# Hazard estimation of the possible pyroclastic flow disasters using numerical simulation related to the 2010 activity at Merapi Volcano, Indonesia

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## Introduction

Fig.1 Merapi Volcano Nov.4,2010

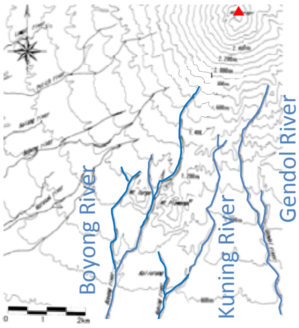


Fig.2 Schematic map of Merapi Volcano

Merapi Volcano, located on central Java Island in Indonesia began to erupt on Oct 26, 2010 and yielded pyroclastic flows on the south slope(Fig.1,Fig2). They flew down along the Gendol River. The potential existed for hazardous pyroclastic flows at that time. Actually, larger pyroclastic flows occurred again on Nov. 4. They flew down along the Gendol River and reached up to 13-18 km distance from the volcano. Both pyroclastic flows killed over 100 people. Immediate after the eruption, we started to prepare several scenarios for pyroclastic flow disasters and conducted 2-dimensional numerical simulations to estimate possible affected area by pyroclastic flows according to the scenarios.

## Governing Equations[1]

Conservation law of flow volume consisting of pyroclastic material and air;

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0 \qquad (1)$$

Conservation law of pyroclastic material;

$$\frac{\partial ch}{\partial t}+c_*\frac{\partial z_b}{\partial t}+\frac{\partial cM}{\partial x}+\frac{\partial cN}{\partial y}=0 \qquad (2)$$

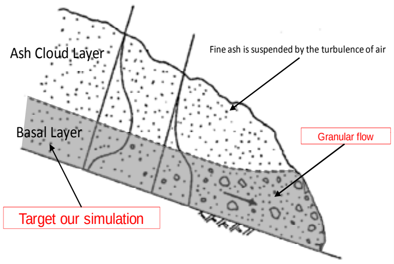


Fig.3 Schematics of pyroclastic flow

Conservation law of Momentum;

in *x*-direction;

$$\frac{\partial M}{\partial t}+\beta\frac{\partial uM}{\partial x}+\beta\frac{\partial vM}{\partial y}=-gh\frac{\partial H}{\partial x}+fu\sqrt{u^2+v^2} \qquad (3)$$

in *y*-direction;

$$\frac{\partial N}{\partial t}+\beta\frac{\partial uN}{\partial x}+\beta\frac{\partial vN}{\partial y}=-gh\frac{\partial H}{\partial y}+fv\sqrt{u^2+v^2} \qquad (4)$$

Weisbach friction coefficient

$$f=\frac{3}{32\sqrt{10}}\frac{c^{1/3}}{1-(c/c^*)^{1/3}}\mu\left(\frac{d}{h}\right)^2 \qquad (5)$$

$h$:depth of flow, $u$, $v$: $x$, $y$ components of depth average velocity of flow, $M$, $N$: $uh$, $vh$, $c$: concentration of pyroclastic materials, $c^*$, $z_b$: concentration of pyroclastic material and elevation at the flow bed, $\beta$: momentum correction coefficient, $g$: gravity acceleration, $H$: flow surface level, $f$: Weisbach friction coefficient

## Scenarios for 2010 eruption

### Background:

(1) The pyroclastic flow on 26th Oct. was not Merapi type one. There was no lava dome which should be a source of the pyroclastic flow.

(2) It seemed that the pyroclastic flow triggered by an explosion from inside of crater.

(3) Vent might not open on 26th Oct.

(4) Event on 26th would be just beginning of a series of the volcanic activity.

(5) The size of the pyroclastic flow could be considered at several millions cubic meter, because the area of the crater might be about several ten thousand square meter and the depth of the explosion might be several hundred meter.

### Scenarios:

(1) A large eruption to open the vent could occur. The eruption could trigger a large pyroclastic flow.

(2) The size of possible pyroclastic flow must be 1 order larger or more. Therefore we estimated the scale of possible pyroclastic flow at 50~100 millions cubic meter.

(3) The descending direction of pyroclastic flow may be for Gendol River because the crater opened for Gendol River.

(4) However we couldn't ignore the possibility that a pyroclastic flows flow down in other directions, especially in adjacent direction, Boyong River.

(5) The duration of pyroclastic flow might be longer than several minutes but not longer than several hours. We take the duration at 20 minutes to 60 minutes depending on the size of the flow.

Table 1 Simulation cases of possible pyroclastic flows related to the 26th pyroclastic flow.

| Case | Direction | Volume ($\times10^6 m^3$) | Duration (minutes) |
|---|---|---|---|
| G-1 | Gendol | 50 | 20 |
| G-2 | Gendol | 50 | 40 |
| G-3 | Gendol | 100 | 20 |
| G-4 | Gendol | 100 | 40 |
| G-5 | Gendol | 100 | 60 |
| B-1 | Boyong | 50 | 20 |
| B-2 | Boyong | 50 | 40 |

# Results

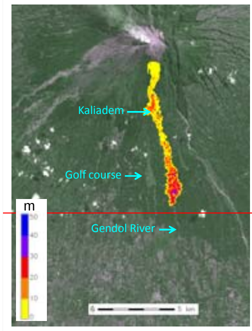


Fig. 4 Case G-1
(V=50x10$^6$m$^3$,D=20min)

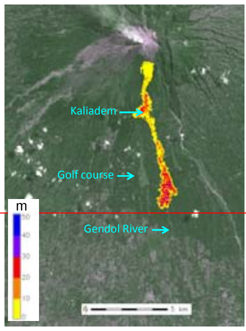


Fig. 5 Case G-2
(V=50x10$^6$m$^3$,D=40min)

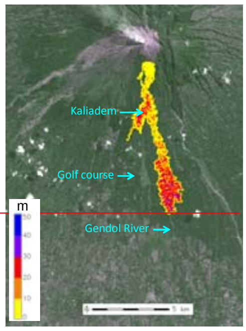


Fig. 6 Case G-3
(V=100x10$^6$m$^3$,D=20min)

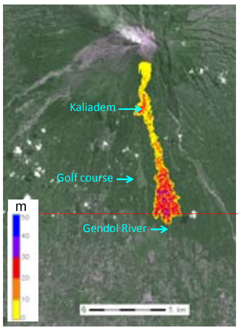


Fig. 7 Case G-4
(V=100x10$^6$m$^3$,D=40min)

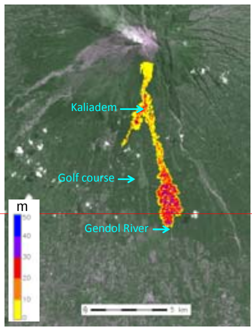


Fig. 8 Case G-5
(V=100x10$^6$m$^3$,D=60min)

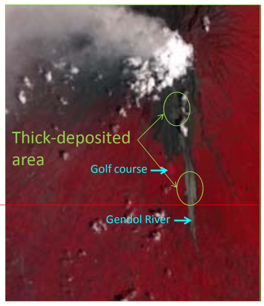


Fig. 9 Aster image after Nov. 4-5th pyroclastic flow

## Gendol River(Fig.4-8)

Simulation results explain well the basic characteristics of actual pyroclastic flow;

(1) The spreading areas of all cases of pyroclastic flows are not so much different(Fig. 4-8).

(2) The pyroclastic flows flow down along to Gendol River and pass through the eastern area of a golf course, and reach to 12-13 km from the crater.

(3) The thick deposited areas are not so much different.

(4) Major deposited areas are slightly upper reach of Kaliadem and lower end of deposited area.

However, simulation results can't explain the spreading of the pyroclastic flow to the lower area of major deposition. The reason of the discrepancy may mainly come from characteristics of the simulation model. The simulation model can't treat the behavior of ash cloud and mixing diameter material. Therefore simulation results can't explain widely spread dark gray area, which may be ash cloud deposit or ash fall area, and also can't explain the spreading to the lower reach of thick-deposited area.

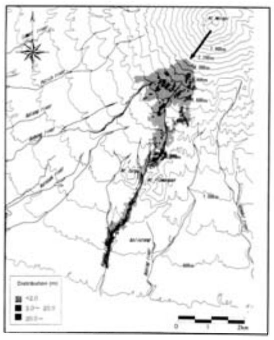

Fig. 10 Yamashita & Miyamoto's Result[2]
(V=3.6x10$^6$m$^3$,D=4min)

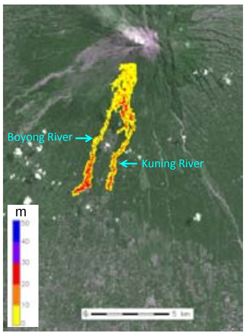


Fig. 11 Case B-1
(V=50x10$^6$m$^3$,D=20min)

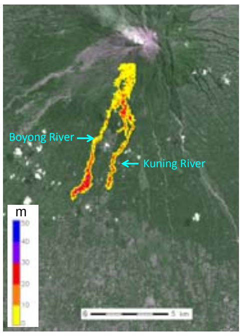


Fig. 12 Case B-2
(V=50x10$^6$m$^3$,D=40min)

## Boyong River(Fig.10-12)

(1) Flowing distance along Boyong River are not so much(Fig. 11 and 12). They are very similar with the result of simulation case of 3.6 million cubic meter(Yamashita & Miyamoto 1993, Fig. 10).

(2) The largest difference between the cases of 3.6 million cubic meter and 50 million cubic meter is that a branched pyroclastic flow descends along the adjacent Kuning River. It means that the area along Kuning River is not be so safe, if 50-100 million cubic meter of pyroclastic flow occur. On the other hand, according to simulation, descending distance of pyroclastic flow along Boyong River is limited, up to about 10 km.

# Conclusion

- After occurrence of 26th pyroclastic flow, we conducted several cases of pyroclastic flow simulations based on some consideration regarding possible and disastrous pyroclastic flow. We compared the results with actual pyroclastic flow generated on 4-5th Nov. It is found that the simulation results can explain fundamental characteristics of the pyroclastic flow.
- We spent much time to prepare the topographical data such as DEM. Therefore, topographical data, at least DEM, must be prepared for emergency use. The accuracy of topographical data is of course important.
- However, to estimate possible disastrous phenomena, we don't know anything about it. Therefore, we have to make scenarios. In this phase, the accuracy of topographical data would not so required.
- To mitigate this kind of disasters, time is important. We need to settle the problem regarding the topographical data as soon as possible.

# References

[1] H. Itoh, J. Takahama, M. Takahashi and K. Miyamoto, 2000, Hazard estimation of possible pyroclastic flow disasters using numerical simulation related to the 1994 activity at Merapi Volcano, Journal of Volcanology and Geothermal Research, Vol.100, pp.503-516.
[2] S. Yamashita, K. Miyamoto, 1993, Model of Pyroclastic Flow and Its Numerical Simulation, Sediment Problems - Strategies for Monitoring and, Prediction and Control -, IAHS Publication No.217, pp.67-74.