

Paper:

The Heisei Eruption of Mt. Unzen-Fugendake and Measures Against Volcanic Disasters

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The Heisei-eruption of Mt. Unzen had started on November 17 in 1990 and continued in the beginning of 1995. Dangerous volcanic phenomena such as pyroclastic flows and debris flows had occurred intermittently during the eruption, resulting in 44 of casualties and 2,511 destroyed houses. Though no one had experienced and estimated the occurrences of such events, the central government of Japan and the Nagasaki prefecture government soon started to ensure the appropriate measures for reducing the expansion of disasters. The first approaches were preparation of hazard-map for evacuation and execution of temporary works such as sediment removal and sensor installation. Furthermore, they had developed many new methods such as unmanned construction and executed the measures to mitigate debris flows and pyroclastic flows disasters. The measures were based on three viewpoints; (1) We have to cope with various phenomena by them. (2) They should be executed in short term. (3) The safety of workers has to be ensured. Inhabitants, academic persons and administrators had coped with the Mt. Unzen volcanic disaster in cooperation. As a result of the execution of the measures, the safety zone of life in the Shimabara city was restored and the communities were reconstructed. Thus, the preventive measures in Mt. Unzen were successful. Recently there is destruction of social infrastructures by volcanic disasters in the world. I can introduce the volcanic sabo work executed by the central and local governments in Mt. Unzen as a model case of the mitigation or prevention measures against volcanic disasters.

Keywords: sediment movement, volcanic disaster, volcanic sabo work, hazard map, volcanic sabo master plan

1. Introduction

The Heisei eruption of Mt. Unzen-Fugendake which started in 1990 had continued until 1995, causing volcanic phenomena such as a pyroclastic flow and a debris flow. Due to the eruption, 44 persons were killed and 2,511 houses were destroyed. For preventing disaster and creating a safe and secured community, comprehen-

sive measures were implemented by the joint efforts of local people, administrators and researchers, and by mobilizing newly-developed disaster prevention technologies. Especially, preparation of hazard maps for evacuation and the volcanic sabo works were made by National government and Nagasaki prefectural government. The emergency constructions for disaster prevention were executed mainly from three viewpoints: applicability to multiple volcanic phenomena, effectiveness in a short-term, and security of construction workers. As a result, damages from a number of debris flows and pyroclastic flows during the long erupting period were minimized. A safe and secured base for living was recovered by the restoration works for the affected area. In this respect, the volcanic sabo works at Mt. Unzen-Fugendake are highly evaluated.

In recent years, destruction of social infrastructures due to volcanic disasters is increasing in the world. The measures implemented at Shimabara, particularly those measures against sediment-related disasters which occupy a large proportion in volcanic disasters, are introduced here as model cases of volcanic disaster mitigation and prevention.

2. Heisei Eruption and Sediment Movements

2.1. Progress of Eruptive Activities

On Nov. 17, 1990, the first eruption of Mt. Unzen-Fugendake started at the Jigokuato crater and the Kujukushima crater after 198 years of dormancy. On Feb. 12, 1991, another eruption occurred from the Byobuiwa crater. By that time, these eruptions were taken as a delighted thing for a tourist attraction by the local people. However, about 140,000 m³ of volcanic ash was deposited on the mountain slope and we worried about presumed occurrence of debris flows by a rain fall.

On May 20, 1991, lava was found in the Jigokuato crater for the first time in the current eruption. After that, lava had been supplied for 3 years and 9 months almost continuously and then a lava dome was created on the top of the mountain. A total of 13 lava lobes were produced and grown into one large lava dome complex eventually. According to the surveys by the Geographical Survey Institute and the Public Works Research Institute of



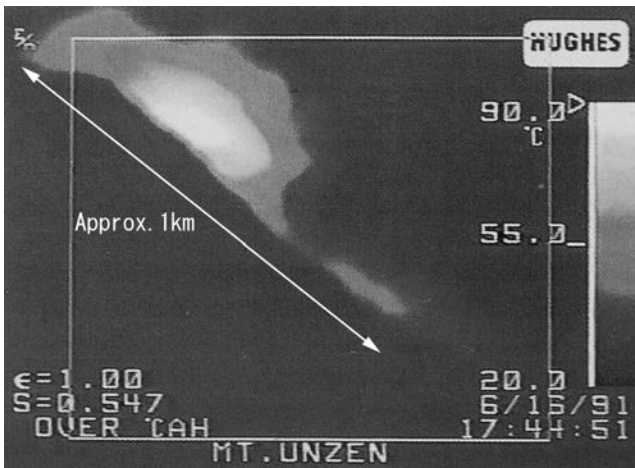


Fig. 1. Pyroclastic flow just running down along the mountain slope of Mt. Unzen-Fugendake (captured by a Thermal Infrared Camera).

the Ministry of Construction, the lava extrusion was particularly large in the periods of Sept. 18 - Oct. 15, Oct. 15 - Nov. 25 (1991) and Nov. 25 - Feb. 19 (1992), with a daily volume of about 300,000 m³, 350,000 m³, and 280,000 m³, respectively.

During the growth of the lava dome, pyroclastic flows occurred frequently due to partial or large-scale collapses of the lava dome (**Fig. 1**). The total numbers of occurrence of pyroclastic flows were 9,432. The total volume of lava extruded during the Heisei eruption was as much as 200 million m³. About half of it still remains as a lava dome, and the remaining was flowed out as pyroclastic flows. About 170 million m³ of the deposits were piled up on the mountain slope, which became a potential source of debris flow. The volcanic activity had weakened since around October, 1994, resulting in no occurrence of a pyroclastic flow. The growth of the lava dome almost ceased in February 1995. Responding to it, the Coordinating Committee for the Prediction of Volcanic Eruptions of Japan declared the end of volcanic activity on May 25, 1995. Four and half years had elapsed from the start of eruption on Nov. 17, 1990 to the end of volcanic activity in February 1995.

2.2. Characteristics of Heisei Eruption

The Heisei eruption of Mt. Unzen-Fugendake had several characteristics in terms of disaster prevention. Firstly, the current phenomenon was different from those of previous two historical eruptions. In the previous eruptions, lava flow occurred in addition to the collapse of Mt. Mayu-yama and a volcanic mudflow in the Antoku area, respectively. On the other hand, in the current eruption, lava dome was formed and pyroclastic flows generated. Furthermore, debris flows occurred when volcanic ash and pyroclastic flow deposit were washed away by rainfall, which is much different from in the previous two eruptions. It indicates that the same volcanic activities do not always occur even in the same volcano. In other

words, it means that volcanic activities are too diverse and difficult to predict.

Secondly, the activity of the Heisei eruption had continued for four and half years. Earthquakes and other disasters, which may be triggered by a heavy rainfall or a typhoon, are transient phenomena which last for a short period. In contrast, volcanic activities tend to continue for a long period and the Heisei eruption was not an exception. A large number of people had to endure a serious impact on their living base for several years.

Thirdly, the Heisei eruption showed a reality of volcanic activities to people that topographical change occurred day by day. The topographical change of Mt. Unzen-Fugendake during the current eruption was extensive. For example, the pyroclastic flow deposit on June 3, 1991 buried the Mizunashi River as thick as 30 m at a place 1.5 km away from the crater, and the pyroclastic flow deposit on June 6 up to 10 m. As a result, the original topography was altered very drastically (**Fig. 2**), introducing changes in the moving direction of a pyroclastic flow and a debris flow. The changes expanded sediment-related disaster hazard area in the downstream instantly.

Fourthly, serious human damage was caused during the eruption with the loss of 44 lives. The human damage was caused by pyroclastic flows. Physical damages including those on land and houses were caused by sediment-related disasters from debris flows and pyroclastic flows.

These facts indicate that prevention of volcanic disasters, especially sediment-related disasters, is important in order to protect the safety and security of social infrastructures.

3. Occurrence of Volcanic Disasters

3.1. Pyroclastic Flow and its Damage

Pyroclastic flow is one of the most dangerous volcanic phenomena because it runs at high speed and high temperature. According to the research by the Geological Survey Institute of Japan, the pyroclastic flow on June 8 ran down at a speed of about 35 m/s (126 km/h) at the exit of the valley. This speed is significantly higher than that of a debris flows which were 5-20 m/s (20-70 km/h). The temperature of this pyroclastic flow was estimated to be 400 °C or more because the tires of vehicles were burned out.

Pyroclastic flow consists of the main body part and the overlying part of hot ash cloud. The main body part contains blocks and fragments of hot lava, and flows down along a topographically low by gravity, just like a debris flow. However, the fashion is not controlled by small topography such as a debris flow, because a pyroclastic flow has a large force of inertia due to its high speed. The hot ash cloud part grows from the movement of the main body part. It is the mixture of high-temperature gas and particularly fine volcanic ash produced by fragmentation of lava blocks. It flows farther than the main body section, because it has the property of gas and a larger force of inertia than the main body part (See **Fig. 3**).

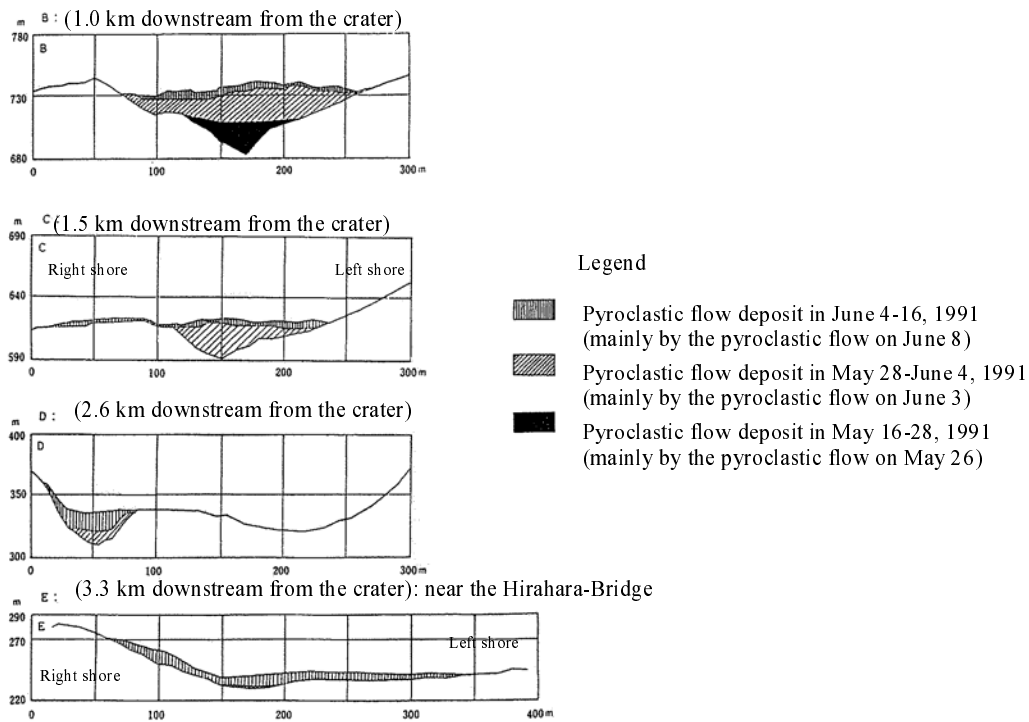


Fig. 2. Topographic change of the Mizunashi River due to accumulation of pyroclastic flow deposit (cross section) [1].

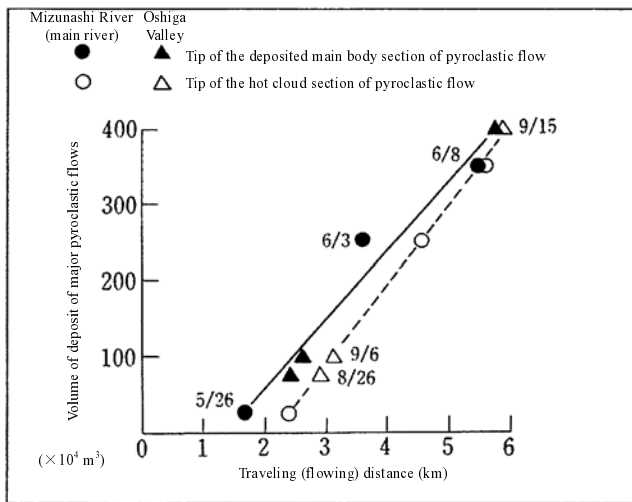


Fig. 3. Sediment volume and traveling distance of major pyroclastic flows [2].

Pyroclastic flows caused a serious damage including a heavy toll of lives. Three major pyroclastic flows occurred during the Heisei eruption. The first major pyroclastic flow occurred around 3:50 p.m. on June 3, 1991 with a sediment volume of 2.5 million m³. The main body and the hot ash cloud of this flow reached up to 3.6 km and 4.5 km respectively from the crater, and attacked areas of Kitakamikoba and Minamikamikoba of Shimabara city, located at the exit of the valley. It resulted in a devastating damage with the dead and missing 43, the injured 11, burned or total collapse of dwelling houses 49, and total

collapse of non-dwelling houses 130.

The second major pyroclastic flow occurred at 6:54 p.m. on Sept. 15, 1991. It continued for 11 minutes and 10 seconds with a total sediment volume of 4 million m³. This pyroclastic flow changed its course to the right at the Taruki terrace and flowed down to the Shiratani Bridge at 5.8 km from the crater. The hot ash cloud went farther to the Kamikoba area of Shimabara city and the Oonokoba area of Fukae town. The Oonokoba elementary school in Fukae town was directly hit by this pyroclastic flow and sustained a destructive damage. Although no human damage occurred because this area was already designated as the evacuation area, 48 dwelling houses and 128 non-dwelling houses including this elementary school were burned down. This sediment volume of 4 million m³ was the largest among all pyroclastic flows that occurred during the Heisei eruption.

The third major pyroclastic flow occurred along the Nakao River. Pyroclastic flows began to flow down the Nakao river basin on May 21, 1993 and the flow tip reached the residential area in Minamisembongi of Shimabara city on May 24. The pyroclastic flow that occurred on June 23 flowed straight down from the lava dome (Lobe 11) to the Nakao river basin. Its main body part was deposited on the Sembongi terrace near the Nakao River in a fan-like form of about 700 m long and 700 m wide. On the other hand, the hot ash cloud went far beyond the Sembongi terrace and reached the Kamiorihashi area at 1.3 km downstream of the main body front (4.8 km from the crater). It brought one death and 209 burned houses.

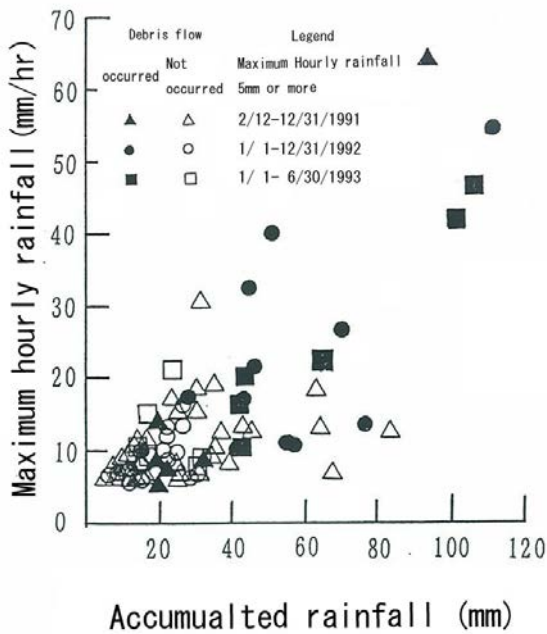


Fig. 4. Relationship between occurrence of debris flow and rainfall [3].

3.2. Debris Flow and its Damage

The Mizunashi river does not have surface water at ordinary seasons as its name implies. From the examination of the relationship between the rainfall and the occurrence of debris flows before the eruption, it is known that no debris flow occurred even when the hourly rainfall exceeds 30 mm. After the eruption started, however, debris flows occurred in almost all cases when the hourly rainfall was 20 mm or more (Fig. 4).

The soil at the mountain slope of a volcano has relatively many voids and quickly absorbs rainwater even though its amount is rather large. Therefore, the surface water does not flow into the river. Due to this reason, rivers with such names as Mizunashi River (river without water) or Shirinashi River (river without downstream water) are often seen around the volcanoes over Japan.

Volcanic ash contains a large amount of fine particles. Therefore, if pyroclastic flow deposit or volcanic ash is accumulated once on the mountain slope of a volcano, a volcanic ash layer having less voids covers the surface with many voids. Then, the rainwater becomes more difficult to seep into the ground than before, and begins to flow over the volcanic ash layer, involving ash particles. As the mountain slope is generally steep, it flows quickly gathering rock fragments, sand and ash. During this process, the flow erodes sediment on the stream bed and grows into a debris flow.

The first debris flow after the eruption started on May 15, 1991, and a large-scale debris flow with a sediment volume of over 100,000 m³ was generated on June 30 for the first time. This debris flow did not originate at the main river where pyroclastic flow deposits were accumulated, but at the left tributary (Oshigatani valley) and the right tributary (Akamatsudani river) of the Mizunashi



Fig. 5. A house damaged by debris flow.

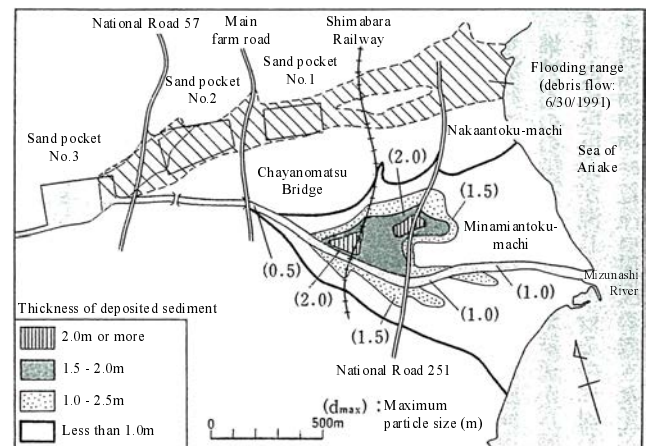


Fig. 6. Flooding range and deposition of debris flows which occurred on April 28-29, 1993 [4].

river. That is, pyroclastic flow deposits at the upstream and mid-stream of the Mizunashi River did not become the source of debris flow. This is probably because the rainwater evaporated due to the still high temperature of the pyroclastic flow deposits and hence the surface flow was not generated. There was no damage to people because the downstream area of the Mizunashi River had already been designated as the evacuation area before June 30 and all residents had already evacuated. Due to flooding of the debris flow and its deposition, however, serious damage was caused including total collapse of houses 40 and half collapse of houses 17 (Fig. 5) with destruction of many farmlands and infrastructures.

In 1993, there was a rainfall of 1,855 mm in the Shimabara area from May 29 (start of the rainy season) to July 26. Due to this rainfall, not only the downstream area of the Mizunashi river but also the national road No.251, the Shimabara railway and the Nakao River basin were buried under debris flow deposit. During the rainy season of 1993, large-scale debris flows were generated six times. As a result, the buried range on the left bank of the Mizunashi river expanded from 80 ha by the first debris flow on April 28 - May 2 to 180 ha (Fig. 6).

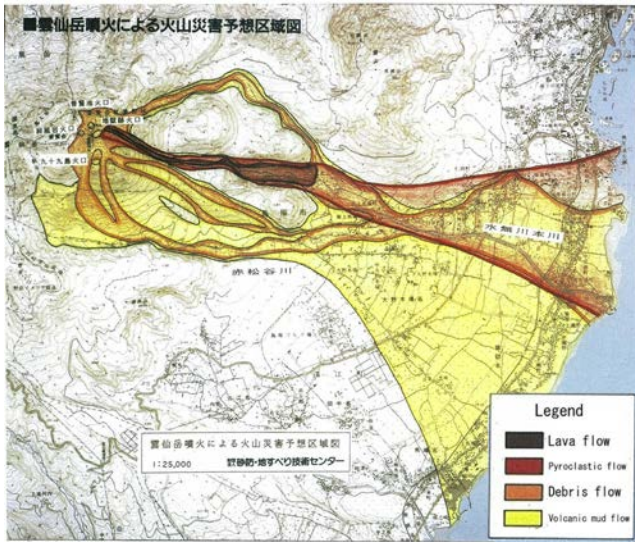


Fig. 7. Hazard map (first version) in Mt. Unzen-Fugendake.

These six debris flows changed the mind of local people who did not necessarily agree to the execution of the volcanic sabo master plan. Human damage caused by the debris flows during the Heisei eruption was only two injuries, but the damage to houses and lifelines such as a national road and a railway was significant. According to the survey by the headquarters of the Nagasaki prefectural government, damage due to debris flows accounted for about 70% (1,692 buildings) of all damaged buildings.

4. Measures Against Volcanic Disasters

As mentioned above, volcanic disasters, particularly those at Mt. Unzen-Fugendake, were sediment-related disasters. Therefore, it was necessary to take disaster prevention measures by using volcanic sabo works could mitigate an impact on the social human life and infrastructures. The example of volcanic sabo works at Mizunashi River basin is shown below in the chronological order. It should be emphasized that these works were executed, carefully monitoring the volcanic activity.

4.1. Initial Response in 1991

(1) Preparation of Hazard Map and Emergency Response

In March 1991, the Nagasaki prefectural government set up the Coordinating Committee on the Emergency measures for Mt. Unzen volcano. Considering lava flows and debris flows as highly plausible phenomena in this eruption by referring to past cases, the committee recommended to take such emergency measures as removal of deposited sediment at existing sabo dams, installation of wire sensors for alarm, preparation of hazard map, etc.

The Nagasaki prefectural government immediately started to take emergency response such as removal of sediment and installation of wire sensors. In April, a

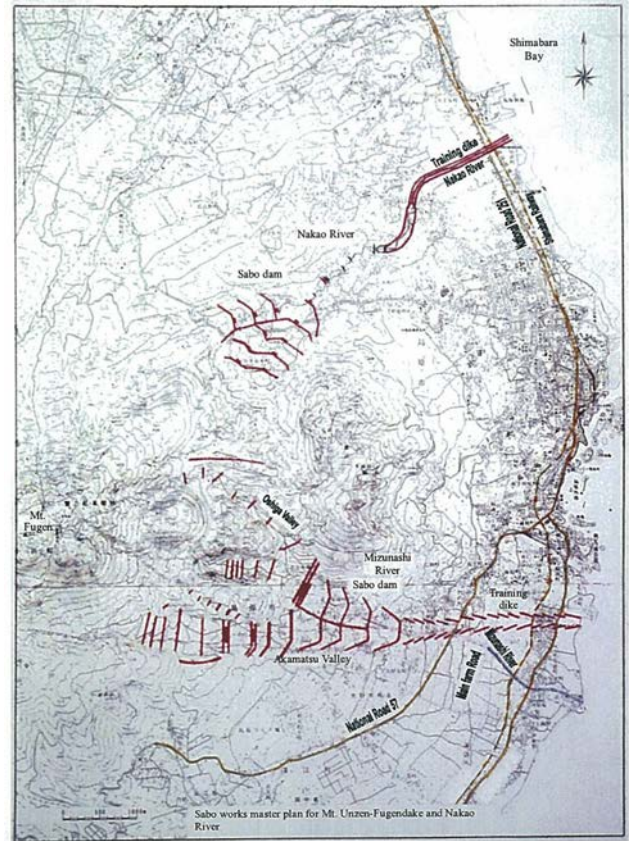


Fig. 8. Volcanic Sabo Master Plan.

debris flow occurred under the influence of rainfall and caused damage.

On the afternoon of June 3, 1991, a devastating pyroclastic flow took place claiming many lives, while the hazard map (Fig. 7) just made by the SABO Technical Center was on the way to carry to the Shimabara municipal government.

To monitor the growing lava dome and the generation of pyroclastic flows, a monitor cameras including thermo infrared camera were installed at Mt. Iwatoko and the Nita Pass (see Fig. 1). Three drop-type debris flow sensors were also dropped from the helicopter to detect debris flow occurrence along the Mizunashi river.

Hazard maps was remade seven times during the eruption by considering the changeable simulation conditions such as the temporal changes in topography, collapsed sediment volume, etc. The maps were delivered to the prefectural and municipal governments to be utilized for establishment of the evacuation area.

(2) Execution of Urgent Measures and Volcanic Sabo Master Plan

As the urgent and short-term effective measures, two temporary sand pockets (Nos. 1 and 2) were constructed in 1992 to prevent damage due to a debris flow. A fence against hot ash cloud of pyroclastic flow was constructed for preventing the pyroclastic flow damages. In February 1992, the Nagasaki prefectural government announced the volcanic sabo master plan (Fig. 8) as the permanent



Fig. 9. Unmanned construction machinery developed ahead of the world and implemented for disaster prevention.



Fig. 10. Sabo dams and dikes were executed.

measures against debris flow disaster. It held its explanatory meetings and offered the plan for public inspection. The hydraulic model tests of the master plan were conducted, inviting the public, local people and mass media such that they could understand the plan and its effect with their own eyes. We also checked the effect of the master plan with numerical simulation. In February 1993, No. 3 sand pocket with a total storage capacity of 630,000 m³ was completed. In addition, compact-type radar rain gages were installed in September 1993 to consolidate a warning and evacuation system against debris flows.

While acquisition of land for construction of disaster prevention works had took time, however, lavas had continuously extruded to grow unstable lava dome which collapsed frequently as pyroclastic flows. The extensive distribution of volcanic ash and pyroclastic flow deposit contributed to a frequent occurrence of debris flows, and the damage due to sediment-related disasters increased in the basin with time.

4.2. Response by the National Government After April, 1993

(1) Unmanned Construction Work and Safety Control System of Manned Construction

As the damage of volcanic disasters was large and measures were difficult, the responsibility of measures against volcanic disasters changes to national government from Nagasaki prefectural government.

In early April of 1993, the national government established a new project office for preventing the Unzen volcanic disasters, and the office directly started volcanic sabo works as the permanent measures based on the volcanic sabo master plan at Mt. Unzen-Fugendake. To prevent expansion of damage by debris flows, sediment removal work was performed at the sand pockets in the hazard area by mobilizing newly-developed unmanned machinery that can ensure the safety of workers (**Fig. 9**). The unmanned construction work which started in 1994 showed the effect immediately by removing about 200m³

of sediment within the same year.

Multiple safety measures such as alarm system and shelter were deployed for workers, and a temporary training dike using sheet piles was executed by workers in the evacuation area. A shelter set up near the work site was based on experience in 1902 Pele volcano disaster in which only two persons, who had hidden in a basement, survived pyroclastic flow.

The completed but temporary training dike extended for a total of 4.8 km both inside and outside the evacuation area.

(2) Construction of the Main Sabo Dam

To prevent sediment-related disasters in the Mizunashi River, construction of the main sabo dam, the Mizunashi River No. 1 sabo dam, started in September 1995 and was completed by the unmanned construction method for the first time in Japan in February 1998 (**Fig. 10**). It is 870 m long, 14.9 m high, and has a sediment storage capacity of 1 million m³. With the completion of this dam, the safety of the area was significantly improved.

(3) Review of the Volcanic Sabo Master Plan

Debris flows sometimes occurred even after the declaration of the end of volcanic activities by the Coordinating Committee for the Prediction of Volcanic Eruptions in May 1995. After entering 2001, however, the occurrence number of debris flows and the volume of sediment discharged decreased. The national government reviewed the volcanic sabo master plan in 2001.

As to the Mizunashi river basin, the target sediment volume of debris flow measure in the master plan was changed from the original 13.3 million m³ to 2.4 million m³ and the plan of related measures, for example, number of planned sabo dams also was changed.

After the draft plan was disclosed, a public hearing was held to know the opinions of local people. Reflecting the results, the plan was revised and announced as the final new master plan.

5. Effective Measures for Protecting Safety of the Area

5.1. Response to All the Types of Volcanic Disasters

Volcanic disasters are caused by various phenomena. The response plan should be formulated and implemented based on the basic policy that every possible measures are taken whatever phenomenon occurs.

During the Heisei eruption, phenomena such as ash fall, pyroclastic flows and debris flows were observed. Response measures were taken to minimize damage from these phenomena.

5.2. Quick Response to Volcanic Disasters

Once pyroclastic flows occurred, valleys were soon filled with the deposits and the valleys' topography was wholly changed (see Fig. 2). It is considered that the topographic modification changed the flowing direction of successive pyroclastic flows or debris flows. Therefore, every time when the topographic condition was changed, the areal data were surveyed and hazard map was remade by reflecting the results. The map was utilized for setting the evacuation area and for implementation of disaster prevention measures.

5.3. Execution of Measures in a Short Time

The phenomenon that triggers a volcanic disaster breaks out in a very short time once the necessary conditions are met.

For example, a debris flow is triggered when the volcanic ash deposit exceeds a certain thickness and a rain falls on it. This means that the time available for taking disaster prevention measures is extremely short. Therefore, there is no time to build an ordinary sabo structure which is constructed taking time and can resist external forces specified by the technical standard.

As the urgent measures for Mt. Unzen-Fugendake, temporary facilities were executed in a short time.

For example, the temporary sand pocket is a trench dug in the river-bed or the rice field and was used for trapping the sediment from pyroclastic flows or debris flows. The temporary training dike is a facility to change their flow direction. It was constructed just by driving sheet piles and placing sediment behind it.

In addition, sediment deposited in existing sabo dams and sand pockets was removed using unmanned machinery to recover their functions.

5.4. Response by the Development of New Technologies

- Preparation of real time hazard map coped with the change of topographical condition in actual field.
- Installation of thermal infrared cameras to monitor pyroclastic flows.
- Development of unmanned construction work in the evacuation area.



Fig. 11. Situation of disaster stricken area in Annaka district (1993).

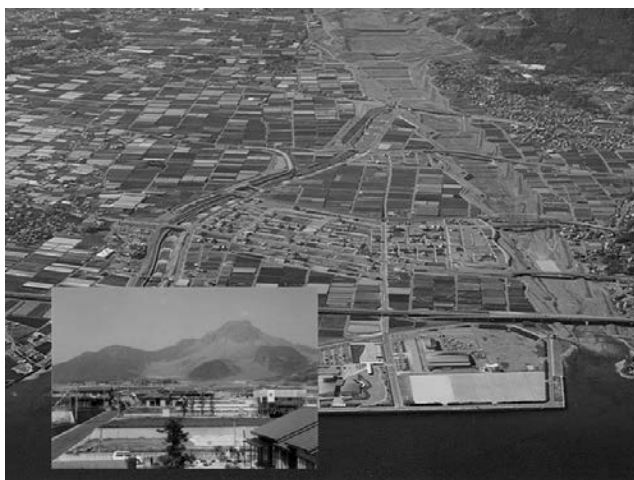


Fig. 12. A new community is creating by incorporating disaster prevention measures (2003).

- Installation of shelters, alarm system for workers of manned construction in the evacuation area.
- Installation of a fence for a hot ash cloud of pyroclastic flow at the Nakanoma river.

For disaster prevention, the above advanced technologies were introduced ahead of the world.

6. Toward the Restoration of the Area

In addition to the disaster prevention measures taken by the national government (Ministry of Construction, presently the Ministry of Land, Infrastructure, Transport and Tourism) and the Nagasaki prefectural government, measures by individual municipalities such as Shimabara city and Fukae town as well as the Forestry Agency and the Self Defense Forces played an important role in ensuring the safety of the area.

Besides the above-mentioned measures, many new

measures were set out for the restoration from disasters during the Heisei eruption by national government, prefectural government and municipalities. They included establishment of the easement to utilize land within the training dikes effectively, presentation of a base land price to support rebuilding of people's lives, setting of the price of land damaged by a debris flow, and confirmation of a land boundary by aerial survey. Other measures taken for the restoration of the area include set-up of a new fund to support restoration, land-raising of the triangle area of the Annaka district, creation of new land by the reclamation of the Antoku coast, construction of new high-standard roads having a disaster prevention purpose, etc. Especially, land raising work in Annaka district by inhabitants was executed using the sediments excavated from sabo dams. Following this, new houses were built in the Annaka triangle area, keeping safe by land-raising (Figs. 11, 12). A new town is creating, the affected area was recovered from the impact of the disaster, and they began to live with the volcano.

Although the number of visitors to the Shimabara City had decreased soon after the eruption, many visitors are returning because of the execution of volcanic sabo works.

It should be rated highly that the national government, Nagasaki prefectural government, local municipalities and local people all joined their forces to execute many measures to retrieve safety and security of the area.

7. Concluding Remarks

The volcanic eruption that started at Mt. Unzen-Fugendake in 1990 required a long-term disaster response that has never been experienced before. People had to endure non-ordinary life, undue rumors and other difficulties. However, with the cooperation of administrators, volcanologists and local people, the affected area was restored to a "wonderful hometown".

We cannot forget that a number of key persons worked hard behind the scene in each field, and that people in this area are tough enough against such disasters since old days.

Measures against volcanic disasters presented in this paper are adaptable to other volcanic disasters. I hope that they would be utilized as the effective information not only for the safety and security in active volcanic regions in Japan but also for volcanic disaster prevention in the world.

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• "Debris Flow Disasters," Iwanami Shoten, pp. 221, 1999.
• "Volcanic Disasters," Chuokoron-Shinsha, pp. 208, 2003.

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