THE DEVELOPMENT OF SABO TECHNOLOGY TO MITIGATE DISASTER CAUSED BY DEBRIS FLOW IN INDONESIA

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ABSTRACT

Indonesia is one of the countries in the world which frequently suffered from natural disaster such as floods, landslides, debris flows, storms, earthquakes, tsunami, volcanic eruptions, droughts etc. After the volcanic eruptions of Mt. Agung in 1963, Mt. Kelud 1966 and Mt. Merapi in 1969, debris flow has occurred and caused a lot of disaster in the area along the rivers which originated from the mentioned volcanoes. The debris flow caused natural disaster such as environment and infrastructure damages, loss of properties, loss of life, people injured, economic degradation etc.

Since 1970 the Indonesian government has been cooperating with the Japanese government to solve the problems of debris flow countermeasure not only at the lahar rivers in the volcanic area but also at the torrent rivers in non volcanic area. Sabo structures such as check dams, groundsills, training levees, spur dykes and the other structures have been constructed at a number of rivers as the structural countermeasure. The mitigation of debris flows is not only structural countermeasure but also non structural countermeasure by establishing forecasting and warning system against debris flow, making hazard maps, and also establishing risk management in order to minimize the disasters when debris flow occurs.

Key Words: Debris flow, Disaster mitigation, Sabo technology, Hazard, Risk management

INTRODUCTION

Indonesia is one of the countries in the world which frequently suffered from disaster such as flood and drought, volcanic eruption, earthquake, tsunami, fire, debris and mudflow, and landslide. The disasters occurred due to the natural and climate condition as well as the degradation of environment condition. Indonesia is a tropical archipelago in equator with more than 5000 km length from west to east and more than 2000 km length from north to south. The number of population is more than 220,000,000 people. Sixty percent of the population lives in Java Island and forty percent of them live in the other islands. Java Island is the densest populated island where the whole ethnics of the Indonesian people live here.

As the densest populated island, Java Island faces so many social problems as well as environment. The people live in almost all over the land in Java. Due to lack of agricultural

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land in the low land, the people move to the upland in the mountainous area where the slope surface of the land is steep. Once the people cultivated the upland, various problems appear especially the natural disaster caused by human interfere to the nature.

There are some conditions which trigger the occurrence of debris flow in Indonesia such as topography, geology, rainfall, and environment. The mountainous topography condition of the islands in Indonesia, heavy rainfall, steep slope of river bed, and the steep slope of land surface are the main causes of debris flow occurrence in the country. The geological condition where Indonesia has 129 active volcanoes, (see Fig. 1) and located at the confluence point of three tectonic plates i.e. Eurasia, Pacific and Australian plate are also plays important role to the occurrence of sediment disaster.

Fig. 1 Mayor Active Volcanoes of Indonesia

The Indonesia Archipelago located between two continents (Asia and Australia) and between two oceans (Pacific and Indian) causes the unique climate of the country where high intensity of rainfall in rainy season and high temperature of air in dry season. The location of the country in equator and monsoon also causes high yearly rainfall depth. In general the occurrence of rainfall with high intensity proceeds to the debris flow disaster is a usual phenomenon in Indonesia. Deforestation and the conversion of land use from conservation forest to agricultural land and settlement area is also trigger the occurrence of disaster caused by debris flow**.**

DEBRIS FLOW DISASTER

Debris flow disaster in Indonesia has caused damages of environment, loss of properties, as well as the number of victims and injured in a large amount. The damages of farmland, forest, rivers, public facilities such as roads and bridges, dams and reservoirs, houses, schools, mosques, government building, and factories after the occurrence of debris flow took place annually. The loss of properties caused by debris flow disaster is billions rupiah annually. Hundreds people died and injured caused by debris flow disaster occurrence every year.

After the volcanic eruptions of Mt. Agung in 1963, Mt. Kelud 1966 and Mt. Merapi in 1969, debris flow has occurred and caused a lot of disaster in the area along the rivers which originated from the mentioned volcanoes. Fig. 2 shows the lahar rivers in Mt. Merapi area.

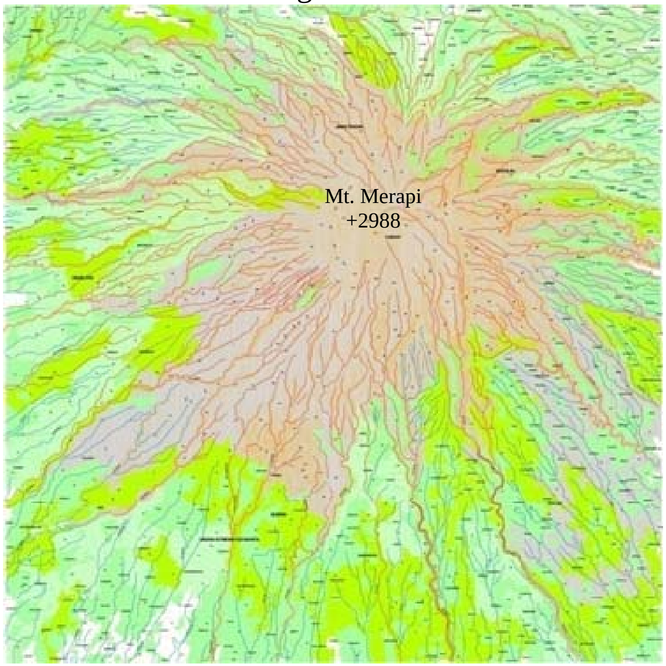

Fig. 2 The lahar rivers origanated from Merapi Volcano (Source: Sabo Technical Centre, Ministry of Public Works, Yogyakarta)

Table 1 Number of Debris Flows in Mt Merapi Area

Year	PA	TR	SE	LA	BL	PU	BA	BE	KR	BO	KU	GE	WO	Total
1931	2		2	2	7		34			2		2	6	55
1932	16		16	15	18		19			1	2	3	30	104
1969			3		1	28		7	4					43
1970						7		1	2					10
1971						8			3					11
1972						1			1					2
1973	2	1	1		1	7				2		1		12
1974						5	1	2	4	3	3		3	21
1975			1			23		5	6	4	4		22	65
1976					1	8	1	2	1	2	1		14	30
1977	1		1			5			4		1	1	7	19
1978	1		1			2		13	16		1	1		34
1985						7		3						10
1986						8		1	1					10
1987						7		1						8
1988						8		1						9
1989						1		2						3
1990								4						4
1991								2						2
1992								3						3
1993								4						4
1994	1				1			8	1	4	1			15
1995	1							4	1	23				28
1996										5				5
Total	**24**	**1**	**25**	**17**	**29**	**125**	**55**	**63**	**44**	**46**	**13**	**8**	**82**	**507**

a) Note: PA: Pabelan TR: Trising SE: Senowo LA: Lamat BL: Blongkeng PU: Putih BA: Batang BE: Bebeng KR: Krasak BO: Boyong KU: Kuning GE: Gendol WO: Woro

b) Source: "Franck Lavigne, the Lahars of Merapi Volcano, Central Java, Indonesia, 1994-1995, University of Braise Pascal"

A debris flow disaster is caused by loose sediment and high intensity of rainfall. Debris flow is a very typical phenomenon that occurs after or during heavy rainfall. Since a debris flow has a high specific gravity, even huge rocks of a several cubic meters in diameter could be carried and moved as if floating in the mass of mud. Debris flow may not necessarily develop during rainfall but is dependent upon the quantity of sediment and the amount of water pouring down within a certain time. In Mt. Merapi area, debris flow starts on the upper slop of the volcano between the elevations of 1,000 and 2,000m. Damages by debris flow have occurred all the way from the upper slopes to the hamlet and agricultural area on the middle slopes in Mt. Merapi. Table 1 shows the number of debris flows occurrence.

In almost every targeted river, debris flows happened many times. Especially in Putih and Woro Rivers, 120 times and 80 times of debris flows have occurred respectively. But recently, Boyong and Bebeng Rivers have actively flown down debris flows. Debris flows have frequently occurred particularly just after eruptions because pyroclastic flows pile up a huge quantity of loose sediments and ashes in the river basins of the volcano. For example, the number of debris flows are 1) 212 times in almost all the rivers (especially in Batang River) during 17 months from December 1930 to April 1932 after the eruption on November 1930, 2) 247 times in many rivers during 10 years from 1969 to 1978 after the eruption on 1969, and 3) 103 times mainly in Putih, Bebeng and Boyong Rivers during 12 years from 1985 to 1996 after the eruption on 1984.

Table 2 Debris Flow Disasters in Mt. Merapi Area

No	Date	River	Death	House	Field	Others	Remarks
1	1933	Kuning	-	-	PF: 5 ha		
2	26 Jan. 1969	Krasak	3	10	PF: 75 ha	-	Mud flow
		Bebeng	-	49	-	-	
		Gendol	-	150	PF: 110 ha DF: 120 ha	Br: 8	
		Opak	-	32	PF: 11ha	Br: 2	Mud flow
		Kuning	-	-	PF: 4 ha	-	Mud flow
		Woro	-	50	-	-	
3	Jan. 1971	Bedog	-	-	PF: 10 ha	-	
4	8 Jan. 22 1973	Gendol	-	-	PF: 10 ha	-	
5	3 Oct. 23 1973	Gendol	-	-	PF: 19 ha	-	
6	26 Jan. 1974	Bebeng	-	9	-	-	
7	22 Oct. 1974	Bebeng	9	6	-	-	
8	21 Nov. 1974	Krasak	-	10	-	-	
9	6 Dec. 1974	Krasak	-	4	-	-	
10	5, 22 Mar. 1975	Gendol	-	-	PF: 30 ha		
		Bebeng	-	102	-	-	
		Putih	-	5	-	-	
		Senowo	-	-	-	Br: 1	
		Krasak	-	-	-	Br: 6	
11	25, 26 Nov. 1976	Krasak	26	358	-	Br: 5	
		Krasak	1	3	-	Car: 2	
		Bebeng	-	22	-	Cattle: 2	
		Putih	-	2	-		
12	30 Dec. 1986	Bebeng	1	-	-	Truck: 1	
13	1 Jan. 1987	Bebeng	-	-	-	Truck: 1	

a) Note: PF: Paddy Field, DF: Dry Field, Br: Bridge
b) Sourse: Mt. Merapi Volcanic Debris Control Project, Yogyakarta.

Sedimentation areas of debris flows that have caused damages since 1933 are identified and shown in Table 2. The large-scale pyroclastic flows occurred on 7 and 8 January 1969, and filled the upper reaches of Batang River with volcanic deposits, which changed the river basin of Batang River to Blongkeng and Putih Rivers. Consequently, large-scale debris flows occurred in several rivers on 26 January 1969. Large amount of sediment flowed down to all the downstream area of the rivers, and a lot of unstable sediment deposited. Debris flows by heavy rainfall in the upstream of Putih, Bebeng and Krasak Rivers, caused damages of 291 houses destroyed, 320 ha of agriculture field losses and 10 bridges destroyed. On 25 and 26 November 1976, large-scale debris flows also occurred and caused large damages in the villages along Putih, Bebeng and Krasak Rivers. In Kricakmesir Village and Ngluar Sub-district in the Krasak River basin, 26 persons were killed, 358 houses and 5 bridges were destroyed.

MITIGATION OF DEBRIS FLOW DISASTER

There are some problems concerning the mitigation of natural disaster caused by debris flow in Indonesia. Damages, loss of properties and victims which always occur after the disaster become the problem which should be solved. Evacuation, emergency, rehabilitation, reconstruction, preparedness and awareness works as well as forecasting and warning system establishment after the disaster occurrence should be executed well. This debris flow disaster mitigation is urgently to be done in order to protect the people from the similar disaster in the future. Fig. 3 shows the procedure of disaster mitigation which has been implemented by local government when the debris flow disaster occurs. The mitigation procedure was established based on *Act of the Republic of Indonesia No. 24/2007, "Disaster Mitigation"*

Evacuation Works

The first action which should be done is to evacuate the victims who suffered from disaster. Usually, the debris flow occurred in the villages at the remote area where the transportation infrastructure is not sufficient, the evacuation works cannot be done by using heavy equipment such as excavator and back hoe. In this case, the evacuation works was done by the people manually. The evacuation was done by army, policemen, local people, and the volunteers. The human corpses were brought to the cemetery to be buried and the injured people were brought to the hospital for medical treatment.

Emergency Works

Before the rehabilitation works started, the people who lost their house and properties stay at the evacuation camp. Just after the disaster, the government constructs evacuation camp for the people who were evacuated from the debris flow disaster site. During they stay at the evacuation camp, they need food and clothes which are prepared by the government and also donated by some donors. Natural disaster caused by debris flow where a lot of victims and damages occurred becomes a national problem for the central government to solve.

Rehabilitation Works

Debris flow caused the damage of local people houses and public facilities such as domestic water supply, bridges, roads, schools, government offices and others. The damaged houses and public facilities needs reparation, reconstruction or relocation to the saver place depends on the magnitude of the damage. For these activities a lot of budget is needed. Before the reconstruction works started, a rehabilitation works for recovering the condition of the people from the emergency stage to the normal condition should be done.

The local and central government have responsibility to allocate the budget for rehabilitation purposes. The rehabilitation budget comes not only from the government, but also comes from the other donor such as NGO, private company, public corporation and others. During the rehabilitation works, not only physical matters to be rehabilitated but also mentally condition of the victims has to be rehabilitated.

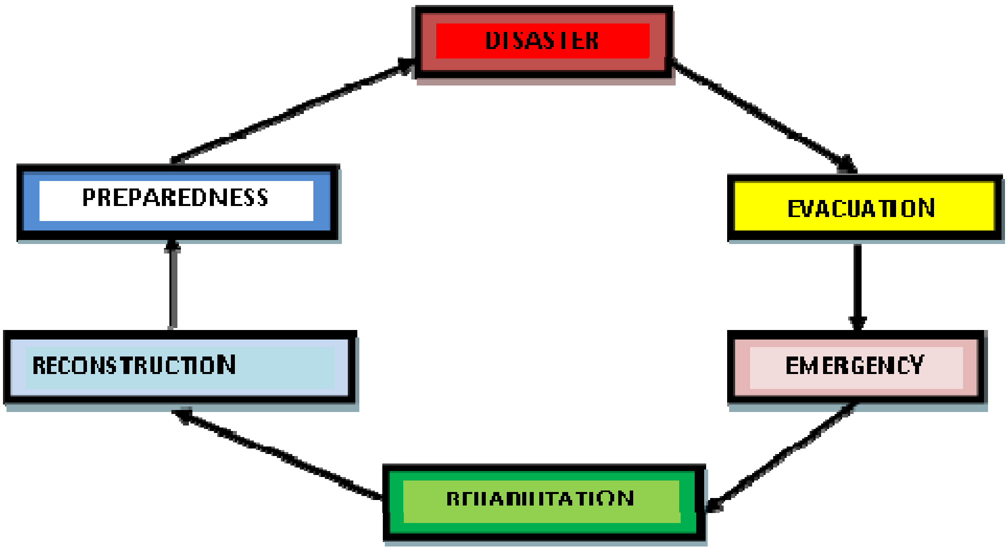

Fig. 3 The procedure of debris flow disaster mitigation (Source: Volcanology and Geological Disaster Mitigation Institute)

Reconstruction Works

The reconstruction works will be started after the condition at the debris flow disaster becomes normal and the inhabitant daily activities are also normal. The damaged facilities such as road, public offices, houses, domestic water facilities and irrigation canals have to be reconstructed. The reconstruction works of the damaged infrastructure costs high so that the government has to allocate a lot of budget for the reconstruction works. The reconstruction works after debris flow occurrence is not only to reconstruct the damage facilities and infrastructure caused by landslide, but also to construct the prevention works against debris flow occurrence. The construction works is initiated with survey and investigation at the disaster area, and then make the design of countermeasure works.

Preparedness

In the stage of preparedness, the people who stay in the susceptible debris flow disaster site and the surrounding area have to understand the method of evacuation from the vulnerable area to the safer site when debris flow occurs. Besides that, the local people have also to know the indication of debris flow before its occurrence, so that they understand when they have to evacuate from the vulnerable area. The people have also to know the evacuation route from the vulnerable area to the safer site which has been designated by the local government**.**

COUNTERMEASURE AGAINST DEBRIS FLOW

Structural Countermeasure

In order to mitigate the disaster caused by debris flow, sabo technology has been introduced by Japanese engineers since 40 years ago through the technical cooperation between Indonesian and Japanese Government. The Indonesian engineers have been cooperated with the Japanese engineers to solve the problems of debris flow countermeasure not only at the lahar rivers in the volcanic area but also at the torrent rivers in non volcanic area. Sabo structures such as sabo dams (check dams), consolidation dams, groundsills, training levees, spur dykes and the other structures have been constructed at a number of rivers. Fig.4 shows the model of debris flow countermeasure in a volcanic area.

Fig. 4 Debris flow disaster countermeasure model in a volcanic area (source: Mt. Merapi Volcanic Debris Control Project, Yogyakarta.)

In the beginning of 1970, sabo works has been implemented by constructing check dams made of stone masonry. After that, some sabo structures were made of concrete and the others were made of the combination of stone masonry and concrete. In 1990 decade, steel double wall check dams have been introduced in Mt. Merapi area. There are some various type of chek dams which were constructed both in volcanic and non volcanic areas such as open type check dams, close type check dams and culvert type check dams. Besides have the function to trap and control sediment discharge, the sabo structures have been developed as multipurpose sabo dams. The other purposes of sabo structures are to divert water for irrigation, domestic water and micro hydro power plant, as the foundation of bridges, and as the submerged bridges. Fig 5 shows a sabo dam in Mt. Merapi area which has another function as a submerged bridge.

The sabo structures has been constructed at Mt. Merapi area in Central Java Province, Mt. Kelud Area and Mt. Semeru area in East Java Province, Mt Galunggung area in West Java Province, Mt Agung area in Bali Island, and also at the torrent rivers in West Sumatra, Lampung, South Sulawesi, Central Sulawesi and North Sulawesi Provinces. Fig. 6 shows the total number of the sabo structure in volcanic and non volcanic area is more than 400 units.

Fig. 5 One of the check dams in Mt. Merapi area has another fanction as a submerged bridge (Photograph taken by Agus Sumaryono)

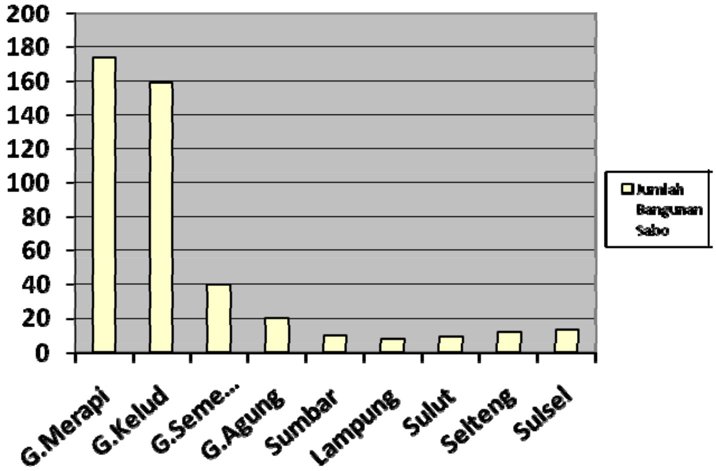

Fig. 6 The number of sabo structures in volcanic and non volcanic area in Indonesia (Source: Directorate General of Water Resources, Ministry of Public Works)

Non Structural Countermeasure

The mitigation of debris flows which has been done is not only structural mitigation by constructing sabo structures but also non structural mitigation by making hazard maps, establishing forecasting and warning system against debris flow, and also establishing risk management in order to minimize the disasters when debris flow occurs.

Based on the history of volcanic eruption and debris flow occurrence in the past, a hazard map can be made. From the hazard map, we can understand the direction of lava flow, pyroclastic avalanche and debris flow, the dangerous area 1, the dangerous area 2, and the dangerous area 3, and also the evacuation camps and the route of evacuation when disaster occurs. The hazard map is a basic map for the local government and the institution concerned for making the plan of mitigation when the disaster occurs and also to make sabo plan for debris flow countermeasures. Fig. 7 shows the hazard map of Merapi Volcano in Central Java Province.

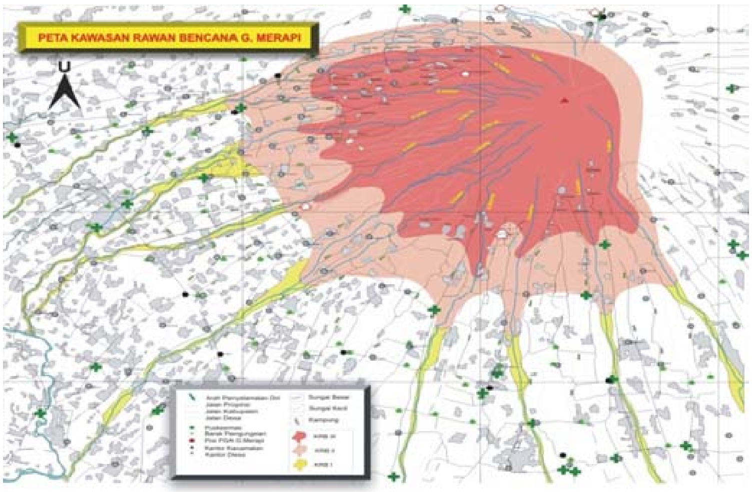

Fig. 7 Hazard map of Merapi Volcano in Central Java Province (source: Volcanology and Geological Disaster Mitigation Institute)

Establishment of forecasting and warning system against debris flow has already done in Mt. Merapi area by installing monitoring equipments around the slope of the volcano. The system consists of some equipment such as automatic rain gauges, ultrasonic water level gauges, debris flow detector equipments, etc. The system is monitored in the main station at Experimental Station for Sabo in Yogyakarta. All the system is equipped with telemetry system, so that the real time hydrological data can be monitored at the main station and the information can be delivered to the offices concerned.

In order to make the local people always in the condition of preparedness, the local government has to conduct the training of evacuation for the local people regularly at list once a year. Socialization of evacuation methods, evacuation route and the indication of debris flow to the local people is very important in order to keep the people always in the condition of preparedness against debris flow disaster. The coordination among the local government officer and the coordination between local government and the local inhabitants must be implemented smoothly. In this condition, when the debris flow disaster occurs, the number of victims, the magnitude of damages and loss of properties can be minimized. After the implementation of structural mitigation by construction the sabo structures as well as non structural mitigation, the number of disaster caused by debris flow for the last 40 years has been decreased.

CONCLUSSIONS

1. Indonesia is one of the countries in the world which seriously suffers from debris flow disaster;
2. Because of the natural condition of Indonesia such as climate, geology, topography, rainfall and the environment problem, debris flow disaster frequently occurred and the number of victims and damages is relatively high;
3. In order to measure the disaster caused by debris flow, the government of Indonesia has already constructed sabo works in volcanic area as well as in non volcanic area;
4. Due to lack of budget and a lot of debris flow disaster, the prevention works of debris flow are applied only at some certain places and at most of the debris flow occurrences, the relocation of settlement and infrastructure is the better choice;

5. The preparedness of the people who stay surrounding the vulnerable area of debris flow is the most important one for minimizing the number of victims and damages caused by debris flowe disaster;
6. Forecasting and warning system for debris flow occurrence should be established in order to minimize the number of victims and damages;
7. After the government has made national act and the regulations of disaster mitigation, the implementation of natural disaster mitigation can be implemented better.

REFERENCES

Agus Sumaryono, Haryadi Djamal. (2002), *Disaster Caused by Merapi Volcanic Activities and Its Countermeasure*, Proceeding of Symposium on Natural Resources and Environmental Management, Yogyakarta, Indonesia, January 21-22, 2002, ISBN 979-8918-32-0. (In Indonesian);

Agus Sumaryono, (2002). *The Role of Sediment Disaster Countermeasure for Water Resources Conservation*, Proceeding National Symposium on Sediment Disaster Mitigation, Directorate General of Water Resources and Japan International Cooperation, Yogyakarta, Indonesia, March, 12 – 13, 2002, ISBN 979-8763-04-1. (In Indonesian);

Agus Sumaryono, et al, (2002), *General Review of Sabo Development in Indonesia*, Research Centre for Water Resources, Agency for Research and Development, Ministry of Public Works, Bandung, Indonesia. (In Indonesian);

Agus Sumaryono, Bambang Sukatja, Oriza Andamari, (2004). *The Application of Sabo Technology to Decrease Reservoir Sedimentation*, Proceeding International Conference on Sediment Related Disaster Management, Yogyakarta, Indonesia, August 3-5, 2004, ISBN 979-8763-04-1;

Agus Sumaryono, Bambang Sukatja, F.Tata Yunita, (2005). *The Application of Sabo Technology for Lahar Flood Mitigation and Warning System in Volcanic Area*, Proceedings The Second Southeast Asia Water Forum, Nusa Dua, Bali, Indonesia, 31 August – 3 September 2005;

Matsushita, T, (1999). *Massage for the 21st Century Sabo Works and Its Achievement*, Sabo Publicity Centre, Tokyo, Japan;

Mizuyama, T. (2008). *Structural Countermeasure for Debris Flow Disaster*, International Journal of Erosion Control Engineering, Vol. 1, No. 2, 2008 p. 38 – 43, ISSN: 1882-6547, Kyoto, Japan;

Takahashi,T. (2007). *Debris Flow, Mechanics, Prediction and Countermeasures*, Taylor & Francis Group, Leiden, the Netherland;

, (2001), *Review Master Plan Study on Mt. Merapi*, Ministry of Settlement and Regional Development, Directorate General of Water Resources, Jakarta;

, (2004), *Act of the Republic of Indonesia No. 7/2004, "Water Resources"*, State Secretary, Jakarta, Indonesia;

, (2007), *Act of the Republic of Indonesia No. 24/2007, "Disaster Mitigation"*, State Secretary, Jakarta, Indonesia;

, (2007), *Sediment-related Disaster Warning and Evacuation Guideline*, Sabo Department, Ministry of Land, Infrastructure, Transport and Tourism, Tokyo, Japan.