Unzen Volcano : the 1900-1992 eruption

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11. Debris Flows in Mt. Fugen

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Introduction

Since a great volume of volcanic ash erupted from a new crater of Mt. Fugen in February 1991, there was a fear that a volcanic debris flow would occur along the rivers in Shimabara City, particularly along the Mizunashi River. The Nagasaki Prefectural Office organized the Emergency Committee to take countermeasures against possible disasters due to eruptions of Mt. Fugen. The role of the Committee was to examine and plan the effective countermeasures against disasters. As a result, the Committee recognized that the Mizunashi River and its branch (the Akamatsu-dani River) are at a considerable risk of debris flows, and proposed the following immediate countermeasures;

1) removing deposited debris from the existing check dams and dredging the river bed at the lower reaches of the Mizunashi River,
2) establishing the danger zone against flooding of debris flows and setting up the facilities to watch out the debris flows, and
3) preparing an information network system for warning and evacuation in case of emergency.

Two of these countermeasures had been accomplished by the end of April 1991. Sand and gravel were removed from the check dams (a volume of about 5,000 m^3 at two dams) and two wire sensors for debris flow were installed at the Mizunashi River and the Akamatsu-dani River.

The first debris flow occurred in the Mizunashi River on 15 May 1991. Though debris piled up almost filling the channel at places in the lower reaches of the Mizunashi River, the damage was slight as the countermeasures mentioned above were effective. A debris flow occurred again in the Mizunashi River on 19 May and two bridges were swept away, but there was no damage to houses. Following this, debris flows took place on 20, 21 and 26 May. Residents in that area were evacuated each time. These debris flows were also small and no damage has been reported.

The pyroclastic flows began to occur frequently since 24 May and the topography around the Mizunashi River changed drastically. Since a great volume of volcaniclastic material had been deposited by the pyroclatic flows, the possibilitiy of debris flows and the potential risk to human life increased in the wider areas, in addition to the risk of the pyroclastic flow itself.

In June, a several small debris flows were confirmed to occur in the Akamatsu-dani River and the Oshiga-tani Creek, both of which are branches of the Mizunashi River. These have been found by cheking the records of seismographs and the aerial photographs taken on 10 and 15 June.

On 30 June a large debris flow occurred in the Mizunashi River and caused severe damage in the downstream. The flows occurred separately in the Oshiga-tani Creek and the Akamatsu-dani River, and merged together to flow along the Mizunashi River. Since the river channel had been buried by the accumulation of pyroclastic material, the debris flow flooded into the protected low land and flowed down into the sea as shown in a photograph of Fig. 11-1. Over a hundred of houses were destroyed by the debris flow, however, no one was killed nor injured because the debris flow stayed within the limited-entry zone.

On the same day, 30 June, a debris flow occurred in the Yue River, too, and caused damage in Ariake town (Fig. 11-2). The debris flow swelled with a lot of dead trees, blocked the bridges and flooded. Despite the larger scale of debris flow, damage was comparatively small, because the rain was heavy but brief and because there were a small number of houses in that area; one person was slightly injured and nine houses

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Fig. 11-1. Debris flow flooded into the protected low land on June 30. About 130 houses were broken. (by Hirano, July 2, 1991).

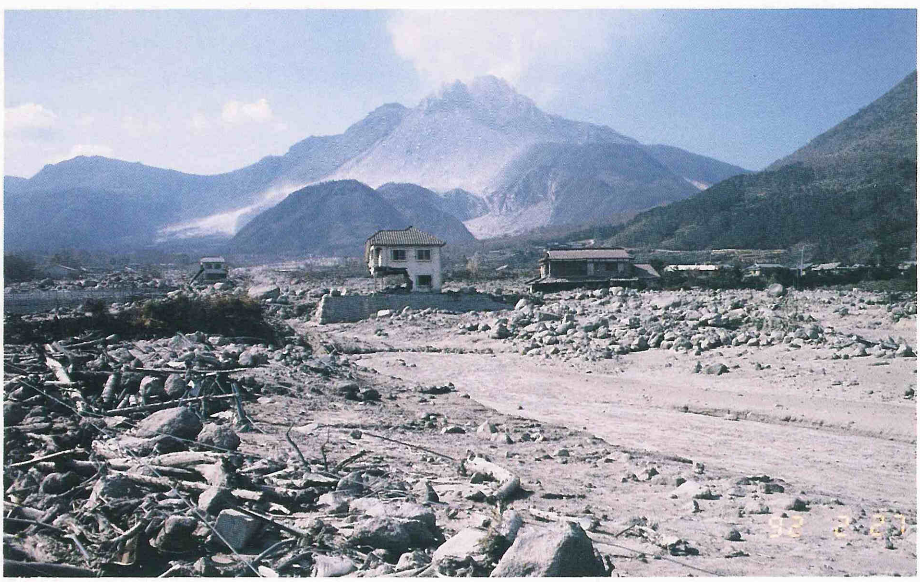

Fig. 11-2. Broken houses by the debris flow on 30 June. Houses have been still left broken in the limited-entry zone. (by Hirano, 22 February 1991).

were partially destroyed.

After July there was no serious rainfall and no damage was reported even after typhoons in September. However, according to the seismograph records, debris flows were confirmed to have occurred five times in July and two times in September.

In 1992 debris flows occurred in the Mizunashi River on 1 and 15 March. These flowed down to the sea along the same couses as the debris flow on 30 June 1991. They cut across the tracks of the Shimabara Railway and caused the closure of National Highway 251 for a while. Each occurred during rainfall of approximately 30 mm/hr. This showed clearly that the risk of debris flows still remained at high level. The precaution system should be therefore strictly maintained hereafter.

Fig. 11-3. Large blocks of rock brought by the debris flow of May 15 at the lower reach of the Mizunashi River. (by Hirano, 24 May 1991).

Fig. 11-4. A house broken by the debris flow of June 30 at the Yue River. (by Hirano, 2 July 1991).

Table 11-1. Disaster by the debris flows on 30 June 1991.

(a) Damage of houses inside the precautionary zone

	Complete destruction	Partial destruction	Total
Houses with residents	40	17	57
Houses without residents	61	16	77
Total	101	33	134

(b) Damage outside the precautionary zone

	Shimabara city	Ariake town
Partial destruction of houses		9
Flooding above floor	15	10
Flooding under floor	140	26
Damage of bridges		3

Outline of the disaster and response of residents

On 15 May the first debris flow occurred in the Mizunashi River. Fortunately, the damage was slight, because the advanced countermeasures, such as the removal of deposits from the chek dams and dredging the river bed, were effective. However, the debris accumulated nearly up to the banks of the river channels at places along the river, and there would have been a great disaster, if it had continued to rain for a little longer. On the other hand, the response of residents to the debris flow was slow, because an evacuation order was issued only after the members of the emergency-services had rushed to the river to confirm the situation, despite that the fixed sensors worked well. The residents watched debris flow coming down fiercely before their eyes and became skilled at evacuation. After then, the evacuations were carried out promptly and smoothly. A great volume of debris accumulated in the river channels at lower reaches of the river clearly pointed out the weak points of the river and dangerous area around them. Based on such observations, the dangerous area were incorporated into the limited-entry zone and the river banks were reinforced. Details of the debris flows and response of residents to them from May to March 1992, are summarized in Table 11-1.

The largest debris flow occurred on 30 June 1991, in the Mizunashi River and destroyed

Table 11-2. The details of damage and evacuation by debris flows.

1991	
May 15	• Wire sensors were cut at 01:48. Confirmed the first debris flow in the Mizunashi River.
	• Warned citizens to evacuate at 02:30. The *416* residents at Shimabara city and *45* residents at Fukae town evacuated.
	• A cottage was carried away at 05:35.
	• Two utility poles were destroyed around 06:00 and the electricity supplied to some *500* households was cut.
	• About *70,000* m^3 of debris accumulated along *4* km of the Mizunashi River.
May 19	• The second debris flow occurred at 13:41.
	• Warned *3,043* residents to evacuate. A total of *1,316* residents evacuated by 21:00.
	• Two Bridges were washed away.
May 20	• The third debris flow occurred.
	• About *81,000* m^3 of debris deposits were dumped into the Mizunashi River by three debris flows.
May 21	• The fourth and fifth debris flows occurred.
	• Warned *456* residents to evacuate.
May 24	• Heavy rain warning by the Meteologocal Office.
	• Evacuated *1,293* residents.
May 25	• Pyroclastic flows occurred intermittently.
May 26	• Warned *1,094* residents to evacuate.
	• Debris flow occurred at 20:18 and *1559* residentsevacuated.
June 3	• A large pyroclastic flow occurred.
	• A number of dead and missing recorded *43*.
June 10	• Residents around the basin of the Nakao River were
	• warned to evacuate at 10:15.
June 30	• Warned citizens to evacuate at Ariake-cho at 17:30.
	• Warned citizens to evacuate at Shimabara city at 17:55.
	• The sensor at the Akamatsu-dani River triggered at 18:18.
	• The two sensors installed at the Yue River triggered at 18:08 and 18:35.
	• Large debris flows occurred along both the Mizunashi River and the Yue River.
1992	
March 1	• Debris flow occurred at the Mizunashi River and flowed down the same course as on June 30, 1991.
	• The flood of debris accumulated and blocked Route 251 and the Shimabara Railway.
March 15	• Same as above.

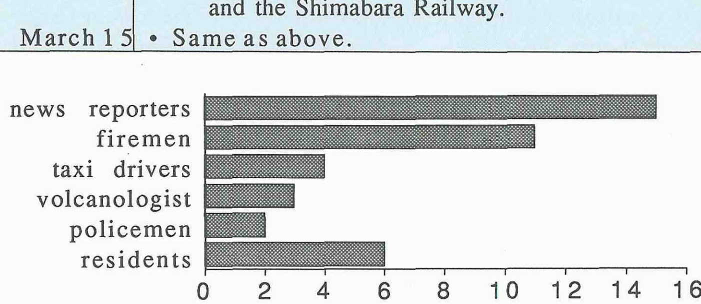

Fig. 11-5. The constituents of victims by the pyroclastic flow on 3 June 1991.

about 130 houses. However, no causualities were reported because the flow occurred inside the limited-entry zone. The Geographical Survey estimated that the total volume of debris deposits is 380,000 m^3. Of this volume, 150,000 m^3 was a removement of pyroclastic flow deposits stayed within the original area of deposition, while 230,000 m^3 was deposited at lower reaches of the river. This volume was much larger than that brought by the debris flows in May. Accordingly, a large disaster would have been caused by the heavy rainfall on 30 June, even if the channel of the Mizunashi River had not been buried. Table 11-2 indicates the disaster by the debris flows on 30 June 1991.

Prevention system against disasters and its problem

The countermeasures against debris flows are considered to have worked quite well except a few problems. This may be due to the following factors. Firstly we had enough time to take countermeasures before the first occurrence of debris flow. Secondly, the engineers in Japan have a lot of experiences and technology to assist in taking countermeasures against debris flows. On the other hand, even though the pyroclatic flows were small in volcanological term, the number of causualities reached 43.

After the disaster due to the pyroclastic flow on 3 June, TV and other media emphasized the difficulty in prediction of pyroclatic flows. But potential risk at the sites of the disaster had been already predicted and an evacuation warning to pyroclastic flow had been also issued. The scale of pyroclastic flows had increased gradually on 26 and 29 May, since the first pyroclastic flow on 24 May. On 3 June pyroclastic flows began to occur frequently in the afternoon and finally caused the disaster with 43 causualities. All damage and causualities occurred within the areas where an evacuation warnings had been given.

Figure 11-5 indicates the details of 41 lost lives due to the pyroclastic flow by the end of July (The Nagasaki Newspaper Documents, 1991. The total number of causualities finally reached 43). It is remarkable that there were so many loss of lives from the TV teams and firemen

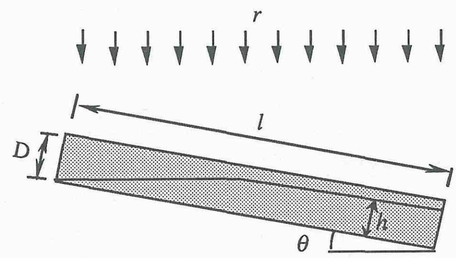

Fig. 11-6. Schematic sketch of a slope.

(vigilancemen). This suggests the followings; the news reporters who had ignored warnings against entering the danger zone; The taxi-drivers chartered by them; and the firemen and policemen who had entered the danger zone to call the reporters and drivers back. This catastrophic disaster seems not to reflect the difficulty in prediction of pyroclastic flow but rather to have originated from the unskilled risk management.

Critical rainfall for occurrence of debris flow

Occurrence criteria of debris flow

According to the experimental results (Hirano et al., 1977), debris flow occurs when surface flow appears on a slope due to the heavy rainfall. The criteria of the surface flow is given as follows. On a slope shown in Fig. 11-6, the momentum and continuity equations of subsurface flow are expressed as

$$\frac{\partial(\lambda h)}{\partial t} + \frac{\partial(\nu h)}{\partial x} = r\cos\theta \qquad (1)$$

and

$$\nu = k\sin\theta \qquad (2)$$

where λ is the porosity, h is the depth of the flow, t is time, θ is the angle of slope, ν is the velocity of the flow, x is the coordinate taken in the downstream direction, r is the rainfall intensity, and k is the hydraulic conductivity.

By solving eqs. (1) and (2) with the kinematic wave theory, one obtains the occurrence conditions of surface flow as

$$l \geq kT\sin\theta / \lambda \qquad (3)$$

and

$$\lambda D \geqq \int_{O}^{T} r\cos\ \theta\, dt \qquad (4)$$

where l is the length of the slope, T stands for the time of concentration and D designates the depth of the deposits.

Assuming that debris flow occurs when surface flow appears on a slope, the occurrence criteria of debris flow is derived from eqs. (3) and (4) as

$$r_T = \frac{1}{T}\int_{O}^{T} r dt \geqq \frac{Dk}{l} \tan\theta \qquad (5)$$

The applicability of this equation was verified by the experiment (Hirano et al., 1977).

Equation (5) shows that debris flow will occur when averaged rainfall intensity within the time of concentration exceeds a certain value related to the properties of the slope. Two parameters, the time of concentration and critical amount of rainfall, should be estimated to obtain the criteria for occurrence of debris flow.

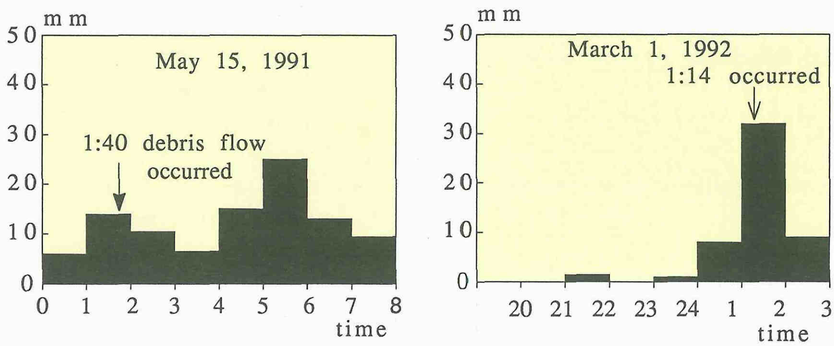

Fig. 11-7. Hyetograph at Unzen Meteorological Observatory.
(The debris flow occurred in the Mizunashi River)

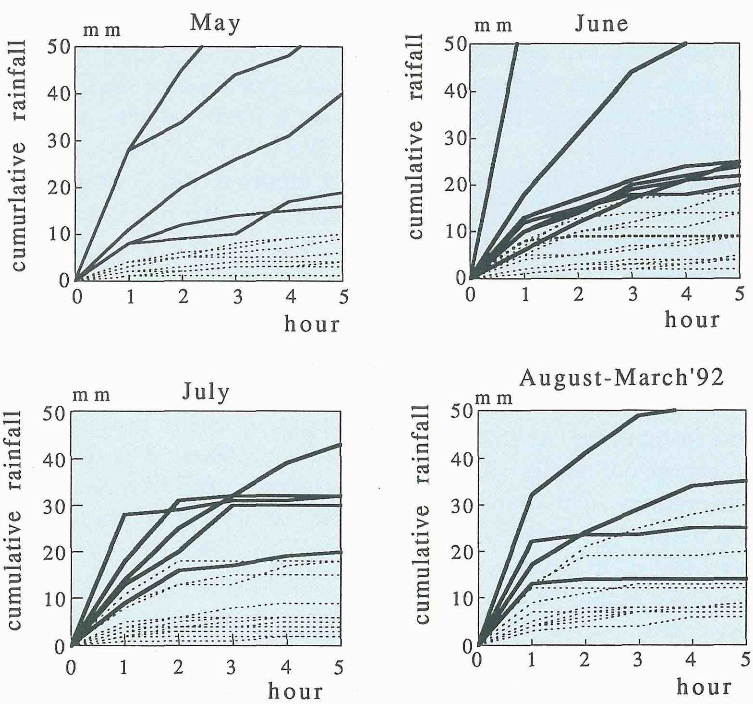

Fig. 11-8. Cumulative rainfall at Unzen Meteorological Observatory.
(Solid lines: debris flow occurred; dotted lines: not occurred)

Critical rainfall of debris flow in the Mizunashi River

Figure 11-7 shows hyetographs recorded at the Unzen Meteorological Observatory when debris flows occurred on 15 May 1991, and on 1 March 1992, respectively. In both cases, debris flows occurred between the first and second hours after it began to rain. This shows that debris flows can occur even without the precursory rainfall.

The maximum cumulative amount of rainfall for the cumulative durations were calculated for both cases with and without debris flows, using the rainfall data collected by the Unzen Meteorological Observatory. In cases when debris flows occurred, the amount of rainfall by the time of the occurrence was computed, and in cases without debris flows, whole data were used.

Figure 11-8 shows the cumulative amounts of rainfall against cumulative durations, for both cases with and without debris flows. The figure represents the following facts; (1) the time of concentration is estimated to be about an hour on average, (2) the occurrence of debris flows is possible when the amount of rainfall exceeds 7 mm / hr, and (3) debris flows will definitely occur for the rainfall over 15 mm / hr. At Sakurajima Volcano, which has been active in this 20 years, debris flows have been generated by rainfall with the amount of 7 to 13 mm over a period of forty minutes. By comparison, we can conclude that the debris flows in the Mizunashi River show the typical property of volcanic debris flow caused by a small amount of rainfall.

Although a great volume of volcanic ash has accumulated around the Mt. Fugen due to the successive pyroclastic flows, no debris flow occurred in other rivers but the Mizunashi River system, with an exception of the Yue River as the second site of debris flow on 30 June. Therefore it seems that the basins of other rivers have not yet been likely to suffer debris flows as easily as the Mizunashi River. However, volcanic activities have still continued, and the factors leading to debris flows in the basins of other rivers, have also increasing as well as an accumulation of volcanic ash and the death of vegetation. Therefore we have to maintain the precaution system against potential disasters caused by debris flows.