Observation System on Rocky Mudflow

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Abstract

It is very important for us to clarify the physical processes of rocky mudflow which have been causing serious damages in many mountainous regions of Japan.

In order to carry out a systematic and practical observation on moving state of a rocky mudflow, we contrived a new observation system, and set it along valleys on the eastern slope of Mt. Yake in the North Japan Alps.

This system consists of two parts. The one is an automatic measurement system which can record frontal velocity, dynamical impact force, visual state of a rocky mudflow and discharge. The other is a combination of various observation instruments and contains rain gauges, ground water level gauges, pressure mark gauges and cylinders to sample the mud from a mudflow head.

During the past four years, we have succeeded six times in observing rocky mudflows. Important results obtained from these observations are reported in this paper. They are the variation of the frontal velocity along the valley, the magnitude of impact force, and the relation between the occurrence of mudflow and precipitation.

1. Introduction

In order to prevent mudflow disasters, the physical mechanism of its occurrence, flow and stopping should be clarified for the reliable forecast of its occurrence and reasonable control of its motion. Though there are several approaches to the clarification of mudflow mecahnism, first of all the quantitative measurements on moving states must be carried out in practice. But they have seldom been executed until recent years.

In these four years, we have devised an observation system on mudflow and been developing it to practical use. Objective elements of observation were selected so as to explain physical characters of mudflow and to be of use for the model experiments and numerical simulation on that phenomena. And for this observation system, we adopted automatic and remote controlling methods as much as possible to be able to measure the necessary elements safely and surely.

With the above-mentioned purpose, we have been putting this observation scheme in practice every summer since 1970 in cooperation with the Matsumoto Sabō work office of the Ministry of Construction.

Because of frequent occurrences of mudflow, we chose the valleys on the eastern slope of Mt. Yake in the North Japan Alps for the test place. This mountain is an active volcano and is composed of deep deposits of volcanic ash and debris mixture over an andesite lava body. Fig. 1 shows the observation area and the measurement reaches by wavelike lines. The drainage area of Valley Kamikamihori is 0.8 km^2 and that of V. Kamihori is 0.7 km^2. The length of both valleys are about 2.5 km.

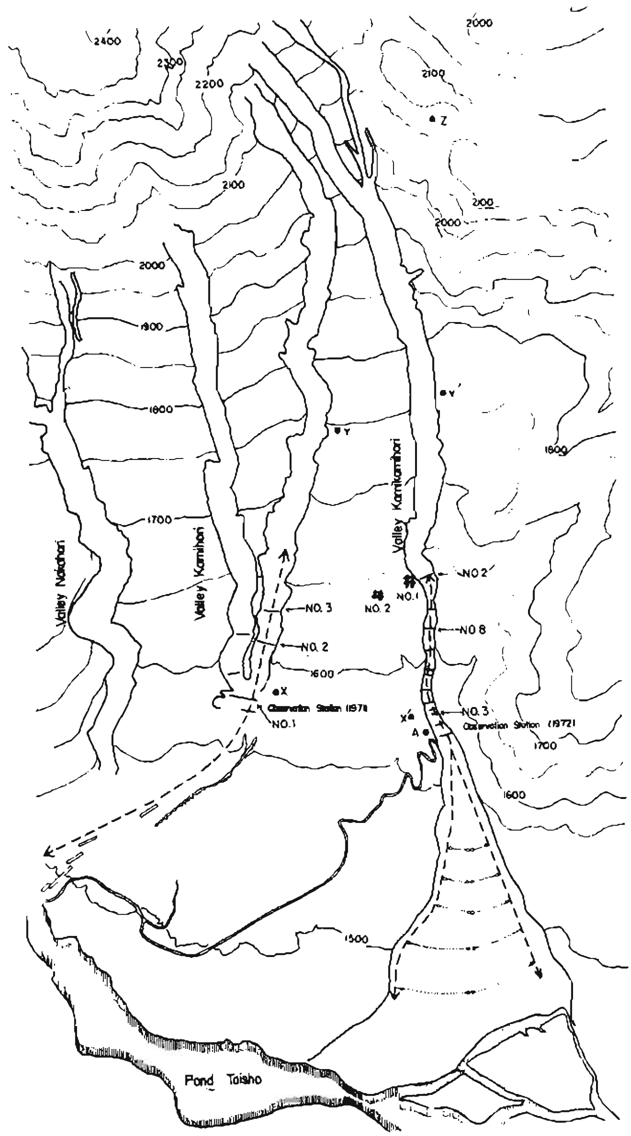

Fig. 1. Observation area at eastern slope of Mt. Yake. Straight distance between point A and X is 400 m. Point X, Y, Z, or X', Y', Z show the positions of rain gauges. Two signes of ♯ show the boring points.

The upper and middle reaches of both valleys have V-letter cross section (Photo. 1) and lower ones run through the alluvial fans.

In the next, the outline of main works and observational position each year are mentioned.

1970, at V. Kamikamihori; General inspection for preliminary survey, Trial production of automatic photographing circuit

Photo. 1. Valley Kamikamihori as seen upward from the left side above the debris barrier NO. 2.

1971, at V. Kamihori; Moving state measurement in the middle reach, Production of the front velocity recorder of mudflow head, Stereo photographing of mudflow head
1972, at V. Kamikamihori; Moving state measurement in the decelerating reach, Trial production of contact sensor, Impact force measurement by pressure mark gauge
1973, at V. Kamikamihori; Decelerating and stopping state measurement in the alluvial fan, Practical application of contact sensor, Estimation of water balance in the drainage basin

2. Observation system

The following statements are about the object elements and measurement methods of mudflow observation. In the first period, we paid much attention to measuring the dynamic moving state in order to study the flow mechanism, which brings about large destructive forces against artificial structures in valleys. Further, the water balance in the small basin, which should probably be related to the occurrence of mudflow, and the decelerating and stopping process at lower gentle slope, which would control the damage area by mudflow attack were added to the phenomena observed.

The measurement system is organized with an automatic measurement circuit and other measurement equipments.

2-1. Automatic measurement system

Front velocity

The destructive force of mudflow is concentrated at its frontal part, where a lot of large stones and stumbled trees are collected.

The front velocity recorder was produced to record the local passing time of mudflow head along a valley by many sensors which send out signals detecting the arrivals of mudflow front. Fig. 2 shows the construction of this recording circuit; the main recording part is set up in the observation room (Photo. 2).

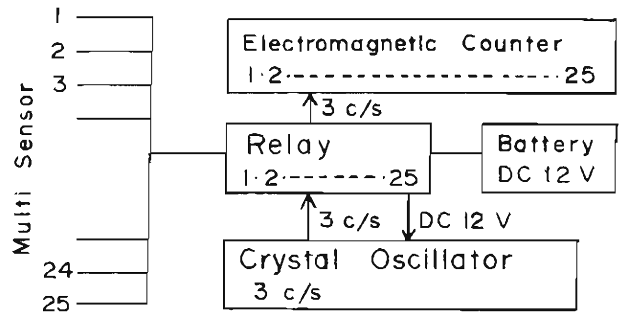

Fig. 2. Construction of front velocity recorder.

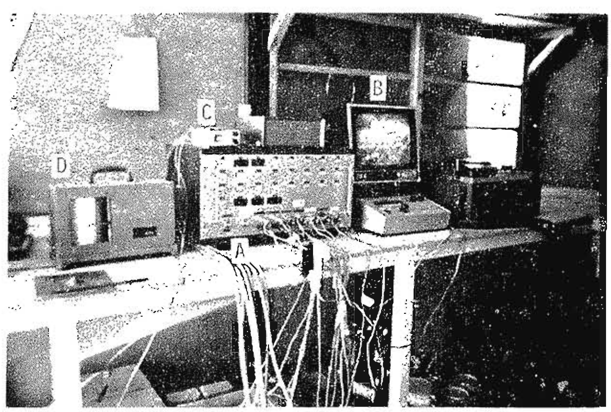

Photo. 2. Inside of the observation room.
A: Front velocity recorder B: Monitor TV.
C: Contact Sensor inner unit D: Rain gauge recorder

We contrived and applied three kinds of sensors which are named wire sensor, multi-video sensor and contact sensor respectively. The first type sends out a signal when the electric wire is cut down (Photo. 3). The second gives an alarm when the brightness of the small appointed area changes in the view field. And the third gives out a signal when the tip of an electric wire comes in contact with mudflow head (Photo. 4).

Photo. 3. Wire sensor stretched across the valley 1 meter above the bed surface.

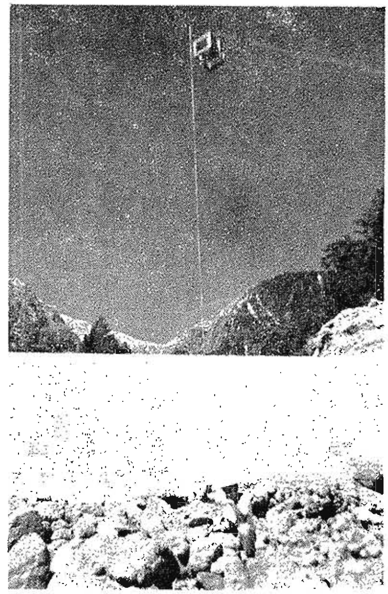

Photo. 4. Upper box is colored water injector and vertical cord is contact sensor.

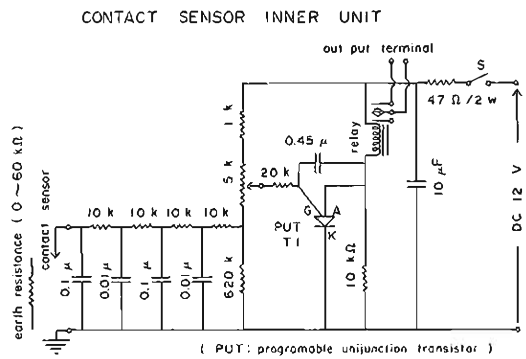

Fig. 3. Electric circuit of contact sensor.

As a result of tests, the first and third types were found to be more applicable, and of these two the third one is better because its ability in repeated operation is better than the first one. The electric circuit of the contact sensor inner unit is shown in Fig. 3. It contains multi-filters to prevent a thundernoise, which often occurs in mountainous regions.

Discharge

One of the most interesting things is the relation between an occurrence of mudflow and water balance of this small mountainous basin.

Under usual weather conditions, there is no water flow in any of the four valleys at Mt. Yake (V. Kamikamihori, Kamihori, Nakahori, Shimohori). And even in the heavy rain a large discharge can seldom be seen. But once a mudflow occurs, there certainly continues a large amount of discharge for several hours.

In order to measure the general value of this discharge, it is necessary to record the height and surface velocity of this flow. But for this measurement ordinary gauges are of no use because of their fragility against the violent flow. So we contrived a new system to measure this sudden and large discharge.

The height of flow head is estimated from its relative height over the side of a debris barrier constructed in the valley. While a water injector (Photo. 4) pours one liter of dye colored water to the flow surface every ten seconds. An 8 mm interval shot camera continues to record these colored spots flowing down and the forementioned flow height for two hours. By this method we attempted to estimate the amount and character of the special discharge during a passing mudflow.

Flowing state of mudflow

For the visual measurment of the mudflow in moving, decelerating and stopping stages we set 8 mm cine cameras, 35 mm constant interval shot camera and VTR cameras at suitable positions along a valley. Especially to catch a three dimensional shape of the mudflow head we used a pair of one shot stereo cameras (Photo. 5).

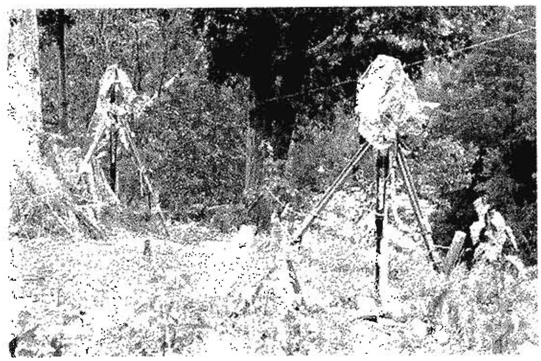

Photo. 5. A pair of stereo cameras.

All these cameras were set to operate when triggered by the relay circuit of the front velocity recorder when a mudflow head came into sight of each camera. Though illuminators of fire flash and electric lamps for filming at night were installed, both of them could only light up small areas because of scanty light flux.

2-2. Other measurements

Besides the above mentioned system, we tried to observe the following physical properties and phenomena related to mudflow.

Precipitation

Three intermittent type rain gauges were set along the valley as in Fig. 1 to measure all precipitations during every summer observation. While a gauge for heavy rain which can record the precipitation every one minute was tested, but this gauge turned out to be less applicable to our observation on account of the difficulties of maintenance and the unimportance of recording the precipitations every one minute.

Ground water

In order to estimate the water balance of drainage area two recorders for ground water level measurement were set up on two boring holes (Fig. 1). The depth of hole No. 1 is 55 m and that of No. 2 is 45 m from the ground surface.

Mud sampling

Stony mud from mudflow head was sampled by many mud samplers. These samplers are stainless steel cylindrical vessels whose inner diameter and depth are 12 cm and 15 cm respectively (Photo. 6). They were inserted into some outer steel cylinders buried in the holes which were dug at different heights of erosion control dams. When a mudflow rides over the dams, the composition of its head is well captured in the vessels instantly. And the mud obtained is carried to a laboratory to be submitted to some physical analysis.

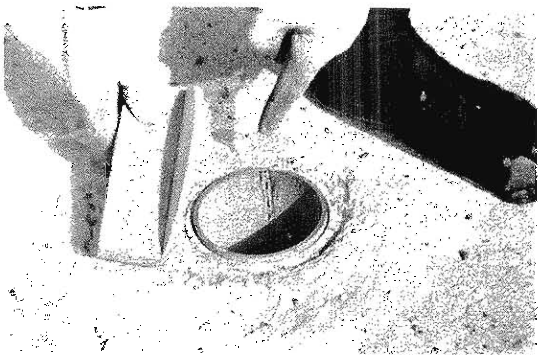

Photo. 6. Mud sampler.

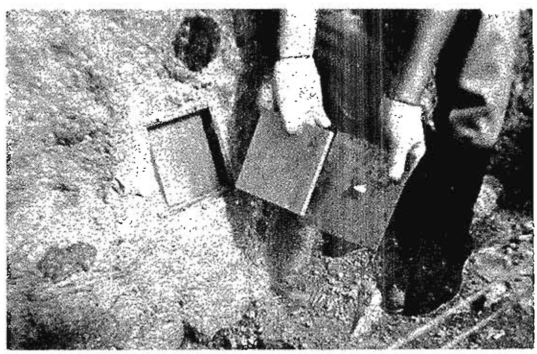

Photo. 7. Pressure mark gauge.
From the leftward, steel frame, aluminum plate (15×15 cm^2, 1 cm thikness) and steel plate with steel cone. Apex of steel cone penetrates into alumi-plate by impact force.

Impact force

Strain gauges and pressure mark gauges were buried in the surface of the upper sides of erosion control dams or on the surface of large stones which were perpendicular to flow direction. The one is for a dynamical measurement in transient course of time, the other is to measure the maximal value of impact force. Photo. 7 shows a simple structure of the pressure mark gauge on whose aluminum plate a point mark is recorded corresponding to the impact force received on the pressure plate.

Others

Further, a lot of large stones on the valley bed were painted, and after an occurrence of mudflow these stones were traced to learn the mechanism of transport.

Level surveys for the longitudinal and transverse form of the valley bed and alluvial fan were scheduled before and after the occurrence of mudflow to get the amount of transported sediment and to clarify the microtopographical changes.

In addition, attempts were made to measure maximal height of mudflow by eight strings stretched horizontally across a debris barrier at heights of every 50 cm from the bed, and to survey the arrangement effect of alluvial fan for the mudflow motion. For the latter subject, the uppermost region in the alluvial fan was artificially arranged to be a flat plane for 150 m length and its width tended to 30 m.

3. Result from the observation system

We have been successful in observing mudflow every year in typhoon and autumn rainy seasons except in 1973. There occurred no mudflow for lack of heavy rainfall in 1973. Photo. 8 is a shot of a mudflow head caught by our observation in the first year. Important results newly obtained from the direct measurements of six mudflows by our system are reported in the following part.

Photo. 8. Mudflow head flowing over dam NO. 7 at Valley Kamikamihori (Sep. 23, 1970). Dense fog flows down with the mudflow.

Front velocity

Front velocity recorder caught the changes in front velocity of mudflow, and Fig. 4–1 and 4–2 show these data with bed profiles. From Fig. 4–1, it can be said that even a large dam when it is filled up with debris could not decelerate the front velocity of mudflow, and that the bed of V. Kamihori in upper reaches above the dam No. 2 was eroded down severely by some mudflows in several hours.

Further it should be possible to estimate a virtual coefficient of dynamical friction and to quantitatively evaluate the controlling effects of frontal velocity of mudflow by these erosion control dams.

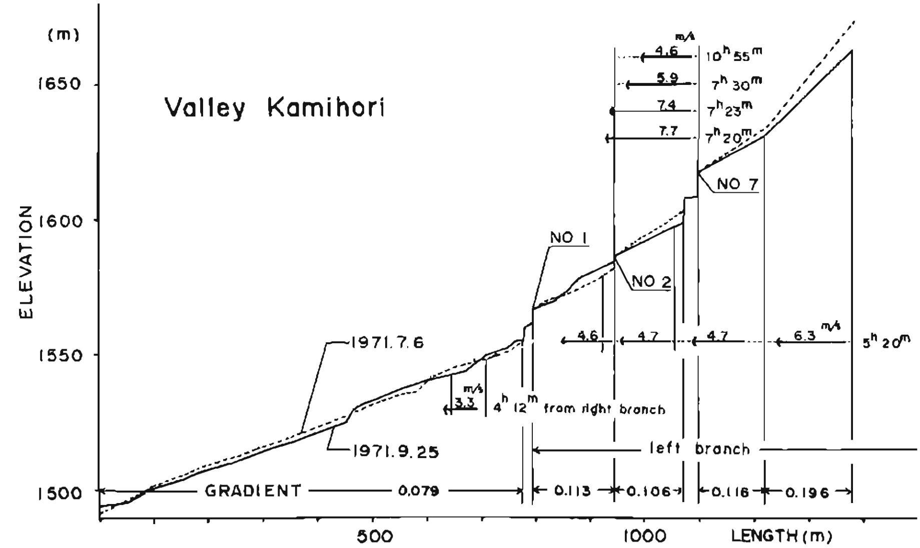

Fig. 4–1. Change in front velocity of mudflow along V. Kamihori on Sep. 6, 1971 and valley bed profile.
Broken and full lines are the profiles before and after the mudflow occurrence respectively.

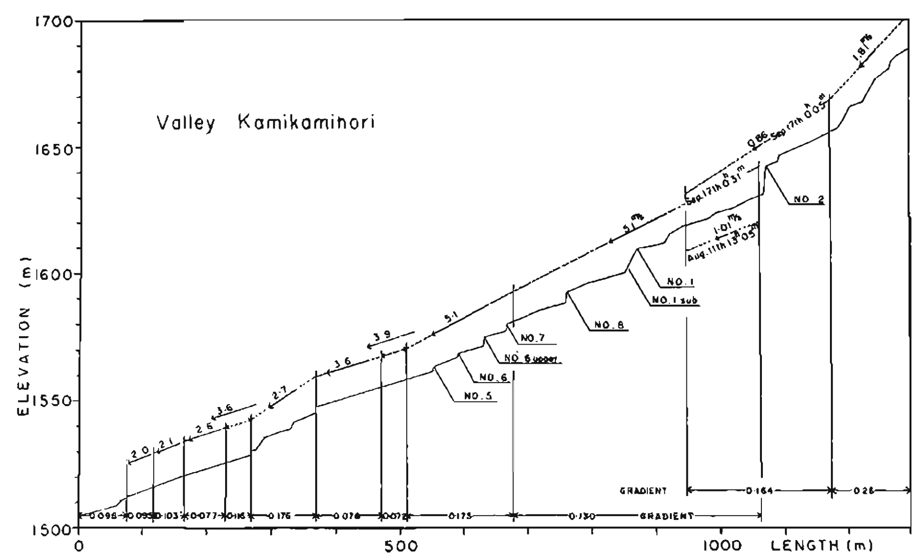

Fig. 4–2. Change in front velocity of mudflow along V. Kamikamihori in 1972 and valley bed profile.

Relation between precipitation and mudflow occurrence

Occurrence of mudflow is considered to require a preceding precipitation to saturate the debris mixture with water and heavy rainfall to get a trigger action.

Concerning the intensity of heavy rainfall, the relation between occurrence and rate of precipitation recorded every ten minutes turned out to be very important. Fig. 5–1 and 5–2 show that an occurrence time of mudflow always coincided with a peak time interval of precipitation.

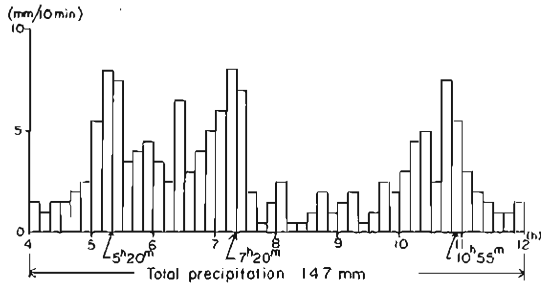

Fig. 5–1. Precipitation every 10 minutes on Sep. 6, 1971. Occurrence time of mudflow is marked by arrows.

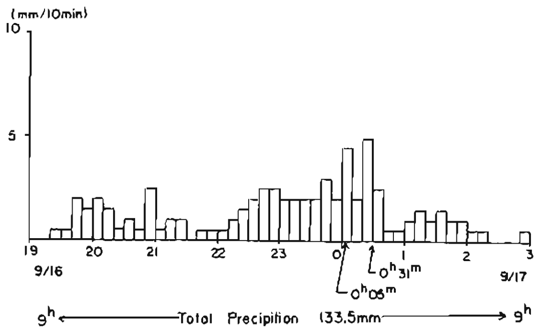

Fig. 5–2. Precipitation every 10 minutes on Sep. 16 to 17, 1972.

Fig. 6 shows the relation between mudflow occurrences and continuous rainfall conditions. Every rainfall at any observation point are plotted in the figure under the conditions that maximal hourly precipitation exceeds 5 mm and one serial precipitation exceeds 10 mm at our convenience. One serial precipitation was defined as a total amount of precipitation from rainfall beginning to maximal hourly rainfall, and if rain stops longer than 4 hours, the rainfalls before and after the cessation are treated as seperate ones. And we adopted 24 hours as the longest period of one serial rainfall considering the real effects of rain infiltration on mudflow occurrence.

The graphical domain of Fig. 6 will surely be more clearly divided into two regions — occurrence or no occurrence cases when more observation results should be added in future. But in present stage we can presuppose that mudflow is ready to occure when precipitation per hour is above 15 mm or a continuous precipitation is above 60 mm at the eastern slope of Mt. Yake.

On the other hand, ground water levels were not measured during all the observation period because of bad condition of the floats. Fig. 7 shows one of the few

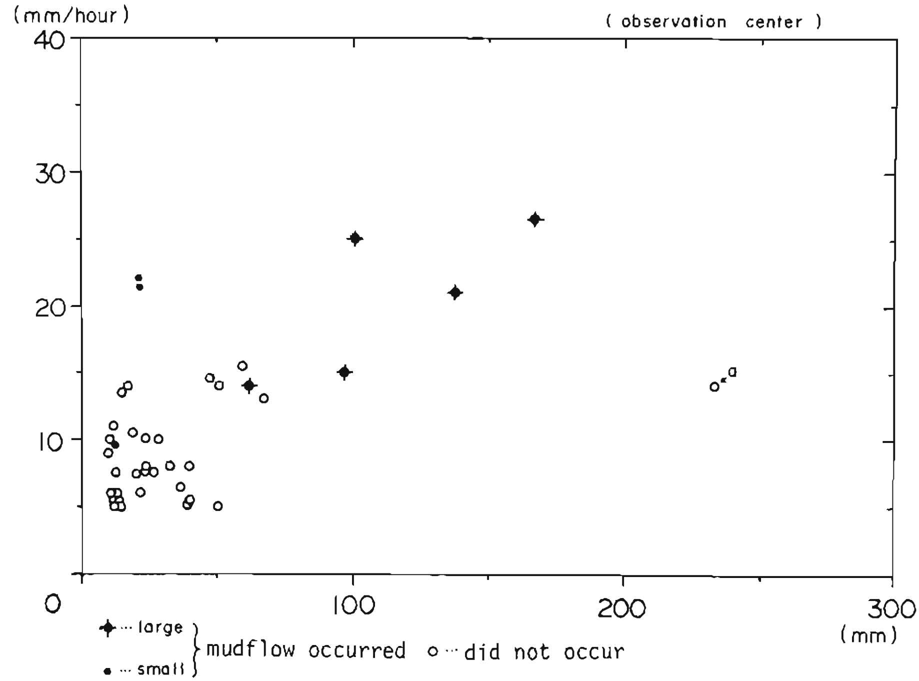

Fig. 6. Relation between mudflow occurrence and rainfall condition. Maximal hourly precipitation in ordinate and one serial precipitation in abscissa.

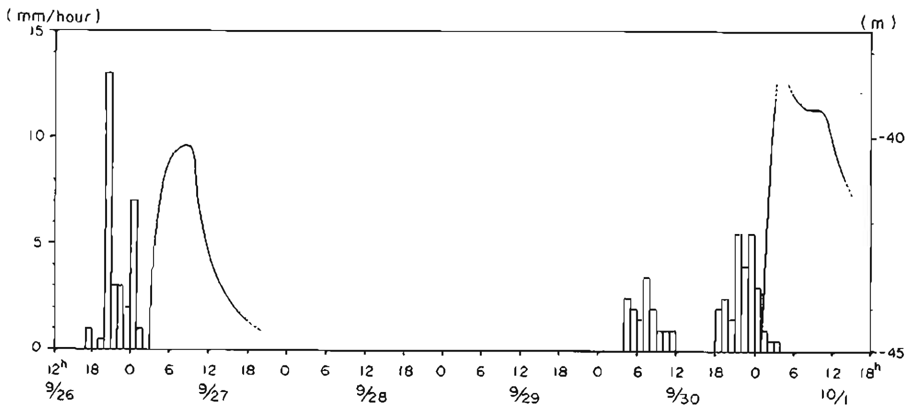

Fig. 7. Relation between precipitation (at point Y′) and ground water level (at point # No. 2) in 1973.

cases in good condition, and from this graph, we can see that a sudden large water level rising occurs about 4 to 7 hours after rainfall peak.

Maximal impact force

Maximal impact force received by 8 pressure mark gauges was estimated from the comparison of the mark sizes with a calibration curve obtained by statical loads in a laboratory.

DATA OF PRESSURE MARK GAUGE

Pressure mark gauge NO.	Maximal impact force estimated from pressure mark (ton)	Front velocity of mudflow (m/sec)
1	0·7	
2	1·0	
3	0·3	5·1
4	1·4	
5	6·0	
6	2·1	3·3
7	1·1	
8	3·3	2·7

pressure plate : 15 × 15 (cm²)

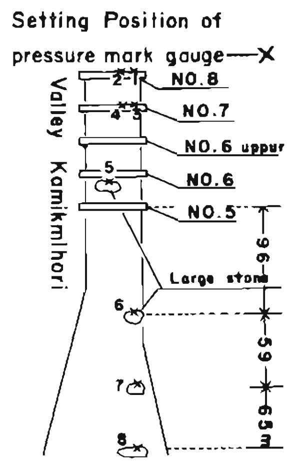

Fig. 8. Maximal impact force from pressure mark gauge.

Fig. 8 shows that the nearer the position of gauge to the center line of flow, the larger the impact force, and that the largest value was six ton weight on an area of 15×15 cm². Such a large value can not be explained by the usual fluid mechanical process of mud liquid, but could be explained by the direct collision of large flowing stone against the gauge plate.

Transportation of large stones

The mudflow on Sep. 17, 1972 transported a lot of large stones which had been painted beforehand. Fig. 9 shows the distribution of these stones. Most of them were distributed along the boundary lines of mudflow path. This seems to be due to the special secondary flow mechanism of rocky mudflow.

Fig. 10 shows one case of size distribution of large stones among the head of mudflow.

Particle analysis of mud

The forementioned cylindrical vessels succeeded in sampling the mud from the mudflow head. The mud in each vessel was sent to our laboratory to be analyzed. Fig. 11–1 and 11–2 show the accumulation curves of particle size distribution with the apparent densities of mud.

From this particle analysis, the size was unexpectedly bigger than that noted in a paper by Dr. DAIDO[1]. So it can be said that extraordinary phenomena around the rocky mudflow at Mt. Yake must be understood by the clarification of flow mechanism of a mixture composed of larger particles.

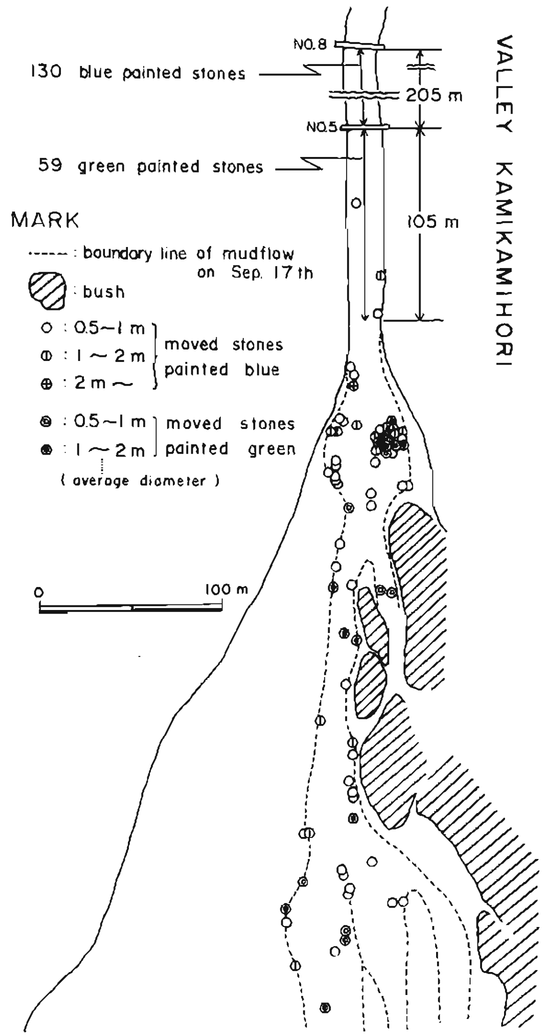

Fig. 9. Distribution of large stones transported by a mudflow on Sep. 17, 1972.

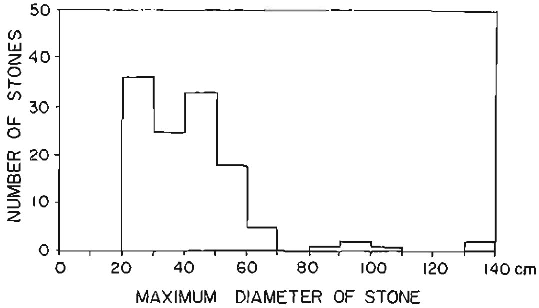

Fig. 10. Distribution of large stones (larger than 20 cm) counted up from one frame of 8 mm cine film which recorded a mudflow front on Sep. 18, 1970.

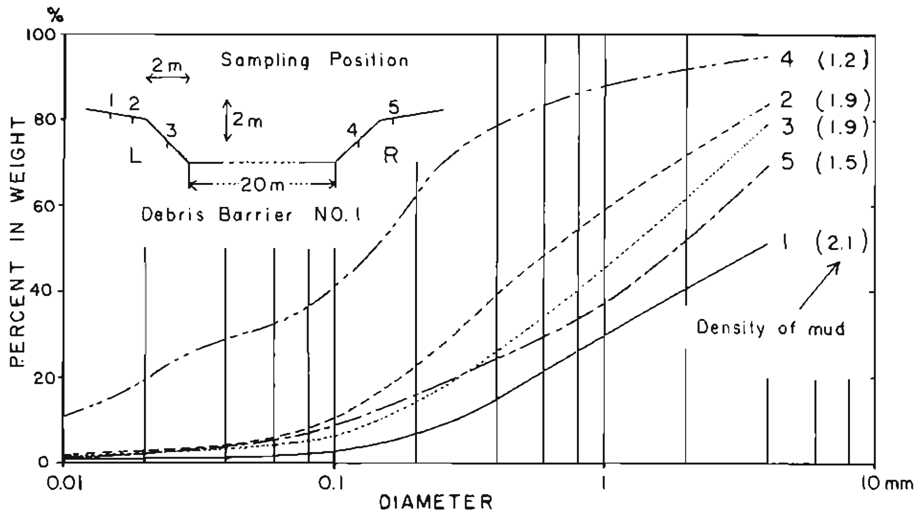

Fig. 11–1. Accumulation curves of particle size distribution of mud sampled from mudflow head on Sep. 6 '1971.

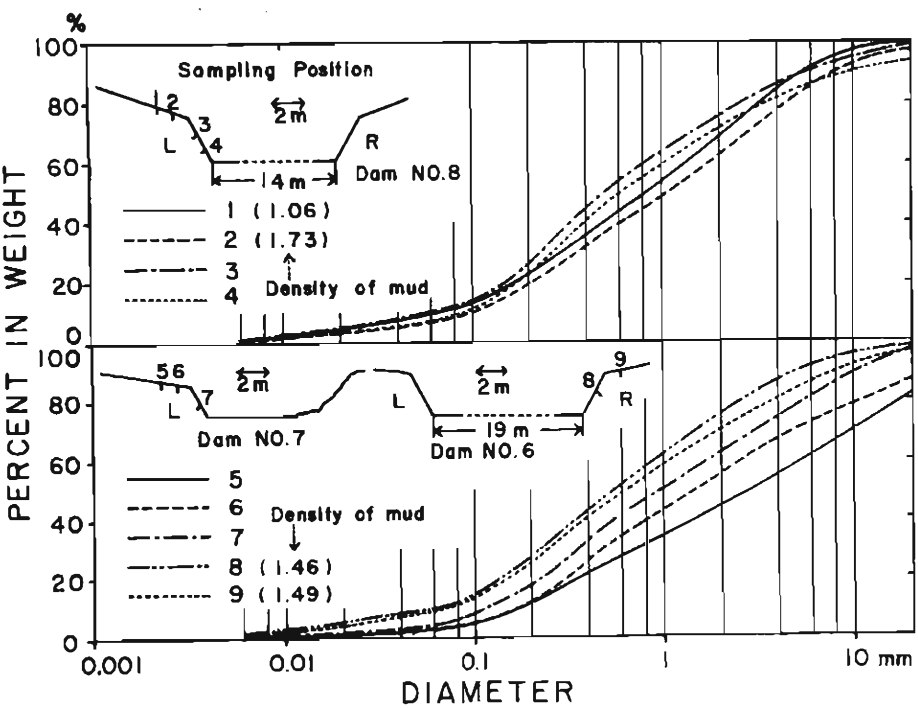

Fig. 11–2. Accumulation curves of particle size distribution of mud sampled from mudflow head on Sep. 17, 1972.

4. Conclusion and unsettled problem

In this paper the outline of a new observation system and the main results obtained from this system were described. Summing up those results in short, they are: 1) Changes in front velocity of mudflow along the valleys 2) Coincidence of occurrence time of mudflow with that of maximal precipitation recorded every 10 minutes 3) Maximal impact force of mudflow against artificial object 4) Data in relation to the transport of large stones and to the composition of mudflow head.

Automatic measurement circuit would be very useful not only for these natural observation, but also for the alarm system against many inhabitants and traffic at lower reaches.

The whole system was developed steadily for four years, but our system is still in need of many improvements and development in so far as the following are concerned. 1) Automatic line printing system of measurement data and continuous repeating operation of whole system 2) Relation between mudflow occurrence and water balance in a drainage area: complete measurement of ground water at many points 3) Mass balance of mudflow head flowing along a valley 4) Relation between the distribution of material and of velocity in mudflow head 5) Quantitative evaluation of controlling effect for artificial constructions against mudflow.

Acknowledgement

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Reference

1) Daido, A.: On the occurrence of Mud-Debris Flow, Bull. of the Disaster Prev. Res. Inst., Kyoto Univ., Vol. 21, 1971, pp. 109–135