Emergency Sabo Works for Volcanic Disaster Reduction in Japan
- Mt. Asamayama: A Case Study -

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This paper, based on new thinking, reports volcano sediment control measures for Mt. Asama with respect to snowmelt-type volcanic mudflow expected to occur on Mt. Asama. Mt. Asama volcanic sabo works have numerous advantages when construction of basic facilities to be used in ordinary times and emergency facilities to be developed in times of emergency are implemented in conjunction. The combined implementation allows various measures to be taken flexibly to cope with the varying phenomena associated with volcanic eruption. The works can maintain the natural environment and landscape in ordinary times when implemented as emergency disaster reduction measures. Since not all planned facilities are constructed during a normal period, implementation of the works involves a relatively low cost. Since Mt. Asama can erupt at any time, it is imperative to further promote measures for volcano-related disasters around the mountain and tackle the works with an awareness of the danger in preparation for future eruptions.

Key words: Mt. Asama, snowmelt-type volcanic mudflows, Sediment and Erosion Control Plan for Volcanic Eruption Emergency Disaster Reduction Measures, measures in ordinary times

1. Introduction

Located near the prefectural borders of Gunma and Nagano in the northern part of the Kanto Region of Japan, Mt. Asama is a volcanic mountain covering six municipalities including Tsumagoi village, Naganohara town, Karuizawa town, Miyota town, Komoro city and Saku city. A traditional resort area, the area around the foot of Mt. Asama has been developed as a scenic summer retreat for over a century, and features villas and resort facilities. Traffic infrastructure established around the mountain includes the JR Agatsuma Line, the Nagano Shinkansen bullet train Line, Shinano Railways, Joshin-etsu Expressway, and Route 144, Route 146 and Route 18. The area within a radius of 2 to 3 km from the crater is designated as a special national park preservation area, which is further surrounded by a special area of the same national park. Hence the marvelous scenic beauty of the area is preserved.

Mt. Asama has a record of many eruptions throughout recorded history. Among the recorded eruptions, particularly large ones occurred in 1108, in the Tennin Era, and in 1783, in the Tenmei Era. The eruption in 1783 caused pyroclastic, debris, mud, and lava flows, including the Azuma Pyroclastic Flow, the Kambara Debris Avalanche, the Tenmei Mudflow, Kutsukake Mudflow, and Onioshidashi Lava Flow, and wreaked havoc not only on the foot of the mountain but also in the areas along the Tonegawa River [1)]. Recent volcanic activities have mainly occurred at Kamayama (2,493 m elevation), one of the peaks of Mt. Asama. A medium scale eruption occurred on September 1, 2004, and a minor eruption on February 2, 2009.

Expected phenomena associated with the eruptive activities of Mt. Asama include ballistic projectiles, volcanic ash, pyroclastic flows, snowmelt-type volcanic mudflows during the snowy season, post-eruption debris flows, and lava flows. One of the characteristics of a snowmelt-type volcanic mudflow is that since it begins to run down simultaneously with the occurrence of a pyroclastic flow, it is difficult to predict the direction or timing of movement, and both its total flow and peak flow are considerable. What characterizes post-eruption debris flows is that they are repeatedly triggered by even a small rainfall, and continue to occur for years. It is expected that devastating damage will occur to the foot of Mt. Asama if such snowmelt-type volcanic mudflows or post-eruption debris flows occur. To mitigate such damage, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) started developing a volcanic sediment and erosion control project for Mt. Asama (referred to below as the Mt. Asama Sabo Works) in 2012. To be specific, the Mt. Asama Sabo Works are comprised of basic scheme measures and emergency scheme measures. The Works intends to effectively and efficiently combine measures to be implemented in ordinary times with those in emergency times in order to protect the life and property of local residents.

In this paper, we suggest a conceptual idea for emergency disaster reduction measures and the effect of those measures as an aid to disaster prevention. Such measures are to be taken with respect to sediment disasters resulting from a volcanic eruption, the occurrence of which is difficult to predict.

2. Disaster History of Mt. Asama

Mt. Asama has had a large-scale plinian eruption once about every 700 years for the past 2,500 years.

The eruption causing the most damage on record occurred in 1783. It claimed the lives of over 1,523 people and destroyed over 2,065 houses. In 1973, a pyroclastic flow occurred during the snowy season, which caused snowmelt-type volcanic mudflows (See Photos 1 and 2).

Since 1900, the mountain has erupted almost every year [2]. The VEI (Volcanic Explosivity Index) since A.D. 500 is shown in Fig.1. Recent major eruptions occurred on September 1, 2004 and February 2, 2009 (See Photo 3).

The eruption on Sept. 1, 2004, was a medium-scale explosion, the first time in 21 years since April 8, 1983. This eruption sent air-shock waves around the mountain and broke window glass, spewed red-hot volcanic cinders over the mountain slope higher than halfway up the mountain, and scattered lapilli about 3 cm in diameter to an area about 6 km northeast of the crater. Volcanic ash fell over wide areas around the mountain including Tsumagoi village, situated northeast of the crater, and in part of the prefectures of Gunma, Tochigi and Fukushima. The ashfall in particular caused agricultural damage in some municipalities around the mountain, including in the villages of Tsumagoi and Naganohara town. The national highways around Mt. Asama were closed, and some residents voluntarily evacuated to safer places.

A day before the eruption of February 2, 2009, a minor eruption occurred and the eruption alert level was raised from 2 to 3. Large cinders were scattered in an area about 1 to 1.2 km northwest of the crater, and the volcanic smoke that reached a height of 2,000 m above the crater edge flowed in the southeastern direction. The ashfall was observed in Karuizawa town, Nagano prefecture, as well as in the southern part of the Kanto Region, including Saitama, Tokyo and Kanagawa, and Izu Oshima Island.

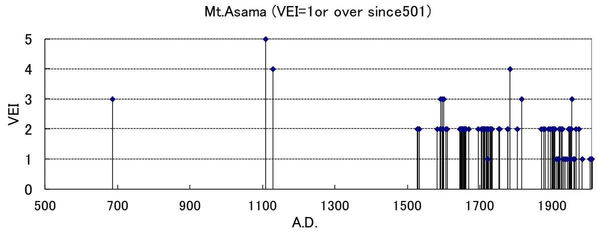

Fig. 1 VEI of Mt. Asama since 500

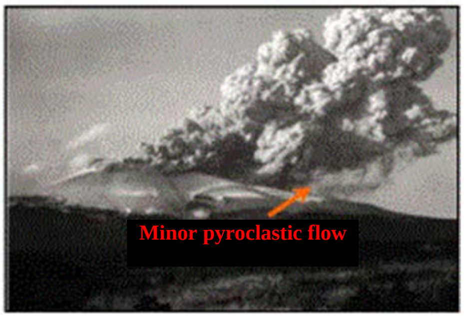

Photo 1 Plume of the Feb., 1973, eruption and pyroclastic flow
(photo courtesy of the Meteorological Agency)

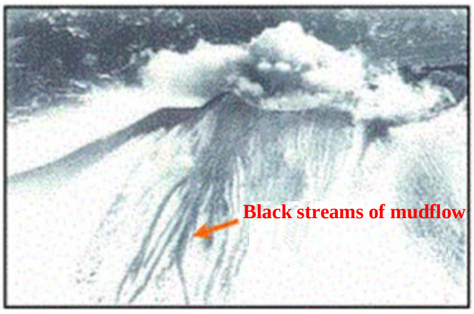

Photo 2 Snowmelt-type volcanic mudflow following the eruption in Feb. 1973
(photo courtesy of the Meteorological Agency)

Photo 3 Eruption in Feb. 2009

3. Emergency Sabo Plan for Volcanic Disaster Reduction

3.1 Concept of the Emergency Sabo Plan for Volcanic Disaster Reduction

Currently, there are 110 active volcanoes in Japan. Disasters have been frequently caused by volcanic eruption, including the eruption of Mt. Unzen-Fugen in 1990 and those of Mt. Usu and Miyake Island in 2000. The Japanese government takes measures to mitigate eruption-related disasters in the form of volcano sediment and erosion control projects and volcanic eruption alert and evacuation promotion projects for the 29 active volcanoes whose eruption would have a large impact on society. It is, however, difficult to completely eliminate damage by eruption-induced lava flows, volcanic mudflows, or debris flows in the present situation where the prevalence of sediment control facilities, such as sediment control dams, is low.

In 2007, the Erosion and Sediment Control Department of MLIT decided to formulate emergency sediment and erosion control plans for volcanic disaster reduction. This was in order to rapidly and effectively implement emergency measures with respect to sediment disasters associated with volcanic eruption which are difficult to predict, and mitigate the damage as much as possible [3]. In the process of formulating the plan, the Guideline for Formulation of the Sediment and Erosion Control Plan for Volcanic Eruption Emergency Disaster Reduction Measures was prepared. The schematic illustration of sediment control for volcanic eruption emergency disaster reduction measures is shown in Fig.2.

3.2 Mt. Asama Volcano Sabo Works

Measures for the Mt. Asama Volcano Sabo Works include basic scheme measures (measures in ordinary times) and emergency scheme measures (emergency measures, from premonitory phenomena to eruption). These measures are effectively and efficiently combined to protect the life and property of local residents. The emergency scheme stipulates two different types of measures: measures to be implemented during an emergency, and ordinary preparation necessary for such measures to be implemented in times of emergency.

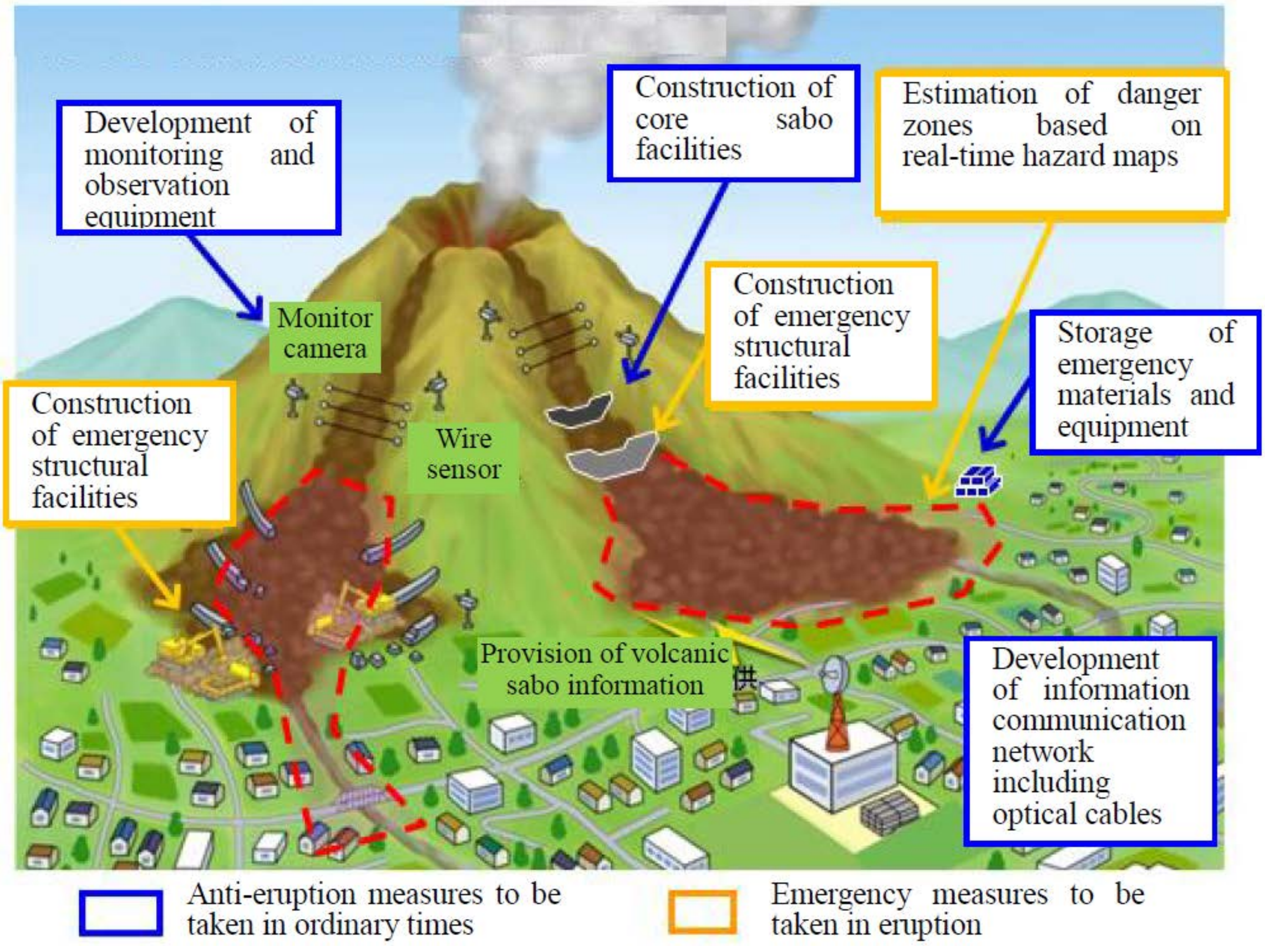

Fig. 2 Schematic illustration of sediment control for volcanic eruption emergency disaster reduction measures [3]

The measures of the basic scheme and those of the emergency scheme are shown in Table1. The schematic illustrations of implementation of emergency disaster reduction measures and development of emergency disaster reduction measures are shown in Fig.3 and 4 respectively.

The preparations to be made in ordinary times consist of a set of activities to realize the smooth and rapid implementation of measures to be implemented during an emergency prior to occurrence of a snowmelt-type volcanic mudflow or post-eruption debris flows.

Therefore, the Mt. Asama Volcano Sabo Works involves the implementation of measures of the basic scheme and those of the emergency scheme. To be specific, the former includes the systematic development of sabo facilities and preparatory work for emergency measures, such as storage of necessary materials and equipment and acquisition of necessary land, and the latter includes implementation of emergency structural measures.

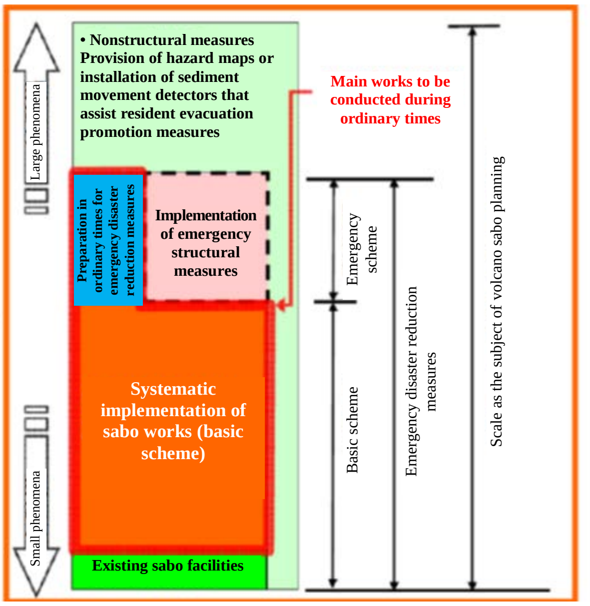

Fig. 4 Schematic illustration of development of emergency disaster reduction measures

Table 1 Measures of the basic scheme and those of the emergency scheme

Basic/emergency	Description	Specific measures
Basic scheme	Systematic development of sabo facilities	Sabo dam works, excavation
Emergency scheme	Ordinary times preparation	Storage of materials and equipment, acquisition of land, construction of work road, etc.
	Emergency structural measures in eruption situation	Sabo dam works, excavation work, training dike works

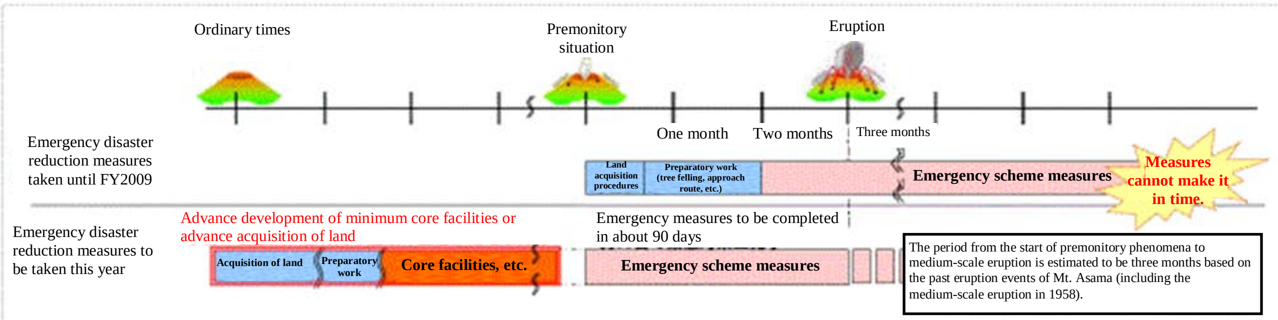

Fig. 3 Schematic illustration of implementation of emergency disaster reduction measures

4. Sabo Plan for Mt. Asama Volcanic Eruption Disaster Reduction Measures

4.1 Premonitory phenomena and the scale of eruption

4.1.1 Premonitory phenomena

The expected phenomena associated with the eruptive activity of Mt. Asama, as identified by past eruption events, include ballistic projectiles, volcanic ash, pyroclastic flows, snowmelt-type volcanic mudflows, debris flows, and lava flows. The snowmelt-type volcanic mudflow is generated, because the pyroclastic flow which is a high temperature melts the snow on the slope. The post-eruption debris flow is generated, because pyroclastic materials deposits on the slope, and infiltration capacity becomes small.

It has been determined that phenomena focused by emergency structural measures out of these are snowmelt-type volcanic mudflows and post-eruption debris flows, whose damage can be mitigated by the current emergency structural facilities. For the other phenomena, emergency nonstructural measures, including the provision of real-time hazard maps, should be taken in conjunction with the relevant organizations to support warning and evacuation measures to be taken by the relevant municipalities.

4.1.2 Scale of eruption

The scale of a snowmelt-type volcanic mudflow or a debris flow is generally determined by the amount of a pyroclastic flow and the amount of snowfall. The scale of a debris flow depends on the amount of unstable sediments such as pyroclastic fall deposits that increase with eruption activity and the amount of rainfall.

The amount of a pyroclastic flow used for estimating the scale of an expected snowmelt-type volcanic mudflow is 270,000 m^3, the amount observed at the eruption in 1958, the largest since 1901, and the snow depth used is 0.5 m, the average snow depth observed at the Kurumazaka Pass Observatory, the closest to the average elevation of the area reachable by the expected pyroclastic flow.

The major eruptions since 1901 whose eruptive volume is known are shown in Table 2 [2)].

For the estimated amount of a snowmelt-type volcanic mudflow, since the run-off direction varies depending on the stream direction of the source pyroclastic flow, the run-off characteristics of the snowmelt-type volcanic mudflows in the case that the pyroclastic flow streams down in eight directions from the mountain top are determined by numerical simulation, and the amount of the mudflow that turns out to be the largest in each stream is taken as the subject amount for each stream.

An assumed post-eruption debris flow after an eruption is a debris flow that will occur when a pyroclastic flow in the amount of 270,000 m^3 occurs, the amount of unstable sediments eventually increased on the mountain slope, and a rainfall with a two-year exceedance probability continued for 24 hours. Since the amount of unstable sediment varies depending on the stream direction of a pyroclastic flow, the amount of unstable sediment that becomes the largest when the pyroclastic flow streams down in eight directions from the mountain top is taken as the amount of unstable sediment for each stream. Such amount or the amount of unstable sediment that can be carried by the amount of two-year exceedance probability rainfall, whichever is smaller, is then taken as the design scale for each stream.

Table 2 Major eruptions since 1901 whose eruptive volume is known

Start year		End year	Eruptive volume (apparent) ($\times 10^3$ m^3)		
			Pyroclastic fall deposit	Pyroclastic flow	Total
1908	→	1914			330
1929	→	1932			300
1934	→	1937			600
1938	→	1942			500
1947					100
1950	→	1951			100
1958	→	1959	95	270	365
1961					700
1973			1,000	100	1,100
1982	→	1983	230	100	330
2004					160
2009					30

4.2 Damage estimation

Damage quantities are calculated for a snowmelt-type volcanic mudflow by conducting two-dimensional flood simulation.

Hydrographs used in this calculation are those from the kinematic wave method that is capable of directly evaluating changes in the shape of the slope (gradient or downward stream width) and treats run-off phenomena as a physical model. The schematic illustration of calculation of hydrographs for a snowmelt-type volcanic mudflow is shown in Fig.5. The calculation conditions for two-dimensional flood simulation are shown in Table 3. The equivalent roughness coefficient for the kinematic wave method is 0.1.

The ranges to be affected by snowmelt-type volcanic mudflows under current conditions are shown in Fig. 6. Damages are estimated for approximately 21,500 people, approximate 8,000 households, approximately 460 ha of rice field areas, and approximately 1,100 ha of field areas in flooding area. The amount of damage is approximate 110 billion yen including approximate 61 billion yen of human suffering.

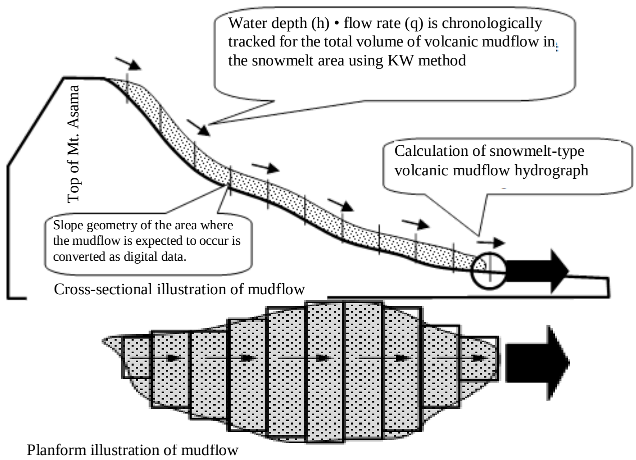

Fig. 5 Schematic illustration of calculation of hydrographs for a snowmelt-type volcanic mudflow

Table 3 Calculation conditions for two-dimensional flood simulation

Item	Sign	Unit	Value	Remarks
Mud water density	ρ	g/cm^3	1.0	
Sandy gravel density	σ	g/cm^3	2.5	General value
Volumetric concentration of sedimentary sandy gravel layer	C*		0.6	General value
Typical grain size of sandy gravel	dm	cm	15.0	Grain size analysis of additional pyroclastic flow deposit
Internal friction angle of sandy gravel	φ	Degree	30	General value
Mesh interval		m	10	Prepared based on the laser survey conducted in 2003
Sediment discharge factor	—	—	8	M.P.M. method

4.3 Sediment control facility layout planning

Designed to respect the status of land use in the area around the foot of Mt. Asama, the basic policy for Mt. Asama sabo facility layout planning attempts to catch a snowmelt-type volcanic mudflow or post-eruption debris flow or mitigate its movement further upstream of the protection area and minimize the damaging effects of the muddy water as it goes down the protection area, flowing downstream. The schematic illustration of the system of sabo facilities is shown in Fig. 7. The area of flooding by snowmelt-type volcanic mudflows under the sediment control facility layout plan is shown in Fig. 8.

The basic scheme should construct a minimum of sabo facility such as one sabo dam in the most upstream part of each stream for disaster reduction in the downstream areas wherever the snowmelt-type volcanic mudflows may flow. Other facilities should be positioned as those of the emergency scheme to be developed during emergency times (from premonitory phenomena to eruption). Furthermore, in order to smoothly implement measures in an emergency situation (from premonitory phenomena to eruption), casting of foundation concrete, production and accumulation of blocks, acquisition of land, construction of work roads, and development of stock yards should be promoted in ordinary times for construction of sabo dams, which is one of the measures of the emergency scheme. During times of emergency, sabo dams and training dikes using blocks should be developed by utilizing the foundation concrete.

(1) Sabo dam works

Sabo dams should be constructed at the most upstream part as core facilities among those of the basic scheme. The overflow section should be made of concrete (including permeable dams) in the scope of the basic scheme. Concrete block construction should be the basic type of structure for measures of the emergency scheme. However, the foundation part should be constructed by pouring foundation concrete during the ordinary times.

(2) Training dike works

Either concrete blocks or large sand bags should be used appropriately depending on the scale of the mudflow expected to occur at each location. This work should be conducted as part of the emergency disaster reduction measures.

(3) Excavation work

Excavated earth should be used to fill non-overflow sections.

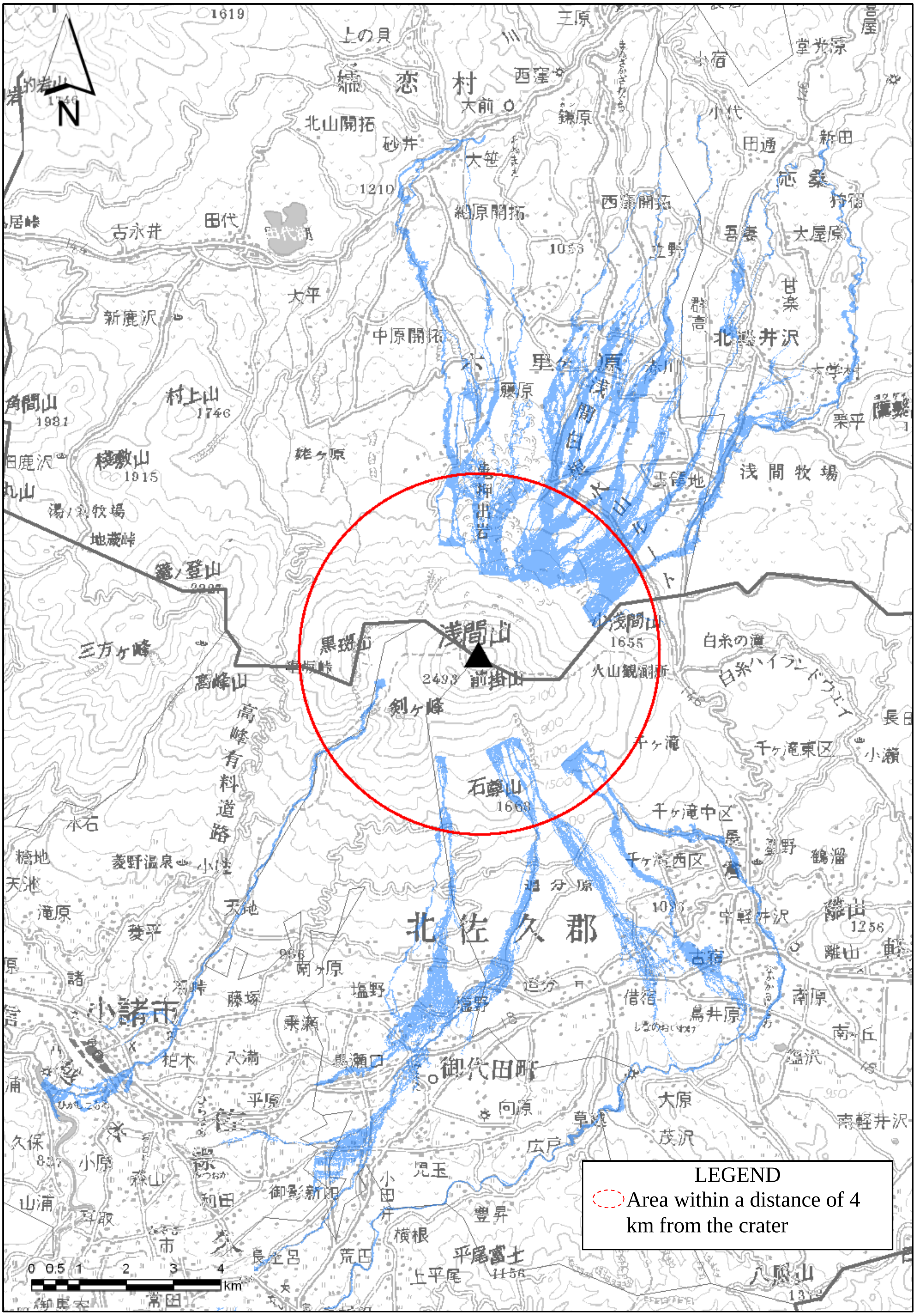

Fig.6 Ranges to be affected by snowmelt-type volcanic mudflows under current conditions

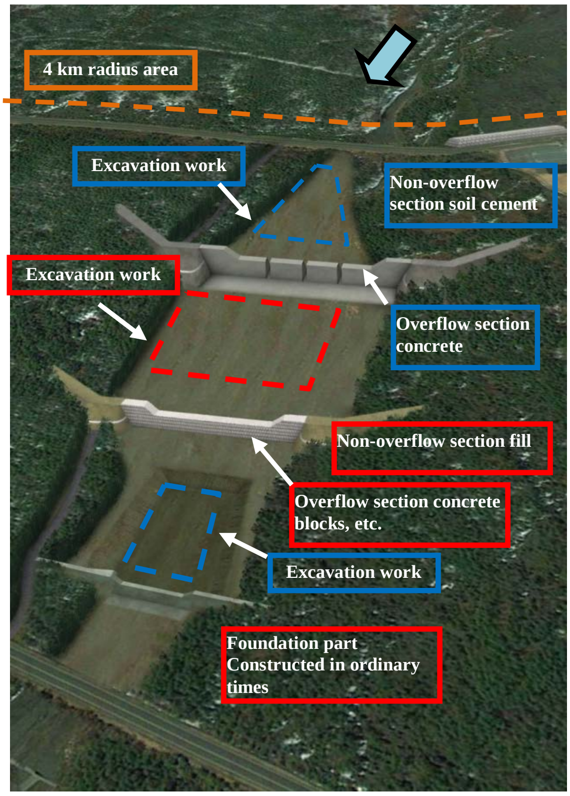

Fig. 7 Schematic illustration of the structure of sediment control facilities

4.4 Nonstructural measures

Nonstructural measures include provision of information, urgent installation of volcano monitoring equipment, development of information communication networks, and emergency surveys to support evacuation promotion measures conducted by the relevant municipalities.Provision of information to support evacuation promotion measures specifically includes provision of real-time hazard maps to Gunma and Nagano prefectures and the relevant municipalities in accordance with volcanic activities or weather conditions about damage expected to be inflicted by post-eruption debris flows and snowmelt-type volcanic mudflows based on the opinions of core group members of the Mt. Asama Volcano Disaster Prevention Council.

Urgent installation of volcano monitoring equipment includes installation of debris flow movement detection sensors, ashfall meters and other necessary equipment with respect to post-eruption debris flows in coordination with the relevant organizations. Equipment to be installed in an area within a distance of 4 km from the crater of Mt. Asama, where entry control is applied, should be installed during ordinary times.

5. Characteristics of Mt. Asama Volcano Sabo Works

5.1 Basic scheme and emergency scheme

The Mt. Asama Volcano Sabo Works are characterized by the joint implementation of measures of the basic scheme, which are those to be developed in ordinary times, and those of the emergency scheme, which are those to be developed in emergency times. Systematic combination of basic and emergency scheme measures is expected to produce works effects never realized before. Expected characteristics of this approach are described as follows:

(1) Flexible measures to cope with the characteristics of volcano damage can be taken

Sediment disasters caused by volcanic eruption are characterized by a variety of phenomena that occur by volcanic eruption, the difficulty of predicting occurrence of those phenomena, and the capability of swiftly and effectively realizing response to eruption by implementing emergency disaster reduction measures. The combination of basic and emergency scheme measures makes it possible to take flexible measures to cope with the actual conditions of volcanic activity.

(2) It is advantageous in terms of preservation of the natural environment and landscape

The area at the foot of Mt. Asama is considered particularly important in terms of preservation of the natural environment and landscape as it is located in a special preservation area and Type 1 special area of a national park. Although no installation of facilities is planned in the special preservation area of the national park, there are some places in the Type 1 special area where construction of some facilities is necessary. Since those facilities are only to be developed as part of emergency disaster reduction measures in the Type 1 special area of the national park, no facilities will be constructed in ordinary times. Therefore, the natural environment and landscape will be maintained in ordinary times.

There are some roads in the foot of Mt. Asama, such as the Onioshi Highway, that may allow installation of concrete blocks on the roadway to effectively serve as training dikes. If such concrete blocks are placed on the roadway in ordinary times, it would certainly disturb the smooth flow of traffic. However, if emergency facilities are constructed at some necessary locations, such as roadways, only in an emergency, those locations will be able to effectively serve the intended effect of emergency measures. It is, however, noted that advance consultation or coordination with Ministry of the Environment or its proprietor is necessary to implement measures as emergency disaster reduction measures.

(3) Works implementation will be less costly

Compared with the case where all facilities are constructed under the basic scheme, implementation of emergency disaster reduction measures whenever necessary will reduce works expenditure. In other words, the basic principle of emergency disaster reduction facilities is to develop emergency scheme measures by predicting the run-off direction of pyroclastic flows to determine the direction of the snowmelt-type volcanic mudflow, rather than implementing all necessary measures.

5.2 Feasible period

The timing of the start of implementation of emergency structural measures should trigger the start of preparation of emergency measures based on comprehensive judgment of the phenomena up to the fourth medium-size eruption as shown in Table 4, including an increase in the number of volcanic earthquakes and occurrence of volcanic glow, as well as the reference information of Volcanic Warnings or Volcanic Alert Levels.

While the period for judgment of implementation start and cancellation is estimated to be about three months based on the eruption scenario, it is the prerequisite to conduct safety measures for the work based on the assumption that the judgment period can be longer or shorter than that. Construction assumed the emergency structural measures a plan to be completed within three months.

6. Conclusion

The Mt. Asama Volcano Sabo Works are comprised of basic scheme measures to be taken in ordinary times and emergency scheme measures to be taken in emergency times. Activities necessary to smoothly realize emergency response, including acquisition of land for emergency disaster reduction measures or storage of necessary materials and equipment, should be conducted in ordinary times as part of these sabo works. Currently ongoing activities include storage of necessary materials and equipment, development of detailed design of sediment control facilities, and surveys to construct facilities that fully consider the landscape or environment.

Since it is no exaggeration to say that Mt. Asama can erupt at any time, we intend to further promote volcano disaster prevention measures in the area at the foot of the mountain.

Table 4 Timing of preparation start for emergency measures and the measure feasible period estimated based on the eruption record

Major eruption day (medium-scale eruption)	Premonitory volcanic activity or eruption record	Interpretation as volcanic phenomena	Phenomena that can be detected with the current observation network	Feasible period for measures (including preparation)
September 1, 2004	June 2004 Trend of Type A earthquakes to gradually increase in frequency (and to continue thereafter)	Earthquakes associated with penetration of magma to the greater depth	Occurrence of Type A earthquake (seismograph)	3 months
April 8, 1983	Very small-scale eruption occurred on Oct. 2, 1982. The height of fume unknown Very small amount of ashfall continued for 10 min. in Asama Ranch or Onioshidashi Park	(Possibly magma penetration to a greater depth already started in around 1972) Increase in crater temperature by high-temperature gas	Colored fume (high-sensitivity camera)	6 months
February 1, 1973	Weak volcanic glow observed at the northern part	Increase in crater temperature by high-temperature gas	Volcanic glow (naked eye)	2 months
November 10, 1958	End of July 1958 Increase in the frequency of volcanic earthquake (rapid increase in the end of September thereafter) Increase in the volume of fume Rumbling from the bottom of the crater (which gradually became intense)	Rise of magma into vent Blowoff of high-temperature volcanic gas	Frequent occurrence of volcanic earthquakes (seismograph) Increase in the volume of fume (high-sensitivity camera) Increase in discharge of SO_2 (DOAS)	3 months

References

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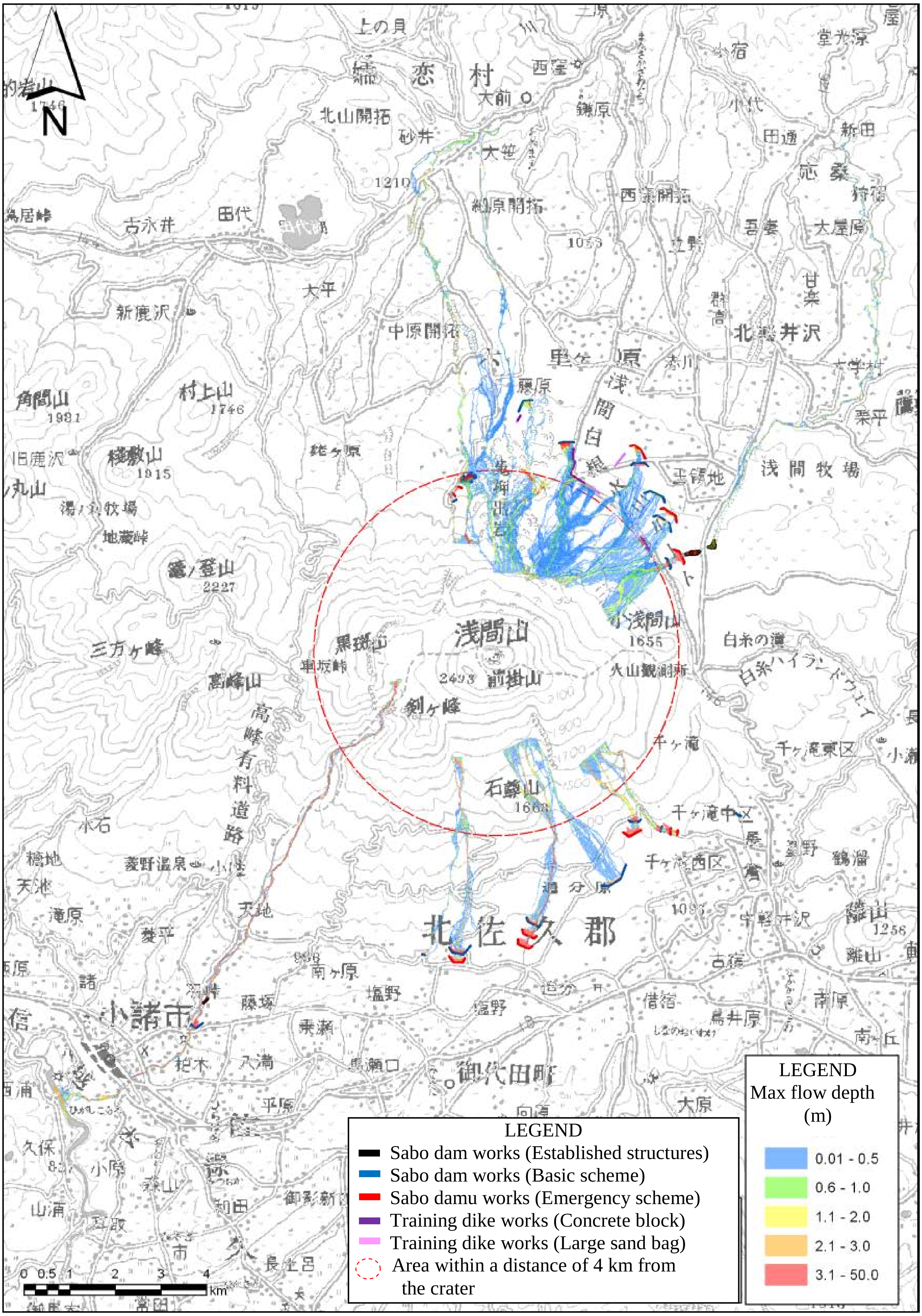

Fig. 8 Ranges to be affected by snowmelt-type volcanic mudflows under the erosion control facility layout plan