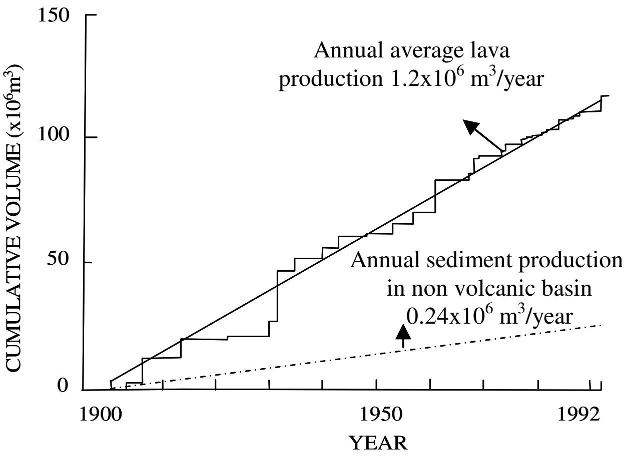

Fig.2 Cumulative volume of the lava productions in Mt. Merapi and the sediment production in non volcanic basin.

Figure 2 shows the sediment production from volcanic active basin and non-volcanic basin in Mt. Merapi.

(2) Sand mining volume

The sand mining volume in the foothills (upper area) of Mt. Merapi in 2000 was estimated at 5-6 x 10^6 m^3/year[1)]. The sand mining persists not only in the foothills of Mt. Merapi but also in the lower reach of river channel, especially in the Progo River. In the Progo River, the sand mining activities are concentrated in the lower reach area. The mining rate in the Lower Progo is estimated at about 2,933 m^3/day or 1.07 x 10^6 m^3/year[3)].

(3) The 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 m^3/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 total sediment discharge in the lower Progo River, Q_s, is estimated at 1.46 x 10^6 m^3/year using Ashida and Michiue's bed load transport formula and Ashida and Michiues's suspended load formula. This result shows annual average sediment discharge is almost equal to annual average sediment production rate. Therefore, the sediment discharge to sea balances with the sediment production rate. If the bed material is not removed by sand mining, degradation does not occur. However, actually total sand mining in the foot hill area and the lower Progo River are 6.07~7.07 x 10^6 m^3/year. Thus, the riverbed degradation has occurred in the lower Progo River and caused unstableness of existing river structures such as sediment control dam, bridge foundation and irrigation intake. In April 2000, one of the bridges, Srandakan Bridge located in lower Progo River collapsed. If no sediment is supplied to the lower reach of Progo River because of active sand mining in the upper reach, the annual average degradation depth is estimated at 1.10 m/year. According the field survey, this estimation agrees with the actual bed degradation.

If sand mining activities in the upper reach is not suppressed, it means sediment does not supplied into the lower reach for a long term. Under this condition, the slope decreased from 0.0015 until the static equilibrium state of sediment transport is reached. The static equilibrium estimated at 0.000156.

3. SUSTAINABLE SEDIMENT MANAGEMENT

(1) Present condition

Sediment deposit in Mt. Merapi area has threatened people; however, its quality attracts sand miners. Sand in Mt. Merapi area has a good quality and is useful as construction material. However, uncontrolled sand mining has caused serious problems. Excessive sand mining at a particular site reduces sediment discharge and causes the river bed degradation in the downstream.

(2) Sand mining management

The sand mining activities are prospering around Mt. Merapi. It is could be realized that sustainable sediment management consideres sustainable sand mining management. Sand mining management is one of alternative to control sediment discharge in Mt. Merapi area. The view point in sustainable sand mining is how to determine the allowable sand mining volume in the upper area around Mt. Merapi. Determining the allowable sand mining volume, the following steps are necessary to do. First, the designed bed slope in the lower reach, i_{bd}, is decided. In consequence of first step, it is necessary to estimate how many groundsills must be installed. If the designed bed slope is less than the original bed slopes, the number of groundsills becomes larger. Next step, sediment discharge to sea, Q_{s1}, is calculated for the designed bed slope. Finally, the allowable sand mining volume, Q_{sa}, can be calculated upon the design sediment supply rate, Q_{spd}, and the sediment discharge to sea as follows.

$$Q_{sa} = Q_{spd} - Q_{s1} \quad (1)$$

Assumed that Q_{spd} is equal to Q_{spm} (1.44 x 10^6 m^3/year), Q_{sa} is expressed by $Q_{spm} - Q_{s1}$. For instance, if the designed bed slope is 0.0015, the sediment discharge to sea, Q_{s1}, is 1.46 x 10^6 m^3/year. Thus, under this condition, the allowable sand mining volume is around zero. In the other case, if the designed bed slope is 0.0010, the sediment discharge to sea is 0.78 x 10^6 m^3/year, and therefore the allowable sand mining volume is estimated at 0.66 x 10^6 m^3/year. Relation between i_{bd} and the allowable sand mining volume, Q_{sa}, is shown in Figure 3. In the Mt. Merapi area, the maximum allowable sand mining volume is limited to 1.44 x 10^6 m^3/year that is the sediment resource annually provided from Mt. Merapi volcanic and non volcanic area.

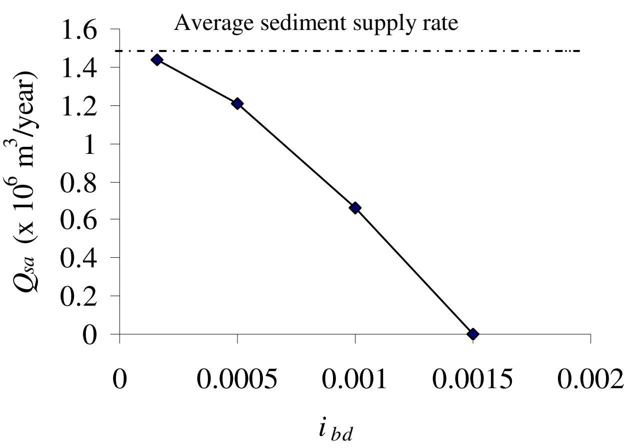

Fig.3 Relation between the allowable sand mining volume, Q_{sa}, and the designed bed slope, i_{bd}

4. OTHER PROBLEM

The lava production volume of individual eruptive events is varied widely from less than 10^6 m^3 to more than 20 x 10^6 m^3. Therefore, the sediment supply rate, Q_{supply}, from the Mt. Merapi also changes very much. Thus, it is very important to determine the allowable sediment supply to the lower Progo River, Q_{s2}, for each designed bed slope. Q_{s2} is defined as sediment supply rate that causes the designed bed slope to return to the original bed slope (i_b = 0.0015). The maximum allowable sediment supply to the lower area is 2.9 x 10^6 m^3/year for the designed bed slope of 0.000156 and this is the maximum allowable supply rate. Relation between i_{bd} and Q_{s2} is shown in Figure 4. If *Qsupply* is less than or equal to Q_{s2}, a series of groundsill is never buried with sediment. But if Q_{supply} is much bigger than Q_{s2}, this condition will cause severe agradation. For instance, if a huge eruption occurs with the sediment production rate of 20 x 10^6 m^3/year like 1930, it is predicted that the bed slope changes from the designed bed slope to 0.0086. This condition is quite danger for the lower reach. If the river bed increased rapidly, it caused some river structures such as irrigation intakes and bridges functioned ineffectively[7]. In order to reduce the predicted sediment disasters, the excess sediment supply should be controlled by the structural method such as sand pockets. For sustainable sand mining management, it is important to release the sediment deposit from the sand pocket at a rate of Q_{sa}. Considering the actual situation of the volcanic activities in Mt. Merapi, a buffer zone such as a sand pocket is strongly required in the deposition area of pyroclastic flows/debris flows for sustainable sediment management.

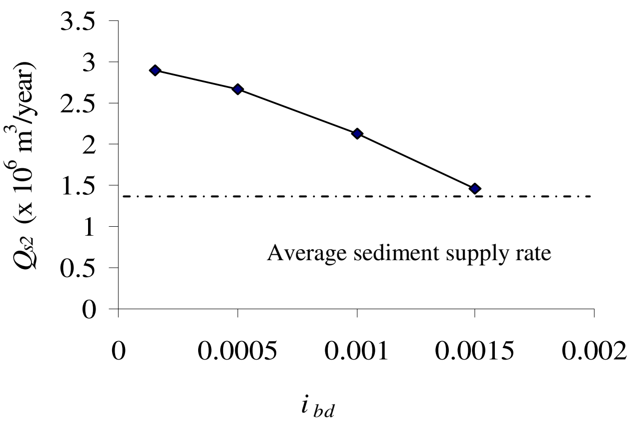

Fig.4 Relation between the allowable sediment supply, Q_{s2}, and the designed bed slope, i_{bd}

5. CONCLUSION

Considering the actual situation of sediment production, bed variation, sand mining activities, we have shown a concept of sand mining management. In this management, firstly the designed bed slope is determined and the difference between the sediment supply and the sediment discharge for the designed slope is used as the resource for sand mining. The relation between the allowable sand mining volume and the designed bed slope was shown. However, a huge eruption that sometimes takes place would cause the severe bed agradation. Thus, we mentioned the necessity of sabo works such as sand pocket that could be a buffer zone for sediment run off. The sediment management system composed of sand mining management and sabo works is strongly required.

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