Effect of Emergency Measures to Minimize Debris Flow Disaster after the Pyroclastic Material Deposition in Gendol River due to the 2010 Eruption of Mt. Merapi, Indonesia

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In 2010, the largest eruption in record occurred at Mt. Merapi in Indonesia. The largest pyroclastic flow which occurred on November 5, 2010 completely buried the valley of the middle reach of the Gendol River. Due to the river blockage, the risk of debris flow inundation in rainy season was increased. In order to guide debris flow to downstream, Mt. Merapi Lahar Control Office carried out emergency measures consisting mainly of temporary guide channel work of 23~30 m width and embankment work during the rainy season between 2010 and 2011. Although the inside of the pyroclastic flow deposit was high-temperature, the construction work had to be implemented using general heavy equipment. As a result, the construction work with excavation volume of 1.3 million m^3 was achieved and effectively prevented the debris flow disaster. This paper describes the outline and effectiveness of the emergency measures so that it can be applied in other volcanoes in the future.

Key words: Merapi Volcano, the 2010 eruption, debris flow, emergency measures, sediment control

1. INTRODUCTION

In 2010, the largest eruption in record occurred at Mt. Merapi in Indonesia. The largest pyroclastic flow in the eruption which occurred on November 5, 2010 flowed down the Gendol River and reached the 15 km point from the crater. Due to the deposition of the pyroclastic flow material on the riverbed, the valley in the middle reach of the Gendol River was completely buried. In this situation, it was obvious that the debris flow which would occur in the following rainy season overflows extensively and causes great damage to the surrounding area. In order to try to minimize the debris flow disaster, the Government of Indonesia carried out emergency measures consisting mainly of temporary guide channel work and embankment work, which are categorized in “river normalization work” in Indonesia.

According to the temperature measurement result of the pyroclastic flow deposit from January to March, 2011, the temperature at the depth of 30 cm from the surface of the deposit was maintained at a high temperature of 90 degrees centigrade or more [*Shimizu et al.*, 2014]. There has been no report of any earth work on such hot pyroclastic flow deposit. Therefore, this paper presents the outline of the emergency measures and introduces the effects and the findings obtained in the measures.

2. MT. MERAPI AND SABO WORKS

Mt. Merapi in Central Java, Indonesia is one of the most active volcanoes in the world erupting once every 3 to 5 years. The surrounding area of Mt. Merapi has been suffered from pyroclastic flow and debris flow disasters caused by volcanic eruption. Since there are densely populated areas including

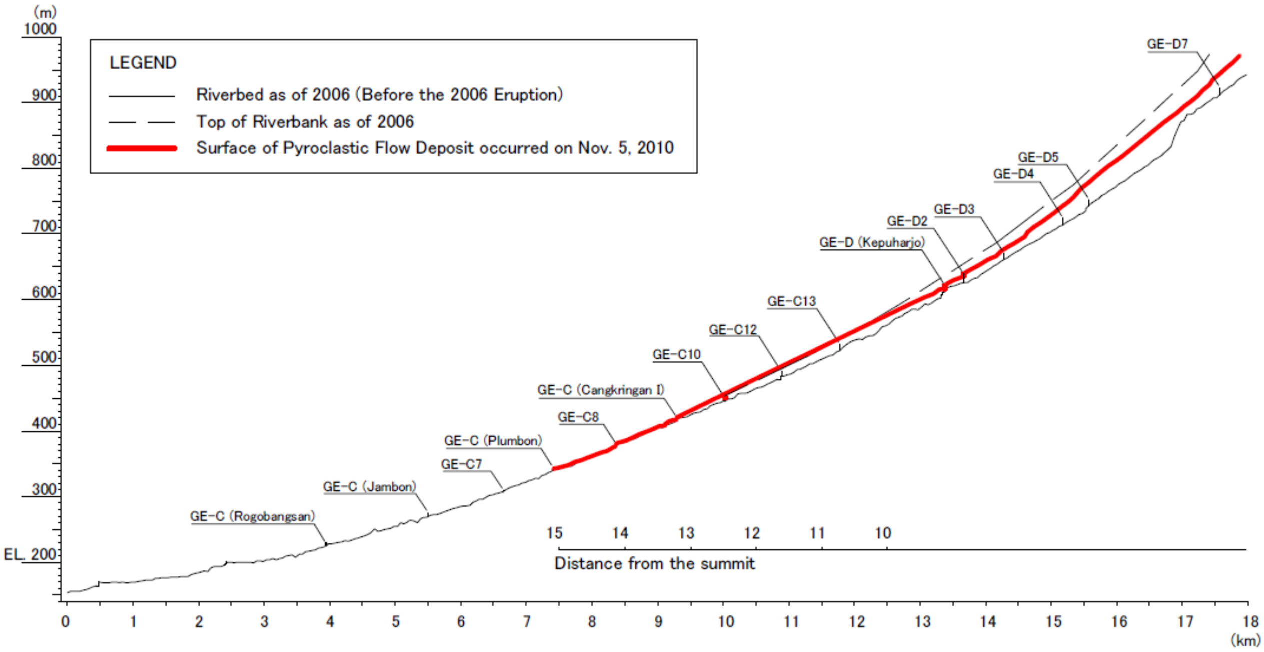

Fig. 1 Longitudinal pyroclastic flow deposit and major sabo dams in the Gendol River

Yogyakarta City at the southern foot of Mt. Merapi, the Government of Indonesia started the national disaster control program consisting of structural and non-structural measures from the 1970s. In order to promote those measures systematically, a master plan for the mitigation of volcanic disasters was formulated under the technical cooperation of Japan International Cooperation Agency (JICA) in 1980. In response to the flowing direction of pyroclastic flows changing from west to south, the master plan was reviewed in 2001. According to the reviewed master plan (hereinafter referred to as "Review Master Plan (2001)"), structural measures are aimed at controlling sediment discharge amount arising from accumulative largest 30 days daily rainfall with 10-year return period after the major eruption occurring once in 10 years, which supplies approximately 5 million m^3 of pyroclastic material. To date approximately 250 check dams and consolidation dams (hereinafter call generically "sabo dam") to control debris flow and to stabilize the riverbed have been constructed in the Mt. Merapi area.

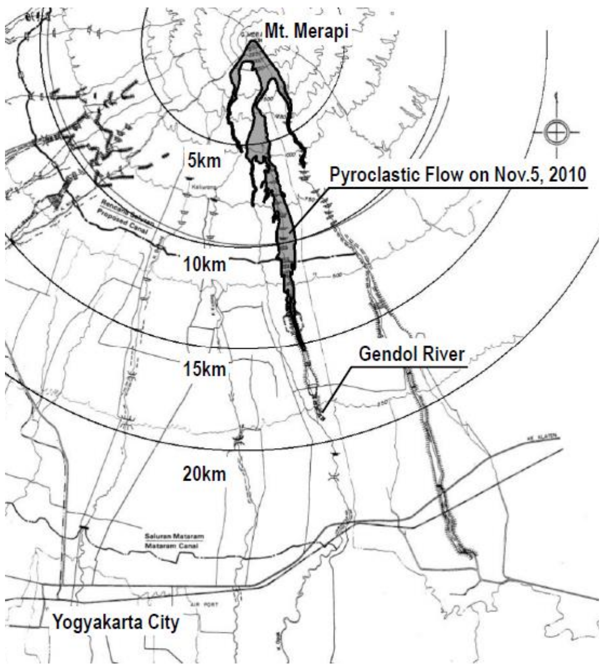

Fig. 2 Pyroclastic flow occurred on Nov. 5, 2010

3. THE 2010 ERUPTION

A series of eruptions which started on October 26, 2010 was not "Merapi-type" characterized by the growth and collapse of lava dome, but was explosive eruptions with a smoke column. Total amount of pyroclastic material ejected during the 2010 eruption reached 140 million m^3 [*Posko Aju BNPB*, 2010]. As the crater of Mt. Merapi has been opened in the direction of the Gendol River since the eruption of 2006, pyroclastic flows mainly ran into the Gendol River several times during the series of eruptions. According to the analysis of radar images, the eruption occurred on October 26, 2010 removed ~6 million m^3 of mainly non-juvenile material from the summit [*Surono et al.*, 2012]. Most of the removed material was flowed down to the Gendol River. Furthermore, on November 5, 2010, the largest pyroclastic flow occurred and

Fig. 3 Riverbed aggradation due to the pyroclastic flow deposition at sabo dam GE-C13, 11 km from the summit

Table 1 Implementation of emergency measures

Year	2010		2011									
Month	11	12	1	2	3	4	5	6	7	8	9	10
Rainy Season	◀━	━	━	━	━	━	━▶					
Event												
Pyroclastic Flow	★ Nov. 5, 2010											
Debris Flow Ocurrence Days	10	11	3	3	4	1	2	0	0	0	0	0
Emergency Measures												
Guide Channel & Embankment Work		■	■	■	■	■	■					
Gabion Work								■	■	■	■	■

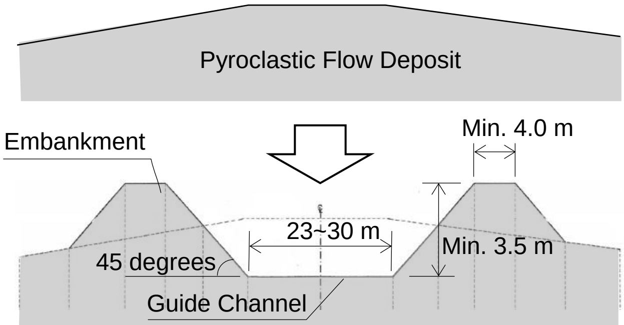

Fig. 4 General cross sectional shape of guide channel and embankment

flowed down to the point 15 km from the summit through the Gendol River. Longitudinal topographic change of the Gendol River and range of the pyroclastic flow are summarized in **Fig. 1** and **Fig. 2** based on topographic survey results and satellite images. Volume of lava dome and non-juvenile material which collapsed due to the eruption on November 5, 2010 was estimated to be ~5 million m^3 and 10 million m^3 respectively [*Surono et al.*, 2012]. According to the above, total 20 million m^3 of materials were flowed down to the Gendol River from October 26 to November 5, 2010. This amount is equivalent to four times the design pyroclastic flow amount assumed in Review Master Plan (2001). The pyroclastic flow raised the riverbed by up to 50 m as shown in **Fig. 1**. Especially in the river section between 10 km and 13 km from the summit, the river channel was completely buried, and surface of the pyroclastic flow deposits became higher than the surrounding riverbank (see **Fig.1, 3**). Because of that, the flooding risk of debris flow, which frequently occurs in the rainy season after the volcanic eruption, was increased.

4. EMERGENCY MEASURES

4.1 Outline

In order to try to minimize the damage from debris flow, Mt. Merapi Lahar Control Office (*PPK Pengendalian Lahar Gunung Merapi*), the execution agency of sediment control works for the Mt. Merapi area, carried out emergency measures after the 2010 eruption in coordination with National Disaster Management Authority (*Badan Nasional Penanggulangan Bencana*) and other organizations concerned. Due to the pyroclastic flow occurred on November 5, 2010, reservoir of the sabo dams upstream from GE-C (Plumbon) were already filled with the pyroclastic flow material, while remaining downstream sand pocket consisting of several sabo dams were still empty (see **Fig. 1**). In order to guide the debris flow to the empty downstream sand pocket, construction of temporary guide channels and embankments was implemented during the rainy season from November 2010 to May 2011. For the embankments located at important places from the viewpoint of disaster prevention, an additional gabion work to protect the surface of the embankments was implemented in the dry season from the end of May 2011 (see **Table 1**).

4.2 Guide channel and embankment

The guide channel is an unlined channel formed by excavating the pyroclastic flow deposits. The excavated materials were dumped on the both bank of the channel as the temporary embankment. Since main objective of the temporary guide channel work and embankment work was to form a series of flow paths on the completely buried river channel in a short period, cross sectional dimensions of those were determined based on the capability and quantity of heavy equipment which can be mobilized in the rainy season, and minimum required discharge capacity of the channel. As a

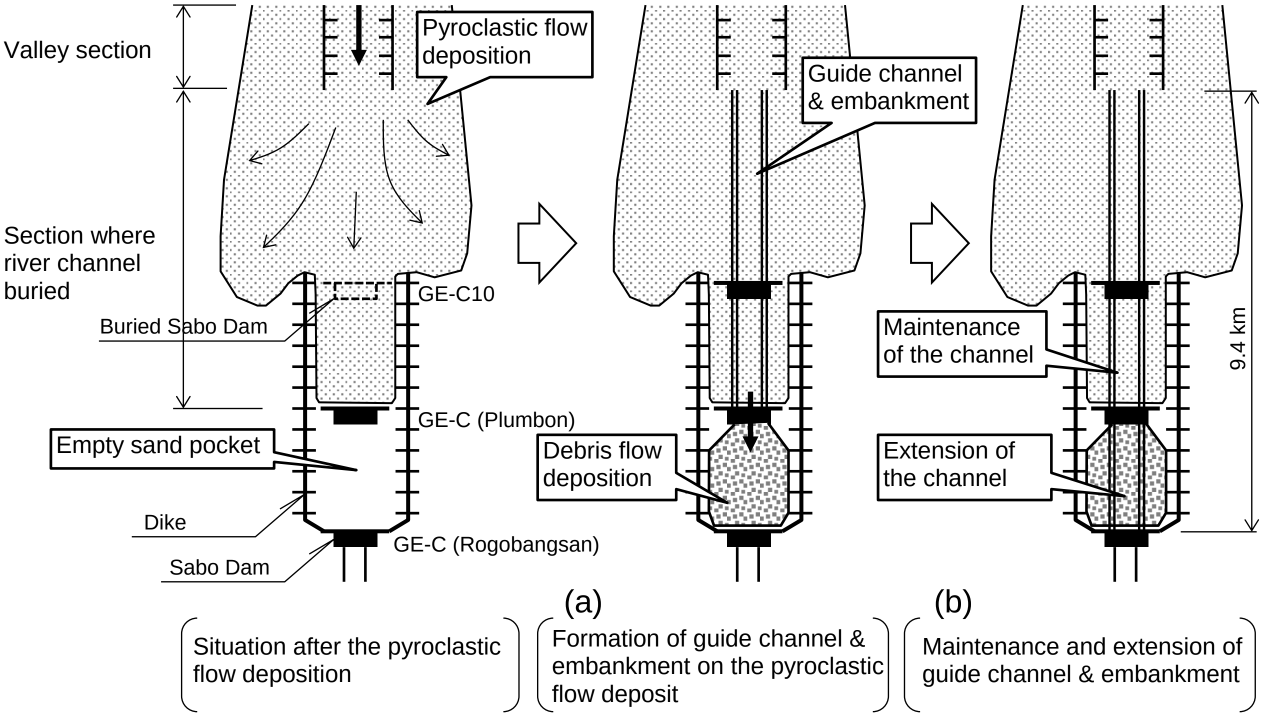

Fig. 5 Schematic plane diagram of the construction areas and process

Fig. 6 Situation of the construction work

result, general width and minimum depth of the channel were set at 23~30 m and 3.5 m respectively. The minimum top width of the embankment was set at 4 m so that heavy equipment can be placed on it to proceed the construction work (see **Fig. 4**). The riverbed slope where the guide channel was constructed was 5 % (1/20) to 2.57 % (1/39) which is generally classified into debris flow deposition zone. The above-mentioned guide channel was confirmed to have the capability to discharge the debris flow of 222 m^3/s caused by daily rainfall with 2-year return period.

4.3 Construction work

The process of the construction of the temporary guide channel and embankment can be divided into the follows:

(a) Formation of the channel on the pyroclastic flow deposit from the upstream valley section to the downstream empty sand pocket, and digging out the buried sabo dam GE-C10 (see **Fig. 5**),

(b) Maintenance and extension of the channel after the deposition of debris flow materials.

The heavy equipment used for this construction work was a backhoe and a bulldozer for general construction work (see **Fig. 6**). Although the construction period was in the rainy season, the construction work could be proceeded during a sunny time because of a simple construction work. Since the construction work had to be interrupted when heavy rain came or debris flow occurred, it was carried out not only on weekdays but also on Saturdays and Sundays. Because debris flow often occurred during the construction period, deposited debris flow material also needed to be removed as mentioned in (b) above. As a result, total 1.3 million m^3 of pyroclastic flow and debris flow deposits could be excavated during the construction period of

6.3 months from November 22, 2010 to May 30, 2011. The average daily excavation amount was 6,900 m^3/day. Average number of heavy equipment for the construction work was about 30 units/day.

4.4 Safety measures

Fig. 7 Debris flow flowing in the guide channel under construction (December 30, 2010)

In order to ensure the safety of construction workers in the river, safety measures not only against general construction accidents but also accidents caused by debris flow or secondary hydro-eruption of the pyroclastic flow deposits had to be taken. The occurrence of debris flow in the Gendol River was monitored by the community organized mainly by local governments. According to the radio communication record of the community, the number of debris flow occurrence days in the Gendol River in the first rainy season after the 2010 eruption was total 34 days (see **Table 1**). Even if debris flow occurred consecutively several times in a day, it seemed that it was recorded as one debris flow. Therefore, we adopted the number of debris flow occurrence days as an index of the frequency of debris flow occurrence.

The safety measures consist of communication system and evacuation system as shown below:

(a) Communication system: When the above-mentioned community observed the occurrence of water flow or debris flow in the Gendol River, where no water flow is in normal times, that information was shared with the Contractor wirelessly from the community.

(b) Evacuation system: The Contractor set up escape routes and evacuation places so that construction workers and heavy equipment can evacuate from the river to a safe high place. Evacuation activities were conducted based on the information from the community.

5. RESULTS

As a result, this simple guide channel was effective enough to prevent flooding of debris flow by guiding it to downstream. **Fig. 7** shows that the debris flow flowing in the guide channel under construction. Despite the high frequency of debris flow occurrence, flooding of debris flow did not occur in the section where the guide channel was constructed. After the occurrence of debris flow, debris flow sediment accumulated on the channel and raised the riverbed maximum 2 m. On the other hand, debris flow often caused maximum 2 meter wide lateral erosion on the foot of the embankment. Maintenance work to remove the accumulated sediment and to fix the partially eroded embankment were required after the occurrence of major debris flow.

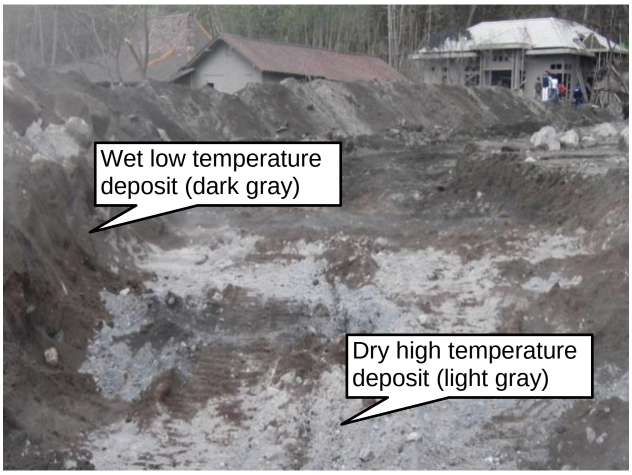

Fig. 8 Difference in color of pyroclastic flow deposit by temperature

We also tried to investigate the rainfall that caused the debris flow. However, there was no available rainfall data because all rain gauge stations in the upstream area did not work properly during the rainy season after the 2010 eruption due to accumulation of volcanic ash fall.

6. DIFFICULTY

Because it rained frequently, the surface of the pyroclastic flow deposit was wet and relatively low temperature, while the interior of the deposit, 30 cm deep or more from the surface, were dry at high temperature of 90 degrees centigrade or more. However, we had no choice but to use a general heavy equipment. High temperature pyroclastic flow deposit immediately after the excavation (light gray soil in **Fig. 8**) often caused the hydraulic pressure hoses of heavy equipment to damage and the shoe sole of construction workers to melt. These damage affected the progress of the construction work. Since the heavy equipment had to be operated manned, there was the possibility of encountering unexpected disasters.

7. CONCLUSION

The findings obtained by this emergency measures were the following two points:

(a) For the river buried with pyroclastic flow deposit, the construction of the simple unlined channel was effective for guiding the debris flow to downstream as long as proper maintenance work is carried out.

(b) It was able to excavate high-temperature pyroclastic flow deposits using general heavy equipment to build and maintain the guide channel.

In order to improve the efficiency and safety of construction, it is ideal to introduce heat-resistant heavy equipment and unmanned construction system. However, it is not always possible to introduce the ideal system for emergency measures in all volcanoes. Further research is necessary for temperature change of pyroclastic flow deposits, but the measures introduced here may be applicable to similar cases in other volcanoes.

ACKNOWLEDGMENT: We are grateful to Muhammad Fahruroyi, ST for arranging construction documents and materials.

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