VOLCANIC DEBRIS CONTROL APPLIED IN INDONESIA

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ABSTRACT

Most rivers in Indonesia originate in volcanic regions. Volcanic eruptions cause enormous flows of ash and lava into these rivers. This debris is easily eroded and often turns into lahars after rain. Lahars erode the sediment of river beds and banks and achieve considerable size and enormous energy on the way down the mountain, overflowing and causing considerable damage. The large amount of sediment brought down by lahars raises river beds and gives rise to flooding. Sediment carried further down to main rivers also causes aggradation, instability of river courses, obstruction of irrigation facilities, and flooding.

Control of excessive volcanic sediment flow has been achieved to a great extent using checkdams built in steep-gradient river beds, but the optimum requirements of these checkdams are still indeterminate. To localise the spread of volcanic material and to safeguard the menaced areas at the foot of a volcano, lahar pockets are built across the streams: As there are no data available regarding the actual nature and mechanism of movement of the volcanic debris, the design of lahar pockets follows experience gained in the past. River courses will be improved at places where the danger cannot be entirely handled solely by such structures for coping with sediment. River course improvement works such as bed excavation, levees, embankments, bank protection works and groynes are therefore provided so that there will be minor river bed fluctuation or meandering or deviation of flow, no flooding or bank collapse, and smooth conveyance of flood waters and sediment downstream.

INTRODUCTION

Indonesia consists of more than 13000 islands, covering an area of nearly two million km^2, extending from 6° north latitude to 11° south latitude and 95° to 141° east longitude (Fig. 1). With a total of about 140 million inhabitants Indonesia forms the fifth most populous country in the world. Some two thirds of the population occupies the islands of Java and Bali; the population density ranges from 500 to 1000 per km^2 on both islands. On the other islands, however, the densities are lower, e.g. on the island of Sumatra 38 per km^2, on the island of Sulawesi 37 per km^2, on the islands Kalimantan, West Irian and others 9 to 15 per km^2.

This archipelago is unique as it forms the junction of three orogenic belts, namely the Alpine Sunda Mountain System, the East Asiatic System and the Circum-Australian System. Active volcanism and high seismicity are characteristic of this island arc.

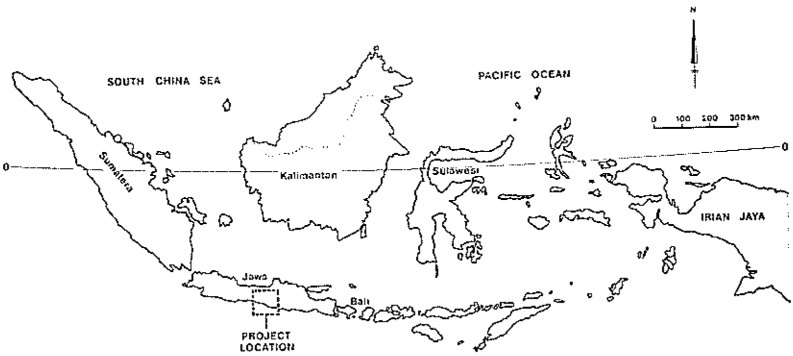

FIGURE 1—Map of Indonesia and location of study area.

Four volcanoes are considered within the present project, all of which are located in populous areas; they are Mt Kelut, East Java; Mt Merapi, Central Java; Mt Agung, Bali Island; and Mt Semeru, East Java. In this paper volcanic debris control and disaster prevention for areas menaced by volcanic activity will be discussed, especially for Merapi volcano, the most active in Indonesia.

VOLCANIC ACTIVITY IN INDONESIA

Volcanoes in Indonesia

Indonesia is one of the largest volcanic areas in the world, with 127 volcanoes, 70 of which (or about 1/7 of the world's total) have erupted in historical time. Since 1800 AD volcanic calamities have occurred on average every third year, causing more than 140000 casualties and the destruction of hundreds of villages and thousands of acres of arable lands and forests. Obviously, if volcanic eruptions can be predicted, people can make preparations to safeguard their lives and properties. For that purpose community preparedness for volcanic disaster has been co-ordinated by the Government.

Hazards caused by lava flows and ejecta

Lava flows are usually easy to avoid although their temperature is approximately 1000°C. Indonesian lava streams are generally andesitic and are thus highly viscous and move very slowly.

Big bombs only affect the immediate summit area which is usually uninhabited. During paroxysmal eruption stages, loss of human life by bombs has been recorded as far as 8 km from the eruption as shown by the 1963 Agung volcano calamity in Bali. The bombs were still glowing and set fire to the jungle and settlements causing several casualties.

Hazards caused by nuées ardentes

Casualties during a volcano eruption are caused mainly by "nuées ardentes" or glowing clouds, a highly heated and gas-charged lava, which is expelled from the crater. Their high temperature, about 900°C near the summit, and high speed, up to 100 km/h, are the reasons why many people are killed if such "clouds" pass dwellings and settlements. The nuées ardentes of the 1963 Agung volcano eruption in Bali, for example, killed 870 people.

Hazards caused by primary lahars

Some volcanoes e.g. Kelut volcano in Java, Awu volcano in North Sulawesi, and Ijen volcano also in Java, contain a crater lake. During an eruption the water of the rain-fed lake is expelled, and after mixing with the erupted loose materials, forms eruption lahars or hot lahars. This kind of mudstream has a specific gravity of more than two, causing huge boulders and blocks to float. The temperature is hundreds of degrees centigrade. These primary lahars are very destructive. The primary lahar during 1966 Kelut volcano eruption, for example, killed 285 people.

Hazards caused by secondary or rain lahars

This phenomenon is not directly caused by volcanic activity but is due to rainfalls after (or during) an eruption. The surface water flowing down the slopes of a volcano covered with ash and other loose materials will add to the rivers, which have their source on the summit area, heavy suspended materials forming mudflows in the valleys known as "rain lahars". High temperatures may also occur in lahars produced by rains falling shortly after an eruption. Rain lahars formed one year after volcanic activity may be still hot, depending entirely on the temperature of the nuée ardente deposit or "ladu" through which the rain lahar is flowing. If the ladu deposit is thick, high temperatures may be preserved for months or even years. Lahars tend to overshoot the bends of a river course and in a very short time (a couple of hours or so) a valley may be changed into a flat area. This change of direction of the lahar flow is very dangerous as it is generally unexpected.

At Merapi volcano, dangerous rain lahars occur when the rain has an intensity of 70 mm within 35 minutes above an elevation of 1200 m. Although both primary and rain lahars are highly destructive, the first type always claims a heavier toll. The number of casualties caused by primary lahars during the 1966 Kelut volcano eruption was 285, whereas rain lahars claimed but three victims.

Hazards caused by submarine volcanoes

When a submarine volcano erupts or whenever a volcanic island is blown out, tidal waves originate. During the cataclysmic eruption of Krakatau volcano in 1883, a huge tidal wave caused the death of some 36000 people along the shores of western Banten (western Java island) and Lampong (southern Sumatra island).

MARAPI VOLCANO AS A CASE STUDY

Physical background of Merapi area

The summit of Mt Merapi is 2911 m above sea level. The summit area has a steep gradient, and valleys form with deep river courses. Topographically the area can be classified into:

1. The upper slope area (above about 2000 m) which is formed from volcanic fragments and lava; the gradient is very steep (more than 35°). Because of the constant eruptions and the addition of new volcanic material, there is no vegetation. At present the crater opens to the south-west side and almost all of the eruptions flow onto the south-west side of the mountain.
2. The middle slope area (500–2000 m). In this area, nuées ardentes and lahars have flowed down into the valleys and changed river courses during major eruptions. When the volcanic activity subsides, material deposits are eroded by rainfall and deep valleys are quickly formed.
3. The lower slope area (under 500 m) is a relatively flat, gently sloping surface with a gradient of less than 3°.

The geology in the area of Mt Merapi can be summarised as follows:

1. Recent volcanic products from eruption of Mt Merapi consist mainly of lava flows and pyroclastic fragments from eruptions since 1888 and lahars that have occurred since 1930.
2. Terrace and other unconsolidated deposits consisting of present river bed deposits, terrace deposits, fan-like deposits in the lower stream area and alluvial deposits.
3. Young Merapi volcanic products including lahar deposits and lava flows before 1930.
4. Old Merapi volcanic products consisting of old Merapi lava flow, intrusive and pyroclastic rocks.
5. Base rocks including volcanic rocks and deposits of Tertiary age forming the foundation of Mt Merapi.

The rainy season in the area of Mt Merapi extends from November through April. The annual range of precipitation is 1500–4500 mm and 80% of the rainfall occurs during the rainy season. The areal distribution of rainfall is usually uneven and rain is concentrated on small areas. Rainfall durations are very short, therefore the intensity is high. Maximum intensity of rainfall has reached 250 mm over four hours. Concentration of rainfall is not the same from storm to storm and is difficult to forecast. Annual rainfall is highest at 1500 m (4000 mm) and decreases at elevations above and below this. At 100 m altitude the rainfall is about 2000 mm and at 3000 m, about 3000 mm.

The flow and suspended sediment discharges of K. Krasak have been observed since early 1978. Observations of discharge are always accompanied by sampling of the suspended load. Observations were made at three points along K. Bebeng and K. Krasak viz. in the upper part of K. Krasak (Puntuk), in the middle stream (Salam) and in the lower part (Blaburan). The maximum concentration of suspended load ever observed in K. Bebeng-Puntuk is approximately 1.4 x 10^6 mg/*l* with a discharge of 50 m^3/s. In K. Krasak-Salam the concentration of suspended load has reached 8 x 10^5 mg/*l* with a discharge of 37 m^3/s, and in K. Krasak Blaburan the maximum concentration of suspended load ever observed is 2.8 x 10^5 mg/*l* with a discharge of 15 m^3/s. Based on observations in K. Krasak, the suspended load concentration decreases downstream.

Nature of eruption

At present Mt Merapi is the most active volcano in the world. The period of dormancy is five years at the most, but renewed activity after shorter periods of quiescence is not uncommon.

The latest eruption cycle started in October, 1967 and reached its peak in a violent outburst on January 8, 1969. During this event a large part of a pre-existing lava dome having a volume of about 6 million m^3 tumbled down and deposited avalanche material to a distance of 13 km from the summit. Within several days lahars destroyed several villages, tens of weirs and barrages, and also buried the main road connecting the cities of Yogyakarta and Magelang for a distance of about 500 metres. Thick ash layers deposited on the southern slope turned into lahars which destroyed the inhabited strip along the river banks as far as Yogyakarta.

The present activity including the extrusion of new lava is expected to culminate in an outburst in a relatively short time.

Scope of the Disaster Prevention Project, and classification of sub-areas

For short term planning we should first select the river system in the area of Mt Merapi that is presently in a dangerous condition. This river system must be the first priority for countermeasures. The rivers involved are K. Krasak, K. Bebeng, K. Putih, and K. Blongkeng on the SW slopes of Merapi.

The goals of the short term plan can be summarised as follows:

1. To protect the inhabitants (about 63000 persons are distributed throughout 102 villages along those rivers within an area of 3809 ha).
2. To protect the social infrastructure, including national roads and bridges between Magelang and Yogyakarta, from damage caused by mud flow.
3. To protect the Mataram irrigation channel crossing K. Krasak and K. Petel, and irrigation intakes along those rivers.

The Mt Merapi Project has received technical assistance in long term planning from the Government of Japan. The aid included the sending of experts to Indonesia to carry out direct observation, and sending instruments for observation and research. This aid was programmed to continue for three years, 1977/1978 until 1979/1980. During this period a Master Plan for land erosion and volcanic debris control in the area of Mt Merapi was evolved. In the meantime this project has constructed several structures to control sediment flow and to protect inhabitants from disaster.

The area of Mt Merapi has been roughly classified into three areas depending on the degree of damage by mud flow and the amounts of sediment produced.

Type I area:

Type I area extends from the southwest side of the mountain. The main rivers included in this type I area are K. Bebeng, K. Krasak, K. Putih, K. Blongkeng, and K. Batang. At present the active crater opens and faces this area and forms an unconsolidated volcanic debris fan. During heavy rainfall the material becomes a source of mud flows to the middle and downstream reaches. Another source of mud flow is sediment along the river itself. The accumulated material in the river bed and banks is easily eroded by flood. River widening may be caused by lateral erosion and bank failure. Therefore the amount of sediment deposition in an average year is fairly large and causes sharp river bed variation.

Type II area:

This extends in a southeast direction from the summit and the main rivers in the area are K. Woro and K. Gendol. There is a sand pocket in the middle reach of both rivers, which is completely full of sediment. Sediment yields in both rivers have recently decreased. Because of continuous sedimentation in the river, the downstream length of K. Woro (called K. Simping) has already become a "ceiling" river with a fine material river bed. The "ceiling" river is the most dangerous part of this river, since its bed is higher than the surrounding land.

Type III area:

This is located west and east of Mt Merapi. Main rivers on the west side are K. Pabelan, K. Senowo, K. Trising, and on the east side are K. Boyong and K. Kuning. At present the rivers carry only small loads in flood, because new debris has not spread to the area.

The Mt Merapi area has also been classified into three categories based on river bed variation (see Fig. 2).

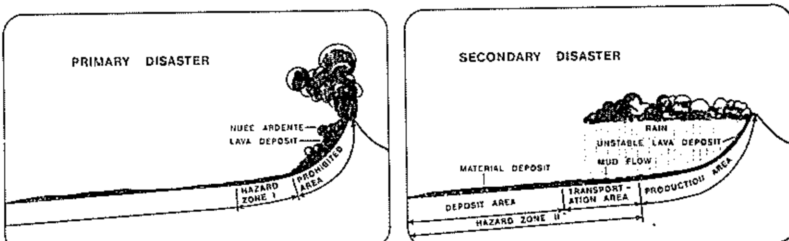

FIGURE 2—Illustration of Mt Merapi disaster.

1. Production area

River bed gradient in this zone is more than 6%. Newly deposited material from lava avalanches has accumulated in this area, especially in the west-south-west part of the slope. This unconsolidated new material deposit is easily eroded by rainfall.

2. Transportation Area
   River bed gradient in this area ranges from 3–6%. In the rainy season material deposited in the production area will be eroded and transported downstream through this area. During transportation of material, the velocity is high and has extraordinary power, often causing destruction of river banks and overflow at river bends.
3. Deposition Area
   River bed gradient in this area is less than 3% and deposition of sediment occurs causing continuous bed level rise.

Disaster prevention works

A. Hazard zone classification and countermeasure (see Fig. 3).

1. Nuée ardente hazard zone (prohibited area). In this zone inhabitants should be protected only by relocation outside the zone and not permitted to stay in the zone. For mitigating damage by nuée ardente in future, the area should be improved by afforestation and reforestation.
2. Hazard zone I. Inhabitants are permitted to stay in this zone, but if Mt Merapi shows signs of activity inhabitants should be warned and they must be ready to evacuate to safe places.
3. Hazard zone II. The hazard in the area is mud flow. Inhabitants, property, and social infrastructure should be protected by sediment control works and by a warning system.

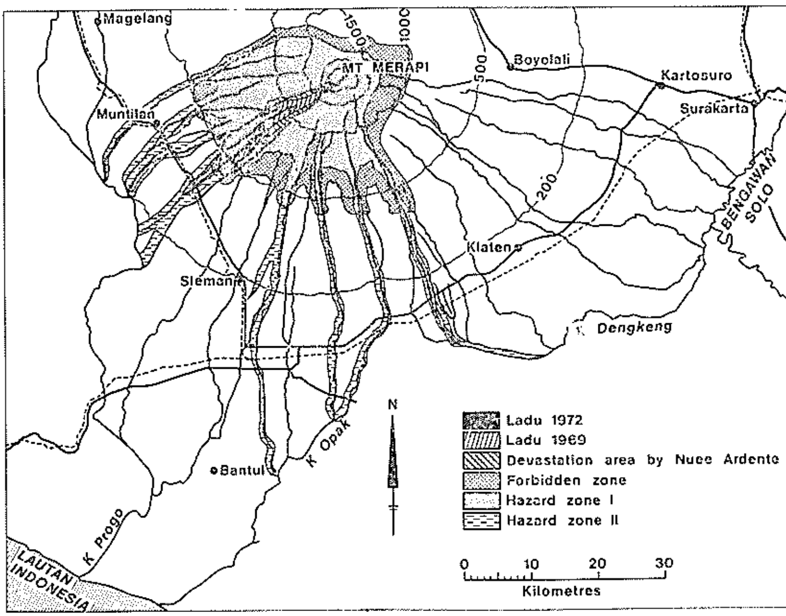

FIGURE 3—Hazard zone classification.

B. Sediment Control Works.

1. Reducing sediment production. Sediment production from the erosion of river beds and collapse of banks will be reduced by a series of checkdam structures in the upper stream, and by other facilities. Some sediment will thus be stopped in the upper stream and sedimentation in the lower stream can be minimised.
2. Controlling sediment discharge. Generally during floods the sediment load is high; existing checkdams cause sediment to be deposited, and river beds rise sharply. At normal discharges sediment concentrations are low, and sediments deposited in floods will gradually be eroded and transported downstream.
   In the zone where the river bed gradient changes from steep to gentle, generally sediment will deposit and spread over a large area forming an alluvial fan. To prevent large scale damage by spreading of mud flows in this area, the downstream part of the slope change zone must be utilised as a sediment storage area (sand-pocket) and equipped with dikes. During floods sediment will be spread and deposited in the area. In the dry season the deposit should be excavated and dumped outside the dikes, to increase storage for the next flood. By controlling sediment discharge through the storage area the rise of the river bed in the lower stream can be reduced.

C. Improvement of river courses

The improvement of river courses is intended to facilitate the passage of mudflows through river courses to the sea without causing any damage. There are many kinds of river course improvements such as:

1. Embankments. This kind of improvement is required at points where a tendency to deposit exists. This effort has been implemented in the downstream reach of K. Krasak, K. Gendol and K. Woro.
2. Improvement of sharp curves and bottlenecks in the river channel. Such improvement should be provided at sharp bends, bridges and intake points where flow capacity is determined by a narrow river course. In the case of flow impeded by a sharp bend, improvement has been implemented in the Mt Merapi area, for example, in the middle reach of K. Putih.
3. Lowering of river beds by increasing sediment flow capacity. This kind of improvement has the same effect as an embankment; it increases the capacity for sediment flow and prevents overflow. Lowering of river beds is accomplished by excavation. This improvement has been implemented in most rivers in the Mt Merapi area. Besides excavating the river bed, in some cases it is also necessary to narrow the river course. For narrowing the river course, embankments, groynes, etc. are required.
4. Protection works at bank collapse points. Bank collapse will be prevented by revetments, groynes etc.

Effectiveness of the system

The advantages of the volcanic debris control structures are:

1. The reduction of damage to inhabited areas, flood production area, and communication/transportation infrastructures by lahar flow.

2. Preventing lahar flows from entering the irrigation scheme covering an area of more than 40000 ha.
3. The limitation of sediment entering the main rivers (K. Progo, K. Opak and Bengawan Solo) to an allowable amount.
4. To maintain the function of rivers originating from the volcano as sources of water and drainage channels.

CONCLUSIONS

The Government of Indonesia has taken appropriate steps in order to cope with the problem of volcanic disasters in an improved and co-ordinated way. Their operational activities are carried out in both social welfare fields and technical fields. For the purpose of volcanic disaster prevention, volcanic hazard maps have been introduced to indicate the correct directions and right places of evacuation. For controlling lahar flows, several structures have been constructed along rivers having their source on the summit. Data recorded during recent years, after the application of the disaster prevention systems, show a decrease in casualties, in destruction of arable lands and in loss of property.

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